Prompt X-Rays from Fast-Neutron-Induced Fission of ^{238}U

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Outline

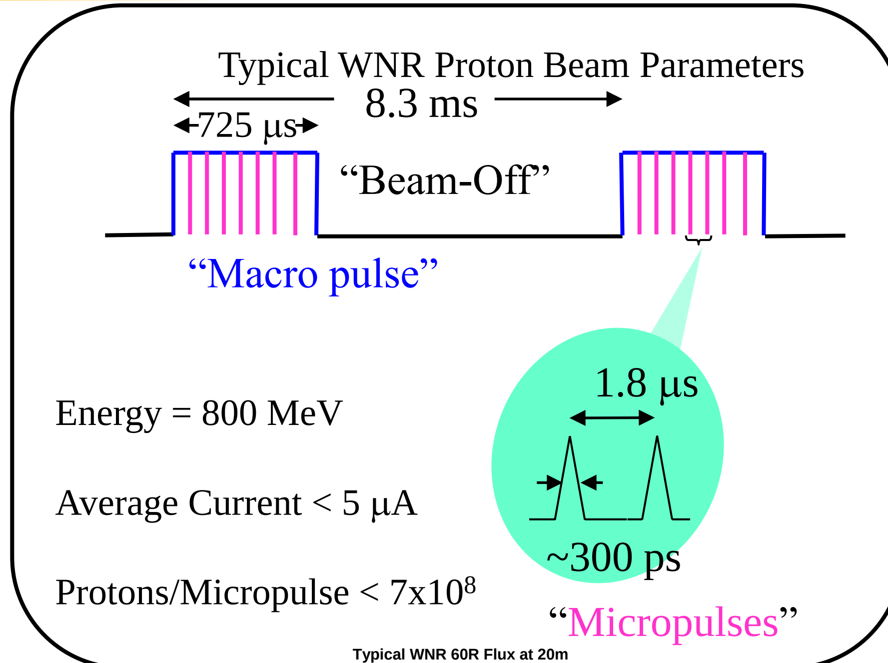
- Introduction – History – Fission K X-Ray Properties
- LANSCE – WNR Facility
- GEANIE & Fission Fragment Detectors
- X-Ray Spectra and Yields
- Calculations
- Charge Yields
- Future
- Acknowledgements

Fission X-Rays a Very Brief History

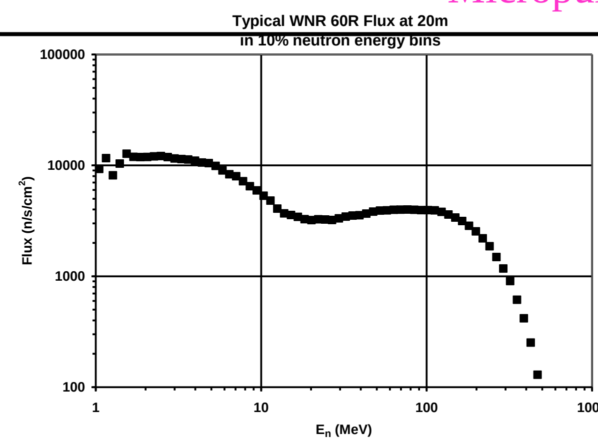
- 1960-70's - Reisdorf, Griffin, Wilhelmy - measurements for spontaneous fission and thermal neutron induced fission only
  - 1965 Glendinin and Griffin calculated K x-ray yields
- Internal Conversion – not fission acceleration ionization!
- Produced by levels with strong internal conversion means odd mass and odd-Z-odd-N nuclei favored
- Provide Z identification
- Complements gamma-ray studies that are most sensitive to even-even nuclei via $2^+ – 0^+$ observations
- LANSCE – with CEA-Bruyeres, first measurements on $^{238}U(n,f)$ with fast neutrons

Overview of the LANSCE/WNR Facility Showing the Beam Structure and Neutron Flux

WNR Spallation Neutron Source

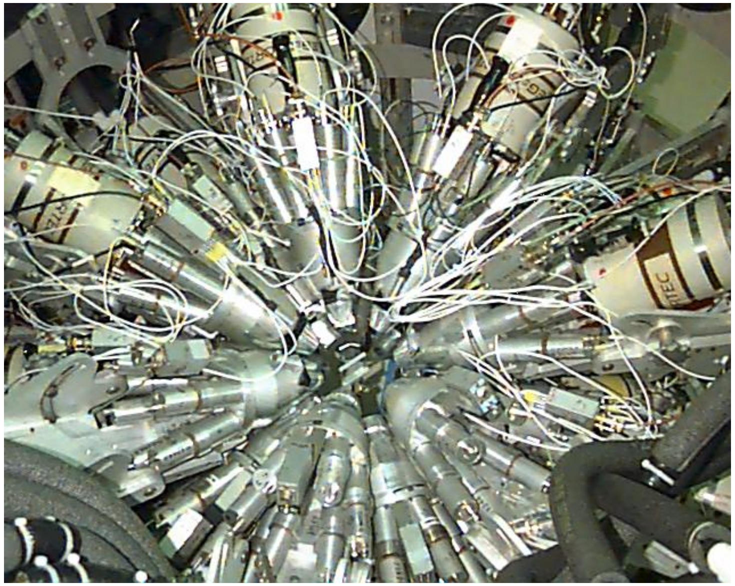


- Intense high-energy "white" neutron source
- $0.1 < E_n < 400$ MeV
- Time-of-flight for efficient excitation function acquisition



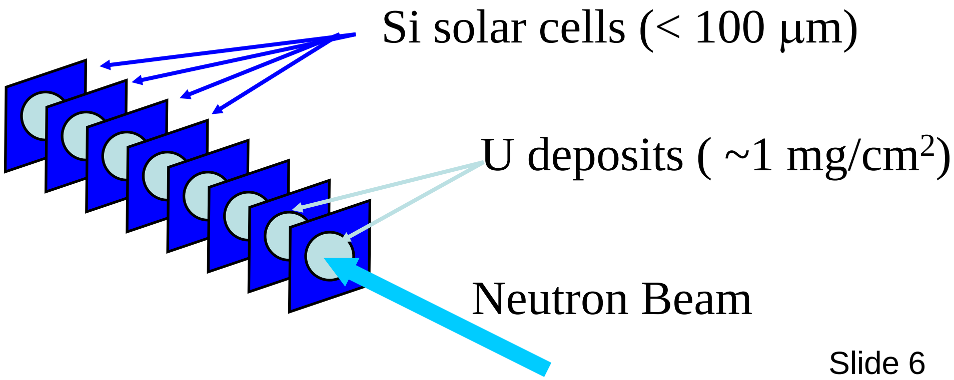
GEANIE – Germanium Array for Neutron-Induced Excitations at LANSCE

- **Located at the WNR spallation neutron source – driven by the 800 MeV LANSCE proton linac**
- **Neutron energy is determined by time-of-flight on a 20 meter flight path**
- **Typical neutron energy range is**
- **1 < En < 200 MeV**
- **Both 25% coaxial HPGe detectors and low-energy planar HPGe detectors are used.**
- **Typical gamma-ray energy range 15 keV < Eg < 4 MeV**
- **Built on the former HERA array from Lawrence Berkeley National Laboratory**

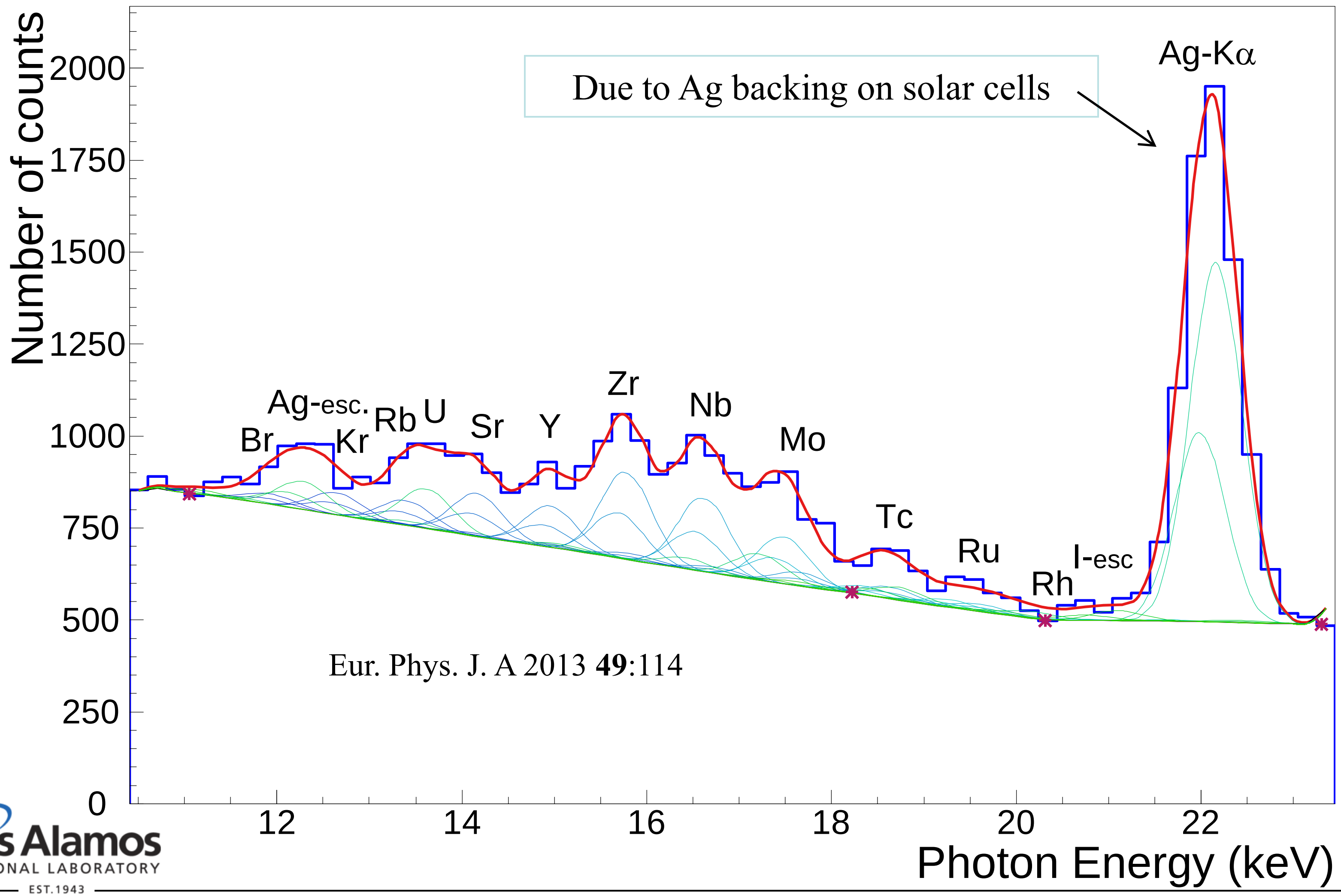


Multiple Solar Cell Fission Fragment Detectors Were Used with ^{238}U Deposited by Mass Separator (CEA)

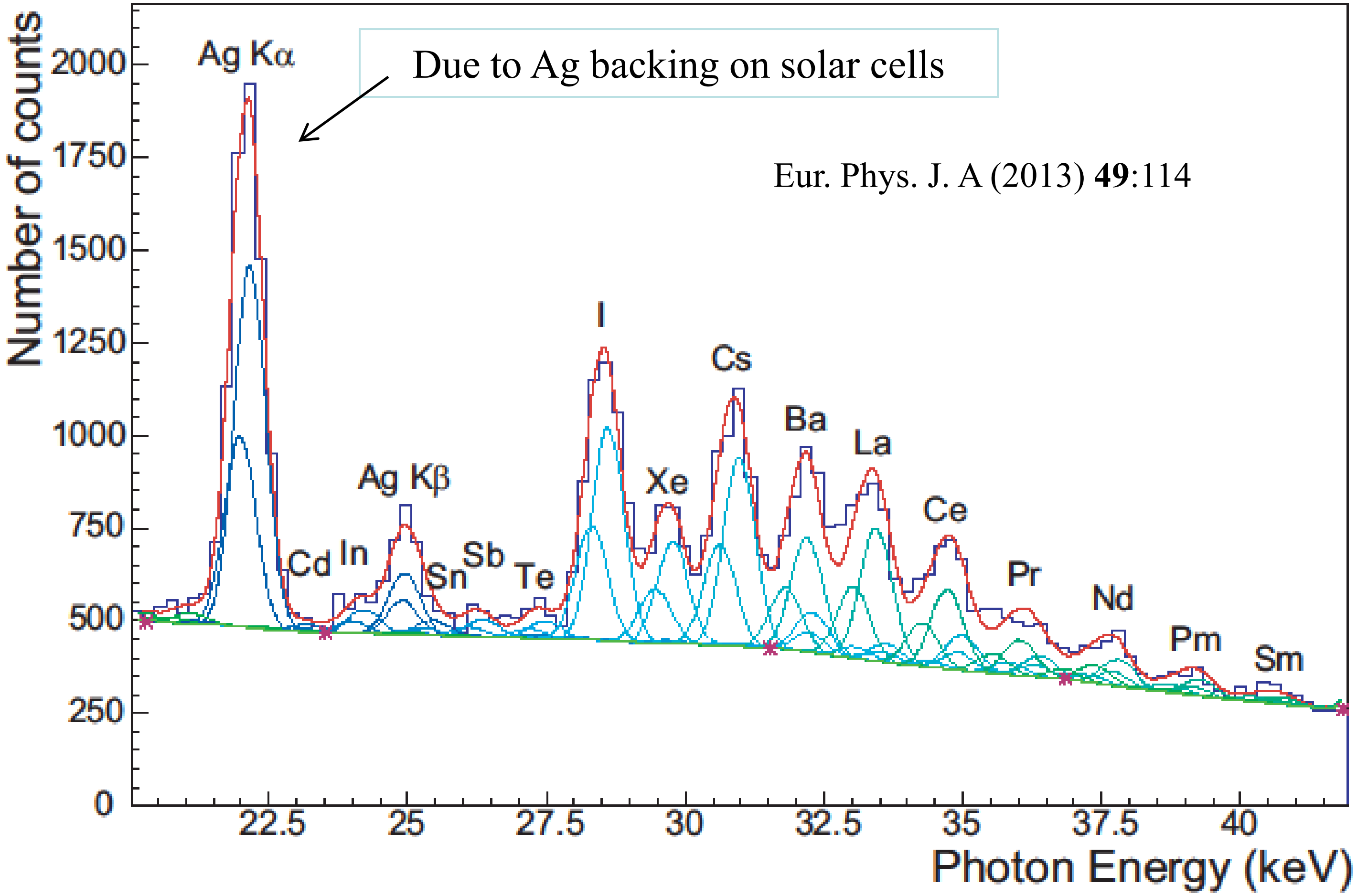
- 11 low energy photon spectrometers for x-ray detection
- 15 coaxial Ge detectors for γ ray detection
- 8 ^{238}U deposits on thin solar cells in the WNR neutron beam as an active target
- Fission-photon coincidences required to eliminate high backgrounds at $E\gamma$<50 keV



X-Ray Spectra for Lighter-Mass Fission Fragments



X-Ray Spectra for Higher-Mass Fission Fragments



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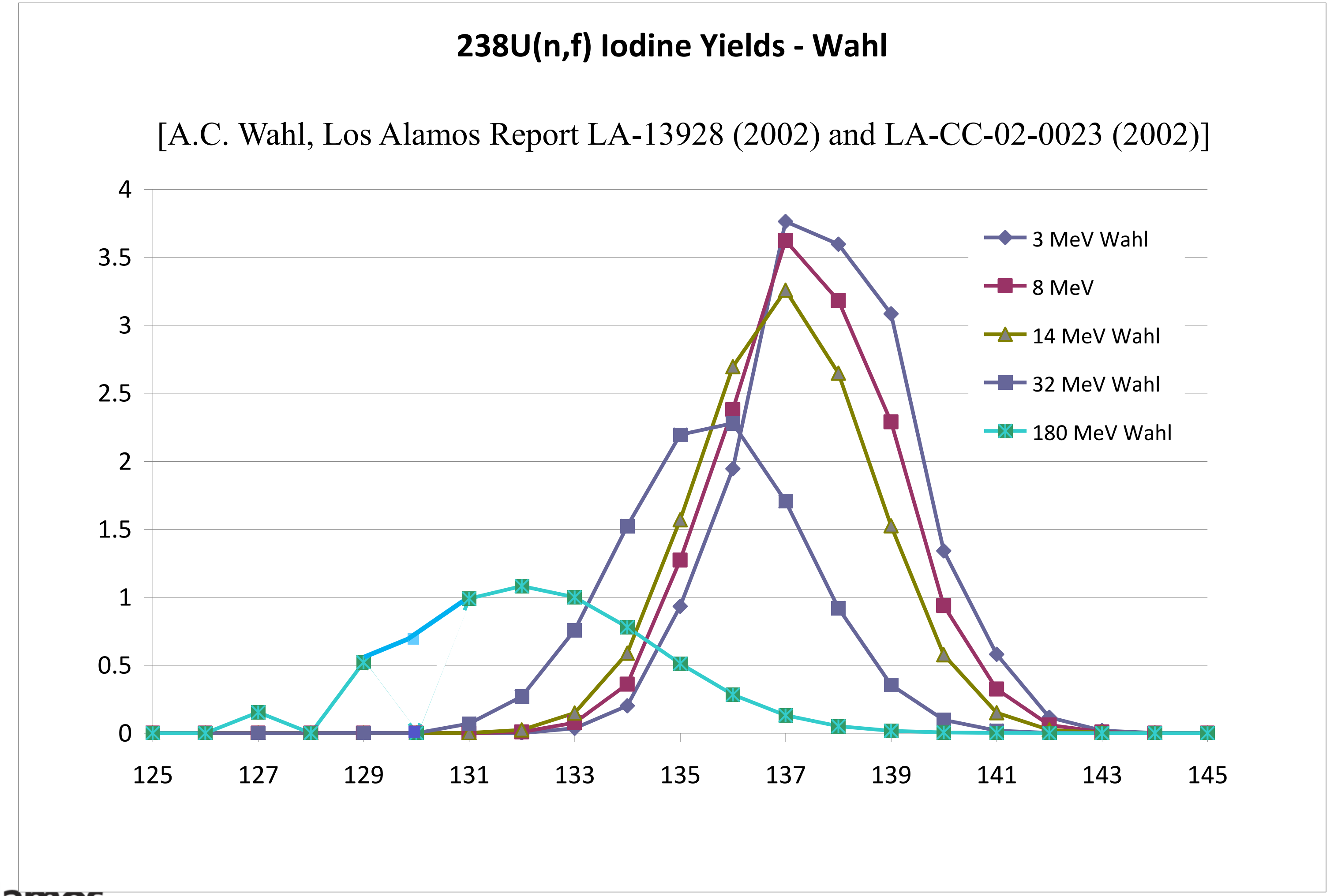
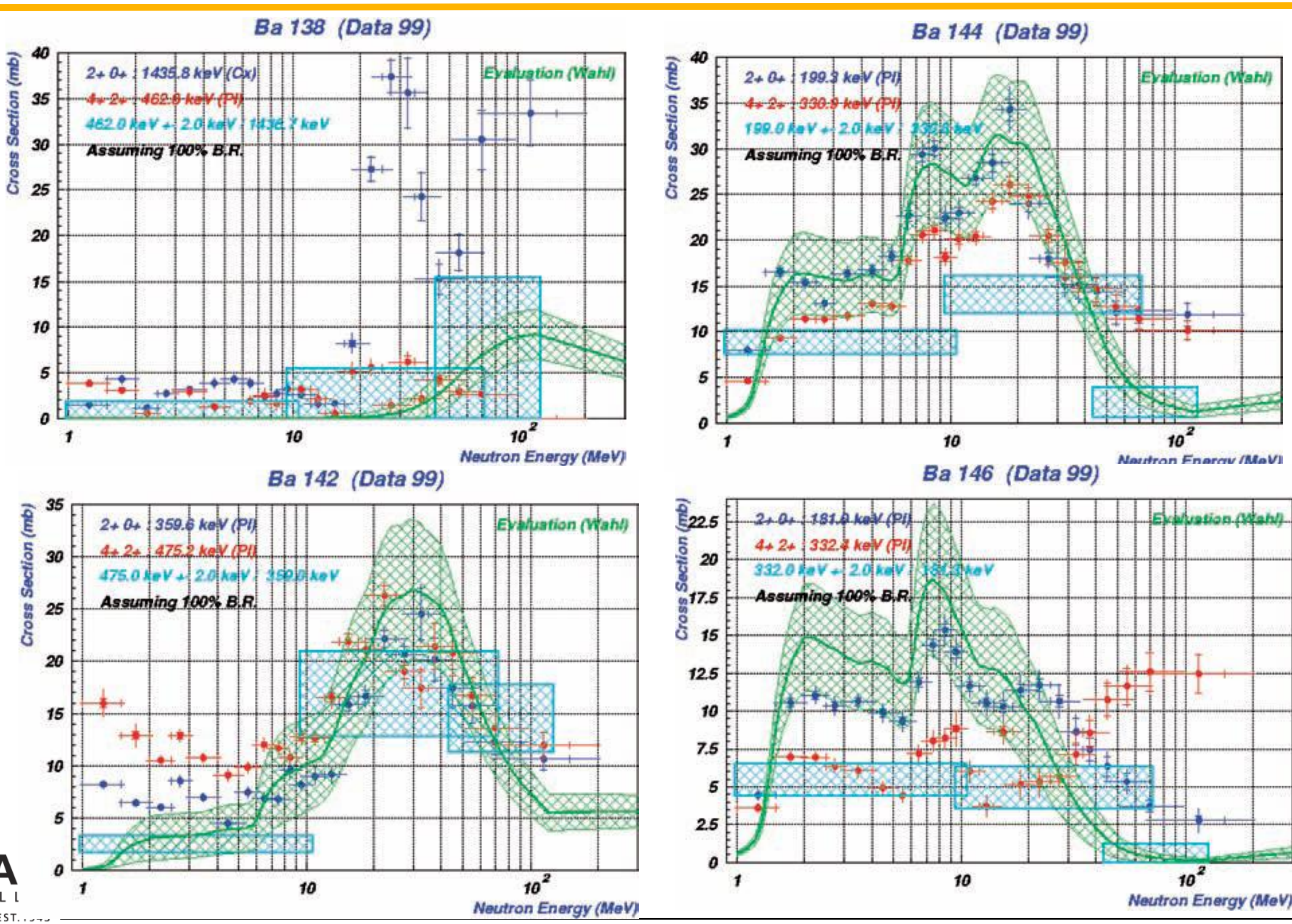
Fission Fragment K X-Ray Decay Properties

- For our data, measured on 100 ns time scale, mainly E2, M1 transitions contribute significantly to the observed K-shell x-ray yields
- Internal conversion rate is small for E1 transitions
- Decay time is much longer for higher multipoles and conversion is much less for higher gamma energies
- Odd-even staggering is observed, especially for heavier fragments

^{238}U(n,f) Mass Yield Distributions vs E_n (for Iodine) Provide a View into Different Masses with changing E_n



Wahl Fission Fragment Systematics Compared with GEANIE Gamma-Ray Yield Data for $^{238}U(n,f)$ vs E_n



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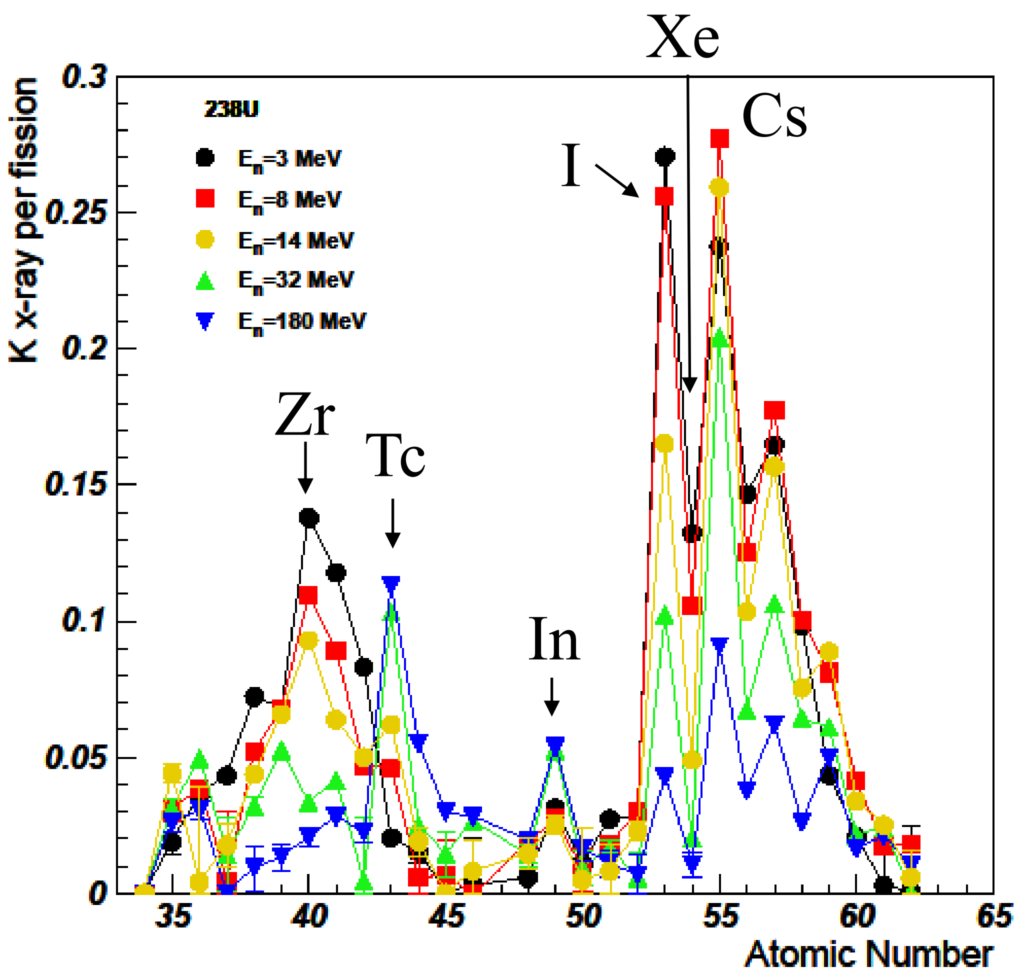
https://www-nds.iaea.org/publications/tecdocs/sti-pub-1286/

Measured K X-Ray Yields vs Atomic Number for Five Incident Neutron Energy Bins from 3 to 180 MeV

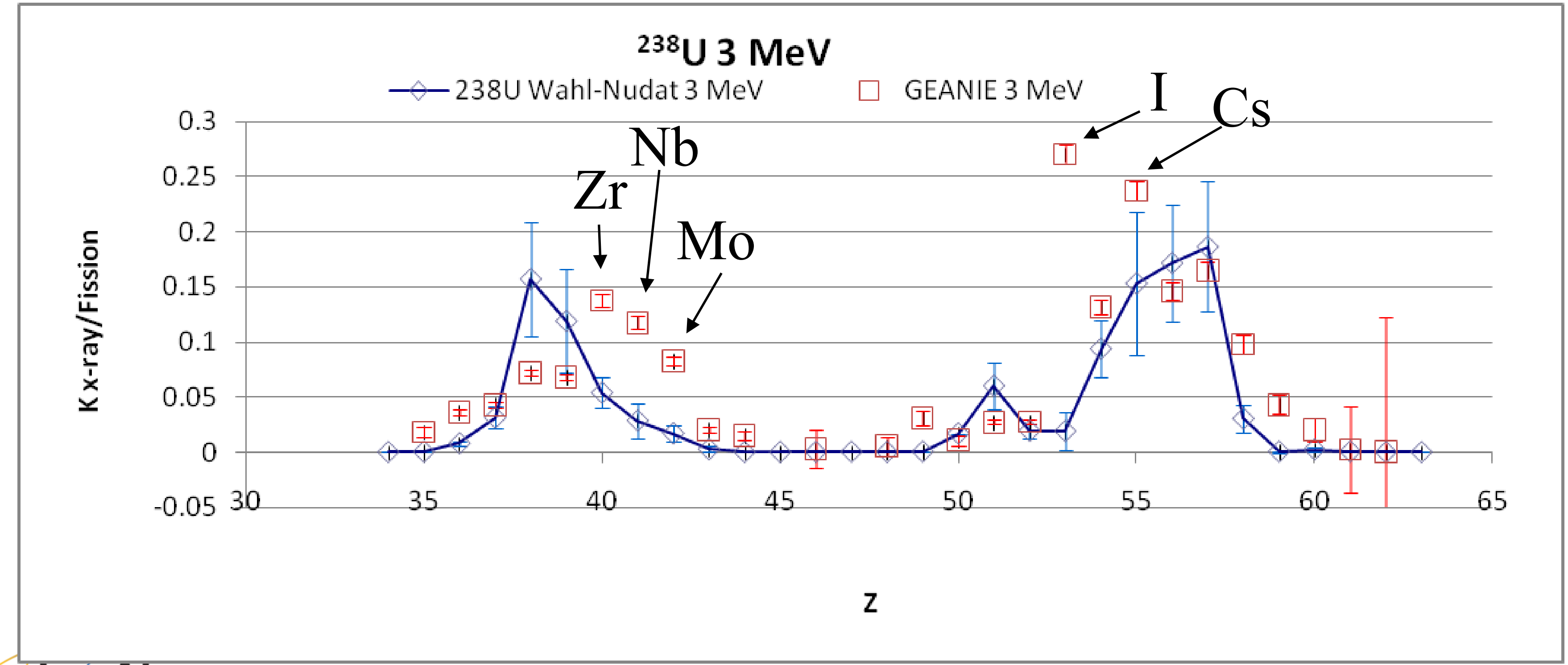


Calculations of X-Ray Yields from Energy Levels, Fission Yield Systematics, and other data

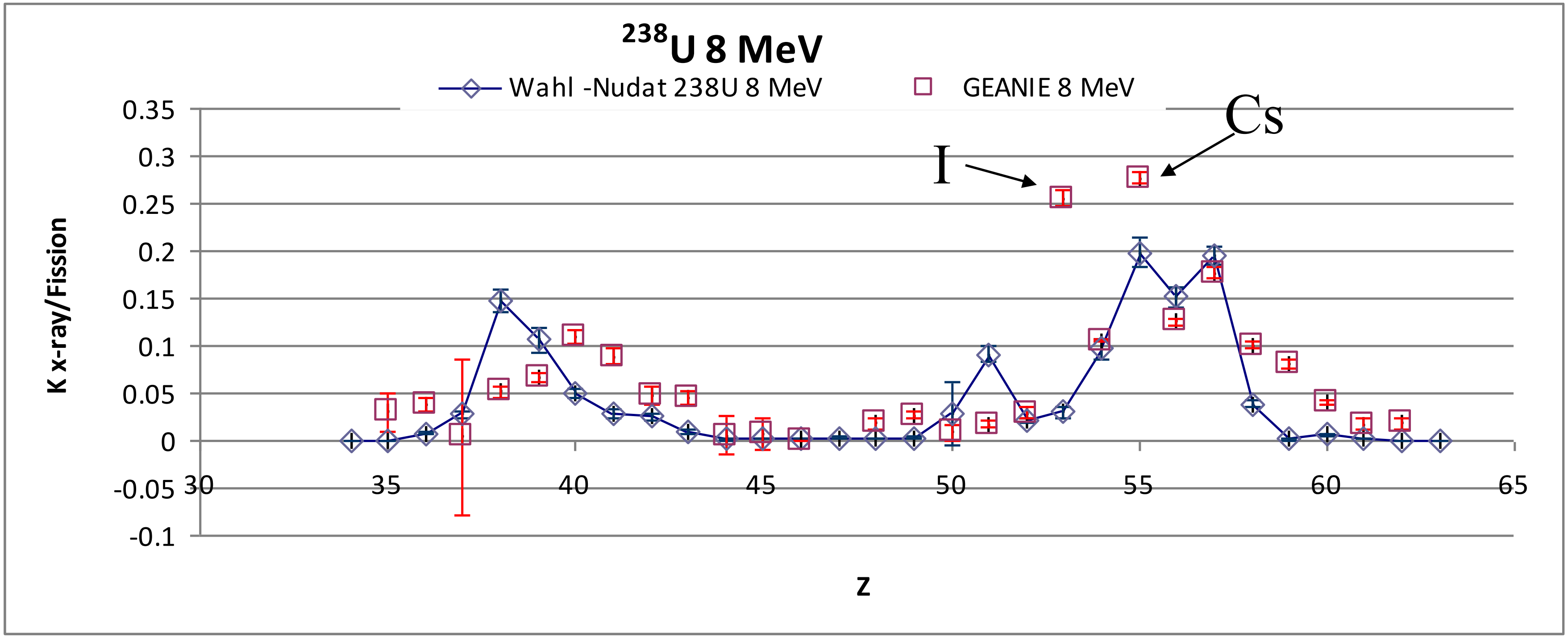
- Calculated K Yield = Sum over all known (NUDAT) IC levels ($\alpha/(1+\alpha)$) weighted by systematic (Wahl) mass yields * branching * lifetime factor * fluorescent yield
- Consider the case of a single low-lying state with large internal conversion coefficient
  - Typically have large feeding from higher levels
  - For ease of calculations assume 100% population
  - But, may be less due to isomers, feeding patterns
  - Multiple x-ray emission is possible
- Estimated uncertainties in calculations include only IC coefficient and mass yield uncertainties

E_n=3 MeV Measured and Calculated K X-Ray Yields

- Data greater than calculation – missing IC levels
- Data less than calculation – 100% feeding not true



E_n=8 MeV Measured and Calculated K X-Ray Yields



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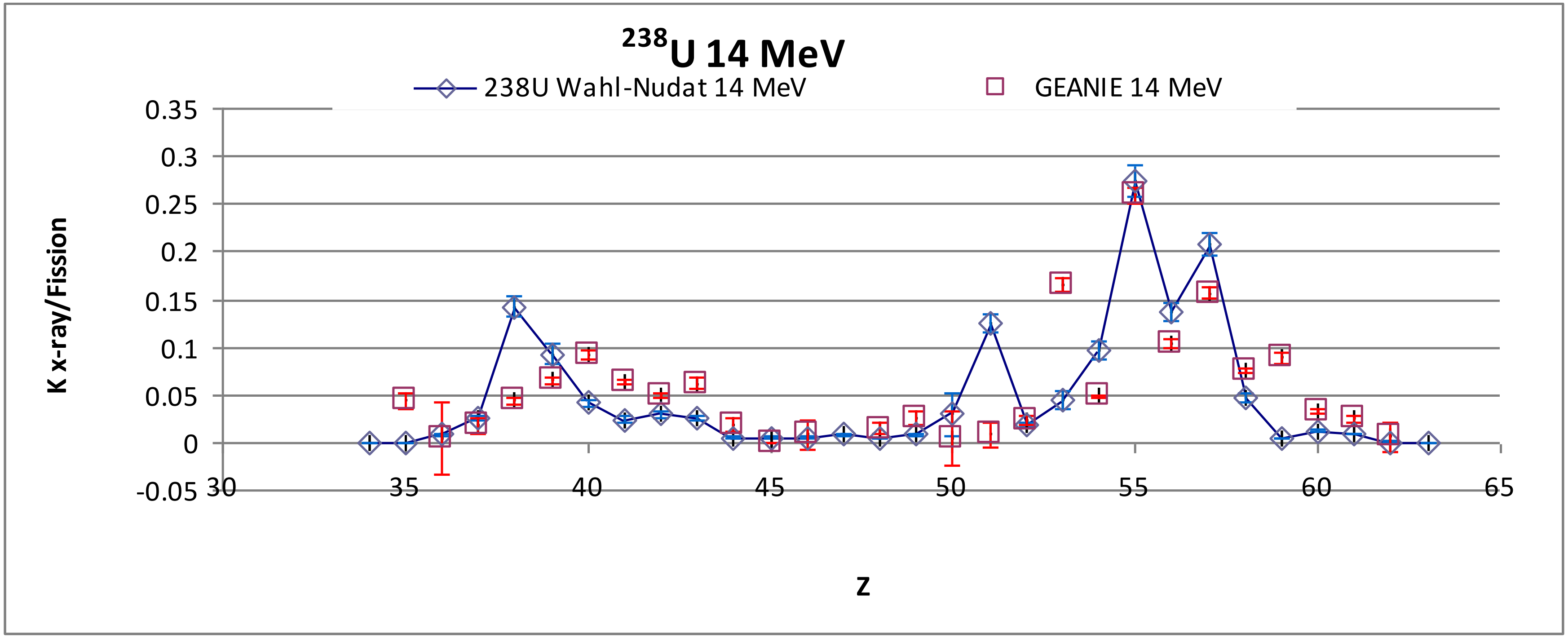
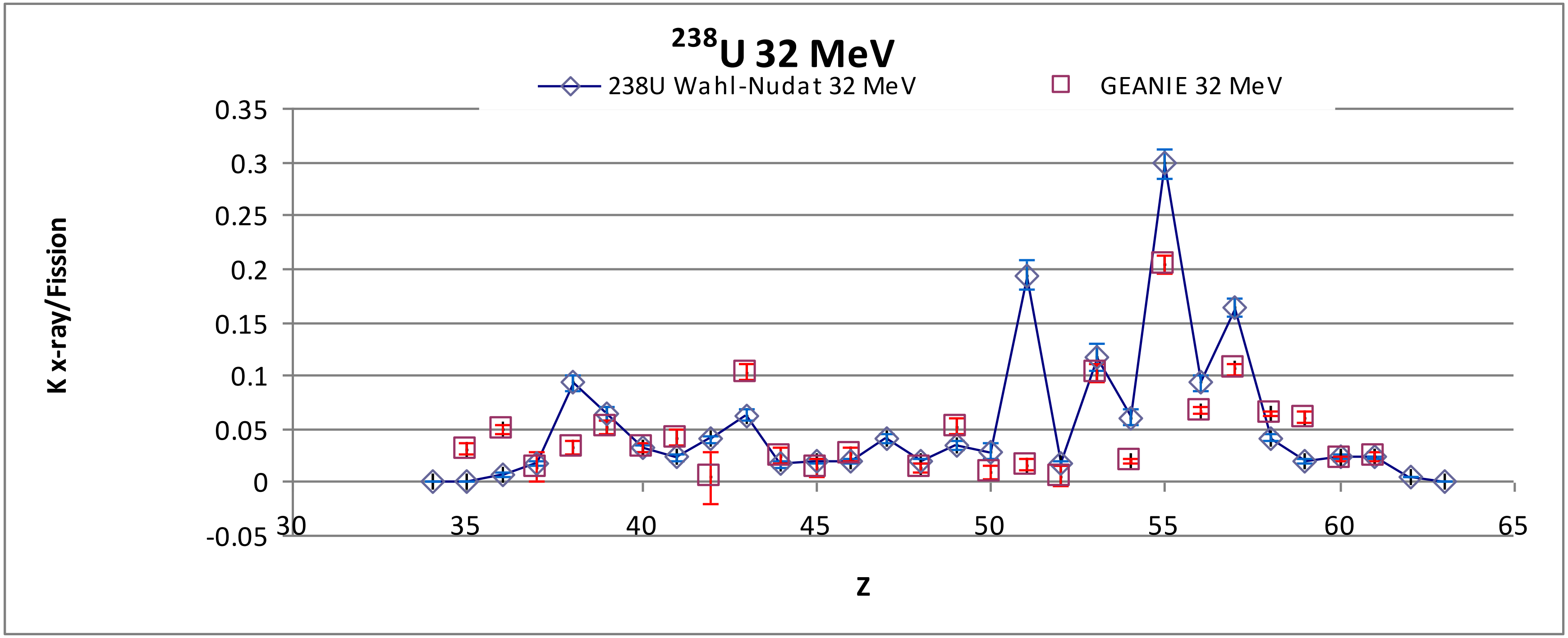
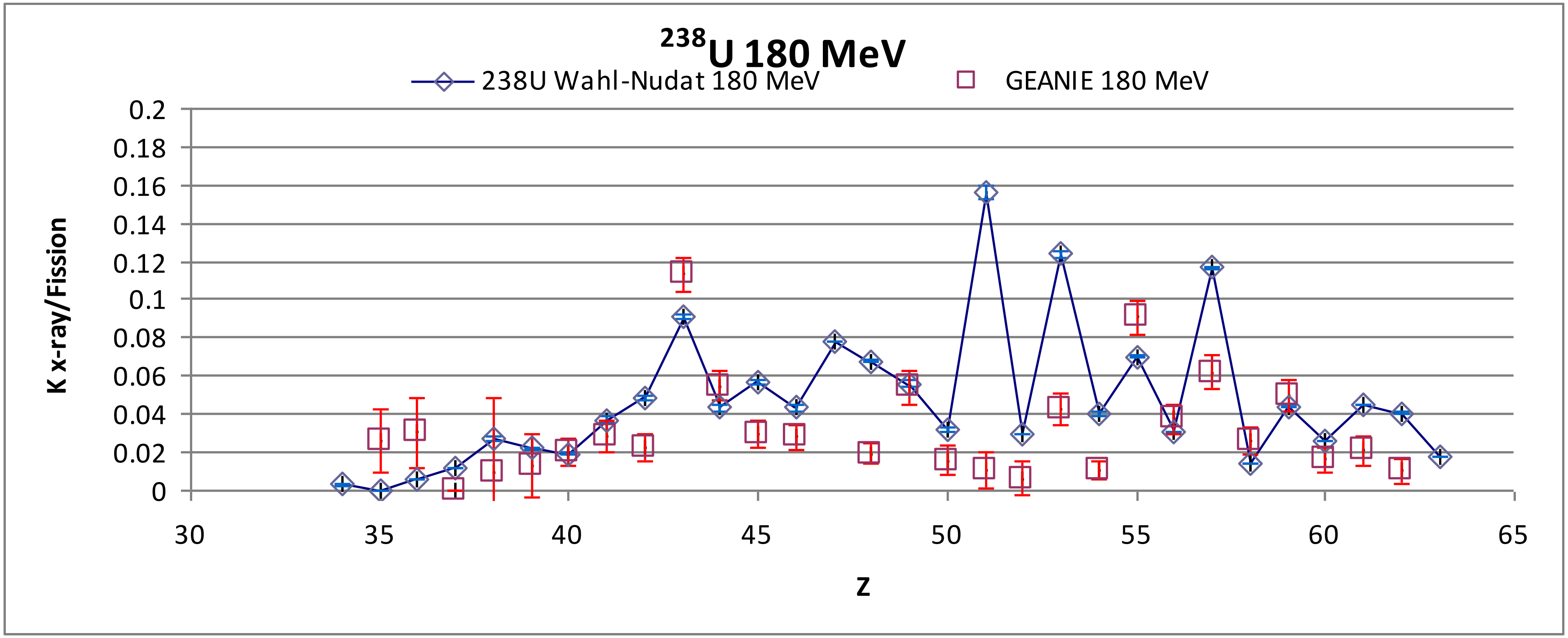
E_n=14 MeV Measured and Calculated K X-Ray Yields



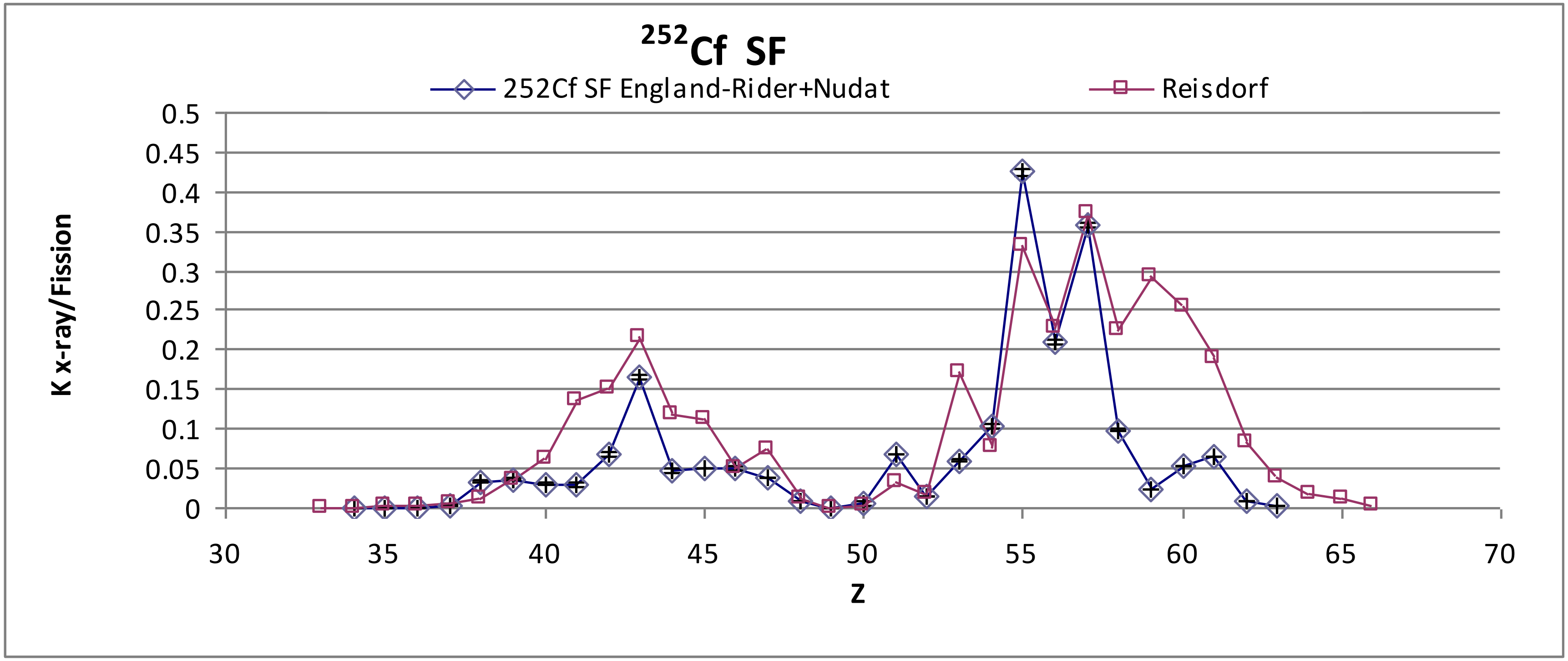
E_n=32 MeV Measured and Calculated K X-Ray Yields



E_n=180 MeV Measured and Calculated K X-Ray Yields



Reisdorf ^{252}Cf Spontaneous Fission K Yields



K X-ray yields for thermal fission of $^{233,235}U$, ^{239}Pu, & spontaneous fission of ^{252}Cf

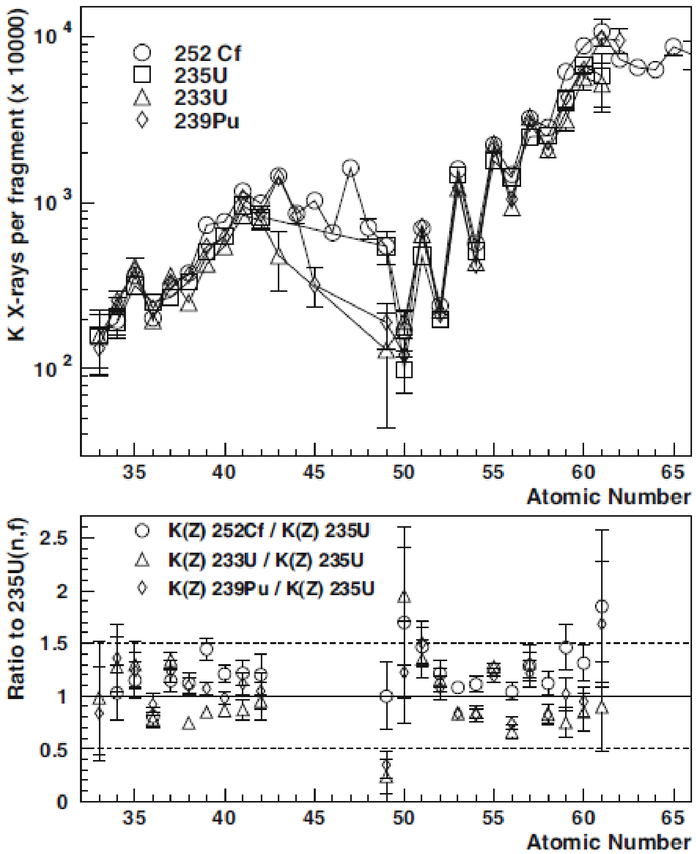


Fig. Top: Mean K X-ray emission probabilities per fragment of charge Z ($K(Z)$) obtained by Reisdorf *et al.* [4] for ^{252}Cf spontaneous fission (circles), ^{235}U(n,f) (squares), ^{233}U(n,f) (triangles) and ^{239}Pu(n,f) (diamonds). Bottom: Ratio of $K(Z)$ in ^{252}Cf spontaneous fission (circles), ^{233}U(n,f) (triangles) and ^{239}Pu(n,f) (diamonds) to $K(Z)$ for ^{235}U (data from ref. [4]).

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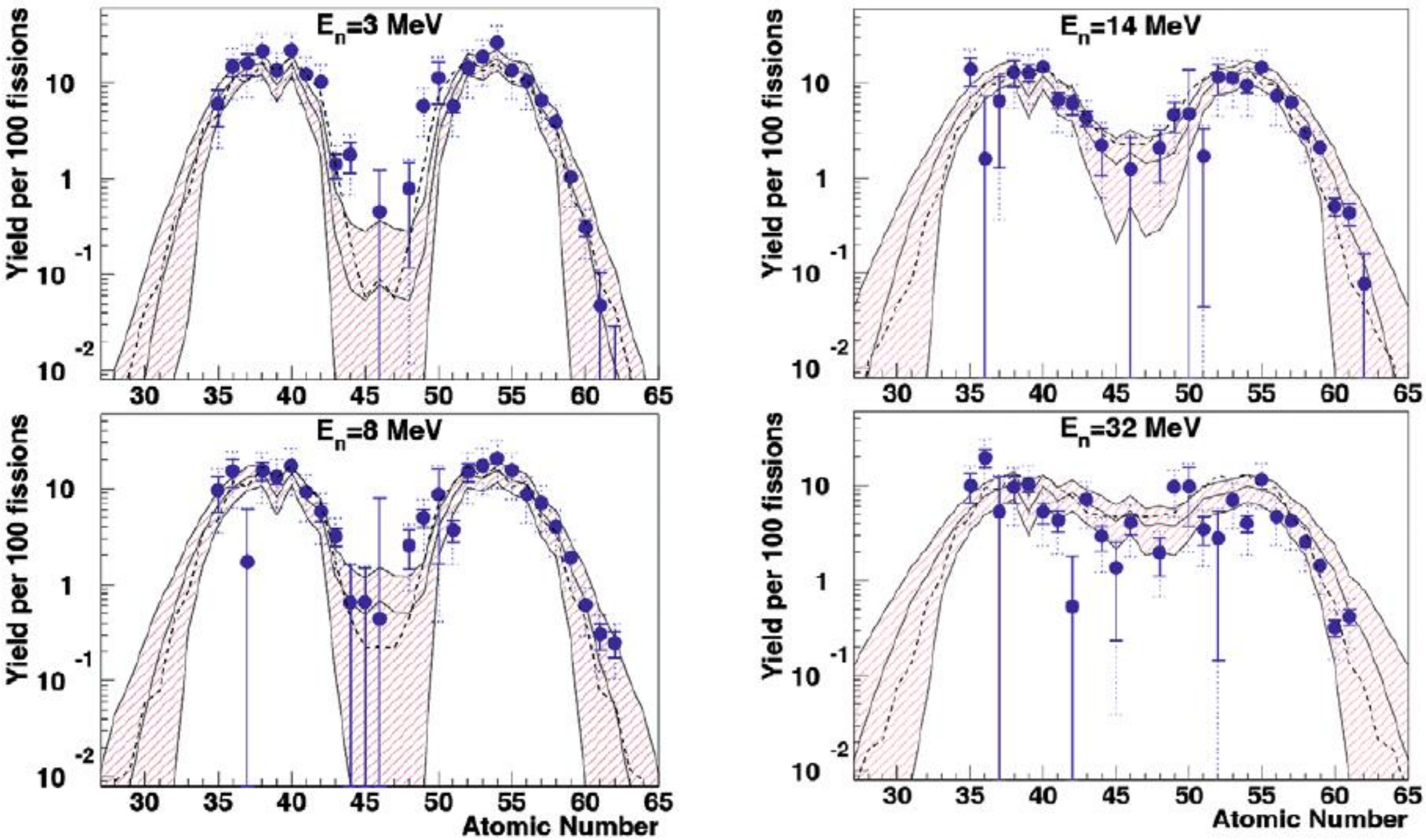
Charge yields inferred from K X-ray yields



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Inferred charge yields for 180 MeV

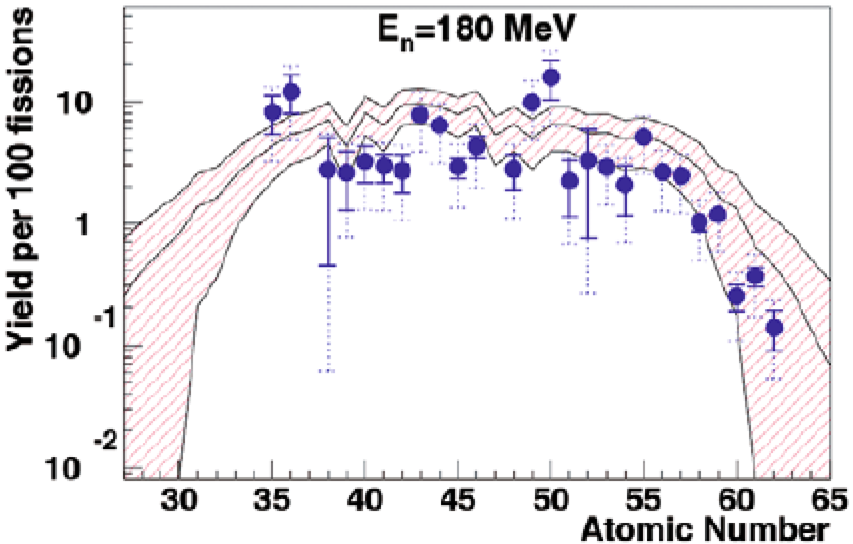

Fig. Charge distributions determined from the X-ray yield measurements (symbols). Top: threshold–6 MeV, $\langle E_n \rangle \simeq$ 3 MeV. Bottom: 6–11 MeV, $\langle E_n \rangle \simeq$ 8 MeV. Solid error bars correspond to propagated fit errors, dotted error bars correspond to the sum in quadrature of the fit error and the 50% relative uncertainty associated with $K(Z)$. Dashed curve is the result of the GEF code by Schmidt-Jurado [43] (see text). Solid curve within hatched area corresponds to Wahl systematics and associated uncertainty obtained for the corresponding energy ranges.

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Future

- High-energy neutron-induced fission of actinides provides a window for spectroscopy of a range of neutron-rich nuclei
- X-ray – gamma-ray coincidences can provide new information on energy levels of specific neutron rich nuclei
- Fission X-ray-gamma-ray coincidence experiments have been proposed using increased actinide mass in a fission counter to enable x-ray-gamma-ray coincidence studies with sufficient statistics

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