Total kinetic energy release in fission

W. Loveland
Oregon State University
Goals of Project

• Understanding the physics of the TKE release in fission and its variation with excitation energy of the fissioning system
• Relative role of Coulomb and dissipative forces in this large scale nuclear collective motion
• Practical applications
Vital statistics/deliverables

• Date project started: 07/01/2016
• Individuals supported:
  • J.S. Barrett, J. King, R. Yanez, L. Yao, V. Desai, K. McCaleb

• Graduates (Lab employment):
  • J.S. Barrett, (Ph.D., now in medical physics, Oklahoma)
  • J. King (now NNSA fellow, Ph. D. thesis defense 3/15/2018)
  • L. Yao (thesis defense March 2018, looking for a job)
  • K. McCaleb (M.S. 2017, Albany Molecular Research, NY)


Experimental

- Expt. done at LANSCE using WNR “white” neutron spec

Neutron energies determined by time of flight with an uncertainty of 4.7%
Expt'l Details

• $^{232}$Th target, 178.9 ug/cm$^2$ $^{232}$Th on 100 ug/cm$^2$ C, 99.99% $^{232}$Th
• $^{233}$U target, 108.3 ug/cm$^2$ $^{233}$U on 100 ug/cm$^2$ C, 99.9% $^{233}$U
• $^{235}$U target, 175.5 ug/cm$^2$ $^{235}$U on 100 ug/cm$^2$ C, 98.12% $^{235}$U
• $^{239}$Pu target, 129.5 ug/cm$^2$ $^{239}$Pu on 100 ug/cm$^2$ C, 99.92% $^{239}$Pu
Flight path geometry
Fission fragments detected by 4 pairs of 1 cm$^2$ Si PIN diode detectors positioned 2.1 cm from the target.
Corrections applied to raw data

- Pulse Height Defect of Detectors (Schmitt calibration with $^{252}\text{Cf}$)
- Fragment energy loss in target and backing (Northcliffe-Schilling)
Benchmarking the data

• The same apparatus, detectors, targets etc were used at the OSU TRIGA reactor to measure the TKE release in the thermal neutron induced fission of $^{235}\text{U}$.

• The measured post neutron emission TKE was measured to be $169.8 \pm 0.4 \text{ MeV}$ in agreement with the known value of $169.1 \pm 0.5 \text{ MeV}$

• A similar comparison was done for $^{233}\text{U}(n_{th},f)$ and $^{239}\text{Pu}(n_{th},f)$

• No normalizations of the data were made.
  • **OUR MEASUREMENTS ARE ABSOLUTE MEASUREMENTS!!**
Our results (TKE distributions)

\[ ^{232}\text{Th}(n,f) \quad ^{233}\text{U}(n,f) \]
Our results (cont.)

$^{235}\text{U}(n,f)$

$^{239}\text{Pu}(n,f)$
TKE($E_n$)
Comparison to Other Data

\[ ^{235}\text{U}(n,f) \]
Comparison to Other Data

![Comparison to Other Data](image)
Viola scaling?

- Viola et al. has suggested a simple semi-empirical formula for calculating the TKE release in spontaneous and thermal neutron induced fission

\[ TKE(MeV) = 0.1189 \frac{Z^2}{A^{1/3}} + 7.3 \]

Suppose we were to scale all the TKE\( (E_n) \) data to \(^{235}\text{U}(n,f)\) using the Viola scaling factors?
Variance of TKE distributions

(a) 

\[ \sigma_{\text{TKE}}^2 (\text{MeV}^2) \]

![Graph](image1.png)

(b) 

\[ \tau_E (b) \]

![Graph](image2.png)

\[ ^{235}\text{U}(n,f) \]

\[ ^{232}\text{Th}(n,f) \]
$^{232}$Th(n,f) - Mass Yields
$^\text{235}\text{U}(\text{n},\text{f})$
$^{233}\text{U}(n,f)$  

$^{239}\text{Pu}(n,f)$
Comparison with **predictive fission models**

- **GEF** The GEF code calculates pre-neutron and post-neutron fission-fragment nuclide yields, angular-momentum distributions, isomeric yields, prompt-neutron yields and prompt-neutron spectra, prompt-gamma spectra and several other quantities for a wide range of fissioning nuclei from polonium to seaborgium in spontaneous fission and neutron-induced fission. K.-H. Schmidt and B. Jurado, NDS 131, 107 (2016)

- **GEF** will also allow one to convert the dependence of various quantities on $E_n$ to dependence on $E^*$ because it knows about multiple chance fission.

- **GEF** will also allow comparisons between $(n,f)$ and $(p,f)$ reactions
$^{235}$U(n,f)
$^{235}\text{U}(n,f)$

TKE$_{\text{post}}$ (MeV) vs. $E_n$ (MeV)

- **Expt.**: Experimental data points
- **GEF**: Model fit

The graph shows the trend of TKE$_{\text{post}}$ with varying $E_n$ for $^{235}\text{U}(n,f)$ reactions.
$^{235}$U(n,f)
A conversation on widths/variances

FIG. 18. Root-mean-square widths of the over-all total fragment kinetic energy distributions for $^{233}\text{U}(\rho,f)$, $^{235}\text{U}(\rho,f)$, and $^{238}\text{U}(\rho,f)$, as functions of compound-nucleus excitation energy.

Ferguson et al., PRC 7, 2510
Lessons Learned

• The TKE release in the fast neutron induced fission of $^{235}\text{U}$ decreases 8.3 +- 0.6 MeV when $E_n$ varies from 0 to 90 MeV. (~ 4.9%). Most of the available energy of the incoming neutron does not go into collective motion in fission. The mean distance between the fragments at scission is nearly constant. A similar situation occurs for $^{232}\text{Th}(n,f)$, $^{233}\text{U}(n,f)$ and $^{239}\text{Pu}(n,f)$.

• This modest decrease is not due solely to the increasing yield of symmetric fission events which have a lower TKE.

• The variances of the TKE distributions reflect the onset of multiple chance fission and are constant for $E_n = 20-90$ MeV.
3rd Year Program

- Reduce statistical uncertainties in $^{233}\text{U}(n,f)$ and $^{239}\text{Pu}(n,f)$ TKE data.
- Measure $\nu(A,E^*)$ and $\nu(E^*)$ for the fast neutron induced fission and proton induced fission of $^{232}\text{Th}$, $^{233}\text{U}$, $^{235}\text{U}$ and $^{239}\text{Pu}$, segregating the neutrons by origin, i.e., pre-equilibrium, pre-fission and post-fission.