The University of New Mexico
Fission Fragment Spectrometer

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Part of the LANL SPIDER collaboration

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UNM Fission Fragment Spectrometer

• Motivation for fission fragment data
• Method
• Hardware
• Characterization and preliminary results
• Next steps
• Summary
The desired data to understand fission, delayed radiation
The desired data to understand fission, delayed radiation

Basically have
Fission cross section
some A distributions

Some frag. distributions N,Z
for thermal, fast, 14 MeV n

 Want N,Z distributions,
fragment cross sections,
over range of En
Motivation – fission theory

Yield varies with fission target, energy. Need data to work back to fission preformation states.

P. Möller et al., Nature 409, 785-790 (15 February 2001)
Motivation – active interrogation
Delayed signal from $\beta$, $\beta(n)$ decay

Delayed radiation:
Beta decay, gamma emission, some neutron emission

<table>
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<tr>
<th>43</th>
<th>Tc 94 4.883h</th>
<th>Tc 95 61d</th>
<th>Tc 96 4.28d</th>
<th>Tc 97 2.6e+06y</th>
<th>Tc 98 4.2e+06y</th>
<th>Tc 99 2.11e+05y</th>
<th>Tc100 15.46s</th>
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<td>42</td>
<td>Mo 93 4000y</td>
<td>Mo 94 9.25</td>
<td>Mo 95 15.92</td>
<td>Mo 96 16.68</td>
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<td>Mo 98 24.13</td>
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<td>Nb 93 100</td>
<td>Nb 94 2.03e+04y</td>
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<td>Nb 96 23.35m</td>
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<td>40</td>
<td>Zr 91 11.22</td>
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<td>Zr 93 1.53e+06y</td>
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<td>Zr 96 2.8</td>
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<td>Y 92 3.54h</td>
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<td>Sr 93 7.423m</td>
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<td>Rb 91 58.42s</td>
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<td>Kr 87 1.272h</td>
<td>Kr 88 2.84h</td>
<td>Kr 89 3.15m</td>
<td>Kr 90 32.32s</td>
<td>Kr 91 8.5</td>
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<td>35</td>
<td>Br 86 55s</td>
<td>Br 87 55.6s</td>
<td>Br 88 16.5s</td>
<td>Br 89 4.4s</td>
<td>Br 90 1.92s</td>
<td>Br 91 0.541s</td>
<td>Br 92 0.343s</td>
<td>Br 93 0.102s</td>
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</table>

Br91 (0.5s) $\rightarrow$ Kr91 (8.6s) $\rightarrow$ Rb91 (58s) $\rightarrow$ Sr91 (9hr) $\rightarrow$ Y91...

http://wwwndc.jaea.go.jp/CN10/CN010.html
The plan: Measure fission fragments vs. $N$ energy, event by event
Pulsed $P$ beam on $N$ convertor
$N$ on fission target

Neutron Time Of Flight to fission target gives $E_n$
Method, E-v spectrometer

TOF followed by Ionization Chamber: TOF-IC
A, Z, E measurements

\[ v:\ \text{TOF} \]
\[ E:\ \text{Ionization chamber} \]
\[ A:\ \frac{m}{v^2} = \frac{2Et^2}{l^2} \quad \frac{\delta m}{m} = \sqrt{\frac{\delta E}{E}^2 + \left(\frac{2\delta t}{l}\right)^2 + \left(\frac{2\delta l}{l}\right)^2} \]

\[ Z:\ \text{Ionization chamber rewiring and analysis, will describe} \]

\[ N:\ \text{A and Z } \Rightarrow \text{ N} \]

Moving towards dual arm for UNM Fission Fragment Spectrometer: get TKE, v
Mass Resolution Requirements

**light fragments**

\[ m = \frac{2E}{\sqrt{\nu^2}} = \frac{2Et^2}{l^2} \]

\[ \frac{\delta m}{m} = \sqrt{\left(\frac{\delta E}{E}\right)^2 + \left(2\frac{\delta t}{t}\right)^2 + \left(2\frac{\delta l}{l}\right)^2} \]

fwhm/centroid = 1/90 = 1.1%

**PUSHING TO heavy fragments**

fwhm/centroid = 1/140 = 0.7%

Interplay of variables

L good, for 1 m need < 7mm

really depends on E and t

absolute max

need \( \delta E/E < 0.7\% \)

need \( \delta t/t < 0.35\% \)

A separation from Cosi Fan Tutte spectrometer

Overview of Instrumentation
Time-of-Flight

- Electrostatic mirror
  - Inner grid: -2.2 kV
  - Outer grid: -6.2 kV
- Insulating frames
  - Carbon foil: -4.2 kV
- Acceleration grid
  - -2.2 kV
- Channel plates
  - -1.2 kV
  - -0.2 kV

- Anode: 0 V

- Sample

- Fission fragment

- TOF Data
  - Entries: 2236
  - Mean: 6.388e+04 ± 6.39e+04
  - RMS: 839.9
  - $\chi^2 / \text{ndf}$: 50.39 / 30
  - Constant: 58.25 ± 2.57
  - Mean: 6.39e+04 ± 5.61e+00
  - Sigma: 158.2 ± 5.4
Overview of Instrumentation
Ionization Chamber

Pu, Am, Cm alpha source
<1.5% resolution, ff expect <0.4% fwhm/centroid

Designs following Oed et al.
NIM 205 (1983) 455-459
January 2014 results from $n + ^{235}U$ at LANSCE

TOF

IC: Energy

80 MeV

110 MeV
Recent Characterization Results
Ionization Chamber

$^{239}\text{Pu} + ^{252}\text{Cf}$ alphas

IC data overnight, low drift, < 2% E resolution alphas

$^{239}\text{Pu} + ^{252}\text{Cf}$

IC: fragment data
Recent Characterization Results

Time Of Flight

$^{252}\text{Cf}$ and $^{239}\text{Pu}$ alphas, 1m, 200 ps sigma

Alphas 63 and 68 ns, 0.7% resolution

resolution with 100 $\mu$g/cm$^2$ C foils

Changing to 20 $\mu$g C foils, lower straggling

especially for fragments - higher Z

→ improve TOF resolution
Recent Characterization Results

Time Of Flight

252Cf, 239Pu alphas
50 cm TOF

Fission fragments from Cf (50 cm TOF)
Next Steps

• Correlated TOF/KE data $\rightarrow$ extract mass distribution

• Improve Resolution:
  – Thinner TOF foils $\rightarrow$ less t straggling
    • from 100 to 20 ug C foils
  – Thinner IC window $\rightarrow$ less E straggling
    • switched to 1.5 um mylar (from 2.5)
    • will change to 0.2 $\mu$m SiN

• Z information from Ionization Chamber will have A,Z,N, KE

• Dual arm: direct measurement of TKE, $\nu$
Z determination - Bragg curve analysis (≥ 1MeV/amu, light fragments)

Bragg curves in P-10 gas tri-nuclide α source similar peaks, different integrals (fast vs. slow amps)

UNM FFS Pu and Cf

Range follows Bethe formula $Z, \nu$ (thus $E, m$) dependent SRIM calc. fission fragments (300 torr P-10)

$^{140}$Xe, 70 MeV

$^{90}$Sr, 115 MeV

$^{80}$Ge, 121 MeV
Z determination - Active Cathode
(> 0.5 MeV/amu, light and heavy)

Range is Z dependent
Measure range from Cathode time vs. anode time using e drift velocity

Range Z dependent

Measure range from Cathode time vs. anode time using e drift velocity

UNM FFS: $\Delta t$ vs. $E$ Plotted, Cf and Pu preliminary
Summary

- Prototyped Fission Fragment Spectrometer
  - TOF
  - Ionization Chamber
  - Tested with Cf at UNM, $n^+{}^{235}U$ at LANSCE
- Correlating TOF and KE for mass spectra
- Improving resolution
- Ionization Chamber tests for Z determination
  - Bragg spectroscopy
  - Active Cathode
- Implementing Z determination in full TOF/IC spectrometer
Thank you

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• Rick Blakeley - TOF
• Lena Heffern - IC
• James Cole - IC
• Graduated MS student Drew Mader - IC

Undergraduate students
• Paul Gilbreath
• Corey Vowell

SPIDER collaboration

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