First Results of Fission Mass Yield Measurements with SPIDER at LANSCE

FIESTA Workshop
Santa Fe, NM
September 12, 2014
Anticipated Benefits - Applications

- Improved input for calculations and simulations

Example of current mass yield distribution

Simulation of mass yield distribution using expected SPIDER measurements

- Interpretation of data collected from device tests

Predictions for $A=148$ (Green) $A=147$ (Red) $A=147$ Uncertainty (Black)

$^{147}$Nd fission yield vs incident $E_n$
Anticipated Benefits – Fundamental Studies

- Comparison to sophisticated fission models
  - LANL nuclear potential-energy model (P. Moller)
  - Model dynamic evolution of fission across the potential-energy surface (A. Sierk)
  - Probe initial conditions (J. Lestone)

Two dimensional energy surface of fissioning $^{236}\text{U}$

$^{236}\text{U}$ fission, $E_n \sim 0.005$ MeV
SPIDER Project Goals

- Measure fission-fragment yields as a function of \((E_n, Z, A, TKE)\)
  - Our measurements will reach 2-5% accuracy from 0.01 eV to 20 MeV

- Develop theory in order to evaluate fission yield data
  - Model dynamic evolution of fission across the potential-energy surface (A. Sierk)

- Provide an evaluation of the Pu-239 fission yields
  - Blend the best of experiment and theory (J. Lestone)

Predictions for
\(A=148\) (Green) \(A=147\) (Red)
\(A=147\) Uncertainty (Black)
The 2E-2v method with SPIDER

- Neutron beam hits actinide target, inducing fission into two main fragments
- Mass ($M$) of both outgoing fission products are determined by measuring each fragments time of flight ($t$), energy ($E$), and path length ($l$)

$$M = \frac{2Et^2}{l^2}$$

$M =$ mass
$E =$ energy
$t =$ time
$l =$ length
SPIDER arm pair prototype

- Time-of-Flight
- Energy
- Flight Path Length

- 7ft
- 5ft

- Particle trajectory
- Neutron beam
- Target
High Resolution Measurement

- Using the 2E-2v method the mass of each product can be measured with improved resolution

**Equation to determine mass resolution**

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

\( M \) = mass, \( E \) = energy, \( t \) = time, \( l \) = path length

**Mass Measurement Goal:**

\[
\frac{\delta M}{M} = 1 \text{AMU or } A = 85 \rightarrow 155 : 1.2\% \text{ to } 0.65\%
\]

This translates into individual measurements resolution as:
- \( \frac{dE}{E} \rightarrow \leq 0.5\% \),
- \( \frac{dl}{l} \rightarrow \leq 0.02\% \),
- \( \frac{dt}{t} \rightarrow \leq 0.7\% \text{ to } 0.3 \% \)
- or \( A \ 85 \rightarrow 155 : 1.32\% \text{ to } 0.72\% \)
Time-of-flight and Position Measurements

- 70 cm flight path
  - Distance between conversion foils
- Micro channel plates (MCP)
  - Chevron configuration
  - 12 µm channel diameter = fast timing
- RoentDek Delay-line anode
  - (x,y) position readout
  - 1-2 mm resolution achieved with similar size and arrangement
Time-of-flight Resolution

- Characterized with Th-229 α-source
- Five main α-lines with energies between 4.8 and 8.4 MeV

TOF Data (black) and Simulation

**Temporal resolution**

$\Delta t=250\text{ps (FWHM)}$
Time-of-flight Detector Efficiency

- The efficiency of the TOF detectors is about 70% for α-particles
- Based on previous work we expect the efficiency for fission fragments to be significantly higher
- Efficiency is not very sensitive to accelerating potential or temporal resolution
Spatial Resolution

- Applied a mask in front of carbon conversion foil

- Overall path length uncertainty: <0.1 %.

- Will ultimately use position information to correct for flight path length
  - Need 8 signals per path length – requires high statistics based on relative high percentage for all signals

Position resolution
2 mm
Energy Measurement

- Axial ionization chamber
  - Isobutane fill gas
  - ~28 sccm flow rate
  - 8 cm path length
  - ~5.5 cm/s electron drift

- Entrance window
  - Started with 2.5 µm Mylar
  - Testing 200 nm silicon nitride membranes, which has been shown to greatly reduce energy losses and straggling

Kottler et al, Paul Scherrer Institute and ETH Zurich, Switzerland
Energy Resolution

Alphas

Energy Resolution
1% for alpha-particles

252Cf
SPIDER Installation

- Fall 2013 - first experiments with spontaneous fission of $^{252}\text{Cf}$ and thermal neutron spectrum on $^{235}\text{U}$, using half an arm pair (1E-1v measurement)

Details
- 100 ug/cm² UF₄ on 100 ug/cm² C
- “Thick” Mylar window: 2500 ug/cm²
- Neutron time-of-flight was recorded
First Results –
One-arm operation, Mylar entrance window

Preliminary thermal $^{235}\text{U}$ mass yield

Spontaneous fission $^{252}\text{Cf}$
New Entrance Window

- Recently moved to using 200 nm silicon nitride membranes, which has been shown to greatly reduce energy losses and straggling.

Window energy loss and straggling TRIM calculations
Energy loss and straggling of 100 MeV light fragment (Tc-97) in different windows

- 2500 nm Mylar: \(dE = 21\) MeV, straggling = 1.8 MeV (1.8%)
- 200 nm Si\(_3\)N\(_4\): \(dE = 3.25\) MeV, straggling = 320 keV (0.3%)
New Entrance Window

Raw Cf Energy Histograms

Mylar Window

Silicon nitride Window
First Results –
One-arm operation, silicon nitride entrance window
First Results –
One-arm operation, silicon nitride entrance window

Preliminary
Further Analysis

- Verify calibration constants
- Known dependencies in TOF measurement
  - Time
  - Position
- Verify energy correction through silicon nitride window
- Add path length calculation from position signals
  - If statistics allow

Shift in Cf alpha peak position over time
Arm pair prototype operation

- **2014-2015 Run Cycle**
  - Thin backing U235 at Lujan (thermal)
  - Thick backing Pu239 at Lujan (thermal)
  - U235 at WNR (no energy binning due to expected low statistics)
Full SPIDER Detector

- **Multiple detectors increases efficiency**
  - Current design calls for 9 arm pairs
    - 36 timing detectors
    - 18 ionization chambers
  - System Challenges
    - large high vacuum ($10^{-7}$ torr) volume
    - 18 vacuum - gas detector interfaces
    - flowing gas system to 18 separate chambers
  - More measurements to be done
    - Lots of interesting actinides have low resolution yields measurements
Summary

- SPIDER is providing improved yield measurements and correlated details about fragment masses, charges, and energies over a wide range of incident neutron energies.
- New SPIDER detector will measure high resolution fission yields as a function of:
  - Incident neutron energy
  - Fragment mass
- Reached individual goal resolution capabilities:
  \[ \frac{dE}{E} \rightarrow \leq 0.5\% \quad \checkmark \]
  \[ \frac{dl}{l} \rightarrow \leq 0.02\% \quad \checkmark \]
  \[ \frac{dt}{t} \rightarrow \leq 0.7\% \text{ to } 0.3\% \quad \checkmark \]
- First 1E-1v measurements of \(^{252}\text{Cf}(sf)\) with silicon nitride window.
- Will take first 2E-2v measurements fall 2014:
  - Both at Lujan (thermal) and WNR.
The SPIDER Collaboration

- **Los Alamos National Laboratory (LANL)**
  Charles Arnold, Todd Bredeweg, Tom Burr, Matt Devlin, Mac Fowler, Marian Jandel, Justin Jorgenson, Alexander Laptev, John Lestone, Paul Lisowski, Rhiannon Meharchand, Krista Meierbachtol, Peter Moller, Ron Nelson, John O’Donnell, Arnie Sierk, Fredrik Tovesson, Morgan White

- **University of New Mexico (UNM)**
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- **Colorado School of Mines (CSM)**
  Uwe Greife, Bill Moore, Dan Shields, Sergey Ilyushkin

- **Lawrence Livermore National Laboratory (LLNL)**
  Lucas Snyder

- **Lawrence Berkeley Laboratory (LBL)**
  Jorgen Randrup
Individual Measurement Resolutions

- **Resolution: ~0.6% (coinc)**
  - Time of flight measurement for 5 alpha particles

- **Resolution: 1%**
  - Energy measurement for 5 alpha energies

- **Resolution: 0.004%**
  - Position measurement with a 1 cm mask

- **Resolution: ~0.6%**
  - Energy measurement for 252Cf fission products