Fission studies with TPC and SPIDER: current status and future directions

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Outline

- Introduction
- The Los Alamos Neutron Science Center (LANSCE)
- Fission Research
  - Cross sections (TPC)
  - Fragment properties (SPIDER, Gridded ionization chambers)
- Outlook and Summary
Introduction

- We are in the midst of a fission renaissance
  - There is a surge in experimental efforts
    - Fragment spectrometers (STEFF, SPIDER, VERDI)
    - Inverse kinematics fission studies (GSI, GANIL, RIKEN)
    - Surrogate reactions (TAMU)
    - The fission Time Projection Chamber (TPC)
    - Activation measurements (TUNL)
  - Exciting theory developments
    - Macroscopic-microscopic model
    - Microscopic model
    - Monte Carlo method for fragment de-excitation

- What can we learn from new experiments?
  - More correlated information
  - Systematic studies of many systems, excitation energies
  - Improve accuracy & precision – uncertainty quantification (UQ)
The Los Alamos Neutron Science Center (LANSCE)

- Spallation neutron source
- Moderated & un-moderated flight paths
- Neutron time-of-flight
LANSCE provide neutrons from thermal to hundreds of MeV

- High neutron flux over the full energy range
- Excellent resolution for fast neutrons, reasonable for slow neutrons
Nuclear Science Capabilities

**TPC**
- Fission cross sections

**Chi-Nu**
- Neutron output

**DANCE**
- Neutron capture, fission γ-rays

**GEANIE**
- Gamma production, Pu(n,2n)

**SPIDER**
- Fission yields

**APOLLO**
- γ-rays for ion beam experiments
**Fission Cross Sections**

- **F. Tovesson, A. B. Laptev, T. S. Hill**, *Fast neutron-induced fission cross sections of $^{233,234,236,238}$U up to 200 MeV*, accepted for publication in Nucl. Sci Eng.
- **F. Tovesson, T. S. Hill**, *Cross section for $^{239,241}$Pu(n,f) in the range $E_n = 0.01$ eV to 200 MeV*, Nucl. Sci. Eng. 165, 224 (2010).
The TPC will reduce measurement uncertainties to 1%

- **Beam**
  - Time-of-flight uncertainty 0.3%
  - Beam profile 0.1%
  - Neutron background 0.2%

- **Target**
  - Total number of atoms 0.3%
  - Uniformity of deposit 0.3%
  - Contaminants 0.1%

- **Fission detection**
  - Efficiency 0.1%
  - Dead-time 0.2%
  - Fission identification 0.2%

- **Normalization**
  - Accuracy of standard reaction 0.3%

Total uncertainty: 0.7%
The fission TPC was miniaturized for fission studies

- ~4π solid angle coverage
- MICROMEGAS detector
  - 5952 readout pads
- Custom digital electronics
  - $55/channel, 30 MB/s sustained data rates
- Large dynamic range - designed for normalization to H(n,n)H
- Complete software suite includes remote online monitoring and detailed GEANT-based simulation

The U-238(n,f) cross section is our benchmark
Fission fragment properties are studied with SPIDER and 2E

- Fragment mass, charge, energy
- Total kinetic energy (TKE)
- Neutron energy dependence

SPIDER (2E-2v)
- High resolution, low efficiency

Gridded IC (2E)
- Low resolution, high efficiency
High resolution mass yields are measured with SPIDER

- The 2E-2v method can provide 1 amu resolution for light fragments
  - Demonstrated with Cosi-fan-Tutti at ILL
- SPIDER uses ionization chambers for energy measurement
  - 1% energy resolution for α-particles, 0.5% for fission fragments
  - Thin entrance window (mylar or SiN)
- Fast, position sensitive TOF detectors
  - Carbon conversion foils
  - Electrostatic mirror
  - Micro-channel plates
  - Delay-line anode
Performance of TOF detectors and ionization chambers meets requirements

- 200 ps coincidence resolution
- 1% energy resolution for alpha-particles
- 2 mm position resolution

Mass yields in $^{252}\text{Cf}(n_{\text{th}},f)$ was measured with one arm instrumented.

- Hit position on **start** detector
- Hit position on **stop** detector

- Fission fragment TOF
  - $1E-1v$
  - $10^5$ Bq $^{252}\text{Cf}$ source
  - 20 $\mu$g/cm$^2$ carbon conversion foils for TOF measurement
  - 64 $\mu$g/cm$^2$ Si$_3$N$_4$ window between vacuum and IC

- Fragment energy
Preliminary mass yield agrees well with literature

\[ ^{252}\text{Cf(sf)} \] Fission Product Yield

- England & Rider
- SPIDER w/ SiN (1 amu bins)

PRELIMINARY
The 2E-method provides mass yields with 4-5 amu resolution

- Kinetic energy of both fragments are measured in coincidence
- The fragment masses are calculated using mass and momentum conservation
- Measurements performed with Frisch-gridded ionization chambers
  - High efficiency
  - Provide emission angle information
- Requires correction for
  - Grid inefficiency
  - Energy loss in target
  - Pulse height defect
  - Nu-bar(A) (“saw tooth”)
A new digital DAQ was developed for the IC measurements

- The large neutron energy range poses a challenge for the DAQ system design
- 12-bit digitizers (CAEN V1720) with 250MHz sampling rates provide sufficient energy and timing resolution
- On-board memory and triggering management allows virtually dead-time less operation
- Digital signal processing allows for better pile-up handling

Mass yields and TKE were measured for $^{235,238}\text{U}$

- Data was collected for U-235 and U-238, analysis in progress
- Plans to measure Pu-239 in fall 2014 / spring 2015

Preliminary
Future developments

- **Time Projection Chamber**
  - Further reduce fission cross section uncertainties
  - Fission fragment studies with Bragg spectroscopy and track length
  - Neutron-induced light charged-particle emission: cross sections and angular distributions
  - Ternary fission studies

- **SPIDER**
  - Study fission yields at fast neutron energies (increase efficiency)
  - Fission fragment studies of several isotopes
  - Correlation between fragments and neutron- and gamma emission
Summary

- The LANSCE facility provides the capability to study fission over ten decades of incident neutron energy.
- Fission cross section have been studied extensively at LANSCE; the Time Projection Chamber will significantly improve the accuracy.
- Fission fragments properties are being studied by a combination of high resolution, low efficiency and low resolution, high efficiency detectors.
- Future developments will further reduce uncertainties on nuclear data and provide a more complete picture of the fission process.
Collaborations

- Lawrence Livermore Nat. Lab.
- Oregon State
- Cal Poly
- Colorado School of Mines