Fission cross section and fragment property measurements at LANSCE

Fredrik Tovesson
Los Alamos National Laboratory

16th ASRC Workshop "Nuclear Fission and Structure of Exotic Nuclei", March 18-20, 2014, Tokai, Japan

Outline

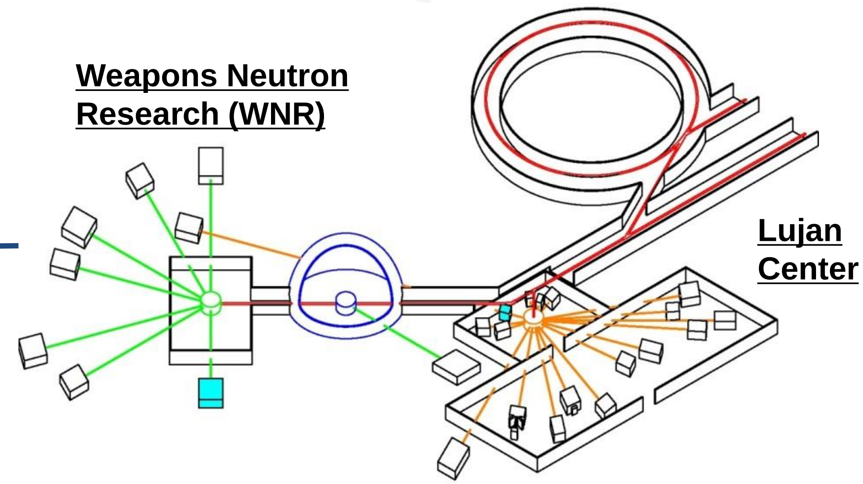
- Introduction
- The Los Alamos Neutron Science Center (LANSCE)
- Fission Research
  - Cross sections
    - Ionization chambers
    - TPC
  - Fragment properties
    - SPIDER
    - Gridded ionization chambers
- Summary

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,CENBG)
    - The fission Time Projection Chamber (TPC)
  - Exciting theory developments
    - Macroscopic-microscopic model
    - Microscopic models
    - 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)

Isotope Production

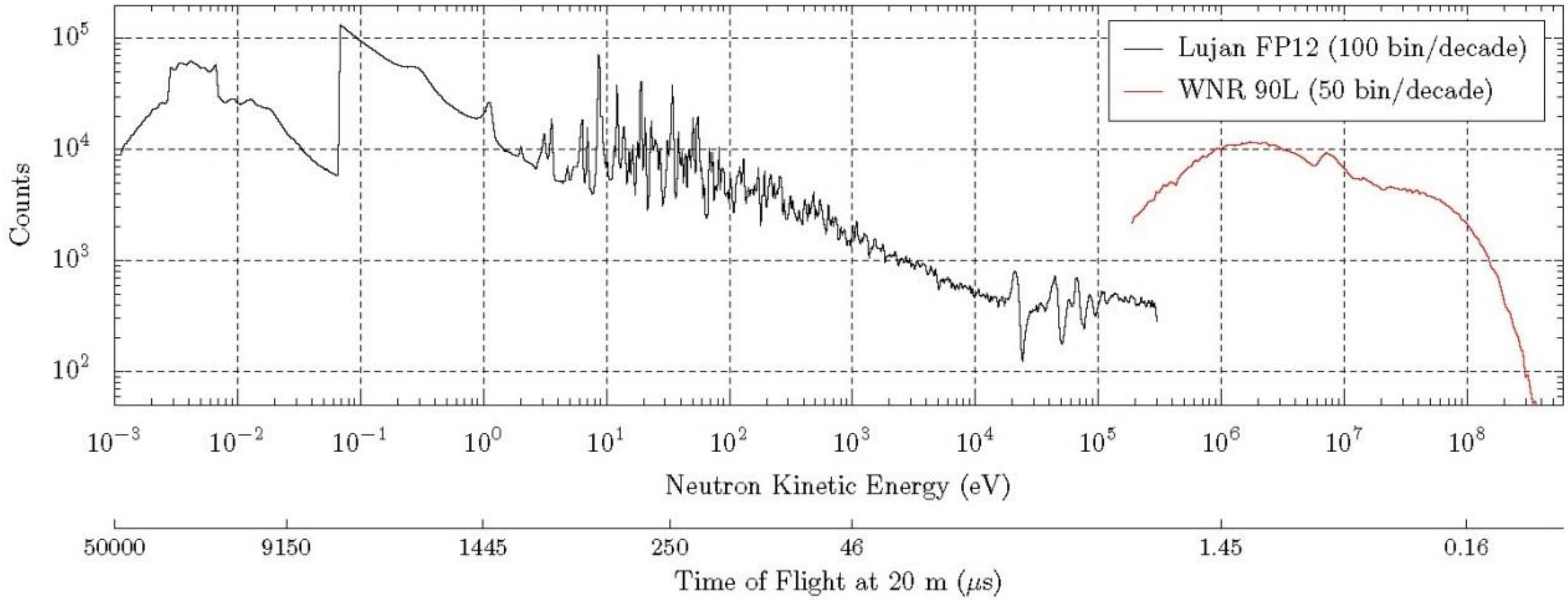


Proton Radiography

UCN Experiment

- Spallation neutron source
- Moderated & un-moderated flight paths
- Neutron time-of-flight

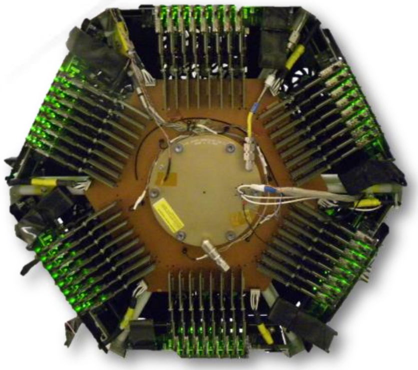
LANSCE provide neutrons from thermal to hundreds of MeV



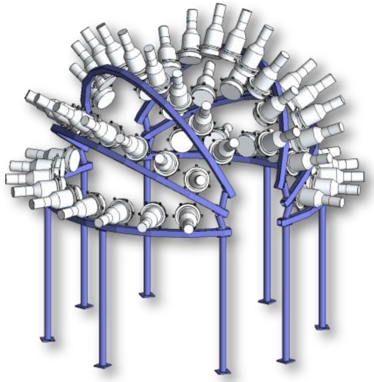
- High neutron flux over the full energy range
- Excellent resolution for fast neutrons, reasonable for slow neutrons

Nuclear Science Capabilities

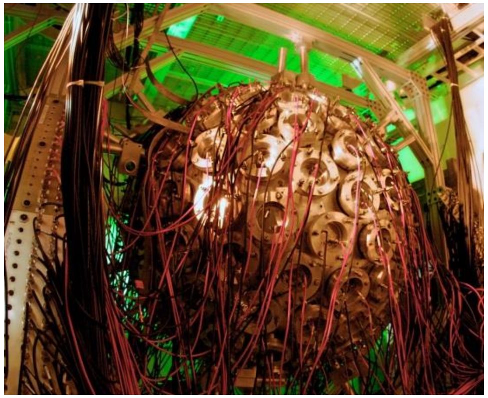
TPC
fission cross sections



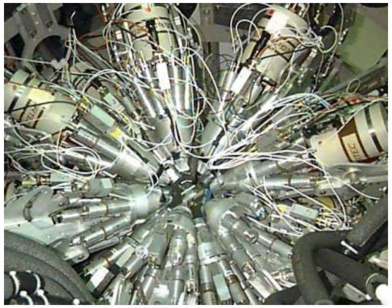
Ch-Nu
neutron output



DANCE
neutron capture, fission ɣ-rays

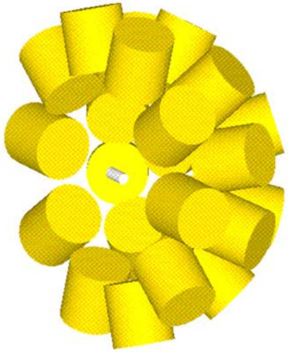


GEANIE
gamma production, Pu(n,2n)

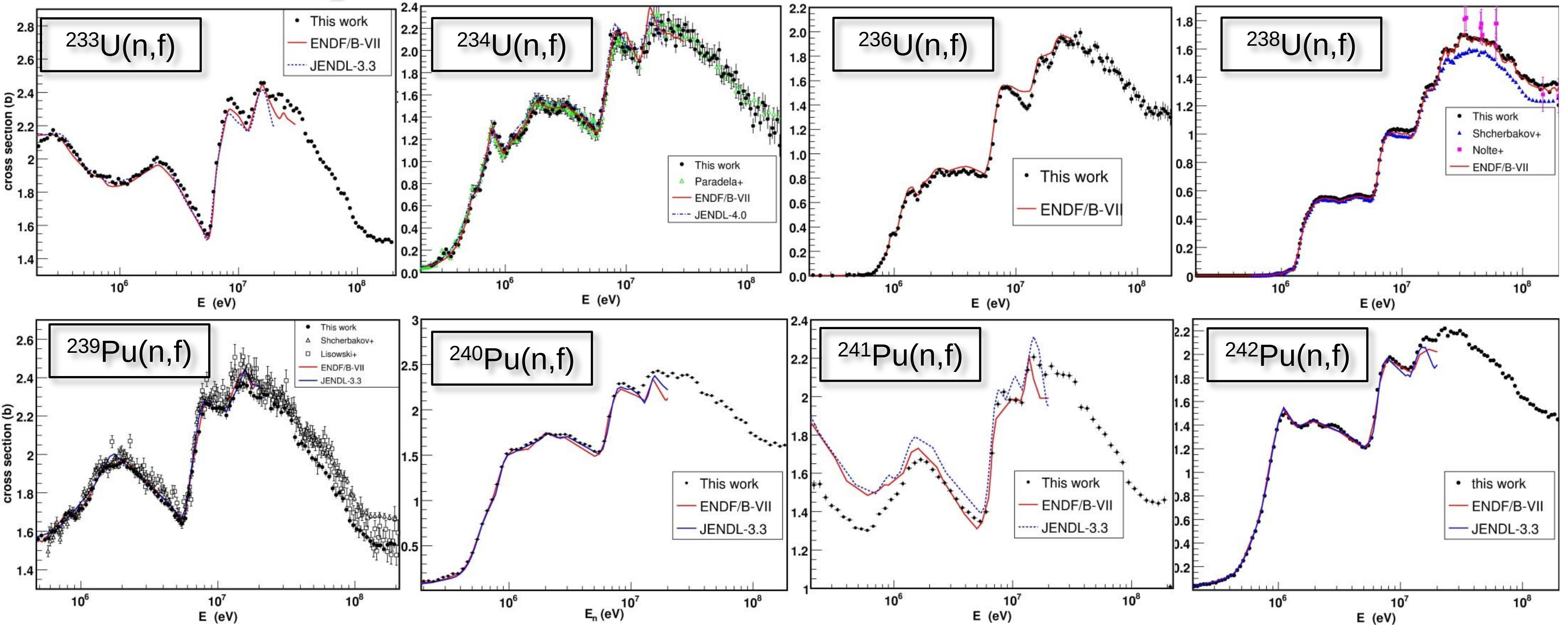


SPIDER
fission yields

APOLLO
ɣ-rays for ion beam experiments



Fission Cross Sections



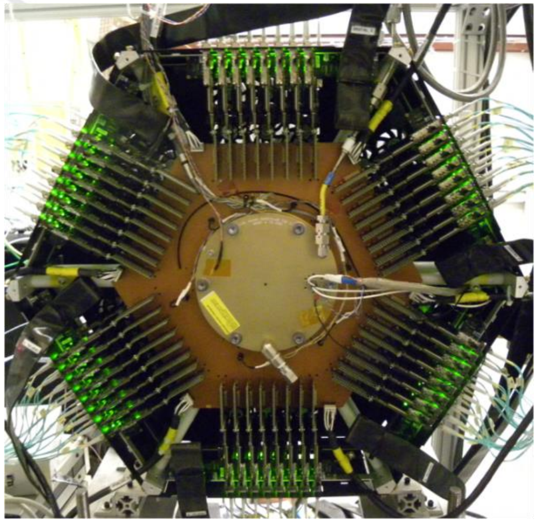
- **F. Tovesson**, A. B. Laptev, T. S. Hill, *Fast neutron-induced fission cross sections of ^{233,234,236,238}U up to 200 MeV*, accepted for publication in Nucl. Sci Eng.
- **F. Tovesson**, T. S. Hill, *Cross section for ^{239,241}Pu(n,f) in the range E_n= 0.01 eV to 200 MeV*, Nucl. Sci. Eng. **165**, 224 (2010).
- **F. Tovesson**, T. S. Hill, M. Mocko, J. D. Baker, C. A. McGrath, *Neutron Induced Fission of ^{240,242}Pu from 1 eV to 200 MeV*, Phys. Rev. C **79**, 014613 (2009).

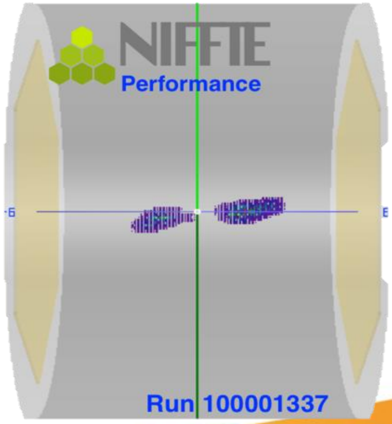
The TPC will reduce measurement uncertainties to 1%

Los Alamos NATIONAL LABORATORY EST.1943

- **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%

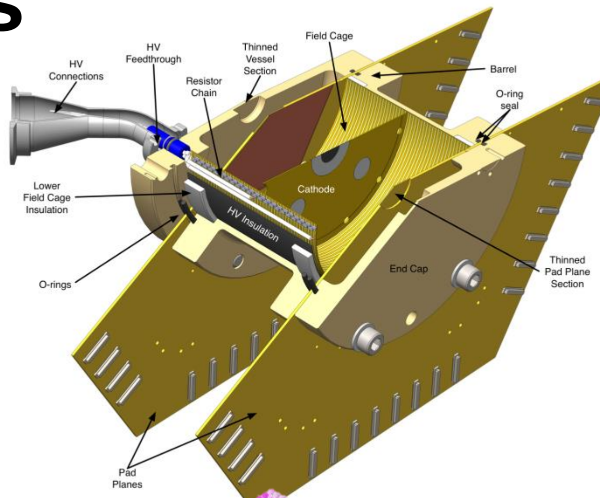
Total uncertainty: 0.7%

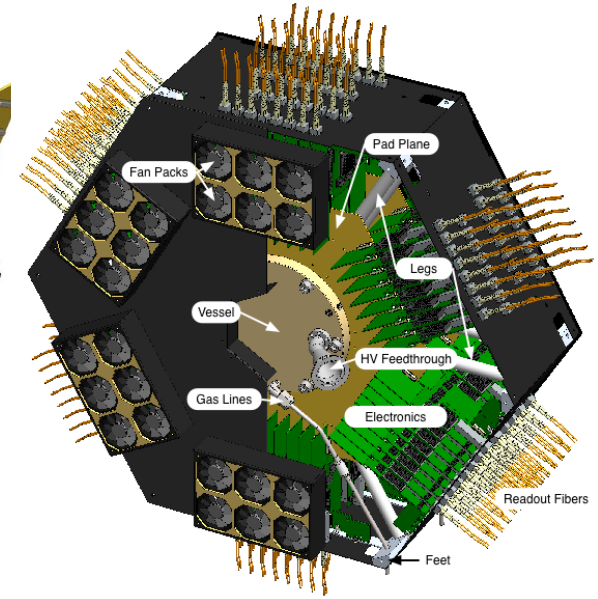


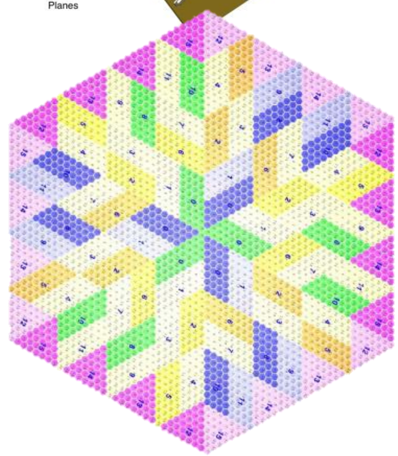


The fission TPC was miniaturized for fission studies

- ~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



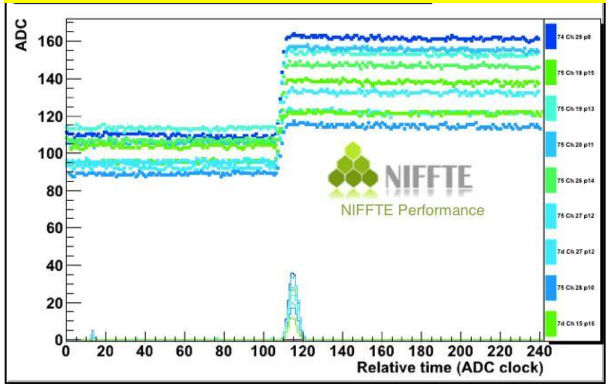




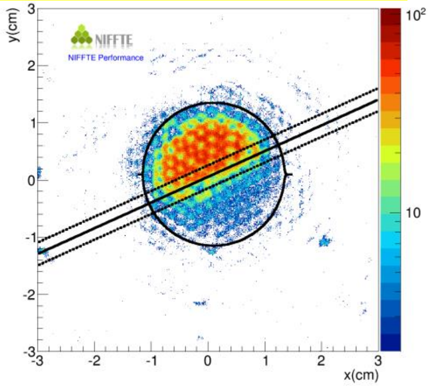
M. Heffner, D.M. Asner, R.G. Baker, *el al.*, *A Time Projection Chamber for High Accuracy and Precision Fission Cross Section Measurements*, **submitted to Nucl. Instr. and Meth.**

The U-238(n,f) cross section is our benchmark

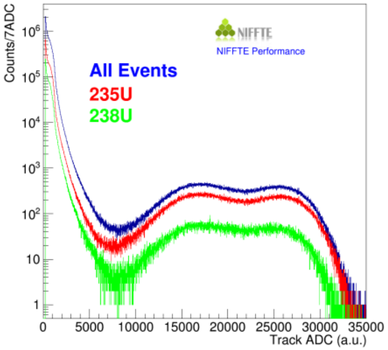
Unprocessed signals



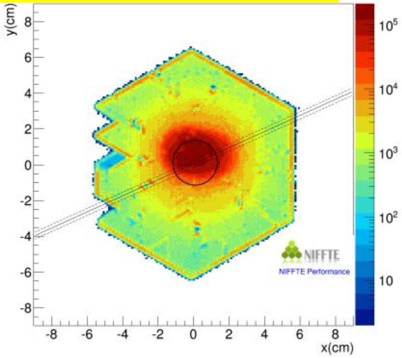
Autoradiograph



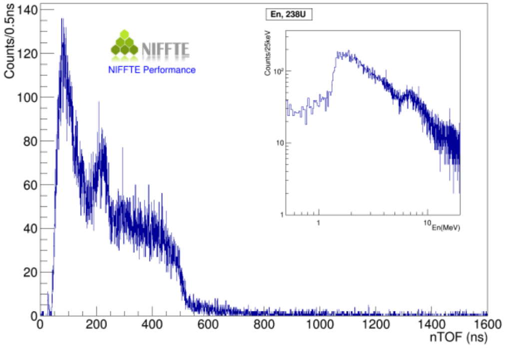
Fragment energy



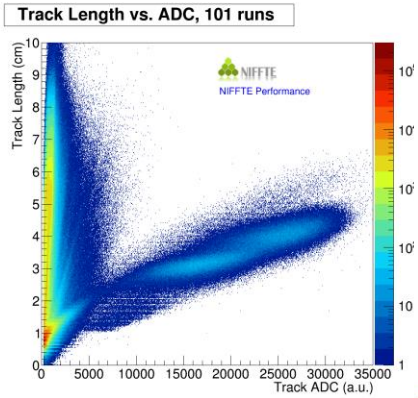
Beam profile



Neutron TOF



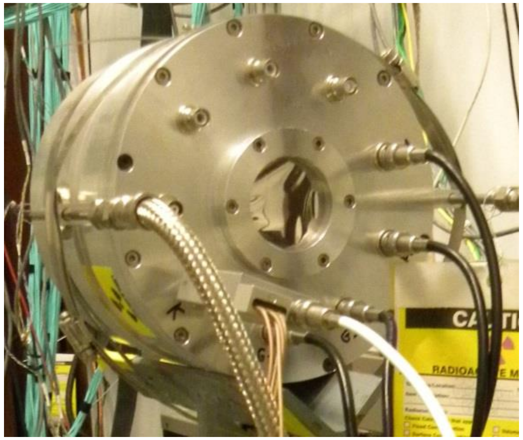
Track length vs energy



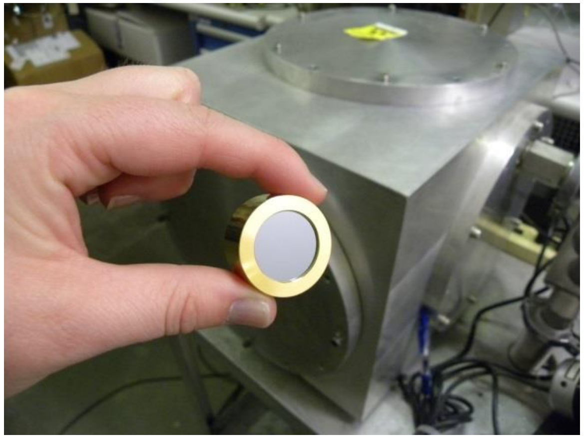
Fission fragment properties are studied with different techniques

SPIDER (2E-2v)

Gridded IC (2E)

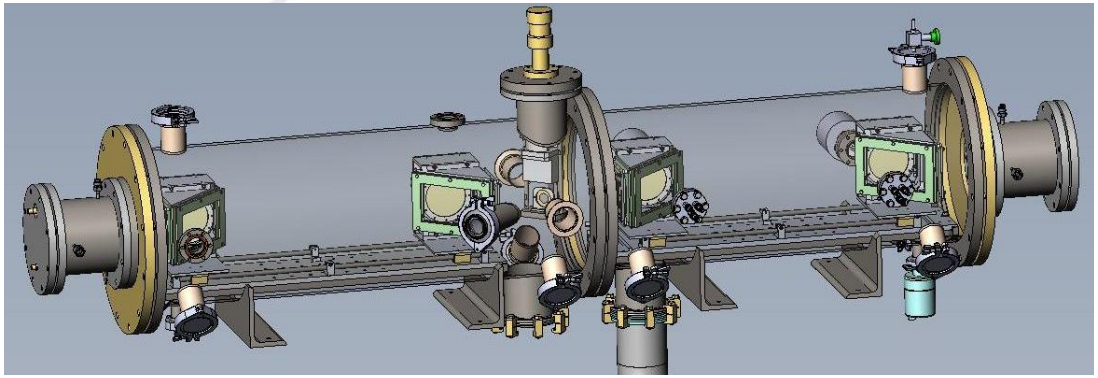


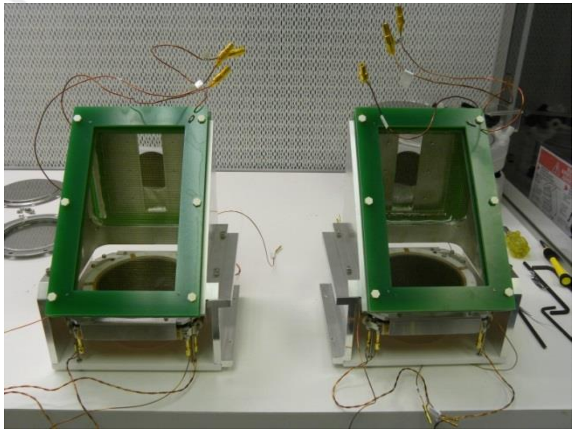
SSBD (TKE)



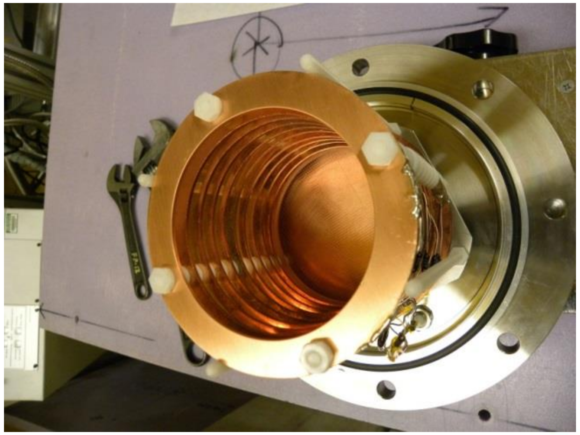
- Fragment mass, charge, energy
- Total kinetic energy (TKE)
- Neutron energy dependence

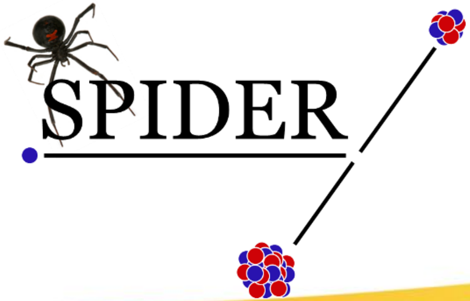
High resolution mass yields are measured with SPIDER





- 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

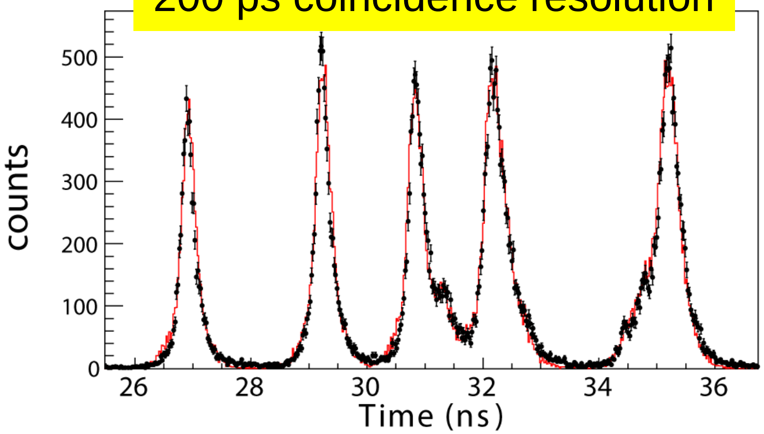


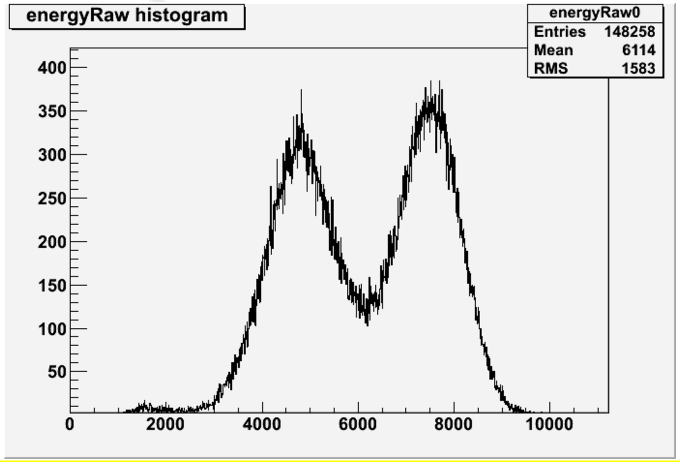


Performance of TOF detectors and ionization chambers meets requirements

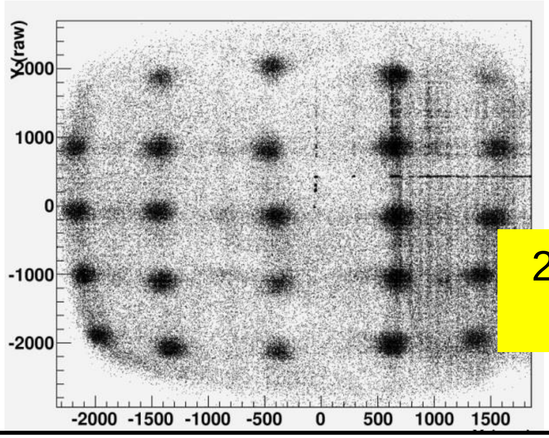
Los Alamos NATIONAL LABORATORY EST. 1943

200 ps coincidence resolution

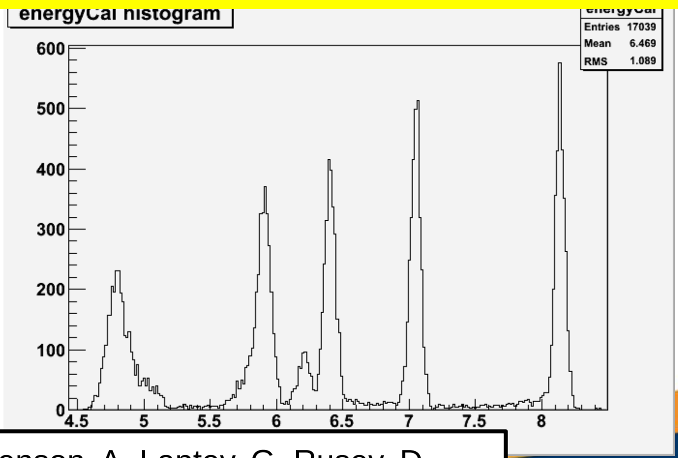




1% energy resolution for alpha-particles



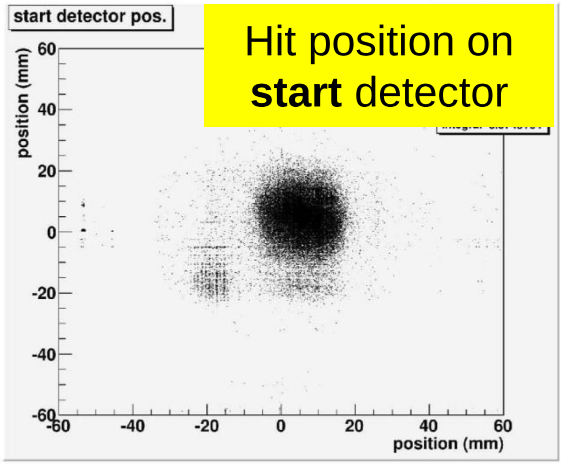
2 mm position resolution



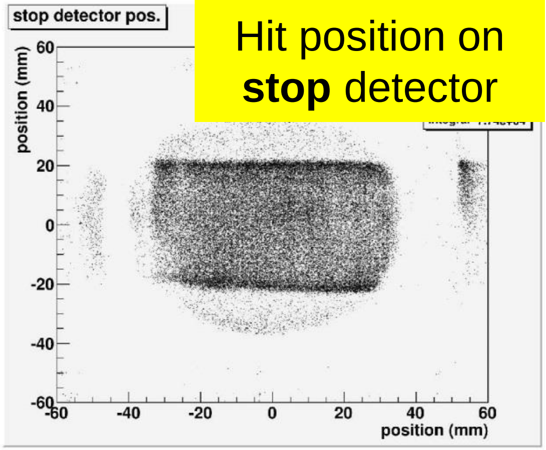
C.W. Arnold, F. Tovesson, K. Meierbachtol, T. Bredeweg, M. Jandel, H. J. Jorgenson, A. Laptev, G. Rusev, D. Shields, M. White, A. A. Hecht, R. E. Blakeley, D. M. Mader, *Development of position-sensitive time-of-flight spectrometer for fission fragment research*, **submitted to Nucl. Instr. and Meth**.

Mass yields in $^{235}U(n_{th},f)$ was measured with one arm instrumented

Hit position on **start** detector

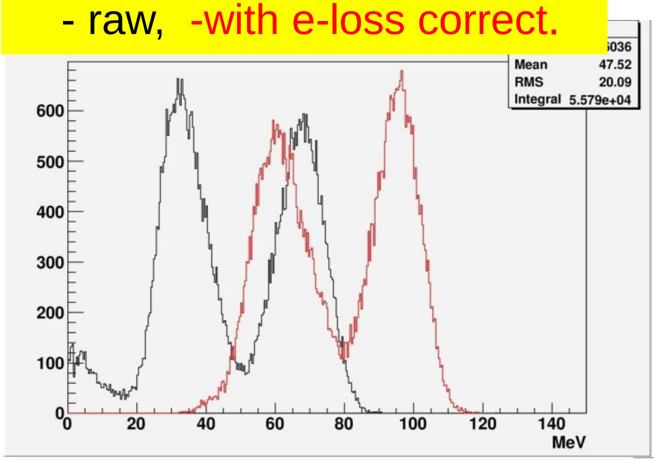


Hit position on **stop** detector

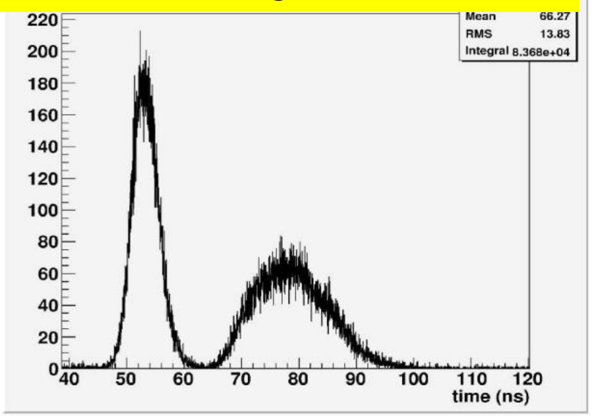


- 1E-1v
- 100 ug/cm^2 UF_4 on 100 ug/cm^2 C
- "Thick" Mylar window: 2500 ug/cm^2
- Neutron time-of-flight was recorded

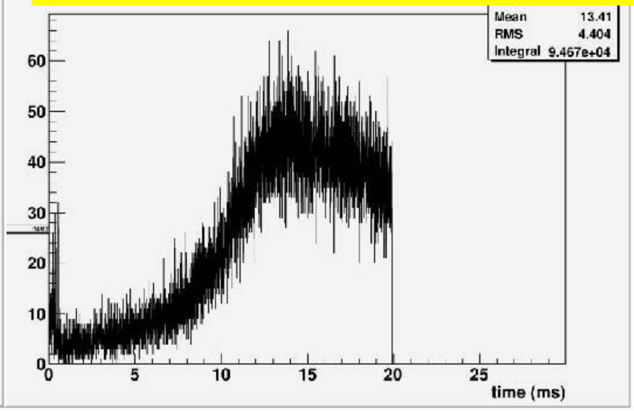
Fragment energy
- raw, -with e-loss correct.



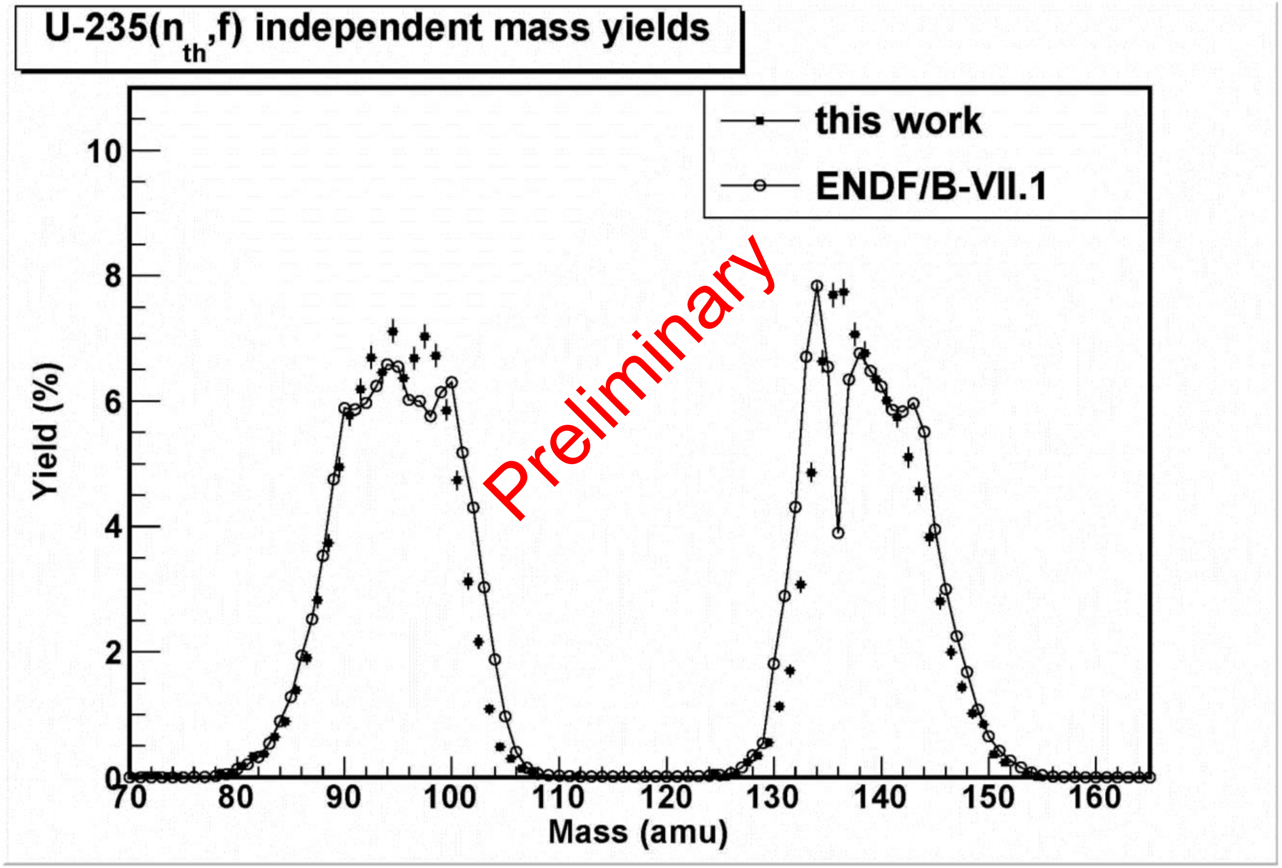
Fission fragment TOF



Neutron TOF

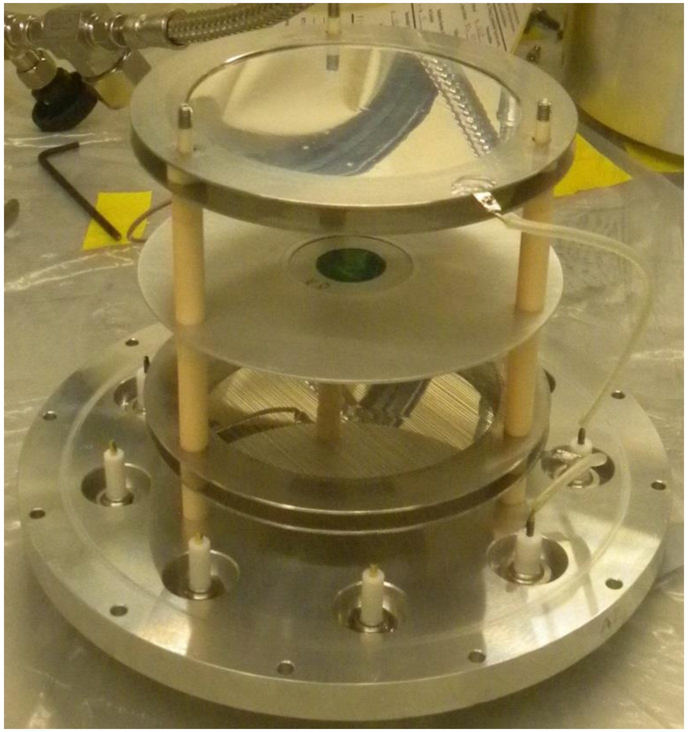


Preliminary mass yield agrees well with literature

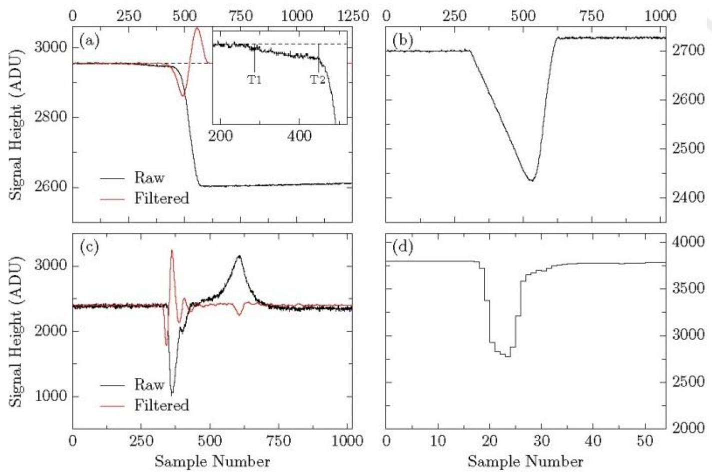


The 2E-method provides mass yields with 4-5 amu resolution

- 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")



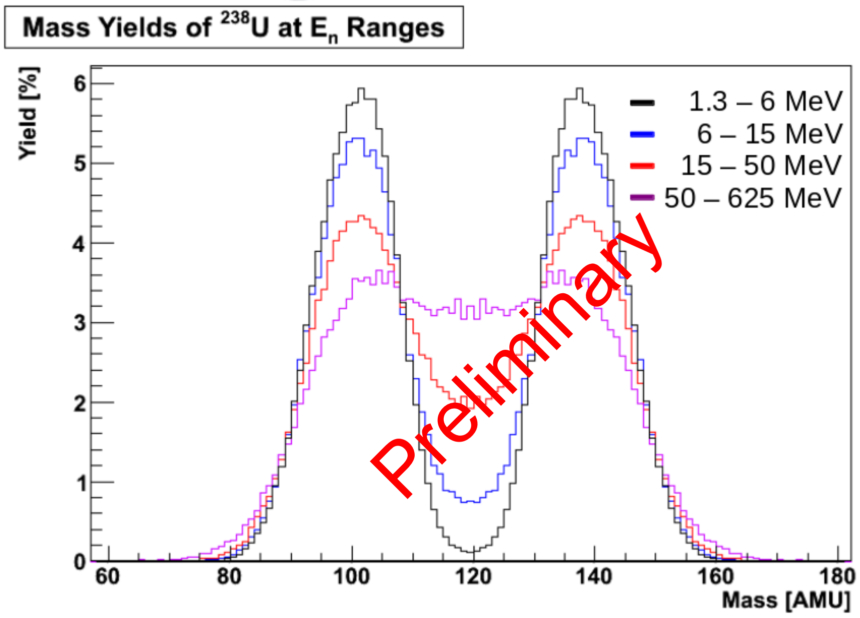
A new digital DAQ was developed for the IC measurements

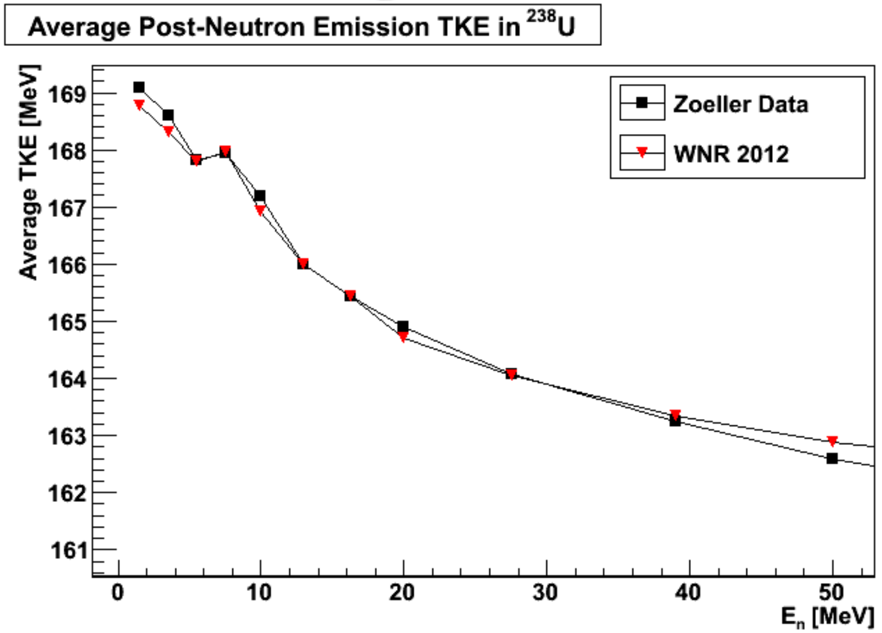


- The large neutron energy range poses a challenge for the DAQ system design
- 12-bit digitizers (CAEN V1720) with 250MHz sampling rates provide sufficient energy and timing resolution
- On-board memory and triggering management allows virtually dead-time less operation
- Digital signal processing allows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

S. Mosby, F. Tovesson, A. Couture, D. Duke, V. Kleinrath, R. Meharchand, K. Meierbachtol, J. M. O'Donnell, B. Perdue, D. Richman, D. Shields, *A fission fragment detector for correlated fission output studies*, **submitted to Nucl. Instr. and Meth.**

Mass yields with 2E were measured for $^{235,238}U$





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

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
  - High efficiency neutron counters
  - Fission barrier studies using various projectiles
  - Fission gamma-rays
  - Inverse kinematics fission studies

Collaborators

- **Los Alamos National Laboratory**
  - C. Arnold, D. Duke, R. Meharchand, K. Meierbachtol, S. Mosby, V. Kleinrath, B. Perdue, D. Richman, D. Shields, M. White, T. Bredeweg, M. Jandel, H. J. Jorgenson
- **University of New Mexico**
  - A. Hecht, R. Blakeley, D. Mader
- **Oregon State University**
  - W. Loveland
- **Colorado School of Mines**
  - U. Greife, B. Moore