Summary of LLNL nuclear data experimental activities

for 2017 CSEWG meeting

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Nuclear Data and Theory Group

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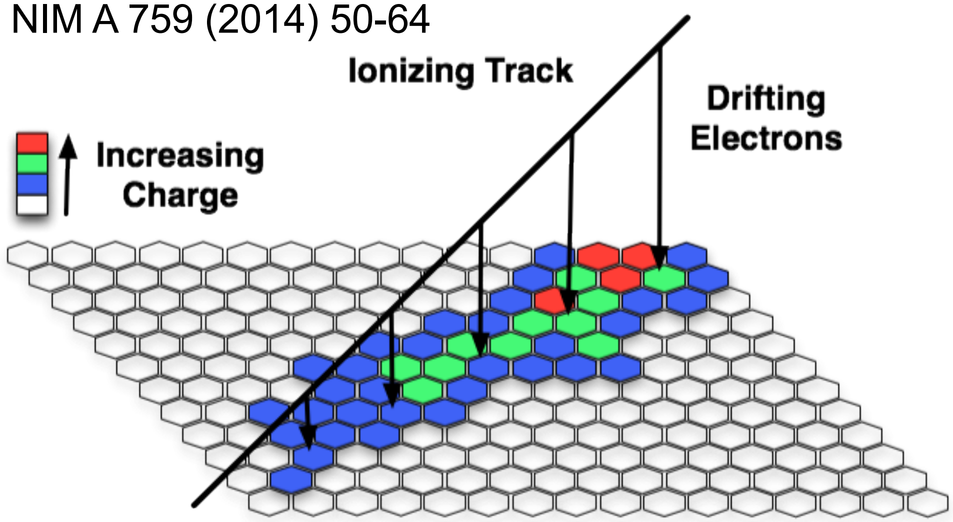
LLNL Experiments and their Results

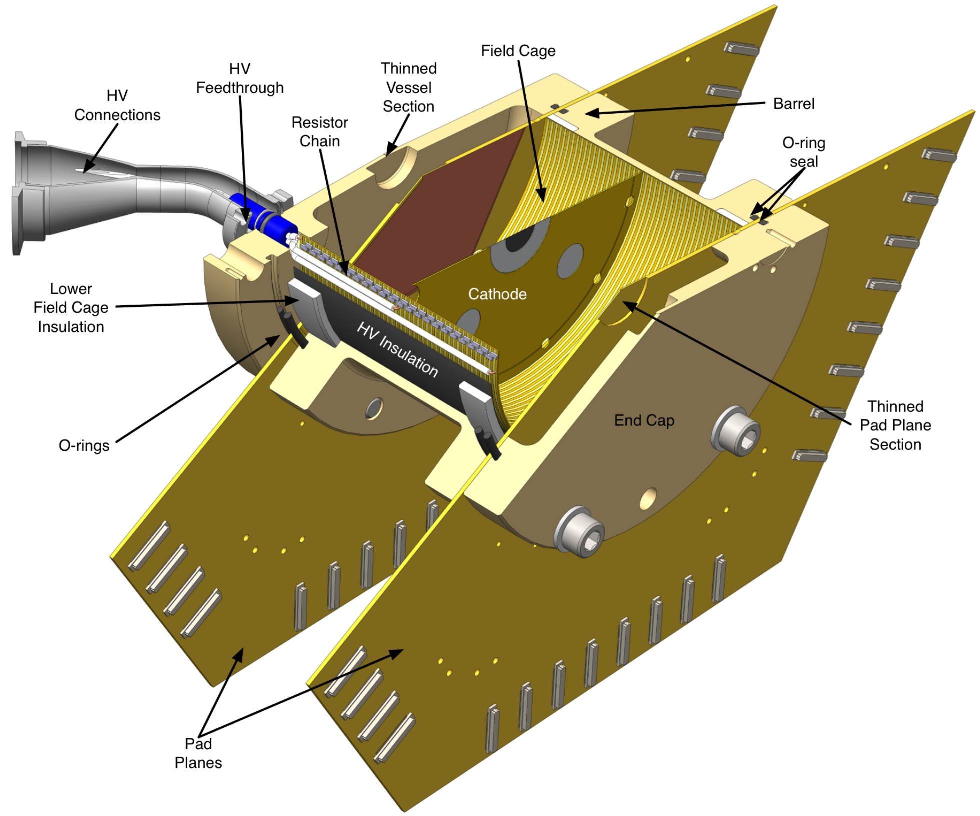
- FissionTPC Cross-Section Results
- NeutronSTARS charged particle and neutron detector array
- Fission Product Yields from critical assembly irradiations
- Energy Dependence of Fission Product Yields
- Neutron Cross Sections using Mono-energetic Beams

The fissionTPC for precision neutron-induced fission cross-section measurements

The fission Time Projection Chamber (fissionTPC) is a two-chamber MICROMEGAS TPC with nearly 6k channels. Actinide targets are placed on the central cathode and irradiated with a neutron-beam. Full 3D reconstruction of fission fragments and other charged particles are used measure fission cross-sections and examine the associated systematic errors. Further details can be found in NIM A 759 (2014) 50-64

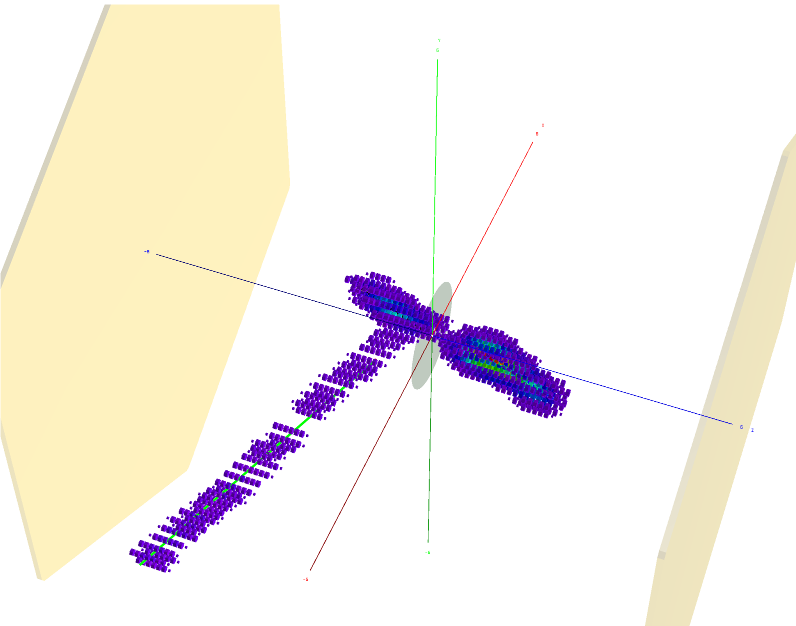


The fissionTPC anodes are hexagonally segmented into nearly 3k pixels with a 2mm pitch. The constant drift velocity of electrons in a gas allows for 3D reconstruction of the ionization left by fission fragments and other charged particles.



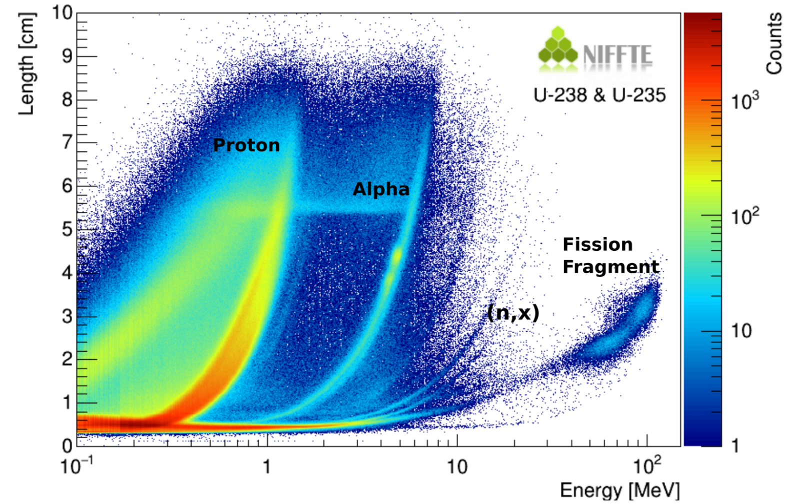
FissionTPC vessel half section. The active volume is 15 cm in diameter. The central cathode splits the chamber into two volumes with a segmented anode on either side.

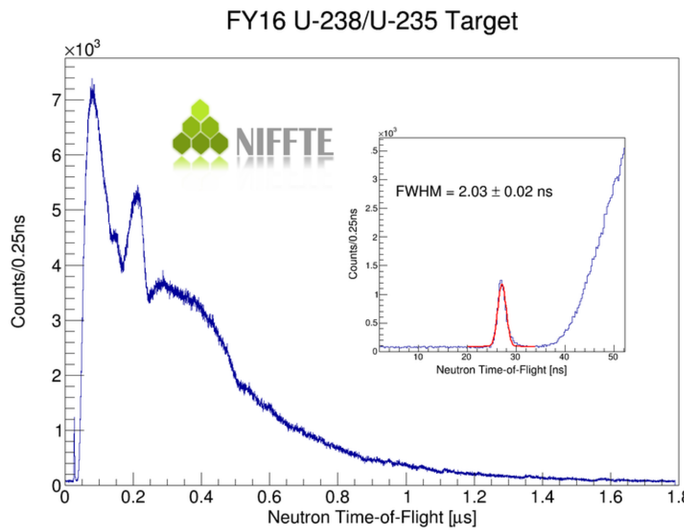
FissionTPC data reconstruction examples from $^{238}U(n,f)/^{235}U(n,f)$ data collected at LANSCE-WNR



An example of a reconstructed event. In this case an α-accompanied fission event from an actinide deposited on a thin carbon backing. The detailed 3D data allows for more than just fission cross-sections to be measured. For example fission anisotropy. (See recent submission arXiv:1710.00973)

Track energy and length can be reconstructed allowing for clear separation of fission fragments from other beam-induced events.

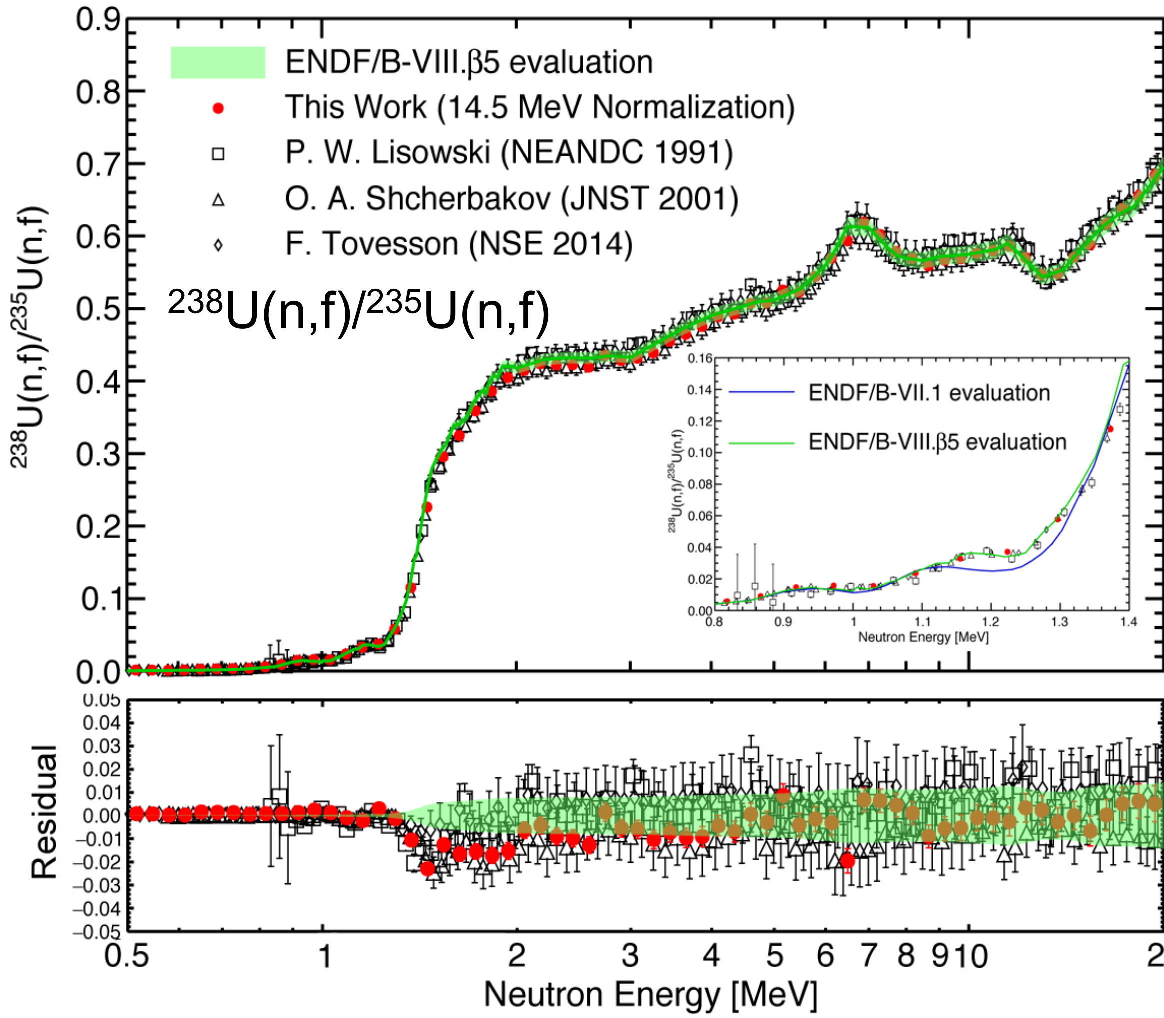




The neutron energy is determined by measuring the neutron time-of-flight with a highspeed signal generated on the central cathode. A 2 ns timing resolution is achieved, more than adequate for the LANSCE-WNR beam.

FissionTPC Cross-Section Results
$^{238}U(n,f)/^{235}U(n,f)$ and $^{239}Pu(n,f)/^{235}U(n,f)$

- $^{238}U(n,f)/^{235}U(n,f)$ results submitted to Physical Review C.
  (See figure right)
- $^{239}Pu(n,f)/^{235}U(n,f)$ results delivered to evaluators at LANL & LLNL
- Results currently being validated with submission to PRC expected soon
- Currently collecting data for $^{238}U(n,f)/^{239}Pu(n,f)$ and $^{235}U(n,f)/H(n,el)$ cross-section ratios



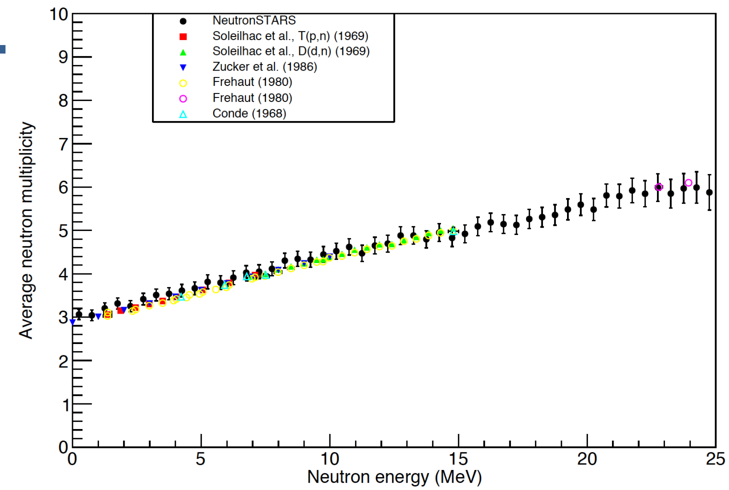
NeutronSTARS charged particle and neutron detector array

J.T. Burke, R.J. Casperson, B.S. Alan, O. Akindele, R.O. Hughes, S. Fisher, A. Tamashiro and A. Padilla

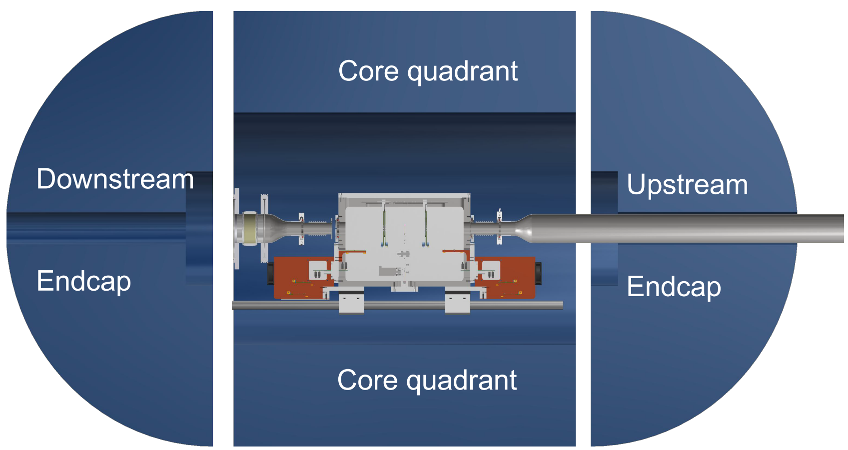
NeutronSTARS is the largest neutron detector in the NNSA complex and the U.S. for low energy nuclear physics at 2.2 tons (3.5t) liquid scintillator + Gd 0.25% by wgt. Fission neutron multiplicity (nu-bar), fission neutron distributions, surrogate (n,n') and (n,2n) measurements will be performed.

First light January 2017.

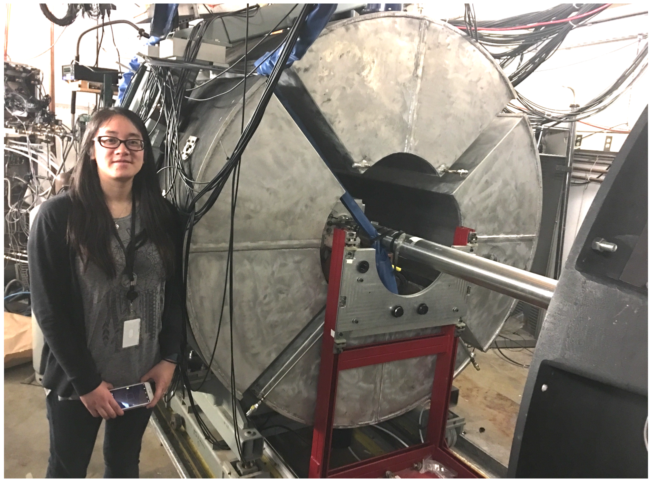
First experiment ^{240}Pu(α,α'fxn), ^{240}Pu(α,α'2n) ^{241}Pu(α,α'2n) and ^{241}Pu(α,α'fxn) April 2017.



Fission neutron multiplicity determined from surrogate ^{240}Pu(α,α'fxn) experiment.



Cross section view of NeutronSTARS array. Gd-doped liquid scintillator surrounds charged particle Si-detector array.



Dr. Barbara Alan standing beside the core of NeutronSTARS which was commissioned in 2017.

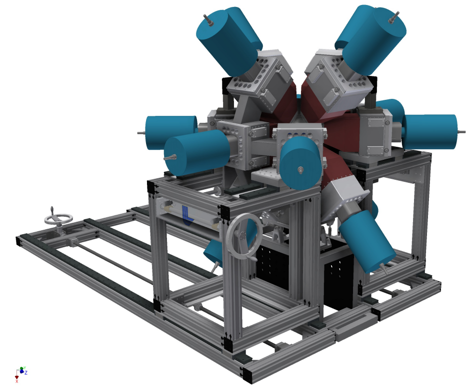
Hyperion array for fundamental and applied science

J.T. Burke, R.O. Hughes, R.J. Casperson, J.E. Escher, S. Fisher, J. Parker

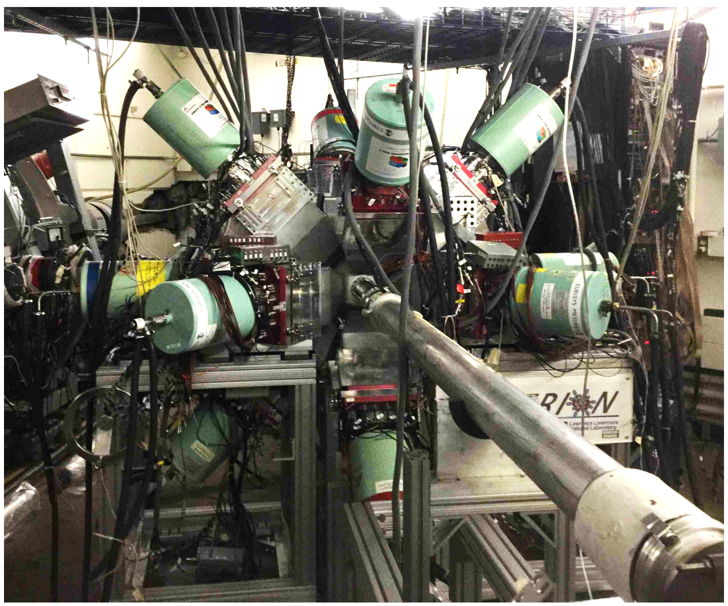
Need high efficiency, highly segmented gamma ray array for surrogate (n, γ) cross section and nuclear structure measurements. Hyperion is a 14 HPGe Clover array with BGO Compton suppression. Located at Texas A&M Cyclotron Institute which provides light ion beams from the K150 Cyclotron.

First results of surrogate (n,g) cross section benchmark ^{90}Zr(n,γ) look promising and paper has been submitted.

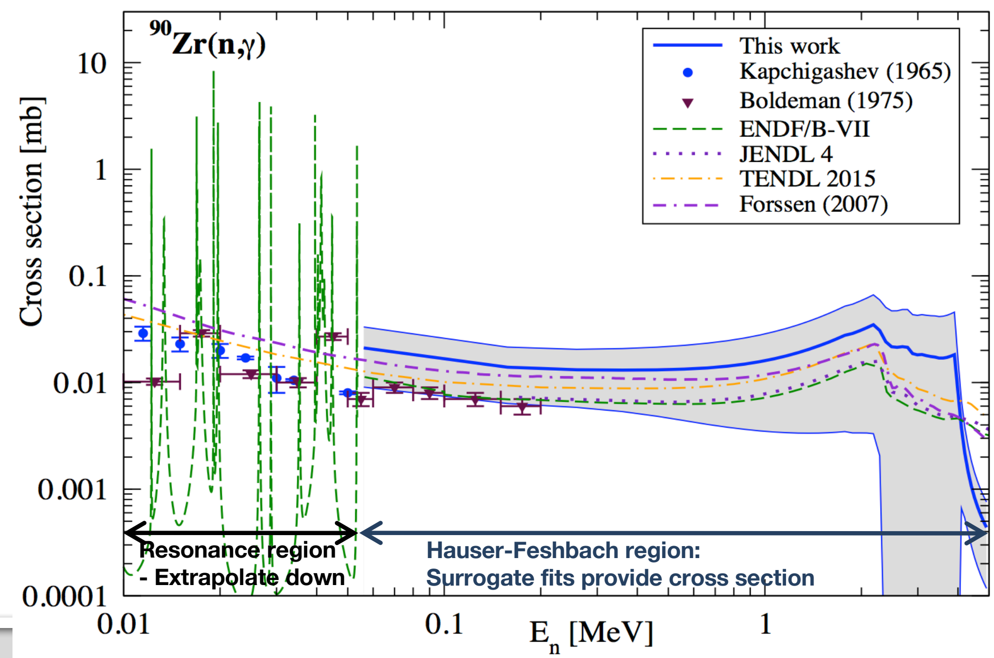
Multiple new states, transitions and branching ratios in Tm, Zr, and Y have been measured.



Hyperion conceptual design 2013



Hyperion installed at TAMU 2015



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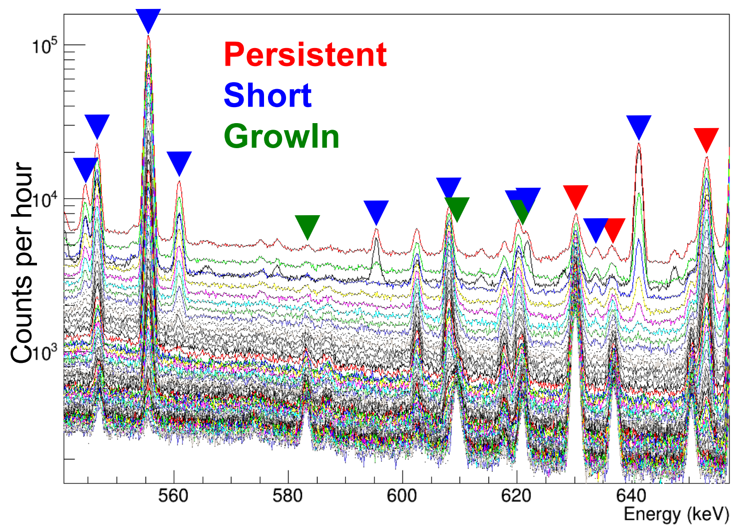
Update on Fission Product Yields from critical assembly irradiations

J.T. Burke, S.A. Padgett, K. Roberts, J. Shusterman, S. Faye, G. Slavik, R.A. Henderson, D. McAvoy. LLNL in collaboration with PNNL/LANL

We have established a reliable and repeatable gamma ray measurement system nearby the Godiva critical assembly. We can retrieve and start counting samples <60 minutes post irradiation. Use 99.9x% isotopically pure actinide targets.

- have reported values on **20 unique isotopes** and **47 unique gamma rays** for ^{235}U fission product yields
- have reported values on **23 unique isotopes** and **74 unique gamma rays** for ^{238}U fission product yields
- approximately **~230 gamma ray lines** that have been identified. More sophisticated gamma ray fitting routines are being developed to extract as much information as possible from the data sets
- full uncertainty analysis and all sources of uncertainty documented in reporting
- finalized results to be released as a set for data evaluation



Collect list mode data of gamma rays emitted over a 7 day period. Data is time binned, examined for gamma ray interferences by looking at time dependent decay of peak of interest. Integral of number of counts and FPY determined for specific isotope.

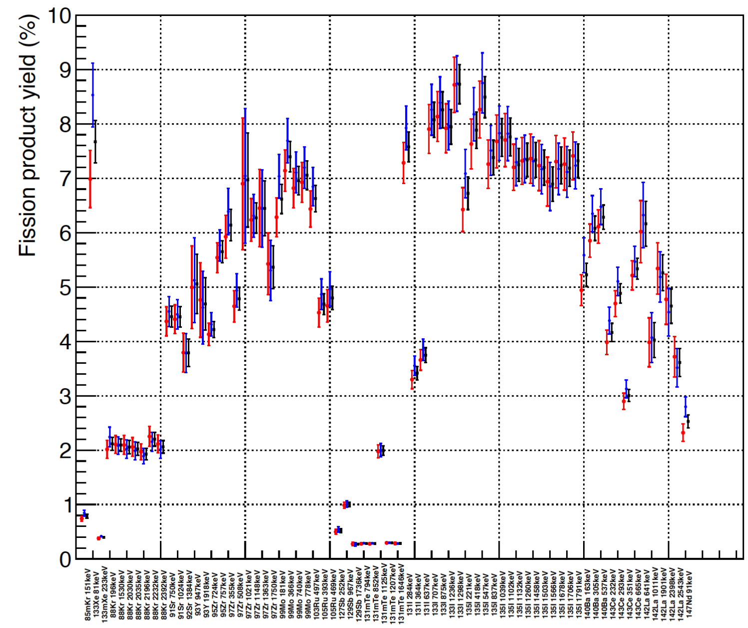


Figure 10: This figure shows the fission product yields derived from the beta delayed gamma ray decay spectrum of the 470 mg ^{238}U sample post Godiva irradiation. The points shown represent the results obtained from the data taken with detector 8815 (red points) and 8816 (blue points). The simple weighted mean of these results is shown in black.

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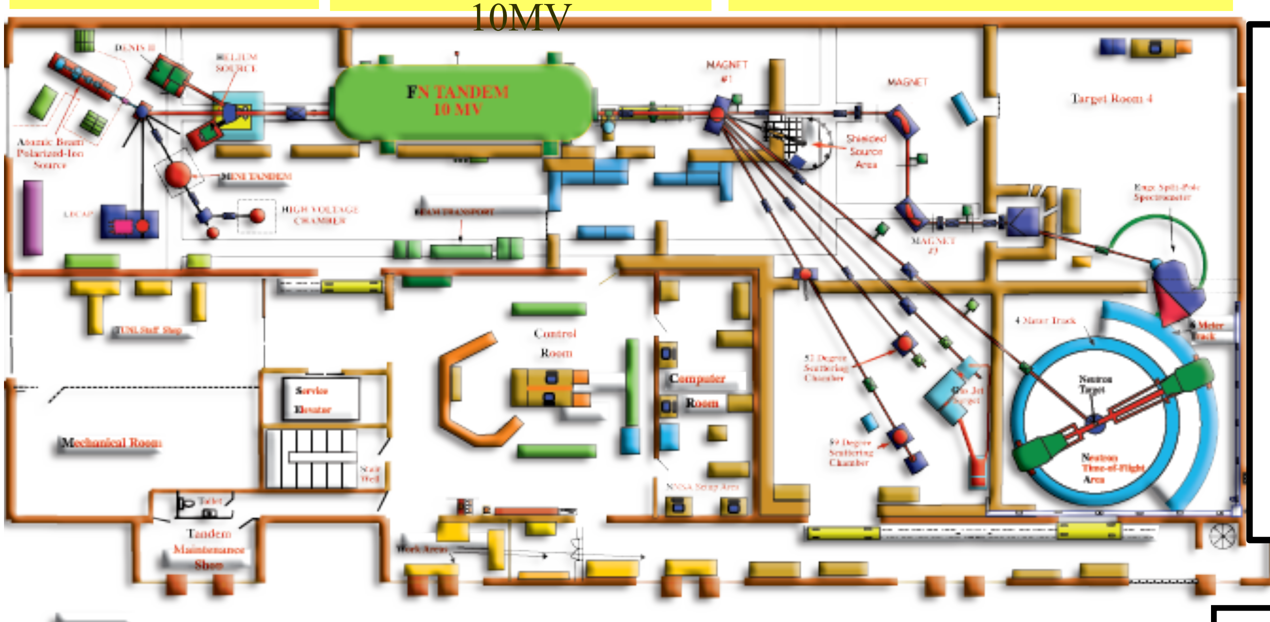
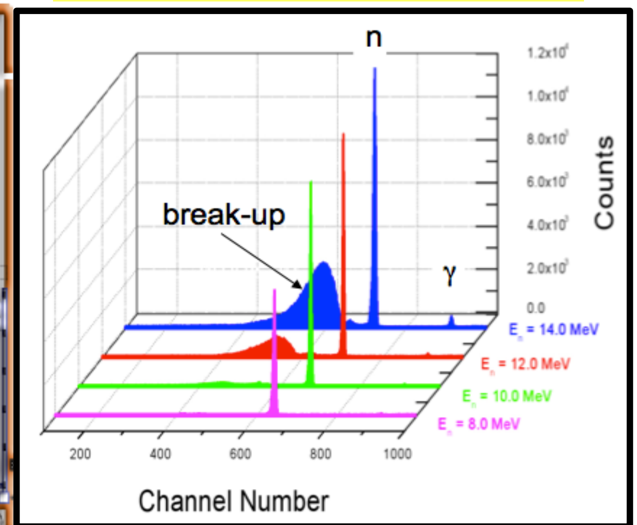
Monoenergetic Neutron Sources available at TUNL
DD, DT, PT, and PLi, Sources

DENIS source | FN TANDEM 10MV | Shielded neutron source area | Quasi-monoenergetic neutrons





Flux on target $(10^7 - 10^8)$ cm^{-2} s^{-1}

Energy spread = 0.1 - 0.4 MeV

^{7}Li(p,n)^{7}Be; Monoenergetic neutrons: 0.1 – 0.65 MeV

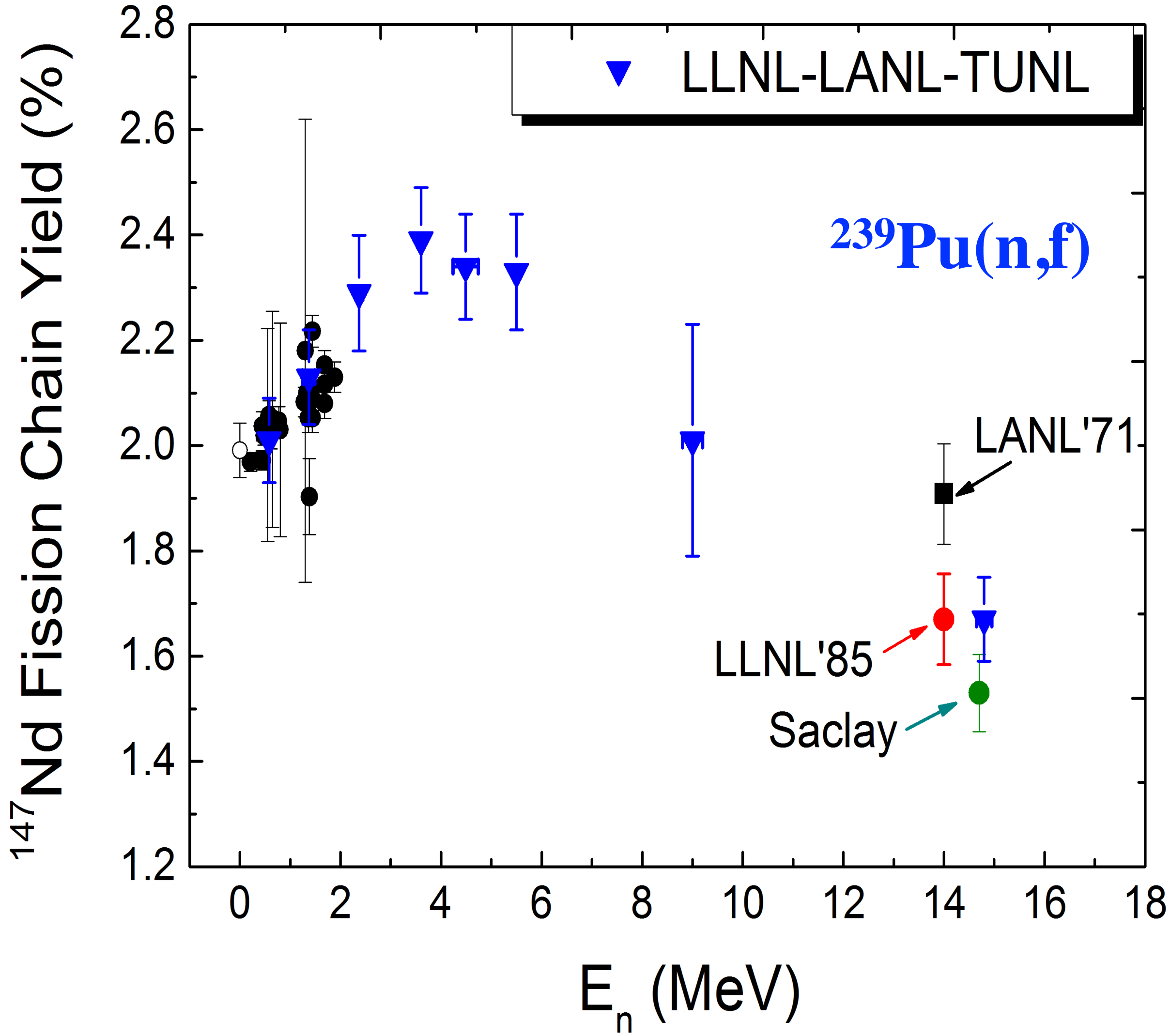
^{3}H(p,n)^{3}He; Monoenergetic neutrons: 0.5 – 7.7 MeV

^{2}H(d,n)^{3}He; Monoenergetic neutrons: 4.0 – 7.7 MeV

^{3}H(d,n)^{4}He; Monoenergetic neutrons: 14.8 – 20.5 MeV

C. Bhatia, et al. NIMA 757 (2014) 7-19

Energy Dependence of Fission Product Yields from ^{235}U, ^{238}U and ^{239}Pu



- Supported critical assembly data using dual fission ionization chambers and monoenergetic neutron beams at TUNL
- There is a positive slope of ^{147}Nd FPY from 0.5 to 4 MeV

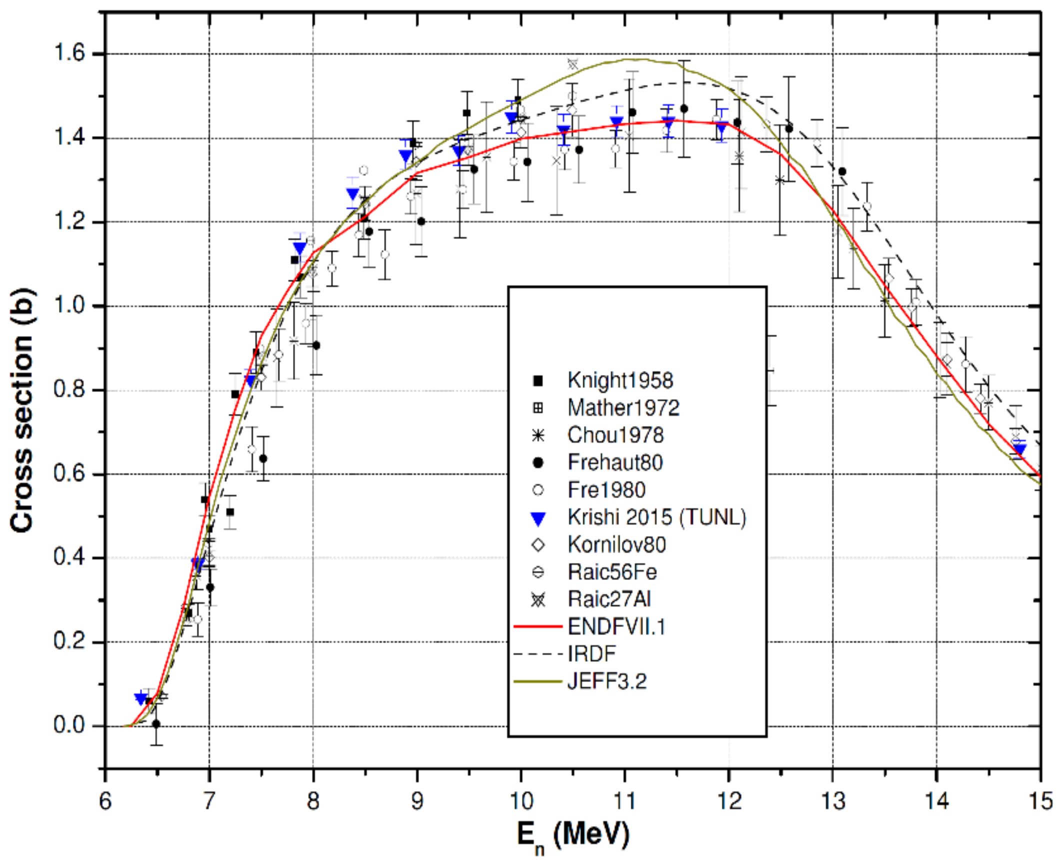
$\Delta Y(^{147}Nd)/\Delta E_n = (7.09 \pm 1.6)\%/MeV$

- At higher energies the FPY for ^{147}Nd turns over and decreases
- The TUNL measurements at 14.8 MeV resolved the long-standing discrepancy at that energy

Nuclear Data Sheets **131** (2016) 319–356
Phys. Rev. C 95, 024608 (2017)
Nuc. Inst. and Meth. in Phys. Res., A, (2017)
Phys. Rev. C **91**, 064604 (2015)
Nuc. Inst. Meth. A, **757**, 7 (2014)
Nucl. Data Sheets **119,** 324 (2014)

Neutron Induced Cross Section Measurements using Mono-energetic Neutron Beams

$^{238}U(n,2n)^{237}U$

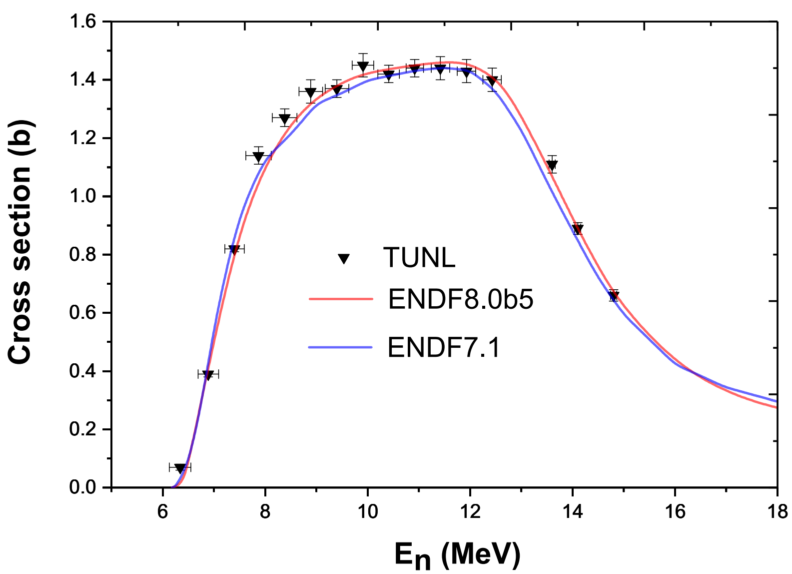


Krishichayan et al. Phys. Rev. C Accepted 9 October (2017)

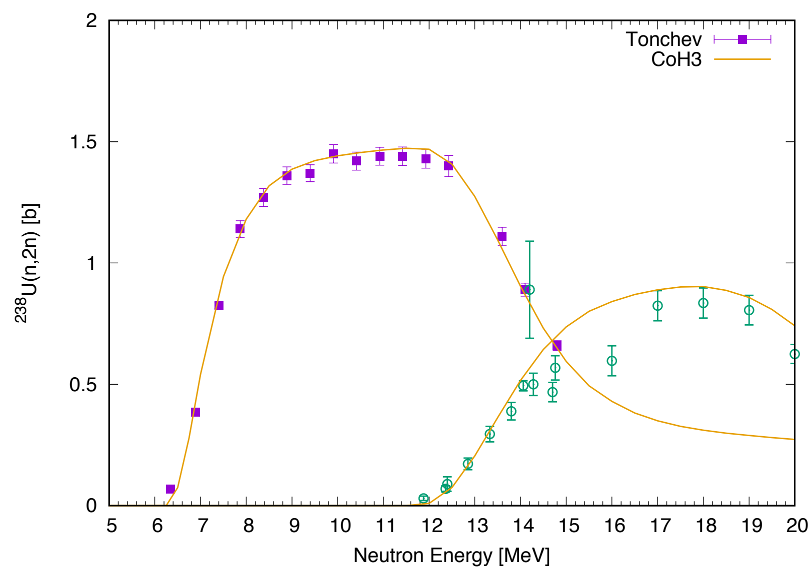
- $^{238}U(n,2n)^{237}U$: Phys. Rev. C Accepted (2017)
- $^{209}Bi(n,4n)^{206}Bi$: Phys. Rev. C **96**, 024622 (2017)
- $^{76}Ge(n,2n)^{75}Ge$: Phys. Rev. C **95**, 054605 (2017)
- $^{169}Tm(n,3n)^{167}Tm$: Phys. Rev. C, **93**, 014611 (2016)
- $^{74,76}Ge(n,\gamma)^{75,77}Ge$; Phys. Lett. B **741**, 150 (2015)
- $^{124,136}Xe(n,\gamma)^{125,137}Xe$: Phys. Rev. C **91**, 011601(R) (2015)
- $^{86}Kr(n,\gamma)^{87}Kr$: Phys. Rev. C **92**, 014624 (2015)
- $^{40}Ar(n,\gamma)^{41}Ar$: Phys. Lett. B **736**, 316 (2014)
- $^{238}U(n,\gamma)^{239}U$: submitted

Neutron Induced Cross Section Measurements using Mono-energetic Neutron Beams

These results appear to be used in ENDF/B-VIII.0 evaluations



Kawano's Hauser-Feshbach Model to fit the new data



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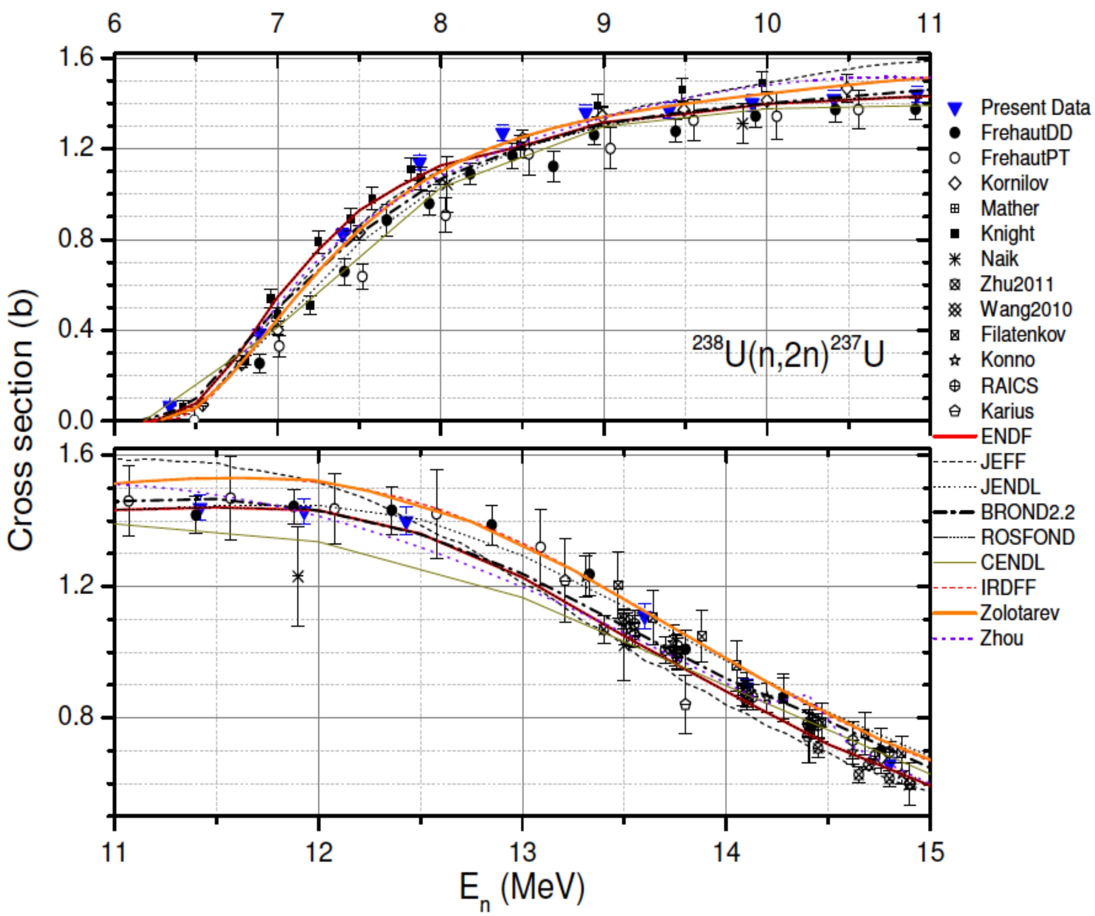
Extra Slides

Neutron Induced Cross Section Measurements using Monoenergetic Neutron Beams



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