Nuclear Physics and Related Computational Science R&D for Advanced Fuel Cycle Workshop
August 10-12, 2006 Bethesda, Maryland

Nuclear Measurements

AFCI Transmutation Engineering Physics

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Advanced Fuel Cycle Initiative (AFCI)

- DOE Advanced Fuel Cycle Initiative (AFCI) was launched in FY03 to address pressing nuclear issues:
  - Nuclear energy and waste management
  - Declining US nuclear infrastructure
  - Global nuclear leadership
- AFCI R&D Research Areas
  - Systems Engineering
  - Fuels Development
  - Separations Engineering
  - Transmutation Engineering

AFCI Transmutation Engineering

- Develop the engineering basis for the transmutation of minor actinides (MA) and long-lived fission products to support implementation decisions.
  - Proof-of principle information in areas that not supported in fuels, separations, Gen IV research or other DOE-NE research programs.
- Transmutation Engineering Physics
  - Provide nuclear cross section data in the thermal, epithermal and fast-neutron spectra to reduce calculation uncertainties associated with the nuclear data

AFCI Transmutation Engineering Physics

- Nuclear data measurements
  - Fission (LANSCE)
  - Capture (LANSCE)
  - Gas Production (LANSCE)
  - Target development/fabrication (INL)
- Nuclear data evaluations
  - Provide nuclear data and covariance data (LANL)
- Code development
  - MCNP(X) (LANL)
- Nuclear Data Sensitivity Analyses
  - Nuclear data target accuracy requirements (ANL)

Initial partial list of potential GNEP measurements

- Actinide neutron cross section measurements
  - Fission (n,f)
  - Capture (n,γ)
  - (n,2n)
  - (n,inelastic)
  - Total

AFCI funded activities

- Materials neutron cross section measurements
  - Gas production cross sections (n,H), (n,He)
  - (n,elastic)
  - Scattering distributions
  - Fission product cross sections

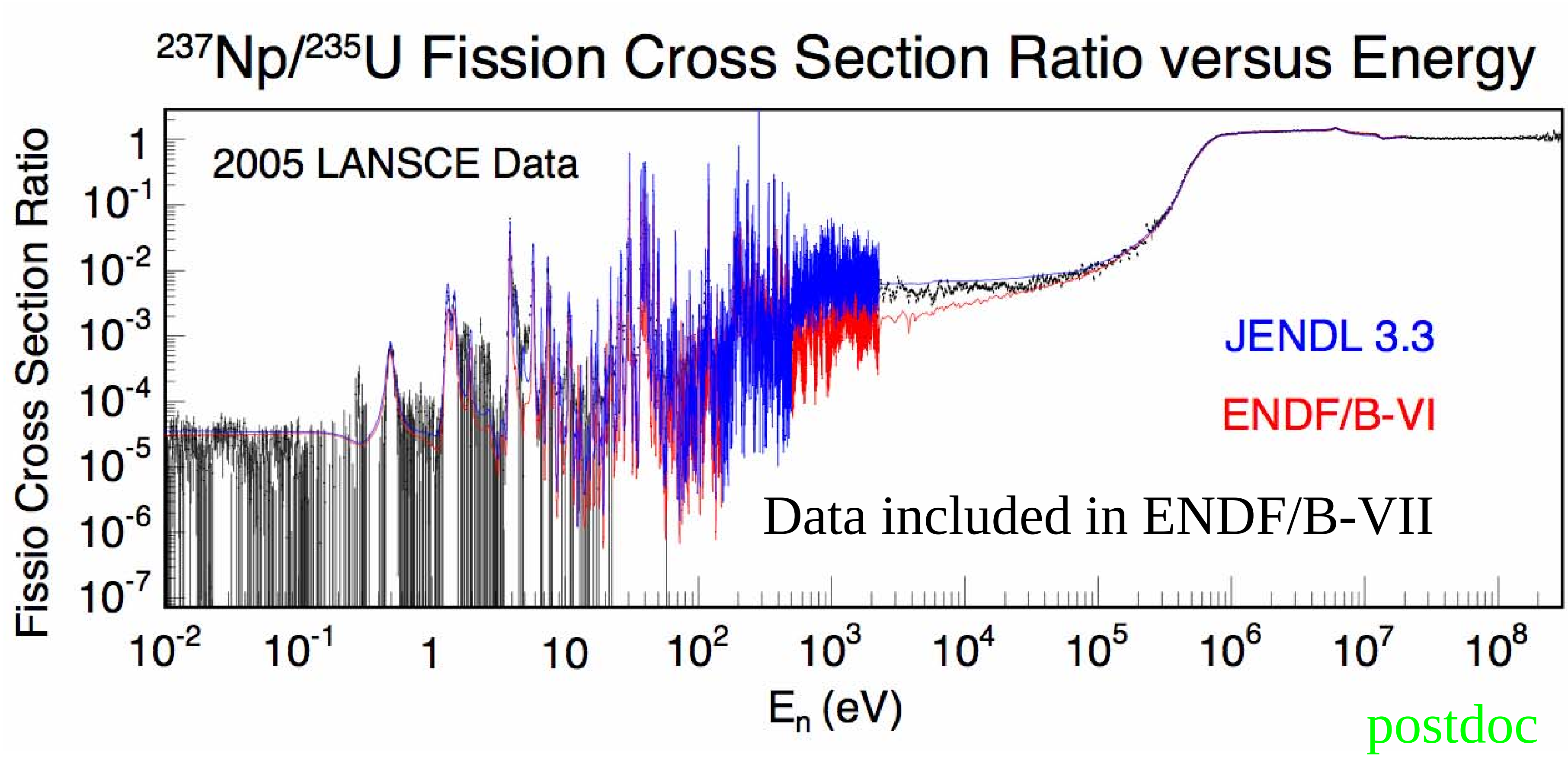
Many opportunities to contribute

- Fission yields, kinematics and decay data
- Gamma and neutron production (prompt and delayed)
- Materials Accountability and Safeguards
  - (γ,f),(γ,γ'),nuclear resonance flourescence

AFCI Nuclear Data Measurements

- Differential fission cross section measurements
  - Parallel plate ionization chambers
  - Lujan and WNR beam lines (thermal to several hundred MeV)
  - Specially designed DAQ to reduce systematics
  - Completed ^{237}Np(n,f)
- Differential capture cross section
  - DANCE detector
  - Lujan moderated beam line (thermal to 500 keV)
  - Completed ^{237}Np(n,γ)
- Differential gas production cross section measurements
  - ΔE detectors and stopping detectors
  - WNR beam line (threshold to several hundred MeV)
  - Completed Cr, Fe, Ta

Fission cross sections over 10 decades in incident neutron energy



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Fission detector development

DAQ R&D

issue in fast region resolved

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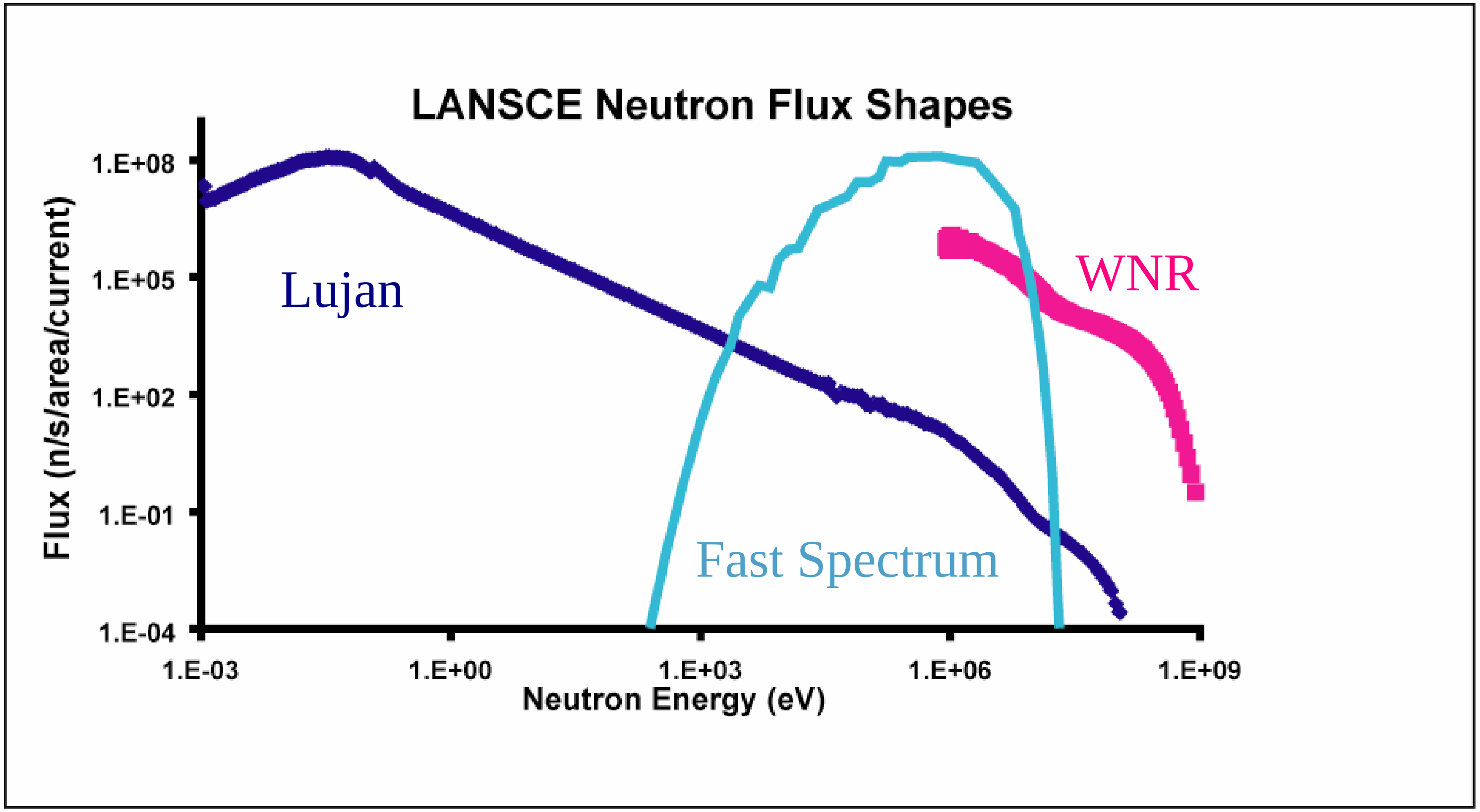
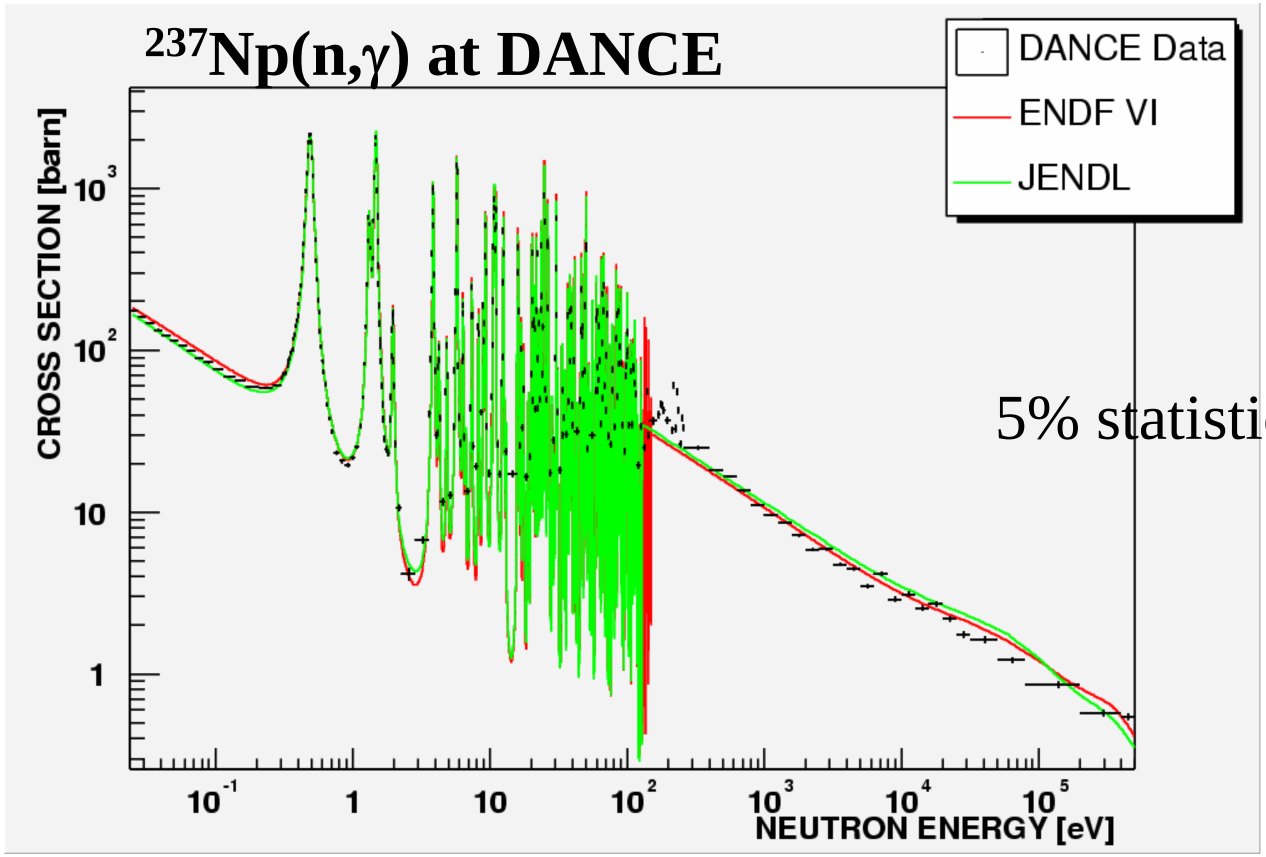
Combining facilities at LANSCE results in 12 decades of neutron energies



Better way: pulse stacking at WNR with fast moderator

$^{237}Np(n,\gamma)$ was first actinide measurement completed at DANCE

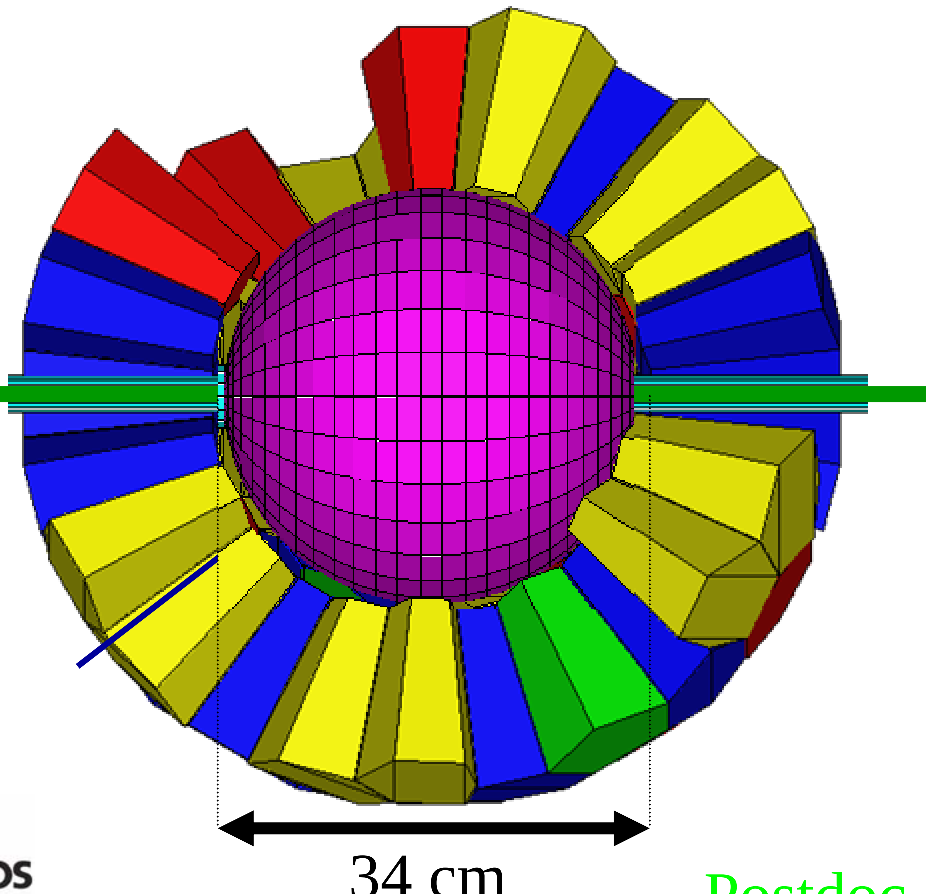


5% statistical binning

These data have been included in ENDF/B-VII

Detector for Advanced Neutron Capture Experiments

collimated neutron beam



Typ. sample
$t_{1/2} > 100$ d
m ~ 1 mg

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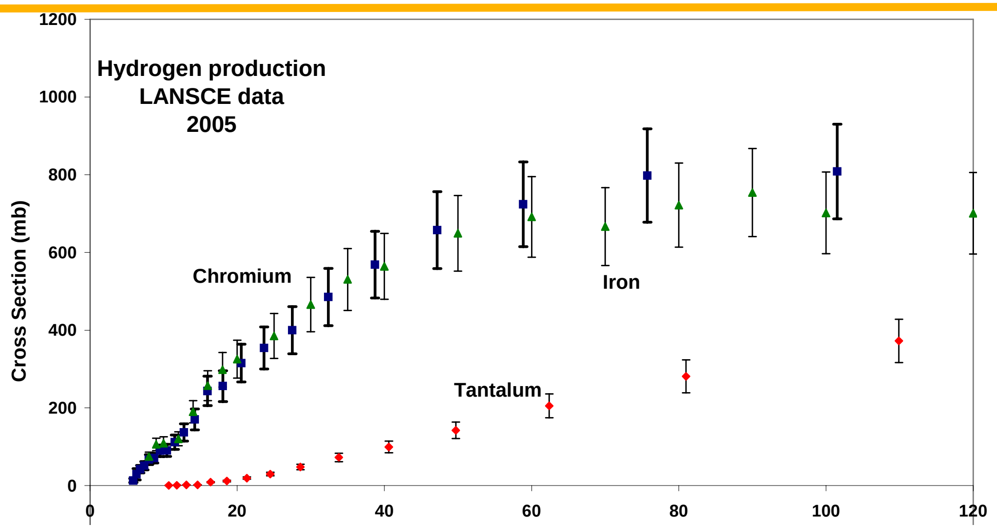
neutrons:

- spallation source
- thermal .. 500 keV
- 20 m flight path
- 3 10^5 n/s/cm^2/decade
- >200 beam days/year

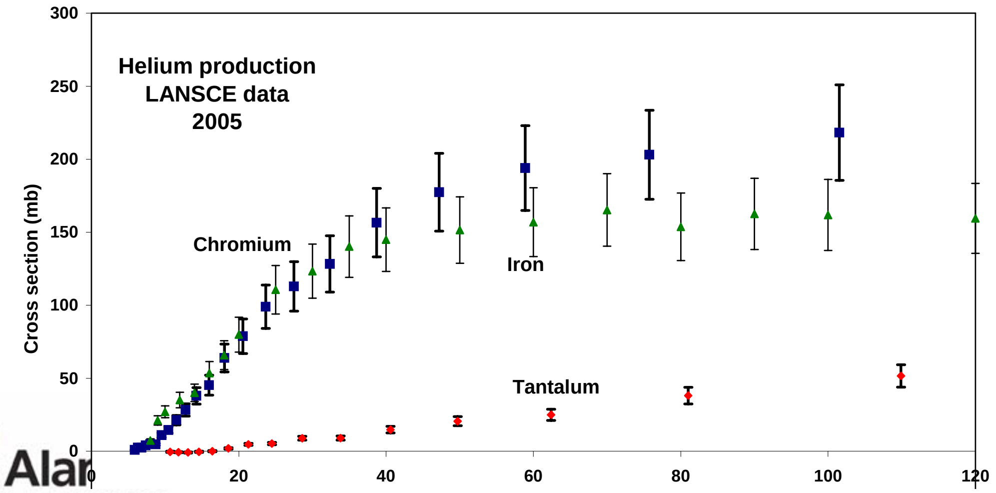
γ-Detector:

- 160 BaF_2 crystals
- 4 different shapes
- R_i=17 cm, R_a=32 cm
- 7 cm ^{6}LiH inside

Completed Gas Production Measurements



Hydrogen production measurements for Cr, Fe and Ta



Helium production measurements for Cr, Fe and Ta

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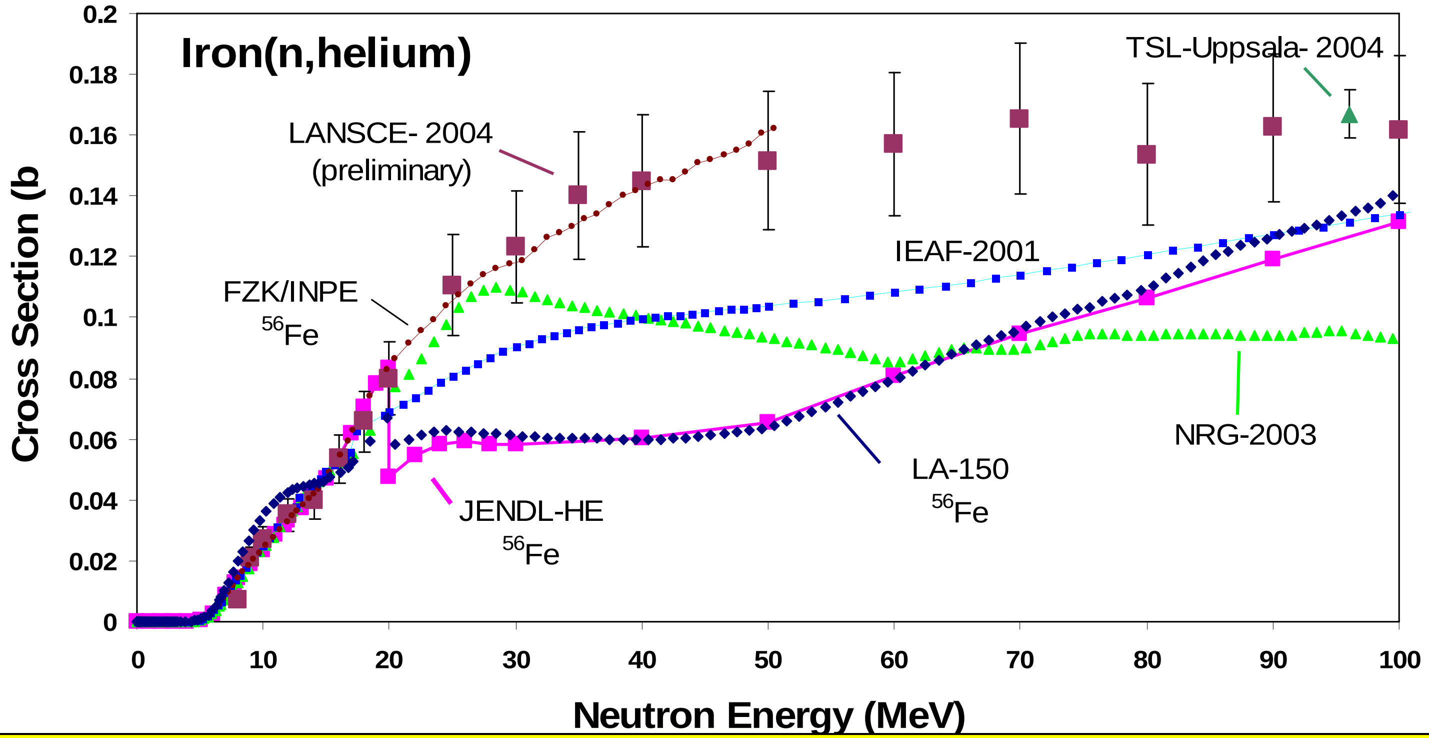
Gas production measurements can differentiate between models



Upgrades to detection system will reduce systematic uncertainties

Construction and Commissioning

DAQ R&D

AFCI FY06 measurements in progress

- Capture cross sections
  - Pu242
  - Pu239 for background subtraction and engineering study
- Fission cross sections
  - Pu242
  - Pu239, Pu241, U233 are backgrounds but will result in measurements
- Gas production cross sections
  - Complete Zr
  - Start Mo measurement

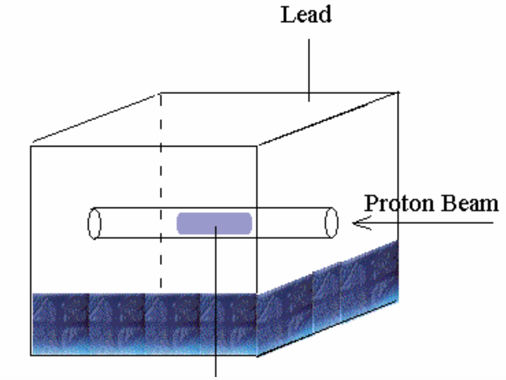
AFCI FY07 measurement tasks

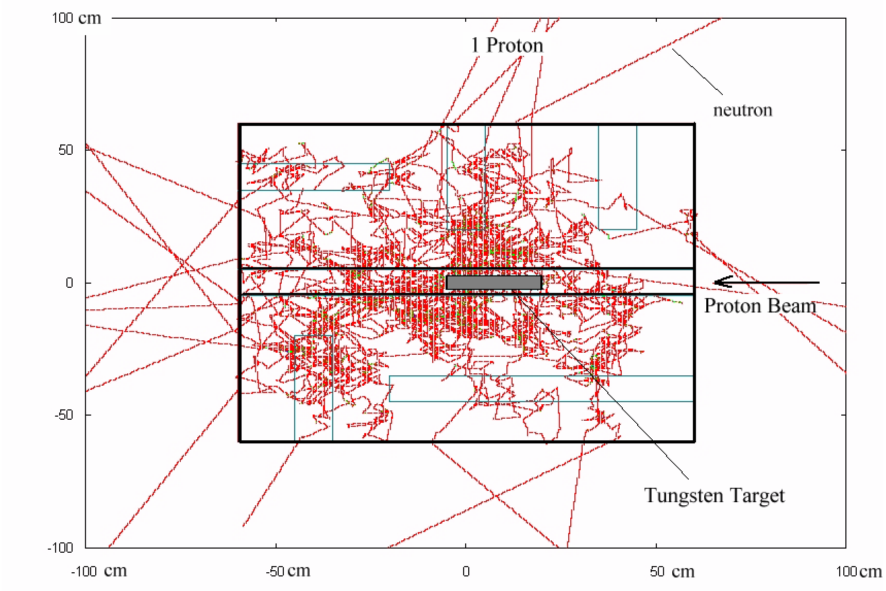
- Fission measurements
  - 240,241Pu
- Capture measurements
  - 240,241Pu
- gas production measurements
  - Mo and others as directed by Materials
- Measurement development
  - 5% inelastic measurements on ^{23}Na and ^{56}Fe
  - Determine if ^{238}U inelastic scattering needs better measurement
  - Develop plan for measurements on highly radioactive samples
- Implement mass separator for target preparation
- Establish nuclear data needs
  - material detection and accountability effort
  - criticality safety effort

AFCI out-year plan

- Fission measurements
  - 241Pu, 241Am
  - Begin LSDS measurement program
- Capture measurements
  - 241Pu, 241Am
- gas production measurements
  - Continue as needed by Materials
- Measurement development
  - ^{23}Na and ^{56}Fe inelastic measurements at GEANIE
  - ^{238}U inelastic measurement preparations
- Prepare isotopically pure samples of interest
- Plan or perform measurements as necessary
  - material detection and accountability effort
  - criticality safety effort

Lead Slowing Down Spectrometer





Neutron trajectories following the interaction of 1 proton with the tungsten target in the lead cube

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detector and DAQ R&D

GErmanium Array for Neutron Induced Excitations

- 26 Hi-Res Ge detectors
  - 15 γ-ray
  - 11 x-ray)
- 15 keV < E_γ < 9 MeV
- $\Delta E/E \sim 1/1000$
- $\varepsilon_{array} \sim 1\%$ (E_γ=1.33 MeV)

GEANIE
LLNL/LANL

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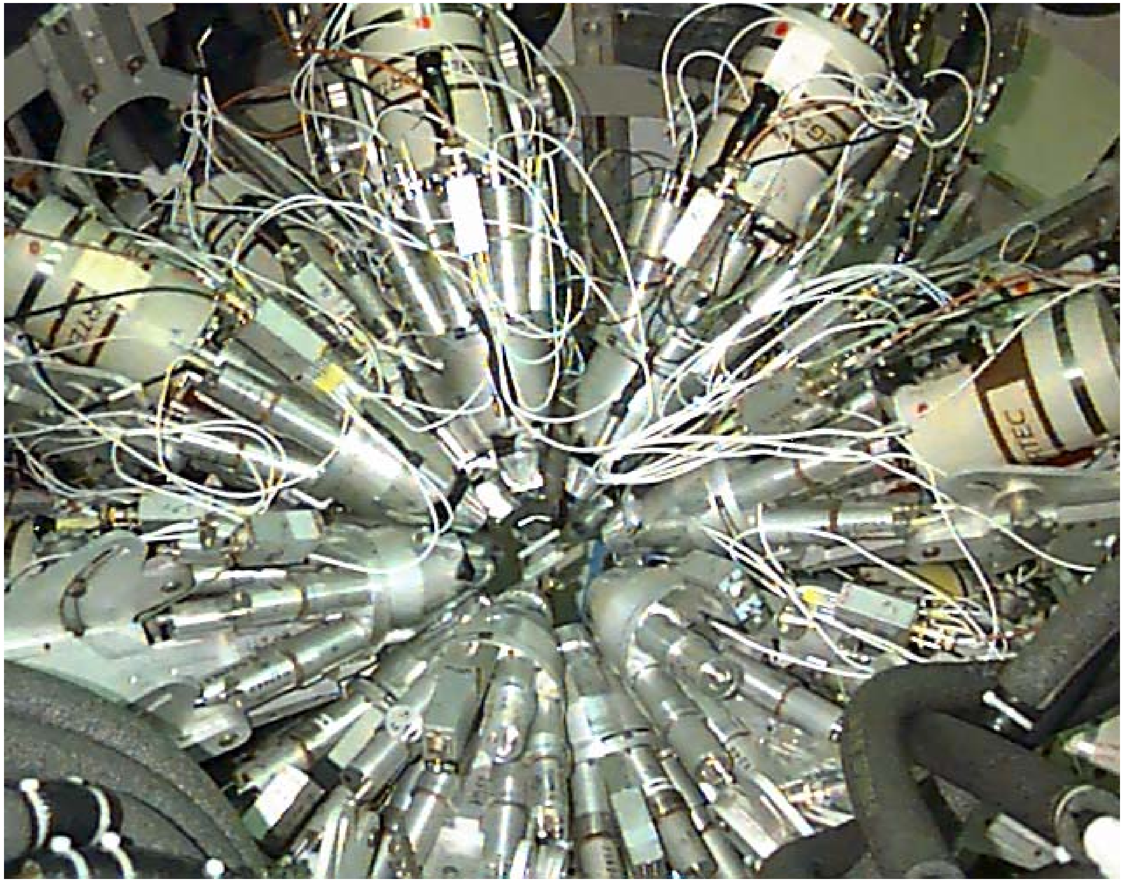

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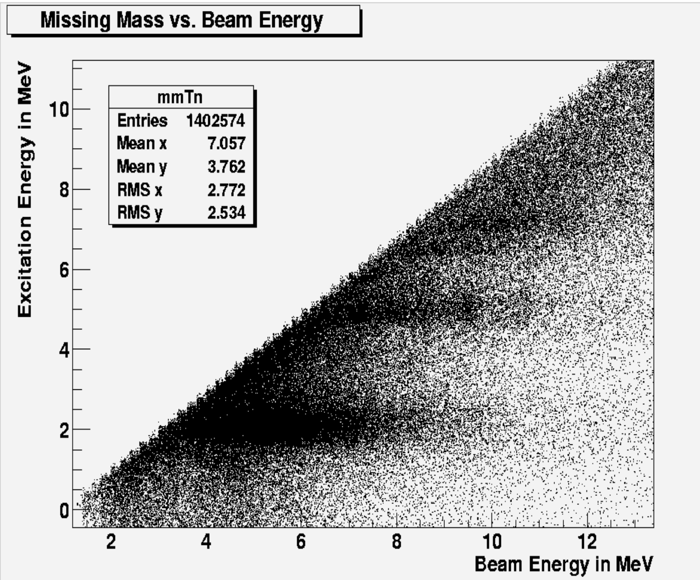
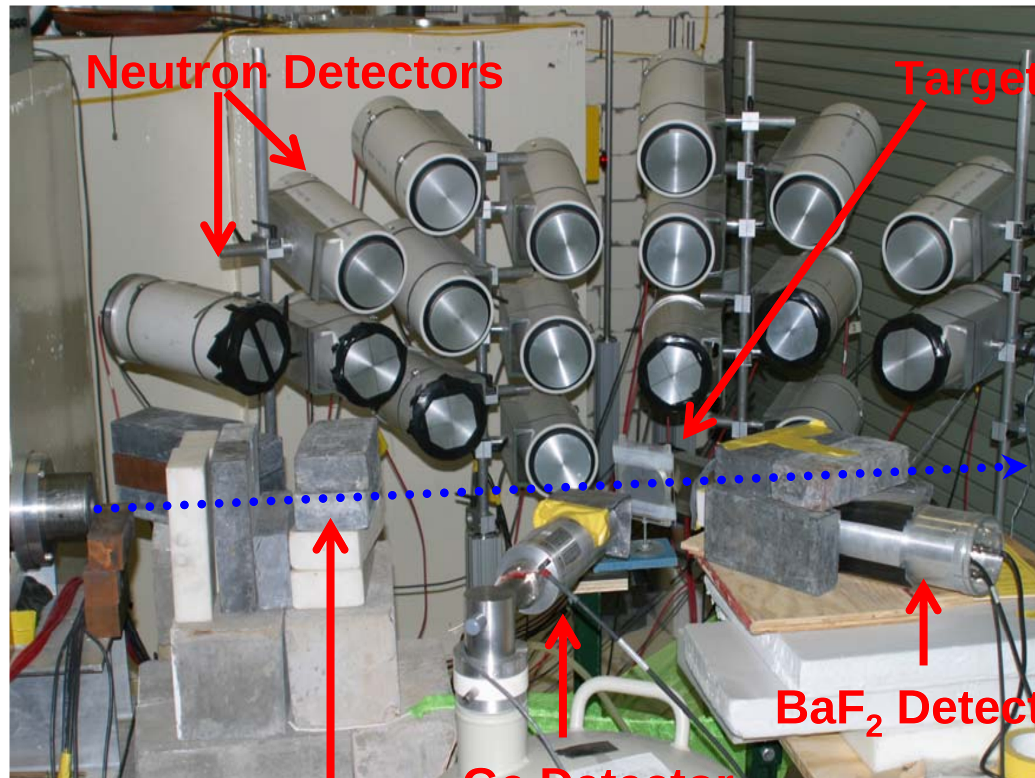
Fast Neutron Induced GAmma Ray Observer

- Gamma-ray detectors
  - HPGe for good resolution
  - BaF2 for good timing and efficiency
- Neutron detectors
  - EJ301 liquid scintillators





Double TOF technique

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Actinide Cross Section Measurements

Isotope	decay	τ	reactions
^{238}U	(α)	4.5×10^{9} y	(n,f),(n,g),(n,n')
^{235}U	(α)	7.0×10^{8} y	(n,f),(n,g)
^{237}Np	(α)	2.1×10^{6} y	(n,f),(n,g)
^{242}Pu	(α)	3.7×10^{5} y	(n,f),(n,g)
^{245}Cm	(α)	8.5×10^{4} y	(n,f)
^{239}Pu	(α)	2.4×10^{4} y	(n,f),(n,g),(n,2n)
^{240}Pu	(α)	6.5×10^{3} y	(n,f),(n,g)
^{241}Am	(α)	4.3×10^{2} y	(n,f),(n,g)
^{242m}Am	(it)	1.4×10^{2} y	(n,f),(n,g)
^{238}Pu	(α)	8.8×10^{1} y	(n,f),(n,g)
^{243}Cm	(α)	2.9×10^{1} y	(n,f)
^{244}Cm	(α)	1.8×10^{1} y	(n,f)
^{241}Pu	(β-)	1.4×10^{1} y	(n,f),(n,g)
^{242}Cm	(α)	4.5×10^{-1} y	(n,f)
^{238}Np	(β-)	5.8×10^{-3} y	(n,f)
^{242}Am	(β-)	1.8×10^{-3} y	(n,f)

High Precision

High activity

Precision fission cross sections require innovative solution - Time Projection Chamber

Current experiments have 10-20% disagreements, evaluations have 2-3% errors

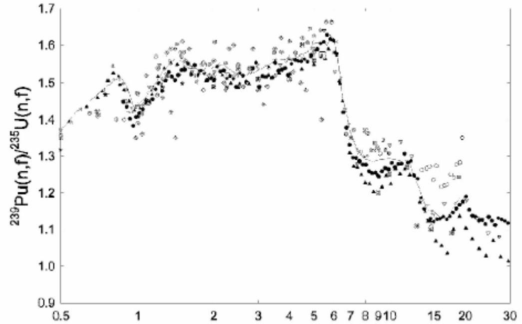
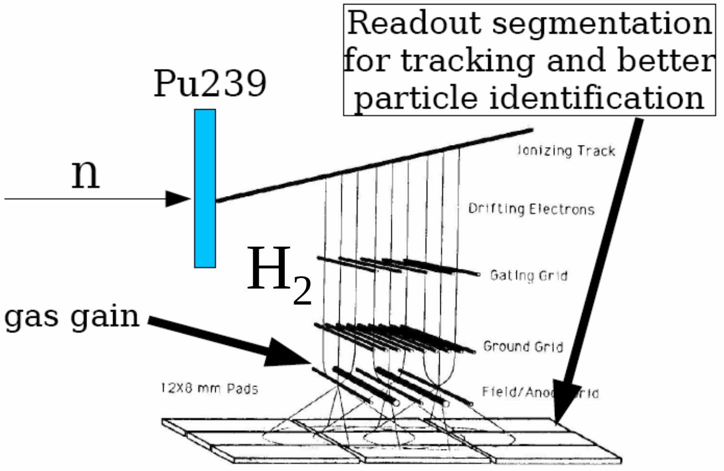


Fig. 3. Ratio of neutron-induced fission cross sections for ^{239}Pu/^{235}U to 30 MeV compared to other measurements (Refs. 1, 7, 8, 17, 19, 20, 23, 24, 25, 26, and 28) and ENDF/B-VI (solid line).

NUCLEAR SCIENCE AND ENGINEERING VOL. 129 JUNE 1998

New innovation: develop a Time Projection Chamber (TPC) to measure ^{239}Pu(n,f),^{235,238}U(n,f)



Technical challenges in developing entirely new detector for fission reaction measurements:

- **Complex construction**
- **High instrumented channel count**

Estimated costs $6M over 5.5 years to execute experimental program

Sub-systems R&D
System Development and Simulation
Construction and Commissioning
DAQ R&D

LLNL & LANL collaboration forming to propose this experiment at LANSCE, using combined expertise in detectors and nuclear physics

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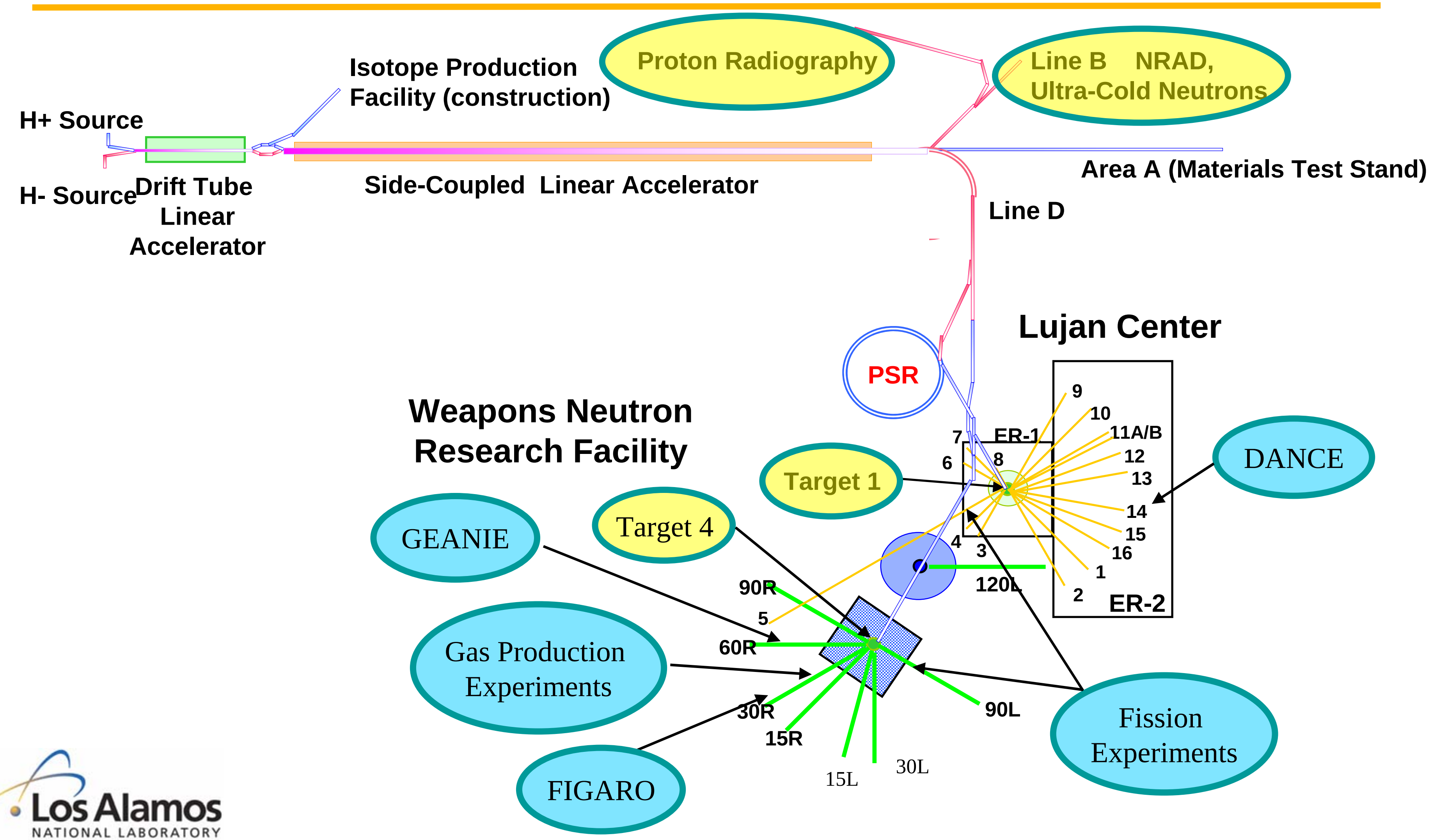
Pulse stacking upgrade to WNR

- Pulse stacking at WNR results in 2 HUGE advantages
  - A minimum factor of 5 increase in protons on target
  - No penalty for changes in time structure of proton beam delivery
- Why these are important
  - Increase in flux can reduce amount of beam time required for an experiment (can get more experiments done)
  - Increase in flux will increase signal to decay backgrounds, opening up new measurement possibilities
  - Dynamic time structure will open up the fast reactor energy region at WNR with high timing resolution

Pulse stacking at WNR will make use of the Proton Storage Ring (PSR)



WNR detection upgrades (pulse stacking)

- Several opportunities to collaborate on detector upgrades may open up at WNR
  - GEANIE II (clover detectors, high-speed DAQ, digitization)
  - Super DANCE
  - Gas production
  - FIGARO FIGARO
- New detector capabilities
  - Fission TPC
  - Total cross section measurements
  - Fission Dual-arm spectrometer

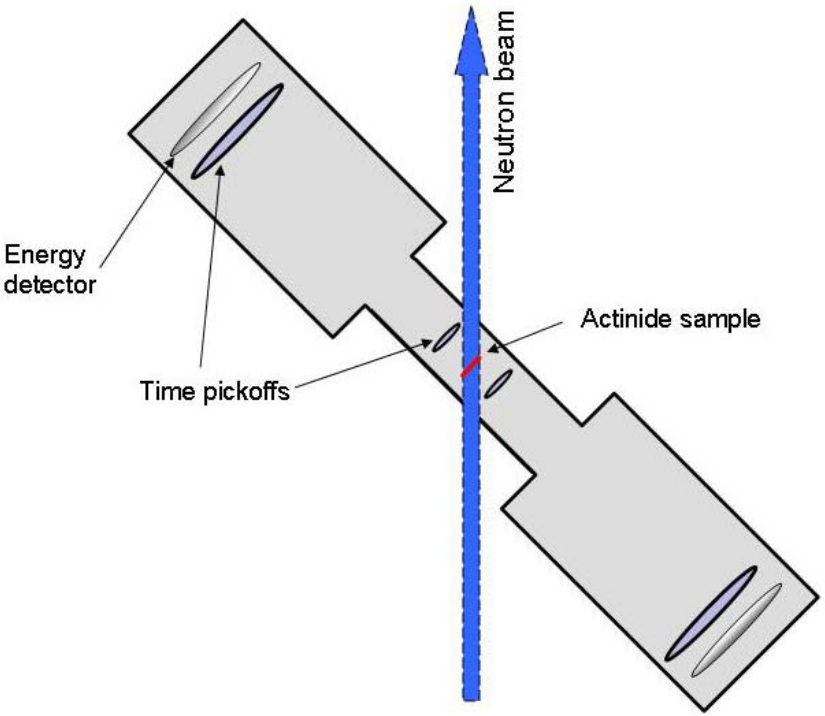
Sub-systems R&D

DAQ R&D

System Development and Simulation

Construction and Commissioning

Dual Arm Spectrometer for Applied and Basic Fission Physics



Mass resolution: 0.5 – 1.0 amu

Energy resolution: 0.5 – 1.0 %

Dual Arm Fission Fragment Spectrometer

- Reactor applications:
  High-precision measurements of total kinetic energy (TKE) release in fission vs neutron energy. Average number of neutrons released in fission as a function of fragment mass. Mass yield vs excitation energy. Fission product production cross sections.
- Fundamental fission physics:
  Provides experimental data on scission configurations, which is invaluable in improving models of the fission process. Will be required for development of fission models with actual predictive powers. Can determine correlations between fragment mass, kinetic energy and compound system excitation energy.

Sub-systems R&D

DAQ R&D

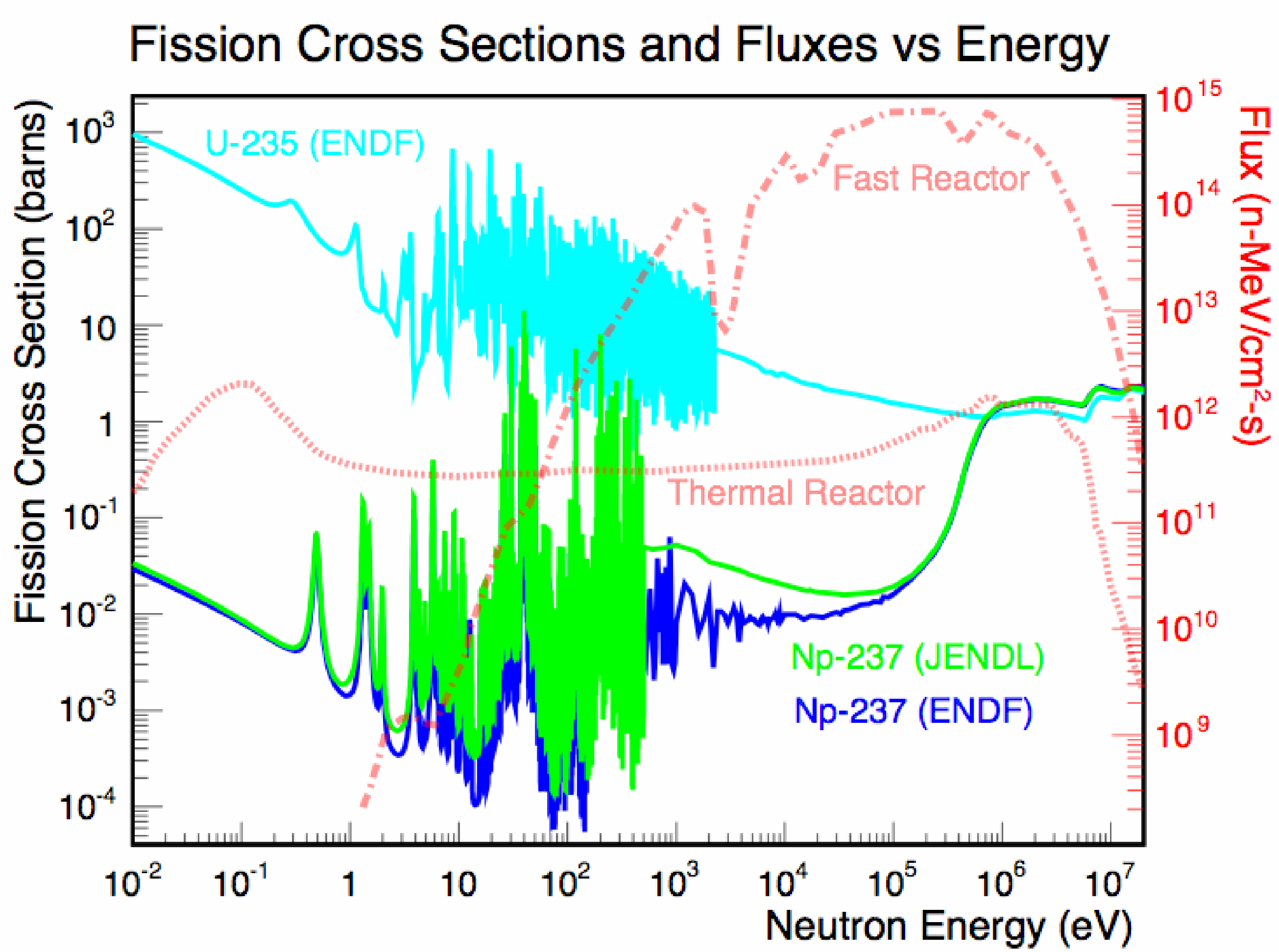
System Development and Simulation

Construction and Commissioning

Summary

- Nuclear data measurements have an impact on the nuclear energy complex (Max's talk)
  - At the foundation of all calculations is nuclear data
- Some of the measurement programs are underway (AFCI)
  - Opportunities for collaboration exist at nearly all levels
- Other measurement programs need to get started
  - Existing facilities and detection systems in place can use help
  - New experiments need to be designed and constructed
- Other measurements are waiting to be recognized
  - Materials accountability and Safeguards
  - Criticality safety
  - Materials Test Station
  - Work closely with designers and analysts
  - Need to be able to address these needs quickly

Fission cross sections and fluxes



^{235,238}U(n,f): neutron energy spectrum and neutron multiplicity

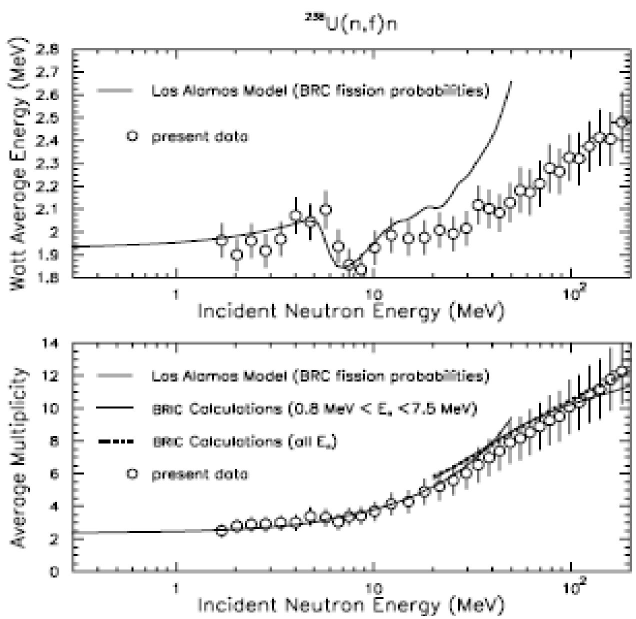


FIG. 3. Prompt-fission neutron average energy (upper plot) and multiplicity (lower plot) for the system ^{238}U(n, f) as a function of incident neutron energy measured with the FIGARO setup.

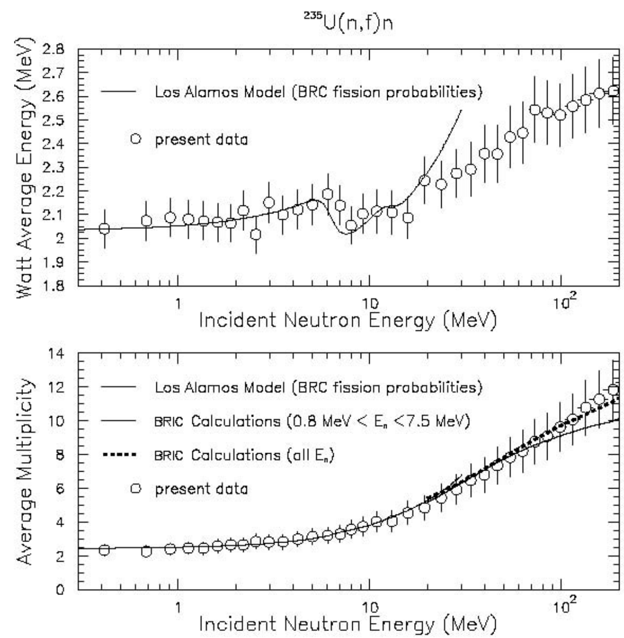


FIG. 4. Prompt-fission neutron average energy (upper plot) and multiplicity (lower plot) for the system ^{235}U(n, f) as a function of incident neutron energy measured with the FIGARO setup.

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