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Nuclear Data Experiments at LANSCE: Highlights

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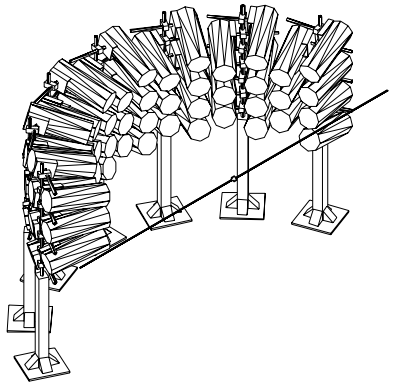
Cross Section Evaluation Working Group Meeting
US Nuclear Data Program Meeting
Brookhaven National Laboratory
November 2-5, 2004

Nuclear data measurements at LANSCE are made with several instruments

GEANIE (n,xγ)

FIGARO (n,xn+γ)



DANCE (n,γ)

N,Z (n,charged particle)

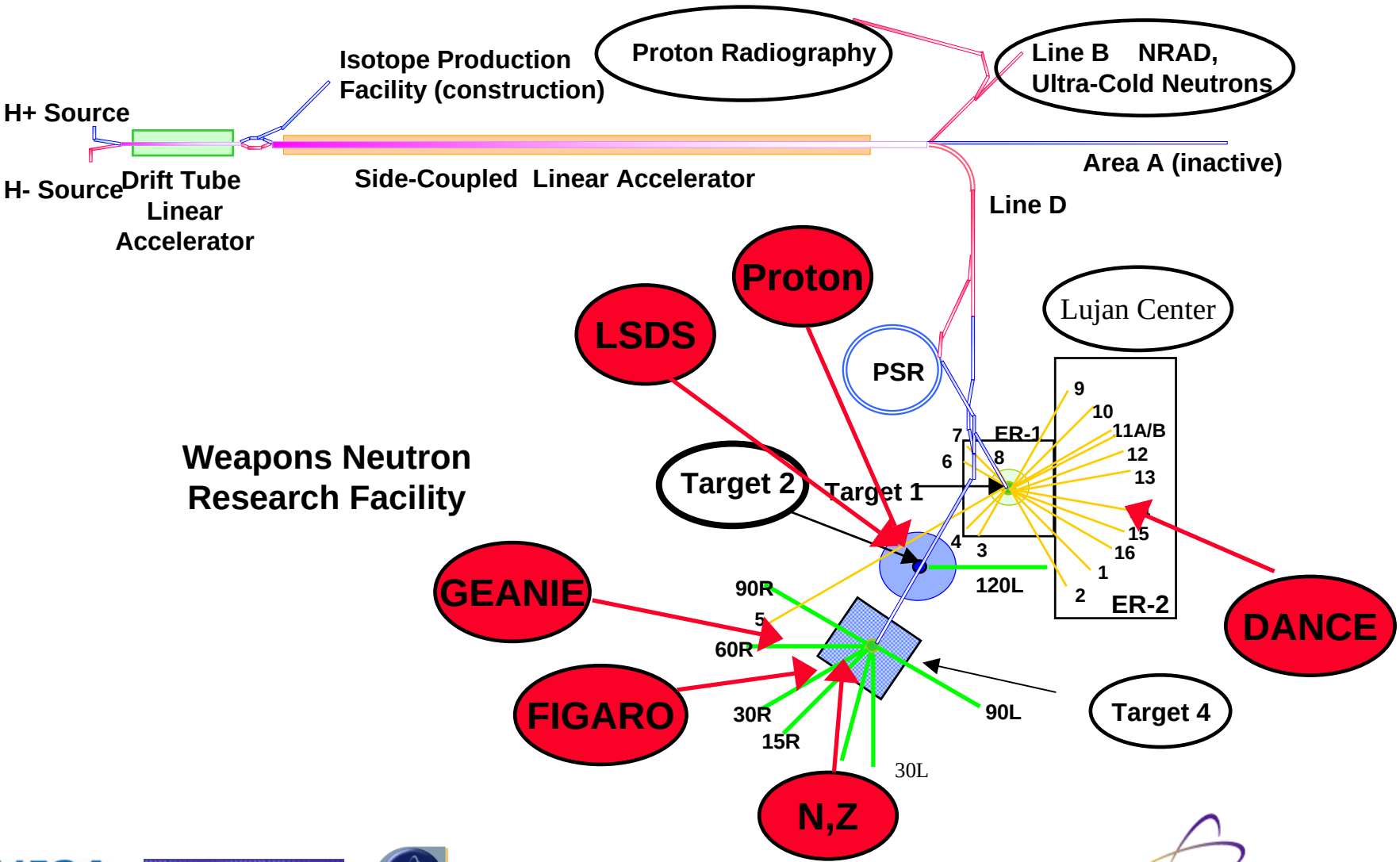
Fission

LSDS

Double Frisch-grid fission chamber; also standard fission ion chamber

Other: (p,X)

Nuclear data experiments at LANSCE use neutrons at three locations: Lujan Center, Target 2 and Target 4.



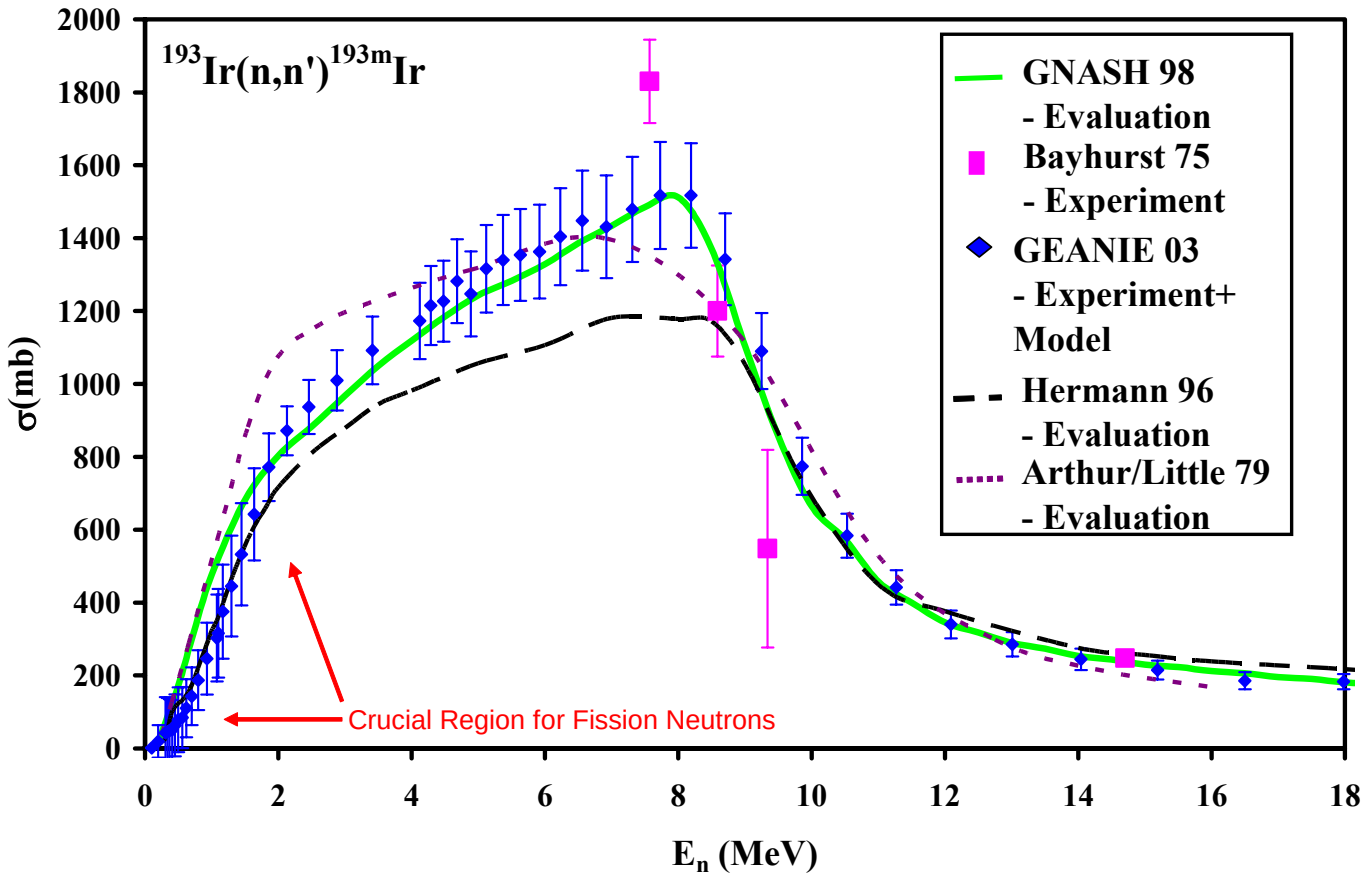
GEANIE (n,xγ)

Recent & planned GEANIE neutron-induced gamma-ray cross-section measurements at LANSCE/WNR

~1 MeV < E_n < 200 MeV

- ^{191,193}Ir(n,n'γ), (n,xnγ), and (n,pxnγ) – results ND2004
- ^{197}Au(n,n'γ), (n,xnγ), and (n,pxnγ) – results APS DNP 10/2004
  - New levels and γ's obtained for ^{191,3}Ir and ^{197}Au
- ^{100}Mo(n,xγ) – analysis starting
- ^{130}Te(n,xγ) – analysis starting
- ^{70,72,74}Ge(n,xγ) – analysis starting (with INEEL)
- ^{nat}Cr + ^{nat}V – relative, for secondary cross section standards
- ^{nat}Cr + ^{nat}Fe – same as above – results ND2004
- ^{48}Ti(n,xγ) – dissertation - D. Dashdorj (NCSU/LLNL)
- ^{150}Sm(n,2nγ) – reported (UCRL-TR-205760)
- Planned Samples: ^{124}Sn, ^{138}Ba, ^{170}Er, ^{186}W, ^{233}U

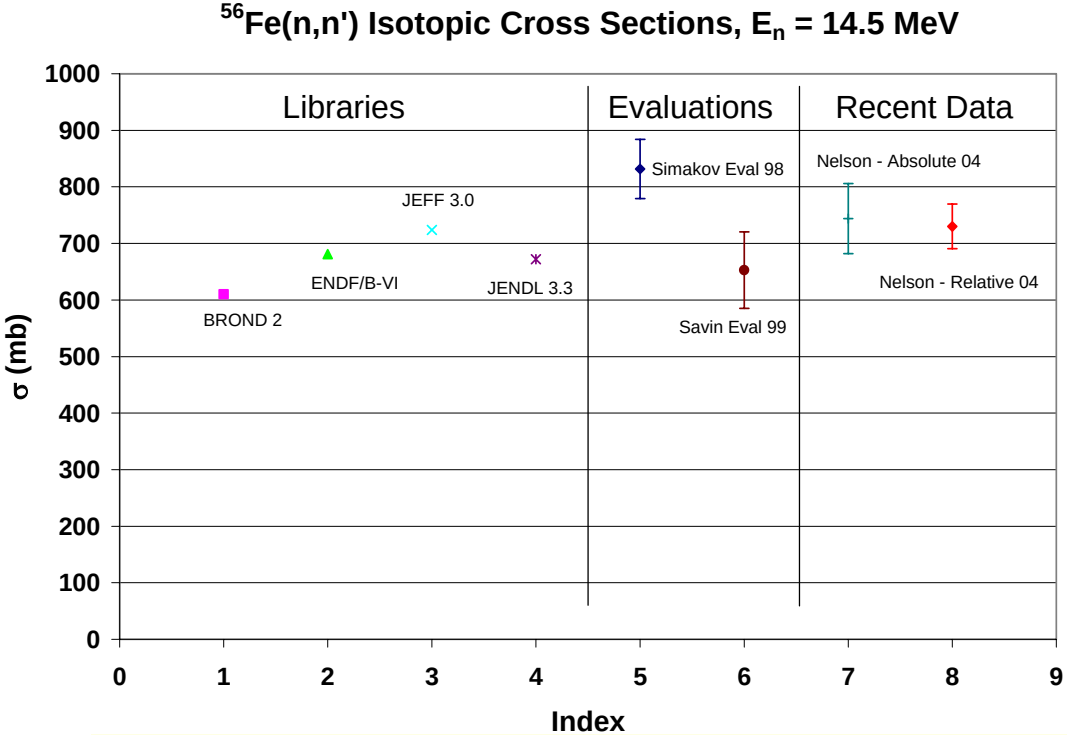
New GEANIE data significantly improve the $^{193}Ir(n,n')^{193m}Ir$ cross section database



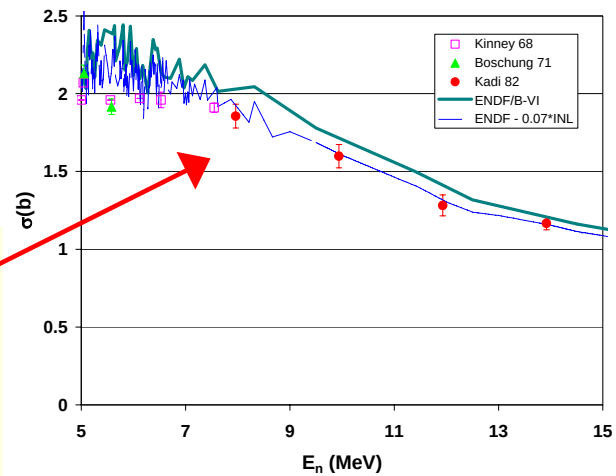
GEANIE
LLNL/LANL

NNSA – SCIENCE – Nuclear Energy — Los Alamos

Recent Fe(n,n'γ) E_γ = 847 keV relative and absolute measurements at E_n = 14.5 MeV agree with JEFF 3.0

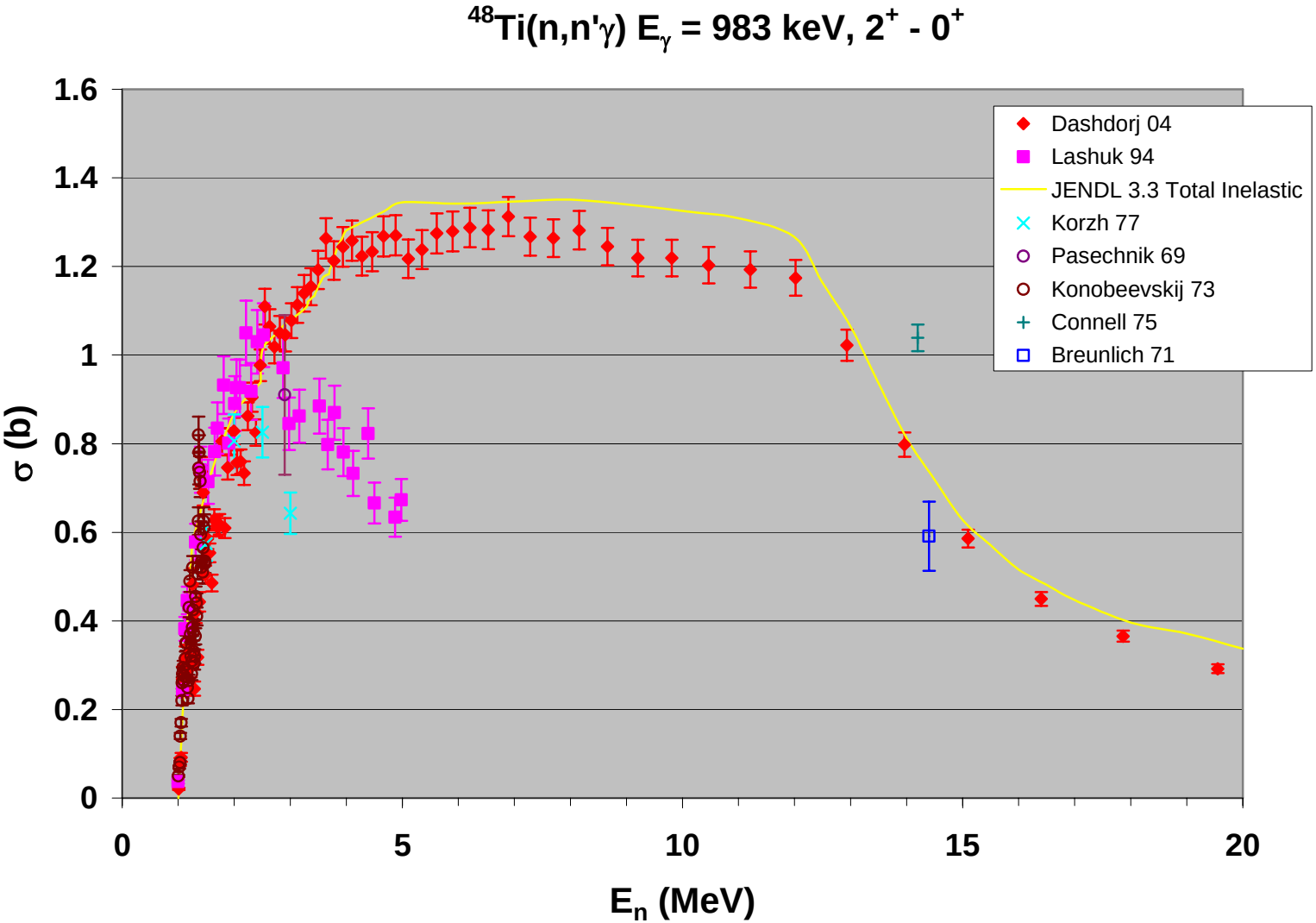


- **Left – Absolute cross sections using ^{238}U(n,f) to measure the neutron fluence & cross sections measured relative to ^{52}Cr(n,n'γ) agree well, but are ~8% larger than ENDF**

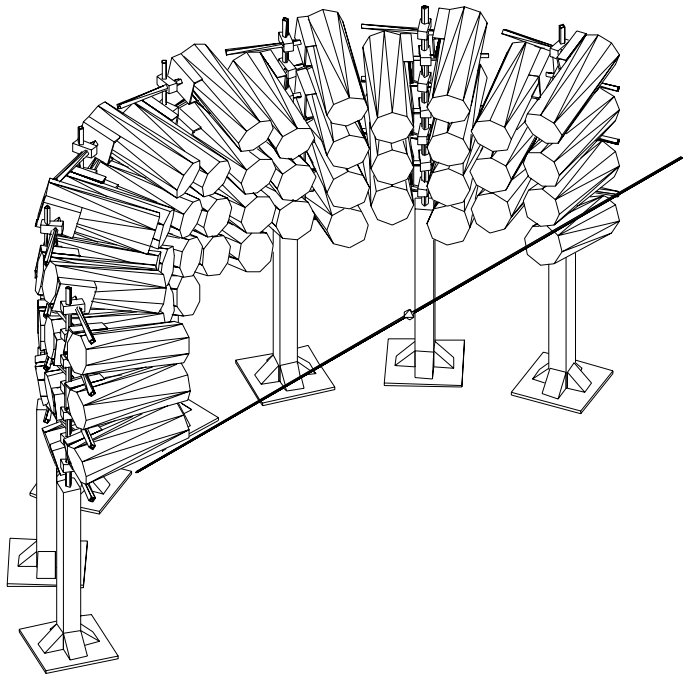


- **Right – Blue curve shows lowering the ENDF ^{56}Fe Elastic scattering cross section by 8% of the inelastic cross section (preserving the total) gives better agreement with elastic scattering data.**

Recent GEANIE (Dashdorj) results for ^{48}Ti(n,n'γ) agree fairly well with the JENDL 3.3 evaluation



FIGARO (n,xn+γ)



Present and future experiments at FIGARO/WNR: neutron-emission spectra and ν-bar in fission

1 MeV < E_n < 200 MeV

Fission Chamber in beam

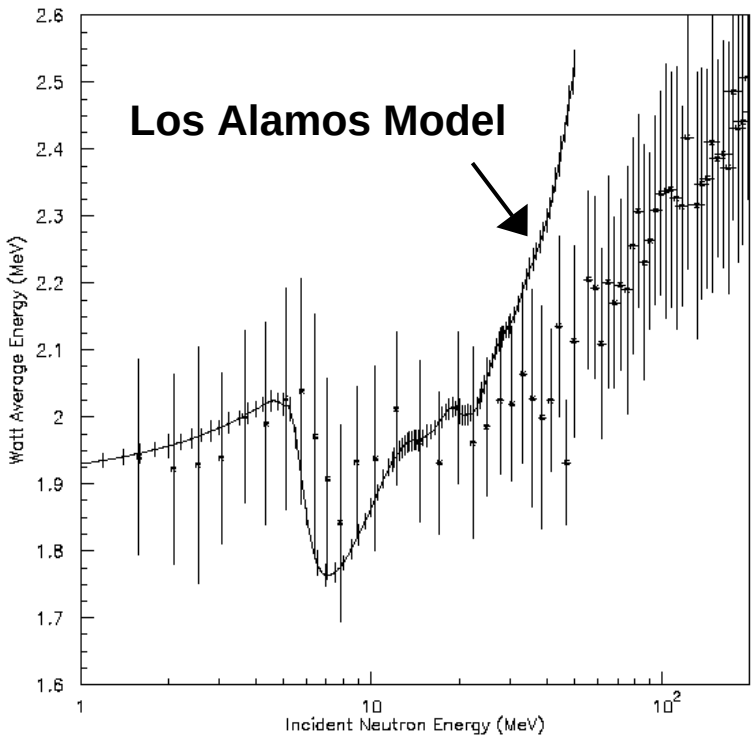
- ^{238}U(n,f): $<E_{fn}>$ — Ethvignot, Phys. Lett. B
- ^{235,238}U(n,f): E_{fn}, ν-bar — Ethvigot, paper submitted on ν-bar
- ^{235}U(n,f): E_{fgamma} — R. Nelson, in progress
- ^{237}Np(n,f): E_{fn}, ν-bar — next run cycle

Gamma-ray trigger (HPGe or BaF2)

- Si(n,n'gamma) — Rochman et al. NIM 523, 102 (2004)
- ^{58,60}Ni(n,n'gamma) — ND2004 contribution
- ^{99}Tc, ^{208}Pb — In progress

The fission neutron spectrum varies with incident neutron energy

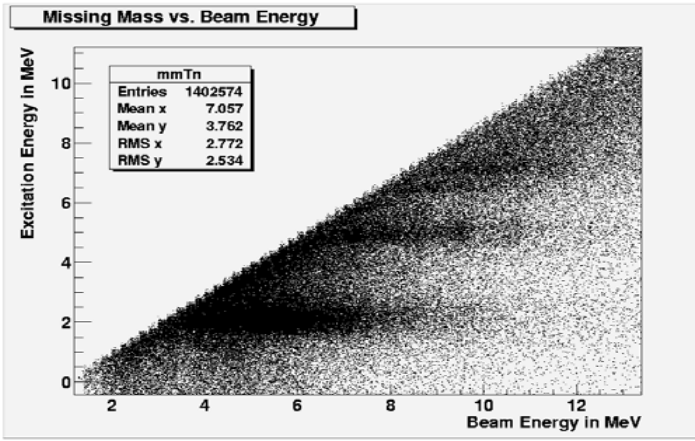
^{238}U(n,f) average neutron energy

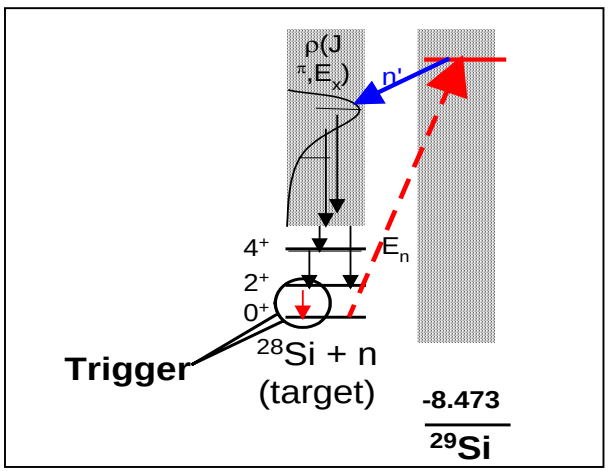


Agreement with Los Alamos Model is good below 20 MeV

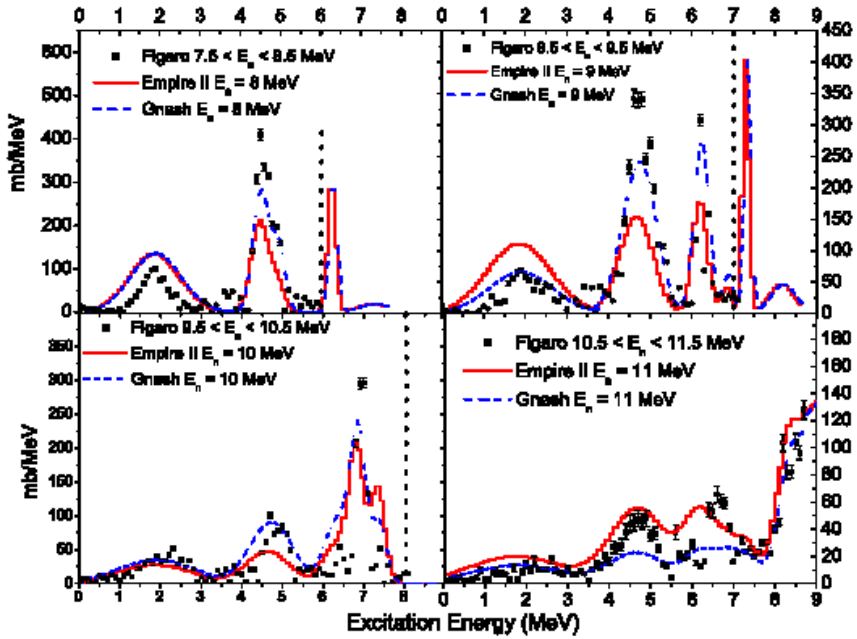
Neutron emission from neutron reactions is studied as a function of incident neutron energy

$^{28}Si(n,n')$

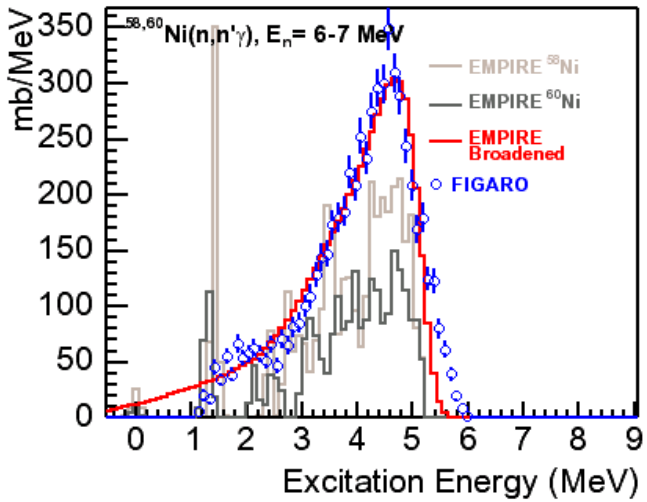


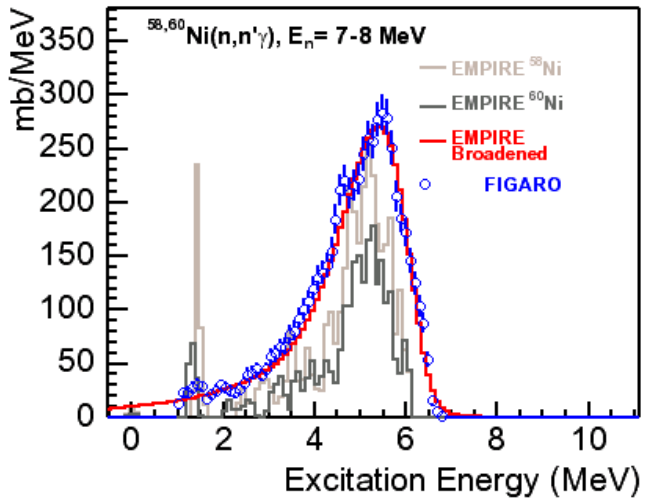


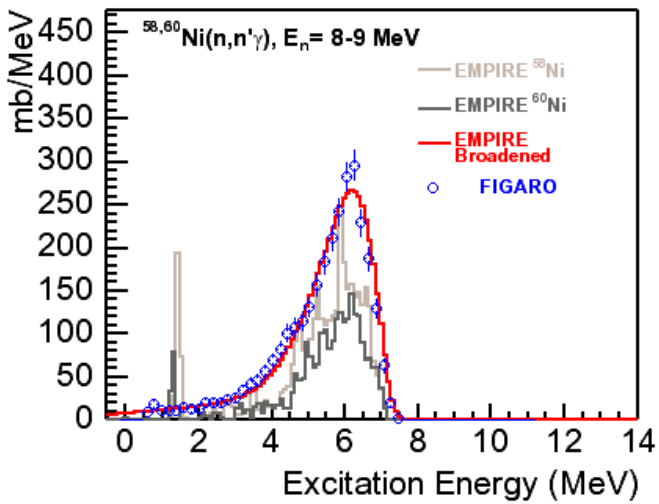
We compare our results with GNASH and EMPIRE calculations

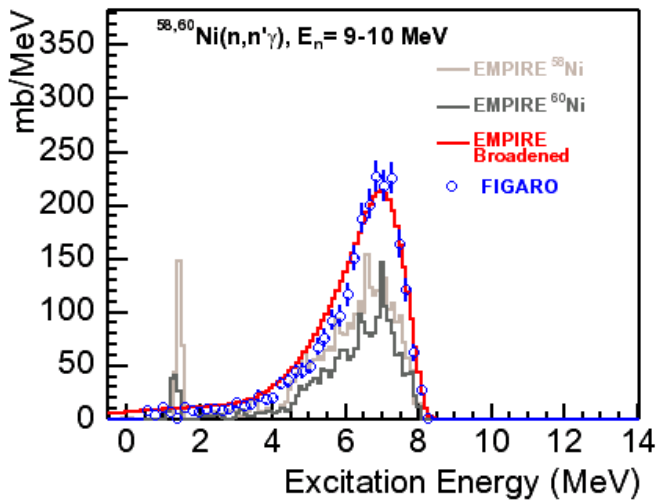


Model-Measurement Comparison for Ni(n,n'γ)









N,Z = (n,charged particle) cross sections

We measure proton, deuteron and alpha-particle production cross sections for the Advanced Fuel Cycle Initiative

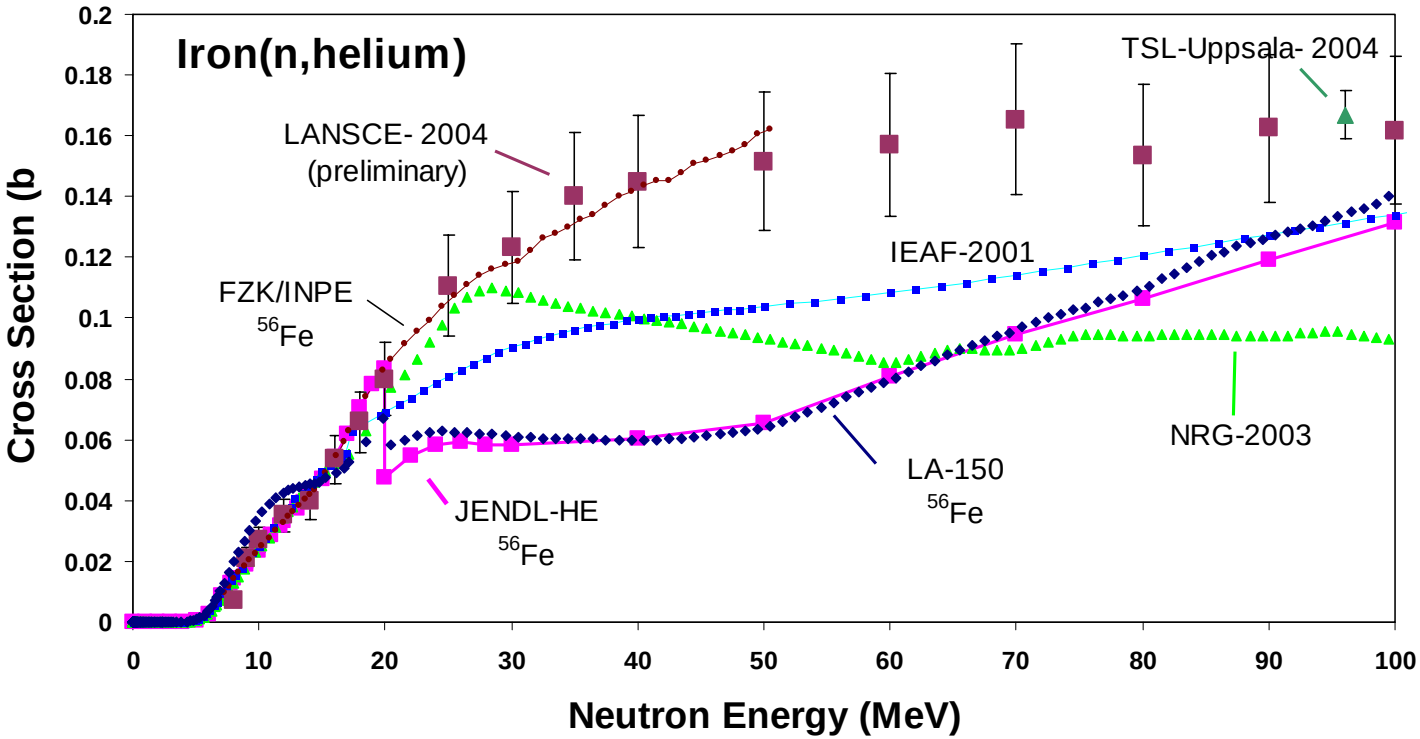
1 MeV < En < 100 MeV

- ^{nat}Fe(n,xp) + (n,xα) — Haight, ANS November 2004

- In progress:
  - Cr(n,xp) + (n,xα)
  - Ta(n,xp) + (n,xα)

Goal is to determine, e.g. helium production / dpa for accelerated radiation damage analysis

New LANSCE data differentiate among evaluations



DANCE (n,γ)

DANCE Progress 2003 - 2004

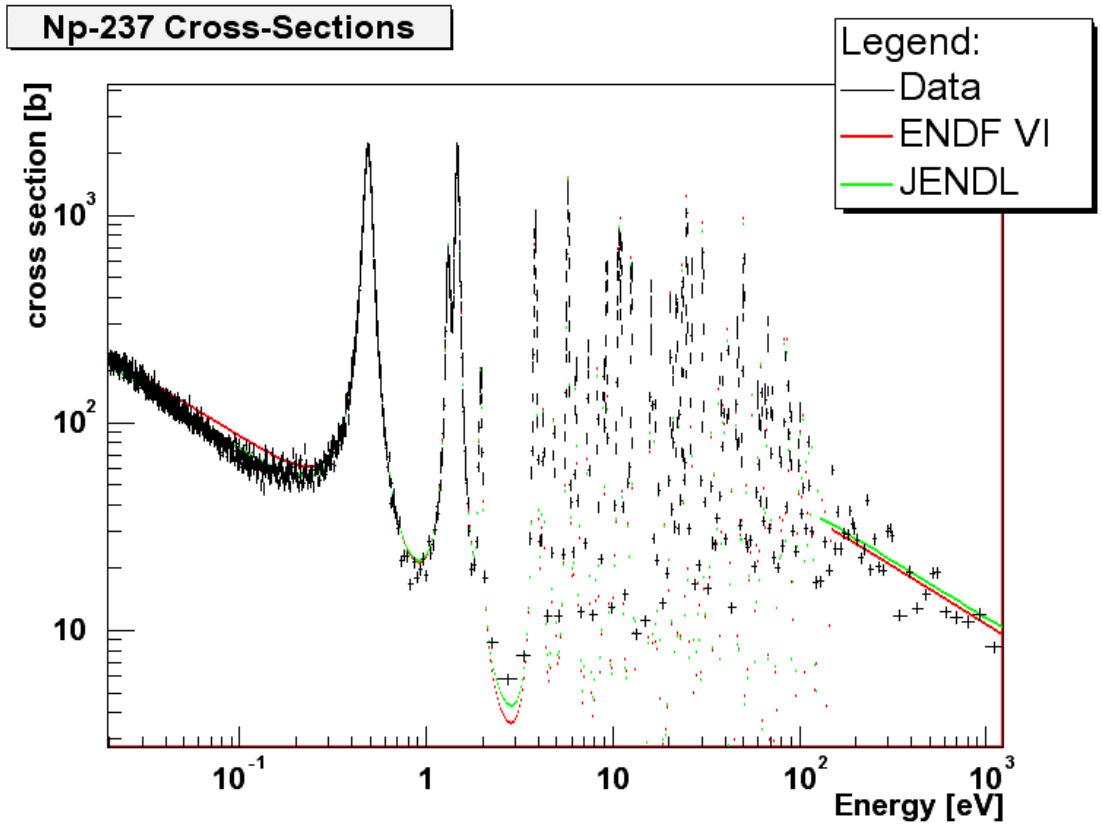
Stable Targets:

- ^{197}Au (well-studied standard)
- ^{139}La,^{45}Sc,^{55}Mn,^{59}Co,Cu,V,Rb,Sr (Gaps in s-process)
- ^{102}Pd (rp process)
- ^{62}Ni ("weak" s-process puzzle)
- ^{151,153}Eu rad-chem diagnostics

Radioactive Targets

- ^{237}Np AFCI
- ^{234,235,236,238}U Known standards and defense programs
- ^{151}Sm Key s-process branch (largely completed)

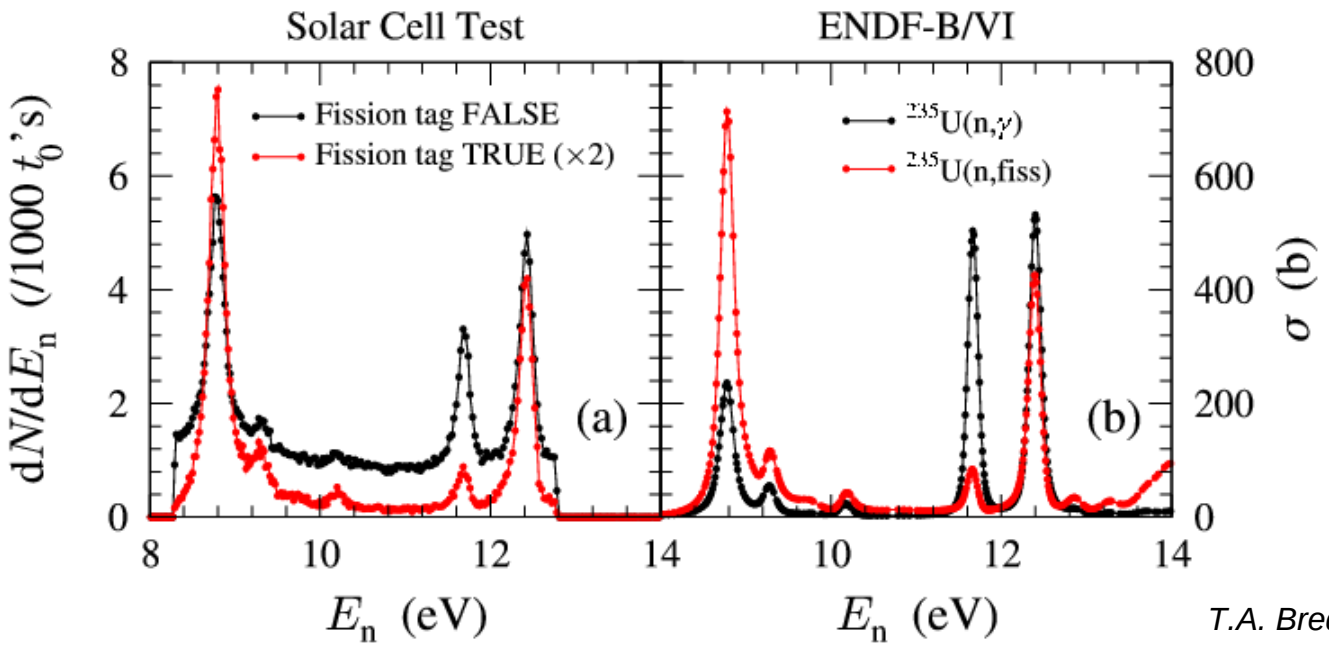
^{237}Np(n,γ) Preliminary Analysis



Target: 0.44 mg ^{237}Np in 6.4 mm dia (1.4 mg/cm^2)

Existing data above 1 keV discrepant

Test measurements with a fission-tagging detector



T.A. Bredeweg, et al.

- **Study:**
  - **Fission-to-capture ratios ("alpha")**
  - **Gamma emission following fission**
- **"Proof-of-principle" experiment used "thin" ^{235}U depost on silicon solar cell (T. Ethvigniot, et al.)**
- **Future: Develop thin gas fission chamber**

DANCE Plans 2004 - 2005

Stable Targets:

- ^{151,153}Eu rad-chem diagnostic
- ^{72,73,74}Ge, ^{75}As. ^{76,77,78,80}Se, ^{54,56,57,58}Fe
  (Capture cross sections with better accuracy for s-process studies)

Radioactive Targets

- ^{240,244}Pu AFCI and defense programs
- ^{147}Pm s process branch - target irradiated, needs chemistry
- ^{171}Tm,^{155}Eu rad-chem diagnostics, target irradiated, needs chemistry

Development

- Improved hardware handshaking between distributed computers
- Further work on resolution and backgrounds
- Further development of “continuous” data acquisition
- Faster distributed computers, wider-range continuous mode
- Ge detector in concidence for fission studies (??)
- Fission-tagging detector for capture/fission and fission gammas
- Improved neutron monitors – more efficient ^{6}LiH, ^{235}U fission chmbr

Astrophysical neutron-capture reactions studied at DANCE include the following:

^{151}Sm

- radioactive
- branch s-process point
- 0.5 mg

^{139}La, Rb, Sr

- closed n-shells
- integrated neutron flux during s-process
- s/r ratio in metal poor stars
- uniqueness of r-process
- integrated neutron flux during s-process

^{62}Ni

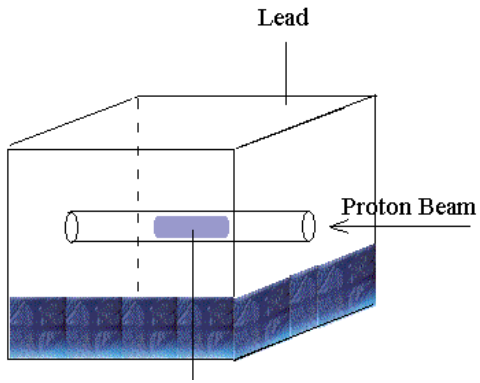
- stable
- only 25 % of MACS from resonances
- until recently: 75% had to rely on theory

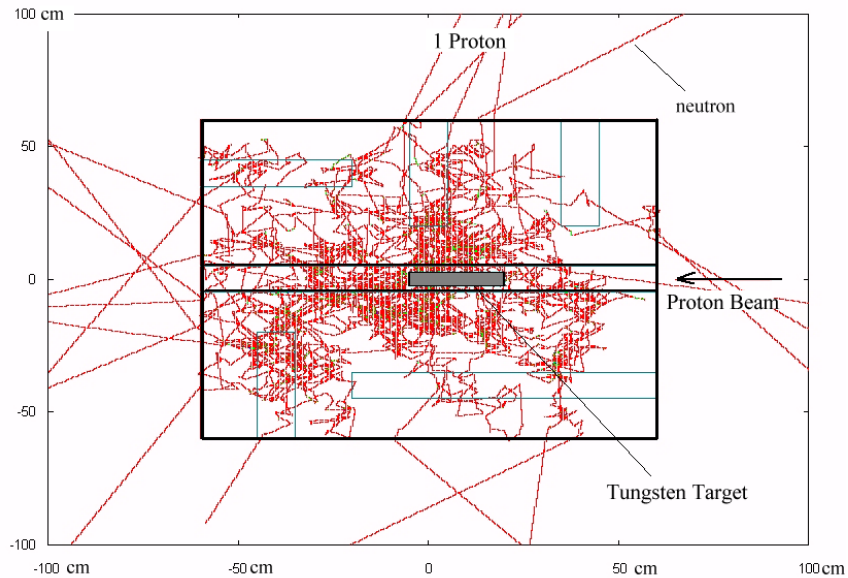
^{102}Pd

- stable
- (n,γ) – (γ,n) equilibrium during p-process
- sample only 80% enriched

Lead Slowing-Down Spectrometer (n,f)

A Lead Slowing-Down Spectrometer is under development, driven by 800 MeV protons from the PSR



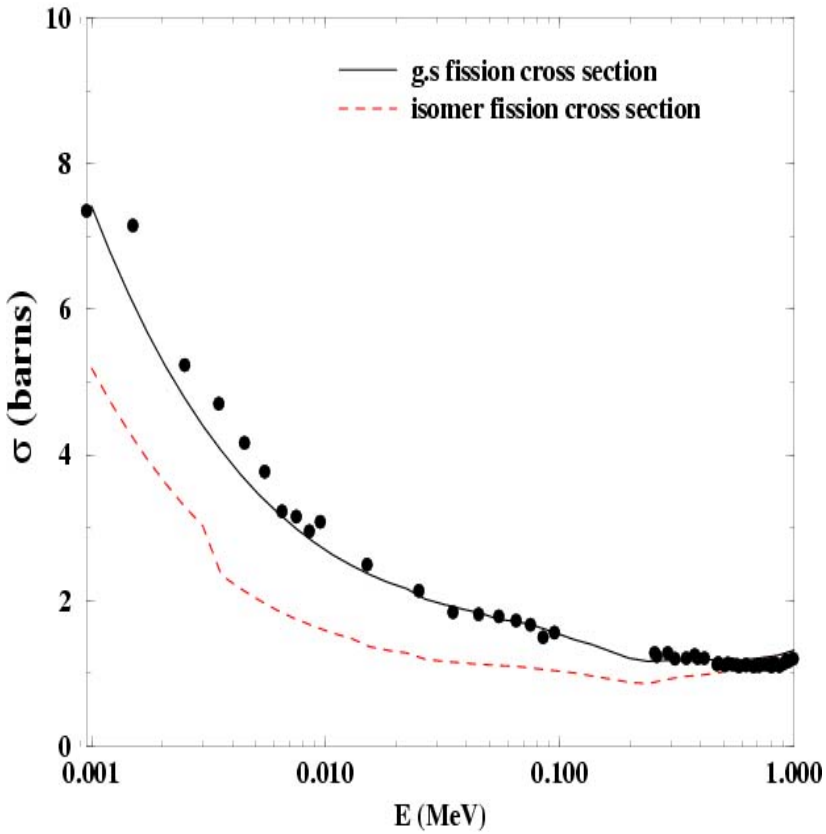


Neutron trajectories following the interaction of 1 proton with the tungsten target in the lead cube

Lead Slowing-Down Spectrometer: To measure fission cross sections of ultra-small samples

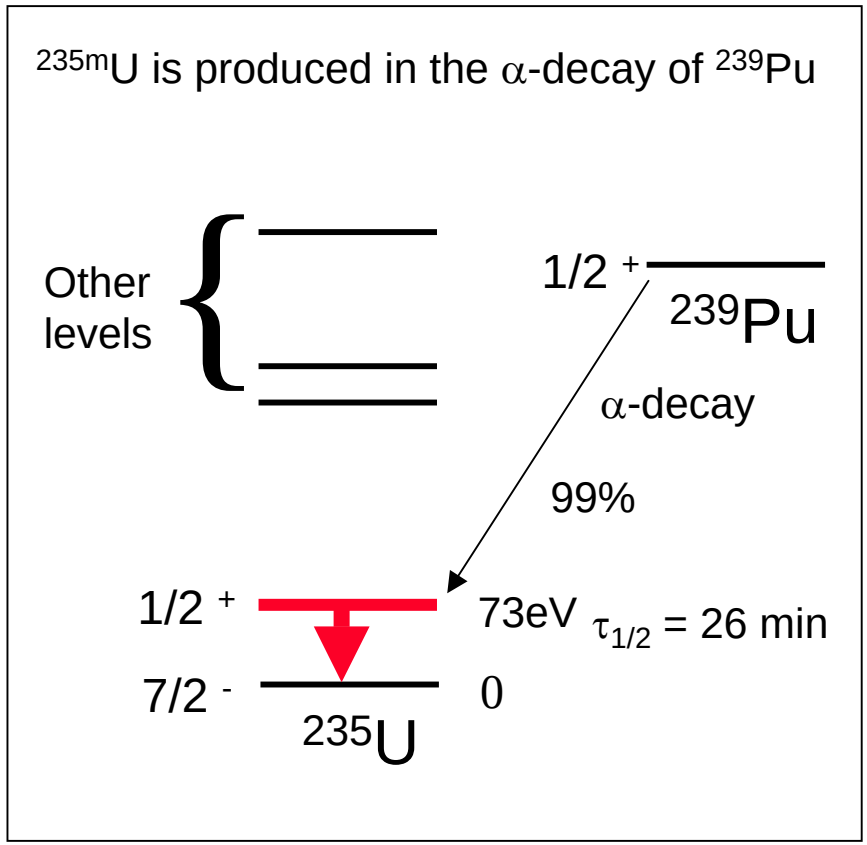
- **Effort motivated by interest in measuring the fission cross section of isomers and small samples of actinides**
- **Calculations show that cross section for ^{235m}U is significantly different than for ground state**
- **Experiments are in collaboration with LLNL, RPI and CEA/DAM**

Fission cross section of ^{235}U and ^{235m}U

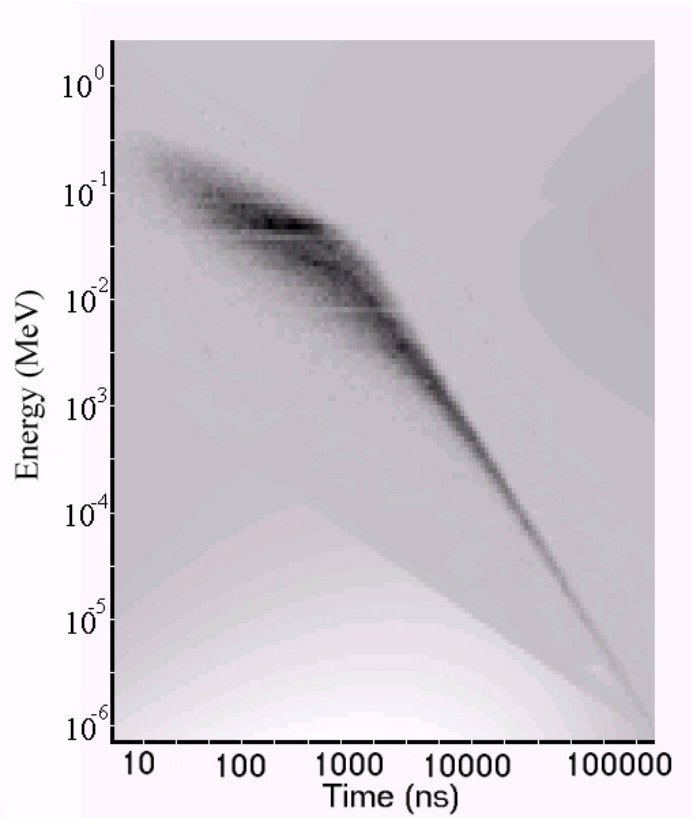


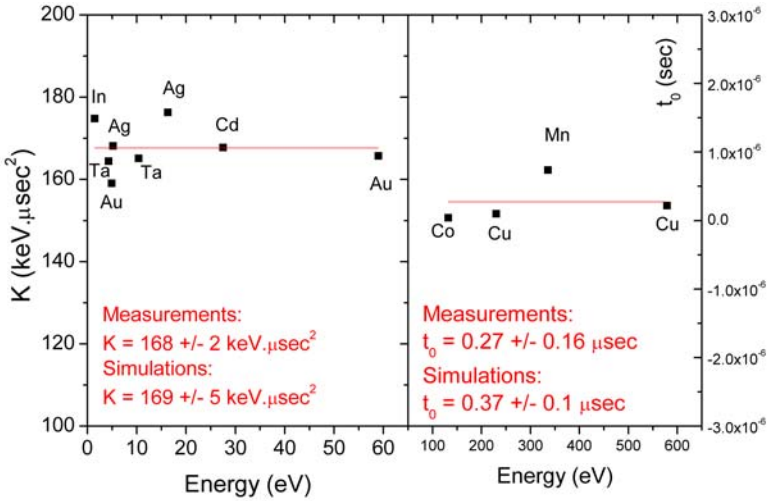
First excited state of ^{235}U is produced in decay of ^{239}Pu

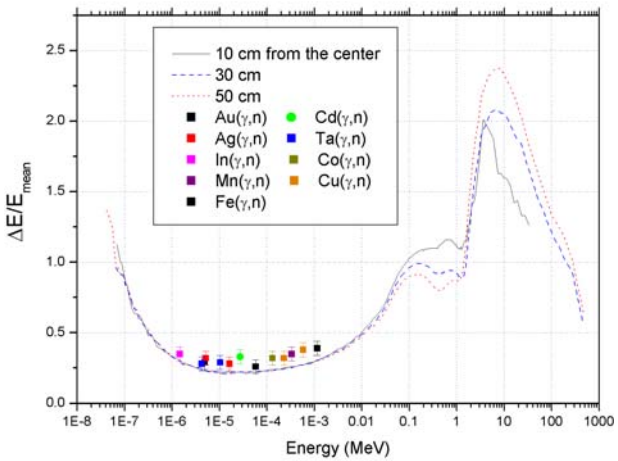
- ^{235m}U
  - 26 min half-life
  - 73eV
  - Decays by internal conversion
  - 99% of 239Pu decays populate ^{235m}U
  - 5 gm of Pu will produce 10ng of ^{235m}U
- Fast extraction of ^{235m}U will be required
- To measure this small cross section, it is necessary to increase the neutron flux by using a lead-slowing down spectrometer (LSDS)



We have characterized the time-energy correlation and measured the resolution in capture resonances



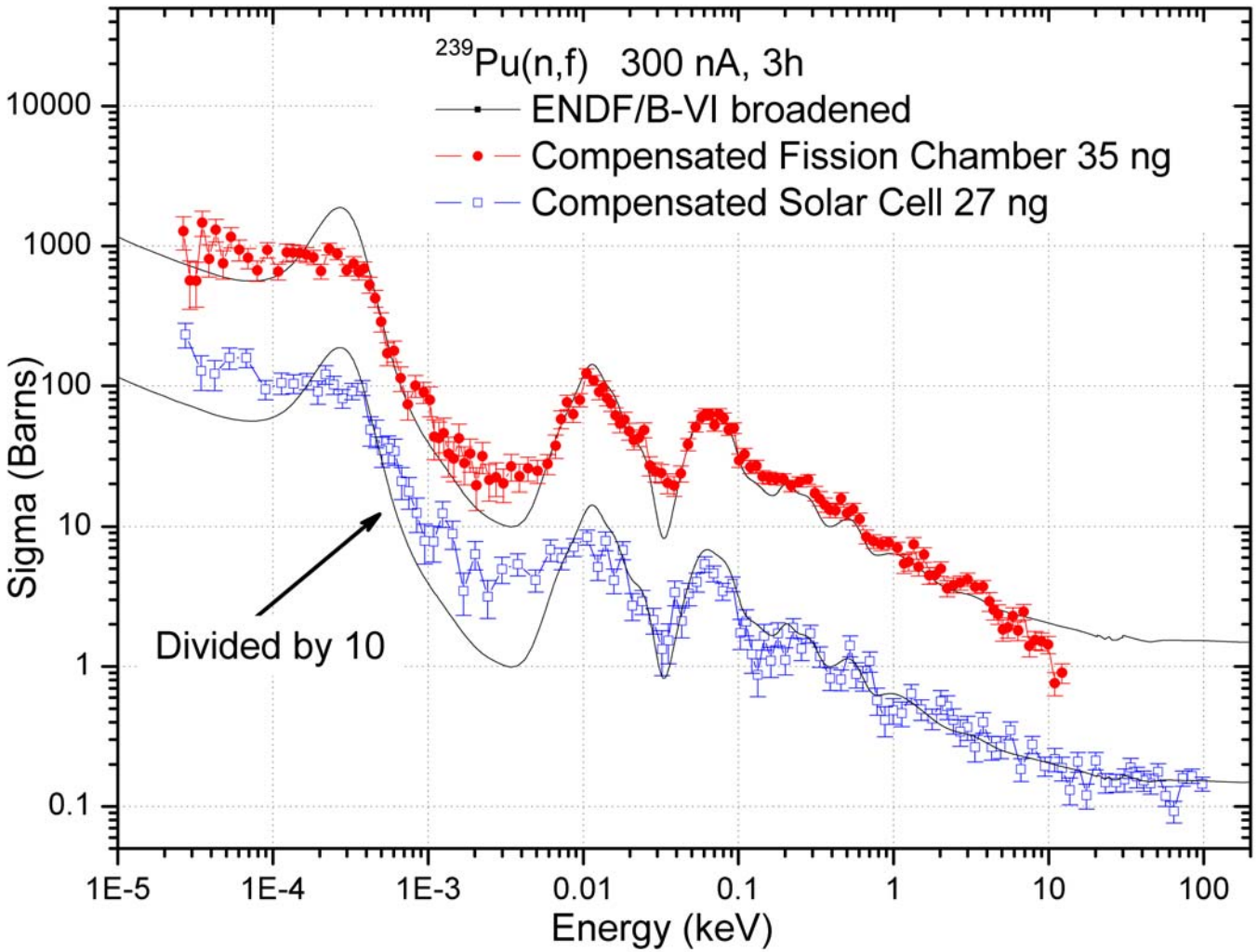




Simulation: $\langle E_n \rangle = K / (t + to)^2$

with resolution, $\Delta E/E \sim 30\%$

With the LSDS, we have measured the neutron-induced fission cross section on ^{239}Pu section with sub-μg samples



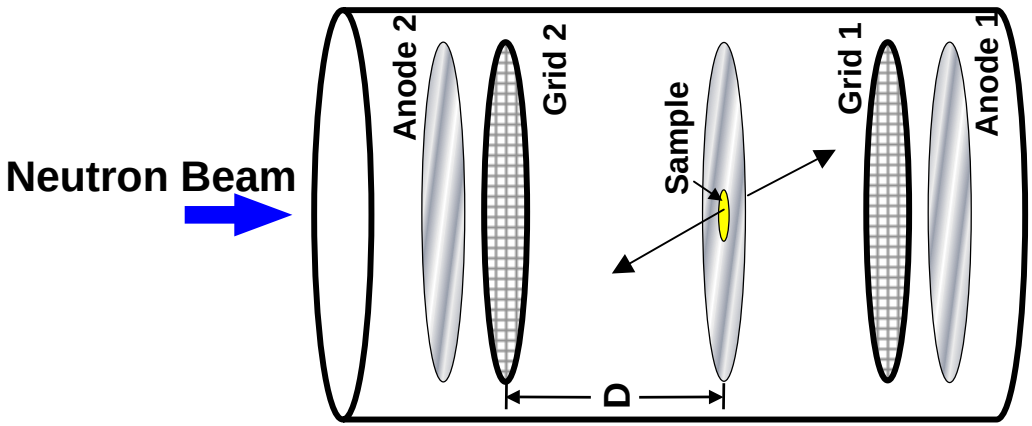
- "High" proton intensity
- 3h runs
- Ultra Small quantity of ^{239}Pu
- Good results up to 100 keV

Measuring fission cross sections with double Frisch-grid fission ionization chamber is a new initiative

- Data for the Advanced Fuel Cycle Initiative
- Preliminary data ^{237}Np (standard fission chamber)
- FY 05: ^{237}Np, $^{240, 242}$Pu with Frisch-grid chamber
- People:
  - Tony Hill
  - Fredrik Tovesson
  - F.-J. Hambsch

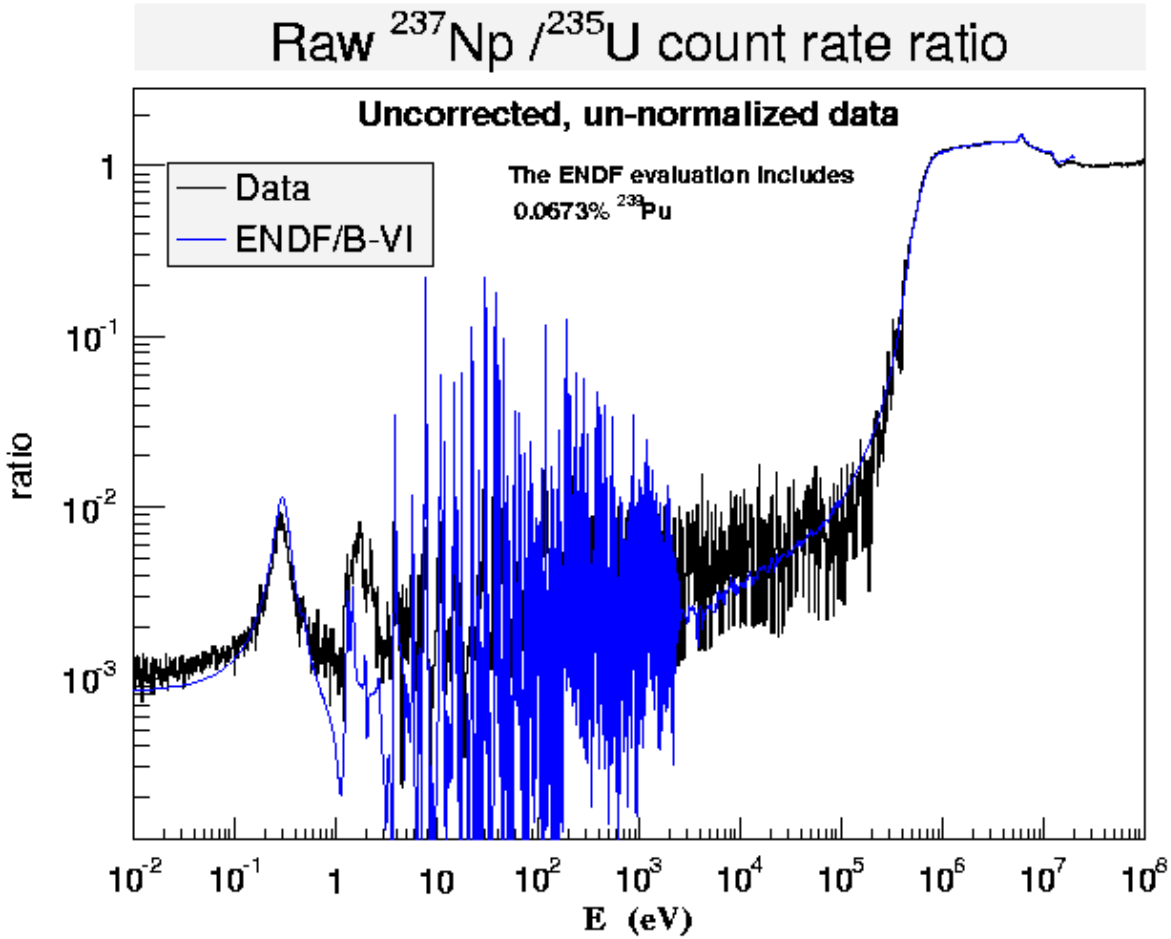
The double Frisch-grid fission ionization chamber allows good identification of fission

Both fission fragments are detected with Z and A resolution



Apparatus from F.-J. Hambsch, IRMM

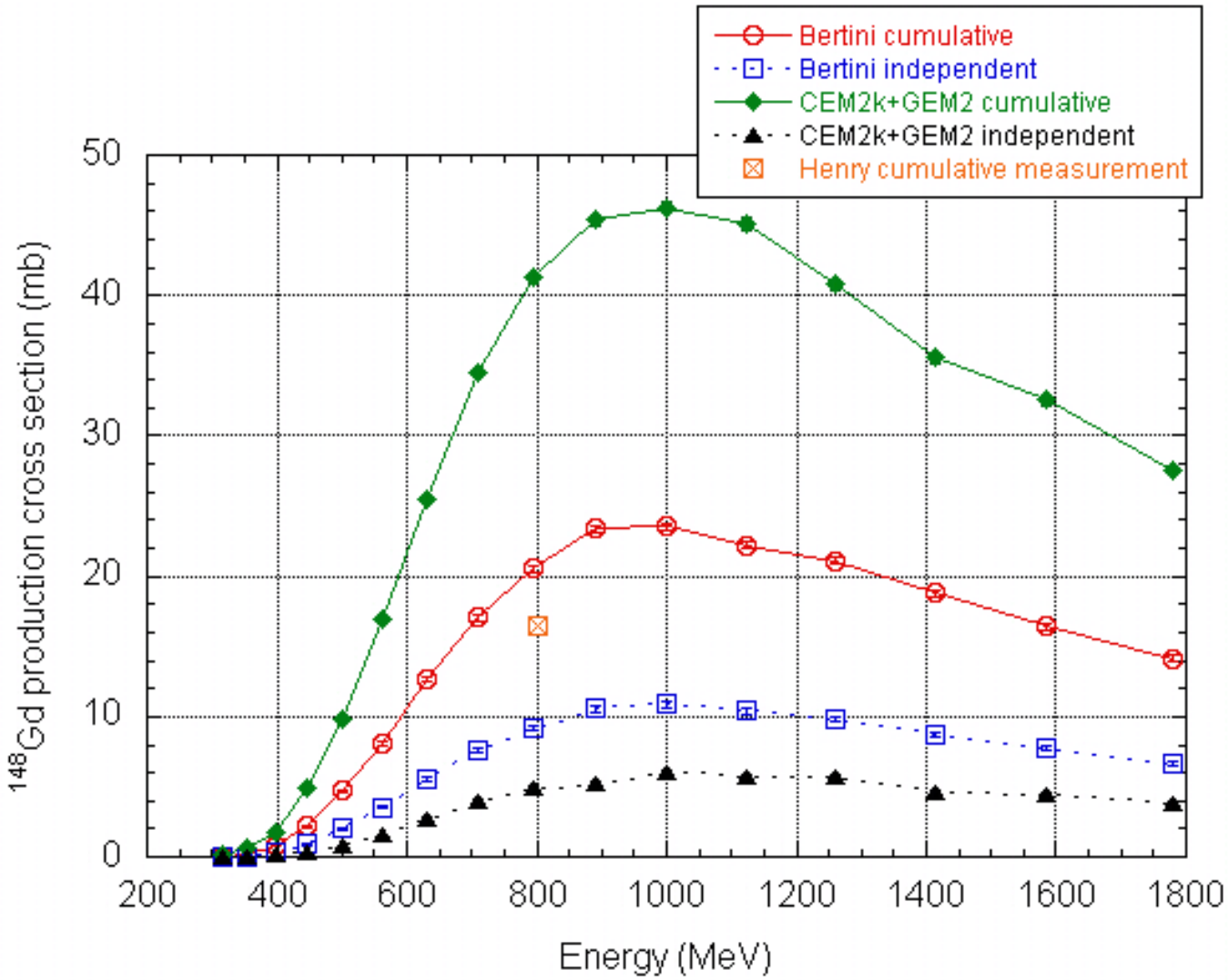
Preliminary measurement of ^{237}Np fission cross section has been made with parallel-plate ionization chamber.



Radionuclide production by protons at 600 and 800 MeV

- Thesis of Karen Corzine Kelley, Georgia Tech
- Focus on ^{148}Gd (alpha emitter) produced in LANSCE targets by proton beam on tungsten
- Many other radionuclides also measured

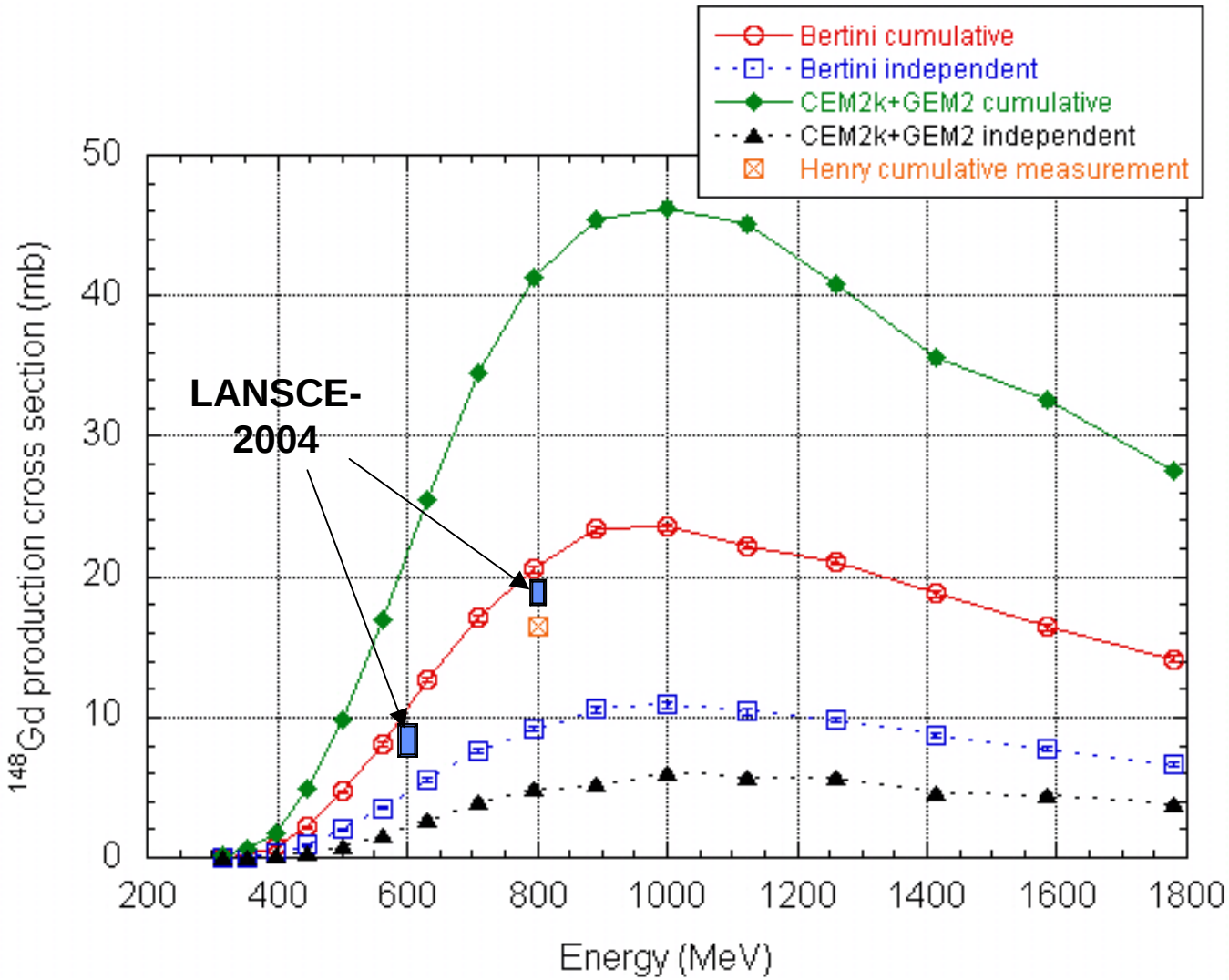
W(p,x)^{148}Gd production cross section — Previous predictions and measurements for W



Cumulative ^{148}Gd production cross section measurements

Target	Energy (MeV)	Foil Setup	cumulative ^{148}Gd production cross section (mb)			
			Current Measurement	Previous Measurement	Theoretical	
					CEM2k+GEM2	Bertini
Ta	600	stacked	15.2±4.0		29.4±0.2	15.5±0.2
	800	stacked	29.7±7.6		45.6±0.3	24.4±0.3
		single	27.6±1.7			
		single	28.6±7.3			
W	600	stacked	8.31±0.92		21.6±0.3	10.9±0.2
	800	stacked	19.5±1.2		41.4±0.4	20.9±1.6
		single	18.0±1.1	16.4±0.8		
		single	20.7±5.3			
Au	600	stacked	0.591±0.155		1.41±0.04	0.929±0.049
	800	stacked	3.86±0.98	3.74±0.19	12.9±0.1	7.23±0.14
	800	single	3.52±0.22			

W(p,x)^{148}Gd production cross section — Previous predictions and measurements for W



Other radionuclide production cross section measurements: 800 MeV p + W

		cumulative production cross section (mb)				
	t_h	current	previous measurements		theoretical	
	(d)	measurement	Titeranko	Henry	CEM2k+GEM2	Bertini
I-126	13.11	0.599±0.063			0.00±0.00	0.035±0.010
Eu-145	5.93	11.1±0.7	11.39±0.46		23.9±0.3	16.8±0.2
Eu-147	23.96	19.5±0.6	18.44±0.82	18.8±1.0	26.2±0.3	18.9±0.2
Gd-149	9.38	19.8±0.5	21.72±0.98		29.1±0.3	19.9±0.2
Gd-153	241.60	22.9±0.9	25.34±1.23		24.7±0.3	24.1±0.3
Yb-169	32.01	53.2±1.5	59.89±2.25	57.1±1.7	38.4±0.4	40.5±0.3
Lu-171	8.24	60.0±3.7	59.70±2.12		37.3±0.4	41.7±0.3
Lu-173	499.69	52.3±1.4	61.66±3.09	55.3±2.4	37.9±0.4	44.7±0.3
Hf-172	682.40	41.1±2.9	48.91±2.80	43.9±2.2	34.5±0.4	34.1±0.3
Hf-175	70.00	49.3±1.4	56.04±2.13	53.2±2.1	35.2±0.4	39.9±0.3
Hf-181	42.40	1.11±0.04		1.4±0.1	0.434±0.044	2.18±0.08
Ta-182	115.00	12.2±0.2	16.95±0.85	13.0±0.4	8.07±0.19	14.9±0.2
Re-184	37.96	1.34±0.05		1.5±0.1	2.07±0.10	1.50±0.06

We address the needs of LANSCE sponsors

- **National Nuclear Security Administration**
  - **Program in radchem cross section measurements**
    - » Neutron capture cross sections on radioactive targets (DANCE)
    - » Cross section measurements on high-order (n,2n), (n,xn) reactions (GEANIE)
  - **Program in neutron-induced fission measurements**
    - » Fission product distributions (GEANIE)
    - » Energy output in fission: neutron and γ-ray spectra (FIGARO)
    - » Nuclear properties of fission products and isomers (GEANIE and FIGARO)
- **Office of Nuclear Energy**
  - Measurements in support of the AFCI program include:
    - » Capture and fission cross section on actinides
    - » Gas production: (n,p), (n,α) reactions in structural materials
- **Office of Science**
  - Support of SNS in understanding pulsed radiation effects on liquid mercury targets
  - Fundamental physics experiments and nuclear data
- **National Resource**
  - Nuclear science User Facility for defense, basic and applied research
  - Industrial testing of semiconductor devices in neutron beams
  - University research in nuclear science

The LANSCE program in nuclear data involves many laboratories

- GEANIE – LANL, LLNL, Bruyères-le-Châtel, NC State
- FIGARO – LANL, Bruyères-le-Châtel
- N,Z – LANL, Ohio U
- DANCE – LANL, LLNL, ORNL, Colorado School of Mines, FZK Karlsruhe
- LSDS – LANL, LLNL, Bruyères-le-Châtel, RPI
- Proton – LANL, Georgia Tech
- Others – MIT, Kentucky, Kyushu, Harvard,…