Experimental program at LLNL

Ching-Yen Wu

Lawrence Livermore National Laboratory

Nov 7, 2007

S&T Principal Directorate – Physical Sciences / N Division
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

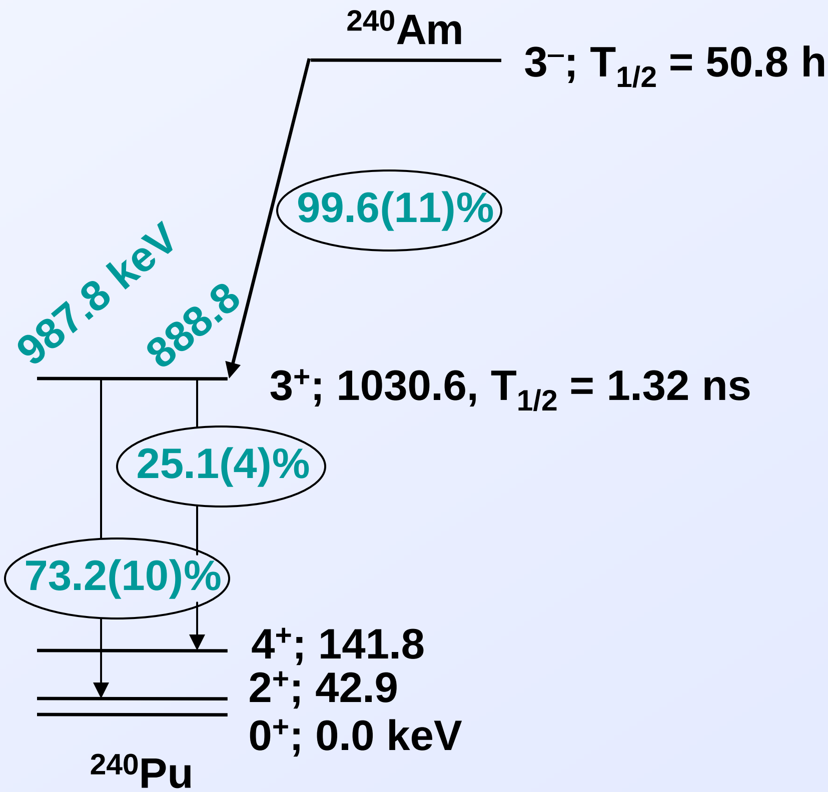
CSEWG 2007 at BNL

Outline

1. Tailored to the need of Stockpile Stewardship Program
2. Direct cross section measurement
   - (n,2n) cross section measurement using *A*. the activation method or *B*. the prompt γ-ray technique
   - (n,γ) cross section measurement using DANCE
3. Indirect cross section measurement using the surrogate technique
4. Direct and indirect (n,f) cross section measurement
5. New capabilities under development:
   - Time Projection Chamber
   - ALEXIS
6. Summary

^{241}Am(n,2n) cross section; activation method

1. Activation technique – counting the γ activity after irradiation of ^{241}Am
2. Fielded at Triangle Universities Nuclear Lab (TUNL) in FY06
3. Monoenergetic neutrons with $7.6 \leq E_n \leq 14.5$ MeV and flux ~ $10^7 - 10^8$ /(cm^2 sec)
4. ^{241}Am targets with a total mass about 1 mg each
5. The neutron fluence measured by multiple witness foils:
   - ^{27}Al(n,α) ($T_{1/2}$ = 15 hr),
   - ^{58}Ni(n,p) ($T_{1/2}$ = 71 d),
   - ^{197}Au(n,2n) ($T_{1/2}$ = 6.2 d)



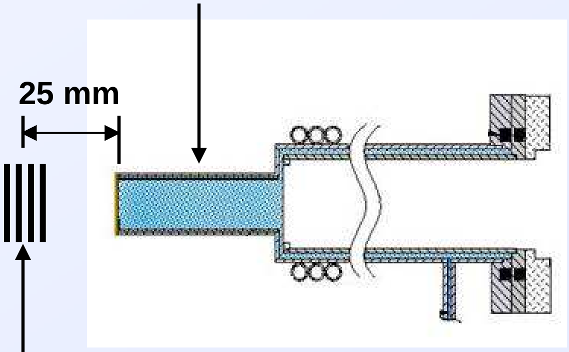
LANL/TUNL/LLNL collaboration

^{241}Am(n,2n): experimental setup at TUNL

Irradiation for ~24 h

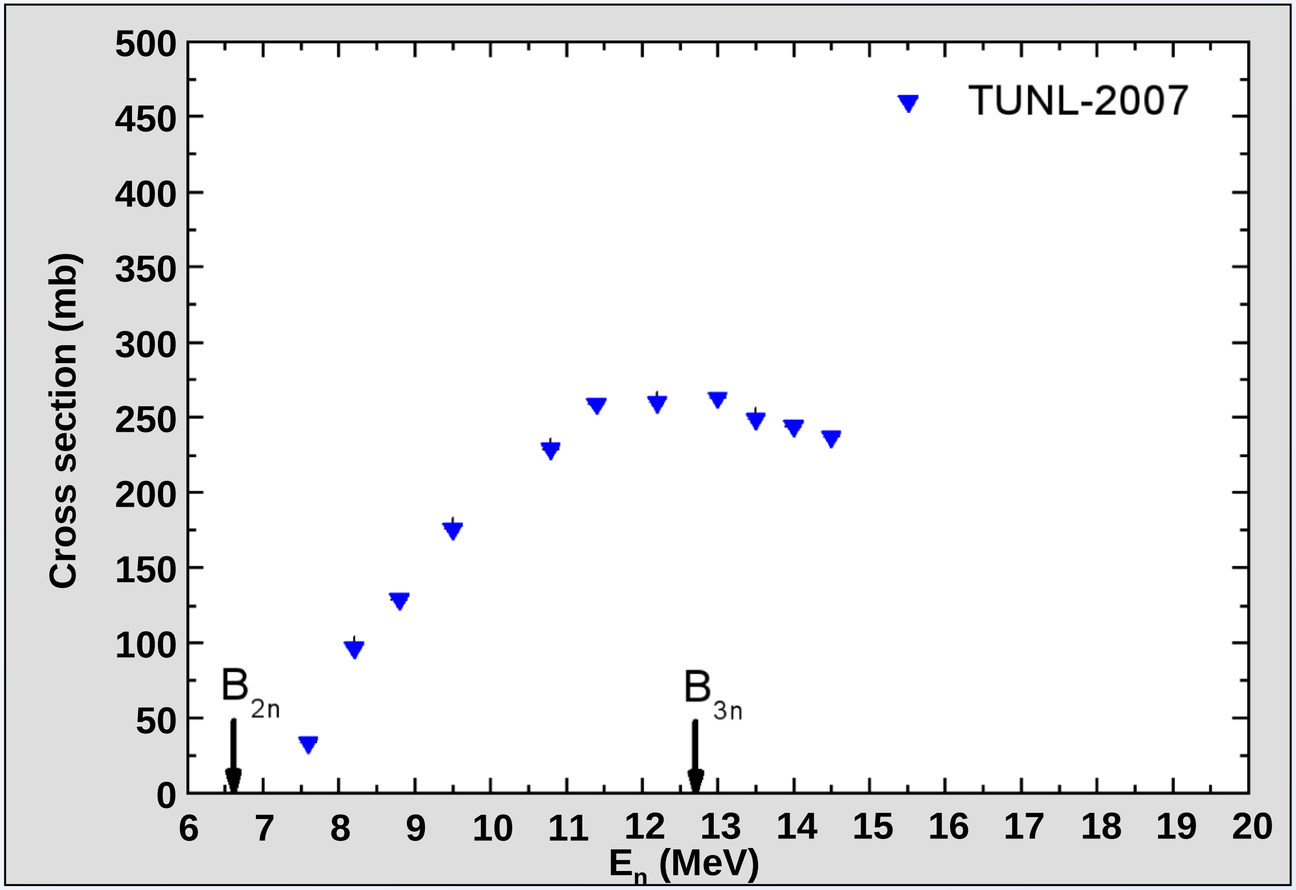
^{2}H(d,n)^{3}He

25 mm



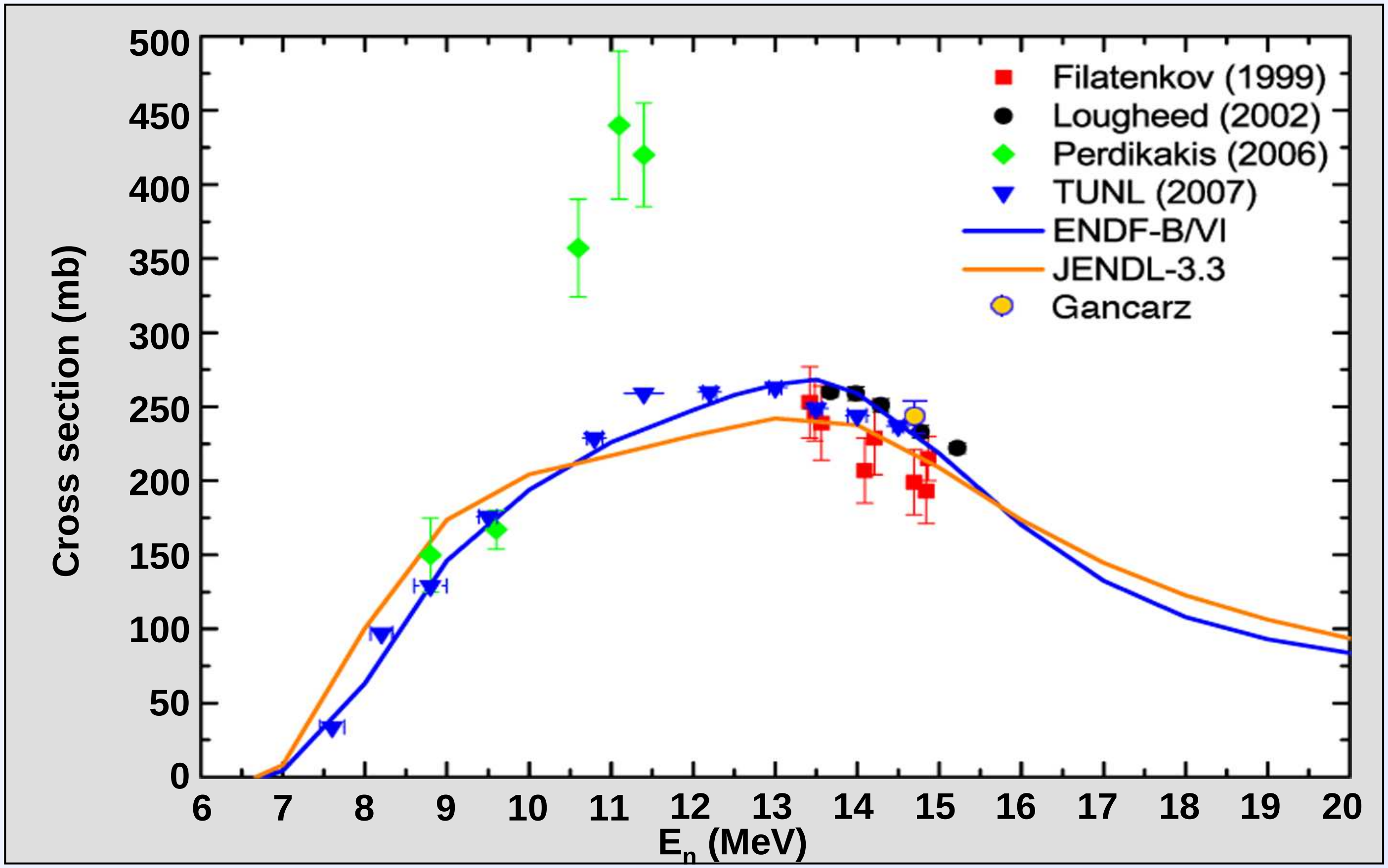
Target assembly; ^{241}Am together Al-Ni-Au monitor foils

^{241}Am(n,2n): results



Eleven data points from 7.6 to 14.5 MeV with excellent statistical accuracy

$^{241}Am(n,2n)$: comparison of cross section

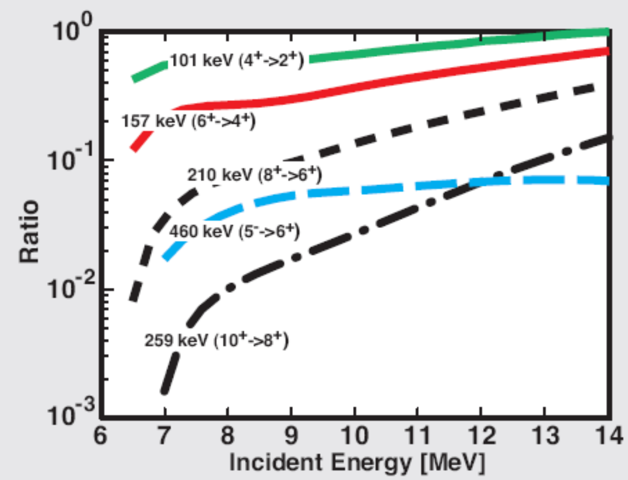


Good agreement with the early measurements except for the data near 11 MeV

^{239}Pu(n,2n) cross section; prompt γ-ray technique

1. ^{239}Pu(n,2n) cross section deduced from the reaction modeling of measured (n,2nγ) partial cross section
2. Cross section was deduced for E_n from threshold to <20 MeV from the $6^+ \rightarrow 4^+$ transition of ^{238}Pu in an earlier work (PRC 65, 02160(R), 2002)
3. The new effort aims to deduce the cross section from the $4^+ \rightarrow 2^+$ transition to reduce the uncertainty introduced by modeling
4. Accomplished by enhancing the sensitivity of γ-ray spectroscopy by excluding the γ rays of fission fragments that tagged by a fission counter
5. Experiments scheduled at TUNL in FY08 and FY09

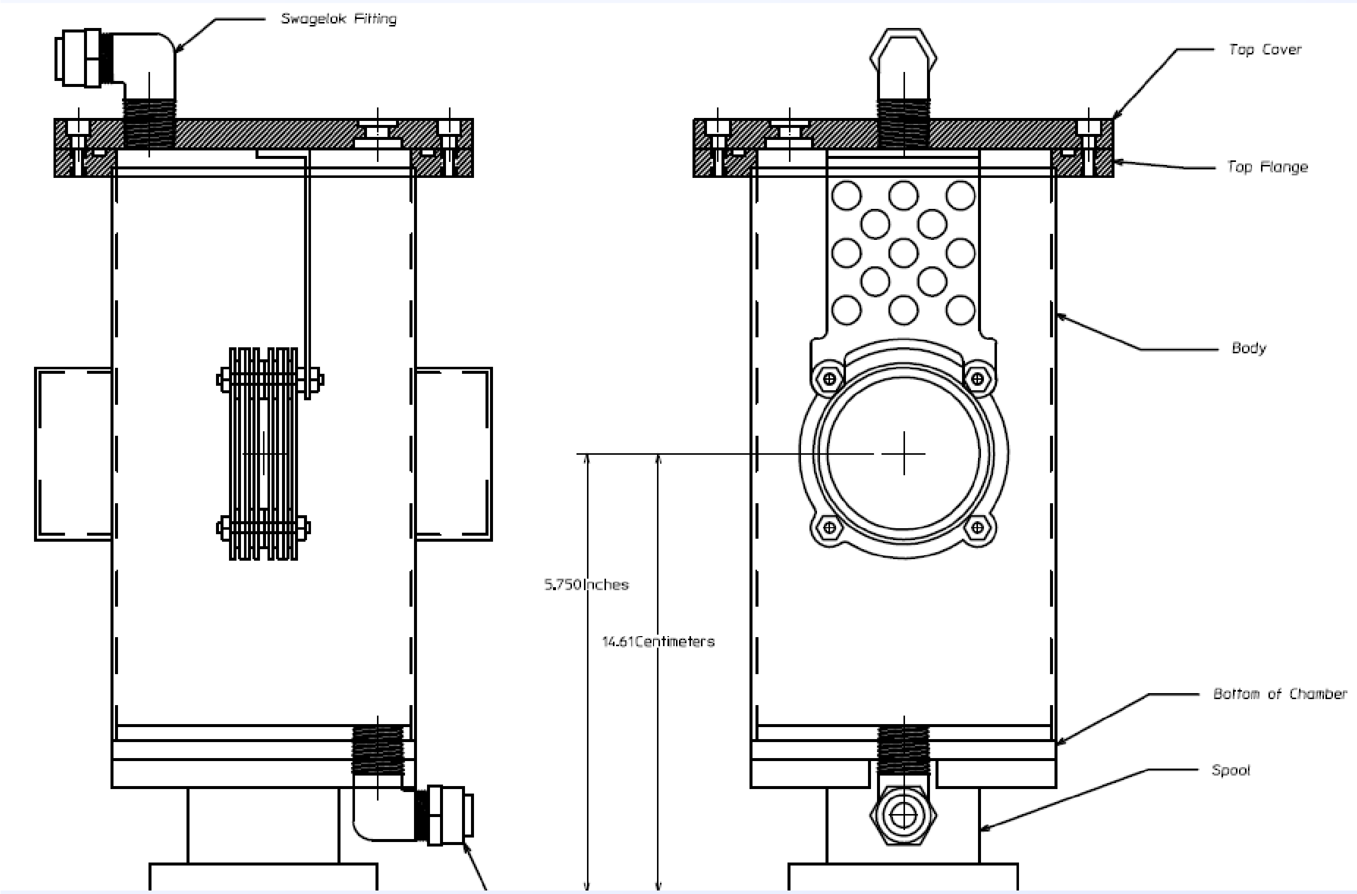
Hauser-Feshbach Model

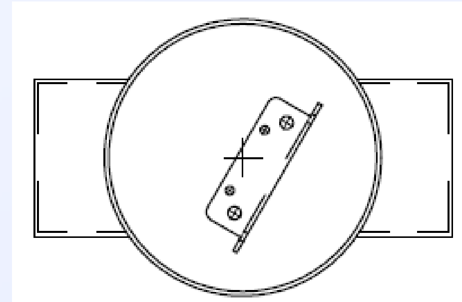


Deduce $\sigma_{n,2n}$ with models

LLNL/TUNL/LANL collaboration

^{239}Pu(n,2n): fission counter

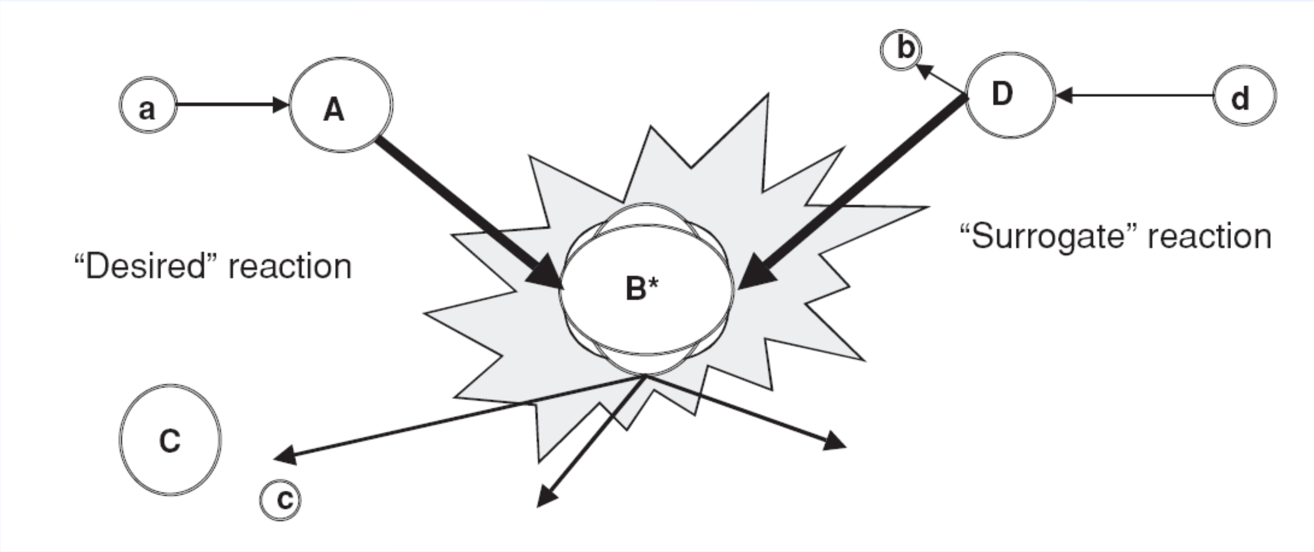




1. Multi-anode structure
2. Four targets with a total mass ~10 – 14 mg
3. Two LEPS for the γ-ray detection in a close geometry

Surrogate technique: introduction

A useful technique for the neutron-induced reaction cross sections that are difficult to measure directly



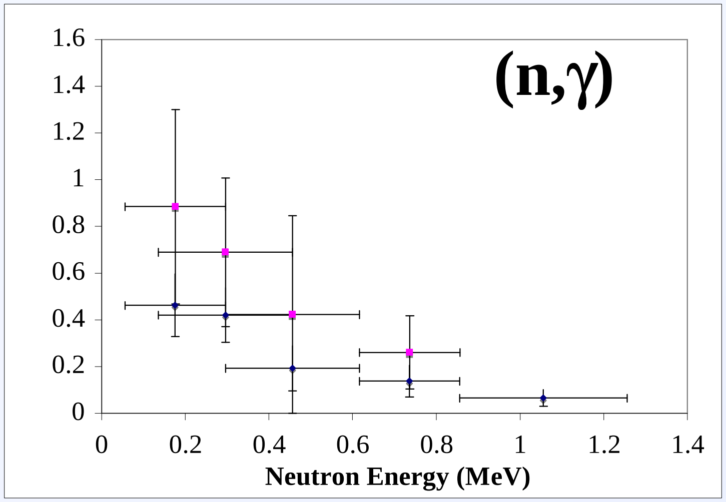
$$\sigma_{\alpha\chi}(E) = \sum_{J,\pi} \sigma_{\alpha}^{CN}(E,J,\pi) G_{\chi}^{CN}(E,J,\pi).$$

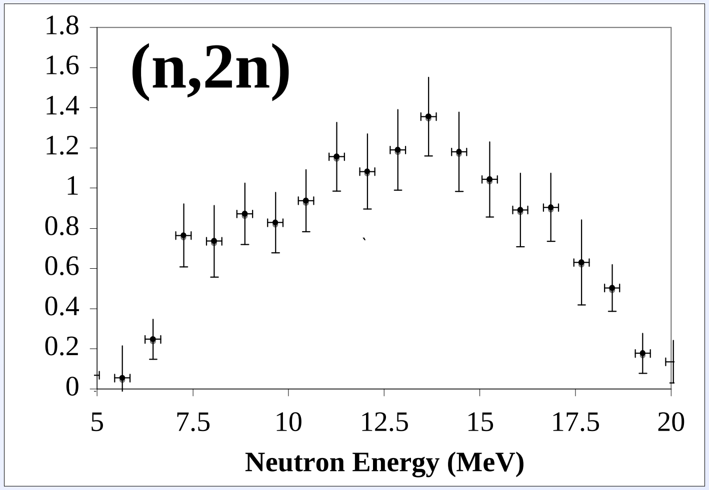
$$P_{\chi}(E) = \sum_{J,\pi} F_{\delta}^{CN}(E,J,\pi) G_{\chi}^{CN}(E,J,\pi),$$

J. Escher et al., J. Phys. G: Nucl. Phys. 31, S1687 (2005)

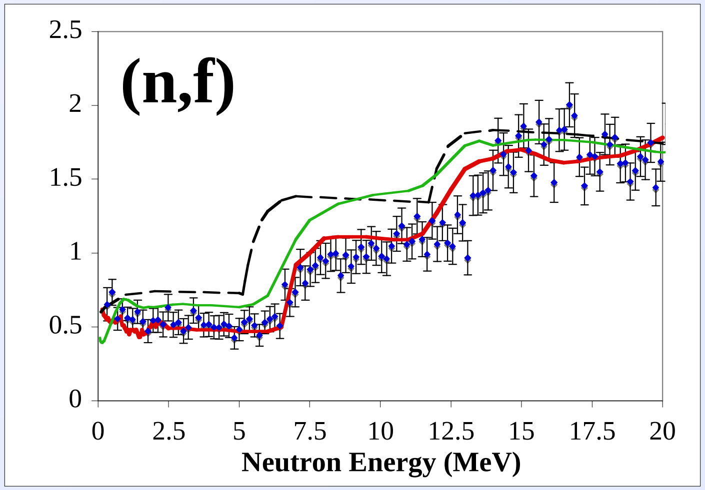
^{237}U(n,destruction) cross section; surrogate technique

Surrogate reaction: ^{238}U(α,α') at E_α= 55 MeV (PRC 73, 054605, 2006)



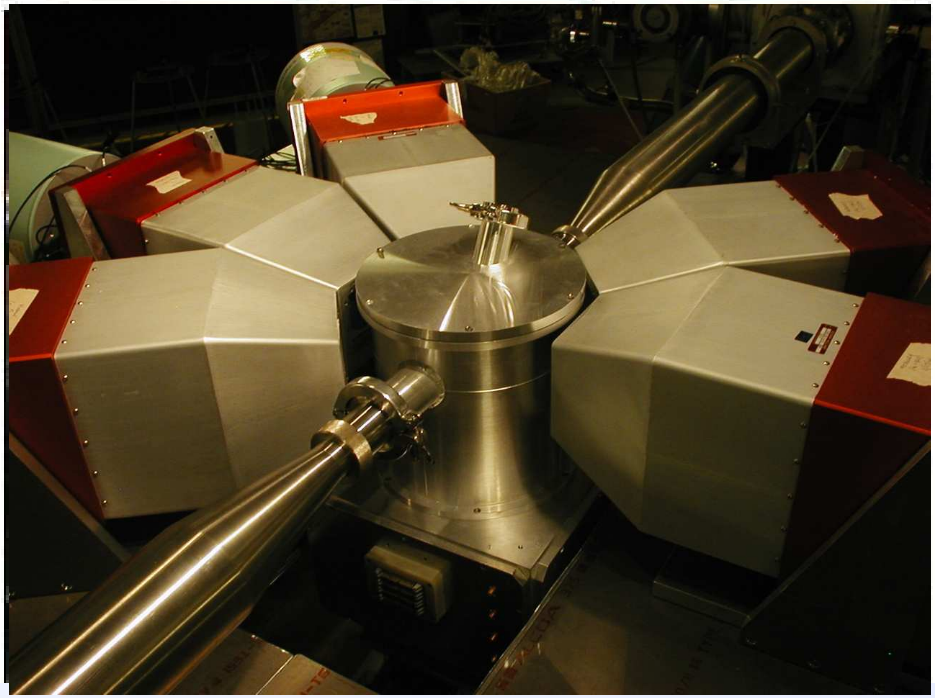


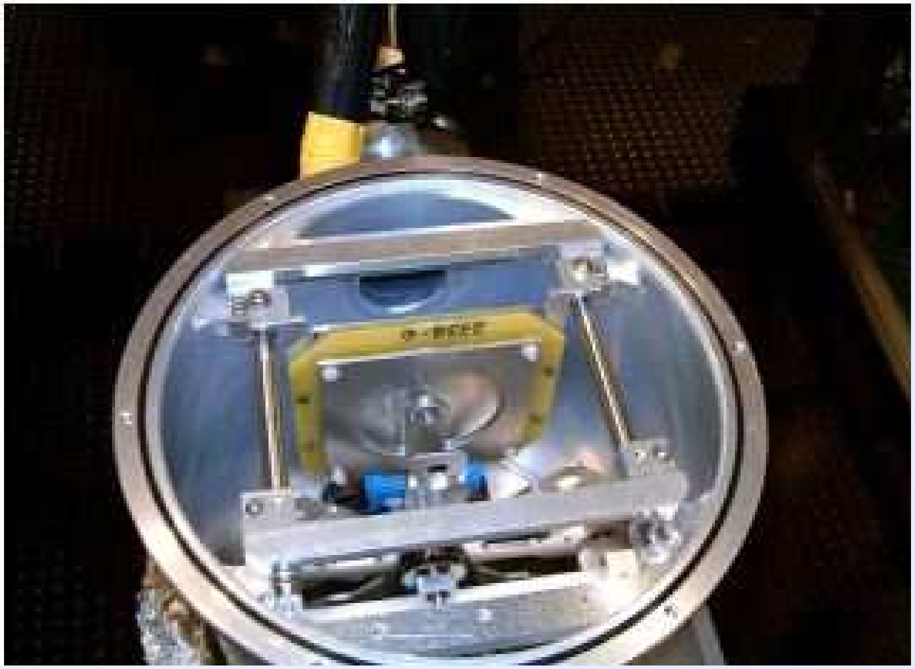
1. Direct cross section measurement for ^{237}U is difficult because of the short half-life, 6.75 d
2. Using the surrogate technique, reaction cross sections for the (n,γ), (n,2n), and (n,f) channels can be determined with an accuracy of 10 – 30%



Surrogate technique: experimental setup at LBNL

1. **Forward ΔE-E silicon array for the light charged-particle identification**
2. **Backward E silicon detector for the fission-fragment detection**
3. **Six clover detectors for the γ-ray detection**



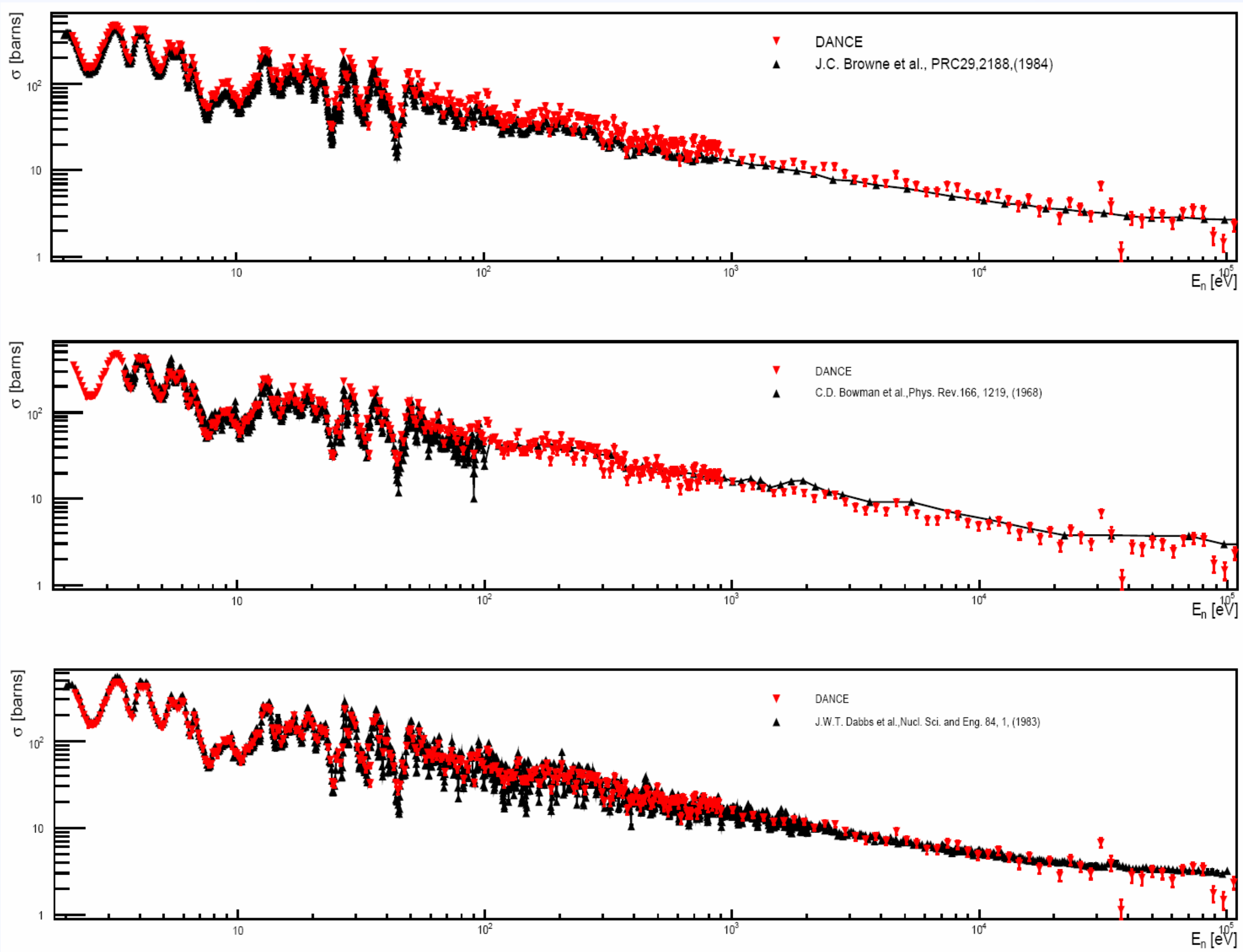


LIBERACE collaboration (LLNL/LBNL/U Cal at Berkeley/U Richmond/Yale)

Direct and indirect (n,f) cross section measurement

1. **Direct measurement**
   - **Fission-fragment detection using the gas avalanche counter**
     - **Together with DANCE at LANL for E_n from thermal to about 100 keV**
     - **Together with two LEPS at TUNL for E_n from 4 to 14 MeV**
   - **Trajectory tracking by the Time Projection Chamber**
2. **Indirect measurement using the surrogate technique; example: ^{237}U(n,f) via ^{238}U(α,α' f)**

^{242m}Am(n,f) cross section: results from DANCE



1. ~47 μg material
2. Six-day beam time
3. σ_f for E_n up to ~100 keV was determined
4. Agreement with early results is reasonable
5. Early results were obtained in 12 – 18 months

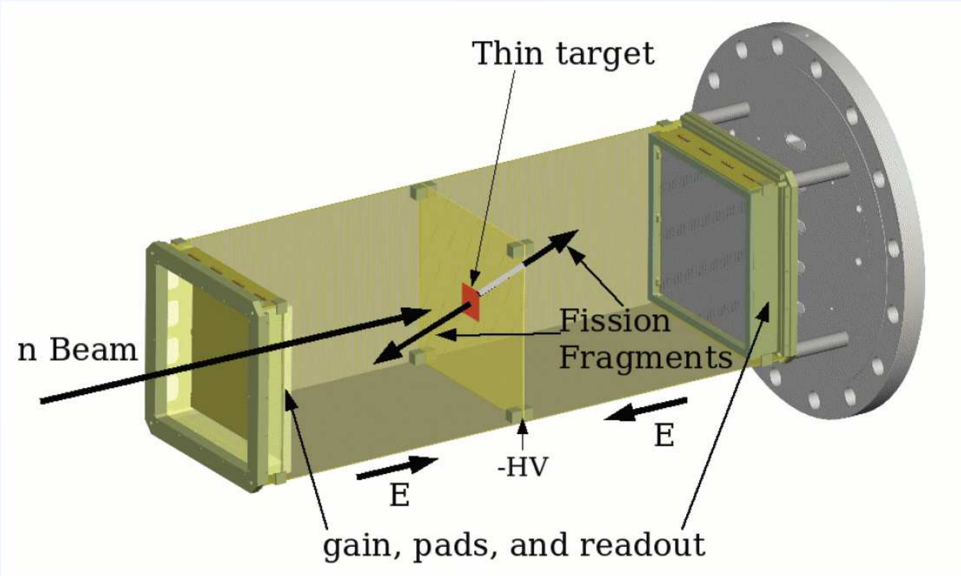
LLNL/LANL/TUNL collaboration

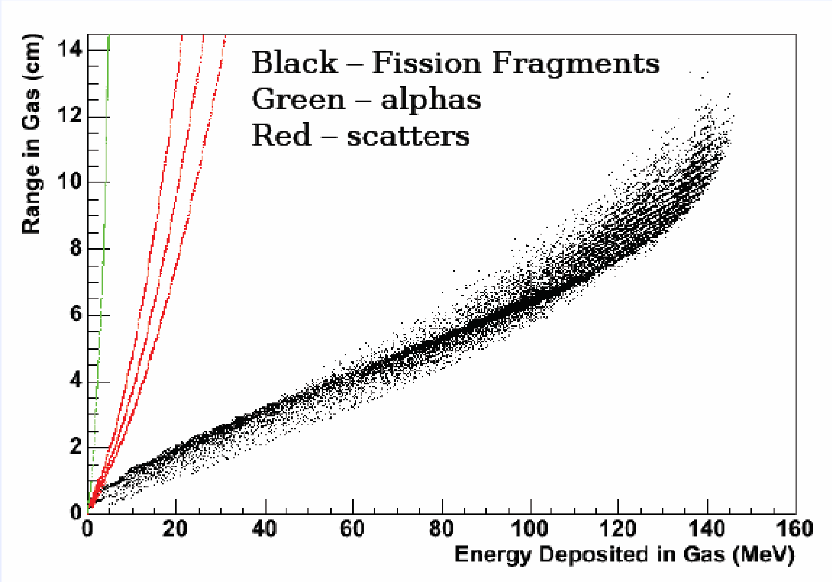
Time Projection Chamber: introduction

Improve the precision of measured $^{239}Pu(n,f)$ cross section to ~1%

Capability:

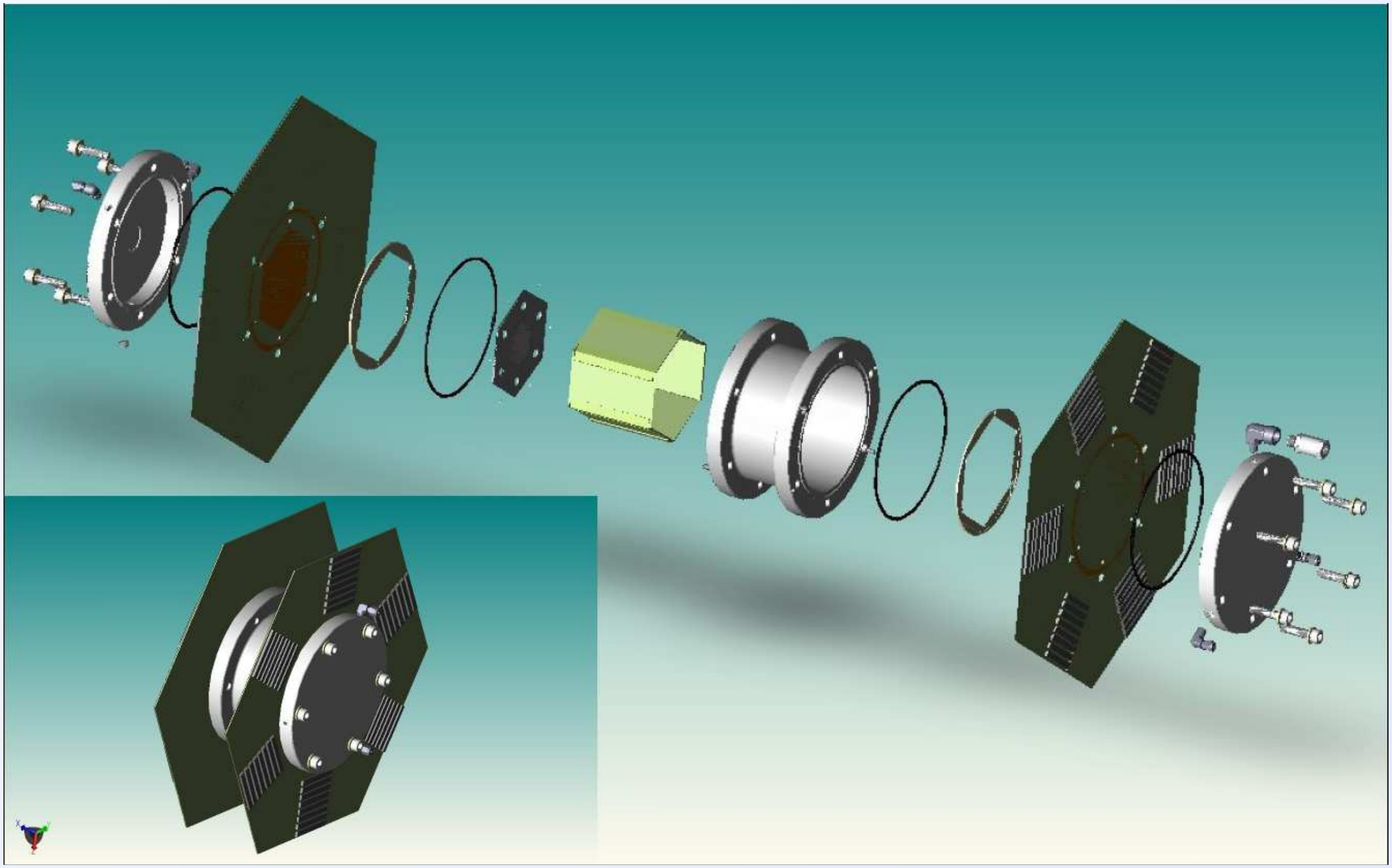
1. **Trajectory reconstruction**
2. **High background-event rejection**
3. **Charged-particle identification**
4. **Standalone or in conjunction with other detectors**





LLNL/LANL/INL/Georgia Inst Tech/Ohio U/Oregon St U/Cal Poly St U/Col Sch Mines/Abilene Chris U

Time Projection Chamber: 3-D view



Physical Sciences

ALEXIS: an intense, tunable neutron source at LLNL

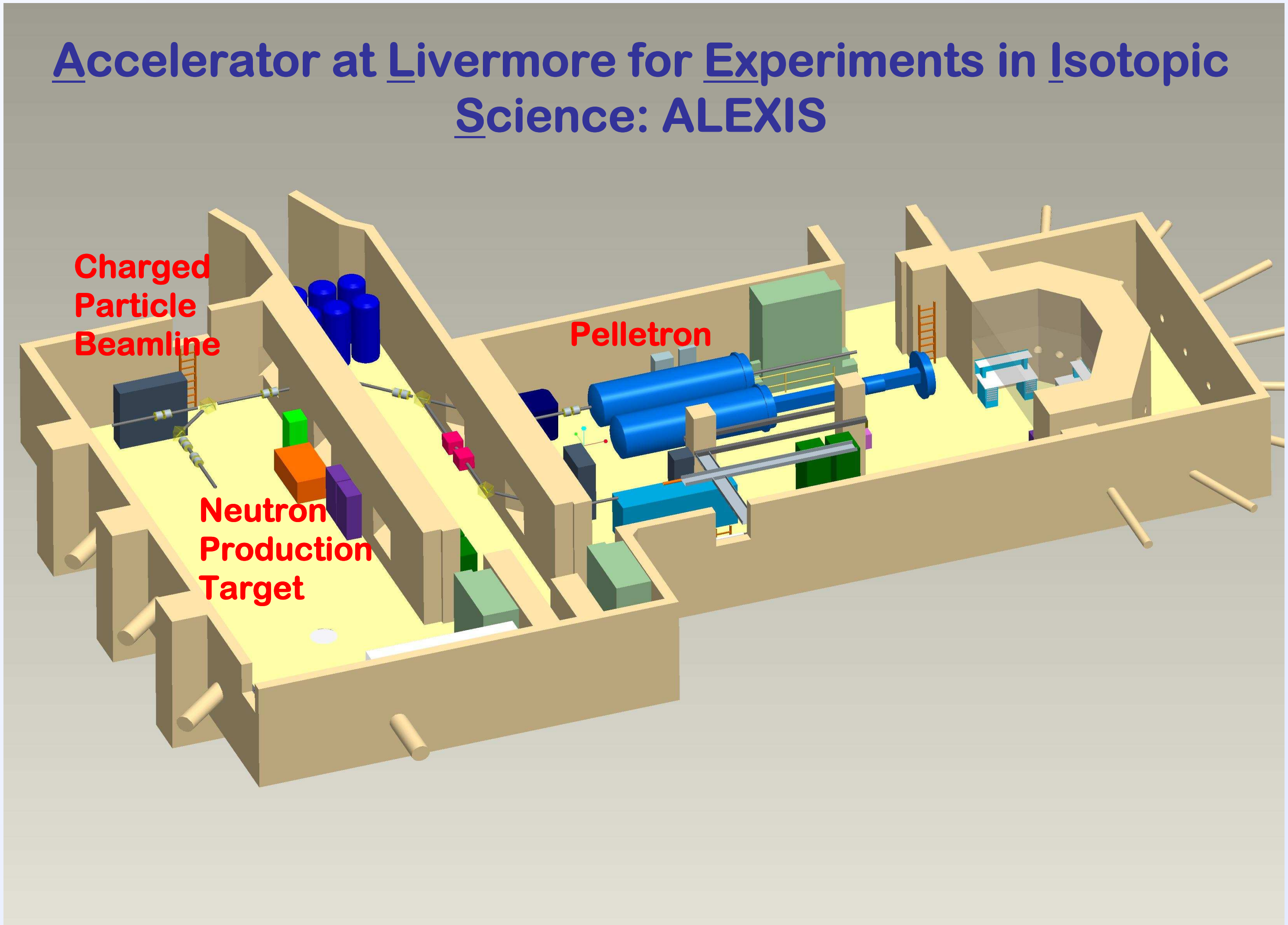
Pelletron accelerates *light ions* (p, d, He) which impinge on various isotopic targets to produce neutron beams with specified intensities and energy spectrum

Neutron Production:

Production Reaction	Neutron Energy Range (MeV)	Neutron Energy Spread (FWHM)	Total Neutron Yield (n/s)	Neutron Flux at 10 cm from target ($n/cm^2/s$)	Notes
$^{7}Li(p,n)^{7}Be$	0.01-0.4	~30 keV	10^9	10^7	4
$t(p,n)^{3}He$	0.5-5.0	~400 keV	$>10^9$	$>10^7$	1,2
$d(d,n)^{3}He$	5.0-9.0	~400 keV	$>10^{10}$	$>10^8$	3
$t(d,n)^{4}He$	13.0-15.0	~100 keV	10^{10}	10^7	1,2

1. 5 mg/cm^2 titanium assumed for tritium target.
2. Same tritium target can be use for both (p,n) and (d,n) reactions.
3. ~0.5 MeV is assumed energy loss in deuteron target.
4. $^{7}Li(p,n)$ produces roughly 30 keV thermal spectra with beam energy of 1.918 MeV.

ALEXIS: 3-D view



Summary

1. Experimental program at LLNL is developed to support the Stockpile Stewardship Program
   - Provide the data in unchartered territory
   - Improve the precision for the measured cross section
   - Improve the predictive capabilities of nuclear modeling
2. Also relevant to GNEP
3. Team with the university personnel funded under NNSA/SSAA, LANL, and LBNL in both experimental and theoretical areas
4. TPC begins the prototyping in FY08
5. ALEXIS begins the beam delivery in FY09
6. Continue to develop new direction and capability as needed

Acknowledgement

1. LLNL – U. Agvaanluvsan, L. Ahle, J.A. Becker, L. Bernstein, J. Burke, S. Lesher, R. Macri, K. Moody, E.B. Norman, W. Parker, M.A. Stoyer, P. Wilk, and C.Y. Wu
2. LANL – T.A. Bredeweg, R.R.C. Clement, A.J. Couture, J.M. O'Donnell, M.M. Fowler, R.C. Haight, M. Jandel, R. Reifarth, R.S. Rundberg, J.L. Ullmann, D.J. Vieira, J.B. Wilhelmy, and J.M. Wouters
3. LBNL – M.S. Basunia, R.M. Clark, M.A. Delaplanque-Stephens, P.Fallon, J.D. Gibelin, I.Y. Lee, B. F. Lyles, A.O. Macchiavelli, M.A. McMahan, L.W. Phair, E. Rodriguez-Vieitez, F.S. Stephens, and M.Wiedeking
4. TUNL – C. T. Angell, D. Dashdorj, B. Fallin, C.R. Howell, H.J. Karwowski, J.H. Kelley, A. Tonchev and W. Tornow
5. U. Richmond – C.W. Beausang
6. Yale U – A. Ai
7. TPC – M. Heffner (LLNL)
8. ALEXIS – L. Ahle (LLNL)