CSEWG-2017
8 Nov 2017

Neutron- and photon-induced cross-section measurements at TUNL*

Krishichayan
TUNL & Duke University

*Supported in part by the NNSA under the Stewardship Science Academic Alliances

Who are we?

TUNL/Duke

Krishichayan
S. Finch
C.R. Howell
W. Tornow

LANL

M. Gooden
T. Bredeweg
M. Fowler
G. Rusev
D. Vieira,
J. Wilhelmy

LLNL

A. Tonchev
M. Stoyer

What motivates us?

Stockpile Stewardship applications

- Excitation functions: (n,γ), (n,el), (n,inel), (n,2n)
- Nuclear forensics
- Remote detection of SNM

Basic and applied nuclear physics

- Nuclear astrophysics
- Fission process
- Nuclear structure and reaction

Practical applications

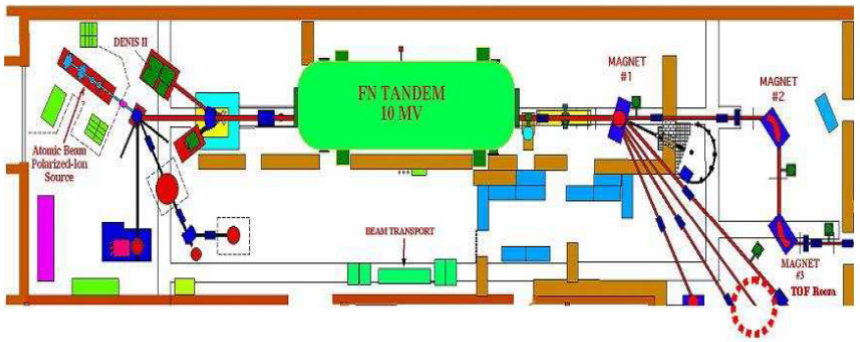
- Advanced nuclear reactor design
- Dosimeter technique
- Determination of weapon yields

Neutrinoless double-beta decay

- Background estimates in 0νββ searches

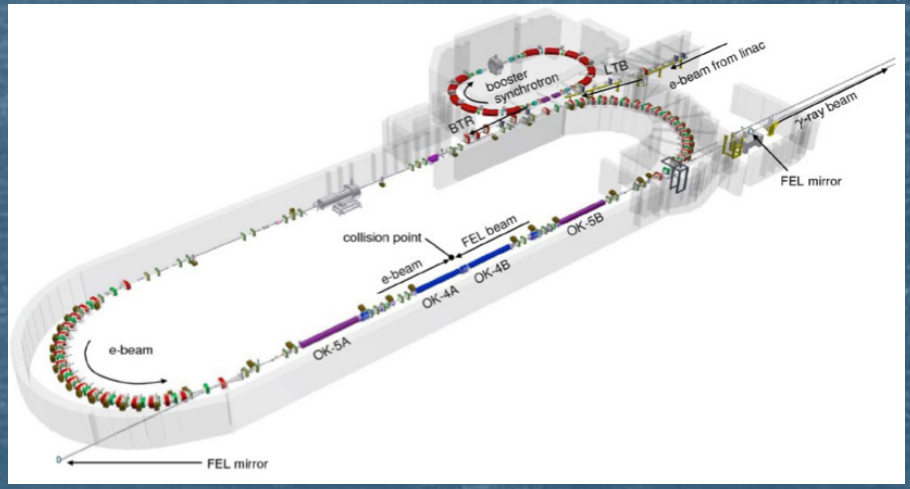
Education of students, including Undergraduates

Tools we use



10 MV tandem
(monoenergetic neutrons)

HIγS
(monoenergetic gamma beam)

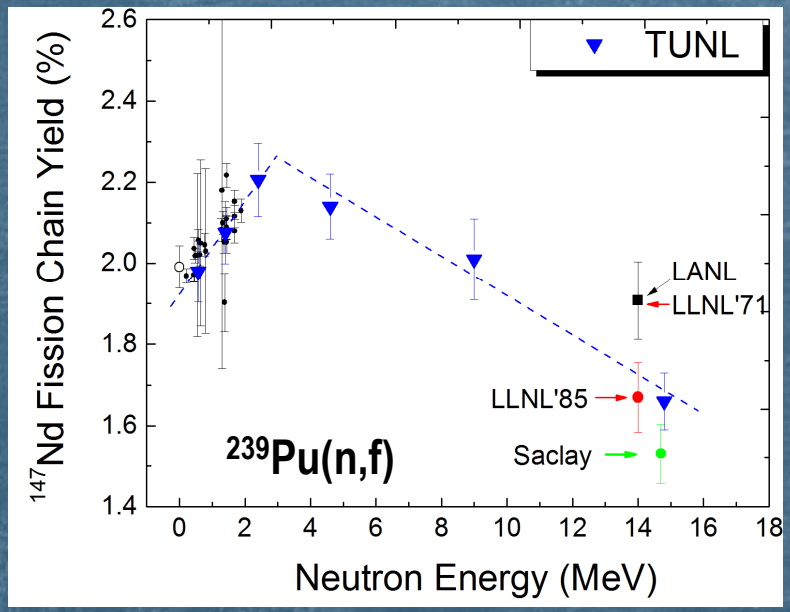


low-background counting facility

γ-ray counting done with Shielded HPGe detectors (SIX stations) using the GENIE DAQ system, with enabled pile-up rejection.

FPY measurements at TANDEM

TUNL-LANL-LLNL joint collaboration



Measure the energy dependence of selected high-yield fission products using monoenergetic neutron beams.

^{239}Pu shows unexpected energy dependency for certain high yield fission products, e.g., ^{99}Mo, ^{140}Ba, ^{147}Nd.

Goal is to provide an accurate, systematic investigation of the neutron energy dependence of several cumulative FPYs in the thermal to 15 MeV energy range.

M. Gooden et al.,
Nuclear Data Sheet 131, 319 (2016)

FPY measurements at HIγS

- The photon-induced FPY measurements provide us a unique opportunity to explore the **effect of the incoming probes on the FPY**, photons versus neutrons.

- Well understood electromagnetic probe offers some principal advantages over hadron-based reactions
  - –***absence of a binding energy and Coulomb barrier***
  - –unlike reactions with neutrons and charged particles, over a wide photon energy range practically the same angular momentum (1ħ or/and with much smaller probability also 2ħ) is transferred to the nucleus

Goal is to investigate the influence of the incoming probe and look for the energy dependency

Exploratory study on Photo-fission

Short activation run (8 hours)
^{239}Pu @ 11.0 MeV
^{197}Au: monitor foil to measure the gamma flux

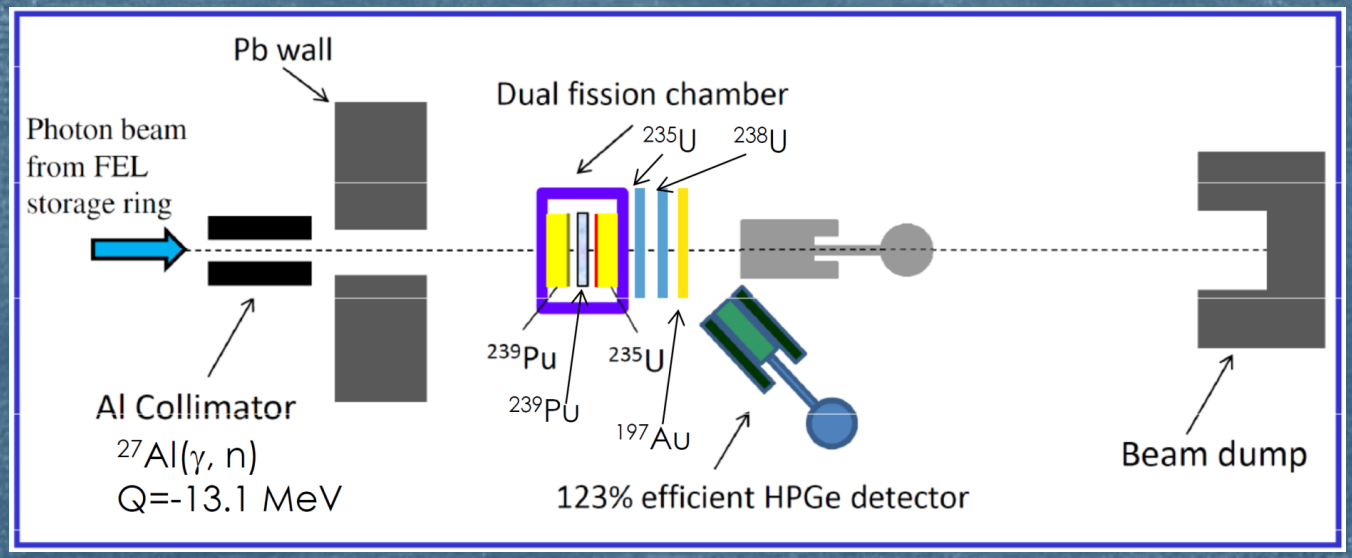
PHYSICAL REVIEW C **95**, 024608 (2017)

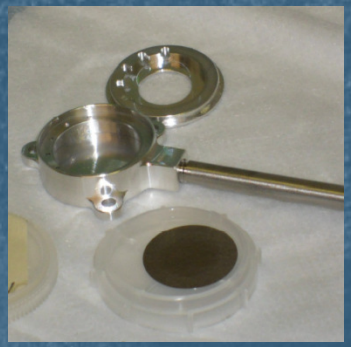
Exploratory study of fission product yield determination from photofission of ^{239}Pu at 11 MeV with monoenergetic photons

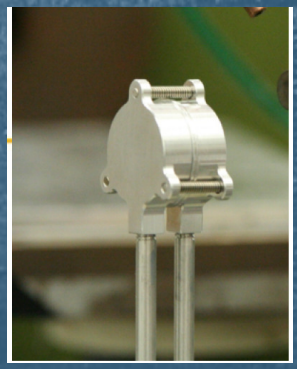
Megha Bhike,[1] W. Tornow,[1] Krishichayan,[1] and A. P. Tonchev[2]
[1]*Department of Physics and Triangle Universities Nuclear Laboratory, Duke University, Durham, North Carolina 27708, USA*
[2]*Nuclear and Chemical Sciences Division, Lawrence Livermore National Laboratory, Livermore, California 94550, USA*

FPY measurements at HIγS using fission chamber

A dual fission chamber provides the rate of fission events

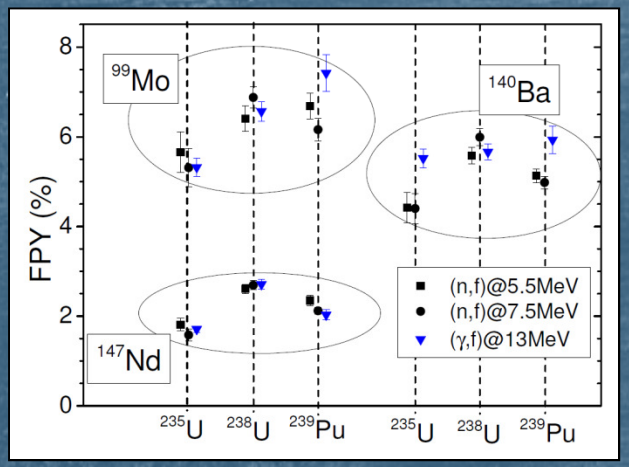


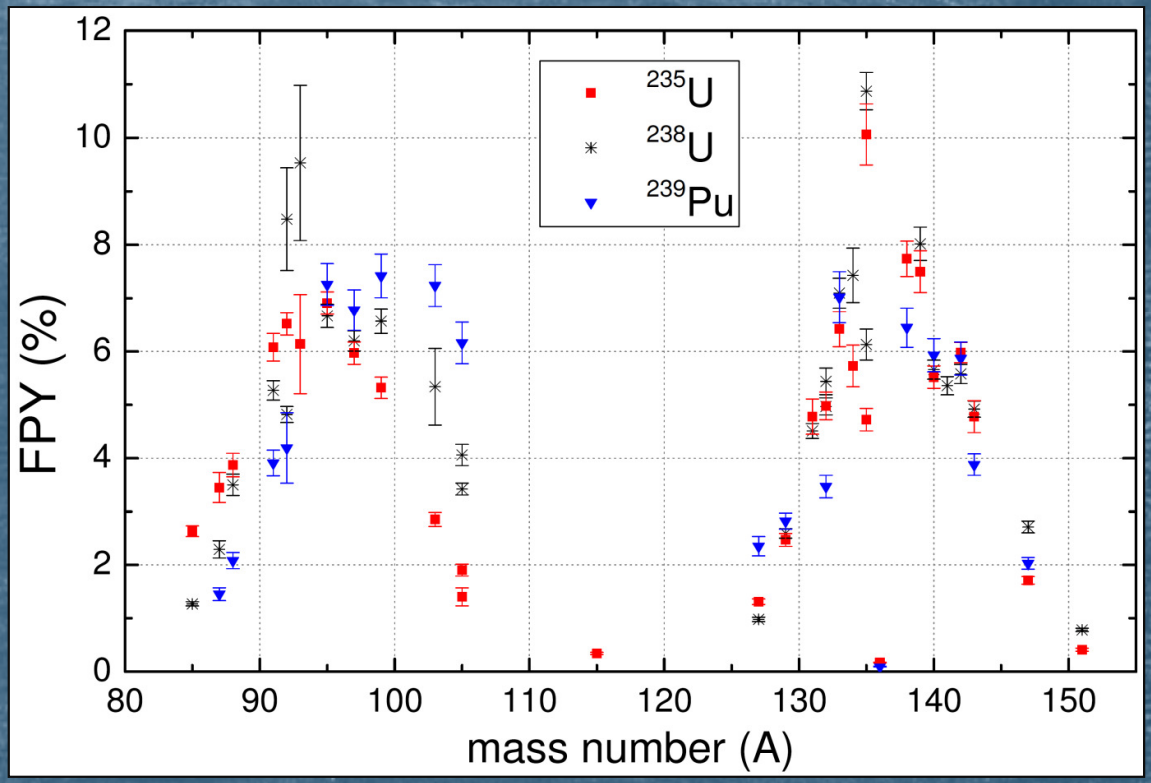




Samples irradiated for ~ 3 days using circularly polarized 13 MeV photon beams

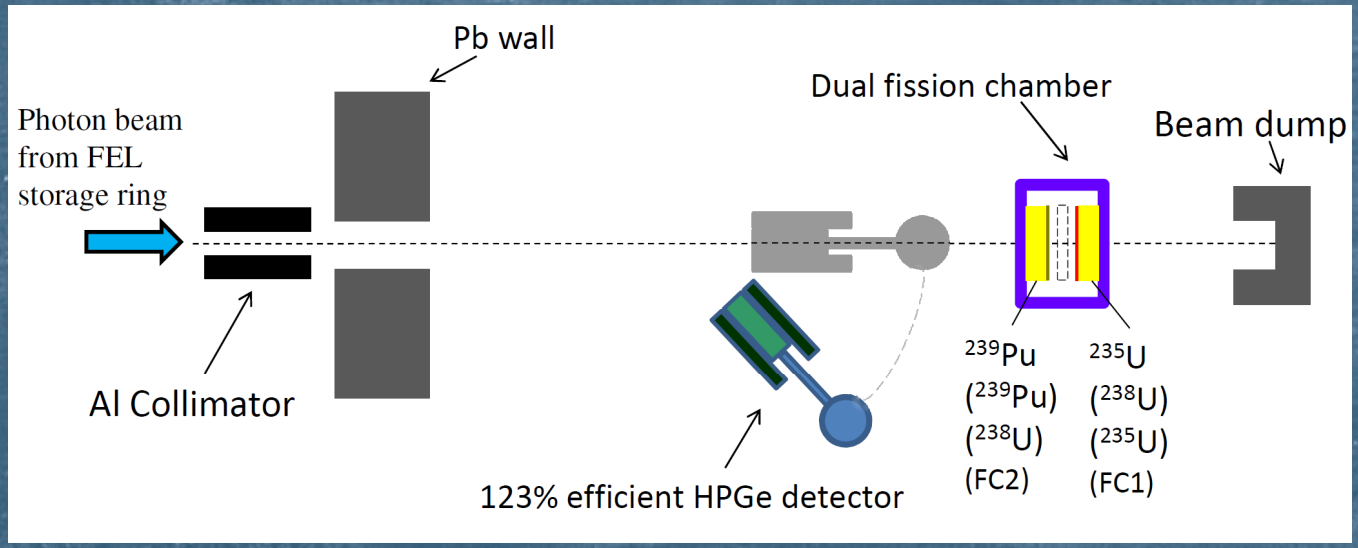
γ-FPY @ 13 MeV results

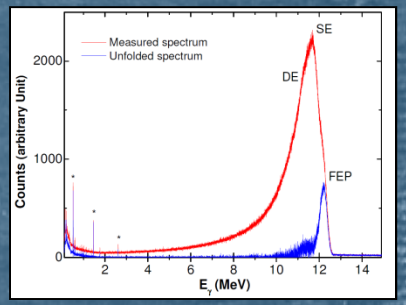




Krishichayan et al., manuscript to be submitted

Photo-fission CS ratio measurements



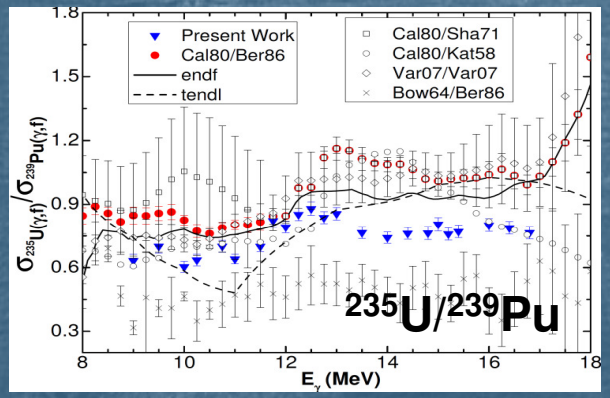


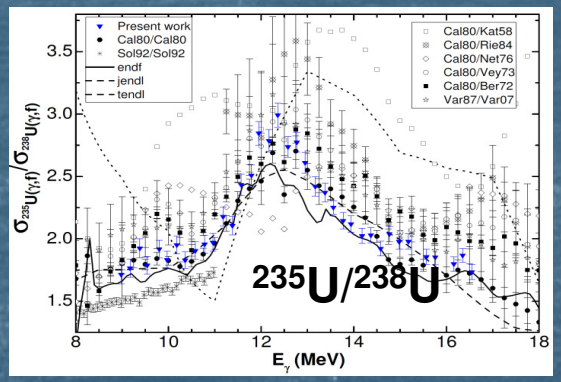
Krishichayan *et al.*, NIM A **854**,40 (2017)

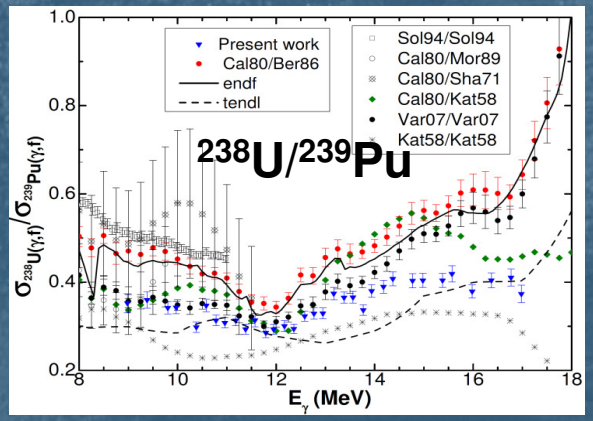
Photo-fission CS ratio measurements

$$R = \frac{\sigma_{f1}}{\sigma_{f2}} = \left(\frac{N_{f1}}{N_{f2}}\right)\left(\frac{\cancel{\phi_{\gamma 2}} n_{t2} \cancel{\varepsilon_2} \cancel{\Omega_2}}{\cancel{\phi_{\gamma 1}} n_{t1} \cancel{\varepsilon_1} \cancel{\Omega_1}}\right)$$

$$R = \frac{\sigma_{f1}}{\sigma_{f2}} = \left(\frac{N_{f1}}{N_{f2}}\right)\left(\frac{n_{t2}}{n_{t1}}\right)$$





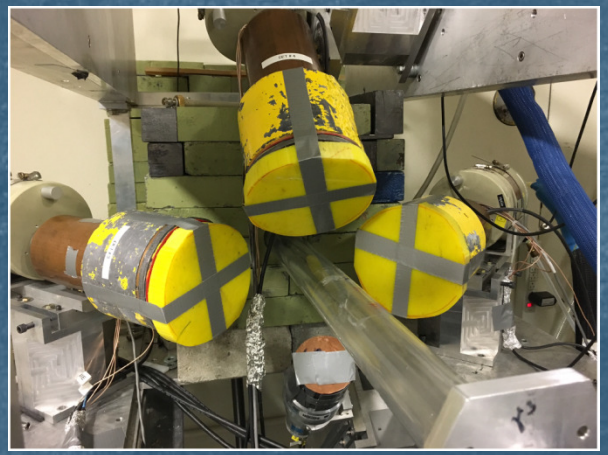


Krishichayan et al.,
manuscript to be submitted

Fission isomers: tool for Nuclear forensic

- Active interrogation of special nuclear materials
  - -Non-destructive
  - -Prompt and delayed radiation
- Production of ^{134m}Te and ^{136m}Xe is unique to fission
- Large fission yield: 2-6%
- Ratio dependent on identity of the fissile material

HIγS (γ-beam)



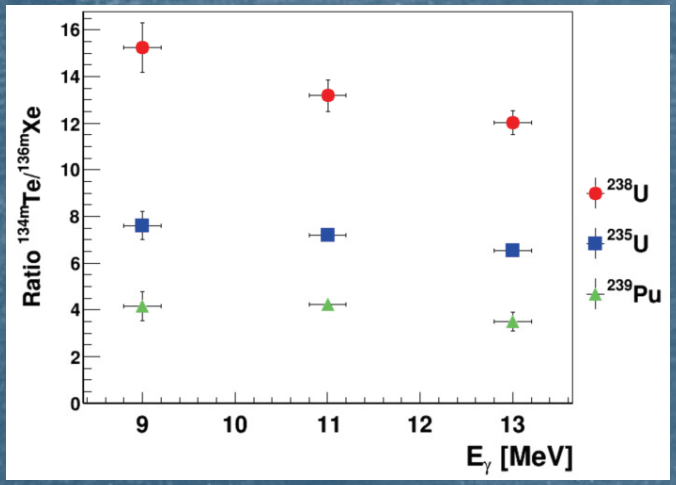
Samples

- -1.5 g ^{235}U
- -2.1 g ^{238}U
- -0.4 g ^{239}Pu

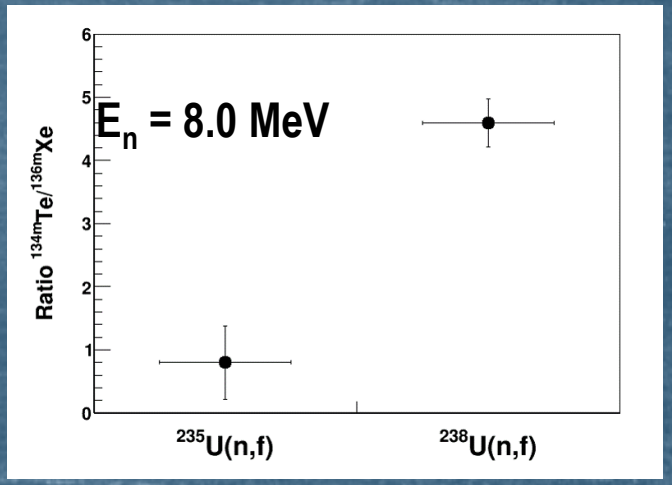
TANDEM (n-beam)

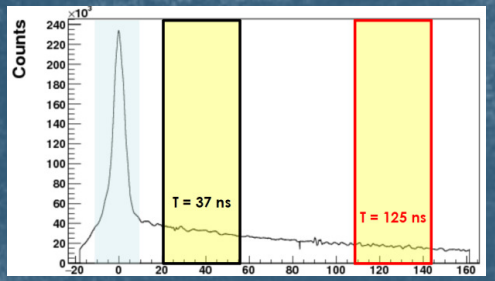
Fission isomers ...

γ-beam



n-beam

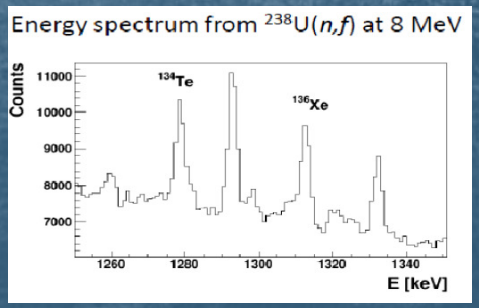




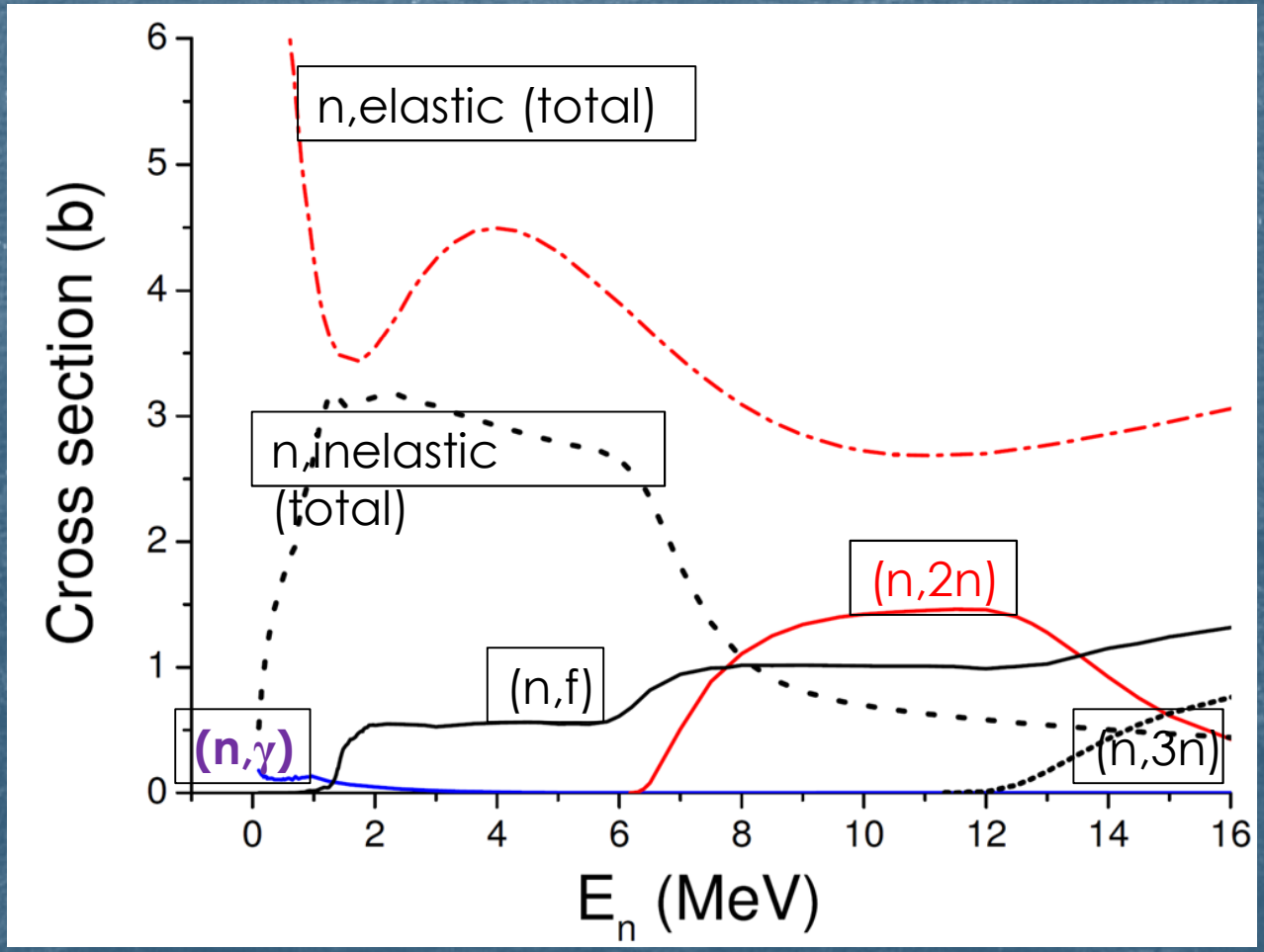
$T_{1/2}$

^{134m}Te : 164.1ns

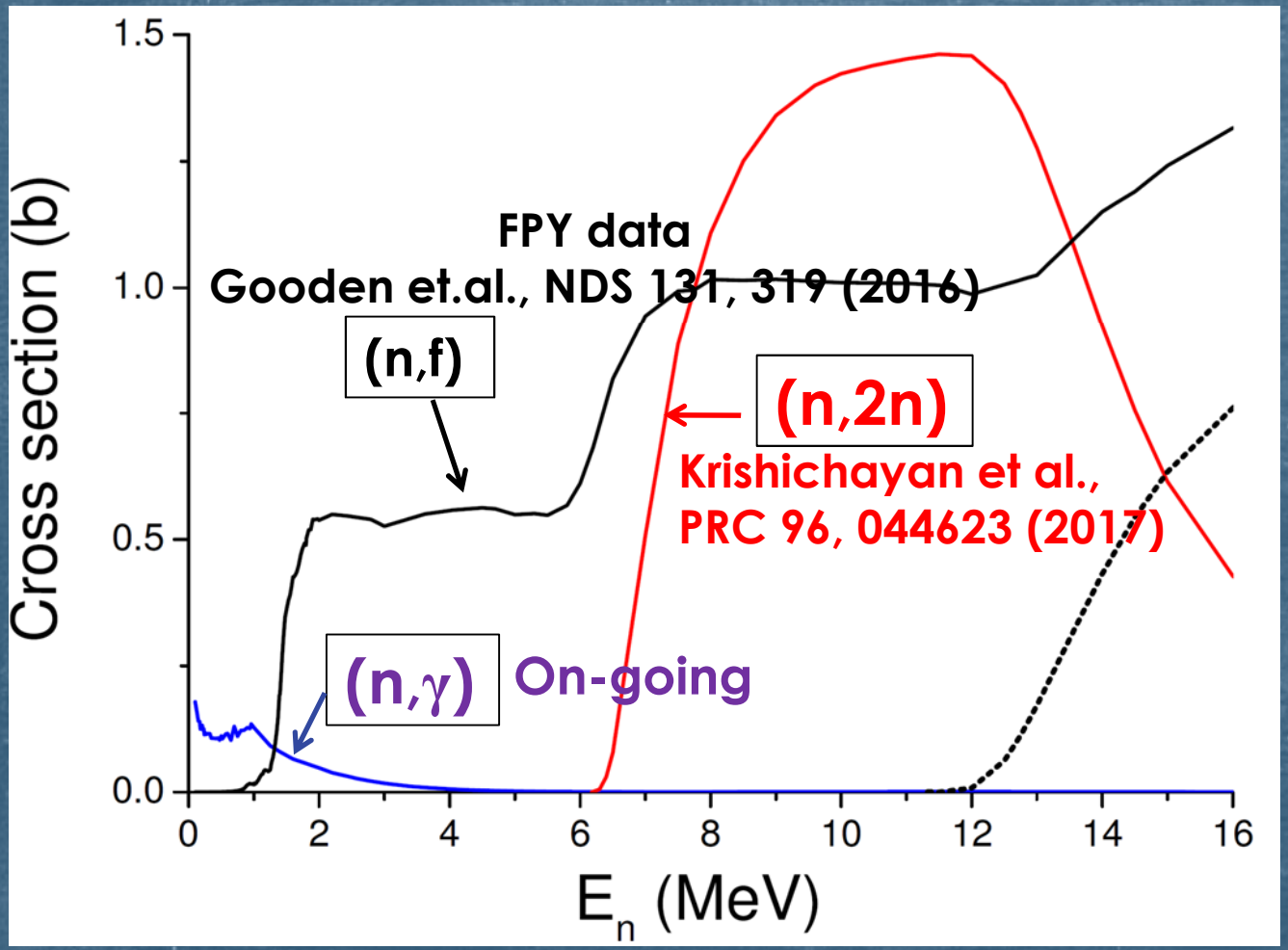
^{136m}Xe: 2.95 µs



Neutron-induced reactions on ^{238}U



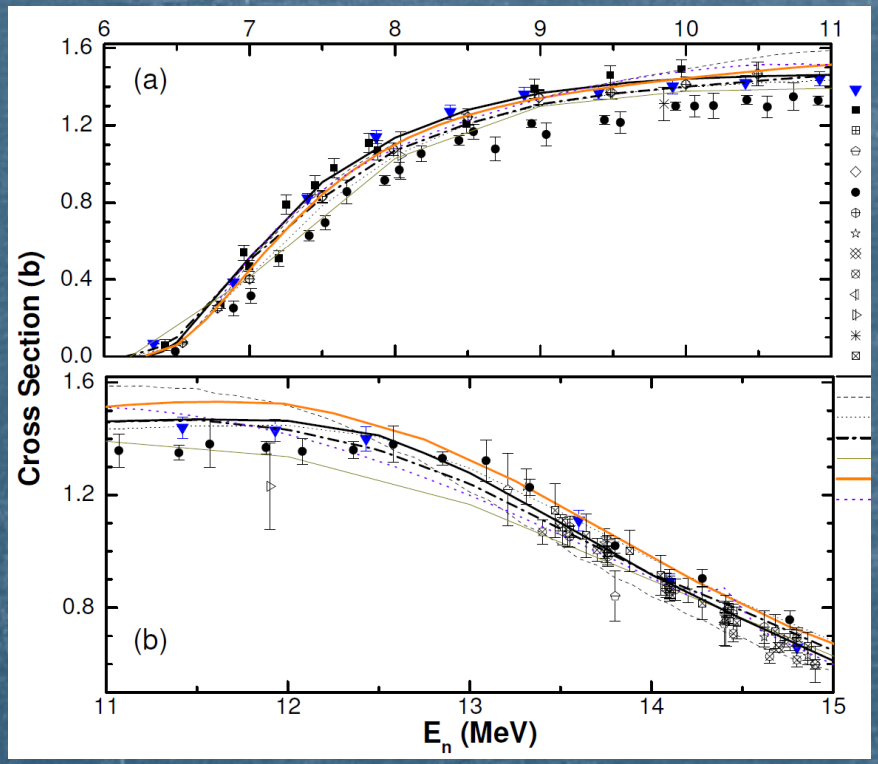
^{238}U CS measurements at TUNL



- Stockpile stewardship
- Nuclear forensic
- Advanced/breed reactors
- Nuclear astrophysics

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

(n,f) and (n,2n) CS compete each other above 6 MeV



The **absolute magnitude** of both (n,f) and (n,2n) CS are important for stockpile stewardship and nuclear forensic as well as safety assessment of the fast reactors.

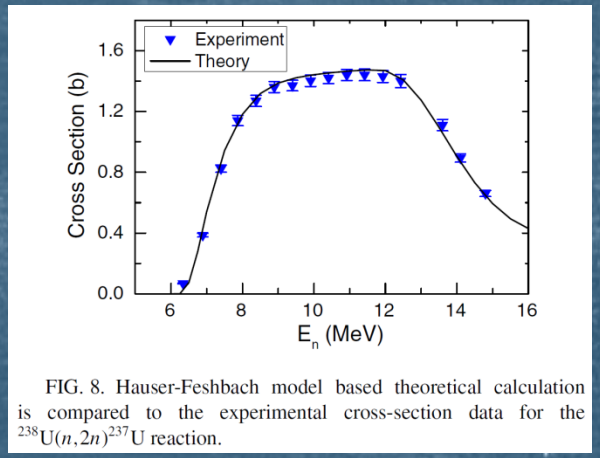


FIG. 8. Hauser-Feshbach model based theoretical calculation is compared to the experimental cross-section data for the $^{238}U(n,2n)^{237}U$ reaction.

Krishichayan et al., PRC 96, 044623 (2017)

$^{238}U(n,\gamma)^{239}U$

High priority

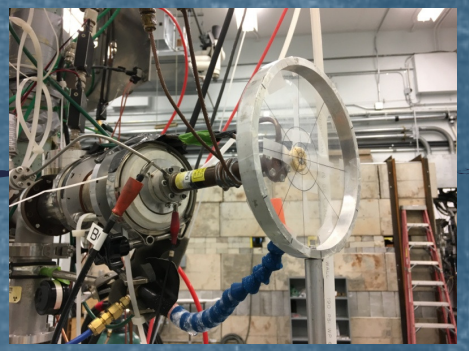
Nuclear Energy Agency

CIELO
(Collaborative International Evaluated Library Organization)

- The radiative capture cross section for ^{238}U has been extensively studied but there still exists inconsistency in the existing experimental data.
- The recent demands require better data sets with lowest possible uncertainties.

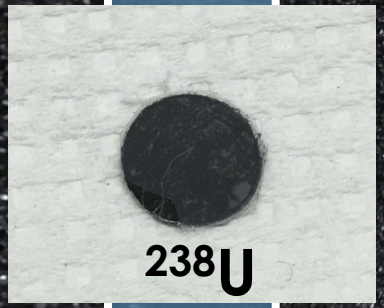
Goal of the present work is to provide an accurate and self-consistent set of high-quality cross-section data for the $^{238}U(n,\gamma)$ from 0.3 to 3.0 MeV.

$^{238}U(n,\gamma)$

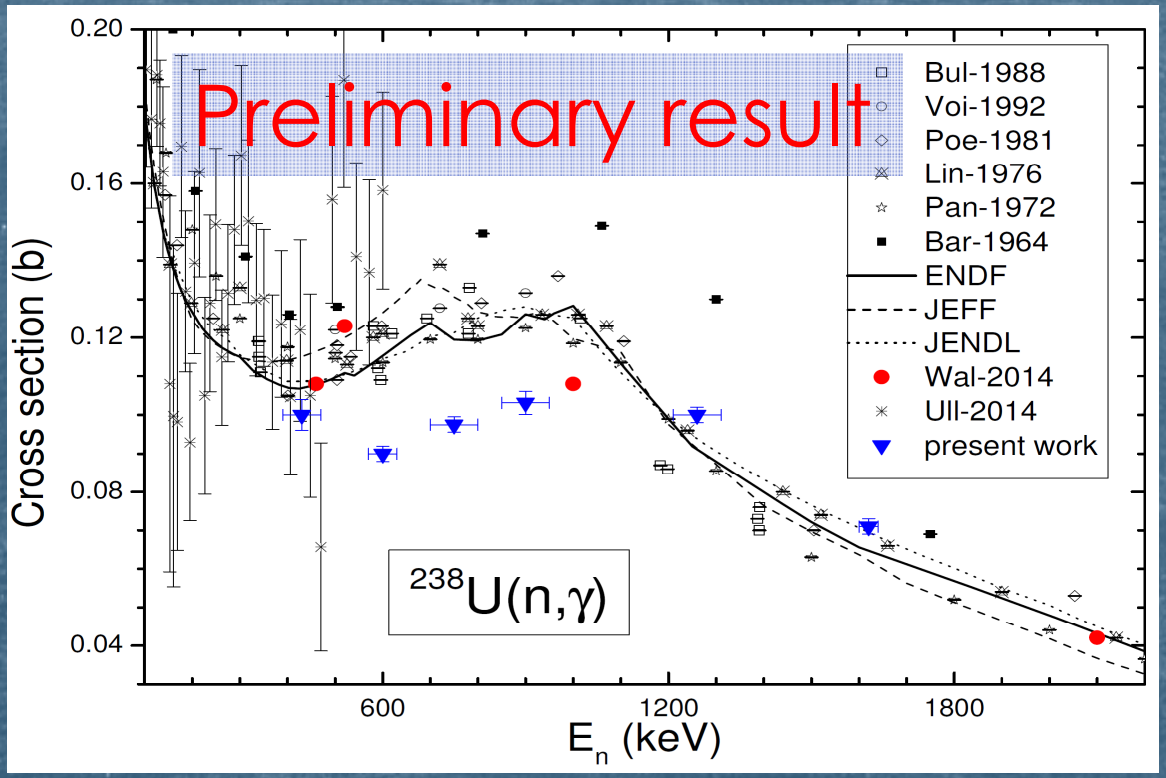


Pill-box

- Great challenge to estimate and/or reject thermal neutron capture cross section (comparatively large cross section).
- Use of a custom designed pill-box ***made of the ^{238}U material itself***.



$^{238}U(n,\gamma)$



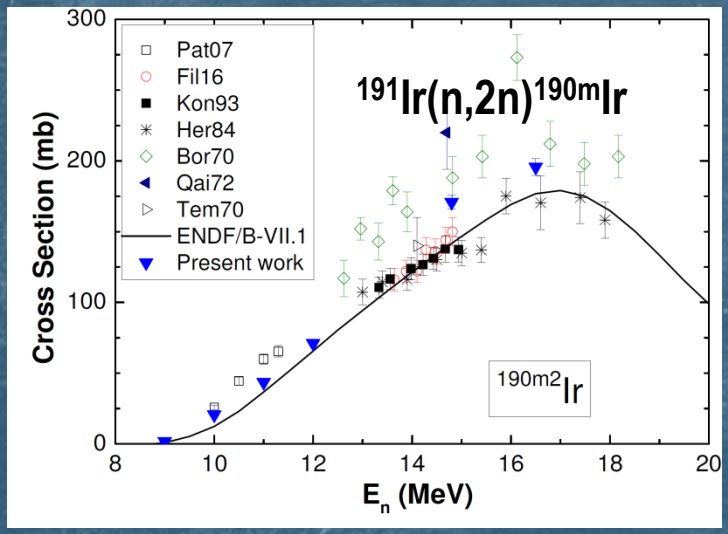
Future plan includes to carry out $^{238}U(n,\gamma)$ CS measurements at several other energies

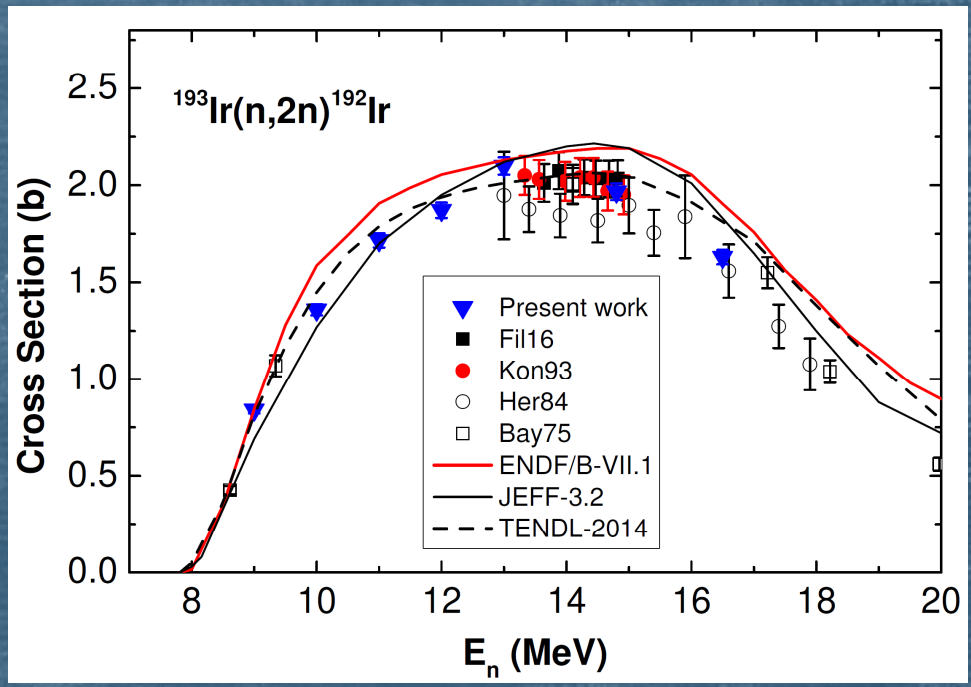
$^{191,193}Ir(n,2n)^{190,192}Ir$

REU project work

Material for constructing activation detector

Medical uses

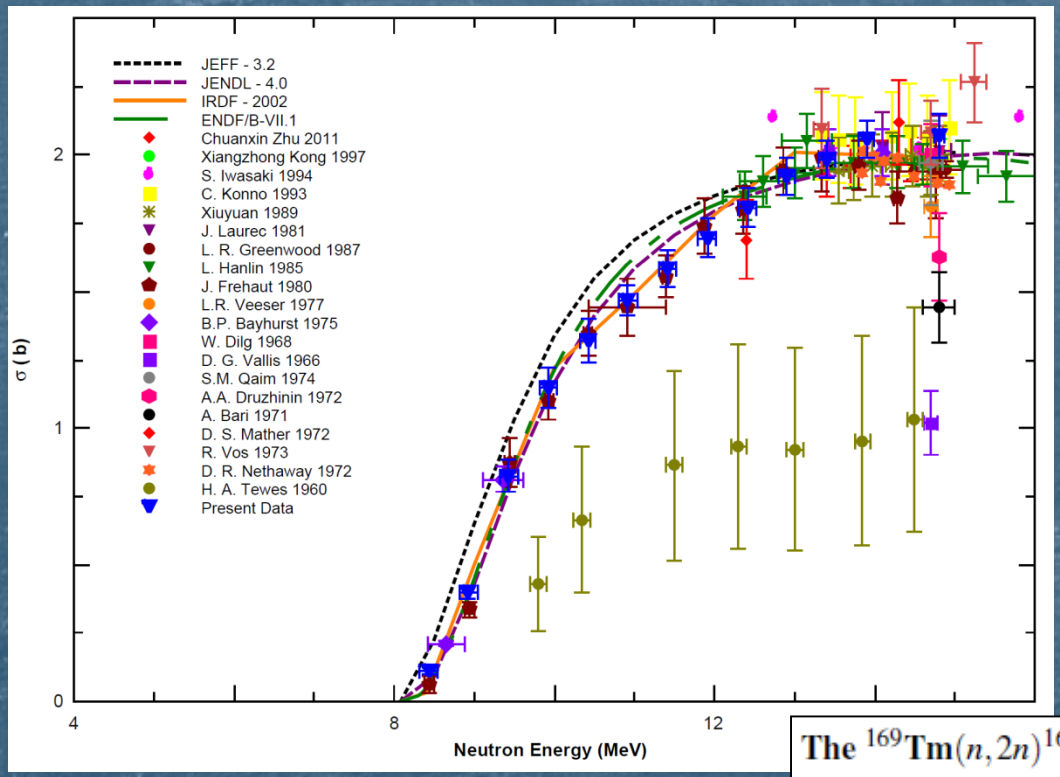




$^{169}Tm(n,2n)^{168}Tm$

REU project work

Diagnostic tool for National Ignition Facility at LLNL



Submitted to PRC

The $^{169}Tm(n,2n)^{168}Tm$ cross section from threshold to 15 MeV

J. Soter,* M. Bhike, S.W. Finch, Krishichayan, and W. Tornow†

Department of Physics, Duke University
Durham, NC 27708 USA
Triangle Universities Nuclear Laboratory
Durham, NC 27708, USA

$^{169}Tm(n,3n)^{167}Tm$
$^{209}Bi(n,4n)^{206}Bi$

Diagnostic tool for National Ignition Facility at LLNL

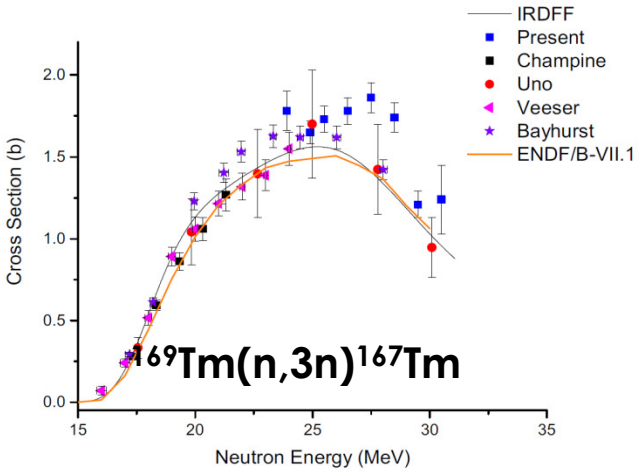


FIG. 7. Present data along with existing experimental data and evaluations for the $^{169}Tm(n,3n)^{167}Tm$ reaction.

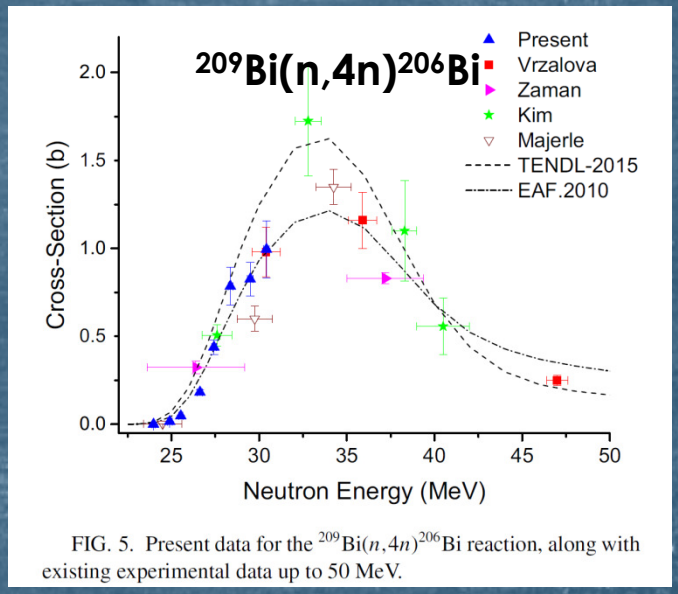


FIG. 5. Present data for the $^{209}Bi(n,4n)^{206}Bi$ reaction, along with existing experimental data up to 50 MeV.

PHYSICAL REVIEW C **96**, 024622 (2017)

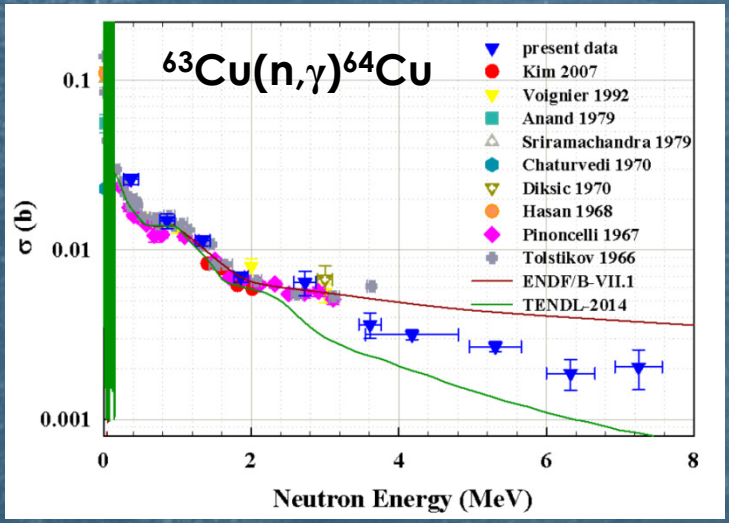
Measurement of the $^{209}Bi(n,4n)^{206}Bi$ and $^{169}Tm(n,3n)^{167}Tm$ cross sections between 23.5 and 30.5 MeV relevant to reaction-in-flight neutron studies at the National Ignition Facility

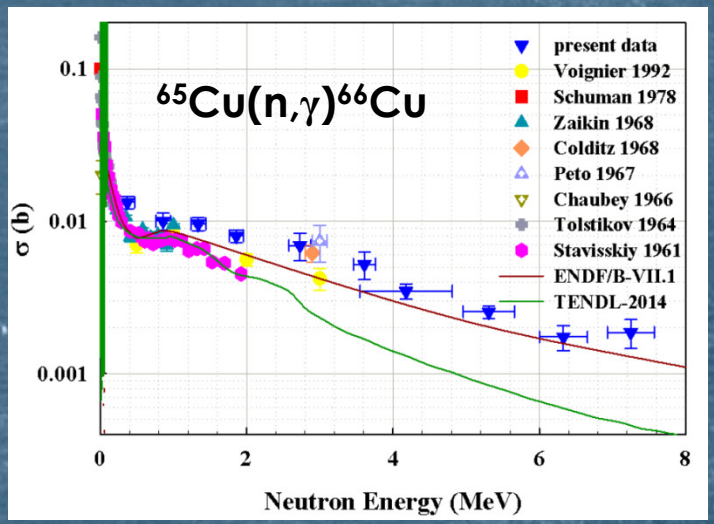
M. E. Gooden,[1,*] T. A. Bredeweg,[1] B. Champine,[2] D. C. Combs,[3,4] S. Finch,[5,4] A. Hayes-Sterbenz,[1] E. Henry,[6] Krishichayan,[5,4] R. Rundberg,[1] W. Tornow,[5,4] J. Wilhelmy,[1] and C. Yeamans[6]

$^{63,65}Cu(n,\gamma)^{64,66}Cu$

REU project work

Used as a cooling and shielding medium in most of the searches for neutrino-less double beta decay ($0\nu\beta\beta$)





To be submitted

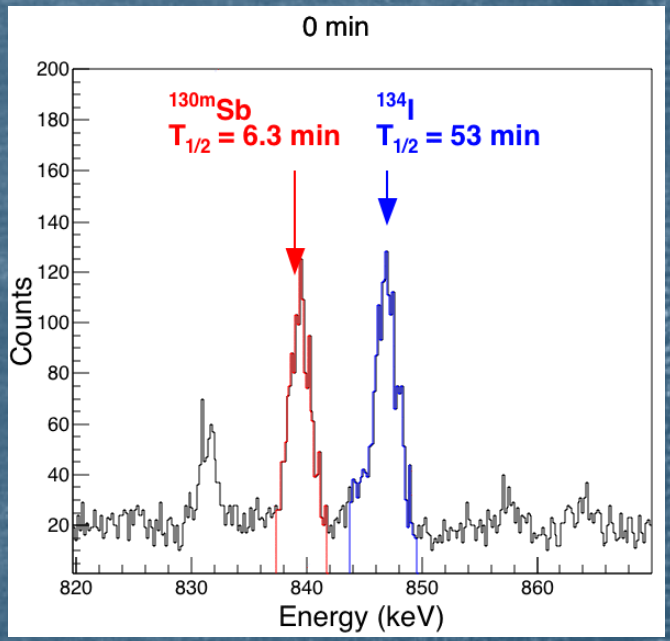
The neutron radiative capture cross section of $^{63,65}Cu$ between 0.4 and 7.5 MeV

Isabel Newsome[1], Megha Bhike[1], Krishichayan[1], W. Tornow[1]

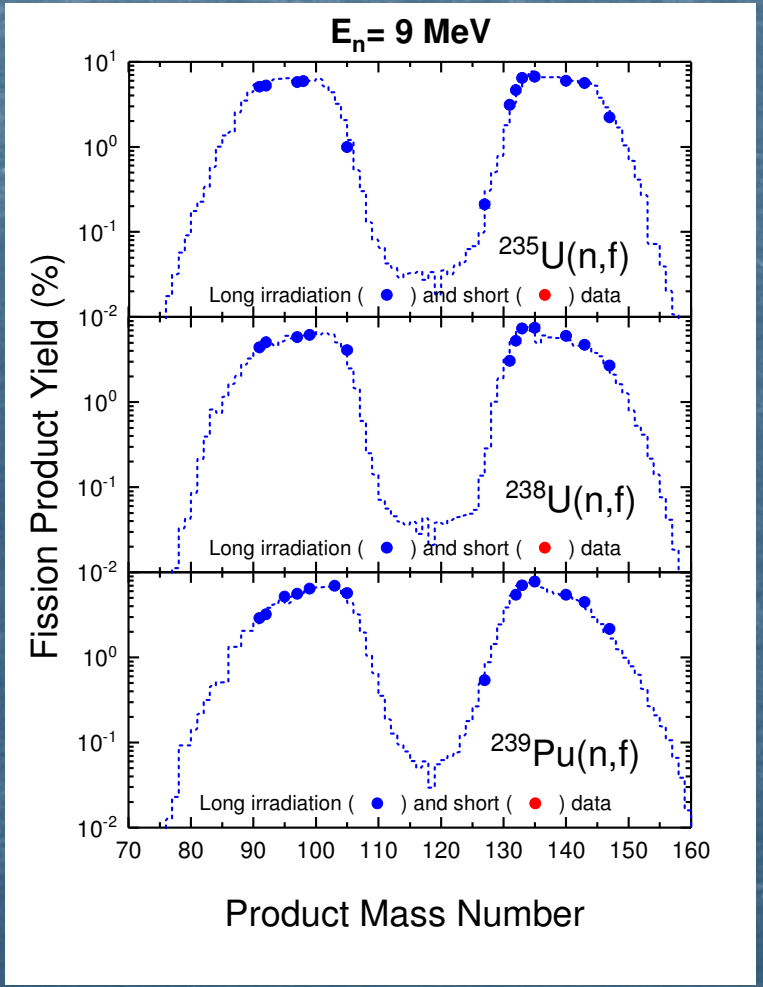
[1]Department of Physics, Duke University and Triangle Universities Nuclear Laboratory, Durham, NC

Short lived neutron-induced FPY measurements

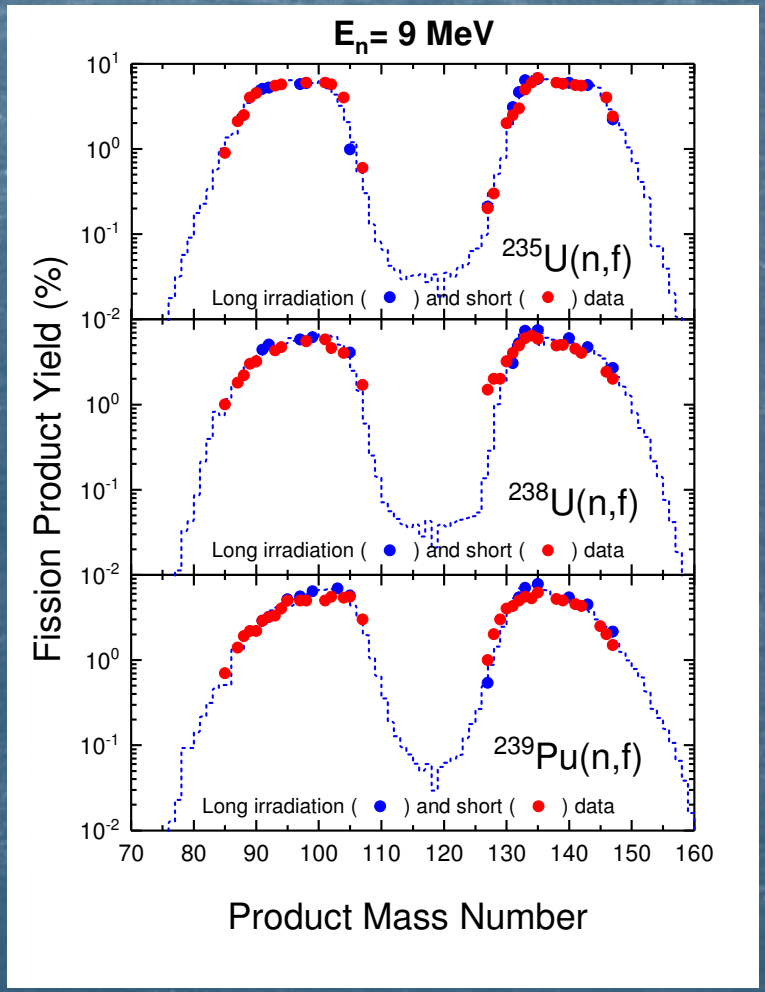
Expose to **neutron beam** for 1 hr, begin counting immediately after (<5 min) and count continuously for 3-4 days
Reduce activity from long lived FPs, halving background



Short lived FPY measurements



Short lived FPY measurements



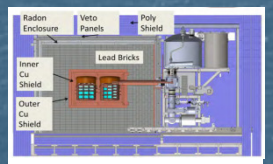
Next goal:

FPY data for isotopes having $T_{1/2}$ ~ 1 s

Background estimates in 0νββ searches

Neutron-induced background reactions are a major concern for the next generation of zero-neutrino double-beta decay (0νββ), dark-matter and supernova neutrino detectors.

GERDA



MAJORANA

Enriched Xenon Observatory
for double beta decay

Zero neutrino double beta decay search
KamLAND-Zen

^{76}Ge(n,2n)^{75}Ge

^{76}Ge(n,n′γ)^{76}Ge

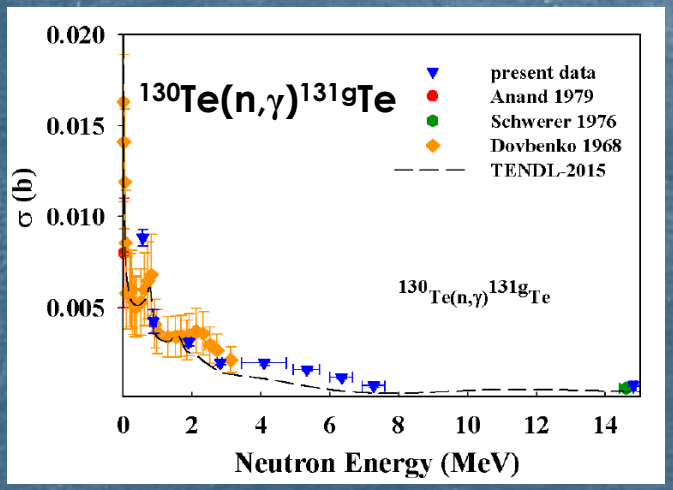
^{136}Xe(n,n′γ)^{136}Xe

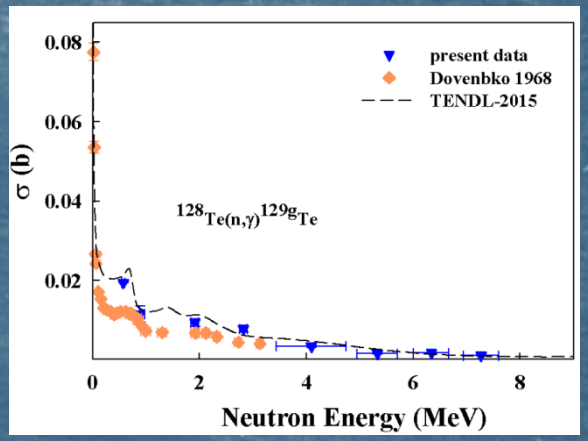
^{134}Xe(n,n′γ)^{134}Xe

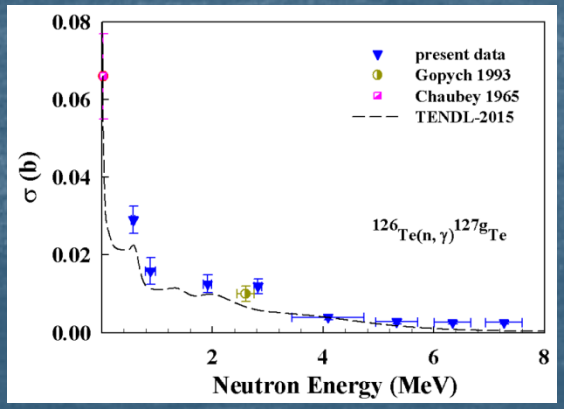
CUORE

^{126,128,130}Te(n,γ)^{127,129,131}Te

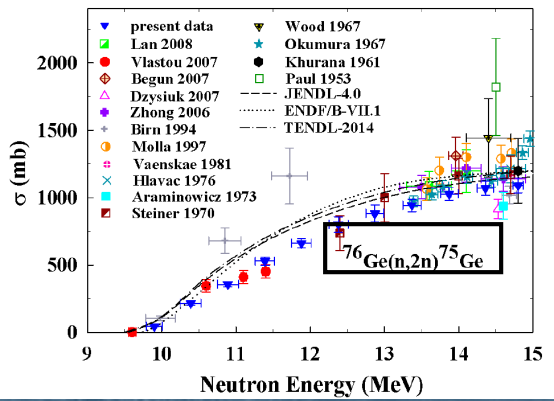
$^{126,128.130}Te(n,\gamma)^{127,129,131}Te$
$^{126,128.130}Te(n,2n)^{125,127,129}Te$

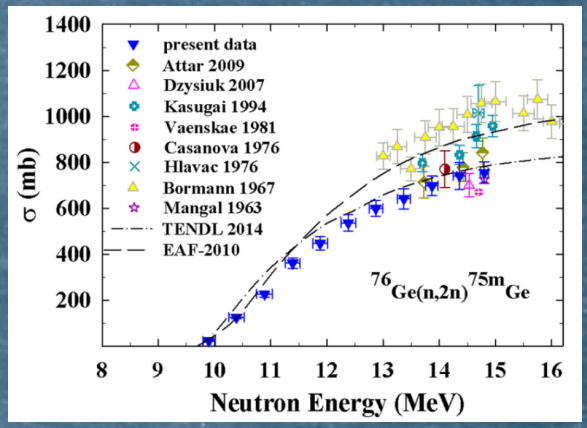






$^{76}Ge(n,2n)^{75}Ge$
$^{76}Ge(n,n'\gamma)^{76}Ge$





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Measurement of the neutron-capture cross section of ^{76}Ge and ^{74}Ge below 15 MeV and its relevance to $0\nu\beta\beta$ decay searches of ^{76}Ge

Megha Bhike [a,b,*], B. Fallin [a,b], Krishichayan [a,b], W. Tornow [a,b]

PHYSICAL REVIEW C **95**, 054605 (2017)

Total and isomeric-state cross sections for the ^{76}Ge$(n,2n)^{75}$Ge reaction from threshold to 14.8 MeV

Megha Bhike,* Krishichayan, and W. Tornow
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Fast-neutron-induced potential background near the Q value of neutrinoless double-β decay of ^{76}Ge

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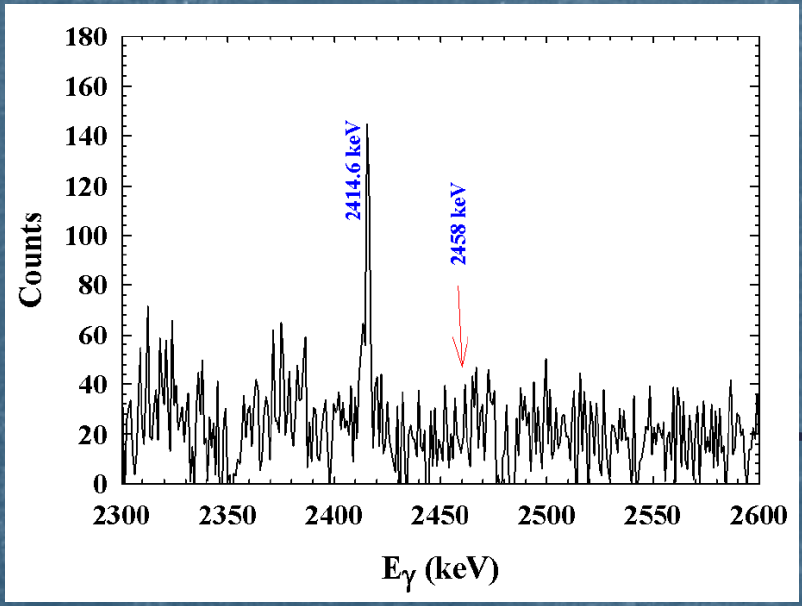
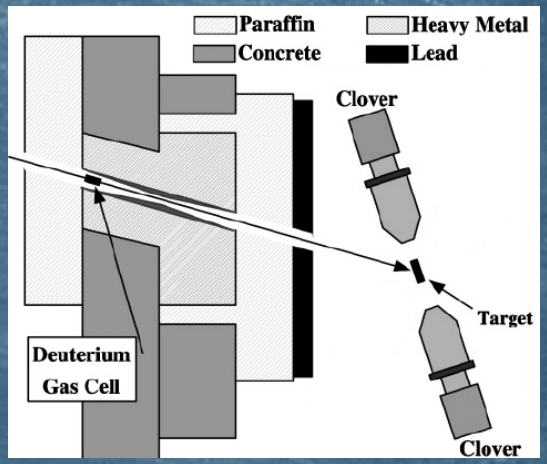
$^{134,136}Xe(n,n'\gamma)$
$^{134,136}Xe(n,\gamma)$





Thank you!!!