Nuclear Data Activities at Mizoram University

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Workshop on Compilation of Experimental Nuclear Reaction Data for EXFOR Database, IAEA's Headquarters, Vienna 24 to 28th October 2016.

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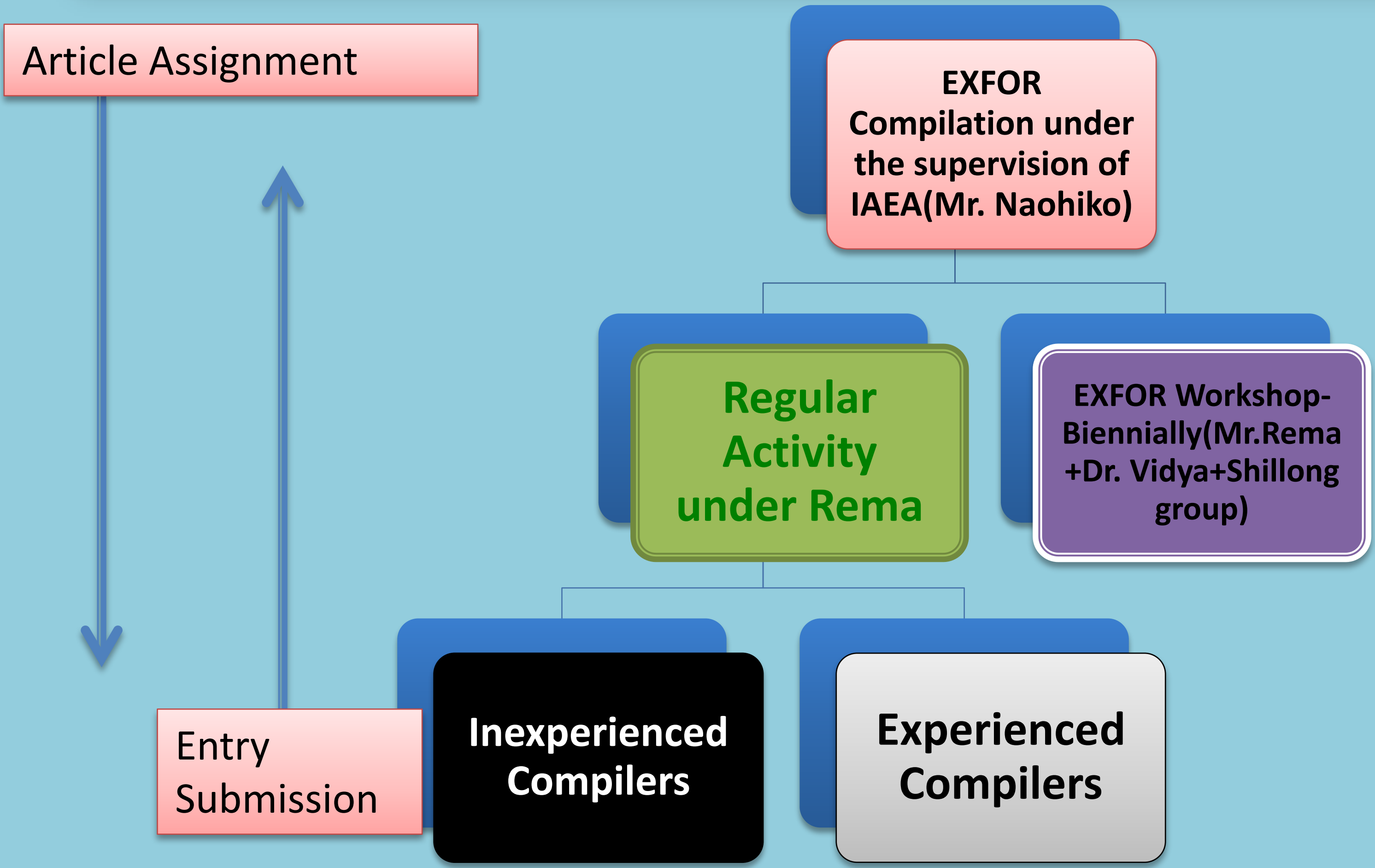
I. EXFOR Compilation activities (Past and Present)



Article Assignment

EXFOR Compilation under the supervision of IAEA(Mr. Naohiko)

Regular Activity under Rema

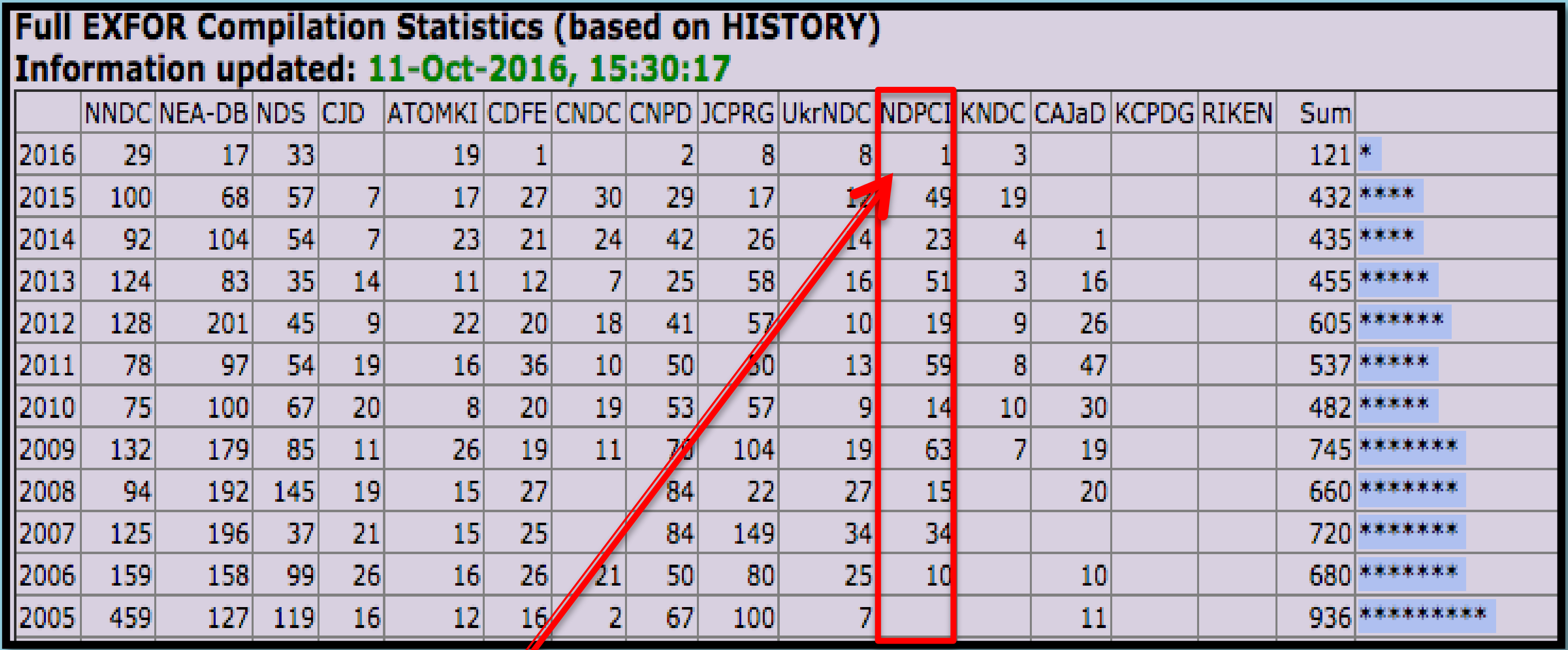
EXFOR Workshop-Biennially(Mr.Rema +Dr. Vidya+Shillong group)

Inexperienced Compilers

Experienced Compilers

Entry Submission

STATUS



Full EXFOR Compilation Statistics (based on HISTORY)

Information updated: 11-Oct-2016, 15:30:17

	NNDC	NEA-DB	NDS	CJD	ATOMKI	CDFE	CNDC	CNPD	JCPRG	UkrNDC	NDPCI	KNDC	CAJaD	KCPDG	RIKEN	Sum	
2016	29	17	33		19	1		2	8	8	1	3				121	*
2015	100	68	57	7	17	27	30	29	17	12	49	19				432	****
2014	92	104	54	7	23	21	24	42	26	14	23	4	1			435	****
2013	124	83	35	14	11	12	7	25	58	16	51	3	16			455	*****
2012	128	201	45	9	22	20	18	41	57	10	19	9	26			605	******
2011	78	97	54	19	16	36	10	50	50	13	59	8	47			537	*****
2010	75	100	67	20	8	20	19	53	57	9	14	10	30			482	*****
2009	132	179	85	11	26	19	11	70	104	19	63	7	19			745	*******
2008	94	192	145	19	15	27		84	22	27	15		20			660	*******
2007	125	196	37	21	15	25		84	149	34	34					720	*******
2006	159	158	99	26	16	26	21	50	80	25	10		10			680	*******
2005	459	127	119	16	12	16	2	67	100	7			11			936	*********

In 2016, 8 entries have been submitted and one is pending

Total Entries =338

Since 2012, Regular activity contributed ~ 50% of all Indian EXFOR entries

- Six NDPCI EXFOR workshops have been conducted at various universities and Research Institutes since 2006
- The 7th workshop will be held at North Easten Hill University from 6-10th March 2017.

Punjab

Bangalore

Challenges for long term Indian EXFOR Compilation

Workshop Activity

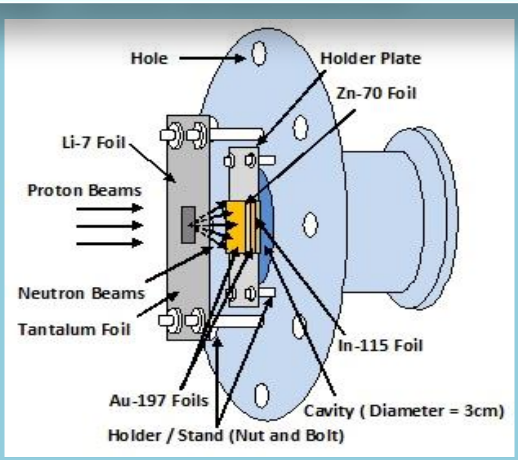
- Every workshop, new participant…do not generate regular compilers…
- How long can we continue…???

Regular Activity

- Regular compilations are done by Universities with funds given by BRNS through NDPCI. No official coordinator for long term basis….
- How long regular compilation activity will last?

NDPCI needs to engage at least one regular compiler on a permanent basis in its headquarter at BARC to coordinate and perform regular compilation.

II. Development of $^{7}Li(p,n)^{7}Be$ neutron spectrum code below 3-body breakup threshold



Measurement of $^{70}Zn(n,g)^{71}Zn^{m}$ cross section at E_p = 2.25, 2.60, 2.80 and 3.50 MeV using $^{7}Li(p,n)^{7}Be$ reaction as neutron source

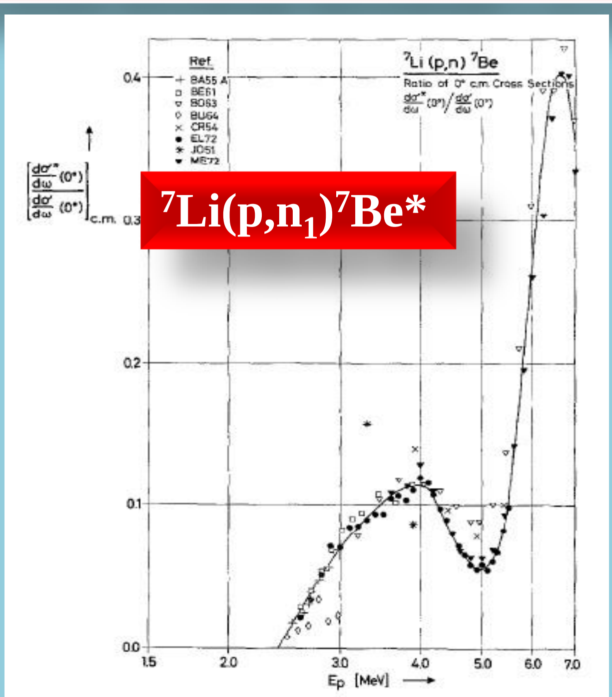
- Proton beam energy spread is ±20 keV.

- Due to continuous proton beam structure, we have to rely on calculated neutron energy spectrum.

^{7}Li(p,n)^{7}Be reaction as neutron source

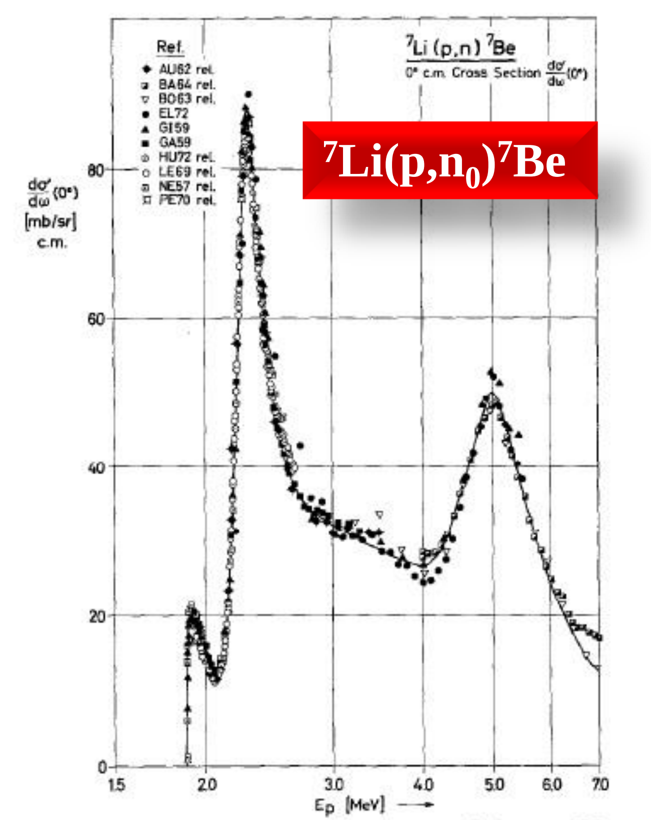
Reaction thresholds

^{7}Li(p,n$_0$)^{7}Be – 1.880 MeV
^{7}Li(p,n$_1$)^{7}Be – 2.371 MeV
Three body breakup threshold ~ 3.7 MeV



^{7}Li(p,n$_1$)^{7}Be*

FIG. Experimental and Recommended Ratio of 0° Center-of-Mass Cross Sections for the Reactions ^{7}Li(p,n)^{7}Be and ^{7}Li(p,n)^{7}Be*



^{7}Li(p,n$_0$)^{7}Be

FIG. 2. Experimental and Recommended 0° Center-of-Mass Cross Sections for the Reaction ^{7}Li(p,n)^{7}Be

H. LISKIEN and A. PAULSEN, *At. Data Nucl. Data Tables*, 15, 57 (1975)

EPEN-**E**nergy of **P**roton **E**nergy of **N**eutron

We developed a new code for

❑ **^{7}Li(p,n)^{7}Be reaction -neutron source.**

❑ **Subtraction of (p,n$_1$) and scattered background neutrons**

❑ **Formalism: Similar to that of Lee and Zhou except that-**

❖ **Kinematic equations in terms of ^{7}Li mass**

❖ **Differences in selection criteria of "±" in the double valued region**

$$\frac{dY\left(E_n\right)}{dE_n} = \int d\Omega \frac{d^2Y\left(\theta, E_n\right)}{dE_n d\Omega} w_1\left(\theta\right) w_2\left(E_p\left(\theta, E_n\right)\right)$$

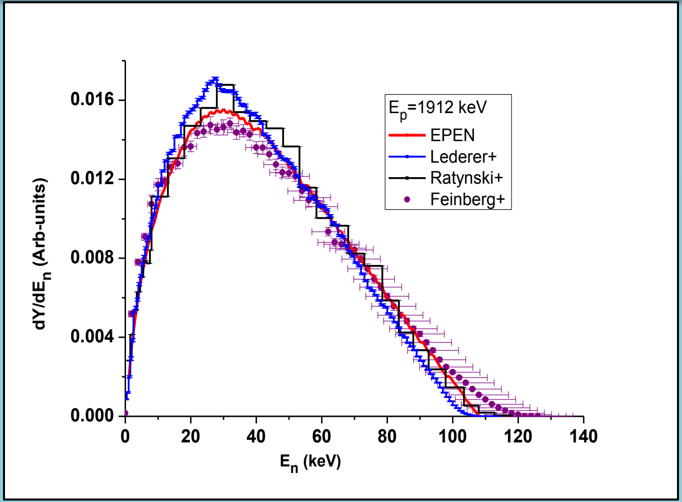
Differential Cross-sections

- **E$_p$ > 1.95 :** Evaluated data - Liskien et. al.
- **E$_p$ near threshold :** Functional form – Macklin & Gibbons
- **1.92 MeV< E$_p$ <1.95 MeV :** Cubic Spline fits

Weighting functions

- Solid angle covered by sample (w_1)
- Proton energy spread (w_2)

RESULTS AND DISCUSSION



Validation

EPEN reproduces experimental spectra well

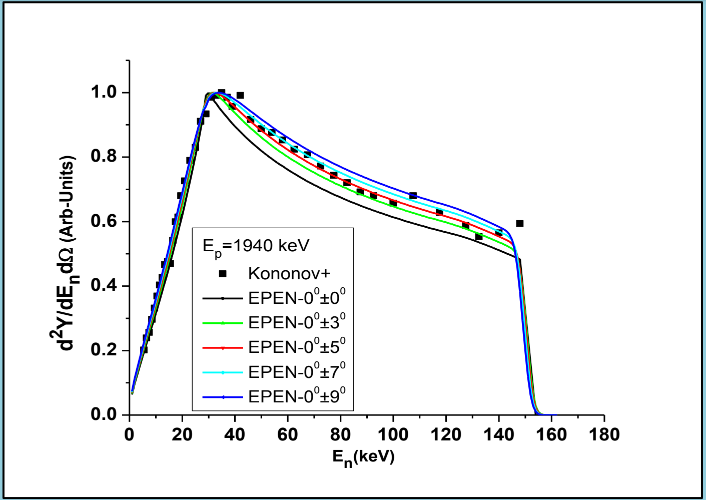


Fig. 1: Comparison of EPEN ^{7}Li(p,n$_0$)^{7}Be neutron energy spectrum at E_p=1912 ± 0 keV with experimental results .

Fig. 2: Comparison of EPEN ^{7}Li(p,n$_0$)^{7}Be double differential neutron energy spectrum at E_p=1940 keV with experimental result.

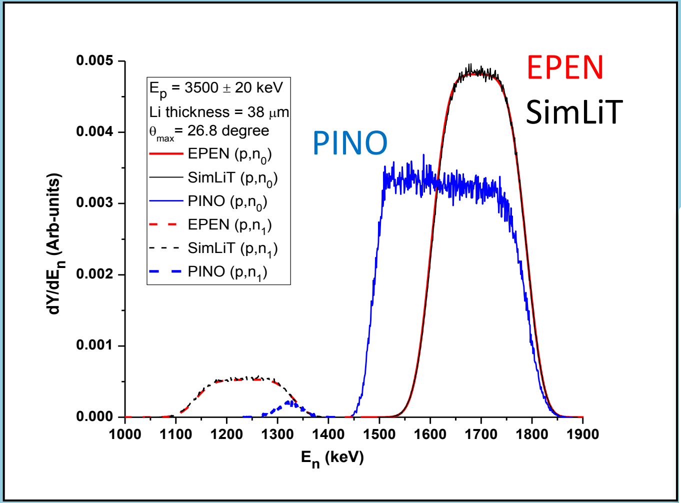


Fig. 3: Lithium target thickness 38 μm at E_p = 3500±20 keV

Comparison of EPEN with Monte Carlo codes

- **EPEN always agree with SimLiT perfectly**
- **PINO – narrow (p,n$_1$) spectrum centred near the upper boundary of the (p,n$_1$) energy spectra of EPEN & SimLiT**

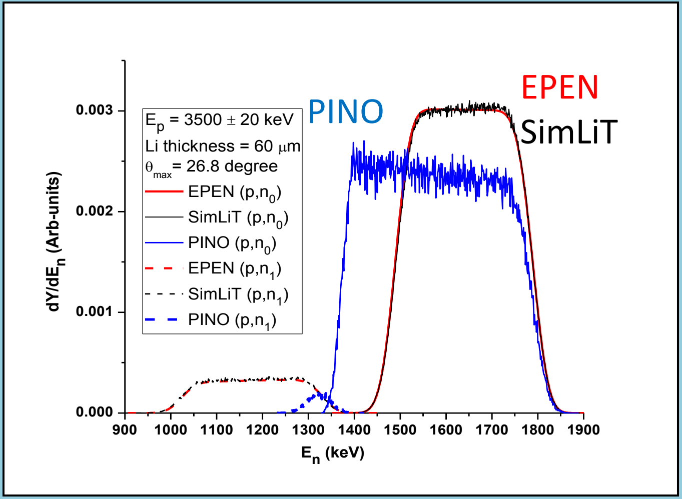


Fig. 4: Lithium target thickness 60 μm at E_p = 3500±20 keV

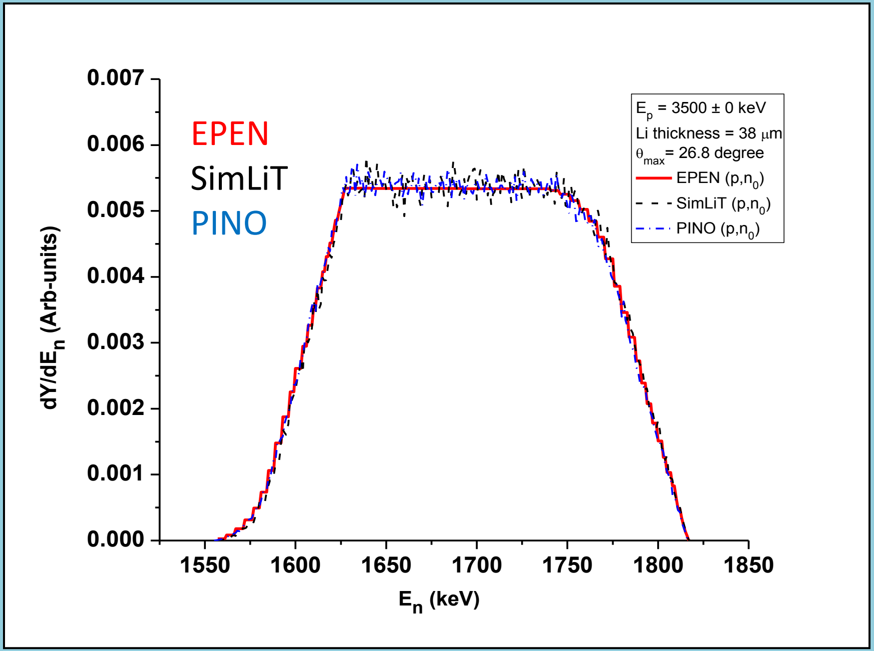


Fig. 5: Comparison between EPEN, SimLiT and PINO neutron energy spectra for lithium target thickness 38 μm at E_p = 3500±0keV.

(p,n_0) neutron spectra of EPEN, SimLiT and PINO - excellent agreement if the proton beam energy spread is negligible.

EPEN output can be used as an input to the Monte Carlo particle transport codes to describe more complicated neutron source systems as done by Friedman *et al.* for SimLiT+GEANT.

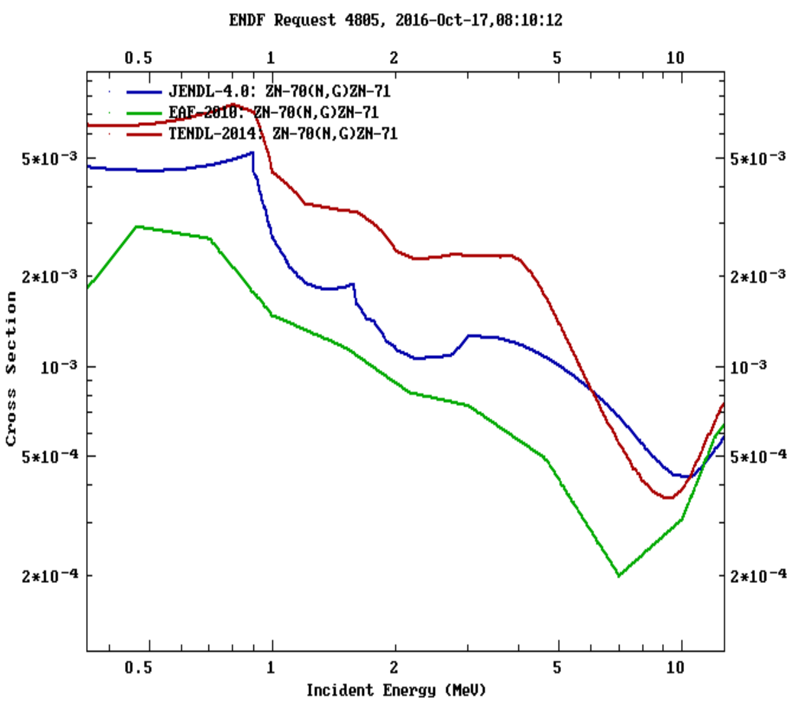
III. Measurements of neutron capture cross sections on ^{70}Zn at $\langle E_n \rangle = 0.96$ and 1.69 MeV

Motivation

The neutron capture cross sections of zinc isotopes are

- Important both for reactor applications as well as for nuclear astrophysics.
- a candidate of dosimetry reactions to study deviation of the epithermal reactor neutron spectrum from 1/E distribution.

No experimental results between the upper boundary of the resolved resonance region and 10 MeV



Large discrepancies between TENDL-2014, JENDL-4.0 and EAF-2010, there are large discrepancies between them

The experiment was performed at the Folded Tandem Ion Accelerator (FOTIA) Facility, BARC, Mumbai.

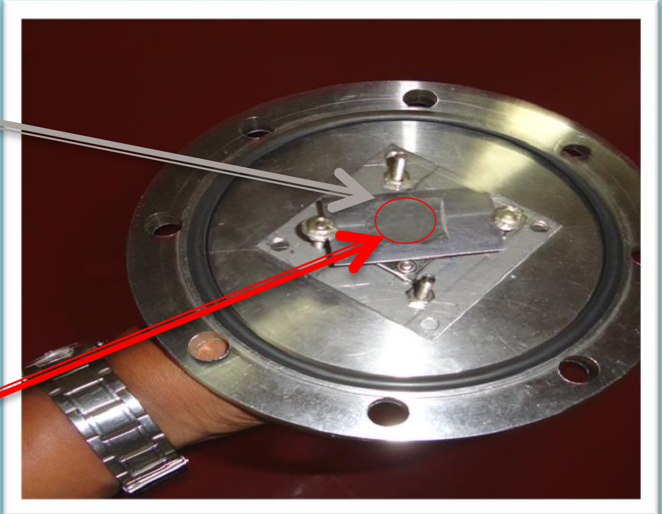
The protons at 2.80 MeV and 3.50 MeV after passing through a beam collimator (0.5 cm in diameter) bombarded a 2.0-mg/cm2 (37.4 µm) thick natural lithium target.

The proton beam energy spread is ±0.02 MeV

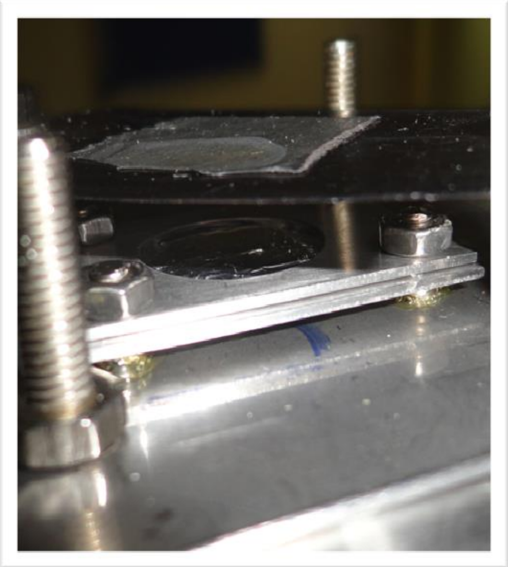
A 0.25-mm thick tantalum foil as a proton beam stopper.

The proton beam current during irradiation varied from 50 to 100 nA.

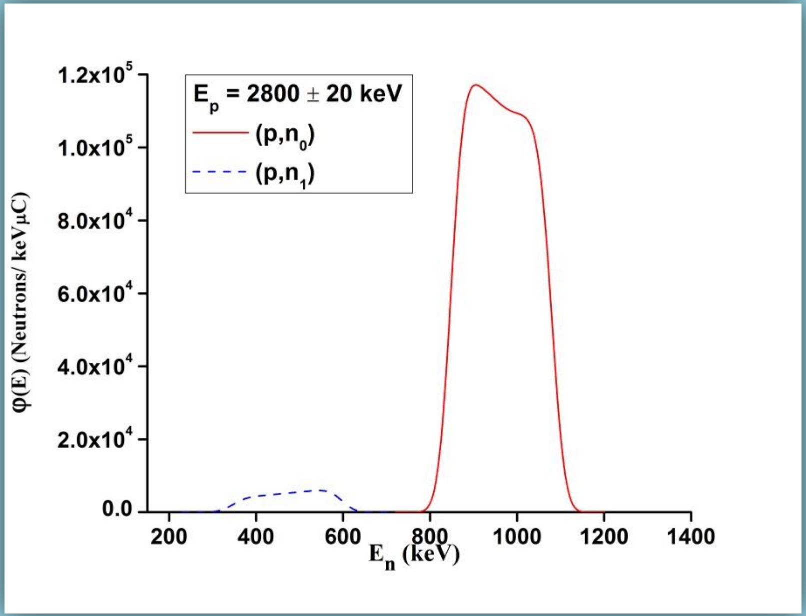
The beam diameter on the lithium target was about 5 mm.

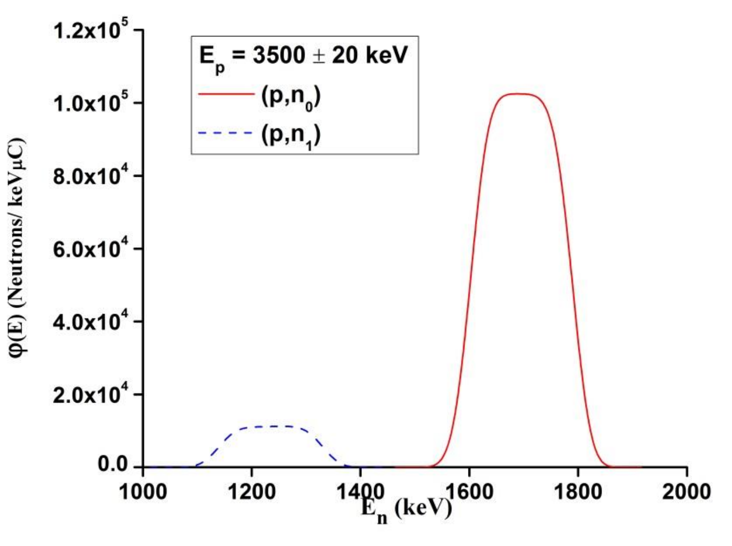


The neutron flux was monitored online by a NE213 neutron detector at zero degree and at 1 m distance from the lithium target.



EPEN neutron energy spectrum at E_p = 2800 ± 20 keV and 3500 ± 20 keV





$\langle E_{p,n0} \rangle$ = 0.96 MeV

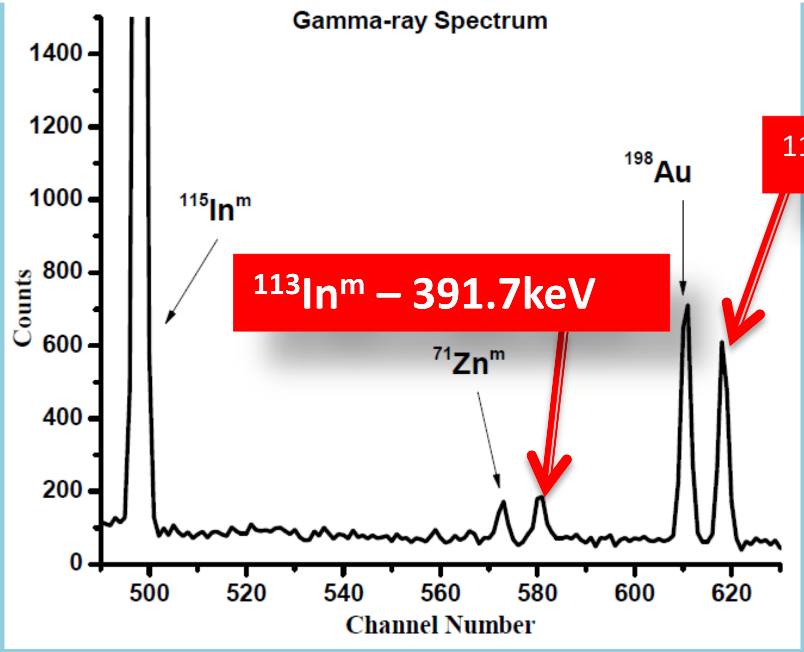
$\langle E_{p,n1} \rangle$ = 1.69 MeV

Details of foils used in the present experiment

Isotope	Enrichment (%)	Purity (%)	E_n (MeV)	Thickness (mg/cm^2)	Number of atoms of the isotope (10^{-4} atoms/b)
^{70}Zn	72.4±1.0 8.49 (^{64}Zn) 8.40 (^{66}Zn) 2.01 (^{67}Zn) 8.70 (^{68}Zn)	>99.97	0.96	87.3±0.1	5.529
			1.69	113.6±0.1	7.194
^{197}Au	100%	99.95	0.96	72.3±0.1 (front) 68.5±0.1 (back)	2.211 (front) 2.094 (back)
			1.69	74.0±0.1 (front) 70.3±0.1 (back)	2.263 (front) 2.149 (back)
^{115}In	95.71%	99.99	0.96	102.0±0.1	5.120
			1.69	129.8±0.1	6.516

Decay data adopted in the present work taken from the ENSDF library

Nuclide	Half-life	E_γ (keV)	I_γ (%)
$^{71}Zn^{m}$	3.96 ± 0.05 h	386.280	91.40±2.10
^{198}Au	2.6947 ± 0.0003 d	411.802	95.62±0.06
$^{115}In^{m}$	4.486 ± 0.004 h	336.240	45.80±2.20



$^{116}In^{m}$ – 416.9keV

$^{113}In^{m}$ – 391.7keV

Typical gamma ray spectrum of radioactive nuclei $^{115}In^{m}$, $^{71}Zn^{m}$ and ^{198}Au at $<E_n>$=1.66 MeV

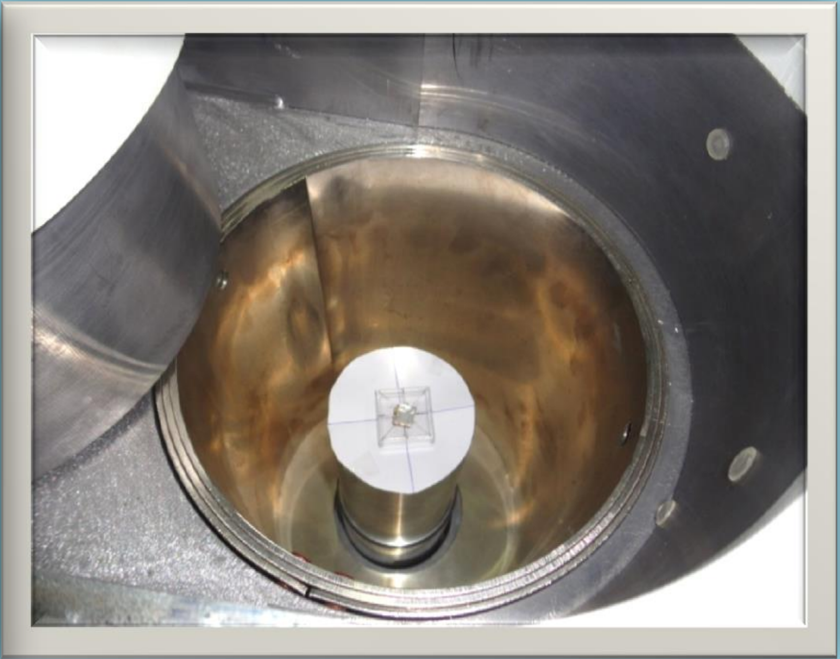
HPGe detector Efficiency Calibration

^{152}Eu point source ($T_{1/2}$ = 13.517 years) of known activity (A_0 = 7582.5 Bq on 1st Oct.1999)

- ☐ **For determination of the absolute photo peak efficiency of the HPGe detector**

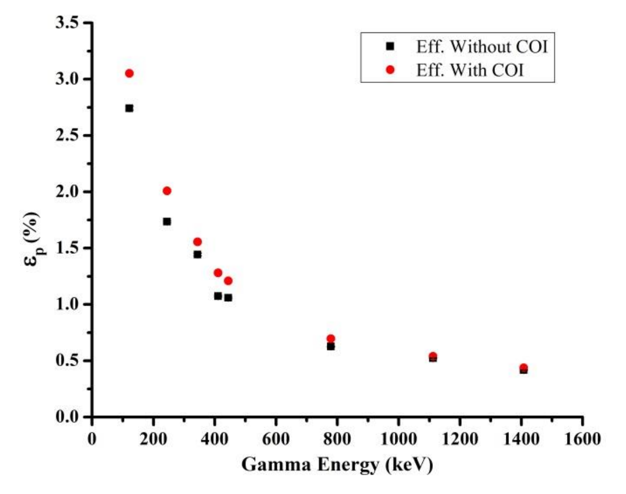
- ☐ **Detection efficiency for the point source placed at a distance of 1 cm from the detector εp was determined by**

$$\varepsilon_p = C\,K_c / (A_0\, e^{-\lambda t}\, \Delta t\, I_\gamma)$$



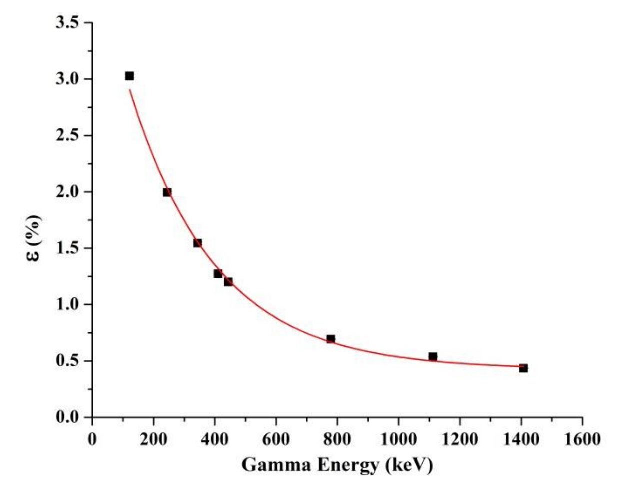
Since the count rate from the ^{70}Zn(n,γ)^{71}Zn^m reaction is rather low, we needed to place the foil stack very close to the detector to obtain high count rate. Therefore the efficiency calibration source had also to be placed at the same distance, which is 1 cm from the detector. However, this introduces the coincidence-summing effect.

In order to correct the measured efficiency for the coincidence summing effect, the correction factor K_c was calculated using the Monte Carlo simulation code EFFTRAN.



Detector efficiencies with and without true coincidence summing corrections (COI)

Since the calibration of the HPGe detector was carried out with the point source while the activated foil stack has finite area (1 cm × 1 cm), the efficiency for the point source geometry ε_p was transferred by EFFTRAN to the efficiency for the foil stack geometry ε.



Detection efficiencies for the point source geometry ε_p and for the foil stack geometry ε at the characteristic γ energies of ^{152}Eu with their γ intensities I_γ

E_γ (keV)	I_γ (%)	C	K_c	ε_p	ε
121.8	28.53±0.16	328049.3	1.113	3.0514	3.0270±0.0178
244.7	7.55±0.04	53997.8	1.158	2.0083	1.9940±0.0136
344.3	26.59±0.20	157183.5	1.078	1.5550	1.5450±0.0123
411.1	2.237±0.013	9647.2	1.193	1.2803	1.2720±0.0149
444.0	3.125±0.018	13292.1	1.142	1.2087	1.2013±0.0125
778.9	12.93±0.08	32542.8	1.112	0.6964	0.6922±0.0058
1112.1	13.67±0.08	28712.2	1.033	0.5399	0.5368±0.0045
1408.0	20.87±0.09	34940.8	1.050	0.4374	0.4349±0.0030

In order to obtain the detector efficiencies at the characteristic γ energies of the $^{70}Zn^{m}$ (E_{Zn}=386.28 keV) and ^{198}Au (E_{Au}=411.802 keV), the point-wise efficiencies in Table 4 were interpolated through the following fitting function:

$$\varepsilon(E) = \varepsilon_0 \exp(-E/E_0) + \varepsilon_c$$

Parameter	Value	Uncertainty	Correlation coefficient		
ε_0	3.889	0.2083	1.000		
E_0	279.54 1	16.880	-0.843	1.000	
ε_c	0.428	0.0194	0.408	-0.687	1.000

The covariance between two interpolated efficiencies ε_{Zn} and ε_{Au} are obtained following the prescription by Mannhart

$$\begin{aligned}\mathrm{cov}\,(\varepsilon_{Zn}, \varepsilon_{Au}) = {} & \exp\,[-\,(E_{Zn}+E_{Au})\,/\,E_0]\,(\Delta\,\varepsilon_0)^2 + (\varepsilon_0{}^2 E_{Zn} E_{Au} / E_0{}^4)\,\exp\,[-(E_{Zn}+E_{Au})\,/\,E_0] \\ & (\Delta\,E_0)^2 + (\Delta\varepsilon_c)^2 + \varepsilon_0\,[(E_{Zn}+E_{Au})\,/\,E_0{}^2]\,\exp\,[-\,(E_{Zn}+E_{Au}) / E_0]\,\mathrm{cov}\,(E_0, \varepsilon_c) \\ & + [\exp\,(-E_{Zn} / E_0) + \exp\,(-E_{Au} / E_0)]\,\mathrm{cov}(\varepsilon_0, \varepsilon_c) + [(\varepsilon_0\,E_{Zn} / E_0{}^2)\,\exp\,(- \\ & E_{Zn} / E_0) + (\varepsilon_0\,E_{Au} / E_0{}^2)\,\exp\,(-E_{Au} / E_0)]\,\mathrm{cov}(\varepsilon_0, E_0)\end{aligned}$$

with $(\Delta\varepsilon_{Zn})^2 = \mathrm{var}\,(\varepsilon_{Zn})$ and $(\Delta\varepsilon_{Au})^2 = \mathrm{var}\,(\varepsilon_{Au})$

This is further propagated to the uncertainty in the detector efficiency ratio $\eta = \varepsilon Au/\varepsilon Zn$

$$(\Delta\,\eta/\eta)^2 = (\Delta\varepsilon Zn/\varepsilon Zn)^2 + (\Delta\varepsilon Au/\varepsilon Au)^2 - 2\,\mathrm{cov}\,(\varepsilon Zn,\varepsilon Au)/(\varepsilon Zn,\varepsilon Au),$$

DATA ANALYSIS PROCEDURE

Estimation of the cross section and its uncertainty

The measured $^{70}Zn(n,\gamma)^{71}Zn^{m}$ cross section $\langle\sigma_{Zn}{}^{m}\rangle$exp was derived with the $^{197}Au(n,\gamma)^{198}Au$ reference cross section $\langle\sigma_{Au}\rangle$ by

$$\langle\sigma_{Zn}{}^{m}\rangle \text{ exp} = \langle\sigma_{Au}\rangle(A_{Zn}/A_{Au})\ [(a_{Au}N_{Au}I_{Au}\varepsilon_{Au}f_{Au})/\ (a_{Zn}N_{Zn}I_{Zn}\varepsilon_{Zn}f_{Zn})]\boxed{(C_{Zn}/C_{Au})}$$

$$\langle\sigma_{Au}\rangle = \int\phi_0(E)\ \sigma_{Au}(E)\ dE\ /\ \int\phi_0(E)\ dE$$

IAEA Standard Cross-section Library

$$(\Delta\langle\sigma_{Au}\rangle)^2 = \Sigma_i\,[\Phi_i{}^2\ \mathrm{var}\,(\langle\sigma_i\rangle)]\ /\ (\Sigma_i\,\Phi_i)^2 + 2\ \Sigma_{i>j}\,[\Phi_i\ \Phi_j\ \mathrm{cov}\,(\langle\sigma_i\rangle\ \langle\sigma_j\rangle)]\ /\ (\Sigma_i\,\Phi_i)^2$$

CORRECTIONS

The correction factor Cx is decomposed to

$$C_x = C_{x,fluc}\cdot C_{x,low}\cdot C_{x,scat}\cdot C_{x,attn}$$

(x = Zn or Au)

Neutron flux fluctuation (fluc)

$$C_{x,fluc}=\langle\Phi_m\rangle[1 - \exp(-\lambda_x t_1)] / [\Sigma_{i=1,n}\, \Phi_{m,i}\, [1 - \exp(-\lambda_x \Delta t_1)]\exp[-\lambda_x(t_1 - i\Delta t_1)]]$$

low energy neutron backgrounds due to ^{7}Li(p,n1)^{7}Be neutrons (low)

$$C_{x,low} = 1 - \int\phi_1(E)\, \sigma_x(E)\, dE / \int\phi(E)\, \sigma_x(E)\, dE$$

Scattered neutron background originating from elastic, inelastic and multiple scattering in the foil stack and the surrounding materials (scat)

PHITS monte Carlo simulation

γ-rays self-attenuation (attn).

$$C_{attn}^{-1}= [(1/x_1)\int_0^{x1}\exp(-\mu_{m,1}\rho_1 x)\, dx] \cdot\Pi_{i=2,n} \exp(-\mu_{m,i}\rho_i x_i)$$

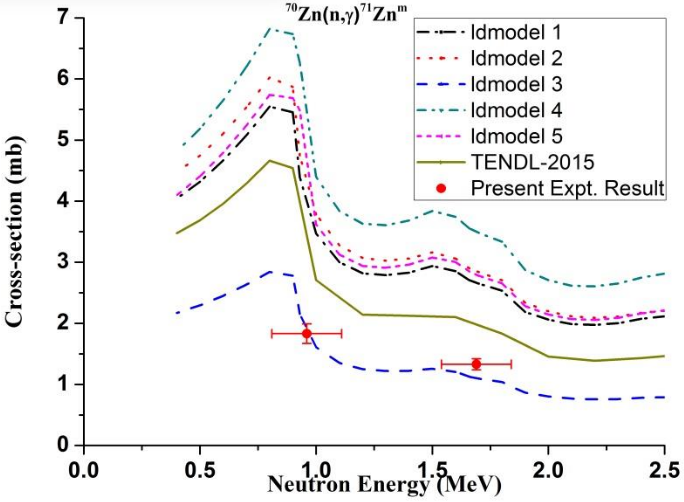
$$= [[1- \exp(-\mu_{m,1}\rho_1 x_1)] /(\mu_{m,1}\rho_1 x_1)]\cdot\Pi_{i=2,n} \exp(-\mu_{m,i}\rho_i x_i)$$

With the help of XMuDat Ver 1.01

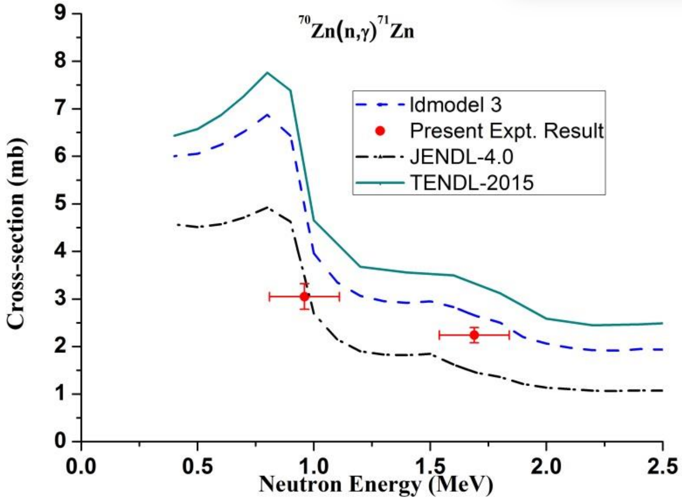
E_n (MeV)	0.96	1.69
$C_{Zn,fluc}/C_{Au,fluc}$	0.869	0.748
$C_{Au,low}$	0.920 (front) 0.921 (back) 0.921 (mean)	0.884 (front) 0.884 (back) 0.884 (mean)
$C_{Zn,low}$	0.948	0.888
$C_{Zn,scat}$	0.985	0.975
$C_{Au,scat}$	0.985 (front) 0.983 (back) 0.984 (mean)	0.981 (front) 0.979 (back) 0.980 (mean)
$C_{Zn,attn}$	1.015	1.016
$C_{Au,attn}$	1.019 (front) 1.010 (back) 1.01 (mean)	1.020 (front) 1.010 (back) 1.015 (mean)

RESULTS AND DISCUSSION

^{70}Zn(n,γ)^{71}Zn^{m}



^{70}Zn(n,γ)^{71}Zn



THANK YOU

FOR YOUR ATTENTION!!