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A BRIEF STATUS UPDATE ON THE ACTIVITIES OF NUCLEAR DATA PHYSICS CENTRE OF INDIA (NDPCI) DURING 2015-2016

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Introduction

NDPCI joined NRDC as a full member in September, 2008. NDPCI is responsible for broad range of nuclear data activities in India. NDPCI is a virtual unit of BARC (Bhabha Atomic Research Centre) Mumbai, India which is part of DAE (Department of atomic Energy). The NDPCI is the nodal centre for the collaboration with IAEA-NDS, CERN, NRDC and others. At present the NDPCI accomplish its data related work by sanctioning collaborative research projects to research group in universities and institutes with full financial support from DAE-BRNS. Many projects in the field of nuclear data including experimental measurement and theoretical evaluation has been granted and completed under purview of NDPCI. NDPCI has been able to accomplish in all the fields of nuclear data as well as nuclear data activities of interest to DAE. This report is based on reported work by various research teams and groups for the duration of 2015-2016. The subject of the report has been kept limited to the nuclear reaction data compilation, measurement and theoretical evaluation activity and it is not a statement of all the work by the NDPCI in the said duration.

1.0 Activity related to EXFOR compilation

Project granted by NDPCI have been proved an efficient way to accomplish EXFOR compilation. The grant of project make man power available for the EXFOR compilation with the associated research work. The Compilers work in close association with guidance from Dr. B. Lalremruata**,** Department of Physics, Mizoram University (Central University), Tanhril-796004, Aizawl, Mizoram, India and Dr. N. Otsuka, IAEA-NDS. The following two projects have been most productive with regards to EXFOR compilation work.

Sanction Number	Title of the Project	Principal Investigator	Principal Collaborator	Cost and Duration	
2012/36/17	Special Project under Nuclear Data Physics Centre of India entitled, "Measurements, EXFOR Compilation and theoretical study of nuclear data"	Dr. B. Lalremruata Department of Physics Mizoram University (Central University) Tanhril-796004 Aizawl, Mizoram India	Dr. S.V. Suryanarayana, NPD, BARC Dr. Alok Saxena, NPD, BARC Dr. H. Naik, RCD, BARC	25.64-Lakhs* 3 years 2012-15	Project Ongoing
2013/36/75	Continuing EXFOR compilations and participation in measurement of High Energy Photon and Neutron induced reaction cross-sections of structural materials (e. g. Fe, Co, Ni, Cr, Zr etc.) and materials related to medical isotopes (e.g. Mo)	Prof. (Mrs.) B. Jyrwa, Department of Physics, North Eastern Hill University, Shillong 793 022	DR. Haladhara Naik, SO(G) Radiochemistry Division, BARC Dr. S.V. Suryanarayana, SO(G), Nuclear Phys. Division, BARC DAE Coordinator Dr. Alok Saxena, NPD, BARC	24.78 Lakhs 3 Years 2013-2016	Project Ongoing

***1 Lakh= 100, 000 (Hundred Thousand)**

The other two project, having EXFOR compilation as a component, have been accepted but funds are yet to be released and are yet to take up EXFOR compilation.

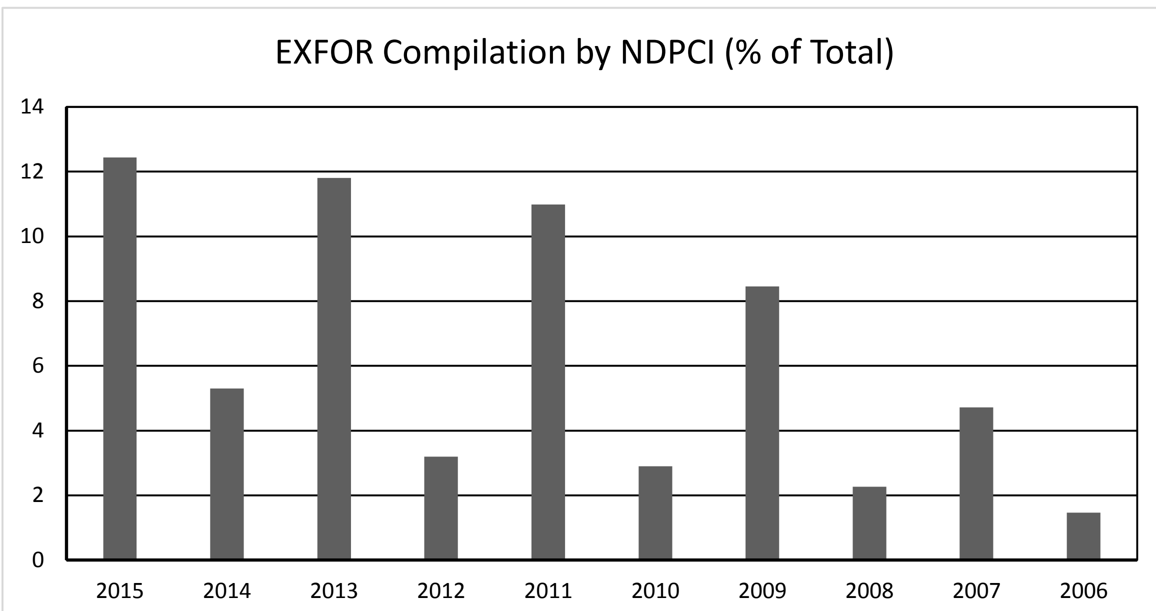
Sanction Number	Title of the Project	Principal Investigator	Principal Collaborator	Cost and Duration	
36(6)/14/92/2014	Dr.Rudraswamy.B Dept of Physics, Jnanabharathi campus,Bangalore University Bangalore- 560056	Compilation of Experimental Nuclear Reaction Data using EXFOR Editor and Measurement of Nuclear Reaction Cross section using Kamini Reactor	Dr. G. Pandikumar, IGCAR Dr. E. Radha, IGCAR	24.12 Lakhs 3 years 2014-2017	Project Ongoing
Accepted for sanction Fund is yet to be released	Dr Vidya Devi Department of Physics, IET Bhaddal Technical Campus, Bhaddal, P.O. Mianpur, District Ropar	EXFOR compilation of nuclear data	Dr. Alok Saxena, Head, NPD, BARC Devesh Raj, RPDD, BARC	11.89 Lakhs 2 years 2016-2018	

Please note that the 2nd project in the table above is exclusively for the EXFOR compilation.

1.1. The statistics of the EXFOR compilation work

Following is the statistics of the EXFOR compilation work as evident from IAEA-NDS website updated till May 24, 2016.

	NNDC	NEA-DB	NDS	CJD	ATOMKI	CAJaD	CDFE	CNDC	CNPD	JCPRG	UkrNDC	NDPCI	KNDC	Sum
2016	12		6				1		2	3	1		2	27
2015	98	37	55	7	15		27	30	29	17	12	49	18	394
2014	92	104	54	7	23	1	21	24	42	25	14	23	4	434
2013	122	82	35	14	11	16	12	7	25	38	16	51	3	432
2012	128	201	45	9	22	26	20	18	41	46	10	19	9	594
2011	78	97	54	19	16	47	36	10	50	50	13	59	8	537
2010	75	100	67	20	8	30	20	19	53	57	9	14	10	482
2009	132	179	85	11	26	19	19	11	70	104	19	63	7	745
2008	94	192	145	19	15	20	27		84	22	27	15		660
2007	125	196	37	21	15		25		84	149	34	34		720
2006	159	158	99	26	16	10	26	21	50	80	25	10		680



The evident discrepancy the number of compilations falling every alternate year is because of organization of EXFOR workshop every 2nd year. Once all the projects having EXFOR compilation as one of the components come in to force such discrepancy will be either alleviated or at least diminish considerably. About 12 percent of the total compilation was accomplished in 2015. Every effort shall be made to keep the number of compilations made every year is not less than 10% of the total.

2.0 Work regarding measurement and Evaluation of nuclear data

Various projects related to measurement of neutron induced reaction cross sections, photon induced reactions and theoretical study of covariance has been granted and several of them has been completed successfully.

The following activity shall look in to evaluation of covariance data from the experimental results. This project is in force since last one year.

Sanction Number	Title of the Project	Principal Investigator	Principal Collaborator	Cost and Duration
36(6)/14/52/2014-BRNS/2708	Evaluation of nuclear data including covariance error matrix for advanced nuclear systems in India	Dr. K. Manjunatha Prasad Professor of Mathematics Department of Statistics Manipal University Manipal-576 104, Karnataka	Dr. S. V. Suryanarayana, NPD, BARC Dr. H. Naik, RCD, BARC Dr. Pandikumar, IGCAR Dr. Ravindra B. Bapat, Professor, Indian Statistical Institute, Delhi	22.27 Lakhs 2 Years

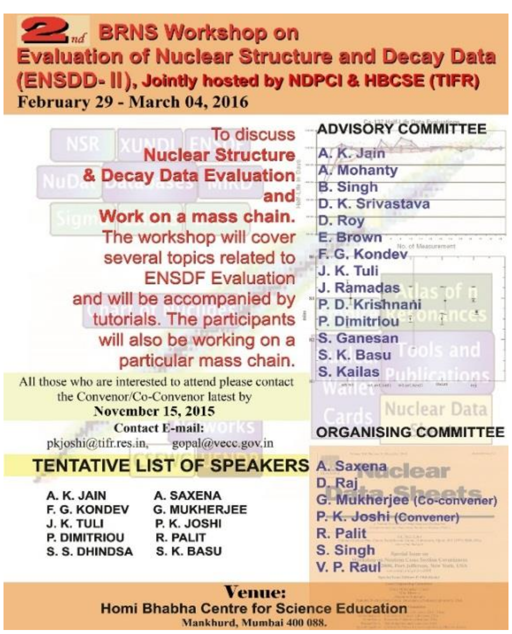
Other two projects which has been granted which shall look in to capture cross sections of Sodium and Iron another one which is intended to measure (n, γ), (n, p) and (n,2n) reaction cross sections in energy range 1MeV to 18 MeV of Isotopes of U, Th, Y, Mn, Bi, and Ag

Sanction Number	Title of the Project	Principal Investigator	Principal Collaborator	Cost and Duration
Accepted for sanction Fund is yet to be released	Cross section measurements for Sodium, Iron and Data compilation	Dr Ajay Kumar B-42, Brij Enclave, Sunderpur, Near Life Line Hospital Varanasi, Uttar Pradesh.	Dr B. K Nayak, SO/H+, NPD, BARC	18.25 Lakhs 3 Years .
Accepted for sanction Fund is yet to be released	Study of neutron induced reaction cross section up to 18 MeV for advanced reactor design	Prof Surjit Mukherjee Professor of Physics Physics Department, M.S. University of Baroda, Vadodara	Dr. H. Naik, RCD, BARC Dr. S. V. Suryanarayana, NPD, BARC	11.28 Lakhs 3 Years

PI of 1st project has expressed possibility of low lying capture resonance in sodium. If detected it shall have far reaching consequence on physics design of sodium cooled fast reactor designs.

3.0 Organization of 2nd BRNS workshop on "Evaluation of Nuclear Structure and Decay Data (ENSDD-II),

A 5 day workshop, during February 29 to March 04, 2016 was organised by Dr. Gopal Mukherjee, VECC and Dr P. K. Joshi, TIFR, and jointly hosted by NDPCI and HBCSE (TIFR) at Homi Bhabha Centre for Science Education, Mumbai-400088. The workshop was consisted of class room lectures and hands on sessions. There were about 40 students who participated in the workshop in both the lectures and hands-on sessions. The participants were from various Universities and research institutes from all over India. The speakers include experts from India and abroad. Dr. P. Dimitriou from International Atomic Energy Agency (IAEA), Vienne, Austria and Dr. J.K. Tuli from National Nuclear Data Centre (NNDC), Brookhaven National Laboratory, USA were among the speakers from abroad. The lectures were held in the morning sessions and the entire afternoon sessions were devoted to the hands-on practical. In the practical hands-on session, A = 223 mass chain was taken for evaluation. Full evaluation of this mass chain was done in 2001. There are several new data available in the nuclei in this mass chain. Therefore, it is required to do the full evaluation of this mass chain. The participants were clubbed into 4 groups with two group



leaders in each. The nuclei in the A = 223 mass chain were divided among the groups. The procedures, techniques, and methodology of a mass chain evaluation were discussed in the lectures, which were shown and practiced during the hands-on sessions. Most of the nuclei have been evaluated during the workshop itself. The nuclides in mass chain A = 223 covered during the workshop includes 223Ra, 223Pa, 223Fr, 223Th, 223Ac, 223Bi, 223Pa, 223At, 223Rn, 223U, 223AmThe group leaders will pursue to complete the mass chain as was done for the A = 215 mass chain taken up for ENSDD-I workshop which was subsequently completed and published. The group leaders will meet in the month of June to finalise the evaluation and to get it ready for publication.

4.0 β -decay measurement of ^{43}K using two methods: a) Total Absorption Gamma Spectroscopy (TAGS) method and b) High Resolution Spectroscopy (HRS) method

The β decay measurements of the odd-A neutron rich nucleus ^{43}K have been performed at VECC, Kolkata by group led by Dr. Gopal Mukherjee, VECC. The measurement was done using two methods, namely,

a) Total Absorption Gamma Spectroscopy (TAGS) method and

b) High Resolution Spectroscopy (HRS) method.

The nucleus ^{43}K was produced by bombarding 18 MeV alpha beam on ^{40}Ar target. The target was a gas shell of ^{40}Ar at 1 atm pressure. Both TAGS and HRS methods were used to determine the feeding intensity and to measure the half-life of the ^{43}K ground state. The reaction products were transported to a low background area using the VECC gas-jet system and allowed to implant on an 'Al' catcher foil. The catcher foil was then brought to the counting station.

4.1 TAGS measurement

The TAGS setup consisted of a 50 element BaF2 detectors each of size 3.5cmx3.5cmx5cm, the setup was tested with different gamma ray sources and the large granularity of the setup helps to cleanly identify the summed gamma rays [G. Mukherjee et al., EPJ Web of Conferences 66, 11026 (2014)].

Fig.4.1.1: The TAGS setup used for the present measurement. The catcher foil is placed in the middle between the two halves

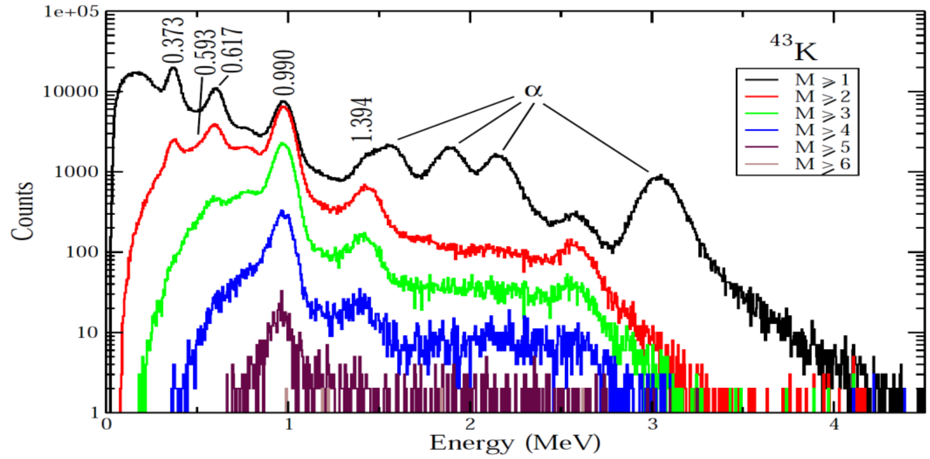


Fig.4.1.2: Sum spectra obtained from the TAGS data with different multiplicity gate M.

4.2 HRS measurement:

In the high resolution measurement, a single-crystal HPGe detector and a clover HPGe detector were used. The setup is shown in Fig.4.2.1.Both singles and coincidence data were taken using standard CAMAC data acquisition system. The decay was followed with fixed time gap to measure the half-life from the decay curve of the gamma rays. The intensity of the gamma rays were obtained to get the feeding intensity from the difference in gamma ray intensities.

Fig.4.2.1: The HRS setup with single-crystal HPGe and clover HPGe detectors. The foil was placed in between the two detectors.

In the preliminary analysis, all the gamma rays from the decay of ^{43}K are seen clearly. The coincidence relations are also obtained. The Decay curve of the 372-keV gamma ray, one of the strong gamma rays in the decay of ^{43}K, is shown in Fig.4.2.2 in different time bins.

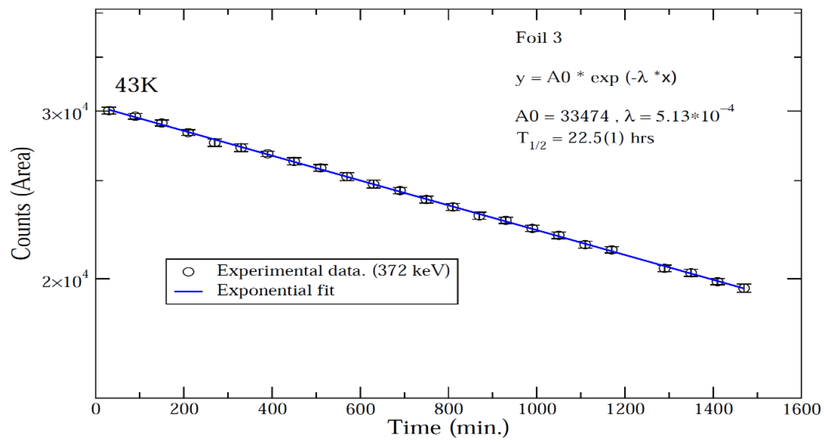


Fig.4.2.2: The decay curve of the intensity of the 372-keV gamma ray from the decay of ^{43}K. The blue line corresponds to the half-life fit. The data are from the single-crystal HPGe detector.

Detailed analysis of both the TAGS and HRS data are in progress.

5.0 Work Related to CERN n_ToF collaboration.

Two BARC scientific officers, Dr. P. C. Rout and Dr. Rajeev Kumar were deputed to CERN n_ToF facility from October 01 to October 16, 2015. The deputed scientists participated in various experiments during the visit to address problems pertaining to nuclear astrophysics and measurement of nuclear fission from ^{235}U and ^{237}Np for neutron energies beyond 15MeV. Some of the experiments are explained briefly.

5.1 Experimental area (EAR-1):

5.1.1- Measurement of neutron capture cross section in ^{76}Ge

The capture gamma rays were measured using C6D6 detector setup and the blank frame measurement was made for background subtraction. The calibration was made with Am-Be and *Cm-C* sources with no beam on target. The measurement with C and Au samples were also made.

5.1.2-Scintilator test using Polyethylene target

A plastic scintillator set up consists of 6 detectors of different thicknesses 0.1, 1, 3, 5 cm and 5cmx5cm cross section coupled to fast PMTs. The detectors are stacked in dE and various E telescope configuration to measure to the recoil protons up to few hundreds of MeV from Polyethylene target using digital DAQ system.

5.1.3- Measurement of (n,f) cross-section of ^{237}Np with the PPAC setup to solve the discrepancies in the MeV region and beyond

The setup consists of 10 Parallel Plate Avalanche Counters (PPAC) and 9 targets, both tilted by 45° with respect to the neutron beam in order to cover the full angular range from 0° to 90°. The fission fragments are detected in coincidence by the two PPACs surrounding each target, so the trajectories can be reconstructed and the emission angle with respect to the beam can be obtained.

There are five 237Np targets with 0.7 μm Aluminium backing as main targets and two 235U and two 238U targets were used for normalization. The data was recorded using a 51 channel digital DAQ system based on SP devices.

5.2 Experimental area (EAR-2):

5.2.1- Measurement of ^{7}Be (n,p) cross section

The measurement was carried out pertaining to the 7Li abundance problems. The experiment was carried out in (EAR-2).

5.2.2- Si detector testing

The Si strip detector made in Edinburgh was tested in beam using LiF (100 mg/cm2) sample. The signals from the reaction are recorded using digital DAQ system. The background measurement was made for 12 hours with empty sample.

5.2.3- Measurement of capture gamma rays in coincidence with Fission Fragments from ^{235}U

A setup consists with two MCP, two MWPC and 12 NaI (Tl) detectors was installed in the EAR-2. The setup was used to measure the gamma rays in the resonance region in coincidence with the fission fragments. A 62 channels digital DAQ was used for this measurement. The detector system was calibrated using the Cf source.

6.0 Measurements of neutron capture cross-section on 70Zn at 0.93 and 1.66 MeV using 7Li(p,n)7Be neutron source.

The work was carried out by the group led by Dr. B. Lalremruata**,** Department of Physics, Mizoram University (Central University), Tanhril-796004, Aizawl, Mizoram, India under NDPCI/BRNS project sanction number 2012/36/17-BRNS dated 14.8.2012.The zinc absorption data is important for reactor applications as well as for nuclear astrophysics. It is a candidate for dosimetry reactions to study deviation of the epithermal reactor neutron spectrum from 1/E distribution. There was no experimental results between the upper boundary of the resolved region and 10 MeV. The purpose of this work was to report new ^{70}Zn(n,γ)^{71}Zn^{m} (3.96± 0.05 hrs) cross sections experimentally determined at incident neutron spectrum averaged energies of 0.93 and 1.66 MeV to achieve improvement in our knowledge of this capture reaction in the MeV region. The Neutron flux energy spectrum from the 7Li (p,n)7Be reaction at incident proton energy 2.8 MeV and 3.5 MeV as

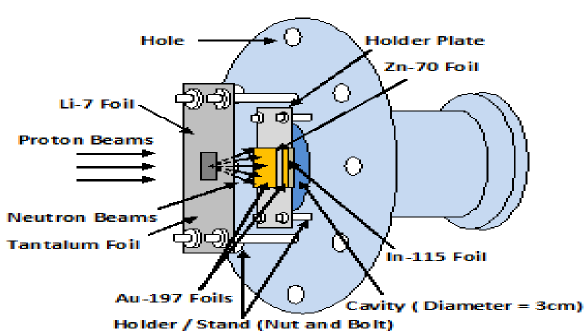


Fig 6.0.1 The schematic diagram of experimental setup

obtained from the code EPEN. (The maximum neutron emission angle in laboratory frame is 35 degree) is depicted in figure 6.0.2 and figure 6.0.3 respectively.

The typical γ –ray spectrum of some nuclides at average energy 1.66 MeV is depicted in figure 6.0.2

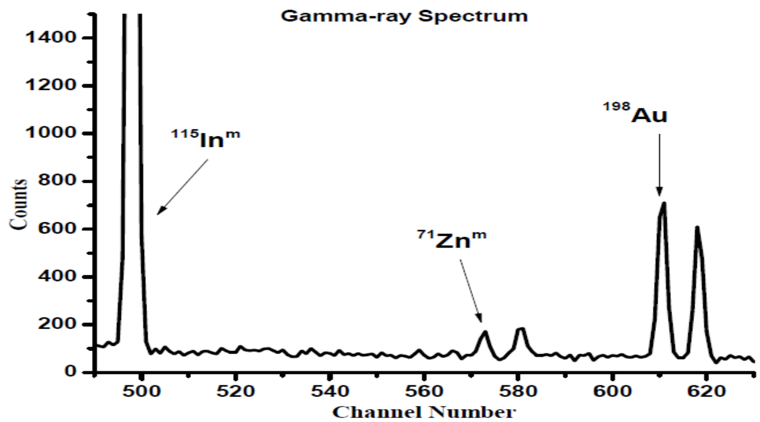


Figure 6.0.2: Typical gamma ray spectrum of radioactive nuclei 115Inm, 71Znm and 198Au at <En>=1.66 MeV

6.1 . Excitation functions of the 70Zn(n,γ)71Znm cross sections

The Comparison of the present measured spectrum averaged cross sections with the cross sections for mono energetic neutrons predicted by TALYS-1.6 with various level density models (LD) and TENDL-2014 has been compared and has been found to be in reasonable agreement. The detailed analysis is being done and a journal article is being written.

7.0 Development of 7Li(p,n)7Be neutron energy spectrum code (Dr. B. Lalremruata et.al)

At low energy regions, the 7Li (p,n)7Be reaction has long been used as a source of neutrons. The threshold energy of the reaction is 1.884 MeV and the Q-value is -1.644 MeV. To accurately determine the neutron induced cross sections using 7Li(p,n)7Be reaction as neutron source, it is crucial to produce reliable neutron energy spectrum. A highly specialized program EPEN – Energy of Proton Energy of Neutron is developed. EPEN produces reliable neutron energy spectrum for different sample-target combinations and for proton energies ranging from threshold to 4MeV.

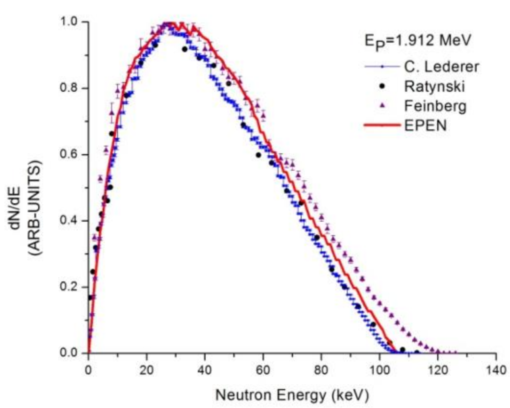


Fig.7.0 Neutron energy spectra from the code EPEN at 1.912MeV

The code is written using C++ programming and it consists of more that 10,000 lines. The lithium target is divided into a number of equal layers (2micron). Protons that pass through the target are slowed down due to loss of energy in each layer. Evaluated neutron yields are available for proton energies that pass through each layer of the Lithium target. For proton energies between 1.95 and 4MeV, the evaluated data compiled by Liskien and Paulsen was used. Below 1.92MeV, the neutron production is double-valued therefore, the formula by Lee and Zhou has been used.

EPEN result is compared with the experimentally measured neutron spectrum by C. Lederer et. al., Ratynski et. al. and Feinberg et. al. for 7Li(p,n)7Be at proton energy of 1.912 MeV and the result of the comparison is shown in Fig.7.0.

7.0 Work by Shillong group under NDPCI

The experiments were carried out by two JRF's viz. Ms. Reetuparna Ghosh and Ms. Sylvia carried under the guidance of Dr. B. Jyrwa, Dr H.Naik and Dr S. Ganesan. They performed neutron activation experiments using the 7Li (p,n) source at FOTIA, BARC and TIFR, Mumbai, India The irradiations carried out at FOTIA and TIFR were at proton energy of 3 MeV-6 MeV The mono-energetic neutrons of 1.12 MeV-4.12 MeV were generated from 7Li (p,n) reaction using proton energies of 3-6MeVThe samples irradiated in FOTIA include oxides of Europium and structural material, i.e., Zirconium. Also Indium , Gold and Cd metal foil were irradiated. 197 Au(n,g)198Au reaction cross section was used as neutron flux monitor .The following reactions cross section measurements was determined using activation and off line gamma-ray spectrometric technique:

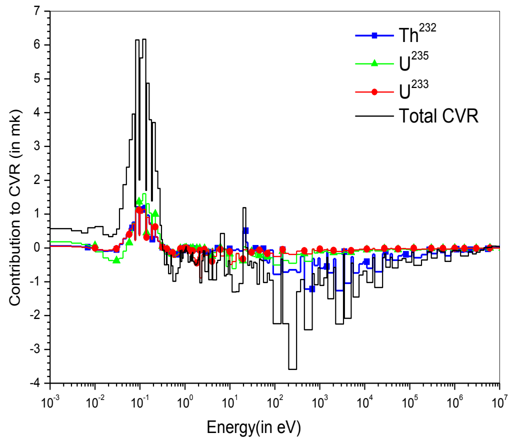
a) 151Eu(n,g)152Eu.
b) 110Cd(n,g)111mCd and 111Cd(n,n')111mCd.
c) 96Zr(n,g)97Zr
d) 94Zr(n,g)95Zr
e) 61Ni(p,n)61Cu.
f) 58Fe(p,n)58Co.
g) 100Mo(n,2n)99Mo

Following is the list of publication made out of these experimental work

1. Reetuparna Ghosh et al (2016) "Determination of 110Cd(n,g)111mCd and 111Cd(n,n')111mCd reaction cross-sections at the neutron energies of 1.12–4.12 MeV", Journal of Radioanalytical Nucl. Chem 307:1481-1487
2. Sylvia Badwar et al (2016), "151Eu(n,g)152mEu reaction cross-section measurement at the neutron energies of 1.12, 2.12, 3.12 and 4.12 MeV" Journal of Radioanalytical Nucl. Chem , 307: 1385-1390 .
3. B.Jyrwa et al (2014), "Calculation of excitation functions of the 54,56,57,58 Fe(p,n) reaction from threshold to 30 MeV" Pramana, 83:545-555
4. B.Jyrwa et al (2015), "Study of Excitation functions of (p,p) reactions for Fe-56 and Fe-57 target from the threshold to 30MeV", Journal Of Nuclear Physics, Material Sciences, Radiation and Applications 3:5-11

8.0 Study of Nuclear Data sensitivity in AHWR design

The normalized reaction rate approach by Ganda and Greenspan have been used to determine the energy wise isotopic contribution of thorium, plutonium, uranium and other isotopes to coolant void reactivity (CVR) and fuel temperature reactivity (FTR) in each of the 172 energy groups. It has been observed that hydrogen is a large positive contributor in the thermal range whereas Th^{232} is a large negative contributor to CVR. In AHWR-LEU Th^{232} is major contributor to FTR than U^{238} .because of larger volume fraction in the fuel material.



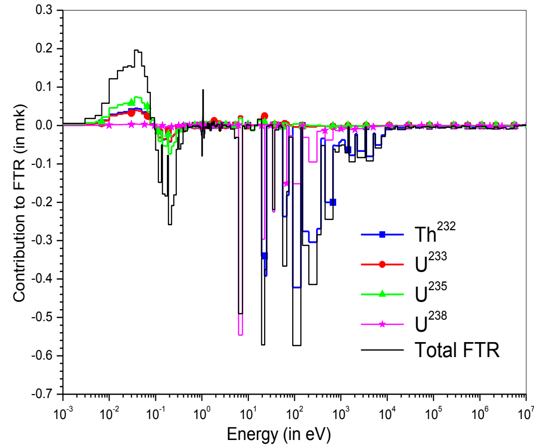


Fig 8.0.1 & 8.0.2 Energy dependent isotopic contributions to CVR and to FTR

9.0 Fission product mass yield distribution for Thorium and Uranium at quasi mono energetic neutron energies of 9.35MeV and 12.52 MeV

Experiments were carried out at BARC-TIFR Pelletron facility at 6 M height direct beam line.

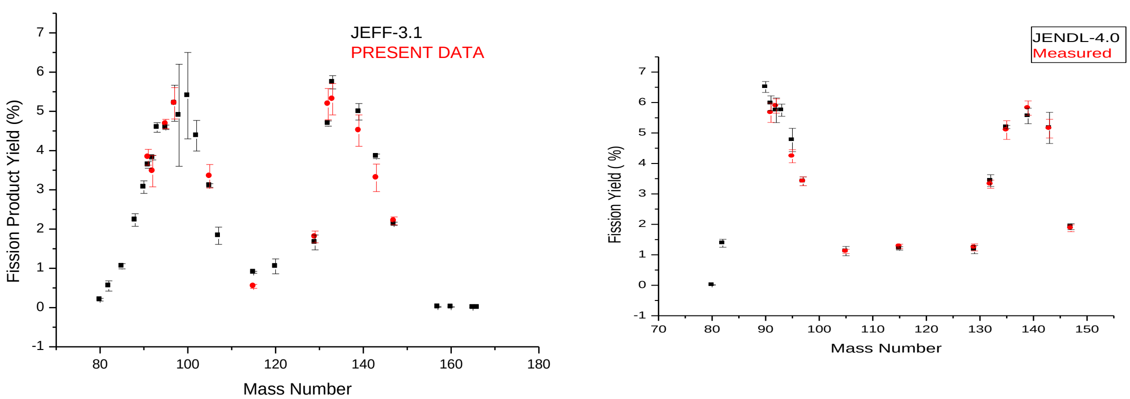


Fig 9.0 Fission yield of fission products for $^{238}U(n,f)$ at En = 12.52 MeV
(Compared to 14 1MeV values taken from JEFF-3.1 and JENDL 4.0)

The results have been published in following publications:

1. “Measurement of fission products yields in the quasi-mono-energetic neutron-induced fission of 232Th” H. Naik, Sadhana Mukherji, S. V. Suryanarayana, K. C. Jagadeesan, S. V. Thakare , S .C. Sharma; Nuclear Physics A 952 (2016) 100–120
2. “Measurement of fission product yields in the quasi-mono-energetic neutron-induced fission of 238U” H. Naik, Sadhana Mukerji, Rita Crasta, S. V. Suryanarayana, S. C. Sharma, A. Goswami Nuclear Physics A 941 (2015) 16-37