P2014-01

A BRIEF STATUS UPDATE ON THE ACTIVITIES OF NUCLEAR DATA PHYSICS CENTRE OF INDIA (NDPCI) DURING 2012-2014

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Introduction

The NDPCI has been successful in pursuing all aspects of nuclear data viz, measurements, analysis, compilation and evaluation involving national laboratories and universities in India. As the youngest member, the NDPCI joined NRDC as a full member in September, 2008. NDPCI with the help from IAEA-NDS is responsible for all EXFOR compilations in India and is making a steady progress to meet and carry out its objectives in many thrust areas. Our scientists are involved in nuclear data measurements using pelletron/Folded Tandem Ion accelerator facility. They have carried out a number of cross-section studies using 7Li(p,n) reaction as mono-energetic neutron source, surrogate technique for unstable targets and also using reactors. They have also used 14 MeV neutron generator both at Pune university and at Purnima, BARC for cross-section measurement. Our scientists have also used electron accelerators at Khargarh and Pohang for photon induced cross-section studies. BARC has a formal MOU with CERN where our scientists have participated in n_TOF experiments on cross-sections relevant to nuclear applications. Our scientists have also carried out extensive measurements of charged particle induced reactions, the results are reported in the symposium proceedings of DAE symposium of nuclear Physics. They have used surrogate technique to measure fission cross-sections for many actinide nuclei where direct measurements were not possible. Our scientists have carried out measurement of prompt neutron spectra in neutron induced fission reaction for ^{238}U under CRP of IAEA. Variable Energy Cyclotron, Kolkata is setting up facility for TAGS studies for decay heat data using BaF2 detectors. Our scientists are also involved in nuclear theory and simulation related to nuclear data for AHWR, and other advanced reactors. They are also involved in criticality bench-mark studies for various reactors. NDPCI has involved some of the universities in EXFOR compilations and has organized a series of theme meetings on EXFOR compilations. NDPCI has also organized a meeting on nuclear data evaluations and a meeting on covariances in nuclear data this year end. The NDPCI has awarded many projects to PIs of various universities on topics relevant to nuclear data. A brief account of NDPCI activities carried out by our researchers during 2012-2014 is described in this report.

A NUCLEAR DATA EXPERIMENTS

Surrogate reaction methods for (*n,f*) cross section determination involving unstable nuclei:

Over the past few years, surrogate methods have emerged as an effective means of indirectly measuring neutron-induced fission cross sections for unstable nuclei which would otherwise be difficult or even impossible to measure directly due to requirement of radioactive target and high neutron flux. These methods have important applications, in determining neutron-induced fission cross sections associated with unstable minor actinide isotopes relevant to fast neutron reactors and incineration studies in ADSS. Recently, experimental group at Nuclear Physics Division have formulated a new surrogate method known as ''hybrid surrogate ratio method'', which has been employed by them to determine ^{233}Pa(n, f) cross-section of interest in Th-U fuel cycle for fast neutrons for the first time. This result is very important because of the primary reaction of importance in the thorium cycle. As a continuation, another experiment has been carried out ^{241}Pu(*n,f*) cross section measurements at BARC-TIFR Pelletron facility, Mumbai by surrogate method employing ^{238}U(^{6}*Li,df*), ^{232}Th(^{6}*Li,df*) reactions, where the half-live of ^{241}Pu is only 14.3 years. Here we have also determined ^{241}Pu(n,f) cross section in the equivalent neutron energy range 11.0 MeV to 18.0 MeV. The present ^{241}Pu(*n, f)* cross-section data are observed to be consistent with the direct measurements, suggesting the applicability of surrogate methods. The surrogate reaction method has been used to determine neutron-induced fission cross sections of the short-lived minor actinides ^{239}Np and ^{240}Np in the equivalent neutron energy range of 10.5–16.5 and 9.0–16.0 MeV, respectively. The ^{240}Np and ^{242}Pu compound nuclei are produced at similar excitation energies in ^{238}U(^{6}Li,αf)^{240}Np and ^{238}U(^{6}Li, df)^{242}Pu transfer reactions at E_{lab} = 39.6 MeV. The ^{241}Pu(*n, f*) cross sections as a function of excitation energy have been used as reference reaction in both cases. We have also measured the fission cross-section for ^{234}Pa(n,f) using hybrid surrogate ratio method. The fission barrier heights corresponding for all the reactions studied above for various isotopes in EMPIRE calculations are obtained from our barrier formula and these calculations describe the experimental results rather well. Fig. 1 shows a typical result from our study published in PHYSICAL REVIEW C **88**, 014613 (2013).

(V. V. Desai, B. K. Nayak, A. Saxena, E.T. Mirgule and S.V. Suryanarayan)

A **two day national workshop on surrogate reactions and its applications** was organized at MSU, Baroda during **24-25 Jan,2013** to involve participation of university in this area of research. B.K.NayaK, Surjit Mukjherjee and Alok Saxena acted as technical and local convener and chairman of the organizing committee respectively. There was active participation from Universities/Colleges/Institution from various parts of the Country – about 59 participants and 12 invited speakers.

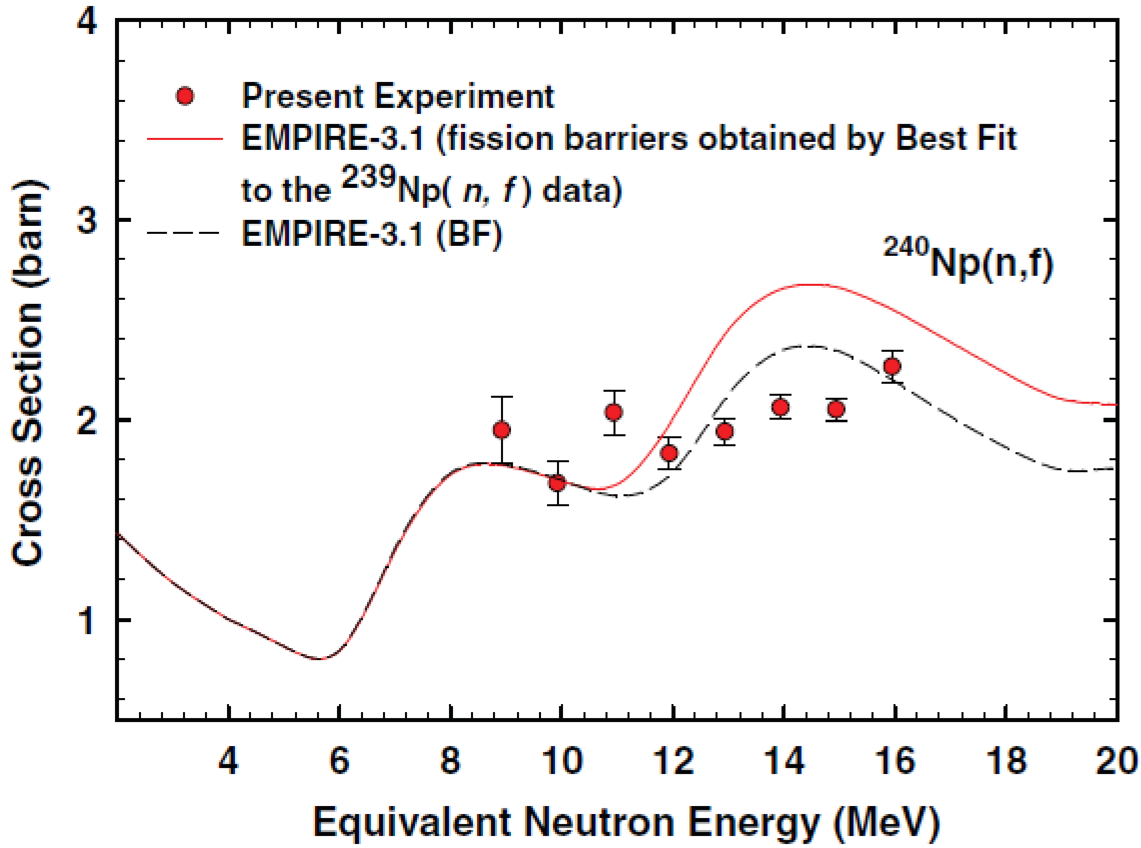


Fig. 1 : Experimental data from surrogate reaction method with EMPIRE 3.1 calculations (Phys.Rev. C **88**, 014613 (2013)).

TAGS measurement:

The Total Absorption Gamma Spectrometer which has been set up using the 50 element BaF2 detectors has been tested using different radioactive sources. The one-, two-, three- and multi-γ line sources ^{137}Cs, ^{60}Co, ^{22}Na and ^{152}Eu were used for comparison. The sum spectra for ^{60}Co and ^{152}Eu are shown in Fig 2. In a modular set up it is possible to choose different multiplicity conditions for obtaining the sum. The investigators have shown here spectra obtained with three (M ≥ 1, M ≥ 2 and M ≥ 3) different multiplicity conditions for summing. It can be seen in Fig. 2 that the intensity of the sum peak at 2.5 MeV remains almost same while there is a drastic reduction in intensity of the individual (1.17 and 1.33 MeV) peaks for M ≥ 2 and M ≥ 3. Therefore, the lines observed in the high-M gated sum spectrum can be directly considered as the energies of the levels to which most of the β-decay take place.

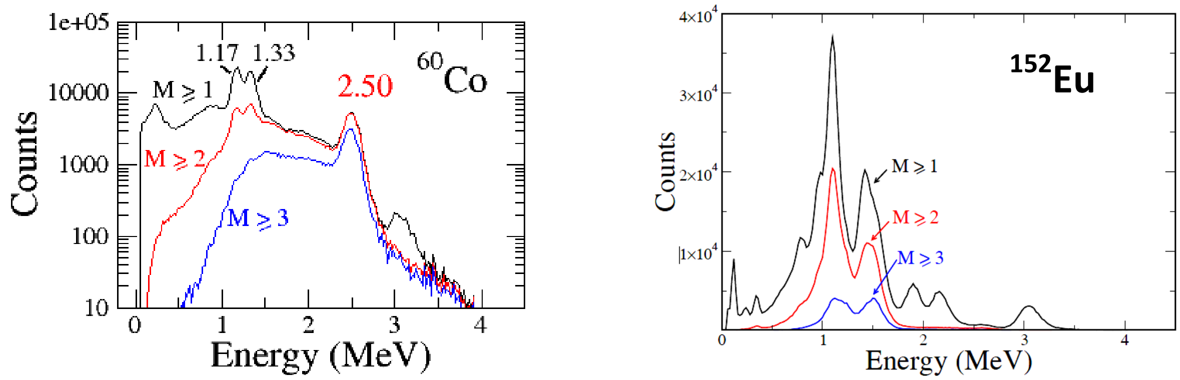


Fig. 2: The sum spectra for radioactive sources ^{60}Co (left) and ^{152}Eu (right) obtained from the TAGS set up at VECC.

The ^{152}Eu source has a complicated decay scheme with several γ-rays as observed in Fig. 2 (right) for M ≥ 1 but at higher multiplicity condition, many of these peaks disappear and only three peaks are seen at 1.1, 1.3 and 1.5 MeV energies. These correspond to the energy of the levels of the daughter nuclei to which maximum β-feeding take place for ^{152}Eu. The setup and the results have been presented in the International Nuclear Physics Conference in Italy (2 – 7 June, 2013).
(*G. Mukherjee, S.R. Banerjee, S. Mukhopadhyay, D. Pandit, S. Pal and B. Dey*)

Measurement of fast neutron radiative capture cross sections for ^{70}Zn(n,γ)^{71}Znm reaction using isotopically enriched ^{70}Zn isotope in the incident neutron energy range 0.3 - 1.5 MeV

The radiative neutron capture cross section is important both for reactor physics applications as well as for nuclear astrophysics. The cross section for the ^{70}Zn(n,γ)^{71}Zn^{m} has not been measured in the past for the energy range above 25 keV. Here, the neutron radiative capture cross section of ^{70}Zn has been measured using ^{7}Li(p,n)^{7}Be neutron source with the lithium thickness 2 mg/cm2. The activation technique is used and the cross section is measured relative to the reactions ^{197}Au(n,γ)^{198}Au and ^{115}In(n,n')^{115}In^{m}. Experiment has been performed at the FOTIA accelerator at BARC, India, employing stacked foil activation technique. The ^{70}Zn(ENR = 72.4%) is sandwiched between Gold foils. Proton beam energies of 2.25 MeV, 2.6 MeV, 2.8 MeV and 3.5 MeV were used for the irradiation of the stack. The ^{152}Eu source of known strength was used to determine the absolute efficiency of the detector at various gamma energies. The HPGe detector resolution is 1.8 keV. The detector is equipped with Roman lead shielding and hence the room background is negligible. The neutron energy spectra analysis are carried out using the code EPEN, the code developed by B. Lalremruata and his group. This code is designed by using evaluated data below Ep =4 MeV taken from H. Liskien and A. Paulsen and it will be made available for other users in the future. The Geant4 simulation for scattered background neutrons is being carried out. The neutron energy and angular spectra obtained from the EPEN code are generated at the Lithium target position, rather than generating the proton since the Geant4 database does not have the evaluated data of H. Liskien and A. Paulsen for the ^{7}LiLi(p,n)^{7}Be reaction.

(*L.R.Mawia Punte,B. Lalremruata,B. Satheesh,H.H. Thanga,N. Otuka,A. Saxena,S.V. Suryanarayana, B.K. Nayak, S. Ganesan,V. Desai*)

Study of neutron and photon (bremsstrahlung) induced reaction cross-sections:

A study was carried out of neutron and bremstahlung photon induced nuclear reactions of such as (n, γ), (n,2n), (γ,n) which are of importance to nuclear data applications such as reactors and radiation dosimetry and radiation therapy. The reactions studied are,

A. Measurement of neutron induced reaction cross-sections

1. (n, γ) and (n, 2n) reaction cross-section of ^{232}Th and ^{238}U at E_n= 3.7 to 17.28 MeV
2. (n, γ), (n, p) reaction cross-section of Fe, Ni, Zr i.e. ^{58}Fe(n, γ)^{59}Fe, ^{64}Ni(n, γ)^{65}Ni, ^{94}Zr (n, γ)^{95}Zr, ^{96}Zr (n, γ)^{97}Zr at E_n=0.025 eV
3. ^{54}Fe(n, p)^{54}Mn, ^{58}Ni(n, p)^{58}Co and ^{90}Zr(n, p)^{90}Y at E_n= 2.45 to 15.5 MeV

B. Measurement of photon induced reaction cross-sections

1. (n, xn) reaction cross-section of Zr, Nb and Mo i.e. ^{96}Zr((γ, n)^{95}Zr, ^{93}Nb(γ, n)^{92}Nb and ^{100}Mo(γ, n)99Mo at E γ (bremsstrahlung) =10 and 12.5 MeV. A typical result is shown below in Fig. 3 below:

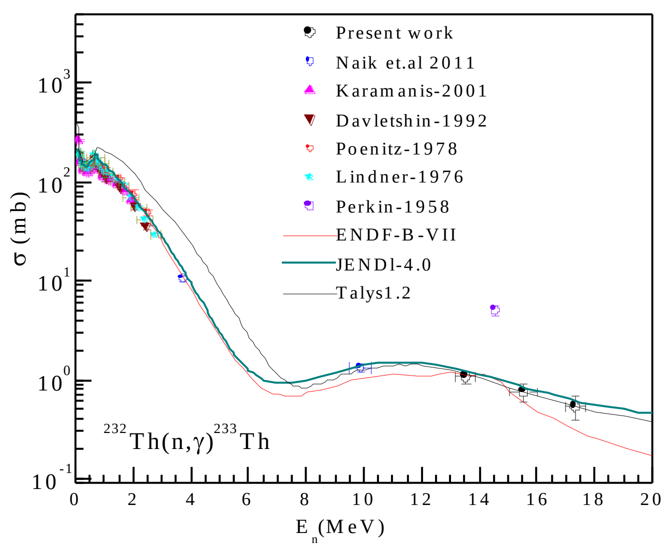


Fig. 3: Measured ^{232}Th(n, γ) cross-sections and calculations and evaluations (Pramana Vol. **79**, pp. 249–262 (2012))

These cross-sections were compared with statistical model such as EMPIRE and TALYS codes. (Sadhana Mukerji, H. Naik, S. V. Surayanarayana, et al.)

Study of production of medical isotopes and in photon induced reactions at EBC

A study was carried out to see the feasibility medical isotope production using EBC at Kharghar Navi Mumbai. The bremsstrahlung photon induced nuclear reactions and nuclear fission were also carried out using 10Me electron beam. For medical applications, the ^{238}U (γ, f) (^{99}Mo yield) and $^{nat-}$Mo(γ, n)^{99}Mo reaction for the production of medical isotopes ^{99}Mo production by using electron LINAC at Kharghar, Navi-Mumbai. The experiments were done for ^{32}S(n,p)^{32}P, ^{33}S(n,p)^{33}P and reaction cross-sections for the production of medical isotopes, ^{33}P using secondary neutrons from bremsstrahlung. In the nuclear reactions study, photo nuclear reaction cross section of structural materials such as Zr, Nb were measured for the first time, using the bremsstrahlung at EBC machine at Kharghar. The cross-sections for ^{96}Zr(γ, n) and ^{93}Nb(γ, n) reaction were measured at the end point bremsstrahlung energy of 10 and 12.5 MeV.

The radionuclide ^{99}Mo, which has a half-life of 65.94 h was produced from ^{238}U(γ, f) and ^{100}Mo(γ, n) reactions using a 10 MeV electron LINAC at EBC, Kharghar Navi-Mumbai, India. This has been investigated since the daughter product ^{99m}Tc is very important from a medical point of view and can be produced in a generator from the parent ^{99}Mo. The production of ^{99}Mo activity from ^{238}U(γ, f) and 1^{00}Mo(γ, n) reactions provides alternative routes to ^{235,238}U(n, f) and ^{98}Mo(n, γ) reactions, circumventing the need for a reactor. This work is now a part of IAEA-CRP project awarded to BARC.
(*H. Naik , S.V. Suryanarayana et al.*)

IAEA-CRP on prompt fission neutron spectra of actinide nuclei:

This IAEA-CRP is an important part in the light of our current perspectives on nuclear data physics activities in India. The BARC team in the early sixties had performed several interesting and new studies in neutron induced fission of ^{235}U. Megha helped in coding the EXFOR data of fission physics experiments done by Ramanna, Kapoor et al., into the IAEA database as part of our deliverables in this IAEA-CRP. In the nineties, the experimental work on fission physics was continued and, for instance, reported in an IAEA Meeting. As a part of our proposal to carry out prompt fission neutron spectra in fast neutron induced fission reaction we have planned a systematic study of prompt neutron energy spectrum and their multiplicities over an incident energy range of neutron from 2 to 3 MeV for ^{232}Th and ^{238}U at Folded Tandem Ion Accelerator, B.A.R.C. In order to carry out such experiments, we require well calibrated neutron detectors whose efficiency to be known well as a function of incident neutron energy. Recently we have procured twenty numbers of NE213 detectors of size 5.0 inch diameter and 2.0 inch thickness for the neutron detector array development. The detection efficiency of these detectors depends on neutron energy, the actual threshold, the size of the detector and the surrounding material near the detector system. We have carried out the efficiency characterization of NE213 neutron detectors by two different fission triggers for TOF measurements. The results for both the methods are in good agreement with each other and also with the Monte Carlo simulation. In the experiment with the neutron beam the fission ionization chamber made of G-10 material was used for fission trigger by replacing ^{252}Cf source with actinide target. The mono-energetic for the experiment are produced by $^{7}Li(p, n)^{7}Be$ reaction with proton beam from FOTIA. Prompt fission neutron spectra from ^{238}U have been measured for incident neutron energies 2.0, 2.5 and 3.0 MeV. Outgoing neutrons have been detected by EJ301 liquid organic scintillator detector. The prompt fission neutron energy spectra are then described by Maxwellian distribution function and the parameters, such as, neutron multiplicity(νn), Maxwellian temperature (TM) and average energy (<En>) have been derived from the present data and compared with the data available in the literature. The measured spectra were also compared with that available in ENDF VII.1 library as shown in Fig. 4. These results were presented in the CRP meeting for IAEA this year. Fig. 4 shows some results from this study.

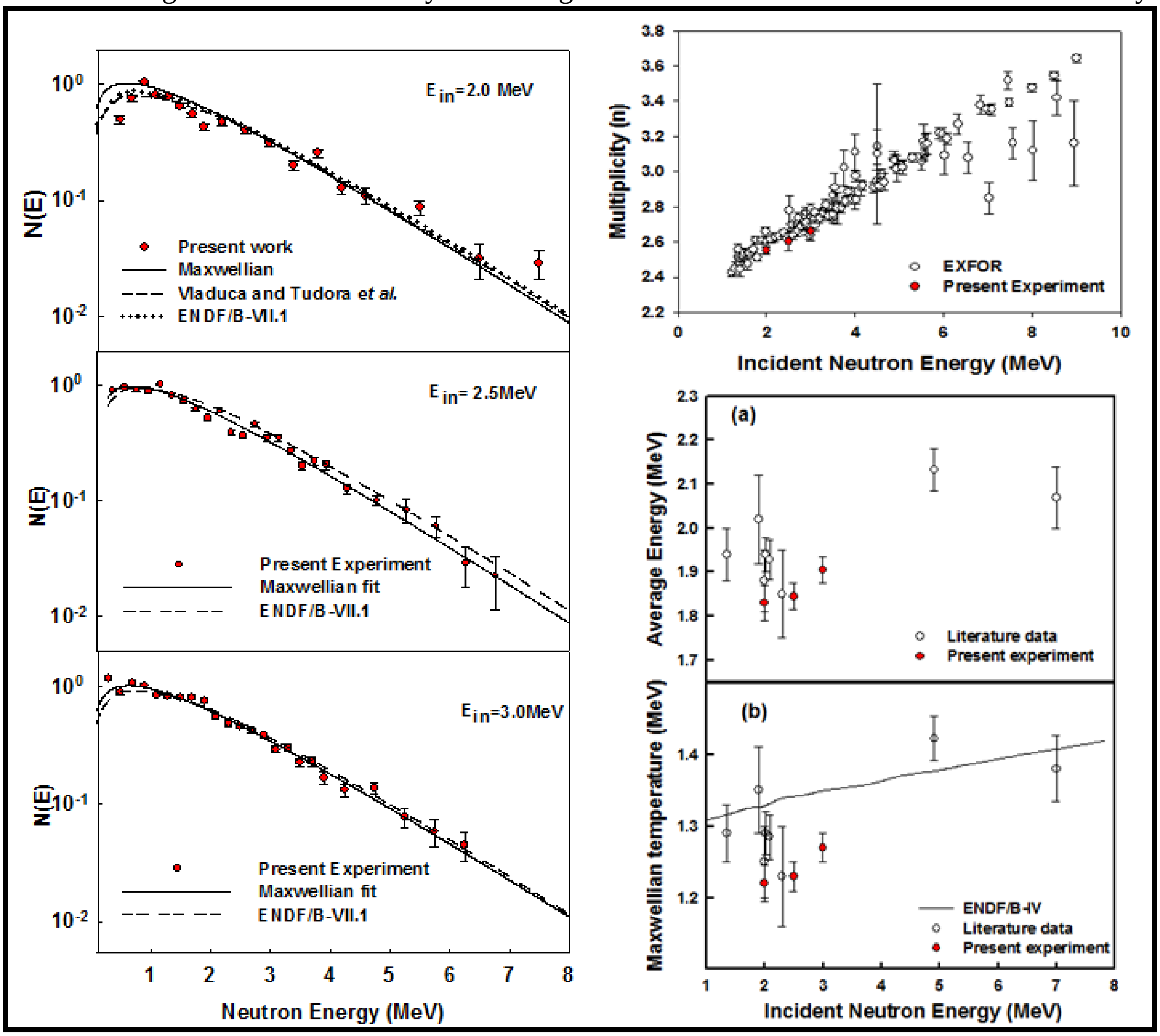


Fig.4: (Left) Prompt fission neutron spectra at 2.0, 2.5 and 3.0 MeV. (Right) (a) Average prompt fission neutron multiplicity, (b) Average energy (c) Maxwellian temperature as a function of bombarding neutron energy.

(Vishal Desai, B.K.Nayak, A.Saxena, S.V. Suryanarayana, Arun Agarwal)

Participation in CERN n_ToF Phase –II experiments:

CERN n_ToF facility is involved in measurement of nuclear data for astrophysics and ADS. Shri. Devesh Raj of RPDD took part in the n-γ data measurement of ^{54}Fe isotope during July,2010. This data has importance for s-process of stellar nucleo-synthesis. Mr. G. Pandikumar of also IGCAR participated in Oct., 2011 in CERN experiments.

In another experiment, Alok Saxena and Amod Mallick participated in Sept., 2012. The experiment involved measurement of the neutron-induced capture cross section of the fissile isotope ^{235}U using a fission tagging set-up. This new set combines the n_TOF 4π Total Absorption Calorimeter (TAC) with MicroMegas (MGAS) fission detectors. The TAC is a segmented 4pi array made of 40 BaF2 crystals forming a spherical shell of 20 cm and 50 cm inner and outer diameters, respectively. The MicroMegas (MGAS) based in the microbulk principle, is a particular ionization chamber with a volume divided in two parts by a thin micromesh. As the ionization takes place in the first part, the produced electrons are multiplied and amplified by an avalanche process in the second part. Such a combination of detectors allows distinguishing with very good reliability the electromagnetic cascades from the capture reactions from dominant gamma-ray background coming from the fission reactions. The accurate discrimination of the fission background is the main challenge in the neutron capture cross section measurements of fissile isotopes. They have taken part in this ongoing experiment and also participated in the testing of the new detectors such as LaBr3, Lacl3 and CrBr3 and plastic detectors for neutron and gamma flash sensitivity. They have also taken part in the analysis of the data using ROOT software and also got familiar with the SAMMY code used in the analysis of resonance data. This experiment will provide as well very valuable information on the distribution of energies and multiplicities of the gamma -rays emitted prompt after capture and fission reactions. S. Ganesan was deputed to attend the 4th International Thorium Energy Conference, ThEC13, at CERN, in Geneva Switzerland, October 27 to 31, 2013 where he delivered an invited talk entitled, "Nuclear Data Development Related to Th-U Fuel Cycle in India", which was well received. CERN n_TOF spokesperson Enrico Chiaveri has requested supply of target samples if available from India. He has also requested us to advise on identification of elements/isotopes which need improved resonance data experiments at CERN.

Charged particle induced reactions:

A number of experiments were carried out to study light charged particles, heavy ion induced reactions involving fusion-fission, elastic scattering, transfer reaction and nuclear structure measuring mass and angular distributions of fission fragments, neutron and charged particle multiplicity, ER cross-sections. Details about such studies can be found in the **Proceedings of Nuclear Physics Symposium for 2012 and 2013 in Volume 57 and 58** and are available online at http://sympnp.org .

Theoretical Simulation of Induced Activity and Production Cross-section of Radio nuclides in Neutron and Charged Particle Induced Reactions

Neutron induced reaction cross-sections for the production of radio nuclides with intermediate to long half-lives produced in 1-200 MeV neutron induced reactions were calculated using the computer codes EMPIRE-2.19, ALICE-91 & TALYS-1.0. The target elements chosen for the purpose are the common constituent materials and experimental targets in reactor & accelerator facilities like Al, Fe, Cu, Ni, Ge, Ta, Au, along with preferred targets for Accelerator Driven Sub critical Systems (ADSS), e.g., W, Hg, Bi & Pb for the production of long-lived radioisotopes on the basis of their half-lives & abundances. The computed excitation functions of intermediate mass range element Fe-54 for the Fe-54 (n,2n) Fe-53 reaction using TALYS, EMPIRE1, EMPIRE2 and EMPIRE3 codes are giving good agreement with the experimental data available (Fig. 5).

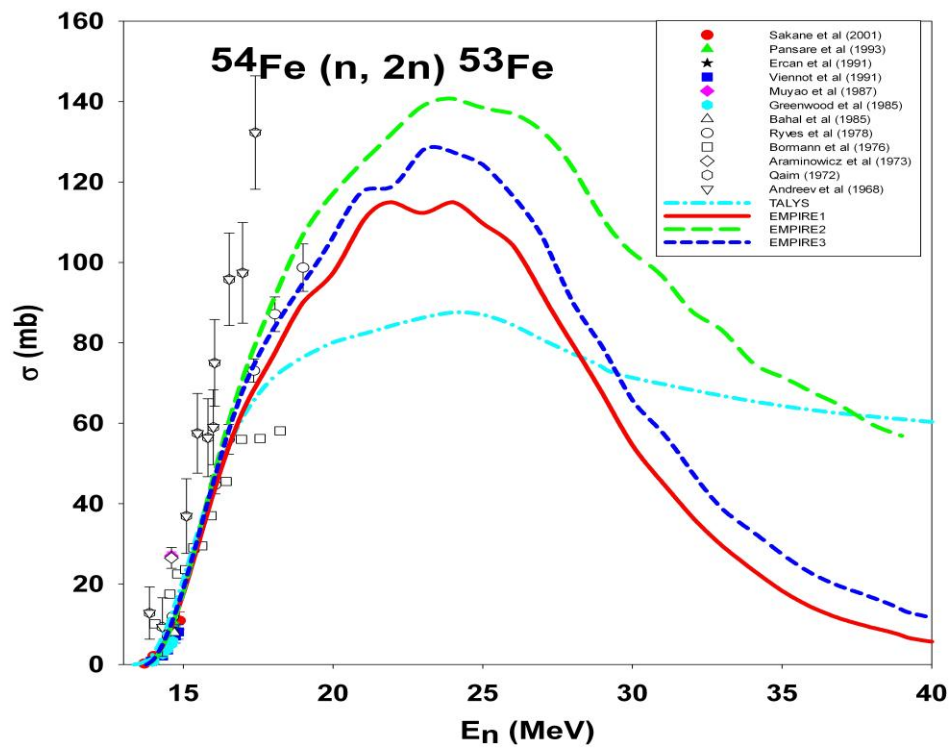


Fig. 5: Comparison of experimental data with various model calculations

(*Sneh Lata Goel, Maitreyee Nandy, P. K. Sarkar, Prabhat Saran*)

Study for the identification of energy regions for maximising the fertile-to-fissile conversion in thorium fuel

A computer code has been developed to solve the nuclide chain for the thorium fuel cycle. The actinide depletion and formation equations are modelled with continuous energy nuclear data. This code is used to estimate the variation of conversion of pure ^{232}Th sample into fissile ^{233}U as a function of neutron energy. Point cross section data sets have been taken from the basic evaluated nuclear data file (ENDF/B-VII.1) for each isotope studied. The potential energy regions, where enhanced breeding can be obtained have been determined.
(Anek Kumar, Umasankari Kannan, S, Ganesan, and P.D. Krishnani)

Development of the code for retrieving the point wise nuclear physics data for use in Monte Carlo codes

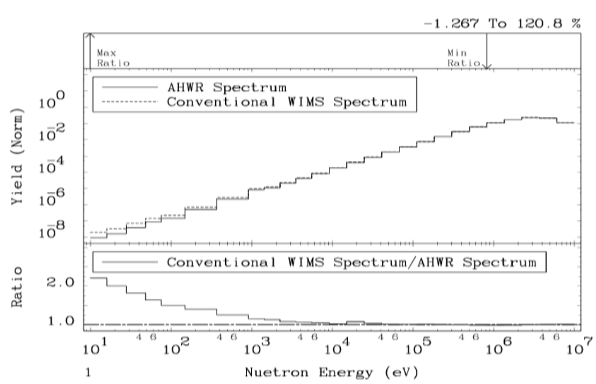
The detailed pointwise nuclear data which is required for Monte Carlo calculation are kept in individual tables that are often organized into libraries in the ACE (A Compact ENDF) format. A FORTRAN subroutine is developed to understand the ACE format and extract the required nuclear data which are stored in the ACE formatted Type 1 library. The same subroutine is used in developed Monte Carlo neutron transport code (M3C).
(Anek Kumar, Umasqnkqri Kannan, S, Ganesan, and P.D. Krishnani)

Development of a continuous energy general geometry Monte Carlo code for reactor physics calculation (M3C code)

A continuous energy general geometry Monte Carlo code (M3C code, Monte Carlo Criticality Calculation code) has been developed from scratch which has many advanced features like unionized energy grid approach, explicit sampling of delayed-neutron spectrum, probability table treatment in unresolved resonance range and thermal treatment for light nuclides. The code has been validated by analysing various theoretical benchmarks. It has also been used to simulate AHWR and PHWR lattices. An additional capability of handling the randomly dispersed fuel Particles in a definite volume has been incorporated. This code uses the ACE formatted nuclear data file for the neutron interaction data.
(Anek Kumar and P.D. Krishnani)

Implementation of unionized energy grid method in the Monte Carlo code, M3C

A considerable speed-up in continuous-energy Monte Carlo neutron transport calculation has been achieved by using the same unionized energy grid for all point-wise reaction cross sections. To reduce the quantity of energy grid search and cross section interpolation, a method using unionized energy grid was proposed. The key idea of which is to merge the grids of all nuclides into an unionized energy grid upon which all cross sections are reconstructed including the material macroscopic total cross sections for rapid calculation of neutron mean free path. In this way, the grid search and interpolation factor calculation is performed only once at each energy. This method has been successfully implemented in the M3C code.
(Anek Kumar and S. Ganesan)



Fission spectrum for Thorium fuel cycle

The fission spectrum as given in the multi-group library of WIMS Library Update Project (WLUP) are based in U-Pu systems and is computed with weights of 54%, 8% and 38% for ^{235}U, ^{238}U and ^{239}Pu respectively. This has been modified for AHWR using the thorium fuel cycle has been computed by averaging over isotopes spectra of ^{233}U**,** ^{239}Pu and ^{241}Pu with weights 65%, 27% and 8%, Respectively (See Fig. 6)

(Anek Kumar and S. Ganesan)

Fig. 6: Plot of the revised fission spectrum w.r.t to the original used in WIMSD library

Uncertainty analysis for AHWR-LEU fuel

A sensitivity study has been done with respect to nuclear data set, modeling uncertainties and manufacturing tolerances such fuel density and enrichments, dimensions etc. has been undertaken for AHWR-LEU fuel. The effect of these uncertainties on the design margins has been quantified (See Fig. 7).

The results of this study are :

- Sensitivity to multi-group nuclear dataset introduces about ~10% in calculated Coolant Void Reactivity (CVR) and 4% in Fuel Temperature Coefficient of reactivity
- Modelling uncertainty w.r.t to discretisation in the number of energy groups was done. Increase of neutron energy groups from 69 to 172 simulations gives 25% deviations in CVR,
- Uncertainties in fuel pellet properties like pellet diameter gives a maximum of about ~11% in the calculated safety parameters.
- Manufacturing tolerances such as fuel density and enrichments accounts for a maximum of 7% in the coefficients.

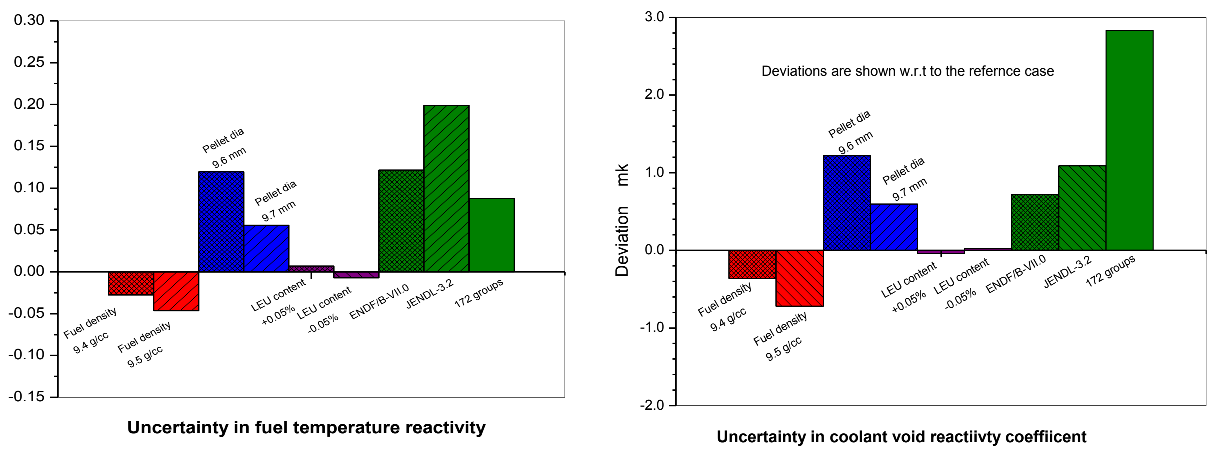


Fig. 7: Uncertainty quantification due to different nuclear datasets

(Umasankari Kannan, Anek Kumar, Neelima Prasad Pushpam, and P.D. Krishnani)

Generation of Spectrum averaged cross sections for Fission Product Noble Gases for failed fuel detection in AHWR-LEU core

^{133}Xe, ^{135}Xe, ^{137}Xe, ^{138}Xe, ^{85m}Kr, ^{85}Kr, ^{87}Kr, ^{88}Kr, ^{89}Kr are used for fission product monitoring.

As they do not have major reactivity contribution, thus they are not treated in the regular multi-group WIMS-D libraries. A methodology has been developed to calculate the capture rates from first principles from the PREPRO code system. This involved :

- Basic data from ENDF/B-VII.1 and TENDL–2011 is acquired and processed – *LINEAR, RECENT, SIGMA1*.
- AHWR spectrum calculated from lattice simulations are used in *GROUPIE* module

- One group spectrum averaged cross section calculated from *GROUPIE*.
- An example for Kr-88 is shown in the Fig. 8.

(Anindita Sarkar, Umasankari Kannan, B.Krishna Mohan)

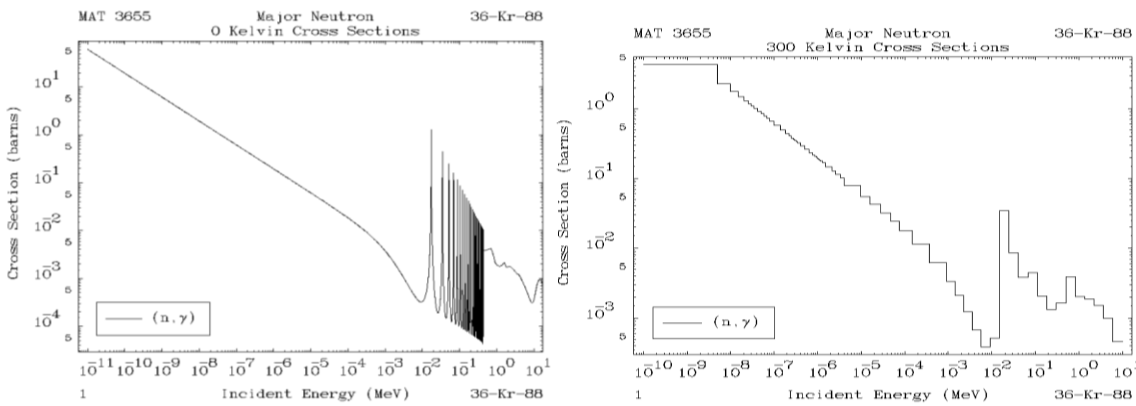


Fig 8: ^{88}Kr – processing to 69 group data and further to one group using AHWR-LEU spectrum with PREPRO code system

Cross section data for point reactor fuel cycle code

The cross section data sets for AHWR and PHWR has been obtained using ENDF/B-VII.0 data available in 172 group WIMSD format and lattice codes WIMSD and ITRAN. The cross section has been obtained by flux and volume weighting of microscopic cross section for each isotope and for each material after a detailed lattice calculation. The burnup dependent one-group cross sections have been obtained by appropriate spectrum weighting. Some of the cross section processed fro for AHWR-LEU fuel to be used in fuel cycle code is shown in table below.

Table 1 One-group-cross sections using AHWR spectrum for some actinides

AHWR-Th-LEU fuel cluster (54 pin cluster 12/18/24 pins with 30%/ 24% and 16% LEU respectively)				
MWD/Gm-Atom		0	13.16	24.44
	n,g (Capture)	1.301	1.462	1.54
U^{232}	n,g (Capture)	10.857	12.104	12.654
U^{235}	n,g (Capture)	12.529	14.733	15.676
U^{235}	n,f (Fission)	58.034	70.764	76.392
U^{238}	n,g (Capture)	1.737	1.76	1.791

(Devesh Raj, P.D.Krishnan and, Umasankari Kannan)

C EXFOR COMPILATIONS

.

The **5th Indian EXFOR workshop** was successfully organized by Department of Physics Banaras Hindu University Varanasi during **February 18-22, 2013**, in continuation of earlier four EXFOR training workshops in BARC, Mumbai (2006, 2007), University of Rajasthan, Jaipur (2008) and Panjab University Chandigarh (2011). A vast group of participants from every part of India, including experimental nuclear scientists, University faculty, Ph.D and M.Sc students took active part and got a first time exposure to a classical nuclear data physics activity of EXFOR compilation culture. The total number of participants in the 5th EXFOR workshop was fifty participants including one from the IAEA, Vienna, Austria, one from RFNC-VNIIEF, Russia, and rest from the different parts of India. The identification for coding into EXFOR of all the suitable Indian articles published in the literature was done in consultation with and by the IAEA-NDS staff. In this workshop, 40 new entries of important Indian data which were missing in EXFOR were compiled during the workshop, which is a remarkable achievement. The data compiled at the workshop were entered into the database through NDS after the usual and final checking procedures done at NDS. These entries were submitted to Alok Saxena and S. Dunaeva after removing the errors in it who gave their comments and suggestions to the participant. S. Dunaeva spent about a week, as a visiting scientist, at BARC, Mumbai after the BHU theme meeting to finalize the entries before they were sent for approval from authors and finally submitted to the IAEA data base. Alok Saxena was technical convener for this theme meeting, whereas Ajay Tyagi and P.D. Krishnani were local convener and Chairman of the organizing committee. This process is continuing even after the workshop as many scientists and students are following up the EXFOR compilation activities after BHU meeting. A group photo of the participants is given below:

Photograph-2: Group Photo of participants in the 5^{th} DAE-BRNS theme meeting on EXFOR compilation, BHU, Varanasi, India, from 18-22 Feb'2013.

We have been invited to host **AASPP-5** meeting **on Asian nuclear reaction database development** in India. It is proposed to be held in Anushaktinagar, Mumbai during **Sept. 22-24, 2014**. The proposal to host this workshop has got the approval of our department.

A DAE-BRNS project with B. Lalremruata from Mizoram university as principal investigator is already in progress which includes EXFOR compilation in addition to nuclear data measurements and evaluation. We have evolved a mechanism to coordinate the EXFOR compilation activities with IAEA-NDS through Mizroam University. Approximately 264 entries have been compiled through such efforts and Fig. 9

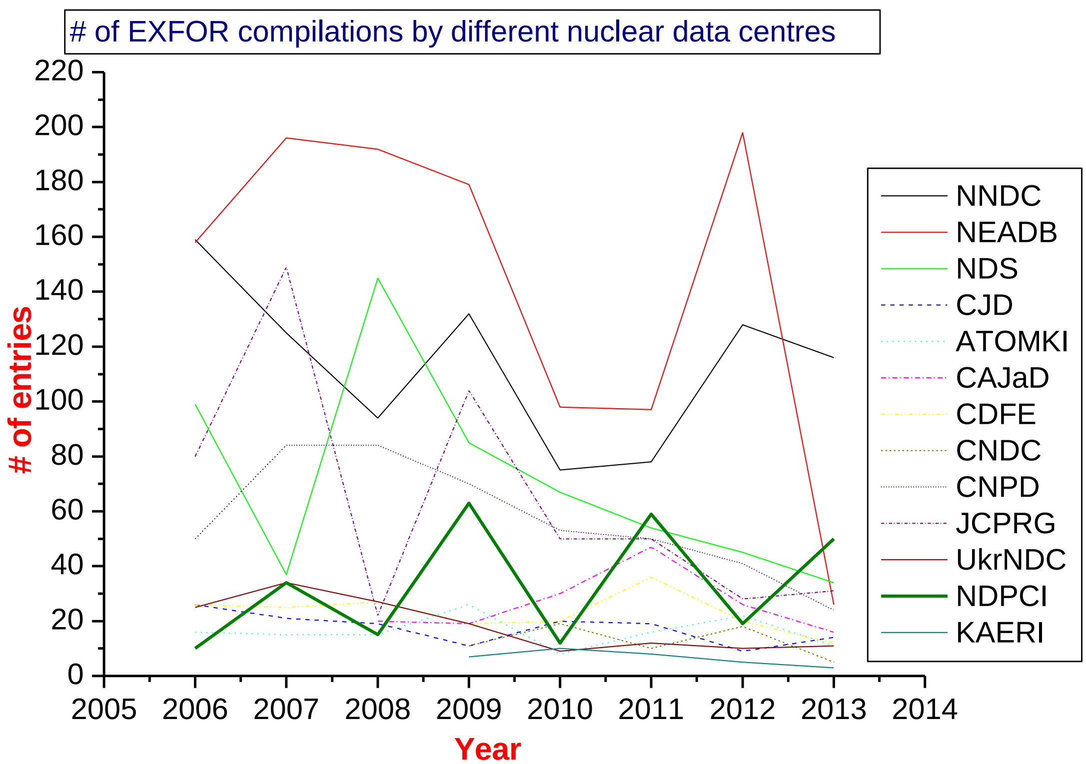


Fig. 9 Comparison of Entries by NDPCI with those by other centres of NRDC.

shows a comparison of entries by NDPCI group with those of other centres of NRDC and it shows that Indian efforts stand out well in comparison with other well established centres. One can see the EXFOR Entries prepared by Indian Compilers at the following website: http://www-nds.iaea.org/nrdc/india/

During 2013, we have started the process of rechecking the previous workshop entries submitted, for which entered data are the digitized values, in terms of their accuracy and the way they are represented. Under this process, we have identified 45 entries which require redigitization and Rema is coordinating this activity. Under the rechecking/redigitization process of previous entries, we have submitted three entries to NDS-IAEA where we replaced the existing entries with the new values. Such updated entries are D6024, D6042 and D6043. In fact, for D6042 entry, we received numerical data from the author and the existing digitized values are replaced by the numerical data. Redigitization is being carried out for the remaining 42 entries. Since compilations have been completed for all articles published upto 2012, we keep all papers published in 2013 and 2014 to be compiled in the upcoming workshop on EXFOR compilation and for that, collection of numerical data for those articles are being done. EXFOR compilation has also been carried out at VECC in collaboration with the Visva Bharati University, Santiniketan and several entries have been made as part of NDPCI project on EXFOR. Apart from these entries, redigitizations of several data sets and numerical data for several data sets for which digitization were used have been re-entered in EXFOR as a part of the IAEA's initiative to improve the EXFOR data base. Vidya Thakur has been invited by NDPCI for a month in April, 2014 to work on identifying old articles missing in EXFOR and scanning of such articles. She will also carry out preparatory work for next workshop on EXFOR compilation.

Vidya Thakur has prepared a list of all journal articles which were not compiled in EXFOR database from CINDA. The identified journal articles are summarized in two tables below. Two articles are in compilation, and the other articles in the first table will be compiled by NDPCI. This work was done in collaboration with Dr. Otsuka of IAEA.

1. Data in absolute unit (to be compiled by NDPCI)

Reference	Year	Author	Quantity	Remark
J,IJP,28,396	1954	Nandi+	CS	Cross section ratio
J,IJP,30,80	1956	Saha+	CS	
J,IPA,12,640	1974	Rama Prasad+	CS	
J,JIN,31,1217	1969	Prakash+	KE	
J,JIN,34,2685	1972	Prakash+	KE	
J,JRN,82,263	1984	Nair+	FY	in compilation (33048)
J,JRN,91,291	1985	Tomar+	FY	in compilation (33049)
J,JRN,125,85	1988	Ramaswami+	FY	
J,NIM,205,145	1983	Ajitanand+	KE	
J,NP,55,127	1964	Koul.	DA	
J,NP,83,407	1966	Bharathi+	DA	
J,NP/A,133,625	1969	Ajitanand	FY	
J,NP/A,213,35	1973	Murty+	CS	Some data are in EXFOR
J,NP/A,235,307	1974	Alam+	CS	
J,NP/A,346,473	1980	Choudhury+	KE	
J,NP/A,355,13	1981	Sharma+	KE	
J,NP/A,502,307	1989	Manohar+	FY	Conf. Proc.
J,PHY,28,1011	1962	Machwe	DA	
J,PR,131,283	1963	Kapoor+	MFQ	PFNS
J,PR,166,1190	1968	Kapoor+	FY	X-ray
J,PR,177,1776	1969	Kapoor+	FY	X-ray
J,PR/C,21,1411	1980	Datta+	FY	
J,PR/C,51,3127	1995	Samant+	NU	
J,PRM,24,131	1985	Sharma+	DA	
J,PS,24,935	1981	Srinivasa Rao+	CS	

J,RCA,31,65	1982	Raghuraman+	FY	
J,RCA,35,15	1984	Srivastava+	FY	
J,RCA,46,177	1989	Bhargava+	FY	

2. Data in arbitrary unit

Reference	Year	Author	Quantity	Remark
J,PR,129,1350	1963	Ramanna+	DA	
J,IJP,30,99	1956	Patro+	CS	
J,NP,25,136	1961	Ramanna+	DA	
J,NP,27,166	1961	Kondaiah+	DA	
J,NP,41,435	1963	Sen.	DA	
J,NP,65,635	1965	Chatterjee	DA	
J,PR,133,B598	1964	Kapoor+	DA	

A 4 day workshop was organized **on covariance in nuclear data during Dec. 16-19, 2013** at Seminar Hall, Homi Bhabha National Institute, Mumbai. The talks included invited tutorials and expert lectures on covariance error matrix and its applications with reference to reactor fuel cycle. The lectures were given by faculties from Manipal University, Indian Statistical Institute, Delhi, Institute of atomic and sub atomic physics, Vienna Institute of Technology, BARC, IGCAR and NEHU, Shillong starting from basic probability distributions, statistical methods and application of covariance matrices in nuclear data. The convener and co-convener of the workshop were Alok Saxena and Sadhana Mukerjee respectively and P.D. Krishnani acted as chairman. A group photo of the participants is given below:

Group photo of participants of **DAE-BRNS Work-shop on Covariance in Nuclear Data December 16-19, 2013.**

A systematic study on the measured excitation functions, obtained from the compiled data sets in this project has been carried out and the cross-section of the evaporation residues were compared with the statistical model calculations using PACE-IV. It can be seen that the qualitative agreement is achieved between the measured and calculated ER cross-section. However, the measured data for the 4n channel of $\alpha+^{113}$In seem to fall earlier at higher energies compared to the calculated ones. The data are not available at higher energies for better comparison. Also, no data on 4n channel are available for $\alpha +^{113}$In reaction. It is therefore, suggested to obtain more experimental data on these two reactions. (G. Mukherjee et al.)

D NUCLEAR DATA EVALUATION UNDER ENSDF

A **workshop on ENSDF Evaluation** was organized between **Nov. 26 – 29, 2012** at VECC, Kolkata sponsored by Board of Research in Nuclear Science (BRNS), India with Gopal Mukherjee as Convener and Alok Saxena as Co-Convener. The topic covered were such as ENSDF Evaluation Methodology, ENSDF Policies, NSDD network Web, NuDat, bibliographic Data base and XUNDL, nuclear theory for experimentalist and evaluators experimental techniques for gamma-ray spectroscopy. The mass chain A = 215 was taken for evaluation in the workshop by the trainees mentored by senior evaluators. Balraj Singh (McMaster Univ., Canada) was the principal coordinator. Other mentors were, J.K. Tuli (NNDC, BNL, USA), D. Abriola (IAEA, Vienna, Austria), A.K. Jain (IIT, Roorkee), S.K. Basu and G. Mukherjee (VECC, Kolkata). The evaluation work was pursued after the workshop and it has been successfully completed and published in Nuclear Data Sheets (NDS vol. 114 (2013) p 2023 – 2078).

Work has been done to evaluate and update the mass chain A=211, 222 and 224. The present status of the work is as follows:

(a) The **A=211** mass chain has been published (Nuclear Data Sheets 114 (2013) 661–749). The students from NDC, IIT Roorkee and MMU Mullana contributed in this mass chain. G. Mukherjee (VECC) and Sukhjeet Singh (MMU Mullana) are among the authors. (b) In mass chain A=215 have been published (as above), two nuclides namely ^{215}Ac and ^{215}Fr are being updated. .

(c) In the **A=224** mass chain, there are total 10 nuclides and three nuclides namely ^{224}At, ^{224}Bi, ^{224}Th have been updated. Out of these three nuclides ^{224}At has been included in the ENSDF database so that the updated information for this nuclide will be incorporated in the upcoming evaluation by Audi et al. 2011AuZZ. The evaluation of ^{224}Po and ^{224}Pa is going on. We are planning to submit this evaluation by the end of July-2012. Evaluation of ^{224}U is also going on which will soon be ready for submission.

This work is being done by. A.K Jain in collaboration with S. Singh (MM Univ, Ambala) and J. Tuli (BNL).

Work has been done to evaluate and update the mass chain **A=139**. The present status of the work is as follows:

(a) There are total 16 nuclides in this mass chain and 10 nuclides namely ^{139}Nd, ^{139}Sb, ^{139}Te, ^{139}Xe, ^{139}I, ^{139}Dy, ^{139}Tb, ^{139}Gd, ^{139}Eu and ^{139}Sm has been up updated.

(b) For ^{139}Cs, the individual datasets and adopted data set have been updated. The results of Pandora are being studied for fine tuning the adopted data set.

(c) The evaluation of ^{139}Ba is also in progress and data from the latest experiment held at BARC is awaited for being included.

(d) The data on ^{139}Pm has been evaluated and a final checking of the evaluation is presently going on.
This work is being done A.K. Jain in collaboration with Paresh Joshi, S. Singh and B. Singh
.
A systematic study of Nuclear Isomers have been done by. A.K.Jain and his group based on which an Atlas of Nuclear Isomers has been prepared (a horizontal evaluation). Details of this study are as follows:
They have prepared an Atlas of all the known nuclear isomers for all the neutron an proton numbers, to highlight the extent of information in this promising and highly interesting field. The total number of nuclear isomers for the complete mass region have been found to be about 2252 including 507 nuclei having single known isomer and 559 nuclei having isomers between 2 and 5. Nuclear isomers have been found all over the nuclear chart, the largest number being near the magic numbers and gap. It was interesting to find ^{180}Ta to have the largest number (13) of isomeric states. ^{179,177}Ta, ^{152}Eu, ^{214}Rn were found to have 10 isomeric states each. A theoretical estimation of the half lives of transitions was made using the Weisskopff single particle estimates which were then compared to the experimental half lives. The number of isomers is found to be highest in the range 1 ns-100 ns. The number falls gradually with the increase in half-life of the isomeric states up to 0.1s and then a small rise being observed at 10s-103s.

Acknowledgements: The author thank all colleagues (names mentioned in various sections of the report) from various Divisions in BARC, VECC, IGCAR and Universities for useful discussions and inputs for this report. The author also gratefully acknowledges the professional interactions with Drs. S. Kailas, P.D. Krishanani, S. Ganesan, V.M. Datar and N. Otsuka.

List of Publications in 2012-14

1. Systematic study of (*n*, *p*) reaction cross sections from the reaction threshold to 20 MeV
B. Lalremruata, N. Otuka, G. J. Tambave, V. K. Mulik, B. J. Patil, S. D. Dhole, A. Saxena, S. Ganesan, and V. N. Bhoraskar
PHYSICAL REVIEW C **85**, 024624 (2012)

2. Measurement of cross section for the reactions ^{232}Th(n, γ)^{233}Th at En = 1.6, 2.2, 3.0, 3.7 MeV and ^{98}Mo(n, γ) ^{99}Mo, 186W(n, γ)187W, 115In(n, γ)116m1In, 92Mo(n, p)92mNb at E n = 3.2 MeV, Megha Bhike, B. J. Roy, A. Saxena, R. K. Choudhury and S. Ganesan, Nucl. Sci. and Eng. **170,** 1-10, (2012)

3. Measurement of ^{232}Th(n,γ) and ^{232}Th(n,2n) cross-section at neutron energies of 13.5, 15.5 and 17.28 MeV using neutron activation techniques,
Sadhana Mukerji, H Naik, S V Suryanarayana, S Chachara, B S Shivashankar, V Mulik, Rita Crasta, Sudipta Samanta, B K Nayak, A Saxena, S C Sharma, P V Bhagwat, K K Rasheed, R N Jindal, S Ganesan, A K Mohanty, A Goswami and P D Krishani
Pramana Vol. **79**, pp. 249–262 (2012)

4. Search for an effect of shell closure on nuclear dissipation via a neutron-multiplicity measurement
Varinderjit Singh, B. R. Behera', Maninder Kaur, P. Sugathan, K. S. Golda, A. Jhingan, Jhilam Sadhukhan, Davinder Siwal, S. Goyal, S. Santra, A. Kumar, R. K. Bhowmik, M. B. Chatterjee, A. Saxena**,** Santanu Pal, and S. Kailas
Phys. Rev**. C 86**, 014609 (2012)

5. Mass-yield distributions of fission products from photofission of 232Th induced by 45- and 80-MeV bremsstrahlung
H Naik; A Goswami; G N Kim, M W Lee, K S Kim, S V Suryanarayana, E A Kim, S G Shin, M-H Cho,
Phys. Rev. **C 86**, 054607 (2012)

6. Measurement of the ^{232}Th(n, γ)^{233}Th and ^{232}Th(n, 2n)^{231}Th reaction cross- sections at neutron energies of 8.04 ± 0.30 and 11.90 ± 0.35 MeV
Rita Crasta, H Naik, S V Suryanarayana, B S Shivashankar, V K Mulik, P M Prajapati, Ganesh Sanjeev, S C Sharma, P V Bhagwat, A K Mohanty, S Ganesan, A Goswami, Annals of Nuclear Energy Volume **47**, September 2012, Pages 160–165

7. Measurement of the neutron capture cross-sections of 238U using the neutron activation technique.
H. Naik, S. V. Suryanarayana, V.K. Mulik, P. M. Prajapati, B.S. Shivasankar, K. C. Jagadeesan, S. V. Thakre, D. Raj, S.C. Sharma, P.V. Bhagwat, S.D. Dhole, S. Ganesan, V.N. Bhoraskar and A. Goswami.
J. Radioanal. Nucl. Chem. **293** (2012) 469.

8. Measurement of reaction cross-sections for 64Ni(n, γ) 65Ni at En= 0.025 eV and58Ni(n,p) 58Co at En=3.7 MeV
B.S. Shivashankar, H. Naik, S. V. Suryanarayana, P.M. Prajapati, V. K. Mulik, K. C. Jagadeesan, S.V. Thakare, A.Goswami and S. Ganesan.
J. Radioanal. Nucl. Chem. **292** (2012) 745.

9. Measurement of neutron-induced reaction cross-sections in zirconium isotopes at thermal, 2.45 MeV and 9.85 MeV energies,
P. M. Prajapati, H. Naik, S. V. Suryanarayana, S. Mukherjee, B. S. Shivashankar, V. K. Mulikf, K. C. Jagdeesan, S.V. Thakre, S. C. Sharma, S. Bisnoi, T. Patel, K. K. Rasheed, S. Ganesan and A. Goswami,
Nucl. Sci. Eng 171 (2012) 78.

10. Measurement of the neutron capture cross-sections of ^{232}Th at 5.9 MeV and 15.5 MeV.
P. M. Prajapati, H. Naik, S. V. Suryanarayana, S. Mukherjee, K. C. Jagadeesan, S. C. Sharma, S. V. Thakre, K. K. Rasheed, S. Ganesan and A. Goswami,
Eur. Phys. J. A 48 (2012) 35.

11. An alternative route for the preparation of the medical isotope
99Mo from the ^{238}U(g ,f) and ^{100}Mo(g, n) reactions
H. Naik, S. V. Suryanarayana , K. C. Jagadeesan, S. V. Thakare , P. V. Joshi,

V. T. Nimje, K. C. Mittal, A. Goswami, V. Venugopal and S. Kailas
J Radioanal Nucl Chem (2012) 295 p.807–816

12. Fission Neutron Spectrum Sensitivity Study for the Case of Advanced Heavy Water Reactor, Anek Kumar and S. Ganesan
J. Nucl. Science and Engineering. Vol. 172 no. 1 Sep 2012 pp 20-32

13. Effect of N/Z in pre-scission neutron multiplicity for $^{16,18}O$ + $^{194,198}Pt$ systems
Rohit Sandal, B. R. Behera, Varinderjit Singh, Maninder Kaur, A. Kumar, G. Singh, K. P. Singh, P. Sugathan, A. Jhingan, K. S. Golda, M. B. Chatterjee, R. K. Bhowmik, Sunil Kalkal[§], D. Siwal, S. Goyal, and S. Mandal, E. Prasad, K. Mahata and A. Saxena**,** Jhilam Sadhukhan, Santanu Pal
Phys. Rev. **C 87**, 014604 (2013)

14. *Performance of the neutron time-of-flight facility n_TOF at CERN*, C Guerrero, A Tsinganis, E Berthoumieux, M Barbagallo, F Belloni, F Gunsing, C Weiß, E Chiaveri, M Calviani, V Vlachoudis, S Altstadt, S Andriamonje, J Andrzejewski, L Audouin, V Bécares, F Bečvář, J Billowes, V Boccone, D Bosnar, M Brugger, F Calviño, D Cano-Ott, C Carrapiço, F Cerutti, M Chin, N Colonna, G Cortés, MA Cortés-Giraldo, M Diakaki, C Domingo-Pardo, I Duran, R Dressler, N Dzysiuk, C Eleftheriadis, A Ferrari, K Fraval, S Ganesan, AR García, G Giubrone, K Göbel, MB Gómez-Hornillos, IF Gonçalves, E González-Romero, E Griesmayer, P Gurusamy, A Hernández-Prieto, DG Jenkins, E Jericha, Y Kadi, F Käppeler, D Karadimos, N Kivel, P Koehler, M Kokkoris, M Krtička, J Kroll, C Lampoudis, C Langer, E Leal-Cidoncha, C Lederer, H Leeb, LS Leong, R Losito, A Manousos, J Marganiec, T Martínez, C Massimi, PF Mastinu, M Mastromarco, M Meaze, E Mendoza, A Mengoni, PM Milazzo, F Mingrone, M Mirea, W Mondalaers, T Papaevangelou, C Paradela, A Pavlik, J Perkowski, A Plompen, J Praena, JM Quesada, T Rauscher, R Reifarth, A Riego, F Roman, C Rubbia, M Sabate-Gilarte, R Sarmento, A Saxena, P Schillebeeckx, S Schmidt, D Schumann, P Steinegger, G Tagliente, JL Tain, D Tarrío, L Tassan-Got, S Valenta, G Vannini, V Variale, P Vaz, A Ventura, R Versaci, MJ Vermeulen, R Vlastou, A Wallner, T Ware, M Weigand, T Wright, P Žugec, Eur. Phys. J. A (2013) 49: 27

15. Determination of 241Pu(*n*, *f*) cross sections by the surrogate-ratio method
V. V. Desai, B. K. Nayak, A. Saxena,D. C. Biswas, E. T. Mirgule, Bency John, S. Santra, Y. K. Gupta,L. S. Danu, G. K. Prajapati, B. N. Joshi, S. Mukhopadhyay, S. Kailas, P. K Pujari, A. Kumar, D. Patel, S. Mukherjee, and P. M. Prajapati
PHYSICAL REVIEW C **87**, 034604 (2013)

16. Neutron multiplicity measurements for $^{19}F+^{194,196,198}Pt$ systems to investigate the effect of shell closure on nuclear dissipation
Varinderjit Singh, B. R. Behera,*Maninder Kaur, and A. Kumar, P. Sugathan, K. S. Golda, A. Jhingan, M. B. Chatterjee, and R. K. Bhowmik, Davinder Siwal and S. Goyal, Jhilam Sadhukhan, Santanu Pal, A. Saxena, S. Santra, and S. Kailas
PHYSICAL REVIEW **C87**, 064601 (2013)

17. A new CVD diamond mosaic-detector for (n, α) cross-section measurements at the n_TOF experiment at CERN
Weiß a,b,n, E.Griesmayer a, C.Guerrero b, S.Altstadt c, J.Andrzejewski d, L.Audouin e, G. Badurek a, M.Barbagallo f, V.Bécares g, F.Bečvář h, F.Belloni i, E.Berthoumieux i,b, J. Billowes j, V.Boccone b, D.Bosnar k, M.Brugger b, M.Calviani b, F.Calviño l, D.Cano-Ott g, C. Carrapiçom, F.Cerutti b, E.Chiaveri i,b, M.Chin b, N.Colonna f, G.Cortés l, M.A.Cortés-Giraldo n, M.Diakaki o, C.Domingo-Pardo p, I.Duran q, R.Dressler r, N. Dzysiuk s, C.Eleftheriadis t, A.Ferrari b, K.Fraval i, S.Ganesan u, A.R.García g, G. Giubrone p, M.B.Gómez-Hornillos l, I.F.Gonçalvesm, E.González-Romero g, F.Gunsing i, P.Gurusamy u, A.Hernández-Prieto b,l, D.G.Jenkins v, E.Jericha a, Y.Kadi b, F.Käppeler w, D. Karadimos o, N.Kivel r, P.Koehler x, M.Kokkoris o, M.Krtička h, J.Kroll h, C.Lampoudis i, C. Langer c, E.Leal-Cidoncha q, C.Lederer c,y, H.Leeb a, L.S.Leong e, R.Losito b, A.Mallick u, A.Manousos t, J.Marganiec d, T.Martínez g, C.Massimi z, P.F.Mastinu s, M.Mastromarco f, M. Meaze f, E.Mendoza g, A.Mengoni aa, P.M.Milazzo ab, F.Mingrone z, M.Mirea ac, W.Mondalaers ad, C.Paradela q, A.Pavlik y, J.Perkowski d, A.Plompen ad, J.Praena n, J.M. Quesada n, T.Rauscher ae, R.Reifarth c, A.Riego l, M.S.Robles q, F.Roman b,ac, C. Rubbia b,af, M.Sabaté-Gilarte n, R.Sarmentom, A.Saxena u, P.Schillebeeckx ad, S. Schmidt c, D.Schumann r, G.Tagliente f, J.L.Tain p, D.Tarrío q, L.Tassan-Got e, A.Tsinganis b,o, S.Valenta h, G.Vannini z, V.Variale f, P.Vazm, A.Ventura aa, R.Versaci b, M.J. Vermeulen v, V.Vlachoudis b, R.Vlastou o, A.Wallner y, T.Warej, M.Weigand c, T.Wright j, P. Žugec k, Then
Nuclear Instruments & Methods in Physics Research A (2013), http://dx.doi.org/10.1016/j.nima.2013.07.040i

18. Determination of the ^{239}Np (n, f) and ^{240}Np (n, f) cross sections using the surrogate reaction method
V.V.Desai, B.K.Nayak, A.Saxena, E.T.Mirgule, S.V.Suryanarayana
Phys.Rev. C **88**, 014613 (2013)

19. Determination of shell correction energies at saddle point using pre-scission neutron multiplicities
K.S.Golda, A.Saxena, V.K.Mittal, K.Mahata, P.Sugathan, A.Jhingan, V.Singh, R.Sandal, S.Goyal, J.Gehlot, A.Dhal, B.R.Behera, R.K.Bhowmik, S.Kailas
Nucl.Phys. **A913**, 157 (2013)

20. Effect of N/Z in pre-scission neutron multiplicity for $^{16, 18}$O + $^{194, 198}$Pt systems
R.Sandal, B.R.Behera, V.Singh, M.Kaur, A.Kumar, G.Singh, K.P.Singh, P.Sugathan, A.Jhingan, K.S.Golda, M.B.Chatterjee, R.K.Bhowmik, S.Kalkal, D.Siwal, S.Goyal, S.Mandal, E.Prasad, K.Mahata, A.Saxena, J.Sadhukhan, S.Pal
Phys.Rev. **C 87**, 014604 (2013); Erratum Phys.Rev. C 87, 069901 (2013)

21.High-accuracy determination of the neutron flux at n_TOF
M. Barbagallo[1*], C. Guerrero[2], A. Tsinganis[2,3], D. Tarrío[4], S. Altstadt[5], S. Andriamonje[2], J. Andrzejewski[6], L. Audouin[7], V. Bécares[8], F. Bečvář[9], F. Belloni[10], E. Berthoumieux[10,2], J. Billowes[11], V. Boccone[2], D. Bosnar[12], M. Brugger[2], M. Calviani[2], F. Calviño[13], D. Cano-Ott[8], C. Carrapiço[14], F. Cerutti[2], E. Chiaveri[10,2], M. Chin[2], N. Colonna[1], G. Cortés[13], M. A. Cortés-Giraldo[15], M. Diakaki[3], C. Domingo-Pardo[16], I. Duran[4], R. Dressler[17], N. Dzysiuk[18], C.

Eleftheriadis[19], A. Ferrari[2], K. Fraval[10], S. Ganesan[20], A. R. García[8], G. Giubrone[16], K. Göbel[5], M. B. Gómez-Hornillos[13], I. F. Gonçalves[14], E. González-Romero[8], E. Griesmayer[21], F. Gunsing[10], P. Gurusamy[20], A. Hernández-Prieto[2,13], D. G. Jenkins[22], E. Jericha[21], Y. Kadi[2], F. Käppeler[23], D. Karadimos[3], N. Kivel[17], P. Koehler[24], M. Kokkoris[3], M. Krtička[9], J. Kroll[9], C. Lampoudis[10], C. Langer[5], E. Leal-Cidoncha[4], C. Lederer[5,25], H. Leeb[21], L. S. Leong[7], R. Losito[2], A. Manousos[19], J. Marganiec[6], T. Martınez[8], C. Massimi[26], P. F. Mastinu[18], M. Mastromarco[1], M. Meaze[1], E. Mendoza[8], A. Mengoni[27], P. M. Milazzo[28], F. Mingrone[26], M. Mirea[29], W. Mondalaers[30], T. Papaevangelou[10], C. Paradela[4], A. Pavlik[25], J. Perkowski[6], A. Plompen[30], J. Praena[15], J. M. Quesada[15], T. Rauscher[31], R. Reifarth[5], A. Riego[13], F. Roman[2,29], C. Rubbia[2,32], M. Sabate-Gilarte[15], R. Sarmento[14], A. Saxena[**20**], P. Schillebeeckx[30], S. Schmidt[5], D. Schumann[17], P. Steinegger[17], G. Tagliente[1], J. L. Tain[16], L. Tassan-Got[7], S. Valenta[9], G. Vannini[26], V. Variale[1], P. Vaz[14], A. Ventura[27], R. Versaci[2], M. J. Vermeulen[22], V. Vlachoudis[2], R. Vlastou[3], A. Wallner[25], T. Ware[11], M. Weigand[5], C. Weiß[5,2], T. Wright[11] and P. Žugec[12]
Eur. Phys. J. A (2013) **49**: 156
http://dx.doi.org/10.1140/epja/i2013-13156-x

22. Nuclear Data Sheets for A = 211
Balraj Singh, Daniel Abriola, Coral Baglin, Vivian Demetriou, Timothy Johnson, Elizabeth McCutchan, Gopal Mukherjee, Sukhjeet Singh, Alejandro Sonzogni, Jagdish Tuli
Nuclear Data Sheets **114**, 661 – 749, (2013)

23. Nuclear Data Sheets for A = 215
Balraj Singh, Gopal Mukherjee, Daniel Abriola, Swapan Kumar Basu, Paraskevi Demetriou, Ashok Jain, Suresh Kumar, Sukhjeet Singh, Jagdish Tuli
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