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A BRIEF STATUS REPORT ON THE ACTIVITIES OF NUCLEAR DATA PHYSICS CENTRE OF INDIA (NDPCI)

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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. This NDPCI is evolving a streamlined and coherent activities of all nuclear data activities in India. The NDPCI has been very successful to bring people in various fields (e.g., Nuclear Physics, Reactor and Radiochemistry Divisions of Bhabha Atomic Research Centre, Mumbai, Indira Gandhi Centre of Atomic Research, Kalapakkam, Variable Energy Cyclotron, Calcutta, etc.) and students and staff from various Universities across India covering both experimentalists and theoreticians. A brief account of NDPCI activities carried out by our researchers during 2010-2012 are highlighted 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. 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 the primary reaction of importance in the thorium cycle. The experiment is being planned to carry 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 ^{242}Pu is only 14.3 years. (B.K. Nayak, A. Saxena, D. C. Biswas, E. T. Mirgule, B. V. John, S. Santra, R. P. Vind and S. Kailas and S. Ganesan and R.K.Choudhury)

TAGS measurement:

One of the main goals of the nuclear data group at Variable Energy Cyclotrom (VECC), Calcutta is to develop a set up for the Total Absorption Gamma Spectroscopy (TAGS) measurement. There are only a few such facilities existed in the world and none in India at this moment. At VECC, a set up for TAGS measurement using the existing BaF2 scintillator detectors has been developed. The dimension of each of these detectors is 3.5 x 3.5 x 5 cm3. The 50 of such detectors were arranged in two halves of 25 each in the staggered castle geometry as shown in Fig. 1.

Fig. 1 : The TAGS set up at VECC using BaF2 scintillator detectors. The 50 detector elements were arranged in two halves each consisting of 25 detectors in the staggered castle type geometry. The two halves are shown in the figure separately.

In the TAGS measurement a sum spectrum is constituted to get the Total Absorption spectrum. This was done in the present measurement on the event-by-event basis after all the 50 detectors are properly calibrated and gain matched. The uniqueness of the present set up is to cleanly separate the sum peaks from the individual peaks. The study carried out shows that in the present set up one can identify the dominant β-decay feeding quite easily. However, to get the quantitative estimate of all the feeding intensities, the spectrum needs to be analyzed in more detail. (G. Mukherjee, S.R. Banerjee, S. Mukhopadhyay, D. Pandit, S. Pal and B. Dey)

Neutron induced nuclear data measurements with 14 MeV neutron generator:

The measurement of the cross-sections of a number of nuclear reactions induced by 14 MeV neutrons were carried out using 14 MeV neutron generator at University of Pune. The 14.8 MeV neutrons were produced through the $^{3}H(d,n)^{4}He$ reaction (Q = 17.59 MeV), in which an 8.6 Curie tritium target was bombarded by deuterium ions of energy ~150 keV at beam current ~ 100 μA. Samples were irradiated at 0^{0} angle relative to the incident deuteron beam. The distance between the sample and the tritium target was ~ 10 mm. Using this facility, the cross-sections for the following nuclear reactions were measured in the laboratory.; $^{nat}Cr(n,x)^{52}V$, $^{52}Cr(n,p)^{52}V$, $^{nat}Cr(n,x)^{53}V$, $^{53}Cr(n,p)^{53}V$, $^{nat}Zn(n,x)^{66}Cu$, $^{66}Zn(n,p)^{66}Cu$, $^{nat}Zn(n,x)^{68}Cu^{m}$, $^{68}Zn(n,p)^{68}Cu^{m}$, $^{nat}Mo(n,x)^{97}Nb^{g}$, $^{97}Mo(n,p)^{97}Nb^{g}$, $^{nat}Mo(n,x)^{97}Nb^{m}$, $^{97}Mo(n,p)^{97}Nb^{m}$, $^{nat}Sn(n,x)^{116}In^{m1+m2}$, $^{116}Sn(n,p)^{116}In^{m1+m2}$, $^{nat}Sn(n,x)^{117}In^{g}$, $^{117}Sn(n,p)^{117}In^{g}$,$^{nat}Sn(n,x)^{118}In^{m1+m2}$, $^{118}Sn(n,p)^{118}In^{m1+m2}$, $^{nat}Sn(n,x)^{120}In^{x}$, $^{120}Sn(n,p)^{120}In^{x}$, $^{nat}Ba(n,x)^{138}Cs$ and $^{138}Ba(n,p)^{138}Cs$. In addition, the cross-sections of these reactions were also estimated theoretically using Talys-1.2 and Empire-2.19 computer codes. The contributions of

(n, np), (n, pn) and (n, d) reactions from the corresponding higher mass isotopes were also estimated and the corresponding cross-sections were corrected.
Most of the cross-sections measured in this laboratory have been converted in the EXFOR FORMATS, which are now available in IAEA website. (B. Lalremruata, V.K. Mulik, V.N. Bhoraskar, S.D. Dhole, S. Ganesan, S. Kailas, A. Saxena, H. Naik, S.V. Suryanarayana)

In another set of measurements, using 14 MeV neutron generators at Purnima, BARC and University of Pune (n,p) cross-sections for ^{208}Pb, ^{67}Zn and ^{92,96}Mo and (n,2n) cross-sections for ^{70} Zn and ^{208}Pb were measured. The results were compared with EMPIRE-2.19 and Talys codes. (M. Bhike, B.J. Roy, A. Saxena, R.K. Choudhury, R. Acharya, S. Ganesan, B. Lalremruata, S.D. Dhole and V.N. Bhoraskar)

Nuclear Data Measurements using BARC-TIFR Pelletron Facility

BARC-TIFR 14-MV Pelletron accelerator at Mumbai was used with ^{7}Li(p, n)^{7}Be reaction to act as the neutron source with the proton beam for nuclear data cross-section measurements. A standard off-line gamma counting method using high purity Ge detector was followed for activation measurement. Neutron-induced reaction cross sections for the reaction ^{232}Th(n, γ) ^{233}Th have thus been measured at neutron energies of 1.66±.03 MeV, 2.26±.03 MeV, 3.06± .03MeV, and 3.76±.03 MeV. The cross sections for the reactions ^{98}Mo(n, γ) ^{99}Mo, ^{186}W(n, γ) ^{187}W, ^{115}In(n, γ) ^{116m1}In, and ^{92}Mo(n, p) ^{92m}Nb at a neutron energy of 3.26±0.03 MeV were measured . Detailed theoretical calculations using the statistical model code EMPIRE-II (latest version EMPIRE-2.19) have been performed. Good agreement with the present data along with the existing data set has been obtained by suitable adjustment of the level density parameter for all the systems. The experimental and theoretical results have been compared with the recent evaluations of ENDF/B-VII.0, JENDL-4.0, and JEFF-3.1. One typical result from these measurements is shown in Fig. 2

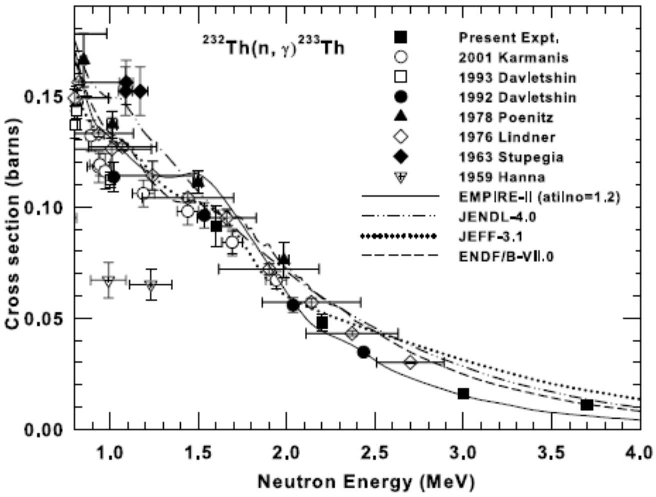

Fig. 2: Excitation function of ^{232}Th(n,γ) (From M. Bhike et al., NUCLEAR SCIENCE AND ENGINEERING: **170**, 1–10 (2012)

It was reported that the calculations done using EMPIRE 2.19 with the level density parameter scaled up by a factor of 1.2 gives a satisfactorily good agreement with the experimental data in this energy range. Also, the measurements at 3.0 and 3.7 MeV are in agreement with the presented EMPIRE-2.19 calculations but are lower than the ENDF-B/VII.0, JENDL-4.0, and JEFF-3.1 libraries. These results were reported in NUCLEAR SCIENCE AND ENGINEERING: **170**, 1–10 ~2012. (M. Bhike, B.J. Roy, A. Saxena, R.K Choudhury and S. Ganesan)

Yields of fission products in the bremsstrahlung induced fission of pre-actinides (^{nat}Pb, ^{209}Bi) and actinides (^{232}Th, ^{238}U and ^{240}Pu):

Cumulative yields of 12 fission products in the 50-70 MeV bremsstrahlung induced fission of ^{nat}Pb and ^{209}Bi have been determined by off-line γ-ray spectrometric technique using the100 MeV electron linac at Pohang Accelerator Laboratory (PAL), South Korea. Similarly cumulative yields of 27 fission products and independent yields of 15 fission products in the 2.5 GeV bremsstrahlung induced fission of ^{nat}Pb and ^{209}Bi have been also determined by the same technique and using 2.5 GeV electron linac of PAL, South Korea. Cumulative yields of 32 fission products have been determined in the 10 MeV bremsstrahlung induced fission of ^{232}Th, ^{238}U and ^{240}Pu by same technique and using 10 MeV electron linac at Electron Beam Centre (EBC), Kharghar, Navi-Mumbai. **(**H Naik, G Kim, A. Goswami, Sarbjit Singh, V.K. Manchanda, Devesh Raj, S Ganesan, Young Do Oh, Hee-Seock Lee, Kyung Sook Kim, Man-Woo Lee, Moo-Hyun Cho, In Soo Ko, and Won Namkung , SVS Suryanarayana, K.C. Mittal, V.T. Nimje. V. Venugpoal, S. Banerjee. S.N. Acharya)

Measurement of neutron yield from thick targets bombarded by heavy ions of energy 7-9 MeV/amu.

Experiments were carried out at the BARC-TIFR Pelletron-linac accelerator facility using 144 MeV ^{19}F and 115 MeV ^{12}C projectiles incident on a thick Al target. Five liquid scintillators of 5cm diameter and 5cm thickness were placed at 1.5 meters from the target. Pulse shape discrimination was used to separate the neutrons from the photons while time of flight technique was used to measure the energy. The experimental results were compared with the statistical model codes PACE and EMPIRE and by the Monte Carlo code FLUKA. Preliminary results (see figure 1) indicate that the codes do not reproduce the experimental data satisfactorily. More analysis is in progress. The analysis using FLUKA code is carried out in collaboration with the developers of the code from CERN.

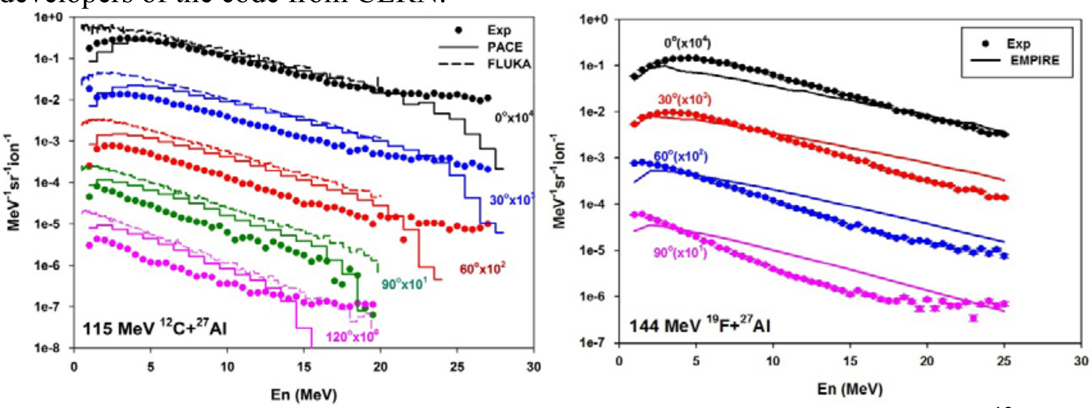

Figure 3. The neutron spectrum from a thick Al target bombarded by 115 MeV ^{12}C (left) and 144 MeV ^{19}F (right) projectiles compared with statistical and Monte Carlo codes.

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(VitishaSuman, Nair Soumya, Sunil C, Shanbhag A, Sahoo G S, Biju K, Joshi D S, Tripathy S P and Nanal V, Pillay R G and Sarkar P K)

Measurement of the neutron capture cross-sections of 232Th at 5.9 MeV and 15.5 MeV

Using the 7Li(p, n) reaction as neutron source ^{232}Th(n,γ) and ^{232}Th(n,2n) cross-sections were determined. The cross-sections were compared with the latest available evaluated nuclear data libraries of ENDF/B-VII, JENDL 4.0 and JEFF 3.1 and were found to be in good agreement. These cross-sections were also calculated theoretically using the nuclear-model–based computer code TALYS 1.2 and compared with the experimental data. (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)

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.

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 2010 and 2011 in Volume 55 and 56 and are available at http://sympnp.org/proceedings/.

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. In the nineties, the experimental work on fission physics was continued and, for instance, reported [3] 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 planned experiment the fission ionization chamber will be used for fission trigger by replacing ^{252}Cf source with actinide target. The mono-energetic for the experiment will be produced by ^{7}Li(p, n)^{7}Be reaction.

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(Vishal Desai, B.K.Nayak, A.Saxena, Y.Sawant, S. Kailas, S. Ganesan and R.K. Choudhury)

B NUCLEAR DATA THEORY AND SIMULATIONS

Review of the fission spectrum for use in thorium fuelled systems like AHWR

A FORTRAN program is developed to generate the multigroup fission spectrum for each important isotope in thorium fuel cycle by processing the fission spectrum data from the basic evaluated nuclear data file (ENDF/B-VI.8). The fission spectra as given in the WLUP is based in U-Pu systems and is computed with weights of 54%, 8% and 38% for ^{235}U, ^{238}U and ^{239}Pu respectively. The modified fission spectra for AHWR has been computed by averaging over isotopes spectra of ^{233}U, ^{239}Pu and ^{241}Pu with weights 65%, 27% and 8%, respectively. (Anek Kumar and K. Umashankari)

Spectrum average one-group cross section for Failed-fuel detection system of AHWR

Spectrum averaged one-group cross sections for gaseous fission products for use in the design of failed fuel detection system have been generated from first principles using the AHWR spectrum. A special procedure has been used to estimate the spectrum averaged capture reaction rates for the volatile fission products like xenon and krypton isotopes, namely, ^{133}Xe, ^{135}Xe, ^{138}Xe, ^{85m}Kr, ^{87}Kr, ^{88}Kr and ^{89}Kr for the fission gas monitoring system of AHWR. The basic physics inputs of decay constants and yields for gaseous fission products were obtained from Indian mirror site http://www-nds.indcentre.org. The capture reaction rates of these fission products have been calculated by averaging over the AHWR spectrum using the PREPRO code system. The activity in the coolant would now be calculated based on an equivalent sphere model as proposed by designers.
(Sudipta Samanta and K. Umashankari)

Simulations:

For the development of various neutron detection systems for measurement of the ambient dose equivalent of high energy neutrons a simulation of several (*n, xn*) reactions was carried out using the FLUKA Monte Carlo code for sensitivity analysis, optimization and detection efficiency. (Biju K, S. P. Tripathy, Sunil C, P. K. Sarkar)

Criticality Benchmark study:

Preparation of integral Indian experimental criticality benchmarks for integral nuclear data validation studies. (KAMINI, PURNIMA-II benchmarks has been completed and accepted by the US-DOE). PURNIMA-I benchmarking in final stage of progress. Nuclear data sets are being used for reactor sensitivity studies –AHWR, CHTR (RPDD, BARC); Fast Reactors (IGCAR), ITER-Test Blanket Module & Indian Fusion Reactors. (CPReddy, T.K.Basu, E. Radha and S. Ganesan).

NSOURCE: A code for calculating (α, n) and spontaneous fission (SF) neutron sources and spectra:

A FORTRAN program, NSOURCE, is indigenously developed at IGCAR, for estimating neutron production rates and spectra in spontaneous fission and (α, n) reactions. It is designed to calculate neutron source for a homogenous mixture of heavy and light nuclides. NSOURCE takes the number densities of the constituents and the amount (gram) of a mixture as input. Neutron production rate from spontaneous fission (SF) is obtained from the product of the SF activity and average number of neutrons produced per SF. The spontaneous fission spectra are approximated by a Watt's fission spectra using two evaluated parameters a and b The quantities, ν_{SF}, $t_{1/2}$ and SF branching ratio and the evaluated parameters a and b for Watt spectrum, which are recently published, are taken in the program. At present, it has data for 44 actinides. (G. Pandikumar and V. Gopalakrishnan)

Validation of PFBR database created for ORIGEN2:

To gain confidence, that the calculational tool together with its data-associate would predict the intended parameters reliably, requires a validation exercise, preferably through a suitable experimental measurement. However, to make things easy, we chose to validate our predictions by comparing against internationally recognized standards. Thus the ORIGEN2 results for decay powers were compared with those given by the decay power standards viz. ANS-5.1 (U.S. 1994) and AESJ (Japan 1991). Literature survey gives the impression that the AESJ standard is superior to the ANS-5.1, since the former has been validated against many more experiments, with thermal and fast reactors. Figure 4 shows how well ORIGEN2 predictions, using major data revised by group at IGCAR, agrees with AESJ over a large cooling time range, thus establishing the reliability of the ORIGEN2 based infra-structure for similar calculations. (G. Pandikumar and V. Gopalkrishnan)

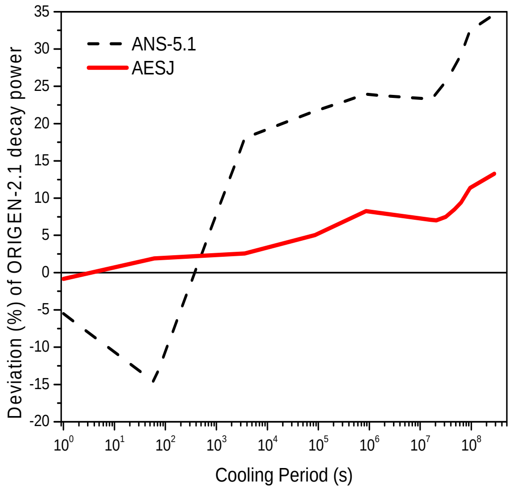

Fig 4: Comparison of PFBR Core-1 FP Decay Power with Standards

C EXFOR COMPILATIONS

The 4th DAE-BRNS EXFOR workshop on EXFOR was held in Chandigarh, April 4-8, 2011 and co-ordinated by BARC. S. Ganesan (BARC), A. Saxena (BARC) and B. Behera (Panjab University) were main organizing committee members as Chairman, Technical convener and local convener respectively. Svetlana Dunaeva (Ex-IAEA), now in Russia and Prof. N. Otsuka from IAEA were invited as experts. About seventy participants from various institutes of India covering a wide geographical scope, but also a wide range of scientific career profiles, from graduate students to several distinguished senior professors attended this theme meeting. Every day after 1 – 2 lectures participants made compilation to EXFOR in small groups on 20 PCs and additionally on 15 laptops. The compilation software ExfEdt and Graf_New were copied to all PCs and could be used for the practical compilation work. Programs ORDER and CHEX as well as the EXFOR Format Manual, the LEXFOR Manual, and the EXFOR Dictionaries were integrated in ExfEdt software. Svetlana Dunaeva also visited VECC, Kolkata (G. Mukherjee, VECC) and BARC (NDPCI). 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. India successfully contributed more than 200 EXFOR entries. This process is continuing even after the workshop as many scientists and students are following up the EXFOR compilation activities after the Chandigarh meeting. One can see the EXFOR Entries prepared by Indian Compilers at the following website: http://www-nds.iaea.org/nrdc/india/ . Personnel from NDPCI participated in EXFOR meetings such as IAEA-NDS, VIENNA, EXFOR WORKSHOP 2010 and 201, AASPP-1, 2010, Hokkaido University Naik, AASPP-2: 2011: Beijing, China We also propose to hold another them meeting on EXFOR compilation in Benares Hindu University in 2013. A DAE-BRNS project with B. Lalremruata from Mizoram university as principal investigator is in review stage which will include EXFOR compilation in addition to nuclear data measurements and evaluation. We are evolving a mechanism to coordinate the EXFOR compilation activities with IAEA-NDS.

D ENSDF COMPILATIONS

A.K. Jain and his team from IIT Roorkee have proposed of Atlas of Nuclear Isomers. Isomers can be viewed as a separate class of nuclei and offer interesting possibilities to study the behavior of nuclei under varied conditions of life-time, spin, excitation and particle configuration. A systematic of the nuclear properties of isomers like excitation energy, half-life, spin, abundance etc. was carried out. Evaluated data for **A=222** was published in Nuclear Data Sheets for A=222, 112 (2011) 2851-2886, by S. Singh, A.K. Jain and J.K. Tuli. Currently evaluation of **A=224** mass chain is going on.

ENSDF Evaluation of **A = 95**

The mass chain evaluation of A = 95 has been completed during this period. The evaluation was done in collaboration with National Nuclear Data Centre (NNDC), BNL, USA. This evaluation was done in the ENSDF formalism and has been published in the journal Nuclear Data Sheets. (S.K. Basu, G. Mukherjee)

ENSDF Evaluation of **A = 150**

The mass chain evaluation of A = 150 has been completed during this period. The evaluation was done in collaboration with National Nuclear Data Centre (NNDC), BNL, USA. The evaluation has been submitted for publication in the journal Nuclear Data Sheets. (S.K. Basu)

E NUCLEAR DATA EVALUATION

A theme meeting on nuclear reaction data evaluation was held at the Homi Bhabha National Institute in Mumbai during 13-17 February 2012. The meeting was organized by the Nuclear Data Physics Centre of India (NDPCI) and was attended by researchers from several universities and national labs of India. The faculty members Dr Andrej Trkov from the Jozef Stefan Institute Slovenia and Dr R Capote Noy from the IAEA trained the participants in the use of the EMPIRE statistical model code (version 3.1) and the GANDR error analysis code.

The Indian mirror web-site of IAEA-Nuclear Data Section (http://www-nds.indcentre.org.in) greatly helps the researchers, and the number of visits to this site is continually on the increase. Therefore, the relevant MOU between DAE/BARC and the IAEA which was to end in 2010 but has been continued. This mirror web-site is being maintained by Computer Division at HBNI campus in Anushaktinagar, Mumbai.

A number of projects have been initiated to facilitate the participation by teaching institutions in nuclear data activities. NDPCI has number of DAE-BRNS funded program involving collaboration between national laboratories like BARC, VECC and IGCAR with various universities such as Manipal university, North Eastern Hill University, Vishwabharati University, Pune University, Bharathiar University, Coimbatore and IIT, Roorkee on various aspects of nuclear data such as nuclear data measurements, EXFOR compilations, ENSDF activities and applications of covariance matrices for nuclear data evaluation etc.

Acknowledgements: The author thanks Dr. S. Kailas, Dr. P.D. Krishnani, Dr. S. Ganesan, Dr. A. Chatterjee, and all other colleagues 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 Dr. N. Otsuka of IAEA-NDS.

List of Publications in 2010-12

1.Inter-comparison of JEF-2.2 and JEFF-3.1 Evaluated Nuclear Data through Monte Carlo Analysis of VVER-1000 MOX Core Computational Benchmark
L. Thilagam, R. Karthikeyan, V. Jagannathan, K. V. Subbiah, S. M. Lee
Annals of Nuclear Energy, 37, 144–165, (2010).
2. **Mass-yield distributions of fragments from photo-fission of ^{nat}Pb induced by 50-70 MeV bremsstrahlung**
Haladhara Naik, Guinyun Kim, Ashok Goswami, Sarbjit Singh, Vijay Kumar Manchanda, Devesh Raj, Srinivasan Ganesan, Young Do Oh, Hee-Seock Lee, Kyung, Sook Kim, Man-Woo Lee, Moo-Hyun Cho, In Soo Ko, and Won Namkung.

J. Radioanal. Nucl. Chem. **283**, 439 (2010).

3. **Measurement of photo-fission cross-section of ^{238}U using microtron facility**
H. G. Rajprakash, Ganesh Sanjeev, K. B. Vijaykumar, H. G. Harish kumar, K. Sidappa, B. K. Nayak and A. Saxena
International Journal of Modern Physics E **20**, (2011) 2361–2375
4. **Measurement of photofission excitation of ^{237}NP**
H G Rajaprakash, Ganeshsanjeev, K B Vijay Kumar, K Siddappa,B K Nayak and A Saxena
Radiation Measurements, **46,** 413 (2011)
5**. Experimental determination of photofission cross-sections of ^{232}Th using electron accelerator**
H.G. Raj Prakash, Ganesh Sanjeev, K.B. Vijay Kumar, K. Siddappa, B.K. Nayak, A. Saxena
Annals of Nuclear Energy **38** (2011) 757–766
6. **Analysis of coolant void reactivity of Advanced Heavy Water Reactor (AHWR) through isotopic reaction rates**, Umasankari Kannan and S. Ganesan
Nucl. Science and Engineering, **167**, Issue 12 (2011) , pp 105-124.
7. **Mass-yield distribution of fission products from photo-fission of ^{nat}Pb induced by 2.5 GeV bremsstrahlung.**
H. Naik, S. Singh, A. Goswami, V.K. Manchanda, S.V. Suryanarayana, D. Raj, S. Ganesan, Md. S. Rahman, K.S. Kim, M.W. Lee, G. Kim, M. –H. Cho, I.S. Ko,W. Namkng
E. Phys. J. A. **47**, 37 (2011).
8. **Measurement of photo-neutron cross-sections in ^{208}Pb and ^{209}Bi with 50-70 MeV Bremsstrahlung.**
H. Naik, S. Singh, A. Goswami, V.K. Manchanda, G. Kim, K.S. Kim, M. –W. Lee, Md.S. Rahman, D. Raj, S.V. Suryanarayana, S. Ganesan, M. –H. Cho, W. Namkng
Nucl. Instruments Methods in Phys. Research B **269**, 1417 (2011).
9**. Mass distribution in the bremsstrahlung-induced fission of ^{232}Th, ^{238}U and ^{240}Pu.**
H. Naik, V.T. Nimje, D.Raj, S.V. Suryanarayana, A.Goswami, Sarbjit Singh,S.N. Acharya, K.C. Mttal, S. Ganesan, P. Chandrachoodan, V.K. Manchanda,V. Venugopal, S. Banarjee,
Nucl Phys. A 853 (2011) 1.
10. **^{233}Pa(2n$_{th}$, f) cross-section determination using a fission track technique.**
H. Naik, P.M. Prajapati, S.V. Suryanarayana, P.N. Pathak, D.R. Pravu, V. Chavan, D. Raj, P.C. Kalsi, A.Goswami, S. Ganesan and V.K. Manchanda
Eur. Phys. J. A **47**,100 (2011).
11. **Measurement of the neutron reaction cross-section of ^{232}Th using the neutron activation technique.**
H. Naik, P.M.Prajapati, S.V. Surayanarayana, K.C.Jagadeesan, S.V.Thakare, D.Raj, V.K. Mulik, B.S.Sivashankar, B.K. Nayak, S.C. Sharma, S. Mukherjee, Sarbjit Singh,A. Goswami, S. Ganesan and V.K. Manchanda
Eur. Phys. J. A **47**, 51 (2011).
12. **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 (2012) **48** 35
13. **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
Phys. Rev. C **85**, 024624 (2012)

14. **Measurement of ^{232}Th(n, γ)^{233}Th, ^{98}Mo(n, γ)^{99}Mo, ^{186}W(n, γ)^{187}W, ^{115}In(n, γ)^{116m}In and ^{92}Mo(n,p)^{92m}Nb reaction cross sections in the MeV range**
Megha Bhike, B. J. Roy, A. Saxena, R. K. Choudhury, S. Ganesan
Nuclear Science and Engineering, **170**, 1–10 ~2012

15. **Fission Neutron Spectrum Sensitivity Study for the Case of Advanced Heavy Water Reactor**
Anek Kumar and S. Ganesan
Nuclear Science and Engineering (in press)

16. **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**
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