A BRIEF STATUS UPDATE ON THE ACTIVITIES OF NUCLEAR DATA PHYSICS CENTRE OF INDIA (NDPCI) DURING 2014-2015

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The NDPCI is operating since 2011 under Board of Research in Nuclear Sciences of DAE and functions through two committees namely Program Implementation Committee and Program Review Committee involving scientists and faculties from various divisions of DAE units and universities. Nuclear Data Physics Centre of India (NDPCI) also provides a platform for coordinated efforts in all aspects of nuclear data, viz., measurements, analysis, compilation and evaluation involving national laboratories and universities in India. A number of projects have been awarded under NDPCI/DAE-BRNS to various universities to involve faculties and students in nuclear reactions, nuclear structure and EXFOR compilations. A brief account of NDPCI activities carried out by our researchers under various activity heads is described in this report.

A EXFOR COMPILATIONS

NDPCI has been successful in contributing to the EXFOR database of IAEA through entries compiled for Indian published articles based numerical nuclear data by participants in various domestic workshops on EXFOR compilation as well as through projects given to various universities. The initiative to organize various workshops by BARC on EXFOR compilation with the support from faculties of nuclear data section (NDS) of IAEA has been very successful. **The sixth workshop cum theme meeting on EXFOR compilations was organized in Bangalore University from 20-25 January, 2015** in continuation of earlier five EXFOR training workshops in BARC, Mumbai (2006, 2007), University of Rajasthan, Jaipur (2008), Panjab University Chandigarh (2011), BHU, Varanasi (2013). The Bangalore EXFOR workshop was exceptionally well organized and hosted with very good web based support. The numerical data from authors were received well in time before the workshop and allocation of articles for compilation in EXFOR database to delegates was done before workshop. The workshop was organized with the help of N. Otsuka of IAEA as main faculty. This workshop is significant as B. Remruata of Mizoram University, Vidya Thakur of IET Jallandhar, Reetuprana Ghosh, and Sylvia Badwar of NEHU provided able support to Dr. Ostuka and helped the participants in compilation of the entries**.** This is a big step forward as now some of the Indian compilers are experienced enough to guide others in EXFOR compilation activities**.** About 40 entries were compiled in this workshop well before time and it was felt that the next workshop should be organized only for four days. I was technical convener for this theme meeting, whereas B. Rudraswamy was local convener. **The number of EXFOR entries created in the EXFOR workshops as well as those compiled by individual compilers as part of NDPCI projects in India is more than over 288 entries which compares well with those compiled by other centres of the network (refer to https://www-nds.iaea.org/exfor-master/x4compil/exfor_input.htm).**

There was action **A59 assigned to B. Remruata in last NRDC meeting in 2014** to check the two duplicate entries for reaction $^{13}C(\alpha,n)^{16}O$. As per that action, Remruata had discussion with N. Otsuka and B. Pritychenko and it was decided to keep the entry D6089.002 in and P0132.002 was deleted for the following reasons: Although they refer to the same datasets but the resonance peak cross sections and alpha widths are compiled only in D6089 and the experiment was done in India.

Two projects on EXFOR compilations have been completed at NEHU and Vishwabharati University, Shantiniketan and many students were trained in EXFOR compilations and B. Remruata is acting as coordinator of this EXFOR compilation activity for pre-screening the entries before sending to Nuclear Data section of IAEA for final checking before the data is entered into database. A project on EXFOR compilation has been submitted by Vidya Thakur for the processing by NDPCI/BRNS. The next workshop on EXFOR compilation is proposed to be organized at NEHU, Shillong in 2017. At the time of writing this report, the proposal is in informal stage. A formal application by the NEHU team for a critical evaluation and appraisal for funding is expected to be made. Another project on EXFOR compilation by B. Rudraswamy of Bangalore University has been sanctioned. His project also involves measurement of integral Nuclear Reaction Cross section measurements and analysis using covariances (for the first time in such integral experiments in India) using the Kalpakkam 30 kW ^{233}U fuelled Kamini Reactor**.**

The 5th AASPP workshop on Asian Nuclear Reaction Database Development was organized by Nuclear Data Physics Centre of India in cooperation with the IAEA and the Board of Research in Nuclear Sciences, Department of Atomic Energy from 22-24 Sept, 2014 . Over seventy participants took part in the workshop representing India, Japan, Republic of Korea, Vietnam, Kazakhstan, Uzbekistan, Mongolia and a representative from the IAEA. The workshop covered the overview of nuclear data activities in different countries and covered the topics related to experiments performed using various facilities, the upcoming and existing accelerators and experimental facilities, EXFOR compilation activities, reactor sensitivity studies to nuclear data, criticality benchmarking studies, requirement of nuclear power reactors, theoretical calculations using various codes, and covariances in nuclear data. About thirty five talks were delivered by participants from various countries on these topics. The concluding session had a panel discussion on possible future collaboration involving participants from different countries. I was technical convener of this workshop and D. Raj and P.D. Krishnani worked as co-convener and Chairman of organizing committee. The proceedings of this workshop have been published in Feb., 2015 and can be found at **https://www-nds.iaea.org/publications/indc/indc-ind-0048/**

The group photograph of the participants in this workshop is given below:

B NUCLEAR REACTION EXPERIMENTS

As a continuation of our program on the cross-section measurements by surrogate method for nuclear data applications, we have used the surrogate ratio technique recently to determine ^{55}Fe(n,p) cross-section, which is relevant for fusion energy utilization efforts, at the equivalent neutron energy range of 7.9 to 20.1 MeV. The ^{56}Fe and ^{47}Ti compound nuclei are produced at similar excitation energy in ^{52}Cr(^{6}Li,d)^{56}Fe* and ^{45}Sc(^{6}Li,α)^{47}Ti* transfer reactions at E(^{6}Li)$_{lab}$= 33 MeV and 35.75 MeV respectively. The proton decay probabilities of ^{56}Fe*[surrogate of ^{55}Fe(n,p)] and ^{47}Ti*[surrogate of ^{46}Ti(n,p)] compound systems have been measured experimentally as a function of excitation energy to determine ^{55}Fe(n,p) cross-section within the framework of surrogate ratio method by considering directly measured ^{46}Ti(n,p) cross section as reference. The present experimental results of ^{55}Fe(n,p) cross-section have been compared with various evaluations such as European Activation File (EAF-2010) data library, ROSFOND-2010 TENDL-2012 and also the predictions of statistical model EMPIRE-3.2.3 code. These results are shown in Fig. 1 below:

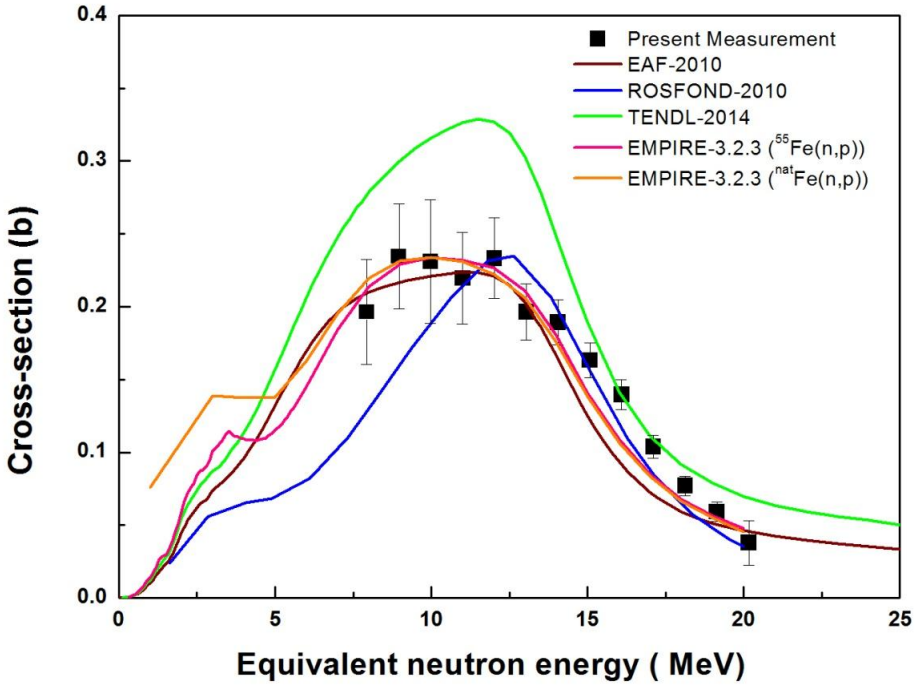

FIG. 1. The ^{55}Fe(n,p) cross-section as a function of neutron energy as obtained from surrogate measurement along with various evaluation results and EMPIRE-3.2.3 code predictions.

The Experimental ^{55}Fe(n,p) cross-sections**, reported for the first time**, are found to be reasonably consistent with EAF-2010 data library but show deviation from ROSFOND-2010 and TENDL-2014 cross-sections at lower energies. The EMPIRE-3.2.3 model calculation has been performed for the best fit of the data. Since in the present experiment natural Cr target was used, the EMPIRE 3.2.3 calculations were carried out to see the effect of natural abundances but calculated cross-section values were found to be insensitive to the details of abundances except at energies below 7 MeV where, in any case, the data is not measured in the present experiment. (B. Pandey et al.)

BARC is also participant in **IAEA CRP on prompt fission neutron spectra of actinides** which 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.

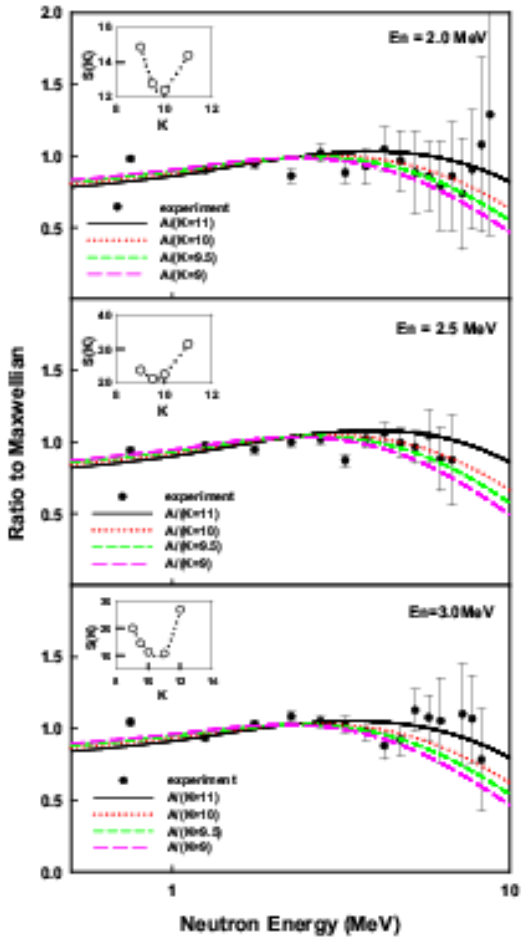

FIG. 2 The experimental (open circles) andthe LA model calculated PFNS spectra obtained using the Total Kinetic Energy values taken from the Madland systematic (solid line),normalized to the Maxwellian distribution at incident neutron energy 2.0 MeV, 2.5 MeV and 3.0 MeV. The effect of changing the level density parameter value is also shown.

. In the nineties, the experimental work on fission physics was continued and, for instance, reported in an IAEA Meeting in 1991. As a part of our proposal to carry out prompt fission neutron spectra in fast neutron induced fission reaction we have carried out a systematic study of prompt neutron energy spectrum and their multiplicities over an incident energy range of neutron from 2 to 3 MeV for ^{238}U at Folded Tandem Ion Accelerator, B.A.R.C

The ratio of measured spectra with Maxwellian fitted using EMPIRE 3.2.3 code with Los Alamos parameterization and sensitivity to level density parameter was studied. Fig. 2 shows such a comparison and it is observed that the level density parameter a = A/k, where k = 10. ± 0.5MeV describe measured prompt fission neutron spectra at all incident energies of neutron. These results are being finalized for publication. (V. Desai et al.)

The CERN n_ToF facility is involved in measurement of nuclear data for astrophysics and ADS and BARC has a MOU with CERN for participation in experiments in phase 2. Recently, Dr. S. V. Suryanarayana of NPD and Shri Kapil Deo of RPDD visited CERN during Nov 24 to Dec 08, 2014 to participate in CERN n_TOF experiments. They participated in 19 shifts during measurement of neutron induced fission data in ^{240}Pu, ^{241}Pu.

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 2014 Volume 59 are available online at http://sympnp.org.

We also have informal collaboration with Legnaro National Laboratory, Italy for experiments on fission dynamics in superheavy region. A number of experiments have been carried out and we have extracted average neutron multiplicity from a spontaneous fission of a superheavy composite system from these measurements for ^{258}Rf as a continuation of our earlier work on ^{288}116 and. ^{312}124.

A project on "Evaluation of nuclear data including covariance error matrix for advanced nuclear systems in India" was approved by NDPCI and has just received DAE/BRNS sanction for funding. This is an extension of phase I where basic understanding of the concept of covariances including assigning uncertainties to experimental data in terms of partial errors and micro correlations were developed.

Our researchers have published in April 2015 issue of Nuclear Science and Engineering (American Nuclear Society) a paper in collaboration with Manipal on measurement and a first time Indian covariance analysis of reaction cross sections for ^{58}Ni(n,p)^{58}Co relative to cross section for formation of ^{97}Zr fission product in neutron-Induced fission of ^{232}Th and ^{238}U at effective neutron energies En=5 5.89, 10.11, and 15.87 MeV.

C. NUCLEAR DATA THEORY AND SIMULATIONS

A number theoretical calculations and simulations were carried out by scientists of NDPCI and some of them are described below:

Estimation of release of energy (decay heat) over an extended period of time after termination of neutron induced fission is necessary for determining the heat removal requirements when the reactor is shutdown, and for fuel storage and transport facilities as well as for accident studies. A Fuel Cycle Analysis Code, ADWITA (Activation, Decay, Waste Incineration and Transmutation Analysis) which can generate inventory based on irradiation history and calculate radioactivity and decay heat for extended period of cooling, has been written. (Devesh Raj)

Sensitivity studies and uncertainty analyses on safety parameters for reactors are an important analysis tool for qualifying the basic nuclear cross section data. It is also helpful in providing adequate margins at the design stage. An exercise was taken up to quantify the components of the safety coefficients such as coolant void reactivity (CVR), fuel temperature reactivity (FTR) and channel temperature reactivity (CTR) for the First-Of-A-Kind thorium fuelled Advanced Heavy Water Reactor (AHWR) being designed in India. (U. Kannan et al.)

A project on Theoretical simulation of induced activity and production cross-section of radio nuclides in neutron and charged particle induced reactions by Dr. Sneh Lata Goyal, Department of Applied Physics, Guru Jambheshwar University of Science and Technology (GJUST), Hissar 125 001 (Haryana) is ongoing. She and her group has carried out exhaustive work done using different codes like, ALICE-91, TALYS 1.2, EMPIRE3.1 etc. with different parameter sets of level density, pairing energy & PEQ models.

A project on Development of a modern computer code with up-to- date databases to estimate the inventory and radioactivity of actinides and fission products during various stages of nuclear fuel cycle by Dr. R. Srivenkatesan Manipal Karnataka is going on. The project is expecting to recruit a person to write the code, if possible.

The second Theme meeting cum workshop on Nuclear Reaction Code-EMPIRE was organized during 10 - 13 November 2014 Department of Physics University of Calicut. R. Capote of IAEA was the main faculty assisted by Paresh Prajapati and Bhawana Pandey of IPR and Shivshankar of Manipal University. There were about 55 participants from university and national institutes and laboratories. The workshop was organized by M. Musthafa as local convener, Suryanrayarana and Alok Saxena from NDPCI.

D NUCLEAR DATA EVALUATION UNDER ENSDF

India has been included as one of the centres of NSDD network and several evaluators from India have contributed significantly to the ENSDF evaluation. The interest of the researchers from India in the nuclear structure data evaluation include the mass chain evaluations, decay data evaluation, horizontal evaluation as well as specific measurements related to important nuclear data. There are about 8 different groups from Universities as well as research laboratories contribute to the mass chain evaluation. In the measurement part, Indian researchers have produced significant and important nuclear structure data using the Indian National Gamma Array (INGA). (G Mukherjee et al.)

The project on ENSDF started in 2011 by Prof. A.K. Jain of IIT Roorkee. This project generated a few of the systematic features of the isomers in terms of the fundamental properties like half-life, spin-parity, energy, etc. Some of them are very new, and enable us to explore the physics behind them. Many of these universal and novel features of the isomers may open new perspectives in the field.

To summarize, the present report presents the highlights of some of the important activities of NDPCI. The NDPCI office is ready at BARC. NDPCI has been identifying and nurturing potential young researchers through the projects and other activities of NDPCI. We continue supporting researchers through funds giving mechanisms to generate basic nuclear data for various applications (Measurements, evaluation and compilation of nuclear data and sensitivity studies for various reactor systems etc) through outreach programmes.

The author thankfully acknowledges various colleagues for useful discussions and inputs for this report.

List of Publications in 2014-2015

1. Measurement of the neutron capture cross-section of 238U at neutron energies of 5.9 ± 0.5 and 15.5 ± 0.7 MeV by using the neutron activation technique, V.K. Mulik, S.V. Surayanarayana, H. Naik , Sadhana Mukerji, et al., Annals of Nuclear Energy 63 (2014) 233–240
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5. The nucleo-synthesis of heavy elements in Stars: the key isotope ^{25}Mg, n_TOF collaboration. EPJ Web of Conferences **66**, 07016 (2014) http://dx.doi.org/10.1051/epjconf/20146607016
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