An overview of activities of nuclear data physics centre of India (NDPCI)

Alok Saxena (on behalf of NDPCI)
Nuclear Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085 India

1. **Introduction**

India has a three stage nuclear power programme which requires accurate inputs of nuclear data for design and safe operation of existing as well as for the design of new and innovative reactors. Apart from that nuclear data is required for accelerator shield design, personal dosimetry, radiation safety, production of radioisotopes, radiation damage studies, waste transmutation etc. To cater to various needs of department, the Nuclear Data Physics Centre of India (NDPCI) was formed in 2010-11 to provide a platform for coordinated efforts in all aspects of nuclear data, viz., measurements, analysis, compilation and evaluation involving national laboratories and universities in India. The NDPCI has projects / collaborations with universities and various units of department of atomic energy (DAE) across India involving physicist, radio-chemists, reactor physicists and computer engineers. A number of projects have been awarded under NDPCI to various universities to involve faculties and students in nuclear reactions, nuclear structure and EXFOR compilations. The NDPCI is presently a virtual centre 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. A brief account of NDPCI activities carried out by our researchers is described in this report.

2 EXFOR Compilations

NDPCI has been successful in contributing to EXFOR database of IAEA through entries compiled by participants in various domestic workshops on EXFOR compilation as well as through projects given to various universities. The initiative to organize various workshops on EXFOR compilation with the support from faculties of nuclear data section (NDS) of IAEA has been very successful. NDPCI has conducted five domestic EXFOR workshops (2006, 2007, 2009, 2011, 2013) in various parts of country and the next EXFOR workshop is scheduled in Bangalore University in the month of January, 2015. The organizers of these workshops have successfully collected many young and senior participants from the universities and institutes and it is a very efficient way of compiling articles from Indian measurements into EXFOR database. The participation of NDPCI to NRDC (International Network of Nuclear Reaction Data Centres) was officially approved in 2008 NRDC Meeting (Obninsk, Russia). The number of EXFOR entries created in the EXFOR workshops in India is more than over 278 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). The mirror of EXFOR website of NDS-IAEA is maintained by Computer Division of Bhabha Atomic Research Centre (BARC). The mirror website is well synchronized with the primary database in Vienna.

3. Nuclear Reaction Experiments in India

The nuclear data experiments in India are performed using various experimental facilities such as

BARC-TIFR pelletron facility, Mumbai, FOTIA at BARC, research reactors like APSARA, DHRUVA and CIRUS in BARC, electron linacs at Khargarh, Navi Mumbai, 14 MeV generator, Pune, Variable Energy Cyclotron, Kolkatta, Inter University Accelerator Centre, New Delhi. More than 35 papers related to nuclear data were published in last two years. Many nuclear data experiments have used ^{7}Li(p,n) reaction to produce quasi-mono-energetic neutrons. An irradiation facility at pelletron above analyzing magnet was extensively used for many experiments. The measured cross-section data were compared with the predictions of statistical model codes such as EMPIRE and TALYS. The various sources of uncertainties in the measurements were also reported. The attempts are being made to calculate covariance matrices in some of the measurements. 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.

A number of experiments were carried out by surrogate method for neutron induced cross-sections of those actinide nuclei where direct measurements are difficult or impossible due to short half-lives of the target nuclei. 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 [1]. 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 for ^{241}Pu(*n,f*) cross section data 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. The ^{241}Pu(*n, f)* cross-section data for this measurement were observed to be consistent with the direct measurements, suggesting the applicability of surrogate methods. The surrogate reaction method has also been used to determine neutron-induced fission cross sections of the short-lived minor actinides ^{239}Np and ^{240}Np. We have also measured the fission cross-section for ^{234}Pa(n,f) using hybrid surrogate ratio method. The fission barrier heights corresponding to all the reactions studied above for various isotopes in EMPIRE calculations were obtained from our barrier formula and these calculations describe the experimental results rather well. 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.

We are also participants 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 [2]. 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 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 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 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. In one of the experiments, where we participated, the measurement of the neutron-induced capture cross section of the fissile isotope ^{235}U was carried out using a fission tagging set-up. This new set combines the n_TOF 4π Total Absorption Calorimeter (TAC) with MicroMegas (MGAS) fission detectors.

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 . 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 ^{288}116, ^{312}124 and ^{258}Rf [3].

4. 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:

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 [4]. 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.

A computer code has been indigenously 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.

The detailed point wise 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 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 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.

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. For details please see reference 5.

5 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. 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. 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).

The work has been done at Indian Institute of Technology, Roorkee to evaluate and update the mass chain A=139, 211, 222 and 224 [6]. Some highlights are given below:

(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.

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.

6. Concluding Remarks

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. More details about NDPCI activities can be found at https://www-nds.iaea.org/nrdc/nrdc_2014/progres/ndpci.pdf.

The author thankfully acknowledges all colleagues from various Divisions in BARC, VECC, IGCAR and Universities for useful discussions and inputs for this report.

References

[1] Determining 234Pa(n,f) cross sections using the surrogate method**,** V. V. Desai, B.K. Nayak, A. Saxena, and E. T. Mirgule**,** Phys. Rev. **C89**, 024606 (2014) and references therein.

[2] Prompt fission neutron spectrum measurement in fast neutron induced fission of ^{238}U. V. V. Desai, B. K. Nayak, A. Saxena, S.V. Suryanarayana, and Arun Agarwal, Report to 3rd RCM on IAEA CRP on prompt fission neutron spectra of actinide nuclei, 2012

[3] Study of binary fragmentation and compound nucleus fission in the reaction ^{50}Ti+^{208}Pb, M. Cinausero et al. Proceedings of the 10th Latin American Symposium on Nuclear Physics and Applications (2014) and references therein.

[4] Activation cross sections of ^{74}Ga and ^{71}Zn formed in neutron induced reactions on ^{74}Ge, Goyal Sneh Lata, Saran P. K., Sarkar P. K. and Nandy Maitreyee, (ICRTNP-2012), Chitkara University, Solan, held on Nov. 19-21, 2012, Published in AIP Conf. Proc. Vol. **1524,** p.120-122 (2013) and references therein.

[5] Sensitivity studies on nuclear data for thorium fuelled Advanced Heavy water Reactor (AHWR), Umasankari Kannan, Anek Kumar, Anindita Sarkar, S. Ganesan* and P.D. Krishnani, Report in this proceedings.

[6] Nuclear Data Sheets for A=139, Paresh Joshi, Sukhjeet Singh, A.K. Jain, and Balraj Singh , Nuclear Data Sheets under review.