A brief status report on selected Indian nuclear data physics activities submitted to the NRDC Meeting-2009[1]

S. Ganesan, Scientific Officer (H+), Head, Nuclear Data Section,
Reactor Physics Design Division, 5th Floor, Central Complex,
Bhabha Atomic Research Centre, Trombay,
Mumbai-400085 India

1. Introductory Remarks

Presently the nuclear data physics activities in India encompass already the following activities to meet the design needs of thermal, fast, fusion and accelerator driven subcritical systems. The nuclear data physics activities are making steady progress and are part of a declared thrust area in the programmes of the Department of Atomic Energy.

- Basic nuclear data physics measurements using facilities in India and abroad. The neutron induced fission cross sections of Pa-233 has been measured and published. Attempts to measure the neutron induced fission cross sections of Pa- using Surrogate technique are underway.
- EXFOR compilations. An EXFOR training Workshop with faculty from the IAEA is planned for the period, November 9-13, 2009. The venue is Mumbai.
- Nuclear model based calculations using codes such as TALYS and EMPIRE are being continued.
- Processing of evaluated nuclear data files to produce plug-in libraries for discrete ordinates and Monte Carlo codes. Updating of ORIGEN nuclear data for radio-toxicity estimations.
- Efforts to digest the status of covariance error methodology in nuclear data and its applications. The concept of evaluation of nuclear data and ENDF/B technology is becoming popular. Evaluation of nuclear data, a new activity to India as such, is expected to be taken up with the formation of the Indian Nuclear Data Centre.
- Preparation of integral Indian experimental criticality benchmarks for integral nuclear data validation studies

This report presents an update over our previous 2008 progress report that India presented at the IAEA Technical Committee Meeting of International Network of Nuclear Reaction Data Centres (NRDC), 22-25 September 2008 at the Institute of Physics and Power Engineering in Obninsk, Russian Federation. *The 2008* progress report from India is available electronically at the website: http://www-nds.iaea.org/nrdc/nrdc_2008/ .

[1] *IAEA Technical Committee Meeting of International Network of Nuclear Reaction Data Centres (NRDC, 25-26 May 2009, IAEA Headquarters, Vienna, Austria, Europe.*

All the reactor physics applications oriented processing tasks at BARC and IGCAR have been actively continuing. The ENDF/B-VII.0 files are preprocessed by the PREPRO and processing by indigenous processing codes to produce our plug-in libraries for neutronic codes for a number of actinides, structural materials and fission products for applications to India's nuclear programme for energy and non-energy applications.

2. Indian EXFOR compilation activities

The details of IAEA accepted Indian EXFOR entries are available in "Full EXFOR Compilation Statistics", in the IAEA-NDS site as communicated by the NDS staff at the IAEA, S. Dunaeva:
http://www-nds.iaea.org/exfor-master/x4compil/progress_stat.htm

At the time of writing this report, the official count for the IAEA accepted EXFOR entries are as follows: 10 new entries in 2006, 33 in 2007, 9 in 2008 and 1 in 2009. The identification for coding into EXFOR of all the suitable Indian articles published in the literature was done by the IAEA-NDS staff.
India gratefully acknowledges and appreciates the initiative by the IAEA-NDS in deputing Dr. Otto Schwerer during September 4-8, 2006 period and Dr. Ms. Svetlana DUNAEVA during October 29-November 2, 2007 period as faculty in the Indian training workshops on EXFOR. India will be hosting the 2009 Workshop in Mumbai during November 9-13, 2009.

India considers the classical nuclear data physics activity of EXFOR compilation as an important activity of the Indian Nuclear Data Centre under formation. India Nuclear Data Centre offers to collaborate with other network of reaction data centres and help host more such training workshops on international co-ordination of EXFOR compilation activity in the coming years.

Presently, India Nuclear Data Centre has a responsibility to continue the EXFOR compilation activity and take up more classical nuclear data physics responsibilities. After the above-mentioned two IAEA-EXFOR training workshops, a Ph. D. student (Paresh Prajapati from MS University, Vadodara) is continuing to work with us in Reactor Physics Design Division. Thus far, this year, he, Dr. H. Naik, Dr. S. Singh (Radio Chemistry Division) together collaborated in the Indian Nuclear Data Centre's activity and have made 6 new Indian EXFOR entries (Reference: EXFOR entry with no: D6064, D6067, 33020, 33021, 33022 and 33023.

3. The online nuclear data services

The online nuclear data services (http://www-nds.indcentre.org.in/) mirror the nuclear data website of the Nuclear Data Section of the International Atomic Energy Agency (IAEA), Vienna (http://www-nds.iaea.org). The mirror site is becoming popular among researchers, students and other users of nuclear data in India.

Presented below for April 2009, as an illustration, is the monthly statistics of the use of online services, as retrieved by C. S. R. C. Murthy, Computer Division, BARC. Total hits were 52471 with a 17051247 Kbytes with a maximum of 14239 hits in one day during this month.

Monthly Statistics for April 2009		
Total Hits	**52471**	
Total Files	**36223**	
Total Pages	**17724**	
Total Visits	**1478**	
Total KBytes	**17051247**	
Total Unique Sites	**548**	
Total Unique URLs	**17791**	
Total Unique Referrers	**206**	
Total Unique User Agents	**214**	
	Avg	**Max**
Hits per Hour	**72**	**13304**
Hits per Day	**1749**	**14239**
Files per Day	**1207**	**2719**
Pages per Day	**590**	**6126**
Visits per Day	**49**	**218**
KBytes per Day	**568375**	**1980491**

The server is being maintained by BARC Computer Division - with manpower and machinery. *The MOU between DAE/BARC and the IAEA is expected to be continued beyond 2010.*

India Nuclear Data Centre which is under formation offers to collaborate with other network of reaction data centres and help in promoting the online nuclear data services in the coming years.

4. Experimental generation of nuclear data

Measurements of nuclear data of relevance to advanced reactor applications such as Advanced Heavy water Reactors, Compact High temperature reactors, thorium fuel cycle studies, fusion reactors, Accelerator driven systems are encouraged in India. Some selected examples of activities in this regard are mentioned below briefly.

- Determination of the ^{233}Pa (n, f) reaction cross-section from 11.5 to 16.5 MeV neutron energy by surrogate ratio method.

- Experimental 14 MeV nuclear activation data generation at the University of Pune, Pune, India.
- Experimental Studies on fast neutron and bremsstrahlung induced reaction and fission of actinides and preactinides.
- Measurements of MeV range neutron activation cross-sections using 14 MV BARC-TIFR Pelletron machine.

Determination of the neutron induced cross sections without using the neutrons and without using the target by surrogate ratio method.

Recently BARC measured ^{233}Pa (n, f) reaction cross-section from 11.5 to 16.5 MeV neutron energy using Li-6 beam hitting a Th-232 target. ^{233}Pa has a half-life of 26.967 days.

See for example:

B. Nayak, A. Saxena, D. C. Biswas, E. T. Mirgule, B. V. John, S. Santra, R. P. Vind, R. K. Choudhury and S. Ganesan,
"Determination of the ^{233}Pa(n,f) reaction cross-section from 11.5 MeV to 16.5 MeV neutron energy by surrogate ratio method,"
Physical Review C 78, 061602(R) (2008).

Presently, an attempt is being made by BARC to perform experiments in order to measure ^{234}Pa (n, f) reaction cross-section in tens of MeV neutron energy using Li-7 beam hitting a Th-232 target. ^{234}Pa has half-life of 6.7 hours.

Experimental 14MeV nuclear activation data generation at the University of Pune, Pune, India.

See for example:

B. Lalremruataa, S.D. Dholea, S. Ganesanb and V.N. Bhoraskara,
"Double differential cross-sections of (n,α) reactions in aluminum and nickel at 14.77 MeV neutrons,"
Nuclear Physics A Volume 821, Issues 1-4, 15 April 2009, Pages 23-35.

F.M.D. Attar, R. Mandal, S.D. Dhole, A. Saxena, Ashokkumar, S. Ganesan, S. Kailas and V.N. Bhoraskar,
"Cross-sections for formation of ^{89m}Zr through 90Zr(n,2n)^{89m}Zr reaction over neutron energy range 13.73 MeV to 14.77 MeV,"
Nuclear Physics A802, 1-11 (2008).

The 14 MeV data generation is continuing.

Experimental Studies on fast neutron and bremsstrahlung induced reaction and fission of

actinides and preactinides.

See for example:

Haladhara Naik, Annareddy Venkatramann Reddy, Srinivasan Ganesan, Devesh Raj, Kwangsoo Kim,Guinyun Kim, Young Do Oh, Due Khue Pham, Moo-Hyun Cho,In Soo Ko and Won Namkung

"Post-neutron mass yield distribution and Photo-neutron cross-section measurements in 209-Bi with 65-MeV bremsstrahlung,"

Journal of the Korean Physical Society, Vol. 52, No. 3, March 2008, pp. 934-939 2008.

Measurements of MeV range neutron activation cross-sections using 14 MV BARC-TIFR Pelletron machine by using ^{7}Li(P,n) reactions as neutron source below 5MeV neutron energy.

See for example:

Megha Bhike, A. Saxena, B. K. Roy, R. K. Choudhury, S. Kailas and S. Ganesan, "Measurement of ^{67}Zn(n,p)^{67}Cu, ^{92}Mo(n,p)^{92m}Nb and ^{98}Mo(n,γ)^{99}Mo reaction cross sections at neutron incident energies of E_n = 1.6 and 3.7MeV"

Accepted for publication in Nuclear Science and Engineering (2009).

It is planned to compliment these data below 5 MeV with measurements at 14 MeV using the D-T neutron generator.

5. CERN n_TOF international collaboration-Phase-2

After a Letter of Intent was signed by all member teams in the n_TOF Collaboration participating in Phase-1, the CERN management and the n_TOF Collaboration started in 2005 a negotiation for the definition of the Memorandum of Understanding (MoU) for the execution of experiments at the CERN n_TOF facility for Phase-2. CERN has accepted the LoI signed by the Director of BARC.

In 2008, a formal MOU between BARC and CERN was signed. The annual O & M fee (100% for 2008 and 50% for 2009) has also been paid by BARC in May 2009.

6. The informal collaboration with the Pohang 100 MeV electron LINAC

Dr. H. Naik, BARC visited Pohang as a visiting scientist for 3 months during the last quarter of 2008 and continued generation experimental data of photo-fission yields and photon induced neutron emission cross sections.

7. ENSDF Evaluation Activities.

The ENSDF evaluation activities and research work are being actively continued by Ashok Jain (IIT Rourkee), M. Gupta (Manipal), Gopal Mukherjee (VECC, Kolkata) and others. The Indian Nuclear Data Centre under formation will factor into account the continuation of these important nuclear data physics activities.

8. Integral nuclear data validation studies

India is formally listed as a contributor since 2005 in the International Handbook of Evaluated Criticality Safety Benchmark (ICSBEP) Experiments published by the USDOE-NEA for integral nuclear data validation studies (hhtp://icsbep.inl.gov). A document on PURNIMA-II (the ^{233}U nitrate solution) criticality experimental Indian benchmark has been published in the 2008 ICSBEP DVD handbook for nuclear data validation studies.

Reference: T.K. Basu, E. Radha, C.P. Reddy, K.K. Rasheed and S. Ganesan, "PURNIMA-II: U-233 Uranyl Nitrate Solution Reactor with Beryllium Oxide Reflector," International handbook of Criticality Safety Evaluation Project Organized by US-DOE (USA) and NEA-DB (France). ICSBEP Reference: U233-SOL-THERM-007, (2008).

9. DAE-BRNS projects on nuclear data physics topics in Indian Universities

The roadmap in nuclear data for the wide range of power and non-power applications in the Indian context encompasses a wide range of activities in the field of experimental generation of basic physics data, compilations, computerized visualizations and large data files information management, evaluations which include nuclear model based predictions, creating of computerized ENDF/B files, physics laws based nuclear data processing for multi-group and Monte Carlo applications, integral measurements and validations by use of experimental critical facilities. These voluminous numerical databases and activities include not only interactions with neutrons but also with gammas and charged particles as incident beams.

In India, we are including all the national laboratories and university teams using the DAE-BRNS mechanisms in order to evolve a streamlined and coherent activity of nuclear data for all our applications that will be sustainable.

Examples of such DAE-BRNS projects under active implementation include the following:

- Ongoing project: 14MeV neutron data physics project in Pune University.
- Ongoing project: Nuclear data physics activities at Jaipur University.
- Ongoing project: Measurements using the Microtron facility in Mangalore University.

- Ongoing project: Covariance error matrix in nuclear data physics at the Department of Statistics, Manipal University, Karnataka.
- Ongoing project, "Nuclear model based calculations of particle-nuclear interaction cross sections," at the Department of Physics, G.B. Pant University, Pantnagar, India.
- Ongoing project: "Studies for 14 MeV and fast neutron induced fission/reaction for AHWR and ADS applications", at the Maharaja Sayajirao University of Baroda, Vadodara.
- Project Proposal under review: Nuclear data physics project at Bharathiar University, Coimbatore, Tamilnadu. The project is entitled, ""Studies on nuclear fission reaction process with orientation to nuclear data needs of India's advanced reactor programme".

10. Efforts towards evolving a strong and sustainable Indian Nuclear Data Centre.

BARC is in the process of formally announcing the formation of a strong and sustainable Indian Nuclear Data Centre. This announcement is expected to be made formally. An EXFOR training Workshop with faculty from the IAEA that is planned for the period, November 9-13, 2009 will be conducted under the auspices of the proposed India Nuclear Data Centre.

Recruitment of permanent manpower to compile and co-ordinate EXFOR activity in India and with network of centres abroad will be one of the urgent tasks under the proposed Indian Nuclear Data Centre

A rather strong consensus that evolved from the various DAE-BRNS meetings during the last 5 years in India on nuclear data physics was the following: India with its serious nuclear programme needs establishing her own national nuclear data centre. The delegates also stressed that as a general rule, the generation of new nuclear data by the international and national communities should continue to be encouraged as more intense neutron sources, purer elemental / isotopic target samples and/or more efficient detectors and better electronics evolve. Required scientific activities also are extensive follow up of experimental data generation with a comprehensive compilation, critical evaluation, production of new ENDF/B formatted libraries extending to higher energies, and quality assured nuclear data processing activities to provide the designers/users/ of innovative systems with "ready to plug-in" processed data, that are integrally validated, for use in applications.

Acknowledgements: The author thanks Dr. S. Banerjee, Dr. R. K. Sinha, Dr. S. Kailas, Dr. R. Srivenkatesan, Dr. R. K. Choudhury and all the colleagues from various Divisions in BARC, IGCAR and other units of the DAE and colleagues in the Universities for having useful discussions and for having made this report possible. The professional interactions with the IAEA-NDS are gratefully acknowledged with sincere thanks.