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India: recent experimental activities in basic and integral nuclear data, and perspectives

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Abstract

An over-view is given of the experimental activities being undertaken in India during 2005-06 towards the generation of nuclear data by various laboratories/groups.

1 Introduction

A summary is given of some of the on-going experimental activities in India identified with basic and integral nuclear data. We also present some brief information on a forthcoming workshop on nuclear data in India in 2006. On-going experimental efforts at BARC to obtain fission product yield data for various actinides are described. Development efforts to obtain accelerator-based neutron sources are noted. Interestingly, neutron activation measurements performed in the mid-1980s using 14-MeV neutrons at Pune University have been erroneously omitted in earlier disseminations of information, and are presented below. Technological improvements in the 14-MeV neutron source facilities planned for the units in BARC and Pune are briefly outlined. An outline is given of the status of the benchmarking of Indian integral experiments to international quality. Efforts to achieve n_TOF capabilities are noted. Finally, a brief description is given of new nuclear data measurements to explore the use of the Pelletron accelerator in Mumbai and the microtron accelerator in Mangalore.

2. Meetings

Several meetings in India on nuclear data have been encouraged, approved and successfully held in the previous two years, sensitizing the Indian scientific community to the importance of nuclear data and related scientific topics and issues. These professional meetings were all well received.

An interesting proposal is being processed by the authorities to hold a workshop in 2006 on nuclear data to cover all known topics in the field of nuclear data and will have a broad scope similar to that of ND2004. The dates and the venue have already been finalized: 8-11 November 2006, Microtron Centre in Mangalore University. A website will be created soon (before the end of May 2006), and international participation is expected and would be most welcome.

3. Fission product yield data of various actinides

The information written in this Section is based upon input generously contributed by H. Naik of Radiochemistry Division, BARC.

Cumulative fission yields of various long-lived fission products have been experimentally determined in the fast neutron-induced fission of ^{232}Th, ^{238}U, ^{237}Np, ^{238,240}Pu, ^{241,243}Am and ^{244}Cm using the track-etch cum gamma-ray spectrometric technique. Some of these data have been analyzed and published. These data were also used to carry out mass and charge distribution studies. A radiochemical off-line gamma-ray spectrometric technique was used to determine experimentally the independent isomeric yields of various heavy mass fission products induced by fast neutrons on the above actinides and by thermal neutrons on other actinides (e.g. ^{229}Th, ^{232,233,235}U, ^{238,239,241}Pu and ^{245}Cm). These data were used to determine the fragment angular momentum of various fission products. There is a need to follow-up the entry of these data into EXFOR in the opinion of the author of this report.

4. Accelerator development for neutron sources

BARC has initiated the development of Low Energy (20 MeV) High Intensity Proton Accelerator (LEHIPA) as the front-end injector of their 1-GeV accelerator. The major components of LEHIPA are a 50-keV ECR ion source, a 3-MeV RFQ and a 20-MeV DTL. It is also planned to use this 20-MeV proton accelerator to generate intense beams of neutrons using indigenously-made beryllium targets. Neutrons produced in this way will be useful in the measurement of neutron cross sections. Extensive calculations and theoretical studies have been performed to assess the neutron source using the FLUKA (CERN) and CASCADE (DUBNA) codes.

The design of the 400-keV, 1-mA RFQ for the generation of deuteron beams has been completed at BARC. The total length of this LINAC including the LEBT section is about 2.25 m, and transmission at the exit is 95 %. A detailed 3D design of this RFQ has been completed, including the beginning and end cells, tuners and vacuum ports. The tuning range of all 16 tuners (each of 4.5 cm diameter) was observed to be -2.1 to 4.29 MHz for a penetration of -15 to 10 mm. Detuning due to all the 8 vacuum ports is 900 kHz, which can be compensated for by inserting the vacuum port assembly in the volume of the RFQ by 3 mm. Thermal analysis of this RFQ has also been done. More details are available in the paper by Rao *et al.*, available at the Website of the Proceedings of INSAC-2005.

5. Neutron activation cross-section measurements using 14-MeV neutrons

India has formally joined the 6 billion dollar ITER Project as an equal partner contributing 500 million dollars. This activity has created increased awareness of the need for 14-MeV fusion reactor related nuclear data for the development of low activation materials and tritium breeding. The latter is a crucial issue to sustaining ITER on the basis of the D-T fuel cycle and to producing sustained fusion power. As a result of these new developments, the high quality FENDL-2 nuclear database of the IAEA-NDS as tailored to the engineering design of ITER is receiving increased usage and attention in India.

The 14-MeV neutron facility (400-kV DC accelerator for deuteron) at the PURNIMA facility in BARC is functional. Since the facility is rather old, the set up is presently undergoing beam line replacement. Tritium targets are made indigenously. However, no experience exists in India in building long and complex structures (such as CW RFQs) to handle high RF power. Therefore, it was thought prudent to develop an RFQ of lower current, requiring lesser RF power at the same frequency of 350 MHz. This RFQ will replace an existing 400-kV DC accelerator for deuteron at PURNIMA, which is used as a neutron generator, and is expected to enhance the neutron output up to about 10^{10} neutrons/sec (actual value will depend upon the beam current and the tritium target design and usage/life).

A totally indigenous (D, T) based neutron source has been functional in Pune University, and has been in operation for teaching and research since the early 1980s. This facility had escaped the attention of the nuclear data community in India. Deuterium ions were accelerated to an energy of 175 keV, and bombarded on an 8 Curie tritium target mounted at the end of the accelerating column. The ion current was varied in the range of 100 to 150 μA to obtain a neutron flux of ~ 10^8 n/cm^2/sec. Powder of a natural element or enriched isotope weighing in the range of 10 to 100 mg was wrapped in an aluminum foil of known weight and packed in a polyethylene vial. Five such samples were made for each element, and the aluminum served as a monitor element. Similarly, other samples were prepared by wrapping elemental powder with Fe powder in a thin polyethylene sheet.

Experimental data for a number of activation cross sections were generated at Pune by Bhoraskar and colleagues in the mid-1980s using the 14-MeV facility. We only became aware of this activity a few months ago as a result of our meetings to discuss nuclear data. These data have not yet been submitted to the IAEA in EXFOR format. This task of coding the data into EXFOR will be encouraged and hopefully performed this year. Measurements of the cross-sections of a few (n, n'), (n, 2n), (n, p) and (n, α) reactions were successfully performed by the Pune team using the activation method (see Table 1). These values are reproduced in this report for illustrative purposes only, and are taken from an unpublished presentation made by Prof. V. N. Bhoraskar in July 2005 at BARC – thus far, that have not been coded into EXFOR.

New measurements of 14-MeV cross sections using the BARC and Pune neutron sources will be undertaken in 2006-2007. Budgetary allocations have already been made, and two PhD students have been recruited.

Table 1. Data measured at Pune in mid 1980s (Courtesy of Prof. V.N. Bhoraskar, Pune University).

Number	Reaction	Experimental cross-section (mb)
1	^{54}Cr (n, p) ^{54}V	18 ± 2
2	^{53}Cr (n, p) ^{53}V	48 ± 6
3	^{52}Cr (n, p) ^{52}V	93 ± 8
4	^{48}Ti (n, p) ^{48}Sc	83 ± 7
5	^{29}Si (n, p) ^{29}Al	103 ± 10
6	^{120}Sn (n, α) ^{117}Cd	2 ± 0.2
7	^{54}Cr (n, α) ^{51}Ti	27 ± 3
8	^{51}V (n, α) ^{48}Sc	18 ± 2
9	^{30}Si (n, α) ^{27}Mg	81 ± 7
10	^{90}Zr (n, 2n) ^{89}Zr	604 ± 28
11	^{79}Br (n, 2n) ^{78}Br	1014 ± 50
12	^{63}Cu (n, 2n) ^{62}Cu	561 ± 25
13	^{58}Ni (n, 2n) ^{57}Ni	36 ± 2
14	^{54}Fe (n, 2n) ^{53}Fe	10 ± 0.5
15	^{50}Cr (n, 2n) ^{49}Cr	24 ± 1
16	^{46}Ti (n, 2n) ^{45}Ti	47 ± 2
17	^{207}Pb (n, n') ^{207m}Pb	160 ± 23
18	^{79}Br (n, n') ^{79m}Br	40 ± 3
19	^{74}Se (n, 2n) ^{73m}Se	45 ± 3
20	^{96}Ru (n, n'p) ^{95m}Tc	135 ± 8
21	^{115}In (n, p) ^{115}Cd	13 ± 1

Future plans at Pune are as follows:

1. Cross-sections for the (n, n'), (n, 2n), (n, p) and (n, α) reactions at neutron energies in the range from 13.48 to 14.77 MeV will be measured by irradiating samples at different angular positions relative to the deuteron beam on tritium target.
2. Cross-sections of the nuclear reactions induced by 14-MeV neutrons on interaction with elements such as tantalum, tungsten, lead, etc., that are likely to be used in the ADS programme.
3. Cross-sections for the formation of the metastable states for nuclei at 14-MeV neutron energy, and estimation of the isomeric ratio (IR= $\sigma_m/\sigma_m + \sigma_g$)
4. Angular distribution of α particles and protons emitted in the (n,α) and (n, p) reactions induced by 14-MeV neutrons.

6. Integral reactor irradiation experiments

Several thorium bundles irradiated in the 220-MWe PHWRs (KAPS) are undergoing PIE and chemical analysis.

Detailed experiments involving integral parameter measurements are being planned in the proposed experimental critical facility for AHWR (already under construction).

The KAlpakkam MINI (KAMINI) reactor is a ^{233}U-fueled light water moderated and beryllium oxide reflected research reactor. Our report on KAMINI has been accepted as a benchmark of international quality**.** The uncertainty of the KAMINI benchmark in characterizing the predicted k_{eff} is ± 0.00744. Thus, India is formally listed as a contributor in 2005 in the International Handbook of Evaluated Criticality Safety Benchmark Experiments as published by the USDOE-NEA.

Preparations for an Indian experimental benchmark on thorium irradiation experiments and burn-up measurements in PHWRs are in progress. Scientists from the Nuclear Power Corporation of India operate these reactors, and are also actively involved in the studies. H. Dalle from Brazil visited BARC under the IAEA visiting Fellowship scheme to undergo training and participate actively in this PHWR-thorium-PIE benchmarking study. The experimental thorium PIE data as generated in India is unique - no other country has irradiated thoria bundles to such high burn-ups in a power reactor (508 days of full power operation in a 220-MWe PHWR) and performed PIE. India is willing to share these unique data and benefit by exchange of information throughout the world.

7. Measurement of neutron total cross-sections by the n_TOF technique

1. BARC Director has signed the Letter-of-Intent to join Phase-2 of the n_TOF experiments in CERN. During the next few months, a formal MOU is expected to be signed between BARC and CERN.

2. Proposals to make a Fermi neutron-chopper based on neutron time-of-flight measurements with our 100-MW DHRUVA reactor facility have gone through an initial peer-review. Activation measurements to characterize the neutron strength and energy spectra in the exit beam hole have been initiated. These source characterization experiments are expected to be completed in the coming few months. If these efforts are successful, a useful tool would become available in India to measure the energy-dependent cross-sections by means of the time of flight (n_TOF) technique in the energy range from thermal neutrons to a few tens of eV to generate nuclear data as well as for research and educative purposes.

3. The neutron Time-of-Flight (TOF) technology is already familiar to basic nuclear physicists in India. For example, energy analyses by n-TOF are being performed by staff at the Nuclear Physics Division of the Pelletron Laboratory located at the Tata Institute of Fundamental Research. These studies focus on the emerging neutrons in heavy ion fusion reaction experiments. Proposals are evolving to build a 100-kW or more powerful electron LINAC-based neutron source in India.

4. The informal collaboration with the Pohang electron LINAC facility is continuing. K. Devan (scientist from IGCAR, Kalpakkam) spent a few months in 2005 as a Post-Doc in Korea at the Pohang facility.

8. Exciting trial runs using the Pelletron accelerator

A multi-divisional collaborative effort has been successfully undertaken to measure neutron cross sections using the Pelletron TIFR accelerator in the 1 to 30-MeV neutron energy region. This experiment was both preliminary and exploratory in nature.

- TIFR accelerator experiments were carried out from 25 to 28 February 2006;
- using Li (p, n) reaction at the TIFR Pelletron Laboratory;
- first such experiments in India;
- relative measurement using ^{197}Au foil as the standard monitor;
- ^{56}Fe (n, p) cross section measured experimentally at 10.2 MeV, and ^{58}Ni (n ,p) and ^{63}Cu (n, p) reactions at 3.2 MeV - energy of the neutron was defined as E(proton) – Q(~ 1.8 MeV) in forward angle;
- we are exploring further possibilities to utilise the TIFR Pelletron for the generation of neutron-induced nuclear reaction data. For example, the measurement of the ^{231}Pa (n, γ) cross section at 0.5 MeV is under consideration at BARC in view of the absence of experimental data in the EXFOR database.

The raw data are being analyzed in detail at the time of writing this report.

9. Microtron at Mangalore

A number of research and development activities have been carried out using the electron accelerator at the Microtron Centre. As the first of its kind in the country, this electron accelerator is capable of delivering electrons with energies of 8/12 MeV, intense bremsstrahlung photons of peak energy 8/12 MeV, and an electron current of 50 mA (max). The bremsstrahlung converter is a water-cooled tantalum circular disc of thickness 1.91 mg/cm^2. At present the machine can deliver intense bremsstrahlung radiation and neutrons with a yield of 10^9 neutrons/sec using a suitable neutron converter of beryllium. The bremsstrahlung photons from the microtron are made to fall on cylindrical beryllium discs of appropriate dimension to get fast neutrons. Beryllium has been selected for this purpose because of its low reaction threshold (1.67 MeV) for neutron production. Neutron yields of 10^9 neutrons/sec were obtained using the neutron converter. Fast neutrons are thermalised using high density polyethylene, borated wood and borated rubber. Both the neutron source strength and energy spectra have been confirmed by calculation and foil activation experiments and unfolding.

The photo-fission experiments using a ^{232}Th target and bremsstrahlung radiation from the microtron facility at Mangalore have already been successfully performed. A self-supporting ^{232}Th target was used in the present study (rolled metallic foil of 2.5 mg/cm^2 thickness and 10 mm diameter). The fission fragments were detected in a Lexan polycarbonate plastic film strip mounted on the circumference of the cylindrical photofission. SSNTD films were employed to study the fission fragments. The experiment was carried out for all possible energy values using the microtron facility. This study will assist in defining the shape of the fission barrier, angular distribution and other important aspects. The data are being analyzed in detail at the time of writing this report.

10. Concluding remarks

We have briefly summarized some of the recent experimental activities that have and are taking place in India to determine basic and integral nuclear data. The culture and practice of coding the basic experimental data into the EXFOR format for submission to the IAEA is being initiated.

Basic nuclear physics experiments to understand the structure of the nucleus are being performed using the FOTIA accelerator in BARC, the Pelletron accelerator in TIFR, the cyclotron at VECC, Kolkata, 15UD Pelletron Accelerator at the Nuclear Science Center (NSC), New Delhi (especially for the study of heavy ion fusion reactions) and most recently at the Microtron Centre in Mangalore. Interested reader may consult the Web for more information.

India has developed indigenously, and operates world class radiochemical laboratories, research reactors APSARA (30-kWth), CIRUS (40-MWth) and DHRUVA (100-MWth), well equipped radiation detection and measurement systems for post-irradiation examination studies, and other associated facilities along with large teams of well-trained manpower.

Indian nuclear data studies are based on the user-oriented approach starting with the nuclear data files available from the IAEA. Current activities in India represent a significant quantum jump, and go considerably beyond earlier perspectives. India is initiating sustainable R&D programmes on her own in the fields of nuclear data evaluation, processing and integral testing, in which nuclear data is viewed as a major area of thrust. Successful initiatives encompass experimental neutron data measurements using accelerator and reactor-based neutron sources and an integral validation programme of the reactor physics data for the Advanced Heavy Water Reactor.

India recognizes that nuclear data measurements involve cutting-edge technologies such as powerful neutron sources, advanced electronics for data analyses, and availability of pure isotopic and elemental targets. Encouragement is being given to these indigenous and creative efforts to develop all of these capabilities and to sustain them over the longer term.

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