

Nuclear data measurement activities at CIAE

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Abstract. China Institute of Atomic Energy (CIAE) is one of the most important bases for nuclear data measurement in China. In this paper, the nuclear data measurement activities at CIAE in recent years are presented. The secondary neutron emission DX and DDX measurement, the integral experiment for nuclear data benchmarking, the excitation function measurement, the neutron induced fission yields measurement and the gamma production yields measurement carried out in recent years are introduced. Furthermore, the progress of some new facilities and proposed plans (e.g. A Gamma ray Total Absorption Facility (GTAF) for (n,γ) reaction cross section measurement, A ^3He detector array for $(n,2n)$ reaction cross section measurement, the back streaming white neutron beam for nuclear data measurement at China Spallation Neutron Source (CSNS)) are also presented.

1. Introduction

The goal of nuclear data activities in China is supplying the nuclear data to feed the needs of the nuclear energy development, nuclear science study and nuclear technology applications. China Institute of Atomic Energy (CIAE) is one of the most important bases for nuclear data measurement in China. The facilities used for nuclear data measurement and study include the HI-13 tandem accelerator, 600 kV-Cockcroft-Walton accelerator and 5SDH-2 2×1.7 MV tandem accelerator. In addition, the China Experimental Fast Reactor (CEFR, 65 MW) reached critical on 21 June 2010, and China Advanced Research Reactor (CARR, 60 MW, the maximum neutron flux: 8×10^{14} n/cm²·s) reached critical on 13, May 2010 at CIAE, were also used for nuclear data related research. The China Spallation Neutron Source(CSNS) [1,2] will also be put into operation in 2018. A white neutron source beam line [3,4] based on CSNS will be available mainly for nuclear data measurement at that time. In this paper, the nuclear data measurement activities at CIAE in recent years are presented, and also the progress of some new facilities and proposed plans are given.

2. Recent progress of nuclear data measurement at CIAE

2.1. Excitation function measurements

1. $^{69}\text{Ga}(n,2n)^{68}\text{Ga}$ cross section measurements.

This measurement was performed with the 600 kV-Cockcroft-Walton accelerator in CIAE at the neutron energy of 14.1 and 14.9 MeV with activation method. Based on the measurement, the existing experimental data of $^{69}\text{Ga}(n,2n)^{68}\text{Ga}$ cross section were re-evaluated and a new evaluation was proposed based on CENDL-3.1.

In this work, the most important finding is that the 511 keV gammas from the positron annihilation of ^{68}Ga are very difficult to measure accurately. Therefore the experimental data obtained by measuring 511 keV gammas may be questionable. And the branching ratio of ^{68}Ga decay should be re-evaluated [5].

2. $^{241}\text{Am}(n,\gamma)$ cross section measurement at thermal energy.

The experiment was carried out to measure the cross section of $^{241}\text{Am}(n,\gamma)^{242g}\text{Am}$ reaction at the thermal neutron beam of the 49-2 swimming pool reactor in CIAE. The ^{241}Am sample was irradiated with a neutron beam with the flux of about 5×10^{10} n/cm²/s. After irradiation, the alpha particles from ^{242}Am were measured with a silicon detector. The preliminary result obtained in this work is 657 ± 14 mb, and proved that this cross section is measurable with current experimental conditions.

2.2. Fission yield measurement

The fission yields of ^{235}U at 3 MeV, 14 MeV and ^{252}Cf spontaneous fission neutrons, ^{232}Th at 14 MeV neutrons were measured. Fission product activities were measured by a HPGe γ -ray spectrometer. Fission yields were determined by method of R-values relative to ^{140}Ba . Combined with previous measurements, part of the energy dependent fission yield for $n+^{235}\text{U}$ fission reaction was shown in Fig. 3. One can see that the fission yields for some energy points can deviate from a linear function more than 10%. They agree with the systematic calculation result.

In addition, the technique for fission product mass yield distribution measurement is under development at CIAE. The E-v method of measuring the kinetic energy(E) and velocity(V) of outgoing fission products has been utilized, with the goal of measuring the mass resolution better than 1 atomic mass units(amu),could identify every mass for light fission products of unsymmetrical fission.

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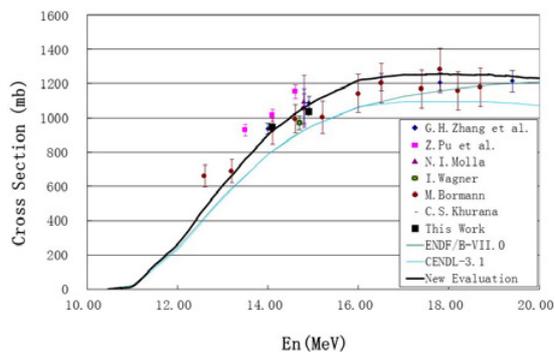


Figure 1. Measured result of $^{69}\text{Ga}(n,2n)^{68}\text{Ga}$ cross section compared with other measurements and evaluations.

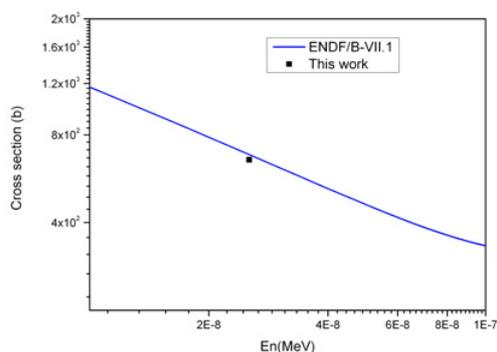


Figure 2. The preliminary result of $^{241}\text{Am}(n,\gamma)^{242g}\text{Am}$ cross section at thermal energy.

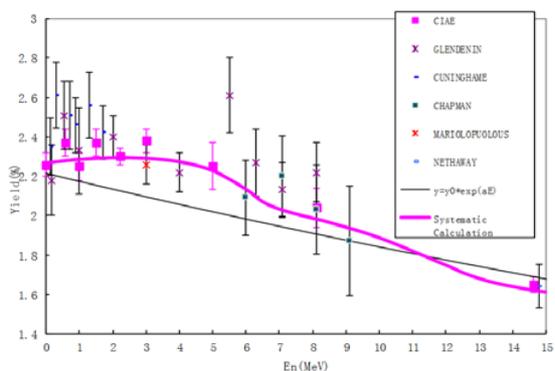


Figure 3. Energy dependent fission yields of ^{147}Nd from ^{235}U fissions.

2.3. The secondary neutron emission double-differential cross section measurement

The measurement of the double-differential cross sections (DDXs) of ^9Be at 22 and 25 MeV neutron energies and the measurement of DDXs of D at 8 MeV have been finished. These measurements are performed with the multi-detector fast neutron TOF spectrometer at the HI-13 Tandem Accelerator in CIAE. The diagram of the spectrometer is shown in Fig. 4. The 22 MeV neutrons were produced by the $\text{T}(d, n)^4\text{He}$ reaction with a tritium gas target, while the 8 MeV neutrons were produced by $\text{D}(d, n)^3\text{He}$ reaction with a deuterium gas target. The scattering samples were placed at 0° with respect to the deuteron beam about 20 cm away from the centre of the gas target. A polyethylene sample was used to obtain the n-p scattering yield, and this yield was used for cross section normalization. More

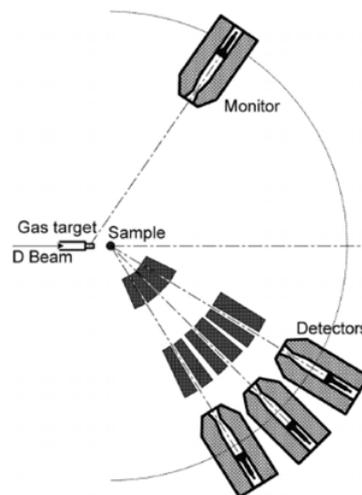


Figure 4. Schematic view of the multi-detector fast neutron TOF spectrometer at CIAE.

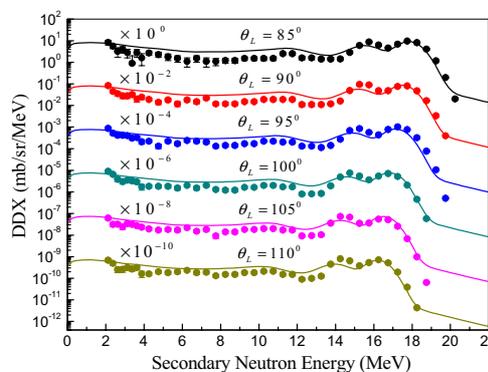


Figure 5. Part of the measured DDXs for Be at 22 MeV.

details about the experiments and the data analysis can be found in Refs. [6–8].

Figure 5 shows part of the measured DDXs result of Be at 22 MeV, comparing with theoretical calculation with the LUNF code.

2.4. The gamma production yields measurement

A HPGe detector array consists of 4 Clover detectors and 4 planar HPGe detectors was developed for this purpose. The detection system was used to measure the prompt γ rays from $(n, xn\gamma)$ and $(n, n'\gamma)$ reaction. Based on the 600 kV-Cockcroft-Walton accelerator in CIAE, the measurements for $^{nat}\text{Fe}(n, n'\gamma)$ and $^{235,238}\text{U}(n, 2n\gamma)$ have been carried out. Pulsed and direct current beam have been used to study the time dependent backgrounds. With the measurement of ^{nat}Fe target, the detection system was validated. In the experiment of ^{238}U target, A few γ rays from $^{238}\text{U}(n, xn)$ reactions have been observed, and the cross sections obtained are consistent with others' measurements. The data analysis of $^{235}\text{U}(n, xn\gamma)$ is ongoing.

2.5. Nuclear data benchmark experiments

The aim of the experiments is to make nuclear data benchmark for various important materials for the R&D of new generation nuclear energy systems such as CIADS(Chinese Initiative Accelerator Driven System) and TMSR in China. For this purpose, the neutron leakage



Figure 6. The HPGe detector array at CIAE.

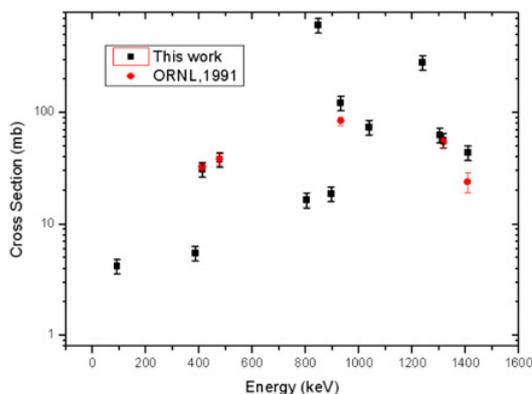


Figure 7. The measured results for $^{56}\text{Fe}(n,n'\gamma)$.

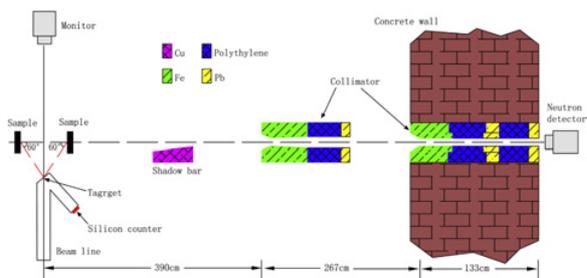


Figure 8. The experimental arrangement for the integral experiments.

spectra in the energy range from 0.8 to 15 MeV from slab samples were measured by time-of-flight technique with a BC-501A scintillation detector. The measurements were performed at China Institute of Atomic Energy (CIAE) using a d-T neutron source. Figure 8 shows the experimental arrangement. The thicknesses of the slabs were 0.5 to 2.5 mean free paths for 14.8 MeV neutrons, and the measured angles were chosen to be 60° and 120°. The measured spectra were compared with those calculated by the continuous energy Monte-Carlo transport code MCNP, using the data in the CENDL-3.1, ENDF/B-VII.1 and JENDL-4.0 nuclear data files. Table 1 list the measured samples in recent years. More details can be found in Refs. [9–12].

Table 1. The measured samples.

Sample	Sample size/cm	Sample thickness/cm	Angle/°
^{238}U	10 × 10	5	45,135
Be	10 × 10	5,11	60,120
^{70}Ga	Φ13	3.2,6.4	60,120
^{187}W	10 × 10	3.5,7	60,120
Granular W	10 × 10	5	60
C	Φ13	20	60,120
SiC	Φ13	20	60,120
Pb	Φ13	5	60
Pb-Bi	Φ13	5	60
ThO ₂	Φ13	5.4,10.8	60,120
H ₂ O	Φ13	5.2	60
PE	Φ13 10 × 10	6 5	60 45

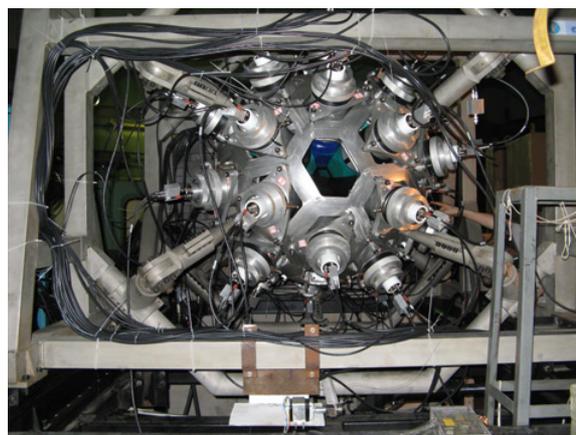


Figure 9. The GTAF facility at CIAE.

3. New facilities for nuclear data measurement

3.1. The gamma ray total absorption facility (GTAf)

To feed the needs of neutron capture cross section measurement, the Gamma ray Total Absorption Facility (GTAf) has been constructed [13]. The detector consists of 40 BaF₂ crystals. The neutron capture event detection efficiency is expected to be more than 95% with this facility. The construction of this facility is now finalized and the test physics run is undergoing.

3.2. ^3He detector array for (n,2n) reaction cross section measurement

Traditionally, the activation method was used to measure the (n,2n) cross sections. The advantage of this method is that the experimental setup is simple and high precise data can be obtained. But the disadvantage is that the half-life of the compound nuclei has to be suitable for off-line measurement, which blocks the measurement of a lot of interesting nucleus. To overcome this disadvantage, a detector array consists of 100 ^3He proportional counters has been developed. Figure 10 shows the detector system. Spherical design was adopted to make the detection efficiency more independent of neutron energy. The neutron detection efficiency is about 30% for neutron energy below 5 MeV.

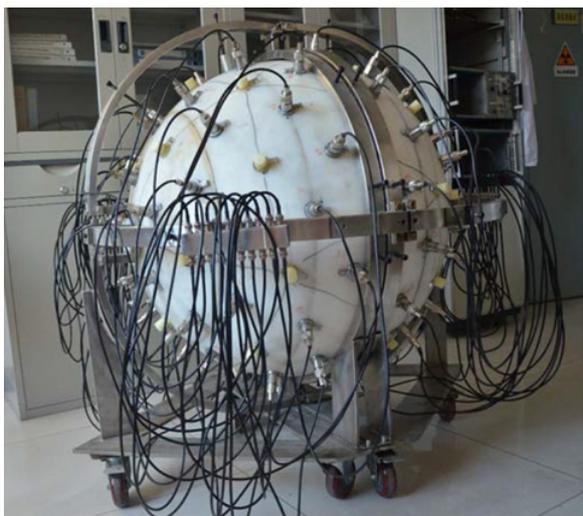


Figure 10. The ^3He detector array.

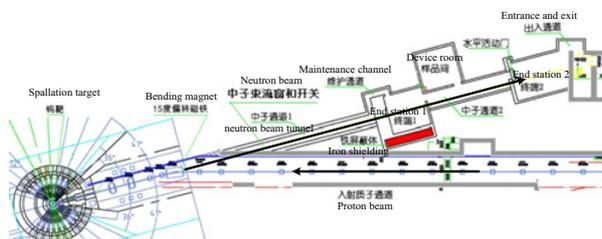


Figure 11. Layout of the CSNS back-streaming neutron beam tunnel and the experimental halls.

3.3. The back-streaming neutron beam line at CSNS

The China Spallation Neutron Source (CSNS) is a large scientific facility dedicated mainly to multidisciplinary research on material characterization using neutron scattering techniques. This project was officially approved by the Chinese central government in 2008, and will be in operation in 2018 for the 1st stage. In the first phase (CSNS-I), the machine will deliver 1.6 GeV protons on a tungsten target (TS1) with 100 kW beam power and a pulse repetition rate of 25 Hz. A back-streaming neutron beam line based on this machine was proposed and constructed mainly for nuclear data measurements.

A detailed study of the characteristics for the back-streaming neutrons at CSNS is described in Ref. [4]. Based on this study, a nuclear data measurement program using the CSNS back-streaming neutron beam was proposed. The layout of the neutron beam tunnel and

the experimental halls are shown in Fig. 11. Two end stations were constructed, with ~ 50 meters flight path for end station 1 and ~ 80 meters for end station 2, respectively. The end station 1 will be used for higher neutron flux required experiment while the end station 2 for better time resolution required experiment. In the first stage, the neutron total cross section measurement, capture cross section measurement with C6D6 detectors and fission cross section measurement with a normal ionization chamber are planned with this back-streaming neutron beam.

4. Conclusion

Substantial progress on nuclear data measurement has been made in China in recent years. More and more needs for nuclear data measurement have been required with the progress of the CIADS, TMSR and ITER projects in China. Some new facilities such as CSNS are under construction. These facilities will greatly improve the capability of the nuclear data measurement in China in the near future.

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