The Nuclear Data Measurement Activities in China

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Abstract. China, as a developing country with a great number of population and relatively less energy resources, actively emphasizes the nuclear energy utilization development. Meanwhile, the application of nuclear technology at different fields plays more and more important role. All these put forward new requirements to nuclear data measurements. The fast neutron physics laboratory in CIAE is the main base of nuclear data measurement in China. Different neutron sources ranged from 0.01MeV to 40 MeV are available. Many kinds of detector systems such as three detectors fast neutron time of flight spectrometer, abnormal geometry multi-detectors fast neutron time of flight spectrometer and HPGe-BaF_2 anti-Compton suppression spectrometer are available and a few new detector systems are under construction. The research activities are focused on ADS, fusion and fission related nuclear data measurements, astrophysics related nuclear data measurements and others. The main results in recent years are reported.

1. Introduction

China, as a developing country with a great number of population and relatively less energy resources, actively emphasizes the nuclear energy utilization development. Meanwhile, the application of nuclear technology at different fields plays more and more important role. All these put forward new requirements to nuclear data measurements.

China Nuclear Data Center (CNDC) is responsible for arranging the nuclear data activities in China under the guidance of China Committee of Nuclear Data. The fast neutron physics laboratory in China Institute of Atomic Energy is the main base of nuclear data measurements in China. There're more than 40 permanent scientific staffs in this laboratory. There're more than 30 students and temporary scientific staffs.

The research activities are focused on ADS, FBR, astrophysics, fusion and fission related nuclear data measurements and others.

2. Neutron Sources and Facilities

The existing facilities used for the nuclear data measurements and studies include China's first experimental heavy water reactor, the HI-13 tandem accelerator, 600kV-Cockcroft-Walton accelerator and 5SDH-2 tandem accelerator located in CIAE and 4.5-MV Van de Graaff accelerator at Peking University and 300kV-Cockcroft-Walton accelerator at Lanzhou university. Different neutron sources ranged from 0.01MeV to 40 MeV are available. The China experimental fast reactor and China advanced research reactor, which are under construction in CIAE and other nuclear experimental facilities under construction in China, will be used for nuclear data related research. The main features of these existing facilities and neutron sources are listed in table 1.

Many kinds of detector systems such as three detectors fast neutron time of flight spectrometer, abnormal geometry multi-detectors fast neutron time of flight spectrometer, HPGe-BaF_2 anti-Compton suppression spectrometer are available and a few new detector systems such as BaF_2 crystal ball, HPGe detector array are under testing.

TABLE I: MAIN FACILITIES AND NEUTRON SOURCES AVAILABLE IN CHINA

Facilities	Neutron Sources	Intensities (n/s)
Reactors		10^{14}
HI-13(15MV x 2) Tandem Accelerator	8-14 MeV (d+D)	10^{9}
	4-10 MeV (p+T)	10^{8}
	22-42 MeV (d+T)	10^{7}
1.7MV x 2 Tandem Accelerator	3-6 MeV (d+D)	10^{10}
	14-20 MeV (d+T)	10^{9}
	0.07-2.5 MeV (p+T)	10^{10}
	0.03-1.7 MeV (p+Li)	10^{9}
Neutron Generator	2.5, 14 MeV (dc/Pulsed)	10^{11}

The diagram of the normal fast neutron TOF spectrometer and the abnormal geometry multi-detector fast neutron time of flight spectrometer at the HI-13 Tandem Accelerator in CIAE is shown in Fig.1. The flight path is 5-10 m, and the size of detector is 4” x 2” and 7” x 4” [1].

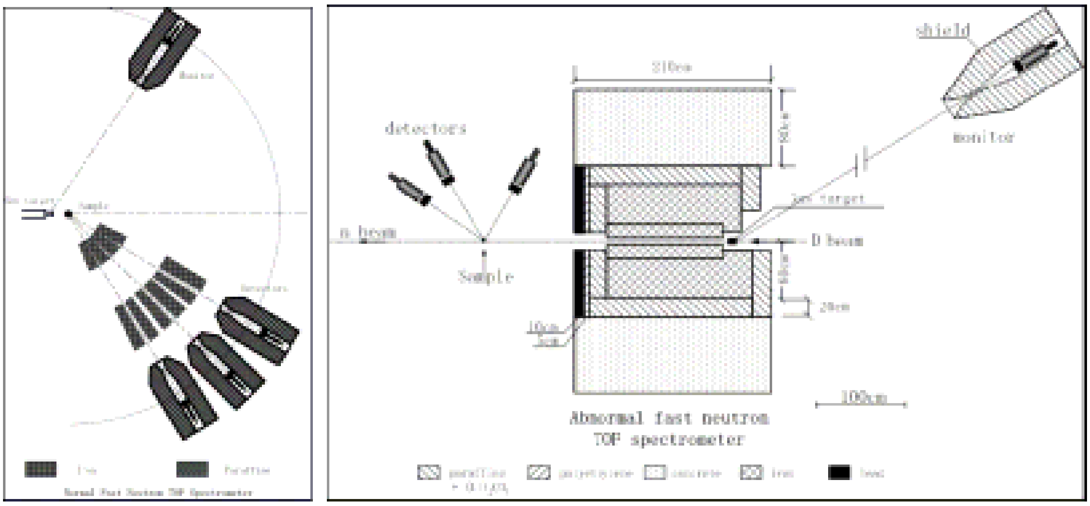

Fig.1 Schematic view of normal(left) and abnormal geometry (right) fast neutron TOF spectrometer.

Since the need of the (n, γ) cross-section is increasing due to nuclear waste transmutation and nuclear astrophysics, a new measurement facility, the gamma total absorption facility has been set up in CIAE, with which the (n, γ) cross-sections will be measured by detecting the prompt gammas from the capture of neutrons,. The detector consists of 42 BaF_2 crystals of 15 cm length and is shown in Fig. 2. Covering the almost full solid angle without gap requires two different crystal shapes. The shapes of the crystals are optimized in such a way that they all cover the same solid angle, although they have different shapes. The crystals described above can be arranged to form a closed sphere with an inner radius of 10 cm and an outer radius of 25 cm. The external support is made of stainless steel. The honey comb and support for crystals are made of aluminium. The construction of this system was finished last year in CIAE. Acknowledge: Nuclear Astrophysics Group in FZK, N-TOF Group in CERN, DANCE Group in LANL.

Fig.2 GTAF in CIAE

A HPGe detectors array to measure prompt γ rays has been built last year in CIAE and is shown in Fig. 3. It consists of 6 CLOVER HPGe detectors and 6 planar HPGe detectors. The relative efficiency of the CLOVER HPGe detector is 38%, and 26% for planar HPGe detector.

Fig.3 HPGe detectors array in CIAE

3. Measured Nuclear Data

The measurements of neutron reaction and nuclear decay data have been performed. A lot of neutron cross section, angular distribution, neutron emission spectra, double differential cross section and nuclear decay data for a mount of nuclei have been measured and the results have been evaluated and provide to the users. Many method studies of the nuclear data measurements were performed and some study fruits of them have been used in our nuclear data measurements. The main activities have been summarized as following.

3.1 Neutron Spectrum

Differential and double-differential cross sections of secondary neutron emission have been obtained for ^{238}U, ^{209}Bi, Fe, ^{9}Be, V, $^{6,7}Li$ etc at different angles in the range between 30 degrees and 150 degrees for 8~14 MeV. For normal geometry measurements, all the energy resolution is better than 5%. For abnormal geometry measurement, the energy resolution is about 17% due to the short flight path. The measured results were compared with the evaluations and the other measurements. A theoretical model based on the Hauser-Feshbach and exciton model for light nuclei was used to describe the double-differential cross sections of $n+^{6,7}Li$. Good agreement between theoretical calculation and measurement has been obtained[2]. Fig.4-6 show the results of $^{6,7}Li$ and ^{209}Bi. Differential cross sections of secondary neutron emission have been obtained for ^{209}Bi etc. at 37 and 40 MeV as shown in Fig. 7. The nd breakup of D(n, np)n reaction at 25MeV has been obtained[3,4].

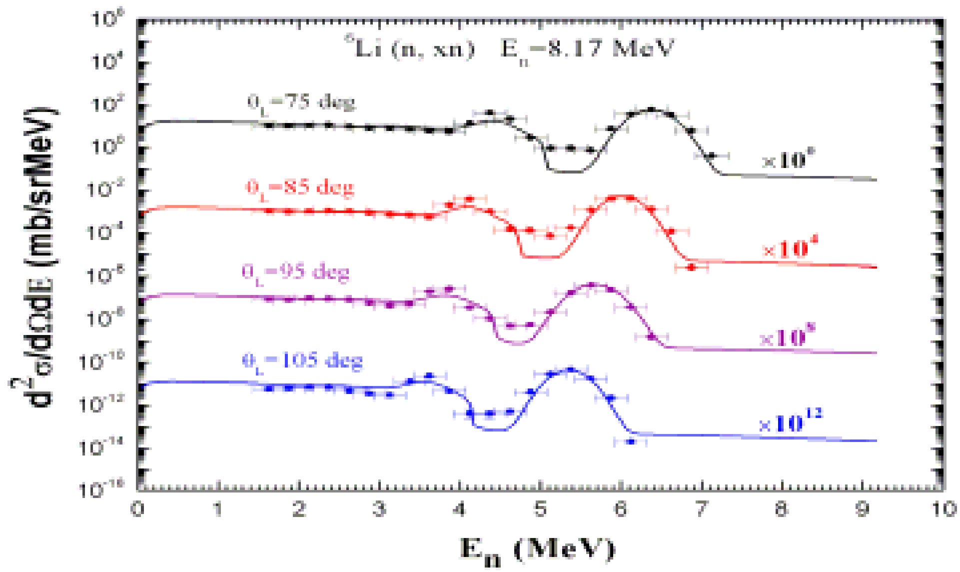

Fig.4 Measured DDXs for ^{6}Li at 8.17 MeV, compared with the theoretical calculation.

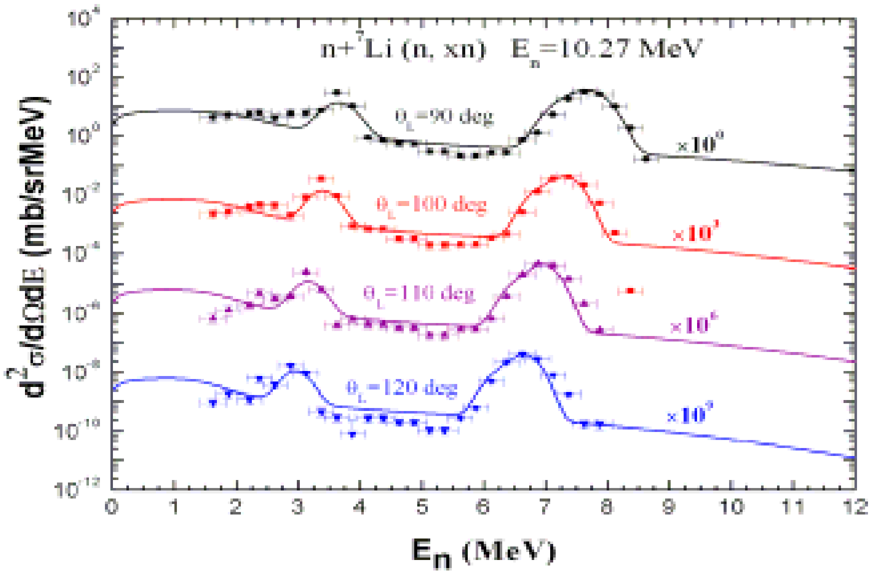

Fig. 5 Same as Fig.4 but for ^{7}Li at 10.27 MeV

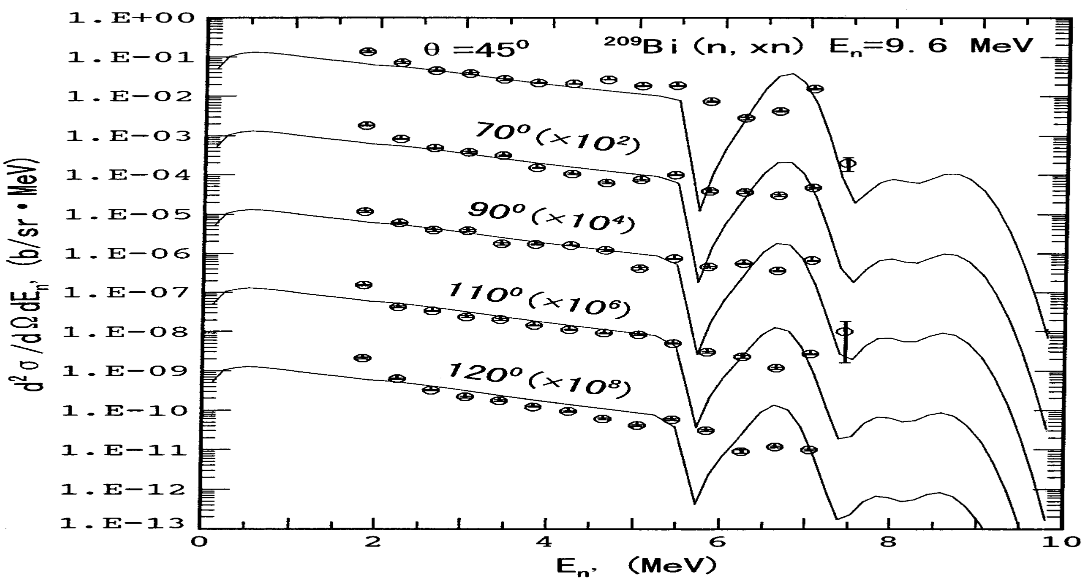

Fig. 6 Same as Fig.4 but for ^{209}Bi at 9.6 MeV

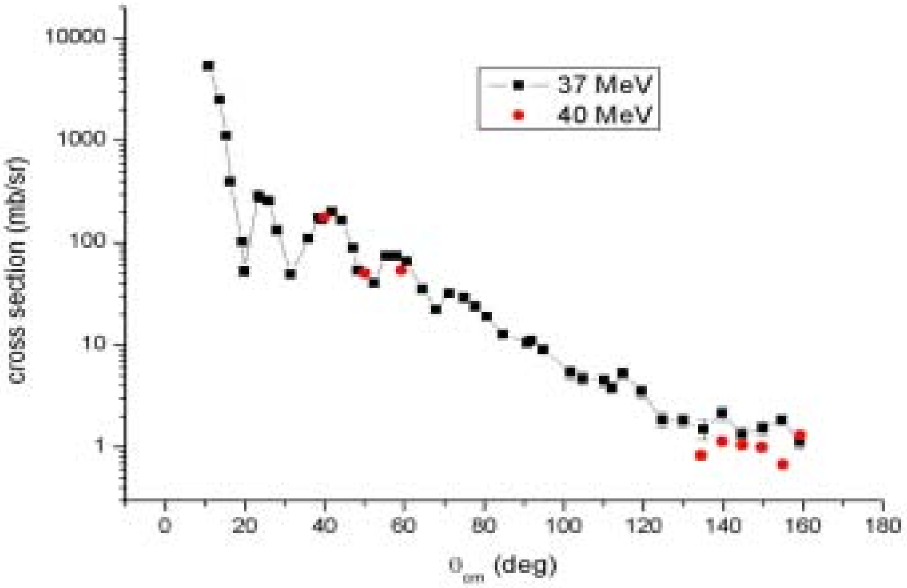

Fig.7 Measured elastic scattering for ^{209}Bi at 37 and 40 MeV

The neutron emission from (p, n) and (α, n) reactions have been obtained for $^{92\text{-}100}$Mo, ^{107,109}Ag, Sc, Sn etc.

3.2 γ production cross sections

The γ production cross sections of Fe, Al, C, O, N, ^{238}U etc have been measured with HPGe-BaF_2 anti-Compton suppression spectrometer. The relative efficiency of the HPGe detector is 60% which is surrounded with BaF_2 crystals.

3.3 Fission

The fission prompt neutron spectra of ^{238}U have been measured. The fission chamber consists of 103 layers of ^{238}U weighted 5 grams.

The fission fragments yields for ^{235}U and ^{238}U at thermal~22 MeV have been measured using the direct gamma spectrum method. The systematic behaviours of incident neutron energy dependent mass chain yields have been studied.

3.4 Excitation Function

Excitation functions of the reactions induced by proton or deuteron beam are very important and quite useful in nuclear technology applications. Some of them can be used to derive the thick-target yields, and this characteristic is significant for medicine isotope production. The excitation function of p, d, α induced activation cross sections and neutron induced cross sections were carefully measured and especially for low energy background (d-D self build in, breakup, etc.) correction[5]. The excitation function for the products of ^{48}V, from p+Ti and d+Ti and of $^{95m,g}Tc$, ^{96g}Tc, and ^{99}Mo from p+Mo, and d+Mo in the incident energy 6-22 MeV were studied.

The cross sections of $^{186}W(n,\gamma)^{187}W$ reaction were measured in neutron energy range from 0.5 to 1.5 MeV by the activation technique[6]. Neutrons were produced through the $T(p,n)^3He$ reaction, and the cross sections of the $^{197}Au(n,\gamma)^{198}Au$ reaction were used to determine the absolute neutron flux.

Using a gridded ionization chamber, the differential cross sections of the $^6Li(n,t)^4He$ reaction were measured at 1.05, 1.54, 1.85, 2.25, 2.67, 3.67 and 4.42MeV in Beijing University[7,8,9]. The total uncertainties of differential cross sections are 5.1~7.3 %.

3.5 Integral experiments

Integral experiments of plat polythene, ^9Be and Iron(100×100×100mm) are performed in CIAE. The leak spectra of 14 MeV neutrons have been measured by TOF technique , and this experiment was simulated by Monte-Carlo calculation with ENDF/B-6 library and CENDL-3.1 library.

3.6 Nuclear Astrophysics

^8Li (d, p) ^9Li[10,11], $^{11}C(d, n)^{12}N$[12], $^{13}N(d, n)^{14}O$[13], $^{13}N(p, p)^{13}N$[14] etc have been measured with the first radioactive beam line in CIAE.

4. Summary

During last decade, many facilities have been built for nuclear data measurements. A lot of neutron cross sections, angular distributions, neutron emission spectra, double differential cross sections and nuclear decay data for a mount of nuclei have been measured and the results have been evaluated to meet the need of the fast development of nuclear energy and the application of nuclear technology at different fields. In near future, the information of the nuclear structure for some important nuclei should be measured, for example, the information of discrete level for ^{238}U, because the information is very necessary for the most nuclear data model codes which are popular used in the nuclear data evaluation now. To meet the need of ADS research, the number of nuclei should be extend in the medium-high energy data file, and the incident neutron energy also should be increased. The nuclear data for light nuclei, structure material are also need for the international project ITER. Although these data have been included in the FENDL and other evaluated data files, higher accuracy and reliability are required, especially for deuterium and tritium etc.

References

1. Dankwart Schmidt, Zhou Zuying, Ruan Xichao et al.
"Application of non-monoenergetic sources in fast neutron scattering measurements", Nucl. Instr. and Methods in Phys. Research **A 545**(2005)658-682
2. Ruan Xi-Chao, Zhou Zu-Ying, Chen Guo-Chang et al.
"Measurements of neutron emission spectra for neutron induced reactions on ^{9}Be and ^{6,7}Li", High Energy Phys. and Nucl. Phys. **31-5**(2007)442
3. Z. Zhou, A.S. Crowell. J. Deng et al.
"The space-star anomaly in nd breakup at 25 MeV", Nucl. Phys. **A 684**(2001)545-548
4. X.C. Ruan, Z.Y. Zhou, X. Li et al.
"Experimental study of neutron-neutron quasifree scattering in the nd breakup reaction at 25 MeV", Phys. Rev. **C 75**(2007)057001
5. X.L. Huang, W.X.Yu, W.R. Zhao et al.
"The Effect of Low-Energy Neutrons on Activation Cross-Section Measurement", Nucl Sci Eng, **131-2**(1999)267-274.
6. G.H. Zhang, Z.M. Shi, G.Y. Tang et al.
"Interference of the Low-Energy Neutrons on Activation Cross Section Measurement of the ^{186}W(n,γ)^{187}W Reaction", Nucl Sci Eng, **137-1**(2001) 107-110.
7. G.H. Zhang, G.Y. Tang, J.X. Chen et al.
"Differential cross section measurement for the ^{6}Li(n, t)^{4}He reaction at 3.67 and 4.42 MeV", Nucl Sci Eng, **134-3** (2000) 312-316.
8. G.H. Zhang, G.Y. Tang, J.X. Chen et al.
"Measurement of Differential Cross-Sections of the ^{6}Li(n, t)^{4}He Reaction at 1.85 and 2.67 MeV", Nucl Sci Eng, **143-1** (2003) 86-89.
9. G.H. Zhang, R.T. Cao, J.X. Chen et al.
"Differential and angle integrated cross section measurement for the ^{6}Li(n, t)^{4}He reaction at En = 1.05, 1.54 and 2.25 MeV", Nucl Sci Eng, **153-1** (2006) 41-45.
10. Z.H.Li, W.P.Liu, X.X.Bai et al.
"The ^{8}Li(*d, p*)^{9}Li Reaction and the Astrophysical ^{8}Li(*n, γ*)^{9}Li Reaction Rate", Phys. Rev. **C71** (2005) 052801(R).
11. B.Guo, Z.H.Li, W.P.Liu et al.
"The ^{8}Li(*d, p*)^{9}Li Reaction and Astrophysical ^{8}B(*p, γ*)^{9}C Reaction Rate", Nucl. Phys. **A761** (2005) 162.
12. Liu Weiping, Li Zhihong, Bai Xixiang et al.
"Determination of ^{11}C(*p, γ*)^{12}N Astrophysical S-Factor via Measurement of ^{11}C(*d, n*)^{12}N Reaction", Nucl. Phys. **A728** (2003) 275
13. Z.H.Li, B.Guo, S.Q.Yan et al.
"The ^{13}N(*d, n*)^{14}O Reaction and the Astrophysical ^{13}N*(p, γ)*^{14}O Reaction Rate", Phys. Rev. **C74** (2006) 035801.
14. Y.B.Wang, B.X.Wang, X.Qin et al.
"^{13}N+p Elastic Resonance Scattering Via a Thick-Target Method", Phys. Rev. **C77** (2008) 044304.