Progress of Nuclear Data Measurement in China during 2013

Ge Zhigang, Ruan Xichao

China Committee of Nuclear Data, China Nuclear Data Center,
China Nuclear Data Key Laboratory, China Institute of Atomic Energy
P.O.Box 275-41, Beijing 102413, P.R.China, Fax:+86-10-69358119, E-mail: gezg@ciae.ac.cn

I. Introduction of China Nuclear Data Activities

The China nuclear data activities consists of nuclear data measurement and related measurement methods development, data evaluation and model study, data library establishment and library management, nuclear data benchmark and validation.

The main activities are being carried out at China Nuclear Data Center(CNDC), China Institute of Atomic Energy(CIAE) and China Nuclear Data Coordination Network(CNDCN). More than 10 institutions and universities are involved in CNDCN.

The facilities used for the nuclear data measurements and studies include the HI-13 tandem accelerator, 600kV-Cockcroft-Walton accelerator, 5SDH-2 2×1.7MV tandem accelerator and the China Advanced Research Reactor (CARR) at CIAE, The 4.5-MV Van de Graaff accelerator at Peking University and 300kV -Cockcroft-Walton accelerator at Lanzhou university.

Table 1 The neutron sources for neutron data measurement in China.

Facilities	Neutron energy	Intensity (1/s/sr)
Reactor	Thermal	10^{14} n/cm^2/s
HI-13 Tandem	8-26 MeV (d+D) 4-23 MeV (p+T) 22-42 MeV (d+T)	10^8 10^7 10^6
2×1.7 MV Small tandem	3-6 MeV (d+D) 14-20 MeV (d+T) 0.07-2.0 MeV (p+T) 0.03-1.3 MeV (p+Li)	10^9 10^8 10^9 10^8
Neutron generator	2.5, 14 MeV	10^8, 10^{10}
Neutron generator in LZU	2.5, 14 MeV (DC)	10^{11}

- Other facilities in China will not exceed this list in neutron energy and intensity

II. Recent Progress of Nuclear Data Measurement in China

- **Fission yield measurement**

The fission yields of ^{235}U at 3 MeV neutrons were measured at CIAE. The absolute fission rate was monitored with a double-side fission chamber. Fission product activities were measured by a HPGe γ-ray spectrometer. All data were normalized to ^{140}Ba(5.8%) as a standard. The preliminary results are shown in table 2.

Table 2 The preliminary measured results for 3 MeV neutron induced ^{235}U fission.

Products	1^{st} measurement	2^{nd} measurement	Averaged yields	Absolute uncertainty	Relative uncertainty
Zr-95	6.18	6.21	6.20	0.30	4.8%
	0.30	0.30			
Zr-97	6.00	6.12	6.06	0.25	4.1%
	0.25	0.30			
Mo-99	5.86	6.24	6.05	0.25	4.1%
	0.25	0.30			
Ru-103	3.36	3.29	3.33	0.12	3.6%
	0.12	0.15			
Ba-140	5.8	5.8	5.8		0.0%
Nd-147	2.39	2.30	2.35	0.10	4.3%
	0.09	0.10			

- **Nuclear data benchmark experiments**

The nuclear data benchmark system at CIAE was improved by adding a collimator and a shadow bar between the slab samples and the detector. And also the sample support frame was improved to precisely position the samples. Fig.1 shows the experimental system for the benchmark experiments.

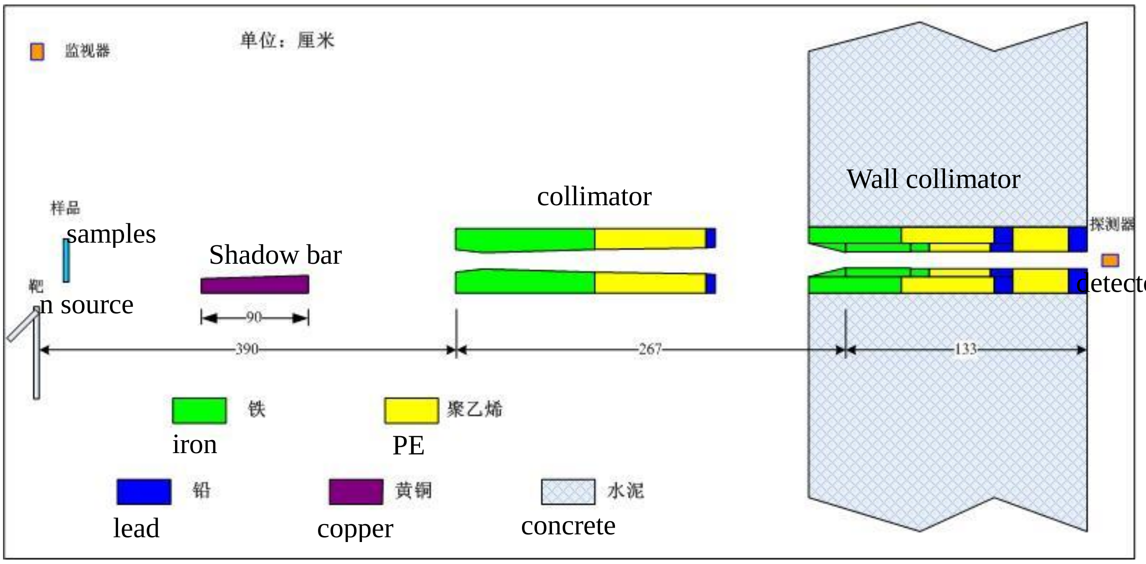


Fig.1 Experimental arrangement for the nuclear data benchmark experiments

With the new nuclear data benchmark system, the integral measurements were carried out for Be, Ga, natural iron and liquid Pb-Bi alloy. The neutron leakage spectra from the slab samples with different thickness induced by d-T neutrons were measured at 60 and 120 degrees. The experimental system was validated by a PE sample measurement during the experiment. Fig.2 shows the measured and simulated neutron leakage spectra for a PE sample. The well agreement between the measurement and the simulation indicate that the measured data are reliable. Fig.3

shows the preliminary result for 5 cm thickness Be at 60 degrees. The detailed data analysis is undergoing.

In addition, the benchmark experiments for ^{232}Th and W samples are planned in 2014.

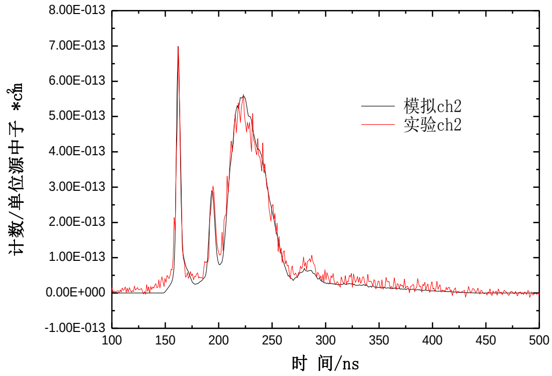


Fig.2 The measured and simulated neutron leakage spectra for a PE sample.

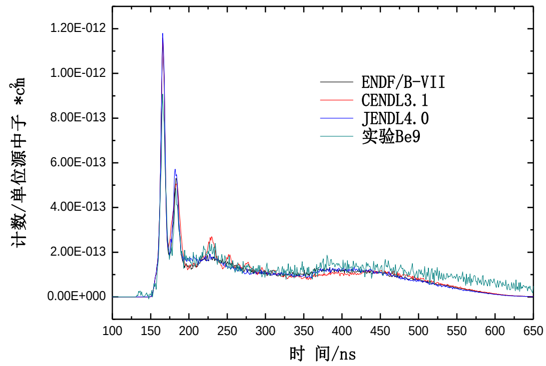


Fig.3 The preliminary result for 5 cm thickness Be at 60 degrees.

- **The measurements of the ^{57}Fe(n,α)^{54}Cr and ^{63}Cu(n,α)^{60}Co reactions in the MeV region at Peking University**

Cross sections of the ^{57}Fe(n,α)^{54}Cr reaction are measured for the first time and those of the ^{63}Cu(n,α)^{60}Co reaction are measured in the MeV region by direct experimental method. Both were carried out at neutron energies of 5.0, 5.5, 6.0 and 6.5 MeV using a double-section gridded ionization chamber and back-to-back double ^{57}Fe and ^{63}Cu samples. Experiments were performed at the 4.5 MV Van de Graaff Accelerator of Peking University. Monoenergetic neutrons were produced through the ^{2}H(d,n)^{3}He reaction with a deuterium gas target. Foreground and background were measured in separate runs. A ^{238}U sample and a BF_3 long counter were utilized for absolute neutron flux calibration and for neutron flux normalization, respectively. Present results are compared with TALYS-1.4 code predictions, existing measurements and evaluations.

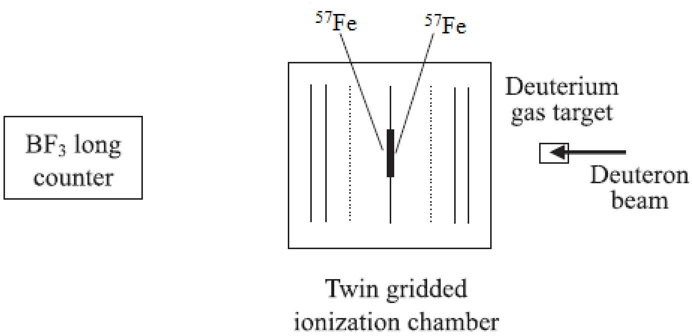


Fig.4 Setup of the experiment at Peking University.

Table 3 Description of samples.

Samples	Material	Isotopic abundance	Thickness ($\mu g/cm^2$)	Diameter (mm)	Backing
^{57}Fe	Enriched ^{57}Fe	95.9%	582.5[a] and 599.1[b]	45.0[a] and 41.0[b]	Ta sheet
^{63}Cu	Enriched ^{63}Cu	99.8%	770.0[a] and 781.0[b]	48.0[a] and 43.5[b]	Ta sheet
^{238}U	$^{238}U_3O_8$	99.999%	493.6 (^{238}U only)	45.0	Ta sheet

[a] Forward sample. [b] Backward sample.

Table 4 Measured cross sections for the $^{57}Fe(n,\alpha)^{54}Cr$ and the $^{63}Cu(n,\alpha)^{60}Co$ reactions (in mb).

E_n (MeV)	^{57}Fe				^{63}Cu
	(n,α_0)	(n,α_1)	(n,α_2)	(n,α)	(n,α)
5.0	1.53 ±0.18	1.44±0.18		3.11±0.34	1.69±0.17
5.5	1.97±0.22	2.33±0.28		4.69±0.47	3.40±0.32
6.0	1.93±0.23	3.31±0.36	0.55±0.11	6.11±0.61	5.01±0.47
6.5	1.84±0.22	3.68±0.40	0.82±0.13	7.27±0.65	8.35±0.80

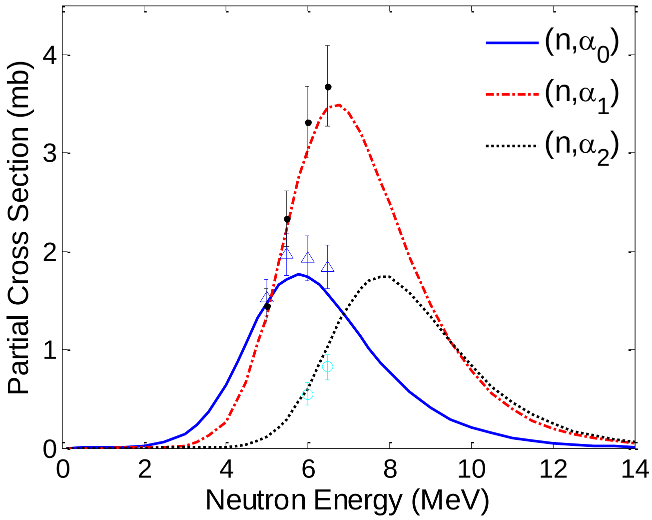
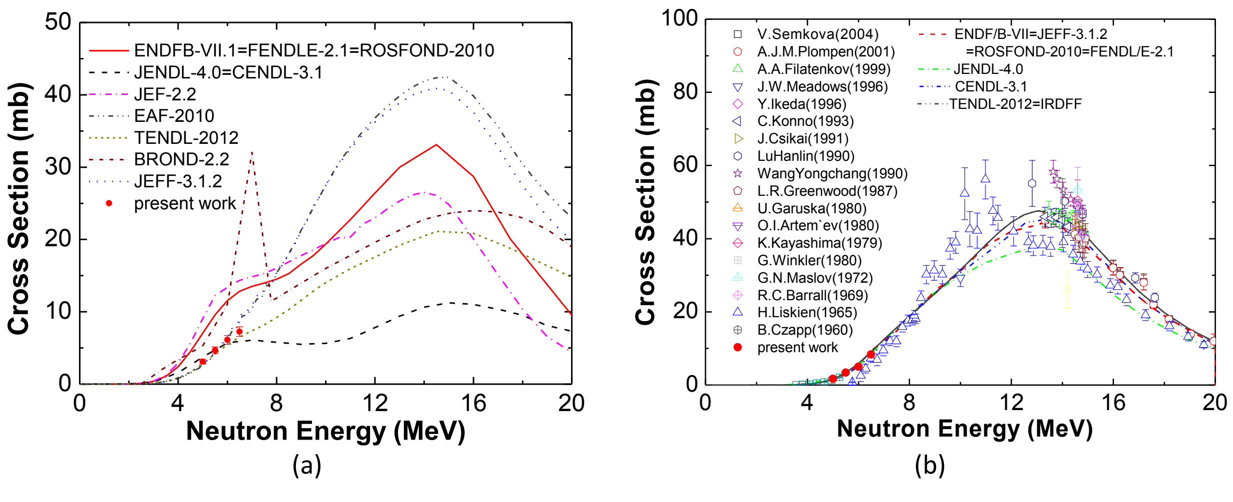
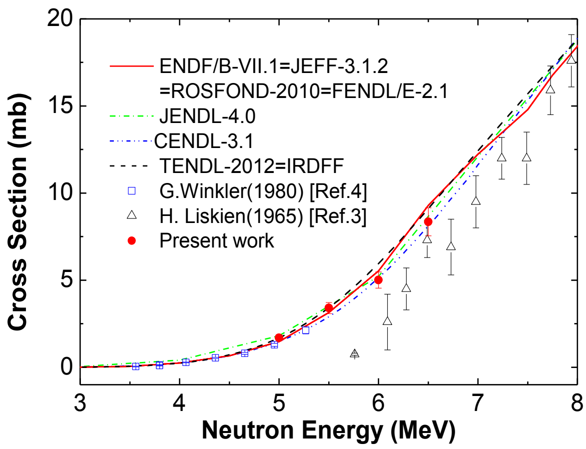


Fig.5 (Color online) Present cross sections of $^{57}Fe(n,\alpha_0)$, (n,α_1) and (n,α_2) reactions compared with TALYS-1.4 code calculations.





(c)

Fig.6 (Color online) Present cross sections compared with existing evaluations, (a) for the $^{57}Fe(n,\alpha)^{54}Cr$ reaction, (b) and (c) for the $^{63}Cu(n,\alpha)^{60}Co$ reaction.

III. New facilities for Nuclear Data Measurement

1. China Spallation Neutron Source(CSNS)

The CSNS is under construction and it will be in operation in 2017. Although this machine is built mainly for neutron scattering study. Two experimental halls for nuclear data measurement are also proposed at the back-streaming neuron beam line. Back-streaming neutrons through the incoming proton channel at the spallation target station of CSNS are harmful to the proton beam line and should be dealt with carefully. On the other hand, those back-streaming neutrons may be useful for other applications. Studies on the characteristics of the back-streaming neutrons show that an uncollimated neutron flux of around 2.0×10^5 n/cm^2/pulse within the given energy range at 80 m away from the target, which accounts for about 53% of the total neutrons. The time resolution of 0.3–0.9%, which is important for the time-of-flight method, can be obtained for both the parasite operation mode with two proton bunches and the dedicated operation mode with a single proton bunch. Fig.7-9 shows the experimental halls layout and the performance of the CSNS.

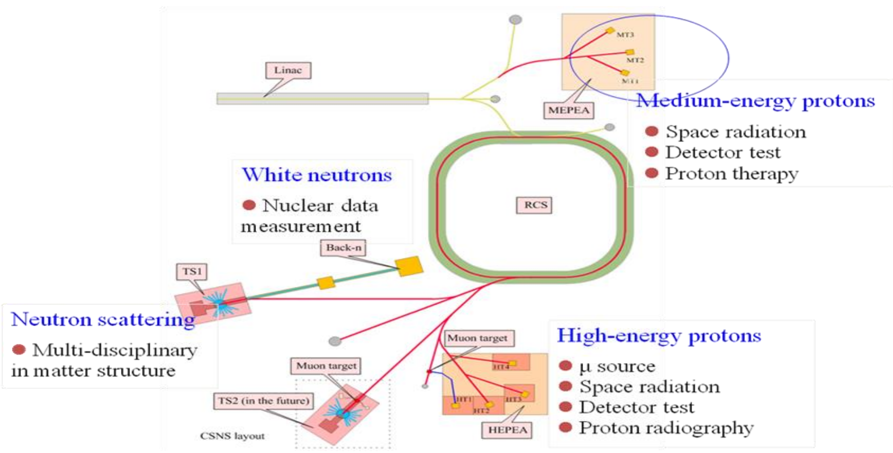


Fig. 7 Schematic for the CSNS multiple platforms

Table 5 The CSNS parameters compared with other facilities

Parameters	United States				Europe		China
	ORELA	LANSCE WNR		RPI	GELINA	CERN n_TOF	CSNS Back-n
Accelerator	e- linac	p-Synch	p-linac	e- linac	e- linac	p-Synch	p-Synch
Energy (GeV)	0.14	0.8	0.8	>0.06	0.12	24	1.6
Flight (m)	10-200	7-55	7-90	10-250	8-400	185	55, 80
Pulse (ns)	2-30	125	0.15	15	1	7	52 (6)
B. Power (kW)	50	48	1.6	>10	11	45	100
Rep. rate (Hz)	1-1000	20	32k	1-500	Max. 900	0.28-0.42	25
Time res. (ns/m)	0.01	3.9		0.06	0.0025	0.034	0.65
n yield (n/s)	1×10^{14}	6.4×10^{13}	2.1×10^{12}	4×10^{13}	3.2×10^{13}	8.1×10^{14}	2.0×10^{16}

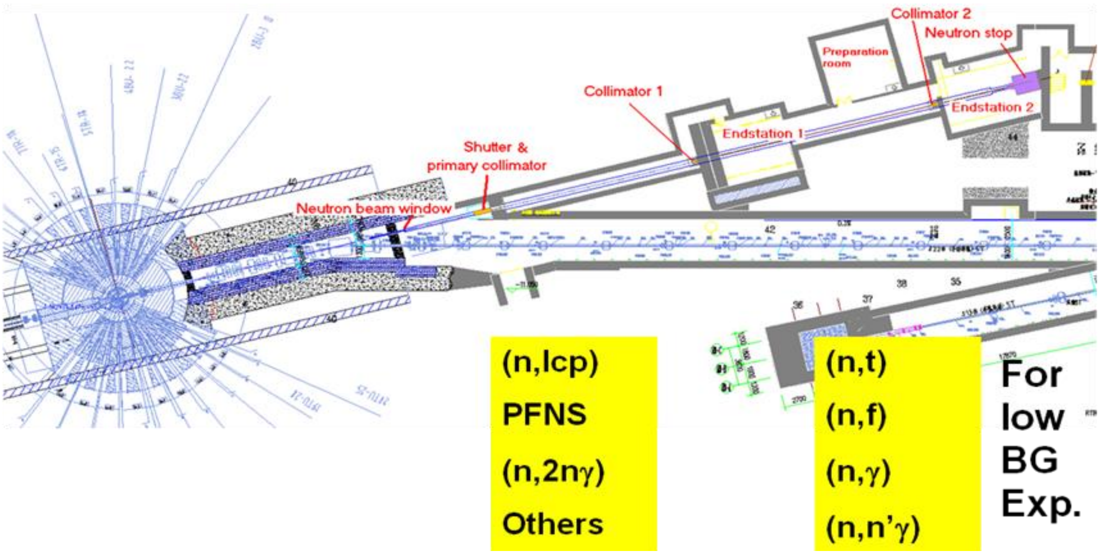


Fig. 8 Layout of the CSNS back-n

Table 6 Background estimation in the end-stations induced by the proton beam and the spallation target

Endstation	By the proton beam line		By the spallation target	
	n (Flux/ $cm^{-2}\cdot s^{-1}$)	γ (Flux/ $cm^{-2}\cdot s^{-1}$)	n (Flux/ $cm^{-2}\cdot s^{-1}$)	γ (Flux/ $cm^{-2}\cdot s^{-1}$)
ES1	0.3	0.4	0.1	0.03
ES2	1.2E-03	5.0E-04	<1E-03	<1E-03

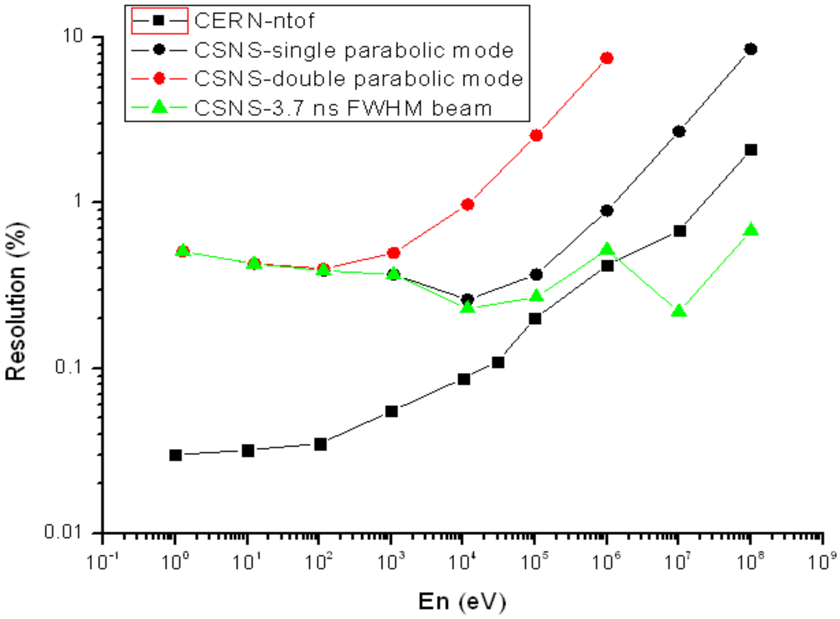


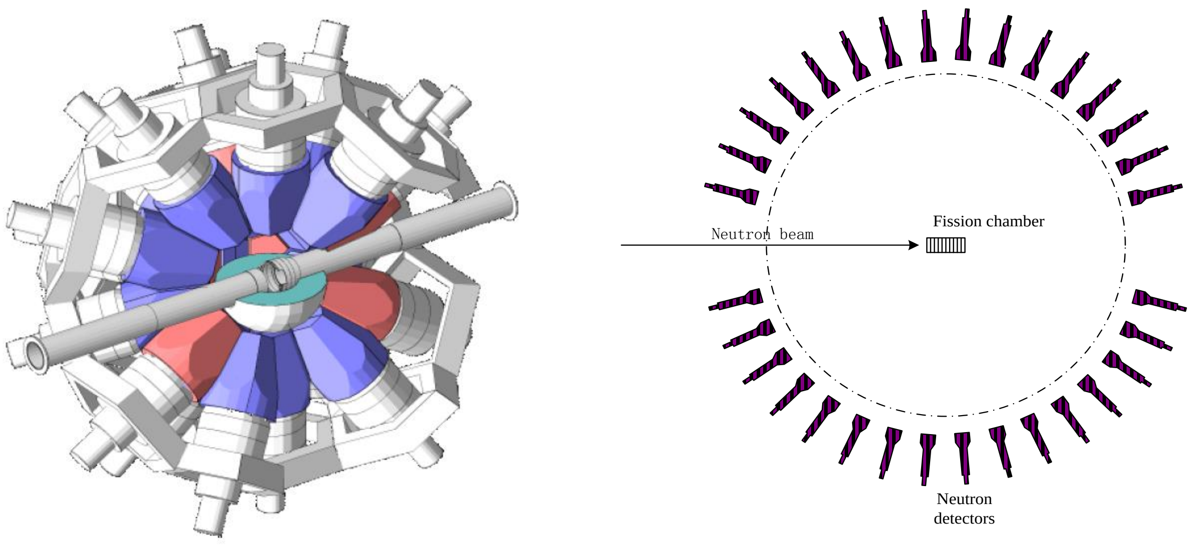
Fig.9 Time resolution for CSNS compared with CERN n-TOF

2. Nuclear data measurements at the CSNS Back-n white neutron source

The measurements of (n,tot), (n,f), (n,γ), (n,x), prompt fission neutron spectra,(n,n'γ) and (n,2nγ) are planning to carry out at the CSNS Back-n.

The following neutron cross section measurement facilities will be established at CSNS

- (n,γ) reaction cross section measurement device: which is a 4π total gamma ray absorption detection array, consist of 42 pieces BaF_2 crystals and FADC data acquisition system. (Fig. 10a).

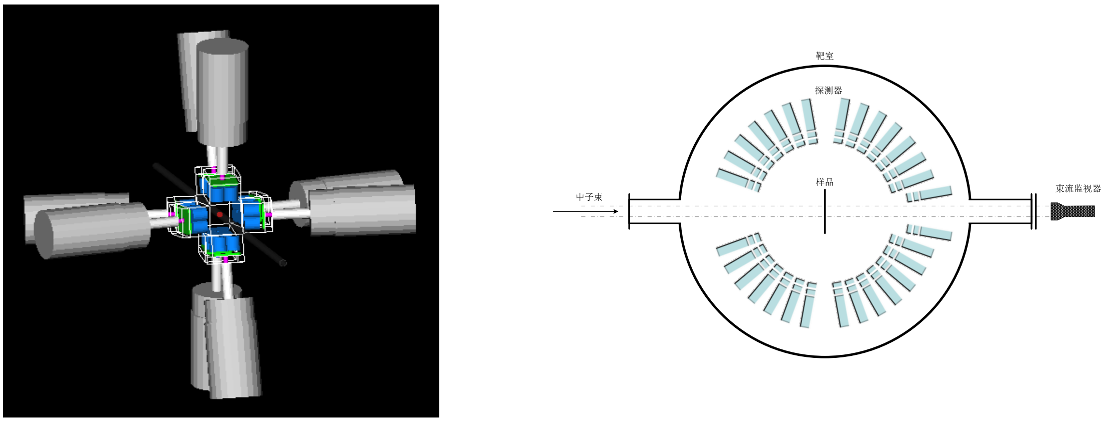


(a) (b)

Fig. 10 The structure of 42 BaF_2 crystals ball(a) and the PFNS detection array(b).

- PFNS measurement platform: A neutron detection array consist of 64 detectors will be built, which can be used for PFNS, (n,n') and nd reaction study(Fig. 10b).

- (n,n'γ) and (n,2nγ) measurement platform: A detector array for high resolution γ spectroscopy consist of HPGe or $LaBr_3$ detectors. (Fig.11a)



(a) (b)

Fig. 11 The array for high resolution γ spectroscopy(a) and (n,lcp) reaction study(b).

- The (n,lcp) reaction study platform: consists of a vacuum chamber, a charged particle detection array and ΔE-E telescope for particle discrimination(Fig.11b)

3. SINAP-NF (neutron facility of Shanghai Institute of Applied Physics)

An electron LINAC with 15 MeV and 0.1 mA electrons is under construction at SINAP. This machine is constructed mainly for the key nuclear data measurement for the TMSR project. They will focus on the nuclear data measurement of (n,tot) and (n,γ) reaction cross sections in the near future.

In 2013, the construction of this machine has finished. And the commissioning started from the end of 2013. Preliminary results show that the neutron flux will be about 3×10^4 n/cm^2/s at the sample position, which is 5 meters far away from the target.

Fig.12 The SINAP-NF facility

4. Nuclear data measurement for ADS at Institute of Modern Physics(IMP)

HIRFL-CSR, a new accelerator project planned at the Heavy Ion Research Facility in Lanzhou (HIRFL), is a multipurpose Cooling Storage Ring system which consists of a main ring (CSRm) and an experimental ring (CSRe). The two existing cyclotrons SFC (K=69) and SSC (K=450) of the HIRFL will be used as its injector system. The heavy ion beams from the HIRFL will be accumulated, cooled and accelerated in the main ring, and then extracted to produce radioactive ion beams (RIB) or highly charged heavy ions. The secondary beams (RIB or highly charged ions) can then be accepted by the experimental ring for internal-target experiments.

Although this machine is mainly for heavy ion reaction study, the PISA(Proton Induced Spallation) terminal(fig.13) was developed for proton induced nuclear data measurement in recent years, to feed the nuclear data needs for ADS project in China.

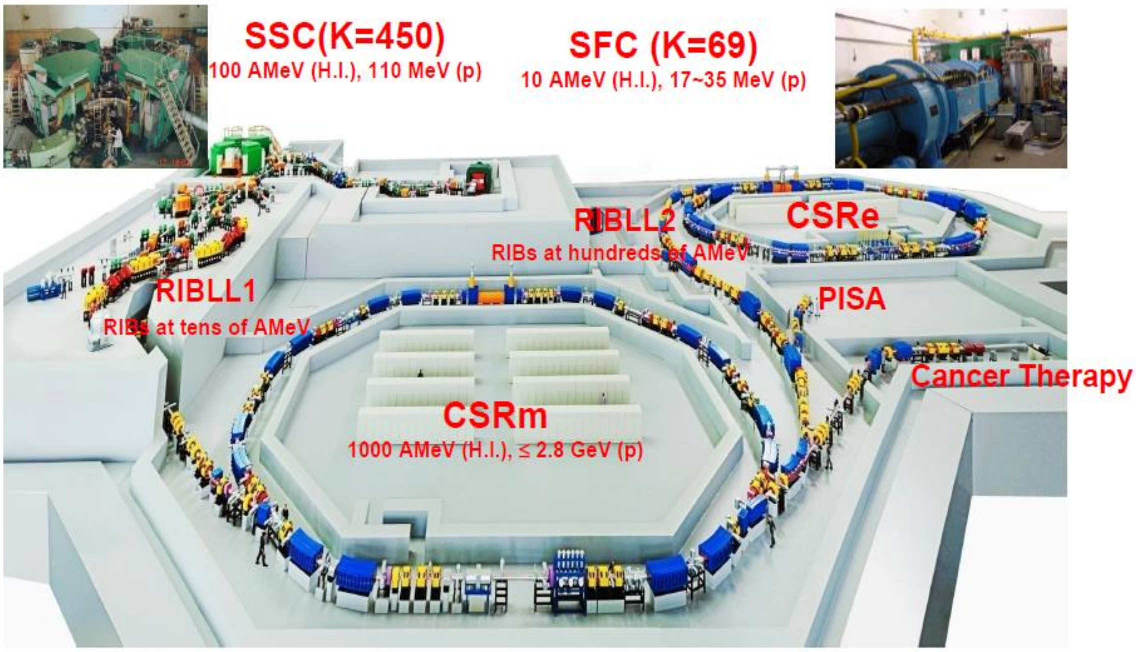


Fig.13 The HIRFL-CSR complex

Detectors for high energy proton induced neutrons, gammas and light charged particles (LCP) detection were built. Fig.14 shows the detector arrangement.

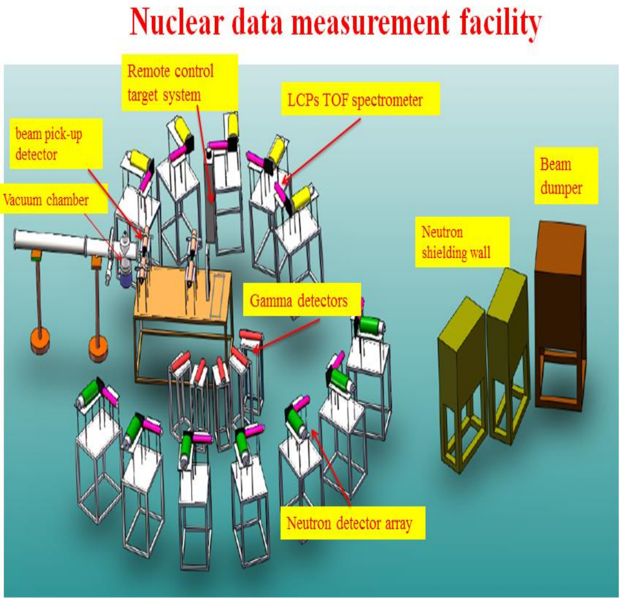


Fig.14 Detector arrays for neutron, gamma and LCP measurements induced by protons

Experiments performed in recent years:

2012:

- 400 AMeV ^{12}C + Pb (thick targets,naked targets)
- Neutron activation method

2013:

- 400 AMeV ^{12}C + Pb/W (thick targets, targets in water tanker)
- neutron activation method
- 165-350 AMeV ^{12}C + H_2O
- LCPs detector tests

2014:

- 250 AMeV H_2^+ + Pb/W (thick targets)

- Neutron activation method
- 400 AMeV ^{16}O + Pb/W (thin,thick targets)
- Online measurement detectors and DAQ system test
- BC501A neutron detectors for neutron measurements
- Plastic + CsI(Tl) detectors for LCPS.

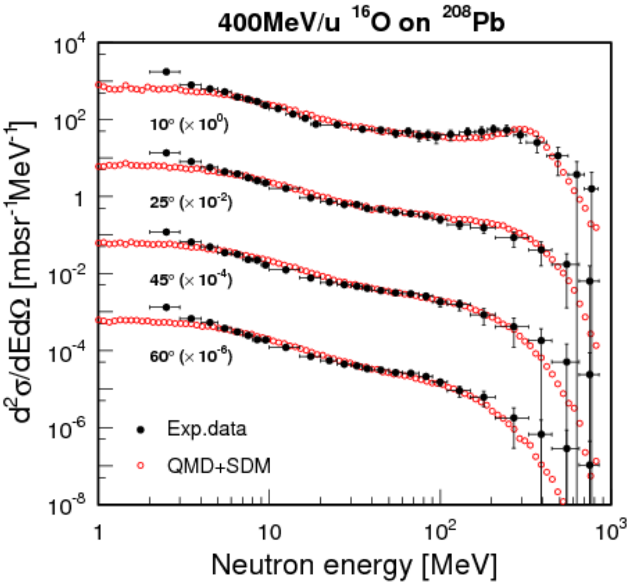


Fig.15 Measured neutron energy spectra induced by 400 MeV/u ^{16}O on ^{208}Pb

IV. Acknowledgement

We thank Prof. Guohui Zhang from Peking University, Dr. Hongwei Wang from SINAP and Dr. Zhiqiang Chen from IMP for providing the detailed materials for nuclear data measurement progress at their home institutes.