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Progress of Nuclear Data Measurement in China during 2011-2012

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I. Introduction of China Nuclear Data Activities

The goal of China nuclear data activities is supplying the nuclear data to feed the needs of the nuclear peaceful applications, which contains the nuclear reactor design, science study, nuclear medicine application and public education et al.

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 and nuclear data benchmark testing and validation.

The mainly activities are being carried out at China Nuclear Data Center(CNDC), China Institute of Atomic Energy(CIAE) and China Nuclear Data Coordination Network(CNDCN) and 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 and 5SDH-2 2×1.7MV tandem accelerator at CIAE. The 4.5-MV Van de Graaff accelerator at Peking University and 300kV -Cockcroft-Walton accelerator at Lanzhou university.

In addition, the China Advanced Research Reactor (CARR, 60MW, neutron flux: 8×10^{14}n/cm2·s), which has reached critical on 13, May 2010 at CIAE, will also be used for nuclear data related research. Some new facilities are under constructing, some of them already are planned to use for the nuclear data measurements when the completion.

II. Recent Progress of Nuclear Data Measurement in China

- **The secondary neutron emission double-differential cross section measurement for deuteron**

  The measurement of the double-differential cross sections (DDXs) of deuteron at 8.2 MeV neutrons has been finished in the last year. The measurement was 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 following Fig.1

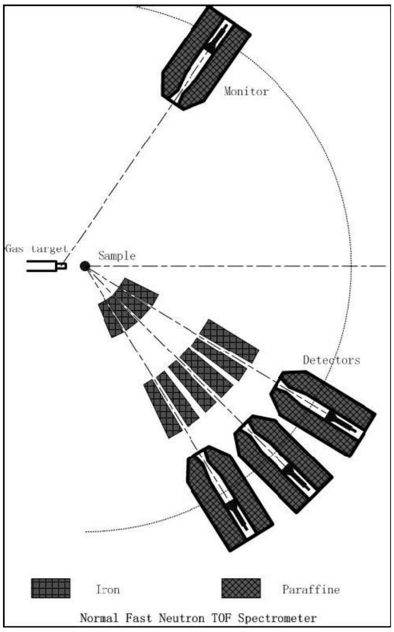

Fig.1 Schematic view of the multi-detector fast neutron TOF spectrometer.

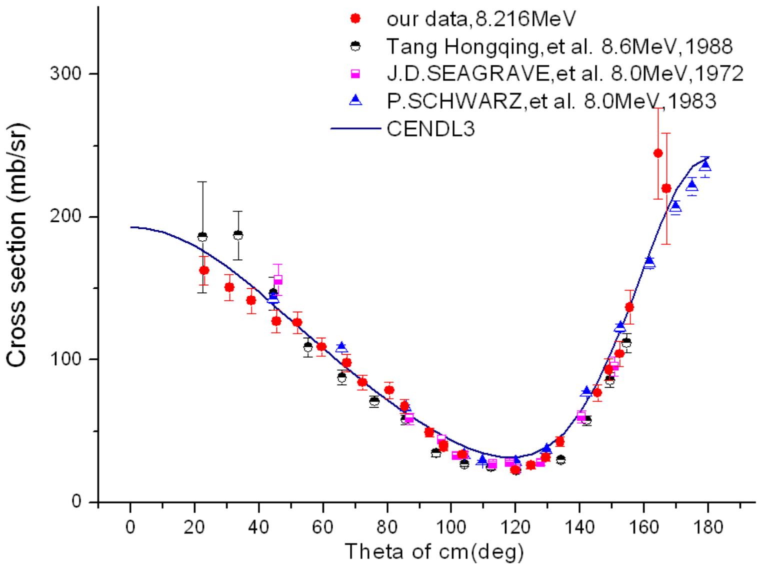

Fig.2 shows the measured differential cross section for n-D elastic scattering compared with other experimental data and the evaluated data from CENDL-3.1.

- **^{69}Ga(n,2n)^{68}Ga cross section measurement**

  This measurement was performed with the 600kV-Cockcroft-Walton accelerator in CIAE at the neutron energy of 14.1 and 14.9MeV. A new measurement was performed at 14.1 MeV. Based on the measurement, the existing experimental data of ^{69}Ga(n,2n)^{68}Ga cross section were reevaluated and improved based on CENDL-3.1

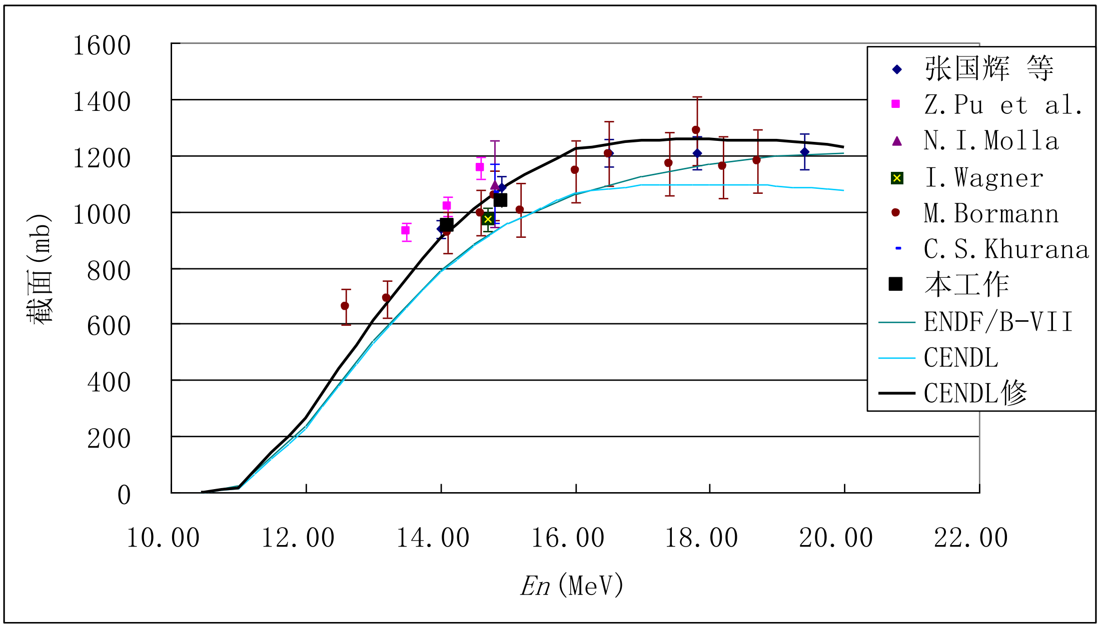

Fig.3 Measured result of $^{69}Ga(n,2n)^{68}Ga$ cross section, and compared with other measurement and evaluations

- **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-fission chamber. Fission product activities were measured by a HPGe γ-ray spectrometer. Combined with previous measurements, part of the energy dependent fission yield for n+^{235}U fission reaction was shown in fig.4. One can see that at peak mass region, a linear function can be used to approximate the energy dependent fission yields, while at valley and shoulder mass region, the fission yields for some energy points can deviate from a linear function more than 10%.

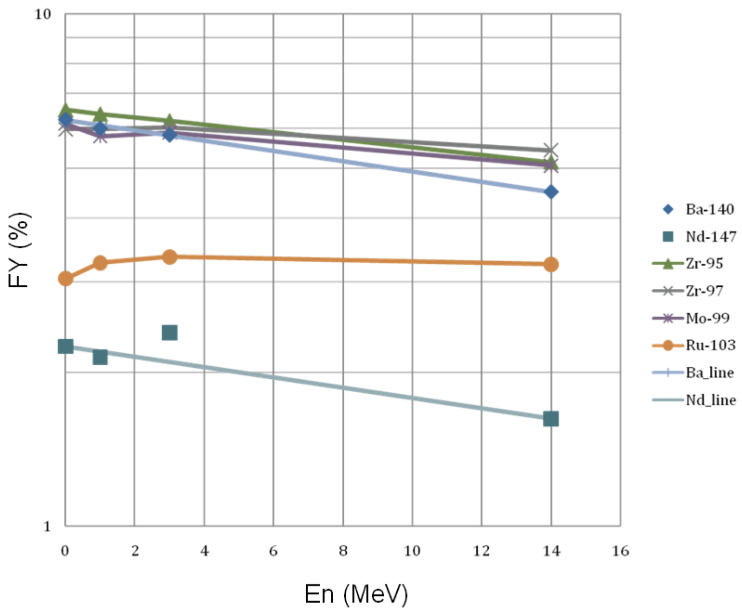

Fig.4 Part of the measured FY for n+^{235}U reaction as a function of incident neutron energy

- **^{66}Ga half life measurement**

Isotope ^{66}Ga has many high energy γ rays, and the highest is 4.8MeV. Its half-life is suitable to measure, so it has often been used for efficiency calibration of γ ray detector in the high energy range. The half-life of ^{66}Ga was measured by a HPGe detector in this work. Natural zinc foils were bombarded by 20MeV protons produced by the HI-13 accelerator in CIAE to produce the isotope ^{66}Ga. The irradiated foils were measured by a HPGe detector, the distance from foils to detector's end-top is 25cm. After measuring 4 to 5 days, the decay curve data of several characteristic γ rays were obtained. Half-lives were determined by fitting the data, the mean value is obtained in this work 9.315(15) hours. Present data from Table of Isotopes V8 and NNDC website is 9.49 hours, and the data from IAEA website is 9.3336(816)hours, respectively.

- **(n,x) measurement at Peking University**

The reaction cross sections of $^{40}Ca(n,\alpha)$ were measured at 4.0-6.5 MeV with the 4.5 MV Van de Graaff accelerator of Peking University with monoenergetic neutrons produced via the $^{2}H(d,n)^{3}He$ reaction using a deuterium gas target. Alpha particles were detected with a double-section gridded ionization chamber having two back-to-back samples attached to the common cathode. Absolute neutron flux was measured using a small ^{238}U fission chamber and monitored by a BF_3 long counter. The differential cross sections for $^{40}Ca(n,\alpha_0)$, $^{40}Ca(n,\alpha_{1,2})$ and $^{40}Ca(n,\alpha_{3,4,5})$ were measured.

The measured results were compared with TALYS calculations, evaluated data and other measurements.

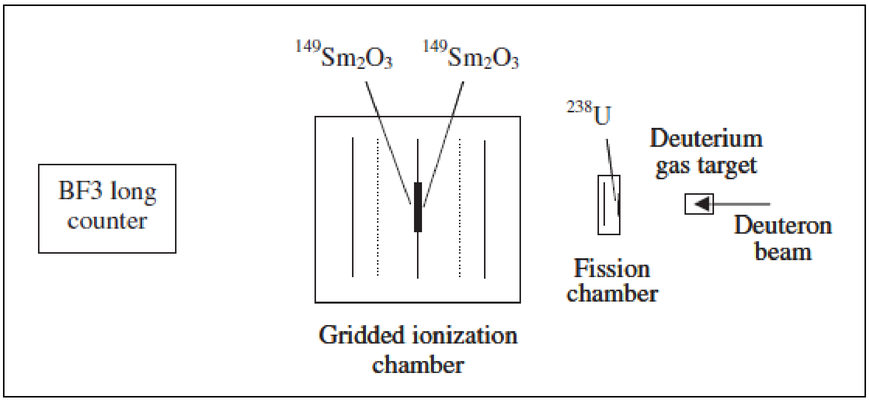

Fig.5 Experimental apparatus of (n,x) measurement at Peking University.

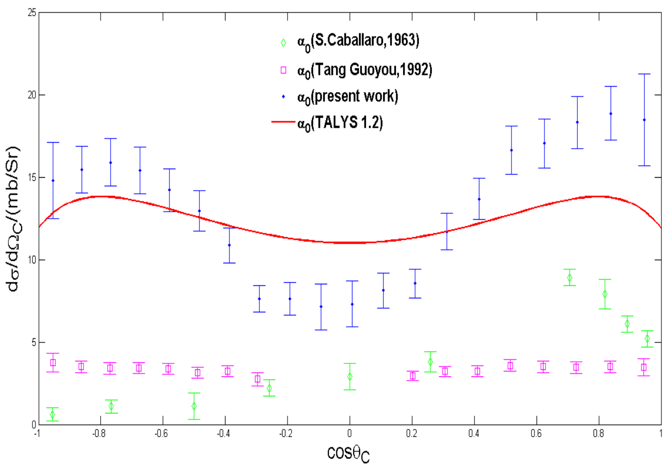

Fig.6 Differential cross sections of the $^{40}Ca(n,\alpha_0)$ reaction compared with other measurements and TALYS code calculations.

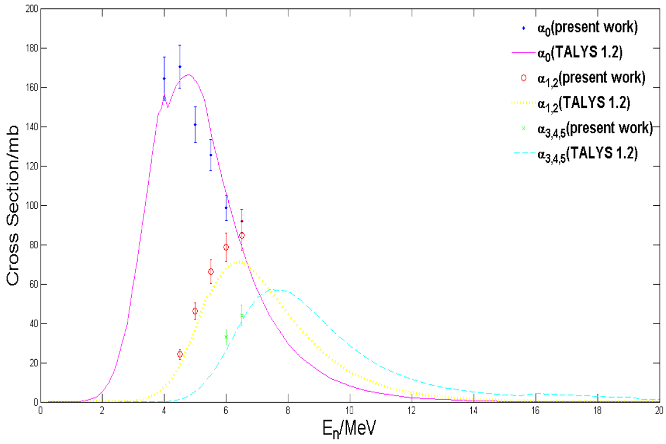

Fig.7 Present partial cross sections of the ^{40}Ca(n,α) reaction compared with TALYS calculations.

- **Excitation function around 14 MeV at Lanzhou University**

Several measurements were performed with the 300kV Cockcroft-Walton accelerator at Lanzhou University. In 2011, ^{58}Ni(n, p)^{58}(m+g)Co, ^{60}Ni(n, p)^{60m}Co, ^{61}Ni(n, p)^{61}Co and ^{62}Ni(n, p)^{62m}Co, ^{115}Sn(n, p)^{115m}In, ^{116}Sn(n, p)^{116m}In, ^{117}Sn(n, p)^{117}In and ^{117}Sn(n, p)^{117m}In, ^{175}Lu(n, a)^{172}Tm, ^{176}Lu(n, a)^{173}Tm and ^{175}Lu(n, p)$^{175m+g}$Yb reactions were measured between 13.5 and 14.6 MeV. In 2012, ^{55}Mn(n,a)^{52}V, ^{55}Mn(n,2n)^{54}Mn, ^{232}Th(n,x)^{89}Rb, ^{nat}Ru(n,x)^{99m}Tc, ^{146}Nd(n,p)^{146}Pr, ^{142}Nd(n,p)^{141g}Nd and ^{160}Gd(n,a)^{157}Sm reactions were measured. Fig.8 shows an example.

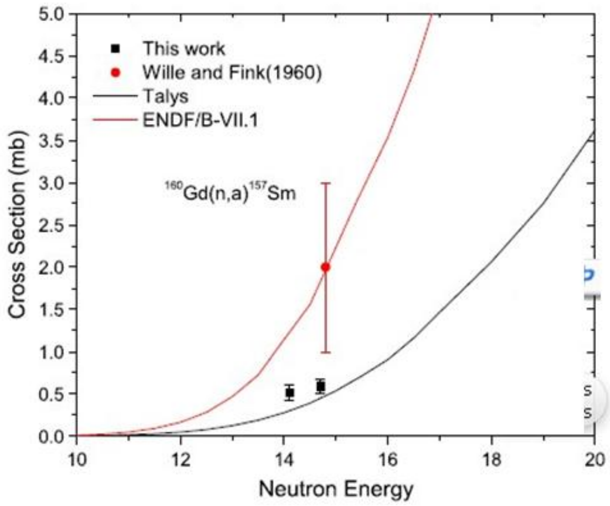

Fig.8 ^{160}Gd(n,a)^{157}Sm reaction cross sections compared with other measurements.

- **Nuclear data for nuclear astrophysics**

Substantial progress has been achieved for nuclear data measurement for nuclear astrophysics. The astrophysics S factor for ^{13}C(p, γ)^{14}N$_{0,1}$ reaction was obtained by measuring the angular distribution of ^{12,13}C(^{7}Li,^{7}Li) and ^{13}C(^{7}Li,^{6}He)^{14}N$_{0,1}$ reactions (Y. J. Li et al. Eur. Phys. J. A (2012) 48: 13). The angular distribution of ^{13}C(^{11}B,^{7}Li)^{17}O* reaction was measured. The reaction rate and the astrophysics S factor for ^{13}C(α,n)^{16}O reaction were determined (B. Guo, Z.H. Li et al., Astrophys. J 756, 193 (2012)). The ^{7}Li (n,γ)^{8}Li reaction cross section has been measured(Li Zhihong et al., Plasma Science and Technology, 14 (2012) 488-491). The angular distribution of the transfer reaction ^{13}C(^{9}Be,^{8}Li)^{14}N has been studied and the proton spectra facton of ^{9}Be has been determined and this work clarified the discrepancy between different measurements(Z. H. Li, Y. J. Li et al., Phys. Rev. C 87 (2013) 017601). They also finished the measurement of $^{12}N(p,\gamma)^{13}O$ reaction (B. Guo, J. Su et al., Phys. Rev. C, 87 (2013) 015805).

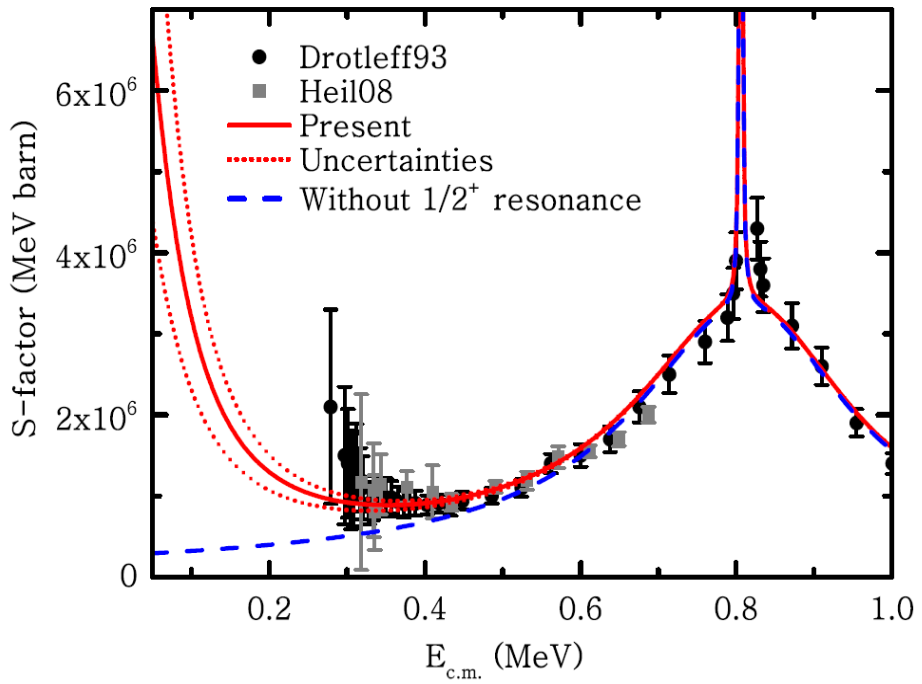

Fig.9 The astrophysics S factor for $^{13}C(\alpha,n)^{16}O$ reaction

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. Preliminary studies on the characteristics of the back-streaming neutrons have been done. The corresponding yields and time structures of the neutrons in the energy range of 1 eV to 1 MeV from a tungsten target for a proton beam of 1.6 GeV in energy and 63 μA in average current have been simulated. From the simulation results, we obtained 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, is obtained for both the parasite operation mode with two proton bunches and the dedicated operation mode with a single proton bunch. Fig.10-12 shows the experimental halls layout the performance of the CSNS.

The civil construction of the experimental halls have been started in 2011, and the construction of the experimental facilities for (n,tot), (n,f), (n,γ) reaction cross sections in the 1st stage have been proposed.

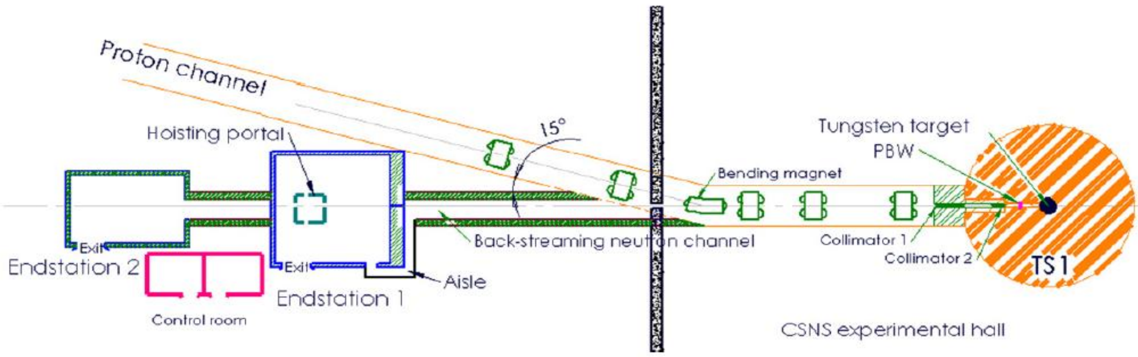

Fig.10 Experimental halls for nuclear data measurement at the CSNS back-streaming neutron beam line

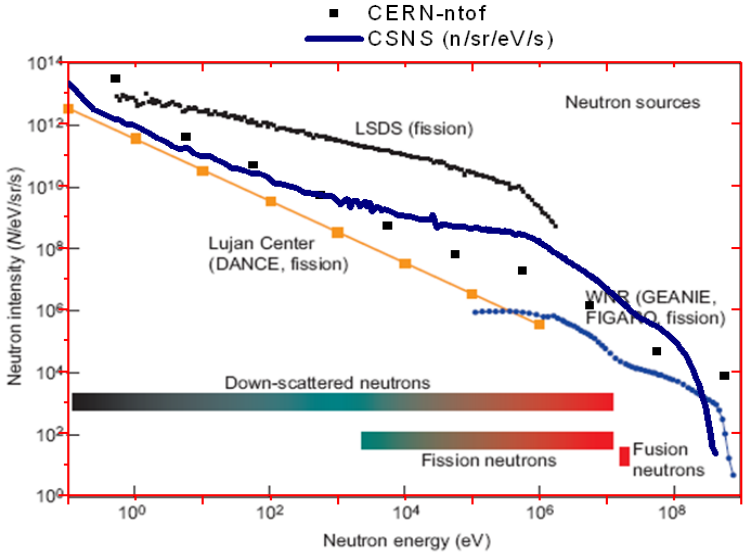

Fig.11 The neutron fluence of CSNS compared with other facilities.

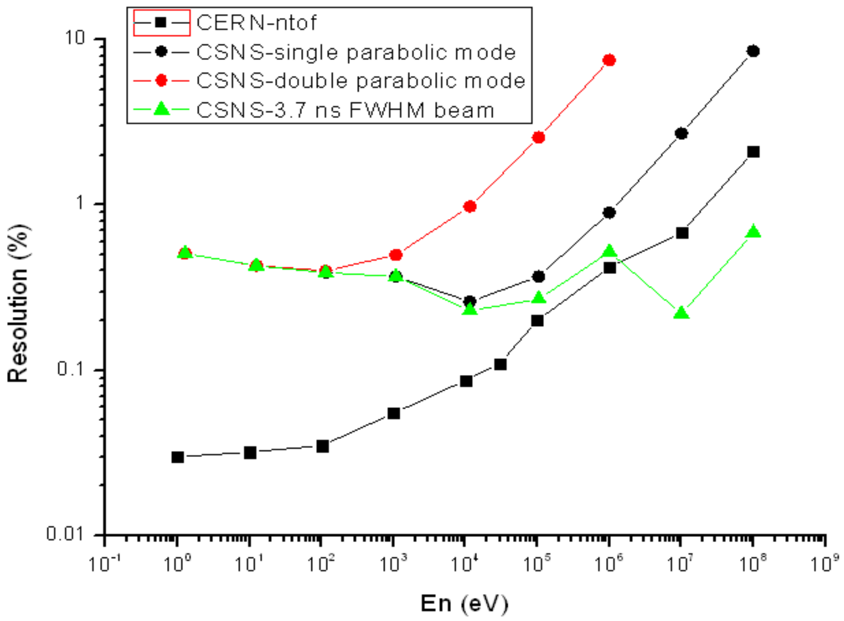

Fig.12 Time resolution for CSNS compared with CERN n-TOF

2. 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. An upgrade of the machine has also been planned in the future, as shown in the following table.

Table 1 Parameters for SINAP_NF I and II

	ORNL ORELA	IRMM GELINA	ELBE	ELBE -SRF	Osaka KURRI	PAL PNF	SINAP I	SINAP II
平均流强/mA	0.045	0.065	0.125	1	0.13-0.22		0.0005-0.1	0.5
电子能量/MeV	180	110	40	40	46	60	15	100
功率/kW	8	7	5	40	6-10	0.2-7	0.0075-1.5	50
靶	Ta	U	Pb	Pb	Ta	Ta	Ta，W	Ta
脉冲频率/Hz	500	800	1.6×10^{6}	5×10^{5}	300	12	10-266	1500
中子脉冲宽度/ns	>4	>1	<0.4	<0.4	2	1500	3-3000	3-3000
飞行距离/m	40	20	4	4	5-22	5.4	1-5	20-30
分辨（@1MeV）%	<1	<2	≈1	≈1	-	-	<1	<1
中子通量/s^{-1} cm^{-2}	$\approx10^{4}$	4×10^{4}	4×10^{5}	3×10^{6}	-	-	1×10^{5}	5×10^{6}
中子产额 10^{13} /s	2.2	3.4	1	1	2.0	0.2	0.4	1.0

3. HINEG

The Hefei Intensified NEutron Generator(HINEG) is under construction at the Institute of Nuclear Safety Technology, Chinese Academic of Science. The beam current will be > 50 mA with 300 keV energy. The neutron intensity will be about 1×10^{13} n/s with d-T reaction. Two beam lines have been considered with one direct beam current beam line and one pulsed beam line for TOF measurement. This machine will be ready at the end of 2014. It will be used for fusion and ADS related nuclear data measurement, such as nuclear data benchmark, activation data for ITER materials, etc.

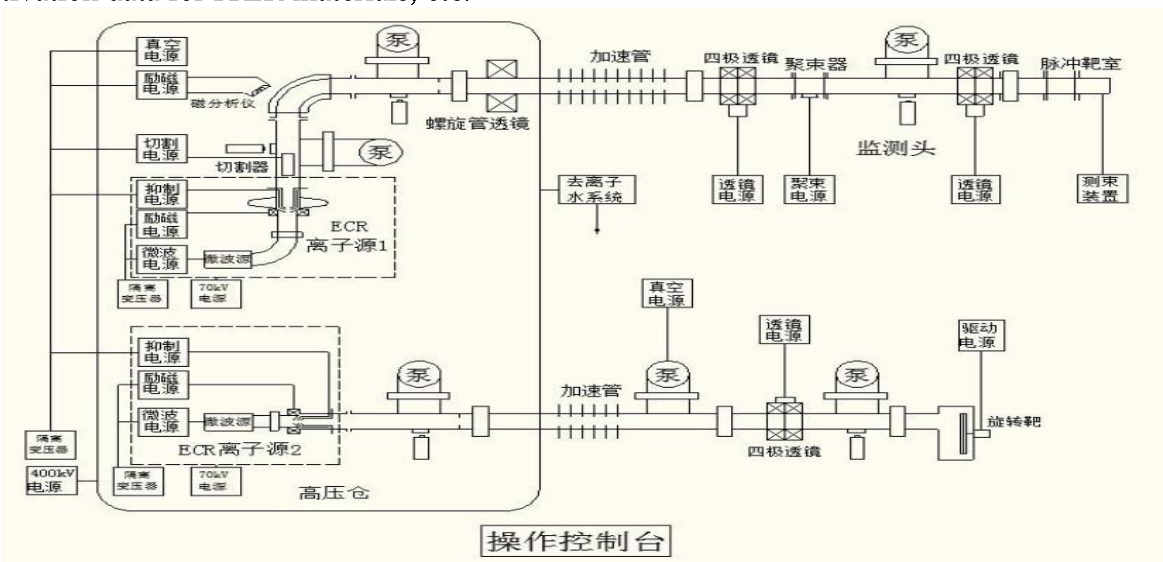

Fig.13 Diagram of the HINEG

IV. 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 ADS, 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.