Neutron Metrology Activities at the CIAE (2007 to 2008)

1. Basic facilities and devices

In the recent two years, neutron metrology has still been developing at CIAE. The 5SDH-2 tandem accelerator, introduced in 1996 from the NEC Corp. of USA in order to establish neutron calibration fields, was improved to make it possess the capability that can produce a pulsed beam with a width of ~1 ns (proton) or ~2 ns (deuteron) and a adjustable frequency from 0.0625 MHz to 4 MHz. Consequently the neutron energy spectra of the calibration fields can be measured by the flight time technique in the future. In addition, the old cesium-spattering ion source was also replaced by a TORVIS gas ion source which can educe a beam current with a maximum intensity of 340 μA (proton) or 280 μA (deuteron). Some devices, such as BC501A liquid scintillation detector, ^{3}He grid ionization chamber and TEPC, were introduced to develop the researches of neutron energy spectra and microdosimetry.

2. Development of neutron calibration fields

The neutron calibration field of 25.5 MeV had been established at HI-13 tandem accelerator in the nuclear physics department of CIAE. The neutron field was produced by the T(d,n) reaction. A gas tritium target was used so as to increase the neutron yields. The neutron energy spectrum, shown in Fig.1, was measured by a flight time spectrometer at a distance of 6m from target. It can be seen that the neutron field is seriously contaminated by the relative lower energy neutrons produced by the breakup of the incident deuterons, the D(d,n) reactions resulted from the incident deuterons bombarding the deposited deuterons on the beam-limited diaphragm and the interactions between the incident deuterons and the materials of the beam-limited diaphragm, etc.

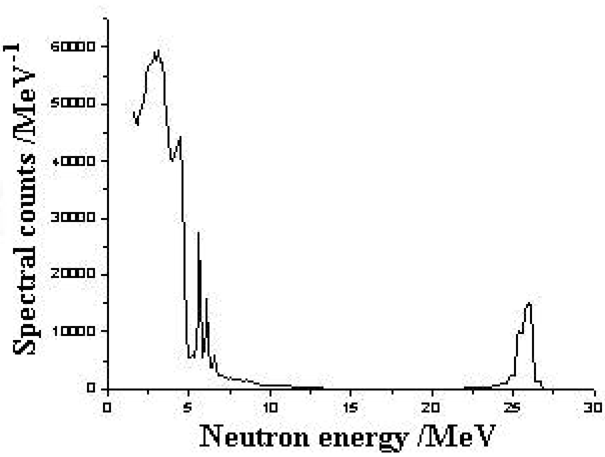

Fig.1 Measured 25.5 MeV neutron energy spectrum

The neutron fluence rate of 25.5 MeV was determined by a ^{238}U fission chamber, whose structure sketch is shown in Fig.2. A sample layer of natural uranium of 44.07 mg is plated on a backing of stainless steel. The backing and the collector can be fixed in the chamber by a ring of 0.5 mm thick aluminum and three supporting bars. The supporting bar is assembled with a rod of Teflon covered with some sleeves of Teflon and those of brass. These sleeves can either insulate the collector from the outer-wall or connect the backing to the outer-wall. The distance of collector-to-backing can be adjusted conveniently by using the sleeves with different lengths. The working gas is a mixture of argon gas of 90% and methane of 10%.

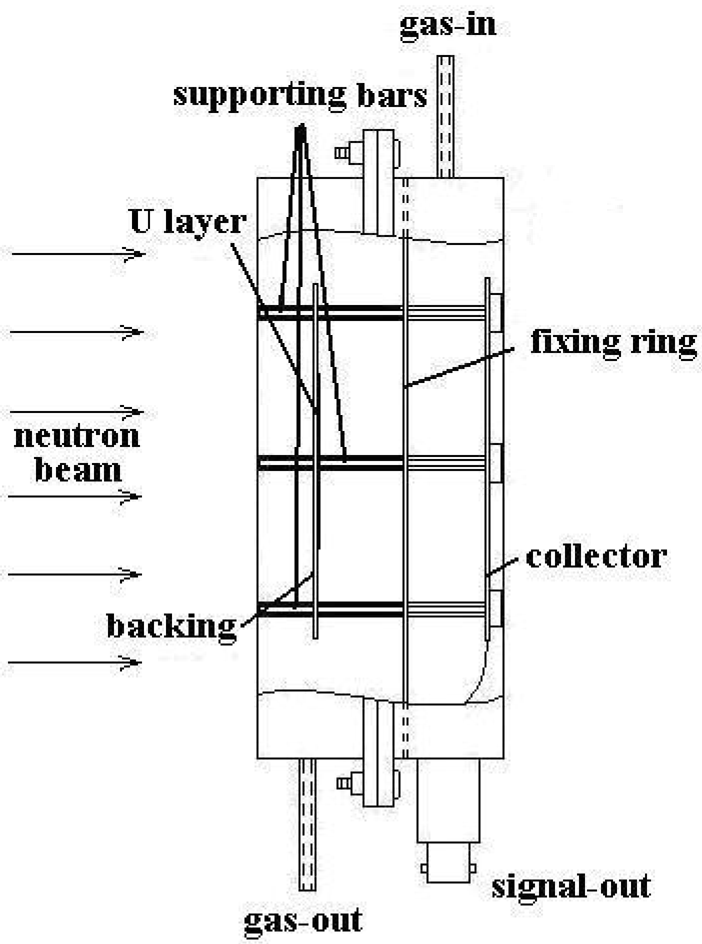

Fig.2 Structure sketch of the fission chamber

The pulse-height spectrum measured by the fission chamber, from which the background resulted from the room-scattering neutrons was subtracted by shadow cone method, is shown in Fig.3. Thus the 25.5 MeV neutron fluence rate at an experimental point can be obtained by Equation (1):

$$= \prod_{j=1}^{n} k_j \cdot \frac{N_\mathrm{f}}{N_\mathrm{A} \sum \frac{\overline{\sigma_i} M_i}{A_i}}, i = 238, 235, 234 \qquad (1)$$

where, $\prod_{j=1}^{n} k_j$ is the product of the correction factors due to the loss of counts below the threshold described as Fig.3 (k_1), the absorption of fission fragments caused by the uranium layer (k_2), the unwanted counts induced by the contamination neutrons below 20 MeV (k_3) and the scattering and absorption of neutrons over 20 MeV caused by the materials of the fission chamber, working gas and air (k_4); N_f is the counts of fission fragments over the threshold; N_A is the Avogadro constant; $\overline{\sigma_i}$ is the spectrum-averaged differential cross sections of the ^{i}U(n,f) reaction ($i = 238, 235, 234$); M_i is the mass of ^{i}U ($i = 238, 235, 234$) in the uranium layer; A_i is the mole mass of ^{i}U ($i = 238, 235, 234$).

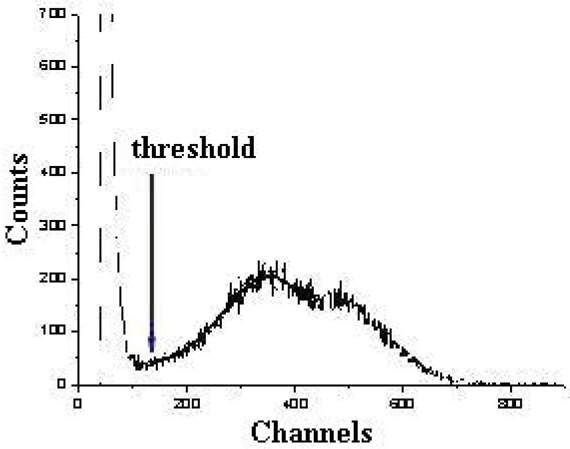

Fig.3 Pulse-height spectrum measured by the fission chamber

The correction factor k_1 can be obtained by the extrapolation of the fitted data as the solid line in Fig.3. The k_2 can be calculated by Equation (2):

$$k_2 = 1 + \frac{(t_U{}^2 + \sigma_{t_U}{}^2)}{2 t_U R_f} \tag{2}$$

where, t_U is the mean thickness of the uranium layer; σ_{t_U} is the standard deviation of t_U; R_f is the mean range of fission fragments in the uranium layer, R_f=（7.5 ± 0.5）mg·cm^{-2}.

The correction factor k_3 was calculated by Equation (3):

$$k_3 = 1 - \frac{f_1 \int_{E_{\min}}^{20\mathrm{MeV}} N(E) \sum \frac{\sigma_i(E) M_i}{A_i} \cdot \mathrm{d}E}{f_2 \int_{E_{\min}}^{E_{\max}} N(E) \sum \frac{\sigma_i(E) M_i}{A_i} \cdot \mathrm{d}E}, i = 238, 235, 234 \tag{3}$$

where, f_1 and f_2 are the corrections respectively for the scattering and absorption of neutrons below 20 MeV and of all energies caused by the materials of the fission chamber, working gas and air. $N(E)$ is the spectral counts of the measured neutron energy spectrum.

The correction factor k_4 was calculated with the Monte-Carlo method.

The result of the 25.5 MeV neutron fluence rate and the main parameters are listed in Table 1.

Table 1 Result of the 25.5MeV neutron fluence rate and the main parameters

Parameters	Values
N_f /s^{-1}	1.160 58
$\overline{\sigma_{238}}$ /cm^2	1.5856×10^{-24}
$\overline{\sigma_{235}}$ /cm^2	2.1232×10^{-24}
$\overline{\sigma_{234}}$ /cm^2	2.1242×10^{-24}
M_{238} /g	4.375×10^{-2}
M_{235} /g	3.175×10^{-4}
M_{234} /g	2.380×10^{-6}
$\prod_{j=1}^{4} k_j$	0.2288
φ/ cm$^{-2}\cdot$s^{-1}	1.498×10^{3} [a)]
Neutron energy /MeV	25.5

[a)] **The value is the neutron fluence rate at the distance of 144.55 cm from the center of tritium target.**

In addition, in order to verify if the quantification of the uranium layer is accurate, the neutron fluence rate of 14.8 MeV neutrons produced by the 5SDH-2 accelerator was also measured simultaneously with the fission chamber and an associated α-particle instrument. The results are accordant within 1%.

3. Developing plan in the near future

(1) Development of the mono-energetic neutron calibration fields in keV energy range based on the $^{45}Sc(p,n)^{45}Ti$ reaction.

(2) Development of a calibration field simulating the neutron energy spectra of the workplace of pressure water reactor.

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19 March 2009