Neutron Metrology Activities at CIAE (2009~2010)

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1. Neutron calibration fields

So far the neutron calibration fields have been developed at the energies recommended in ISO 8529-1. Recently we are establishing the 8 and 24keV neutron calibration fields and the simulated workplace neutron fields for pressure water reactors. The details are described as follows.

(1) 8 and 24keV neutron calibration fields

The 8 and 24keV neutron fields can be produced by the $^{45}Sc(p,n)^{45}Ti$ reaction at 5SDH-2 tandem accelerator. A new target pipe of which structure is shown in Fig.1 was designed in order to bombard the scandium target with a larger beam current than 20μA, so as to increase the neutron yields. The whole target pipe is made of oxygen free copper for the sake of good heat conductivity. The scandium target evaporated on a tantalum back can be fixed on the end of the target pipe by a cylindrical copper sleeve. Refrigerant is driven by a compressor to flow around the target pipe. The target pipe can be connected with the pipeline of the accelerator by flanges. At present we are to test the target using the 3MeV proton beam of 30μA.

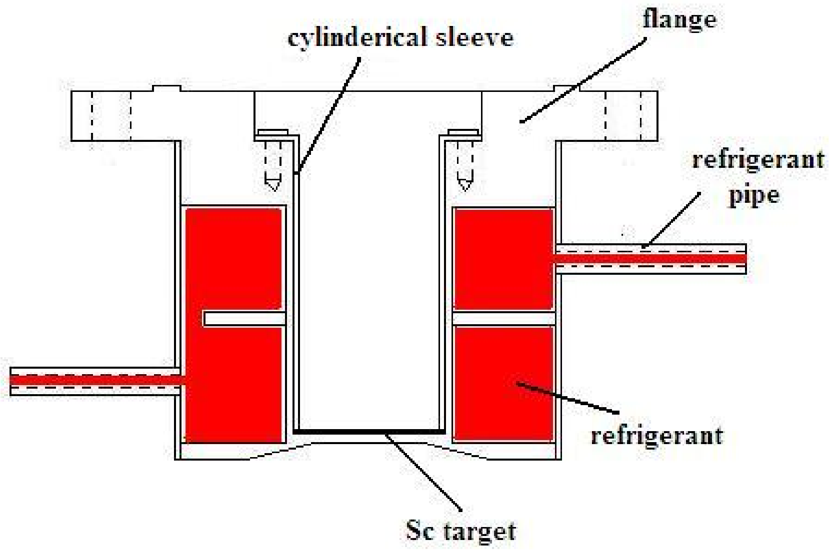

Fig.1 Sketch map of the new target pipe for the ^{45}Sc(p,n)^{45}Ti neutron source

Due to the lower neutron energies, the hydrogenous proportional counter used for 144keV～1.2MeV neutron fluence measurement is not appropriate for 8 and 24keV energies. Hence a detector of Si semiconductor with a ^{6}LiF converter of which structure is shown in Fig.2 was designed for the purpose. The ^{6}LiF with atomic abundance 85.43% of ^{6}Li was evaporated on a 10μm thick aluminum foil. The thickness of the ^{6}LiF converter is approximately 800μg·cm^{-2}. The α particles produced the ^{6}Li(n,t)^{4}He reaction can be stopped in the aluminum foil and the tritium can penetrate it although some energies may be lost. The residual energy of tritium entering a Si(Au) detector was calculated to be equal to 2.2MeV. The range of 2.2MeV tritium in silicon was also calculated to be approximately equal to 30μm, therefore, a passivated surface of Si(Au) semiconductor with 100μm thick depletion layer was chosen as the detector. In the near future the excitation curve of neutron yields as a function of incident proton energies is to be measured using a long counter, and the neutron spectra of a thick target（~500μg·cm^{-2}） and a thin target（~70μg·cm^{-2}) are to be measured using a lithium glass detector by time-of-flight method.

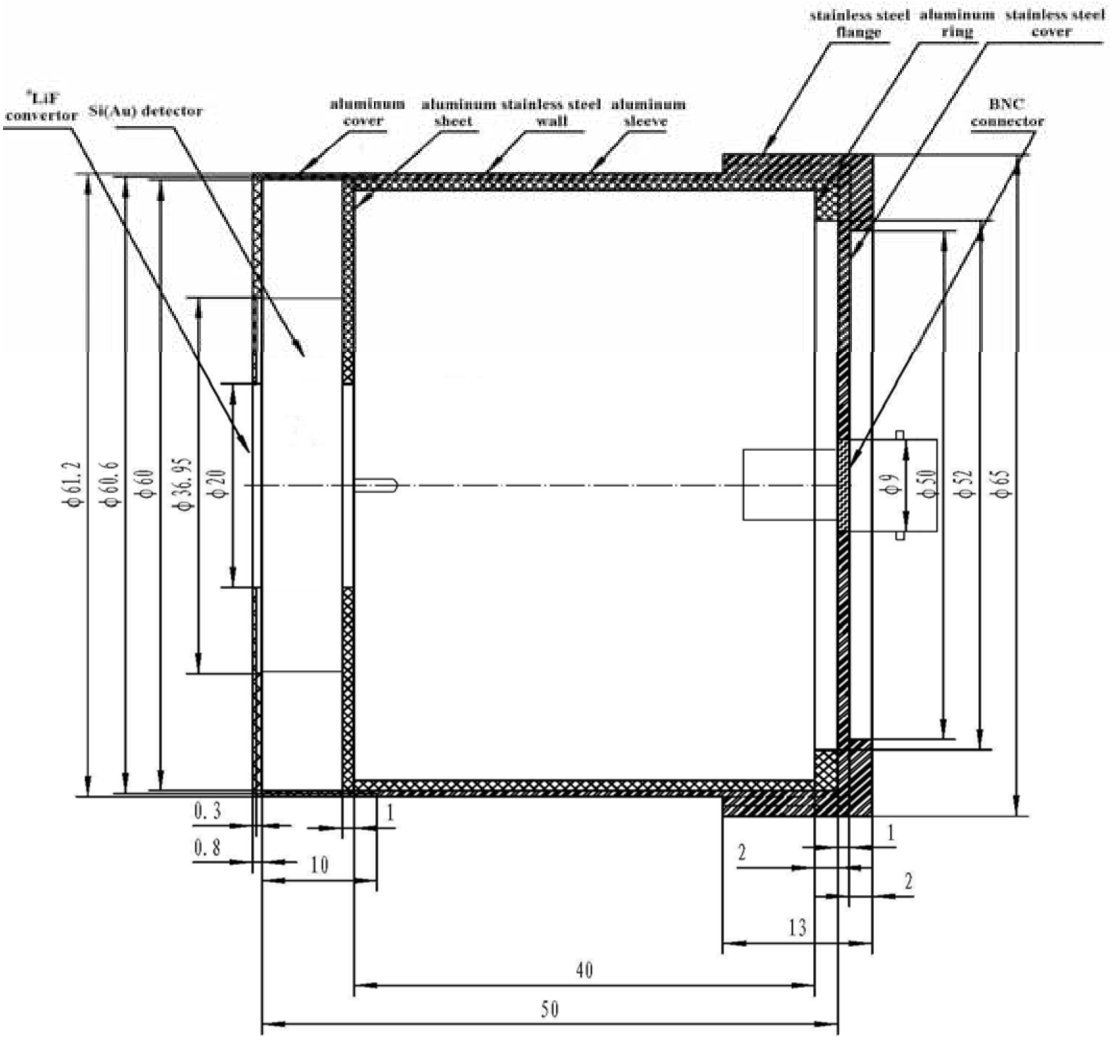

Fig.2 Sketch map of the ^{6}LiF-Si(Au) detector

(2) Simulated workplace neutron fields

The simulated workplace neutron fields for pressure water reactors are developing at 5SDH-2 tandem accelerator. A neutron calibration source facility has been developed as shown in Fig.3 according to a prototype as described in ISO 12789.

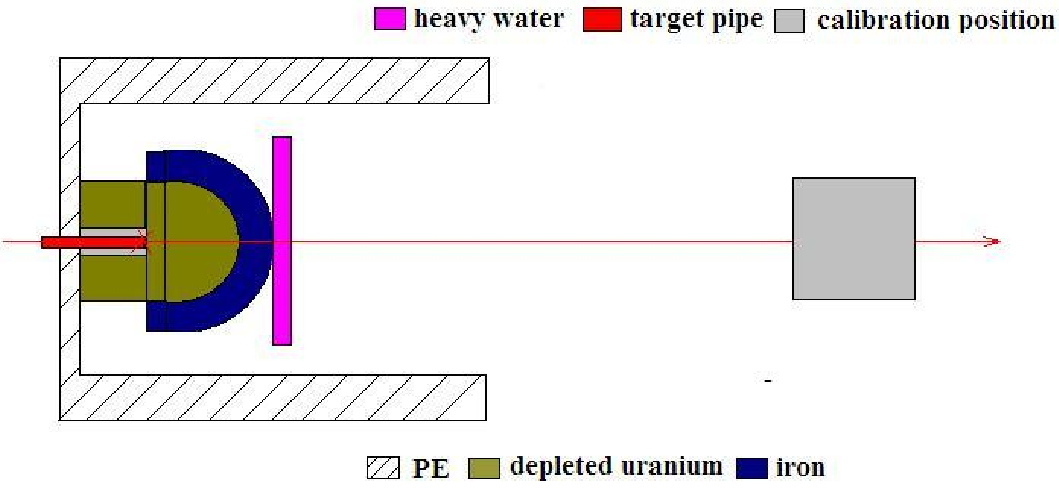

Fig.3 Sketch map of the neutron calibration source facility at CIAE

The 5MeV monoenergetic neutron field produced by the $^{2}H(d,n)^{3}He$ reaction is to be used as the primary source. The neutron fluence rate spectra at the calibration position had been simulated with Monte Carlo program as shown in Fig.4. Spectrum-1 represents the simulated neutron spectrum when light water substitutes for heavy water (see Fig.3) which was used to simulate spectrum-2.

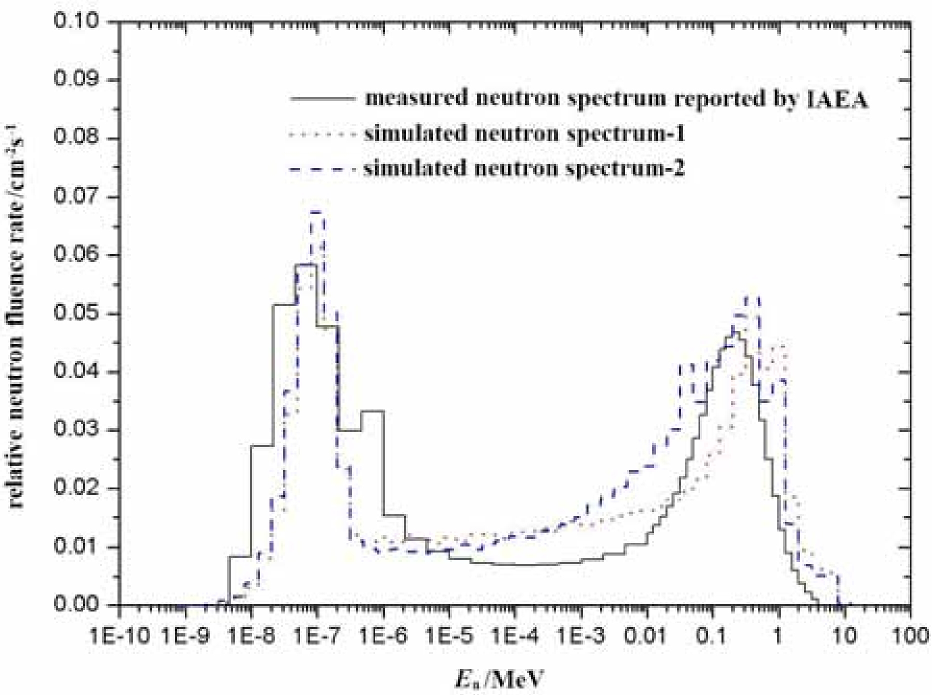

Fig.4 Simulated workplace neutron spectra for pressure water reactor

A ROSPEC spectrometer and a SSS spectrometer are to be introduced from the BTI Corporation of Canada to measure the neutron field spectra and the dose equivalent rates. The results will be compared to that measured by a Bonner sphere system.

2. Neutron measuring instruments

(1) Bonner sphere system

A Bonner sphere system has been developed in recent years. The system is composed of a set of polythene spheres (density $0.909\text{g}\cdot\text{cm}^{-3}$) as 3, 3.5, 4, 5, 6, 8, 10 and 12 inch in diameters with a ^{3}He proportional counter (SP9, Centronic Ltd.) as the central detector. The response functions of the system were calculated preliminarily with Monte Carlo program as shown in Fig.5. The angular responses of bare ^{3}He counter and 3inch sphere were also analyzed as shown in Fig.6. Here, $R(0^\circ)$ is the response when neutron incidence is from the nose of the ^{3}He counter, $R(90^\circ)$ is the response when neutron incidence is from the vertical direction to the stem of the ^{3}He counter, and $R(180^\circ)$ is the response when neutron incidence is from the end of the ^{3}He counter. For the bare ^{3}He counter the maximum anisotropy ($R(180^\circ)/R(90^\circ)$) is 1.22, and for 3inch sphere the maximum anisotropy ($R(180^\circ)/R(90^\circ)$) is 1.07. In addition, the spheres with different thick boron shells were designed to improve the energy resolution in the epithermal region so as to apply the spectrometer to the BNCT epithermal beam. The response functions of 2, 3, 4inch spheres with different thick boron shells are shown in Fig.7. The reason for the drop of the responses in the vicinity of 30keV should be investigated.

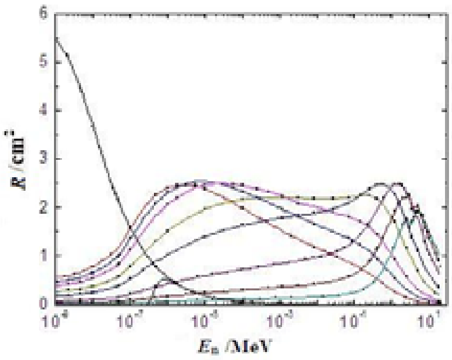

Fig.5 Response functions of the Bonner sphere system

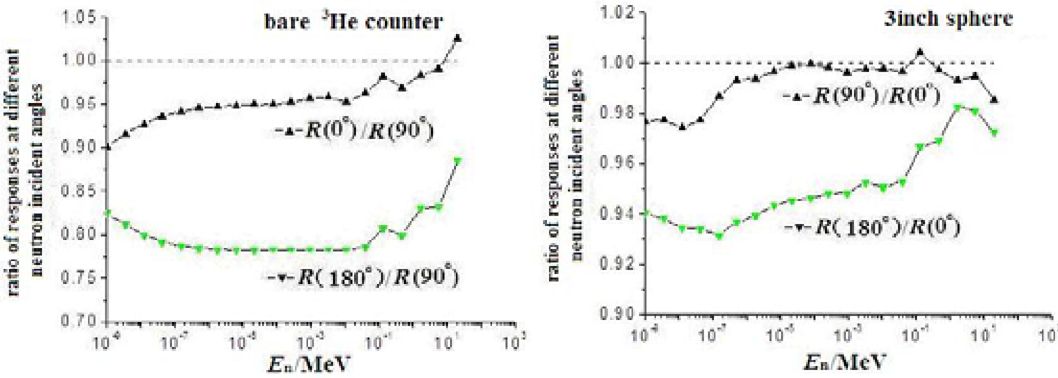

Fig.6 Ratio of the angular responses of bare ^{3}He counter and 3inch sphere

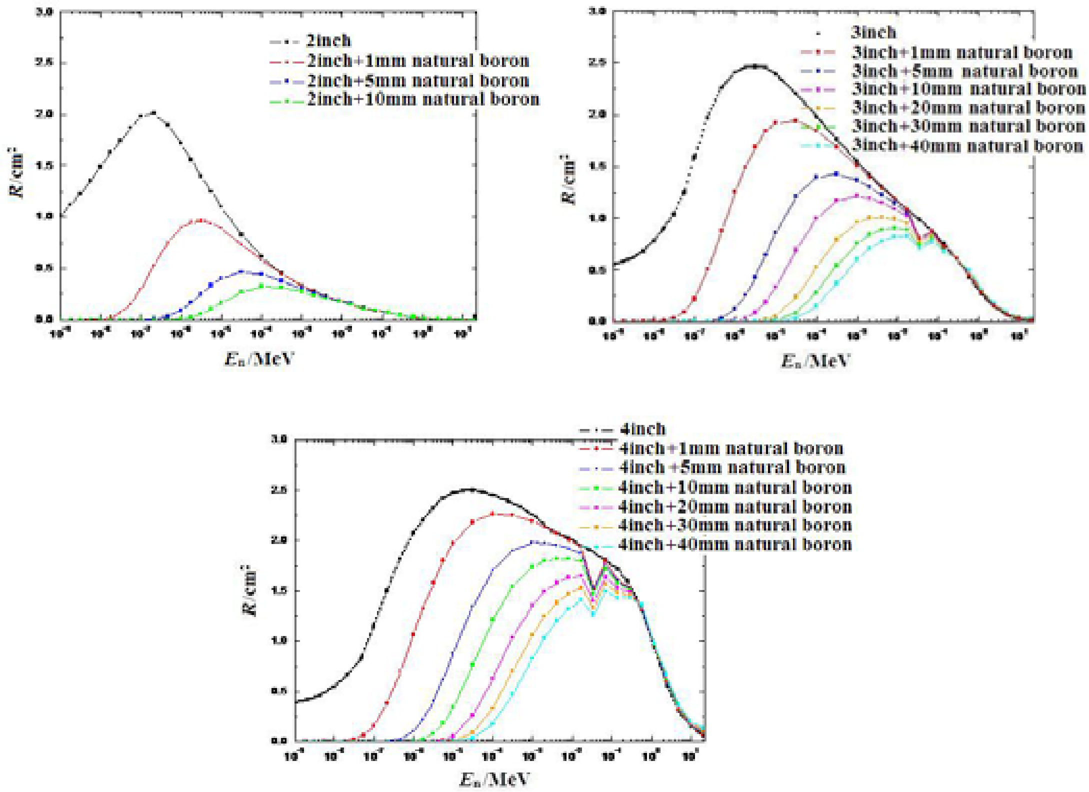

Fig.7 Response functions of 2,3,4inch spheres with different thick boron shells

Subsequently, the atomic density of ^{3}He in the proportional counter will be determined in a thermal field. And then the responses of the detectors will be calibrated experimentally in the monoenergetic neutron fields.

(2) Tissue equivalent proportional counter

A TEPC of which structure is shown in Fig.8 was introduced from Farwest Corporation of USA. The detector with a spherical A150 plastic wall can simulate a tissue cell with the diameter of 2μm.

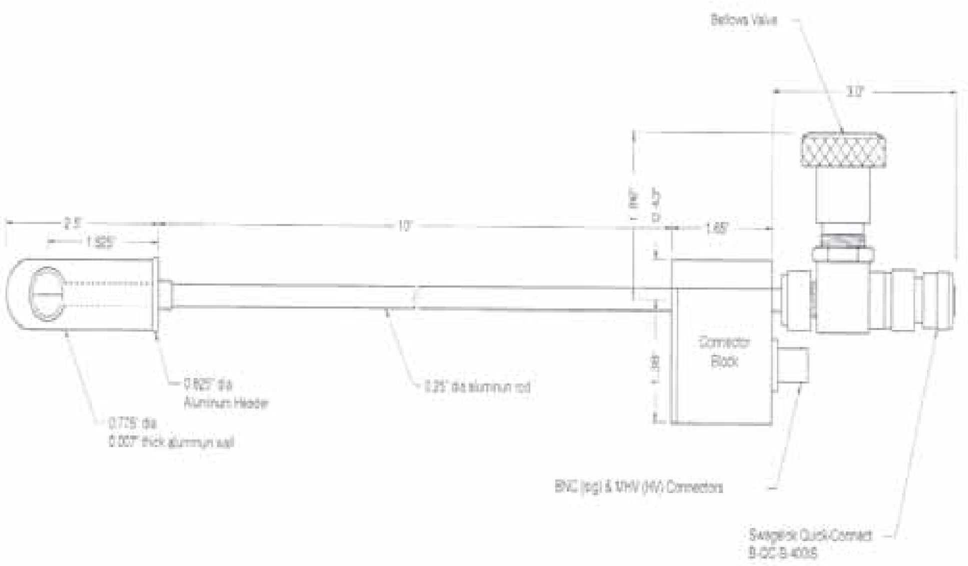

Fig.8 Sketch map of the TEPC with a spherical A150 plastic wall

The TEPC filled with the tissue equivalent gas comprising 63.99% CH_4, 32.9% CO_2 and 3.11% N_2 was preliminarily tested using ^{252}Cf, ^{60}Co and ^{137}Cs sources. The measured linear energy spectra are shown in Fig.9. Furthermore, the linear energy spectra for ^{60}Co and ^{137}Cs sources were also simulated by Monte Carlo program as shown in Fig.10. Because only one amplifier was used in the measurement, the amplification gain could not adapt well to the full range of the linear energy spectrum for ^{252}Cf source. This is the reason why the low linear energy events are rare as shown in Fig.9. Consequently two amplifiers should be used in the electronics of TEPC, and the reason why the measured linear energy spectra for ^{60}Co and ^{137}Cs sources are deviated from the calculated results also will be investigated in the next work.

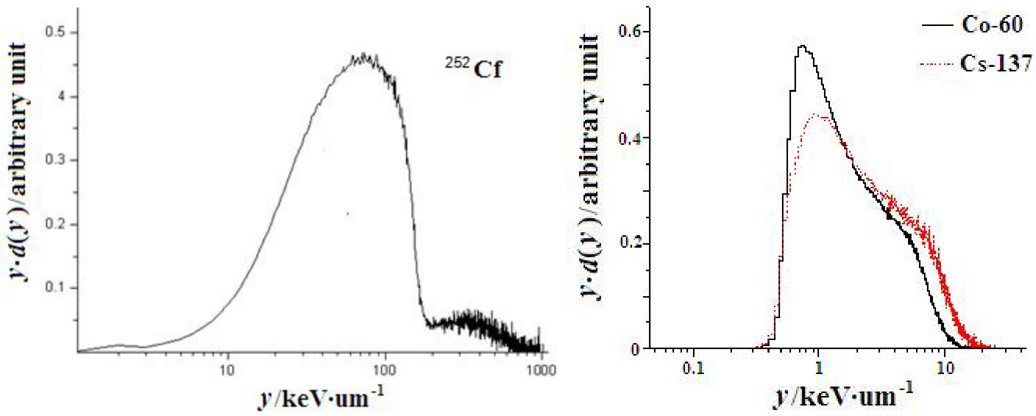

Fig.9 Measured linear energy spectra in the fields of ^{252}Cf, ^{60}Co and ^{137}Cs

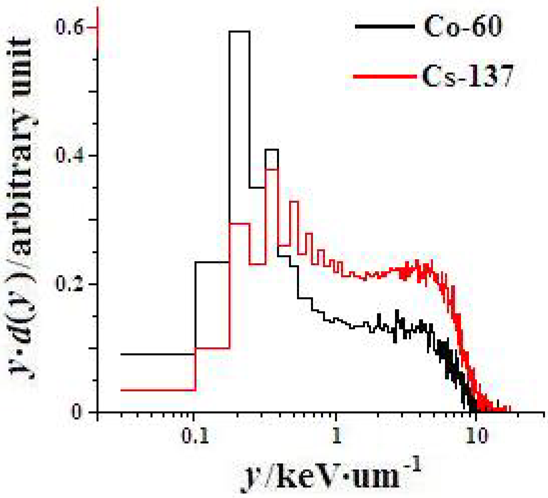

Fig.10 Simulated linear energy spectra in the fields of ^{60}Co and ^{137}Cs

3. Summary

In recent years neutron metrology has been developed continuously at CIAE. The 5SDH-2 accelerator was pulsed in order to measure neutron the monoenergetic field spectra by time-of-flight method. That can improve the characteristic parameters of the monoenergetic neutron calibration fields. A Bonner sphere system has been developed to make it possible that the neutron spectra at workplaces can be measured for the radiation protection purpose. A TEPC was introduced for developing the microdosimetry. The monoenergetic neutron calibration fields at 8 and 24keV and the simulated workplace neutron fields are also being developed. We believe that the neutron metrology at CIAE can make further progress in the near future.