A New Fission Chamber Neutron Detector Based On Helium Scintillation

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Main Contents

1Introduction

- In the fission radiation field, the neutron measurement is very important, which can indicate the fission of the nuclear matter. But in this radiation environment, the measurement could encounter some problems, such as the great influence of gamma rays, the lower intense neutrons and so on. Therefore, the better neutron detectors should have higher neutron sensitivity and relatively lower γ sensitivity.

- Some neutron detectors were designed to measure the fission neutrons, such as the scintillation detector, semiconductor. However, these detectors don’t have excellent n/γ discrimination, and the gamma rays always bring bad influence to the results of neutron measurement.
- So a helium scintillation fission chamber neutron detector was designed to solve those problems . The detector could be hoped to have excellent n/γ discrimination, and show better performance.

2 The Design of The Detector

2.1 Theory Model

Two thin $^{235}UO_2$ target foils are used as radiators, which could produce fragments when they undergo fission reactions with incoming neutrons.
Helium in the gas chamber could be excited by the charged particles from a fission event, and emits visible light photons, which are detected by a photomultiplier.

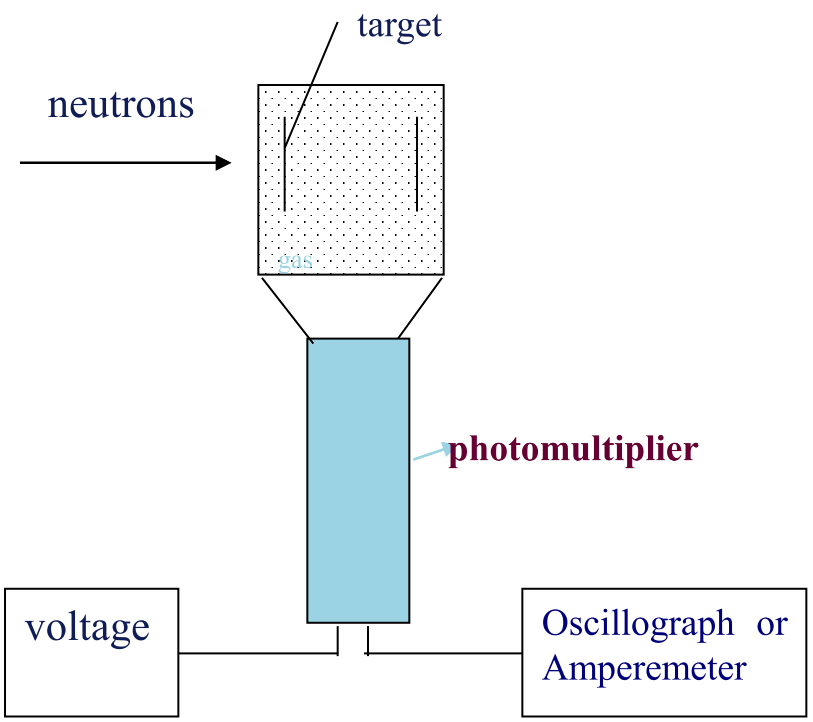


Fig.1 The structure of the detector

2.1.1 The distance between targets

The average range of fragments decreases as the thickness of targets increases. When the thickness is above 7.7mg/cm^2, the average range keeps invariable. Therefore the distance between two targets should be decided by the thickness of targets .

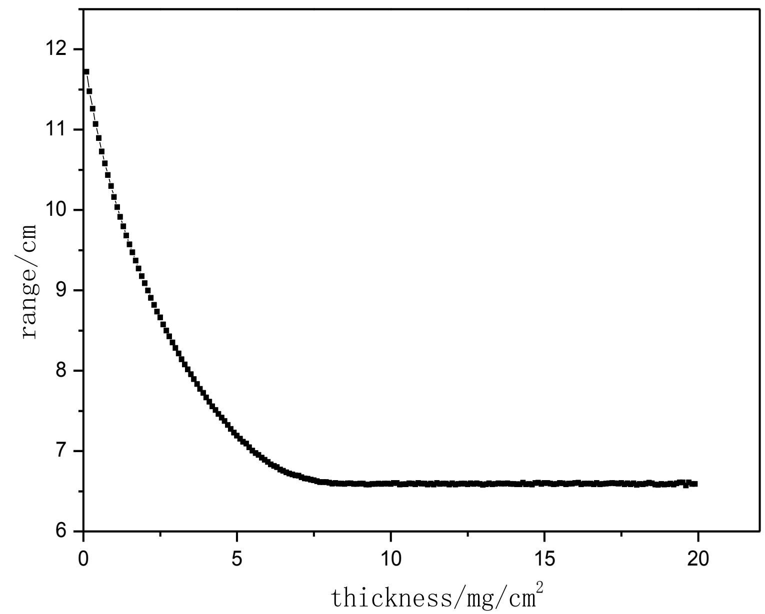
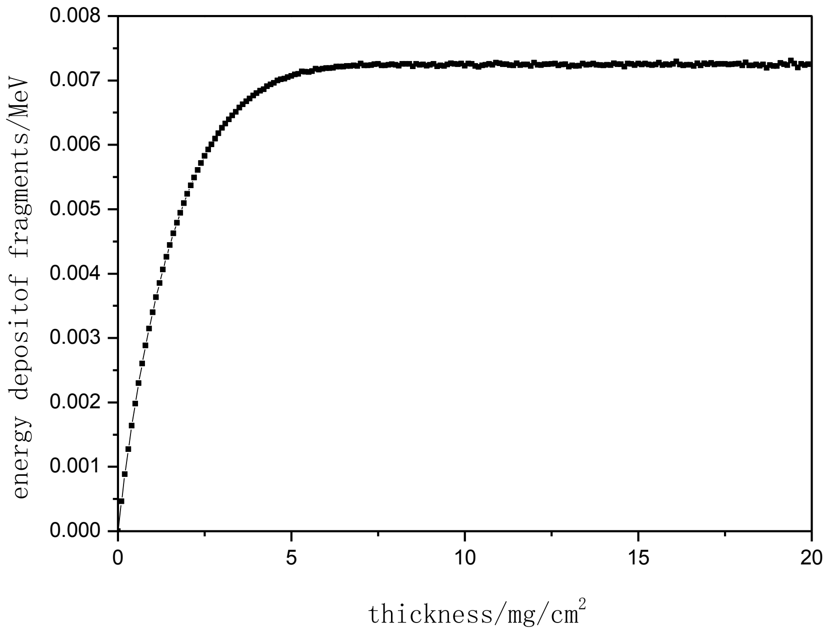


Fig.2 The average range of fragments from different thick ^{235}U targets

2.1.2 The thickness of targets



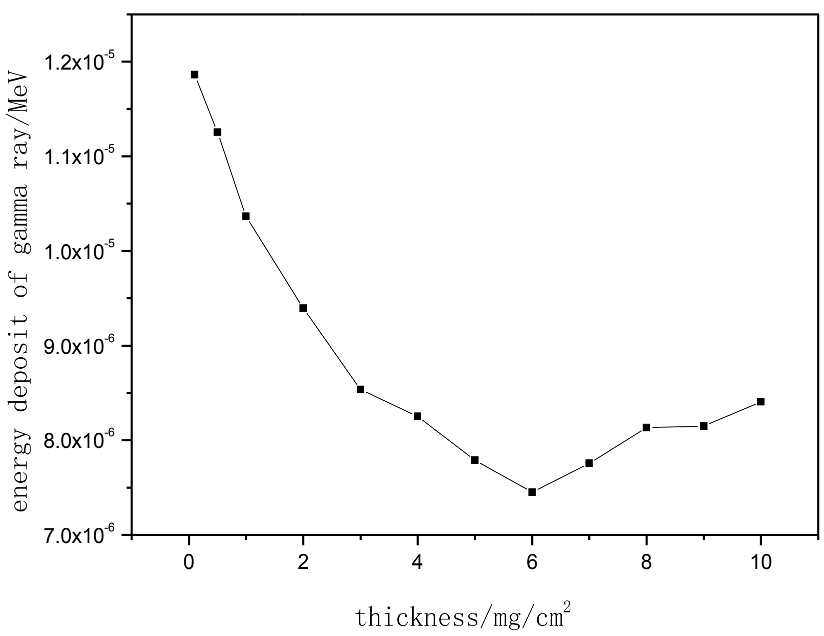


Fig3 The energy deposit of fragments from different thick ^{235}U targets

Fig4 the energy deposit of gamma rays in helium

2.2 The Detector

The shape of the neutron detector can be designed as a cuboid, the size of Which is about 30×10×10 cm^3.The Fig.5 shows the photo of the detector .

Fig.5 The photo of the detector

3 Performance of the Detector

Generally, one atmospheric pressure helium is filled in the chamber. Two ^{235}U targets are fixed inside, which are 1mg/cm^2 in thickness and 40mm in diameter. Two photomultipliers are used to detect the photons emitted from helium.

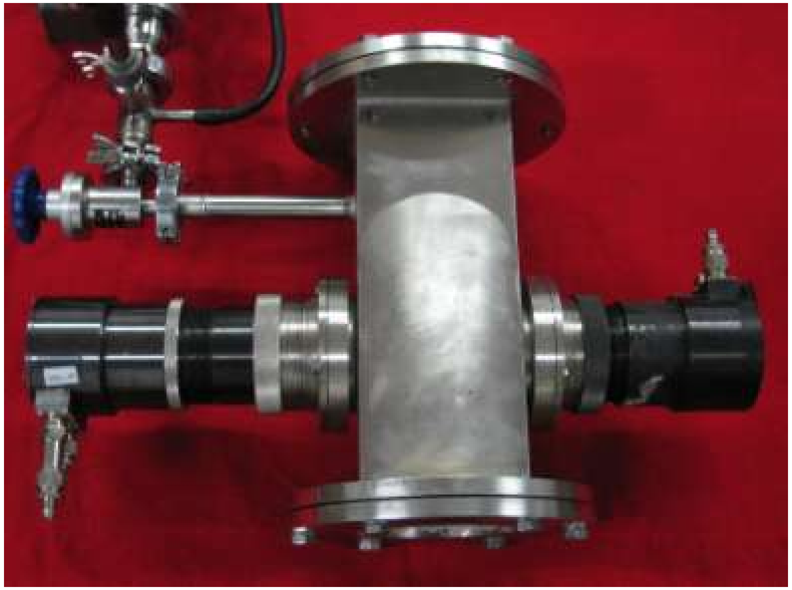


Fig.6

3.1 The neutron sensitivity theory calculation

If we assume neutrons energy deposit is E_n, fragments energy deposit is E_U, the gas scintillation efficiency is η, photons detected efficiency is ε, the quanta efficiency and gain of the photomultipliers are separately ζand G, the charge of a electron is e, the neutron sensitivity can be calculated by the formula:

$$S_n = (E_n + E_U)\,\eta\varepsilon\zeta G\,e$$

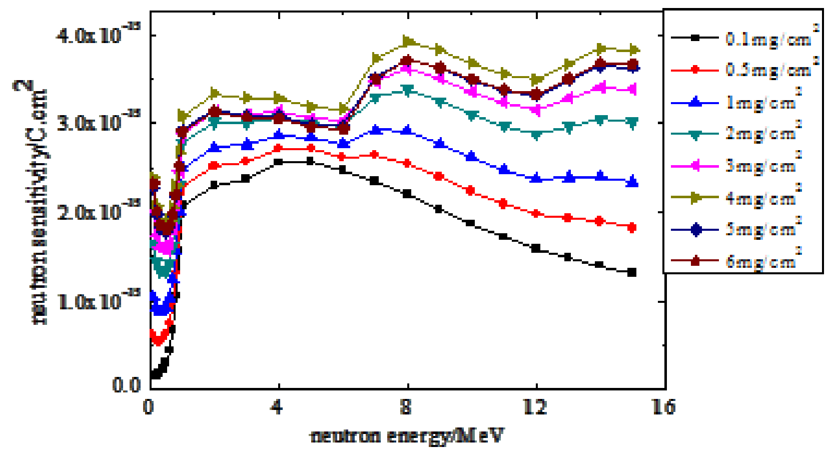


Fig.7 The calculation results of neutron sensitivity

3.2 The gamma sensitivity theory calculation

If we assume gamma energy deposit is E_γ,the gas scintillation efficiency is η, photons detected efficiency is ε, the quanta efficiency and gain of the photomultipliers are separately ζand G, the charge of a electron is e, the gamma sensitivity can be calculated by the formula:

$$S = E_\gamma \eta \varepsilon \zeta G e$$

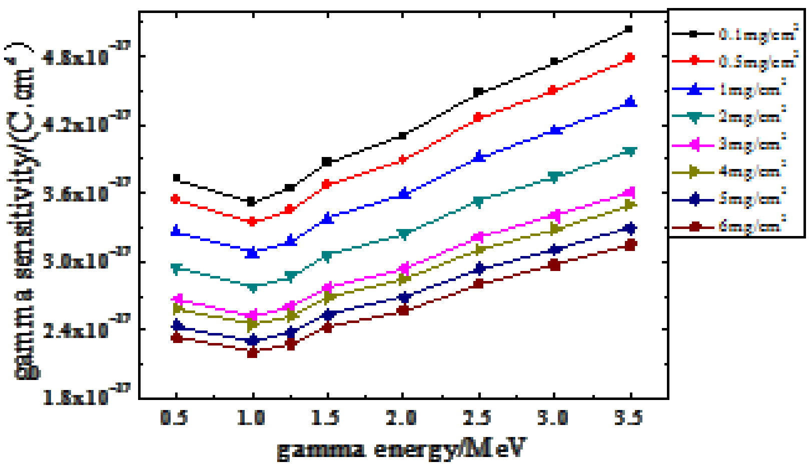


Fig.8 The calculation results of γ-ray sensitivity

3.3 n/γ discrimination

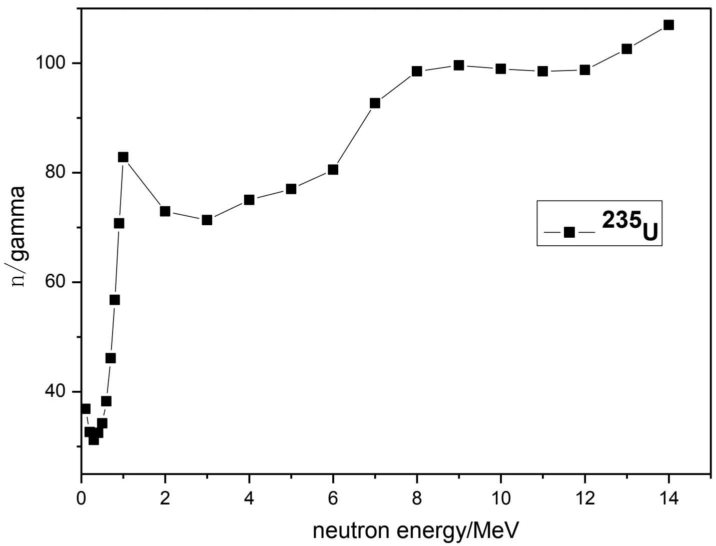


Fig.9 The ratio of neutron sensitivity to 1.25MeV γ-ray sensitivity

- **The thickness of ^{235}U targets : 7.7mg/cm^2 .**
- **n/γ discrimination: more than thirty.**

3.4 The time response

The time response of the detector can be decided by the flying time of the fragments, the time decay of helium, and the time response of the photomultiplier.

The flying time of the fragments can be calculated .The results are showed in the table.

Thickness/mg·cm^{-2}	0.1	0.5	1	2	3	4	5	6
Average energy/MeV	78.3	69.1	61.4	50.9	44.0	39.2	35.7	33.6
Average flying distance/cm	11.7	10.9	10.2	9.1	8.3	7.7	7.2	6.9
Average flying time /ns	22.3	22.1	22.0	21.5	21.1	20.8	20.4	20.1

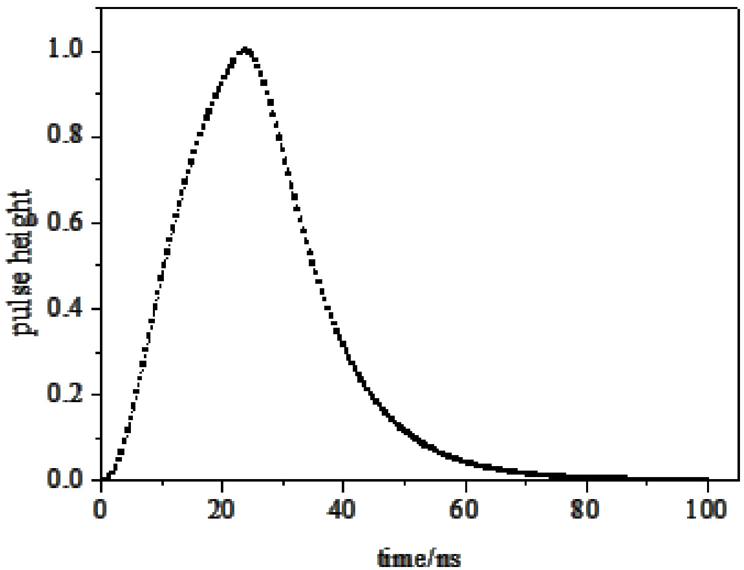
The time function of fragments can be show by the formula,

$$g_{\mathrm{f}}(t)=\begin{cases}\eta E_{\mathrm{d}},0\le t\le t_{\mathrm{f}}\\ 0,t>t_{\mathrm{f}}\end{cases}$$

The time function of the detector can be show by the formula,

$$g_{\mathrm{sys}}=\begin{cases}\frac{I_0\eta E_{\mathrm{d}}\tau}{\tau_2-\tau_1}[(\tau_2-\tau_1)-\frac{(\tau_2-\tau_1)\tau^2}{(\tau-\tau_1)(\tau-\tau_2)}\exp(-\frac{t}{\tau})+\frac{{\tau_2}^2\exp(-t/\tau_2)}{\tau-\tau_2}-\frac{{\tau_1}^2\exp(-t/\tau_1)}{\tau-\tau_1}],0\le t\le t_{\mathrm{f}}\\ \frac{I_0\eta E_{\mathrm{d}}\tau}{\tau_2-\tau_1}\left\{\frac{{\tau_1}^2}{\tau-\tau_1}[\exp(\frac{t_{\mathrm{f}}-t}{\tau_1})-\exp(\frac{-t}{\tau_1})]-\frac{{\tau_2}^2}{\tau-\tau_2}[\exp(\frac{t_{\mathrm{f}}-t}{\tau_2})-\exp(\frac{-t}{\tau_2})]+\right.\\ \qquad\left.\frac{(\tau_2-\tau_1)\tau^2}{(\tau-\tau_1)(\tau-\tau_2)}[\exp(\frac{t_{\mathrm{f}}-t}{\tau})-\exp(\frac{-t}{\tau})]\right\},t>t_{\mathrm{f}}\end{cases}$$

The decay time of helium gas scintillation is about 10ns, the respond time of photomultiplier is about 3ns .



- The time respond is about 24.5ns .

Fig.10 The respond time of the detector

4 Experiments

The neutron measurement experiment was performed with the D-T neutrons, of which energy was about 14MeV. The neutron sensitivity was about $2.56\times10^{-15}C\cdot cm^2/n$ that was inconsistent with the theory calculation, because the pressure of helium was 0.7atm in this experiment.

Fig.11 The neutron measurement experiment

The γ-ray sensitivity measurement experiment was performed with the ^{60}Co source, of which energy was about 1.25MeV. The γ-ray sensitivity was about 3.04×10^{-17} C•cm^2/γ that was consistent with the theory calculation.

Fig.12 The γ-ray measurement experiment

The time respond measurement experiment was performed with DPF, of which energy was about 14MeV. The result of time respond was about 29ns that was consistent with the theory calculation.

Fig.13 The time respond experiment

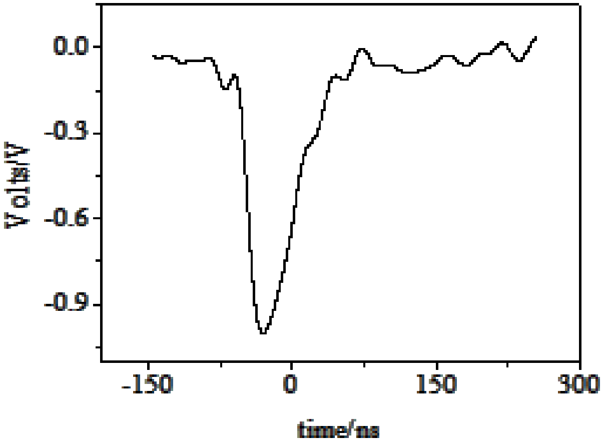
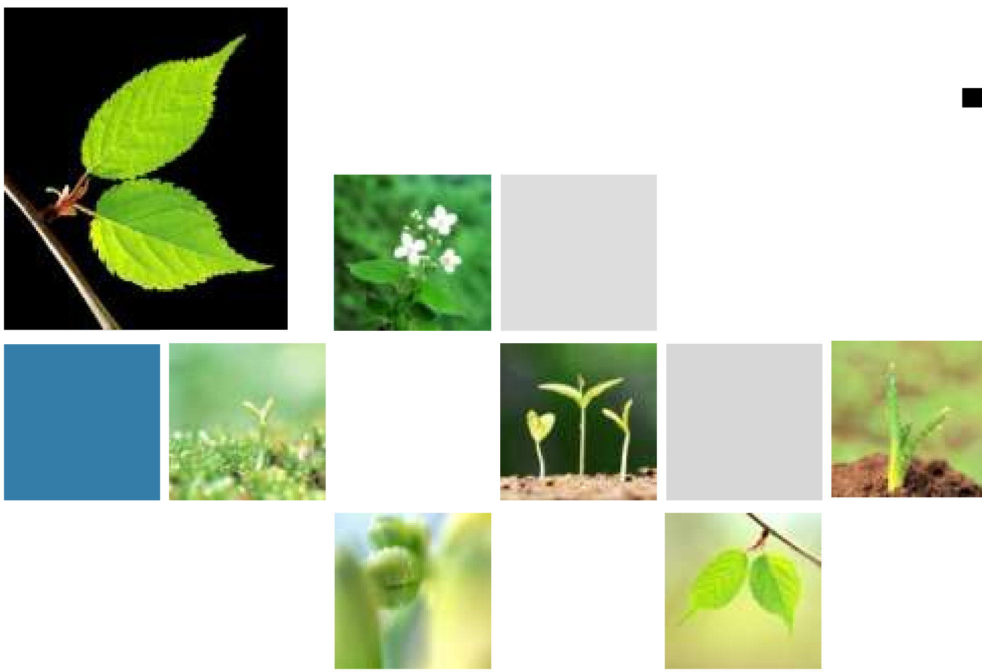


Fig.12 The wave of experiment

Conclusion

The helium scintillation fission chamber neutron detector combines the advantage of fissionable material and helium scintillator. The neutron sensitivity of the detector is about 10^{-15} $C\cdot cm^2/n$, which is about 80 times more than γ-ray sensitivity. The excellent n/γ discrimination makes the detectors be used well in the low intensity fission radiation field.



Thank You!