SILVER NEUTRON ACTIVATION DETECTOR FOR MEASURING BURSTS OF 14 MEV NEUTRONS

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In order to measure bursts of 14 MeV neutrons, a silver neutron activation detector was designed. The detector was made up of neutron moderating material natural silver plastic scintillator and a PMT. The output current of the detector was recorded by a micro-current meter. By comparing and analyzing the differences between the output current curves of the detector which measured under the constant neutron generator and that of the pulsed neutron source, typical parameters were deduced. Then yields of bursts of 14 MeV neutrons could be calculated. This new method reduces the dependence of the cross-section data, and it is very simple and convenient to be used for on-line measurement.

1. Introduction

It is important to measure the yield of 14 MeV neutrons accurately in DT fusion reactions. The measurement is helpful for the studies of ICF and Tokamak devices [1-2]. Because of its simplicity and convenience, Neutron Activation Analysis (NAA) has become the most common method of measuring the neutron fields [3-4]. The basic principle of NAA is as follows: Firstly, adopting an appropriate thin sample; then the sample being irradiated by neutron, some of the nuclide will be activated and give off gamma rays; Secondly, putting the sample to semiconductor detector, such as a HPGe detector, in order to measure the intensity of these gamma rays. At last, the neutron yield can be calculated by the time and the activated cross-sections.

This paper introduces another neutron activated method. The detector was made up of neutron moderating material natural silver plastic scintillator and a photo-multiplier tube (PMT). The output current of the detector was recorded by a micro-current meter. This method does neither need semiconductor detector to measure gamma rays off-line, nor need other equipments, such as main amplifier, discriminator and so on. So, it is simple and has few transition factors. It is suitable for measuring bursts of 14 MeV neutrons repeatedly.

2. Silver Neutron Activation Detector

2.1 Neutron Activation Reactions

Cross-sections values for fast neutron reactions on silver isotopes are very low [5]. It is hard to measure 14 MeV neutrons directly when the yields are not high. Usually, it is necessary to convert fast neurons to thermal neutrons in order to use activation methods [6]. Nature silver includes ^{107}Ag and ^{109}Ag, the abundance of which are 51.82%, 48.18%, respectively. The reactions of thermal neutrons activating nature silver and the half-lives of the products are as follows [7]:

$^{109}Ag + n \rightarrow \gamma + {}^{110m}Ag \rightarrow {}^{110}Cd + \beta^-$ （ E_β=2.24 MeV or 2.82 MeV ）

$$(T_{1/2} = 24.2\,s\;,\;\sigma_{n,\gamma} = 89 \pm 4\,b)$$

$^{107}Ag + n \rightarrow \gamma + {}^{108m}Ag \rightarrow {}^{108}Cd + \beta^-$ （ E_β=1.49 MeV ）

$$(T_{1/2} = 2.42\,\min\;,\;\sigma_{n,\gamma} = 37 \pm 2\,b)$$

$^{109}Ag + n \rightarrow \gamma + {}^{110m}Ag \rightarrow {}^{110}Cd + \beta^-$ （ E_β=1.77 MeV ）

$$(T_{1/2} = 252\,d\;,\;\sigma_{n,\gamma} = 4.7 \pm 0.4\,b)$$

Obviously, the first and the second reactions play important roles in the neutron detections because of their shorter half-lives and larger cross-sections.

2.2 Internal Structures of the detector

The silver neutron activation detector was made up of neutron moderating material、natural silver、plastic scintillator and a PMT. The nature silver foils were clipped between the plastic scintillators. It could be used to measure bursts of 14MeV neutrons in its linear range. The current of anode of PMT varied directly as time was recorded by a micro-current meter. Comparing with other detectors, it has very fast response, about 5 ns. So, it does not need make any corrections of dead time and discriminating time.

The internal structure of the detector is described as follows: 9 pieces of natural silver foils (150×120×0.25mm^3 for each piece)、10 pieces of ST401 plastic scintillaor (150×120×3mm^3 for each piece)、a cone-shaped light guide and a PMT. Each piece of foil was clipped by two pieces of plastic scintillaor like a sandwich. Outside the sandwich, there was a sheath made up of cadmium foil. The thickness of the cadmium foil was 1.5mm. It was used to reduce the effects of the scattered neutrons of the surroundings. Outside the cadmium sheath was 20mm boron-doped polythene. The sketch of internal structure of the silver-activated detector is shown as figure 1.

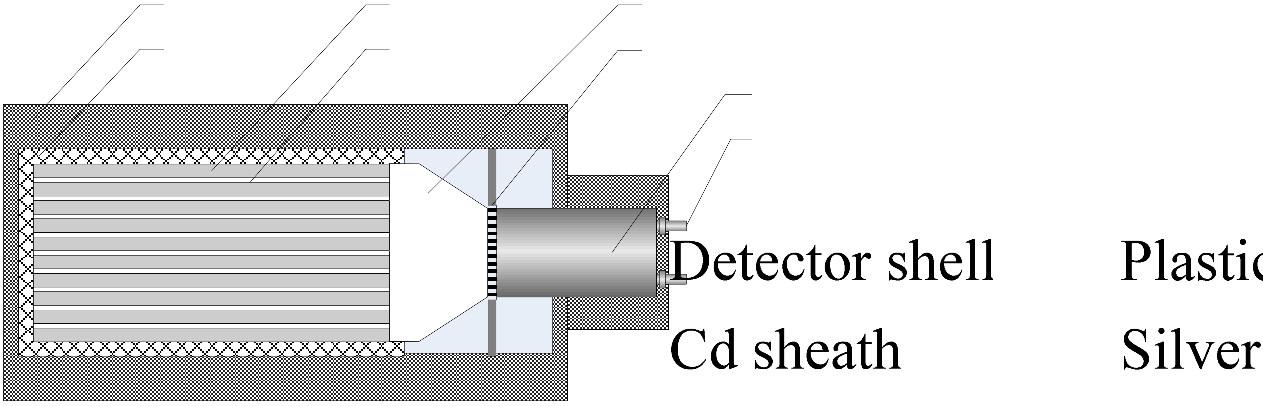

Fig.1 Sketch of the structure of the silver-activated detector

The sensitivity of the silver neutron activation detector could be adjusted to a certain extent by changing the numbers or the sizes of the silver foils, or varying the thickness of neutron moderator.

As it is known, when the detector is relative far from the neutron source, scattered neutrons would be the main factor of backgrounds [8]. Large contributions of the scattered neutrons would increase the dependents of the calibration results to the environments. This would increase the uncertainties of the final results of the detector applied in a new environment. So, the detector should be set up in a shielded cylinder made of 10cm polythene in order to decrease the effect of backgrounds.

2.3 Efficiency Calibration

It is difficult to calculate the neutron flux by using cross-section datum directly. Because when the fast neutron interacted with the moderator, the energy spectrum becomes more complicated. It is hard to find a standard pulsed neutron source for calibration. But it can be calibrated directly against an absolute technique using a "steady current" neutron generator by accelerating D^+ particles to interact with ^3H. The reaction is written as:

$$D + T \rightarrow {}^4He + n + 17.6\ MeV \quad (E_n = 14\ MeV)$$

The sketch of efficiency calibration of the silver-activated detector is shown as figure 2.

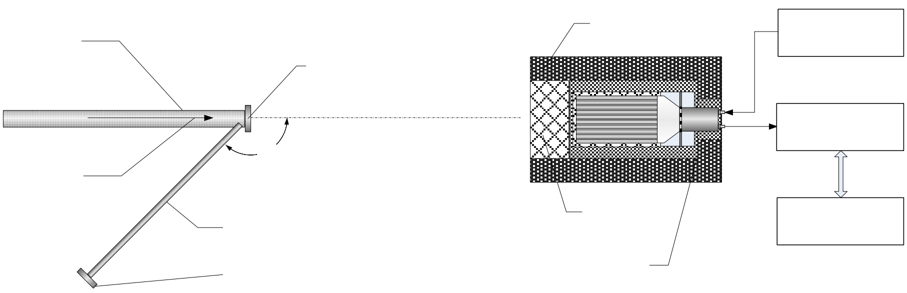

Fig.2 Sketch of efficiency calibration of the silver-activated detector

In order to determine the detection efficiency, the neutron generator was turned on and kept with a constant intensity. (The measurement uncertainty of the intensity was less than 5%). The exposure time must be larger than 150 seconds in order to let ^{110}Ag (half-life:24.2s) activation and decay be approximate to a balance. Then, the neutron generator was turned off immediately. The current of anode of PMT varied directly as time was recorded by a micro-current meter. An automatic data collection program was developed by using TESTPOINT software development platform. Real-time data was transmitted to a remote computer by using IEEE-488 card. So, a series of files including current data versus varied time could be got in the computer. So, beta decays of the nature silver were reflected by these files. The recorded time usually was set to 400~600 seconds so that the later analyses would become very convenient. The neutron flux was absolutely measured by the associated particle method [9].

A typical sequence of the efficiency calibration is shown as Figure 3.

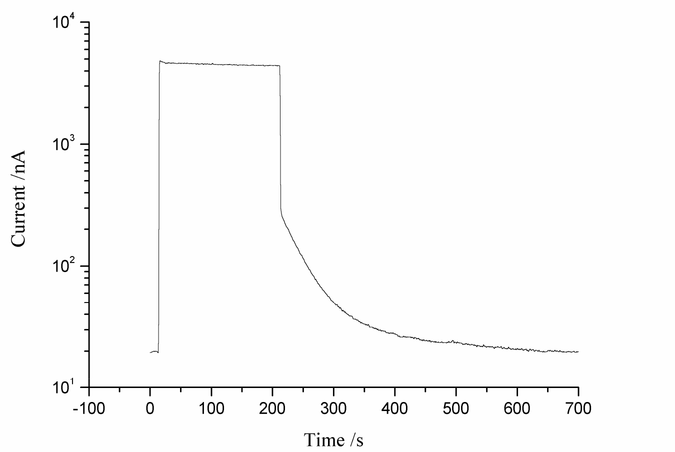

Fig.3 Output current as a function of time at the time of efficiency calibration

The working process of the silver-activated detector was reflected by the current data varied as time. Firstly, only background current; then when the neutron generator was turned on, the current was raised sharply to a high platform and kept stable for a while. This was owed to the fluorescence of the recoiled proton and beta decays. After the neutron generator was turned off, the current was not deduced sharply as the same raising slope. But down sharply to a certain value then was decreased slowly. At this time, the beta decays of nature silver could be observed clearly.

From the reactions described above, the decay process was divided into two parts: ^{110}Ag ($T_{1/2} = 24.2\ s$, fast) and ^{108}Ag ($T_{1/2} = 2.4\,\text{min}$, slow).

When the neutron generator was turned off, the output current of the detector could be expressed as:

$$I(t) = I_1 \mathrm{e}^{-\lambda_1(t-t_0)} + I_2 \mathrm{e}^{-\lambda_2(t-t_0)} + I_\mathrm{b} \qquad (1)$$

where：λ_1——the decay constant of ^{110}Ag，$2.86\times10^{-2}s^{-1}$.

λ_2——the decay constant of ^{108}Ag，$4.81\times10^{-3}s^{-1}$.

t_0——the moment of the neutron was turned off, s.

I_b——background current, nA.

I_1、I_2——undetermined coefficients, nA.

The current data recorded can be fitted by Formula (1). The parameters: I_b、I_1 and I_2 are determined by Least-Square methods.

The detection efficiency is defined by the decay rate of ^{110}Ag:

$$\varepsilon = \frac{I_1}{\phi} \qquad (2)$$

where：ϕ - the neutron flux incident to the detector, n/cm^2.

I_1 - the same meaning as Formula (1).

At the above definition, it was assumed that the duration of the burst of 14 MeV neutrons must be far less than the fasted decay time of the detector, i.e. $1/\lambda 1$. Usually, the duration of the burst was less than 5μs, and $1/\lambda 1$ is 34.91s. In other words, the silver neutron activation detector was valid to be used in a very short time burst, no more than 1s. Otherwise, the efficiency calibration could not be done by the method described above.

After the efficiency having been got from the calibration by using a “steady current” neutron generator, the yields of bursts of 14 MeV neutrons could be calculated by using the silver-activated detector and Formula (2).

The efficiency calibration has been done three times. After data processing, the average of the detection efficiency, $\varepsilon=1.84\times10^9$/nA, was adopted.

3. Application

DPF (Dense Plasma Focus) is a common pulsed neutron source at the laboratory. It could be operated repeatedly. It gives off 14MeV neutrons with the duration of 20~30 ns. The detector was designed to measure the neutron yield of this kind of single pulsed, DT fusion neutron source. Which should be pointed out was that there was an electrical-operated mechanical shutter (with the diameter of 60mm). The shutter was closed firstly. It was used to avoid the PMT become saturated because of the high radio-fluorescence produced by the neutron beam in a short time. When the neutron beam passed, the shutter was opened. The relative zero-time was the time of which DPF was turned on. The measurement was performed at the neutron laboratory hall of Northwest Institute of Nuclear Technology, China. The detector was set up with the same position as it was calibrated. So, the distance from the source to the detector was fixed.

A practical output current of the detector is shown as figure 4.

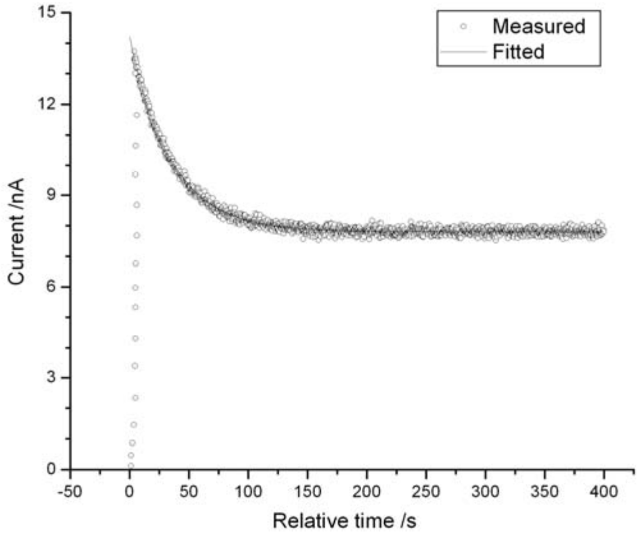

Fig.4 Output current of silver-activated detector as a function of time at the time of measuring DPF neutron source

Fitting the curve of Fig.4 according to formula (1), the parameter I_1 could be easily acquired. Then, it could be calculated through formula (2) that the yield of this burst of 14 MeV neutrons was: 8.74×10^9.

According to the analysis, the measurement uncertainty was about 20% (k=2).

4. Conclusion

In order to measure bursts of 14 MeV neutrons, a silver neutron activation detector was designed. By comparing and analyzing the differences between the output current curves of the detector which measured under the constant neutron generator and that of the pulsed neutron source, typical parameters were deduced. Then yields of bursts of 14 MeV neutrons could be calculated. This detector is very simple and convenient to be used repeatedly.

Acknowledgements

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