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A new method to diagnose the time constant of a subcritical device

Baiyun[1,2,3],Yangbo[1,2*], Dengli[1,2],Pengxianjue[1,3]

[1] Institute of Applied Physics and Computational Mathematics Beijing 100094, China
[2] CAEP Software Center for High Performance Numerical Simulation, Beijing, China
[3] Key Laboratory of Neutronics,China Academy of Engineering Physics,Mianyang 621900,China
Bai_yun@iapcm.ac.cn,heroyb@hotmail.com,deng_li@iapcm.ac.cn ,pengxj@ceap.ac.cn

Abstract

The DPF (Dense Plasma Focus) pulsed neutron source method is a new method to confirm the instantaneous time multiplication constant (usually called α eigenvalue) of a sub-critical device, its feasibility is proved by our research before.In this article, a new experiment method of measuring γ intensity in the subcritical device to diagnose the time constant is raised ,and turned out to be practical by the numerical calculation and the experiment, Considering the two different DPF pulsed neutron source, the validity of this method and the limitation of this method is also discussed.

Keywords: Subcriticality, Pulsed source, Time multiplication constant

1. Introduction

From the 1940s to now, different measurement methods to diagnose the prompt neutron time constant of the subcritical device have been developed. Pulsed neutron source method[1] is the most intuitive and convenient way in the all methods of prompt neutron time constant, which is determined by measuring the time decay curves of a large number of neutron injected into nuclear system, then prompt neutron decay constant is derived by the curve fitting. The method can be applied in the nuclear systems which require to get prompt neutron decay constant fastly. However, this method requires that single neutron pulse intensity should be strong enough. Then, the neutrons generated by a single neutron pulse can meet the statistical precision requirements and the counts on the detector are high enough to meet the count rate.

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In actually determining the degree of the reactor subcritical method using DPF (Dense Plasma Focus) measurements[2] [3] [4], the applicabilities of the method are closely related to the DPF source.

* Corresponding Author: Tel: +86-10-59872183, Fax: +86-10-59872300.
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In recent years, with the continuous development of the neutron source technology, the quality of the DPF neutron source is high enough, then it is possible to measure damping signal of long enough time to gain time constant

Based on the latest parameter of the DPF, and the measurement limit of the detector, the possible signal on the detector is calculated and discussed. The time after which the whole system will reach the stable distribution after the strong pulse signal is calculated and discussed here.

2. A brief description of the principle and test system

2.1 A brief description[2]

The principle of DPF pulse neutron source method for measuring time constant is that: first,injecting instantaneous pulse neutron to the subcritical device, then, measuring the leakage neutron of the device to identify the important parameter. Assume that at the time t=0, the neutron pulse is injected into a subcritical device, then the neutron flux of the system should be described by following equation:

$$\frac{1}{V}\frac{\partial\phi(\vec{r},t)}{\partial t} = D\nabla^2\phi(\vec{r},t) - \Sigma_a\phi(\vec{r},t) + \nu\Sigma_f\phi(\vec{r},t) \qquad (1)$$

The initial conditions of pulse source is $\phi(r,0) = \phi(r)$:

V : Neutron velocity;

D : Diffusion coefficient;

Σ_a : Macroscopic absorption cross section;

Σ_f : Macroscopic fission cross section;

ν : Each fission neutron number。

Aftre the injection of the pulse neutron,the the neutron flux of the system will approach the asymptotic form：

$$\phi(r,t) \approx A_1\psi_1(r)e^{-v[\Sigma_a - \upsilon\Sigma_f + DB_g{}^2]t} \qquad (2)$$

$\psi_1(r)$: the fundamental mode distribution of the device;

B_g : the geometric buckling or eigenvalue of this fundamental mode.

For a fast pulse,the time characteristic of neutron flux is decided by the prompt neutron.If the response signal of the detector: $R(r,t) \sim \phi(r,t)$, then,the time constant can be described：

$$\alpha = \frac{1}{R}\frac{dR}{dt} = V[\upsilon\Sigma_f - \Sigma_\alpha - DB^2] \quad (3)$$

2.2 The detection system

Assume that the main parameters of DPF (Dense Pulse Focus) is ～100ns for the pulse width and 10^{11}(n/p) for the pulse intensity of source strength, analysed a plutonium bare sphere system of radius 6.3cm. The ignored effects of the energy and transport in equation(3)is included here by program JMCT[6].In our calculation, the space of the DPF and the detector is 1m, and the device is between the DPF and detector, and the space of the device to the DPF and to the detector are all 0.5m, and the measure limit of the detector is $10^8\ \gamma / \mu s$.

3. The results of the calculation

If the neutron number of DPF is Sn, the distance of the DPF to the device is L, the radius of the subcritical device is r, then the DPF neutron number received by the subcritical device is the external neutron source system is:

$$N = S_n \cdot (1 - \sqrt{1 - \left(\frac{r}{L}\right)^2})/2 \quad (4)$$

In the system discussed here, the neutron number N is 3.38×10^8n/p. First, considering the DPF source is deuterium-deuterium, the source neutron energy is 2.45MeV, pulse width of the DPF is 100ns, the results are as follows:

3. 1 The leakage flux spectrum of the neutron

After the injection of DPF neutron ,the characteristic of the leakage neutron spectrum ,by the equation (3),which can be measured by the neutron detector system is shown in Figure 1:

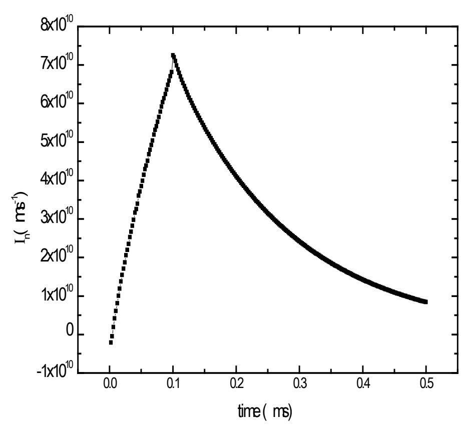

Figure 1 The neutron flux spectrum of the dense pulsed source

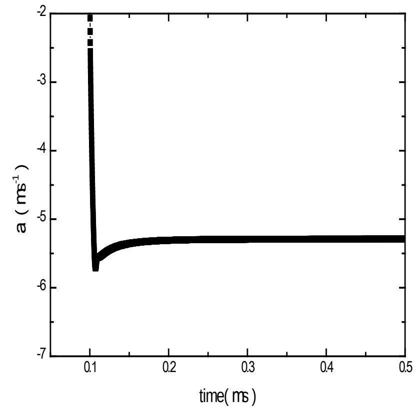

Figure 2 The α eigenvalue gained by neutron flux spectrum

Then the time constant of the device is caculated and shown in figure 2. After the pulse neutron entering the subcritical device, the stable distribution can be formed after a period of relaxation time.Thedamping distribution can be caculate time constant model. The numerical results show that the stable distribution, based on the model system of neutron flux spectrum after 0.072 μs relaxation time, known as the syndrome distribution.

3. 2 The leakage flux spectrum of the gamma

In order to diagnose the time constant of subcritical device more accurately,another approach is tested by measuring the leakage gamma ray intensity of the device. Since the lowest limit leakage of the gamma detector is about 10^8 γ /μs. So,if the the leakage gamma ray intensity is less then 10^8 γ /μs, then the signal cann't be measured. According to the current level of sensitivity test distance and detector, the actual DPF deuterium source in accordance with the 10^{11}(n/p) is injected in this subcritical device, the neutron、gamma coupled transport is calculated, the leakage gamma intensity changes with time as shown in figure 3:

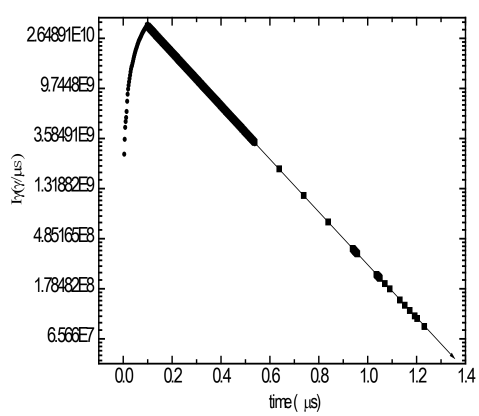

Figure 3 The gamma flux spectrum of dense pulsed source

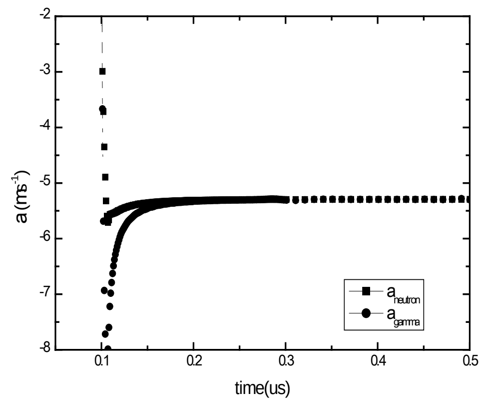

Figure 4 The α eigenvalue gained by gamma flux spectrum

From the results, when the source parameters is 10^{11} (n/p), the effective detected time range of the gamma detector is 1.1μs during which the all the intensity can be measured by gammadetector, the method to diagnose subcritical system time constant by gamma is feasible.

Considering such system, relationship between the source strength and the spectral intensity is linear dependence.If the source parameters is 10^{10} (n/p), the intensity would appear to be at least an order of magnitude less than before.At this time, the lower limit of the range of measured before 0.6μs signal can meet the test requirements. If the source parameters is 10^{9} (n/p), only the signal before 0.2μs can meet the test requirements. So,in order to detect the signal attenuation and stability, the DPF must be greater than or equal to 10^{9} deuterium intensity (n/p).

The time constant of the system is caculated by the flux spectrum shown in figure 3,by the equation (3),the processing to achieve stable distribution spectral gamma intensity figure 4 is about 20ns more than the relaxation time of the neutron flux spectrum to achieve stable relaxation time, The processing time constants were obtained in the numerical results are consistent with the neutron flux spectrum.

3. 3 The discussion on the source strength

If the deuterium-tritium source is selected, source neutron energy is calculated by the 14.1MeV, then the neutron and gamma intensity of the system is shown in figure 5. The energy of the neutron of deuterium-tritium neutron source is higher than deuterium-deuterium source,so intensity spectrum generated by the deuterium- tritium source is strongger than deuterium-deuterium source. However,the time of

the syndrome distributionis is basically the same of deuterium-tritium source and deuterium-deuterium source.

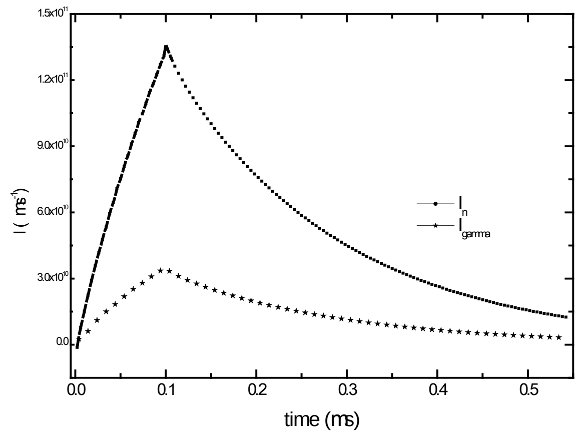

Figure 5 The neutron and gamma flux spectrum of pulsed DT neutron source

According to the 3.1、3.2 ,when the source intensity is greater than or equal to 10^9 (n/p), the spectrum of neutron and gamma can all get good test results. For the measurable lower gamma intensity of DPF deuterium-tritium source is before 1.45 μs, the spectrum of the system were higher than those of the detector.

If it is required that the time of the a measurable signal stability must be at least 0.2μs ,the strength of the DPF deuterium-tritium source must be greater than or equal to $\geqslant 3\times10^8$ (n/p) .

4. Conclusion

In this paper, the intense spectrum of pulsed neutron and gamma sources of the subcritical device was simulated, the time multiplication constant is calculate by the leakage spectrum. The results show that:

(1) According to the present DPF parameters, this method is feasible to use DPF source to measure the prompt time constant of the subcritical device.

(2) In the condition of the system discussed in this paper, the external neutron source can achieve the stable distribution with the same system properties after about 60 generations of reaction time.

(3) DPF deuterium-deuterium and deuterium-tritium source can be used in this method both, if the lower limits of the measured signals is10^8 (γ /μs) , the intensity of the DPF should be greater than or equal to 10^9 (n/p) of deuterium- deuterium source and 3×10^8 (n/p) of deuterium and tritium source.

(4) This paper demonstrates the time constant can be diagnosed by DPF source through numerical simulation, using this method to the actual measurement of shielding device placement and other factors may cause changes in the test layout.

(5) The effect of some factors such as the different location of the shielding device、the environment scattering of laboratory、the design of testing layout, etc. were not studied here, it's summarized that optimized shielding design is very important for this kind of close range measurements.

(6) Meanwhile, the diagnosis system, the diagnosis arrangement can have a greater effect on the diagnosis results. Subcritical device, diagnosis systems, protection and shielding systems are placed in limited space. So the background interference by intense neutron source and surrounding environment is very complex, especially in the initial stages of a nuclear reaction.

5. References:

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