Feasibility Analysis of Unfolding Fast Neutron Spectrum by Using (n, n'γ) Reaction

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Abstract: Multi-nuclide neutron activation method is usually used to unfolding the fast neutron spectrum. This method has the limitation of the number of candidate nuclides for the reaction cross section, products' decay characters etc. In this paper, a novel approach was proposed to break the limitation, which can employ a large number of γ rays emitting from the given (n, n'γ) reactions. Considering the number of isotopes and the (n, n'γ) cross sections, Mg, As, Mn, V, Br, Rb, Y, Nb, Rh, Sb, I, Pr, Ho, Gd, Sm, Nd, Pd and Ru were selected as the candidate target elements. By grouping some of these elements, it is easy to find dozens of γ rays from their (n, n'γ) reactions to unfold the fast neutron spectrum. Two target composing mode were supposed in this paper. The multi-γ-ray mode seemed better than the multi-nuclide-mode. Vertical experiment mode was suggested.

Keywords: fast neutron, unfolding spectrum, (n, n'γ) reaction

1 Introduction

Multi-nuclide neutron activation and flying-time methods are the main approaches to get the fast neutron spectrum[1, 2]. Flying-time method can be used to directly measure the neutron spectrum. But high time-resolution is needed for the high energy neutrons. And if the neutron flux is small, much time will be needed to accumulate enough counts. So flying-time method has its limitation. For multi-nuclide neutron activation method, researchers must get enough neutron activation channels. However, up to now, the number of the practicable neutron activations does not exceed twenty-five. Furthermore, those candidate nuclides can't be used at one time in one experiment. Then the neutron spectrum can't be unfolded finely in this condition, sometimes even can't be unfolded. So the limitation of this method is obvious.

Inelastic scattering reaction (n, n'γ) is an important energy-threshold reaction channel among all of the (n, X) reactions between neutron and nucleus. In the reaction process, nucleus will be activated to a high energy state. Mono-energy γ-ray will be emitted from the excited nucleus. So each high energy state of the nucleus is equivalent a selected nuclide in multi-nuclide neutron activation method. In 1997，Fehrenbacher G. etc. used the 692 keV γ-ray produced in ^{72}Ge (n, n'γ) in HPGe detector to unfolding the neutron spectrum of ^{252}Cf and got a preliminary result[3]. In 2013, A. Oberstedt etc. measured two γ-rays produced in Br(n, n'γ) in $LaBr_3$:Ce detector and got the coarse neutron spectrum of ^{252}Cf[4]. In 2014, A. Ebran etc. in CEA measured the efficiencies of five γ-rays produced in (n, n'γ) of La and Br in $LaBr_3$:Ce detector and the fast neutron detection efficiency relative to 306 keV γ-ray from Br(n, n'γ) was determined up to 0.5％[5]. So it is obvious that this method has a good sensitivity of neutron which is suitable for unfolding the spectrum of low neutron flux.

Up to now, it is the preliminary stage for the usage of (n, n'γ) in unfolding neutron spectrum.

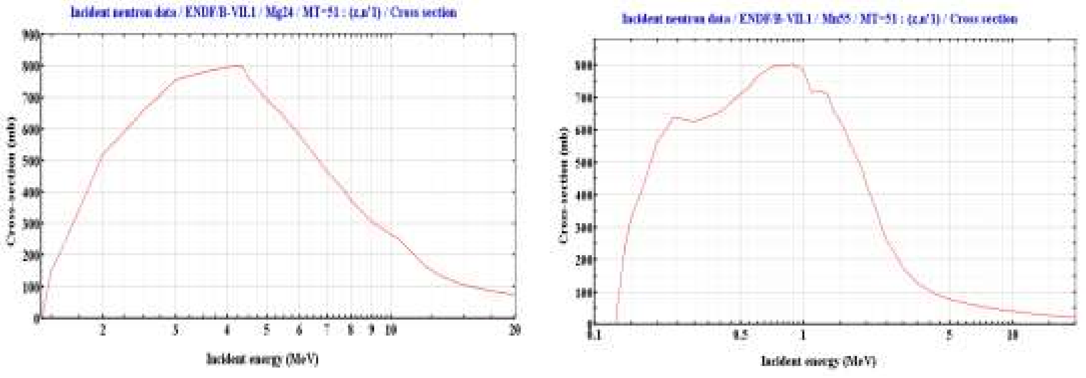
In this paper, two modes of using (n, n'γ) reaction as the unfolding reaction channel were proposed and discussed.

2 Selection of nuclide for (n, n′γ) target

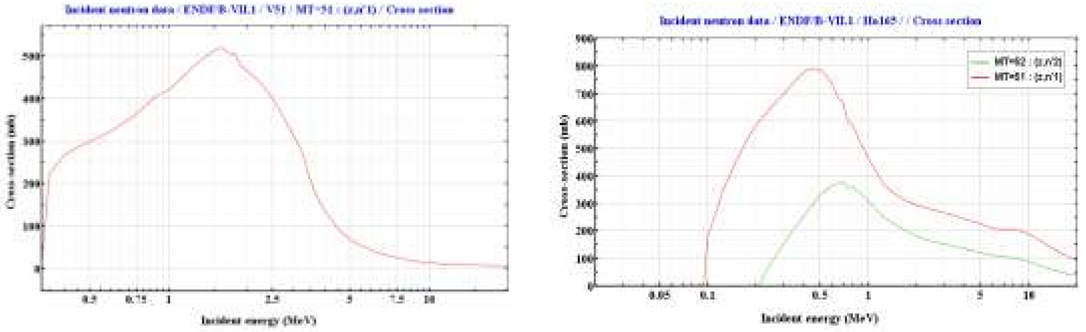
As we all know, in inelastic scattering reaction, nucleus can be activated to different excited states expressed as (n, n'm) which depends on the neutron energy, 'm' means the mth excited state. Whether the mth excited state is suitable to use is up to the reaction cross section. It must meet the need of experiment. In article [5], the fast neutron detection efficiency relative to 306 keV γ-ray from Br(n, n'γ) was determined up to 0.5％. Here, 306 keV is from Br(n, n'4) whose reaction cross section has the max value 0.161 bar at 614 keV[6]. In the next discussion, 0.2 bar was selected as the lowest standard cross section value. Nuclide which would be selected as the target material must obey this rule.

2.1 Multi-nuclide-mode target

Multi-nuclide-mode target was emphasized on the number of nuclides even if each nuclide has only one usable γ-ray from (n, n'γ) according to our standard. That means many nuclides will be selected to compose one usable target. When fast neutrons react with them through the (n, n'γ) channels, many γ-rays will be emitted. We can measure these γ-rays and unfolding the fast neutron spectrum. After investigated in ENDFB 7.1 data library, Mg, As, Mn, V, Br, Rb, Y, Nb, Rh, Sb, I, Pr and Ho were selected as the target materials. Fig. 1 shows the cross section curves of part of these elements.



(a) ^{24}Mg(n, n'1) (b) ^{55}Mn(n, n'1)

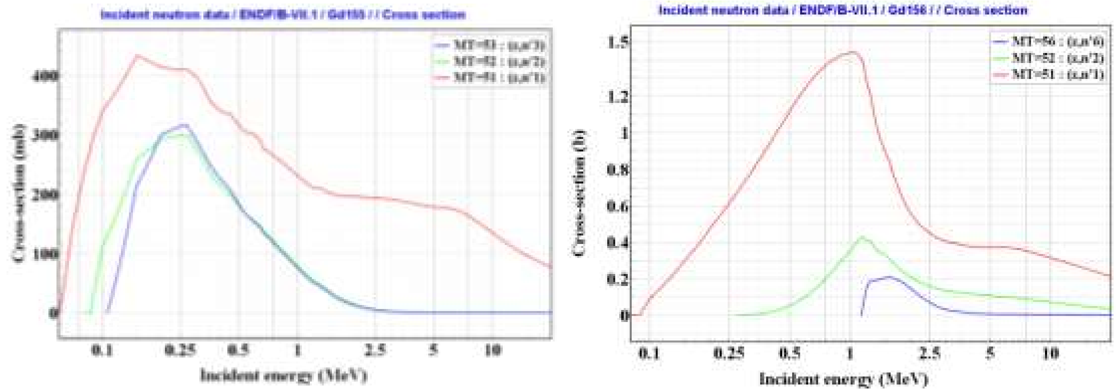


(c) ^{51}V(n, n'1) (d) ^{165}Ho(n, n'1) and (n, n'2)

Fig. 1. The cross section curves from ENDFB 7.1 data library.

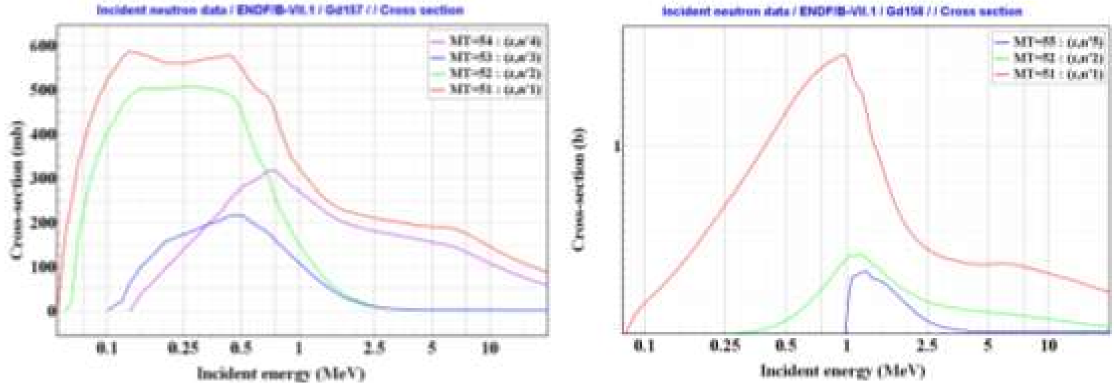
2.2 Multi-γ-ray-mode target

Multi-γ-ray-mode target was emphasized on the number of usable γ-rays from (n, n'm) in one isotope. That means there are a lot of excited states which cross sections of (n, n'm) reach our standard. If an element has several isotopes and each isotope has several usable γ-rays from (n, n'm), the number of usable γ-rays will be easily enough to unfolding the neutron spectrum. After investigated in ENDFB 7.1 data library, Gd, Sm, Nd, Pd and Ru were selected as the target materials. Fig. 2 shows the cross section curves of the main isotopes of Gd. Gd has seven isotopes and five of them have the abundance from 14% to 25%.



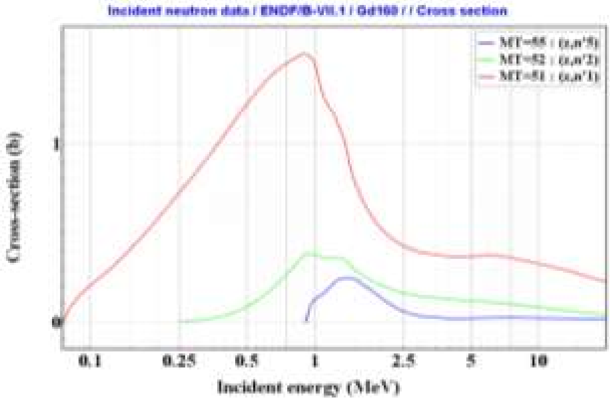
(a) ^{155}Gd(n, n'm)

(b) ^{156}Gd(n, n'm)



(c) ^{157}Gd(n, n'm)

(d) ^{158}Gd(n, n'm)



(e) ^{160}Gd(n, n'm)

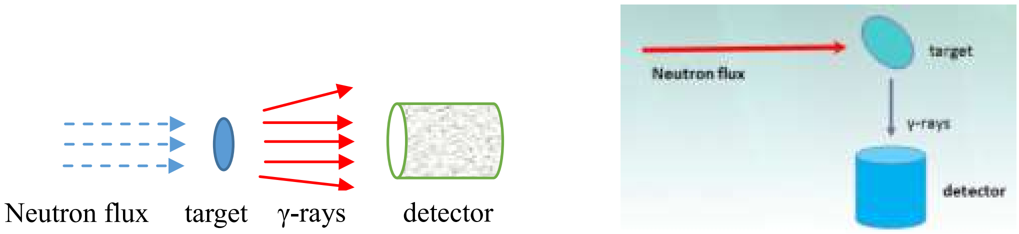
Fig. 2. The cross section curves of the main isotopes of Gd.

From Fig. 2, almost each isotope of Gd has three or more usable γ-rays according to our cross section standard. And 16 γ-rays can be employed to unfold the fast neutron spectrum. As the same way, Sm has six isotopes and 12 γ-rays can be used, Nd has seven isotopes and 20 γ-rays can be used, Pd has seven isotopes and 14 γ-rays can be used, Ru has seven isotopes and 14 γ-rays can be used. Thus one element can almost meet the need of unfolding neutron spectrum. Two or more elements group will be better.

As the light nuclides are easier to change the neutron spectrum than the heavy ones, it is better to use the heavy nuclides as the target material. So multi-γ-ray-mode target seemed a better way because of its selected heavy nuclides. At the same time, several factors must be considered carefully in using (n, n'γ) γ-rays: (1) for the (n, n'γ) reaction cross section, the bigger the better, (2) for the target material element, the heavier the better, (3) for the (n, n'γ) γ-rays, the less interference the better, (4) for the detector, energy resolution must be fine.

3 Supposed using conditions for (n, n’ γ)

Fig. 3 shows two basement experiment schemes designed to measure the γ-rays.



(a) horizontal measurement scheme (b) vertical measurement scheme

Fig. 3. Two basement experiment schemes.

As for the Fig. 3(a), there were two main shortcomings. One was that the neutrons can directly hit the detector, which might make the detector damaged. The other was that there would be high background for the detector because of the incidental γ-rays with neutrons. So Fig. 3(b) showed the vertical experiment mode. This mode could apparently avoid above two processes.

Then the count rate of γ-ray from(n, n'γ) reaction could be coarsely estimated by equation (1).

$$n_{\gamma i} = N_{\mathrm{n}} \sigma_{\gamma i} N_{\mathrm{iso}} \varepsilon_{\gamma i} \tag{1}$$

In which, $n_{\gamma i}$ is the i^{th} γ-ray count rate with the unit cps, N_{n} is the neutron flux with the unit s^{-1}, $\sigma_{\gamma i}$ is the cross section with the unit bar, N_{iso} is number of isotope in target, $\varepsilon_{\gamma i}$ is the detection efficiency of i^{th} γ-ray .

Based on the equation (1), if N_{iso} was set to 10^{21}, $\varepsilon_{\gamma i}$ was set to 1%,$\sigma_{\gamma i}$ was set to 0.2 bar, N_{n} was set to 10^5/s, the $n_{\gamma i}$ would be estimated to 0.2 cps. In this condition, it is easy to get a good result. Greater target can improve the sensitivity.

Because many (n, n'm) reaction cross section curves were got by calculation, there are some difference in different nuclear data library. So it is better to measure the cross section curves for the designed targets and make them be a sequence of standards.

4 Summary

It was feasible to use the (n, n'γ) reaction to unfolding the fast neutron spectrum by analyzing the γ-ray characters of (n, n'γ) and preliminary estimation. Two target designing mode were supposed after analysis. The multi-γ-ray mode seemed to be better than the multi-nuclide-mode. Vertical measurement scheme was suggested.

References

1. Berg S., Groy W.N. Mce. A Computer-Automated Iterative Method for Neutron Flux Spectra Determination by Foil Activation[R]. Atomic International. Tech. Rep. No.AFWL-TR-67-41, Sept.1967.
2. Shin-ichiro Meigo, Fujio Maekawa, Hiroshi Nakashima & Takashi Ino. Development of Current Mode Time-of-Flight Technique for Measurement of Thermal Neutron Spectrum[J]. Journal of Nuclear Science and Technology, 2000, Supplement 1: 789–793.
3. Fehrenbacher G., Meckbach R., Paretzke H.G. Fast neutron detection with germanium detectors: Unfolding the 692 keV peak response for fission neutron spectra[J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 1997, 397(2): 391-398.
4. A. Oberstedt, R. Billnert, S. Oberstedt. Neutron measurements with lanthanum–bromide scintillation detectors—A first approach[J]. Nuclear Instruments and Methods in Physics Research A, 2013, 708:7–14.
5. A. Ebrann, O. Roig, V. Méot, O. Delaune. Neutron efficiency of LaBr3:Ce detector. Nuclear Instruments and Methods in Physics Research A. 2014, 768: 124–129.
6. ENDFB 7.1 nuclear data library, USA.