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ELSEVIER

Particle identification in the measurement of differential (n,x) cross sections

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Abstract

An electronics system for five-parameter data collection was used for measuring double-differential (n,x) cross sections in a multitelescope system. The charged particles have been identified by using energy loss ΔE spectrum, pulse-shape discrimination (PSD) spectrum, and their combination E–ΔE, E–PSD and ΔE–PSD spectra. Three two-dimensional spectra are combined to identify proton and alpha particles in the experiment of measuring double-differential ^{nat}Ni (n,x) cross sections. Excellent particle identification has been obtained.

1. Introduction

Investigations of neutron-induced charged particle reactions in structural materials for neutron energy near 14 MeV are very important for fission and fusion reactors and nuclear model research. Reactions can lead to build up of hydrogen and helium gas and residual radioactivity. In recent years, the IAEA has been encouraging nuclear scientists to develop this area of research for measuring cross sections of (n,α) reactions [1].

Measurements of charged particles emitted from fast neutron-induced nuclear reactions are very difficult because of several experimental problems. The event rate is very low because the cross sections of (n,p) and (n,α) reactions are usually small. Neutron scattering, (n,γ) reactions and other unwanted reactions introduce very large background count rates [2]. Competing reactions give rise to various particle emissions so that charged particle identification is also required. Measurements of differential (n,x) cross sections therefore require a high-quality spectrometer that can discriminate against backgrounds and particle type. In the past 20 years, some new spectrometers [3–6] have been established to measure differential (n,x) cross sections. In 1992 a multitelescope system was set up at the University of Science and Technology of China (USTC) [7]. This system consists of a cylindrical counter chamber and a CsI(Tl) scintillator which has the property of good pulse-shape discrimination (PSD) [8]. Using this system, we have measured some differential (n,xp) and (n,xα) reaction cross sections [9–11]. In these measurements, two-dimensional particle spectra have been used to identify alpha and proton particles, and a very good property of particle identification has been obtained.

2. The electronics system

The USTC multitelescope system has been described in great detail in Ref. [7]. This system consists of 32 outer-ring proportional chambers, 16 inner-ring chambers and a CsI(Tl) scintillator which was installed in the center of the cylindrical counter chamber. The ring-like target is fixed in the inner wall of the chamber. Each of the proportional counters of the outer ring, in conjunction with the central scintillator, acts as a normal counter telescope. The proportional counter chamber is operated with a gas mixture 5% CO_2 + 95% Ar at a gas pressure of 100 mbar. Some of the main performance characteristics of this system are summarized in Table 1.

A block diagram of the system electronics is shown in Fig. 1. For each (n,x) reaction the following five

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Table 1
The performance of the USTC multitelescope system

Reaction angle range (16 chambers)	Solid angle of CsI(Tl) scintillator	Target area (16 chambers)	Maximum neutron strength without excessive pile-up	Minimum energy threshold for identifying p and γ
25°–164.5°	14.7 msr	40×289 mm^2	2×10^9 n/s[a]	0.6 MeV

[a] The distance from neutron source to CsI(Tl) is 400 mm.

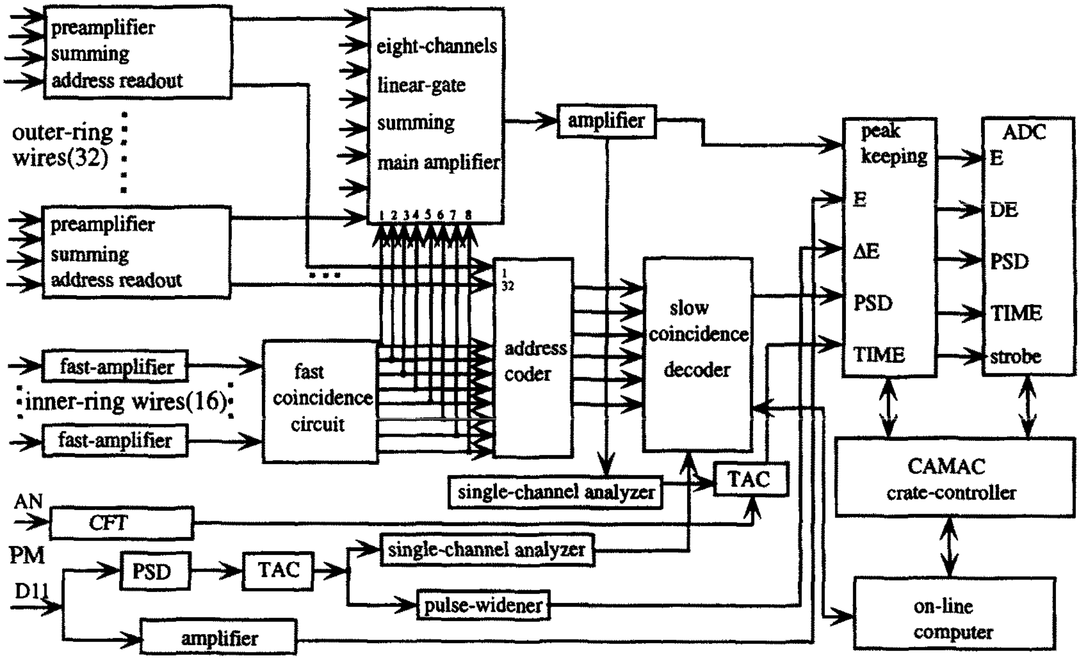

Fig. 1. Block diagram of the system electronics.

parameters were collected and recorded in the buffer region of CAMAC: the energy loss (ΔE) signals in the outer proportional counter, the wire addresses signals, the energy (E) signals in the CsI(Tl) crystal, pulse-shape discrimination (PSD) signals and time-of-flight (TOF) signals. The system is controlled by an intelligent CAMAC crate controller [12].

When charged particles from neutron-induced reactions pass through the outer proportional counter, the ΔE signals are produced as an analog and a trigger signal [13]. Four analog signals are first summed, which make 32 analog signals reduce to 8. Then all 8 signals are fed into a linear gate, which is opened only in case of coincidence between inner wire signals and the E-detector signals. In this way, pile up effects can be held at a minimum. Finally, all analog signals are summed into one total ΔE signal. The energy resolution of the ΔE spectrum is tested by a ring-shape ^{241}Am α-source. The energy resolution is about 15% for each counter chamber and 20% for the total ΔE signal. Fig. 2 is a ΔE spectrum which is obtained from the ^{nat}Ni(n,x) reaction at $E_n = 14.6$ MeV. In this experiment the low-energy cutoff is 1.5 MeV for equivalent proton energy, and this cutoff energy is the same in Figs. 2–7. It shows that a fairly good distinction between alpha- and proton particles has been obtained. The 32 trigger signals are converted into 6 bit addresses. In order to distinguish the true signal and the random signal, addresses codes are increased to 7 bits. These codes are locked only when a triple coincidence signal enables the recording circuit.

A CsI(Tl) scintillator coupled to a GDB-50L photomultiplier was chosen as the energy detector because CsI(Tl) has very small (n,p) and (n,α) cross sections, and the property of pulse-shape discrimination. The energy resolution of the CsI(Tl) scintillator is also tested by using ^{241}Am α-sources, and the result is approximately

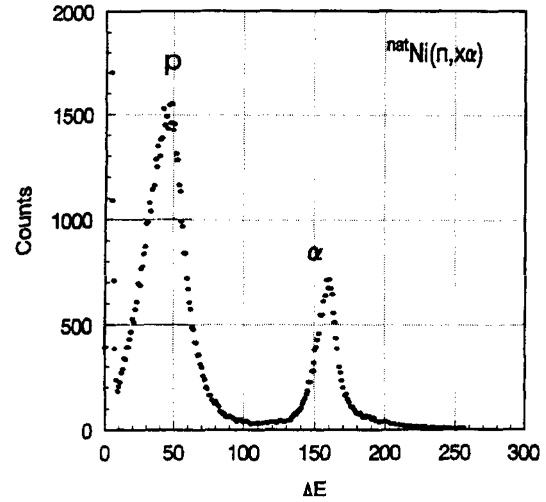

Fig. 2. The ΔE spectrum obtained from ^{nat}Ni(n,x) reaction at $E_n = 14.6$ MeV.

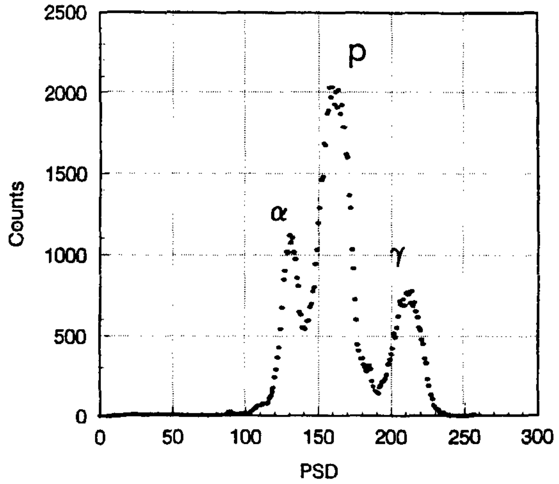

Fig. 3. The PSD spectrum obtained from ^{nat}Ni(n,x) reaction at $E_n = 14.6$ MeV.

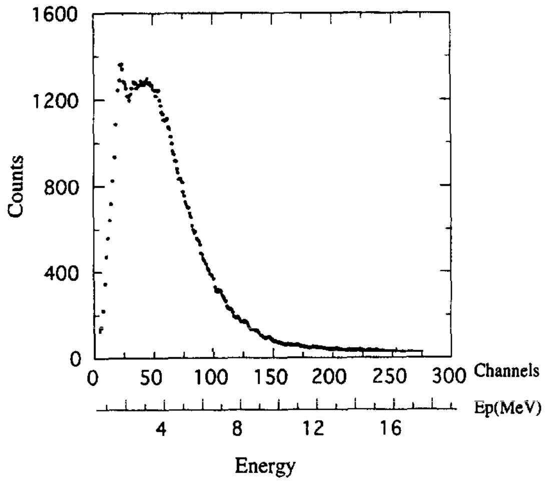

Fig. 4. The E spectrum obtained from the same experiment.

7.2% for 5.5 MeV α-particles. A circuit of the pulse-shape discrimination has been designed [8] with which an excellent identification of p, α and γ was obtained. Fig. 3 is a typical PSD spectrum obtained from the ^{nat}Ni(n,x) reaction. In this spectrum a large fraction of the gamma rays have been cut off because the low-energy threshold of the PSD signal is about 1.5 MeV.

The triple coincidence signal is used for reducing the relatively high background of random coincidences and data transfer rates into the on-line computer. The slow-coincidence signal is used as strobing signal to open all ADC gates. In order to assume that the four signals (ΔE, TOF, E and PSD) are transferred by ADC at the same time, these signals are first sent into a peak-hold circuit [14] which is opened only when a slow coincidence signal arrives. The data of (n,x) reactions were collected and stored in the buffer region of CAMAC according to the same form. When the buffer region is full or the collection is finished, the data is read out and stored on disk by the host computer. The host computer can display the histogram, the scattered plot, etc.

3. Particle identification

To test the performance of the system for identification of particles, the multitelescope system was irradiated using a neutron strength 2×10^9 n/s at energy 14.6 MeV. A natural nickel target with 0.5 mm thickness and 40 mm height was installed in chambers. The other 16 chambers were used for the simultaneous measurement of the background.

When the experiment of an (n,x) reaction was finished, all of the data stored on disk must be analyzed by off-line. From this process the double differential particle emission cross sections $d^2\sigma/d\varepsilon\, d\Omega$ can be obtained. One of the main objectives of the off-line data analysis is to identify the particle type as proton or alpha-particle, etc. As it has been mentioned above, most gamma rays were first deleted by PSD spectrum. The identification of p and α particles is done by the two-dimension particle spectra.

The energy spectrum obtained from the same reaction is shown in Fig. 4. Because a thick Ni target was used in this experiment, the counts at the low-energy region of the E spectrum are higher than that from a thin target. In this spectrum, all protons, alpha particles and part of the gamma rays are included. Fig. 5 is a two-dimensional E–PSD spectrum. It shows that the pulse height of PSD is changed with the energy of charged particles. When the energy of the charged particles is smaller than 4 MeV, it is very difficult to identify the alpha and proton particles from the two-dimensional E–PSD spectrum. Fig. 6 is a two-dimensional E–ΔE spectrum obtained from the same experiment. The identification property of this spectrum depends on the resolutions of the E and ΔE signals. Fig. 7 shows that the α-particle and proton groups have a clear valley with which one may distinguish between p and α-particles. This is because both individual advantages have combined together, that is, in the low-energy region the ΔE has better identification and in the high-energy region the PSD has better identification.

By combining the three types of two-dimensional particle spectra described above, excellent particle identification has been obtained in the measurement of double-differential $^{nat}Ni(n,x\alpha)$ cross sections. This procedure also can be used for other experiments where it is necessary to identify the types of charged particles.

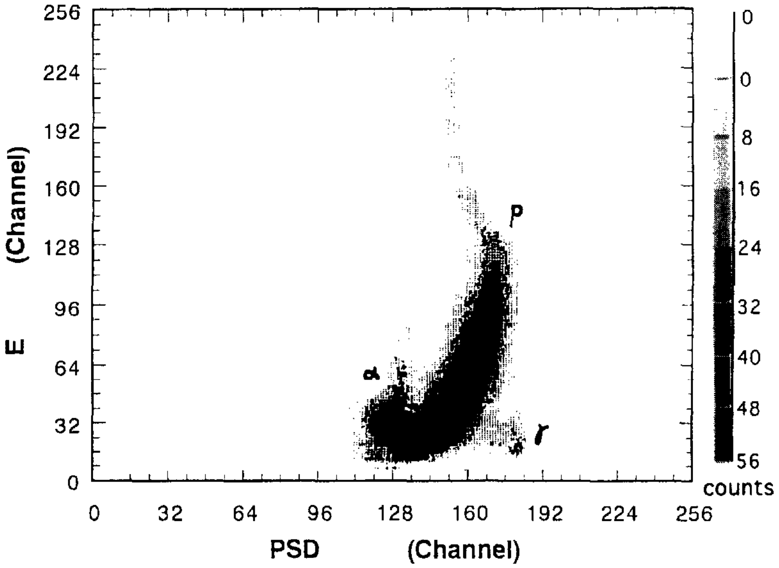

Fig. 5. The two-dimensional E–PSD spectrum.

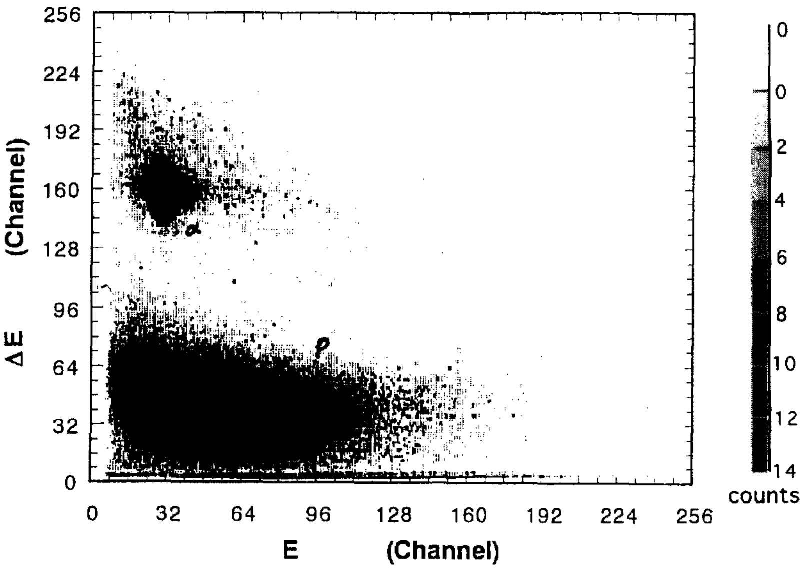

Fig. 6. The two-dimensional E–ΔE spectrum.

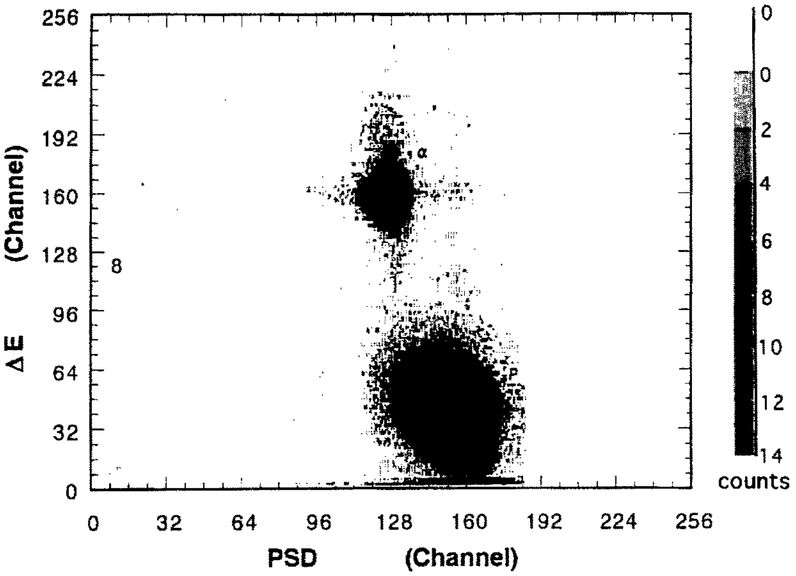

Fig. 7. The two-dimensional ΔE–PSD spectrum.

Acknowledgements

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