METHODOLOGICAL TESTS OF PROMPT GAMMA-RAY SPECTROSCOPY FOR (N, XN) CROSS SECTION MEASUREMENTS AT VARIOUS FACILITIES

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In Accelerator Driven Systems the external neutron flux provided by the accelerator is produced by spallation reactions, which means that its spectrum extends to several hundreds of MeV. Thus \((n, xn)\) reactions have more importance than in conventional reactors since they have a threshold increasing with \(x\). On the other hand, the cross sections of these reactions are badly known. This is due only in part to the fact that few neutron beams with energies above 20 MeV were available up to now. Actually, no universal method exists so that only some systems could be measured, and data bases are often fed by model predictions, especially in the heavy nuclei. With a white beam like Gelina or nTOF, there is only one method which can be used, the in-beam \(\gamma\)-spectroscopy. This method was reported for the first time in 1994 by Los Alamos. We tested the feasibility of this method at the fixed beam facility of the cyclotron of Louvain-la Neuve (Belgium) and the Gelina white beam neutron source. The methodological tests performed so far towards these measurements are presented.

**Measurement of \((n, xn)\) Reactions**

An established method for obtaining \((n, xn)\) cross sections is the detection of prompt \(\gamma\)-rays\(^1\). \((n, xn)\) cross sections up to \(x = 15\) were measured\(^2\) by the Geanie Ge array at Los Alamos\(^3\). Also other particles like protons and \(\alpha\) particles were included in these cross sections and reported in literature\(^4,5\). This method is particularly suited for white beam neutron sources like WNR, Gelina or nTOF\(^6\) at CERN where the cross section dependence on neutron energy may be determined simultaneously for all neutron energies. Suitable final nuclei are even-even nuclei which decay by a series of transitions like \((2^+ \rightarrow 0^+)\), \((4^+ \rightarrow 2^+)\), ..., and exhibit strong lines in the resulting \(\gamma\)-spectra. Substantial difficulties arise at the WNR source, Los Alamos, when measuring \((n, xn)\) cross sections of radioactive samples. Due to the high frequency of the source (in the MHz range), \(\gamma\)-rays from transitions following \((n, xn)\) reaction are superimposed by \(\gamma\)-rays following radioactive decay and reactions related to slow neutrons from preceding frames. Since the data acquisition at neutron sources with high repetition rate is practically active all the time, a separation of \((n, xn)\) events and decay or other background events is nearly impossible. The ratio between events coming from the neutron induced reactions and from the activity of the target is more favorable at facilities such as Gelina and nTOF than at WNR because of their low beam frequency. At nTOF this frequency is below 1 Hz and the events corresponding to \((n, xn)\) reactions are concentrated in a few \(\mu s\) after the \(\gamma\) flash. Thus one must work with instantaneous counting rates two orders of magnitude higher than what is possible with state-of-the-art electronics for gamma spectroscopy. Our objective is therefore to develop a new technique, based on digital electronics and externally reset preamplifiers. A typical example for the output of such a preamplifier
Figure 1. Methodological experiments for \((n, xn)\) cross section measurements with a \(^{nat}W\) sample. (a) \(\gamma\)-spectrum taken at the neutron source of the Louvain-la-Neuve cyclotron at a neutron energy \(E_n = 45\) MeV. Reactions up to \(x = 5\) were observed. (b) Total \(\gamma\)-spectrum taken at the Gelina neutron source in a white neutron beam up to about \(E_n = 10\) MeV. (c) \(\gamma\)-intensities as a function of neutron energy for a specific \(\gamma\)-line (\(2^+ \rightarrow 0^+, \(^{186}W\)) from the Gelina data are presented as points. The solid line shows the corresponding cross sections taken from the JENDL 3.2 data base. (d) Signal output from a planar Ge detector with reset preamplifier and flash ADC.
in combination with a flash ADC is shown in Fig. 1(d). We performed methodological experiments with the aim to measure \( n, x n \) cross sections at the fixed energy neutron source of the Louvain-la-Neuve Cyclotron\(^7\) and at the Gelina pulsed neutron source\(^8,9\) of IRMM. Characteristic results are summarized in Fig. 1(a-c). In all measurements we used natural tungsten samples which contain the stable isotopes \(^{182}\)W, \(^{183}\)W, \(^{184}\)W and \(^{186}\)W with a small amount of \(^{180}\)W (less than 1\%). At Gelina we have mainly observed \((n, n')\) reactions owing to the energies of the incident neutrons up to about 10 MeV. Such reactions are particularly important for ADS since they shift the neutron energy spectrum in these facilities. At Louvain the energies of the incident neutrons peaked at 45 MeV. This energy corresponds to a cross section close to the maximum for the \( W(n, 5n) \) reaction, just below the \((n, 6n)\) threshold. There, values up to \( x = 5 \) were reached, e.g. the \(^{178}\)W line can practically be fed by the reaction \(^{182}\)W\((n, 5n)\), only. Also the \(^{180}\)W lines, absent in the case of the Gelina measurements, are clearly visible and come mainly from \((n, x n)\) reactions with \( x = 3 \) to 5. In Fig. 1(c) we show the dependence of the \( \gamma \)-intensities as a function of neutron energy by time-of-flight as measured at Gelina.

In summary, we have successfully tested a method based on the observation of prompt \( \gamma \)-ray following \((n, x n)\) reactions at various neutron sources. The digital electronics to be used at the nTOF facility is in progress.

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