THE USE OF GE DETECTORS FOR (N,XN) CROSS-SECTION MEASUREMENTS AT INTENSE AND LOW FREQUENCY PULSED NEUTRON BEAMS

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Abstract

In Accelerator-driven Systems (ADS), (n,*x*n) reactions have more importance than in conventional reactors. Indeed in ADS the external neutron flux provided by the accelerator is produced by spallation reactions, which means that its spectrum extends to several hundreds of MeV. On the other hand, the cross-sections of these reactions are often badly known. This is due in part to the fact that few neutron beams with energies above 20 MeV were available up to now. The new facility n_TOF at CERN may give the opportunity to extend the measurements above 100 MeV. However with a white beam like that of n_TOF, there is only one method which can be used, the in-beam γ spectroscopy. But because of the high intensity of the beam related to its very low frequency, conventional electronics are not suitable. Our objective is therefore to develop a new technique, based on digital electronics and externally reset preamplifiers. The methodological tests toward this new technique performed so far at Gelina (IRMM Geel), CRC (Louvain-la-Neuve) and n_TOF are presented.

Introduction

In Accelerator-driven systems, an external flux of neutrons is provided by a spallation source. The energy spectrum of these neutrons extends to hundreds of MeV. This implies that data bases which all stop now at 20 MeV, have to be extended to higher energies. While capture reactions are not concerned by this extension, fission and (n,xn) have cross-sections which approach 1 barn at given energies above 10 MeV. The consequences on the predictions of the codes will be strongest for (n,xn) reactions, which have a threshold increasing with x, and have therefore much more importance in ADS than in conventional reactors. From this point of view, the new facility n_TOF at CERN [1] offers the possibility to perform such measurements over a broad energy range.

Actually, data bases for (n,xn) reactions rely for many isotopes on model predictions. This is not only due to the lack of high energy neutron beams but also to the difficulty to measure their cross-sections. No universal method applicable to all isotopes exists. With a white beam like that of n_TOF on-line γ ray spectroscopy is the only method which seems possible.

The measurement of (n,xn) reactions with this method has been performed since long for x=1, and has more recently been applied for x=2 to 13 at WNR (Los Alamos). [2-4] It is applicable whenever one or a few transitions in the final nucleus are strongly fed and easily separated in the spectrum. This is the case for many light nuclei, and for even-even isotopes of heavy final nuclei. Even then the (n,xn) cross-section has to be inferred from the measured γ-ray production cross-sections by model calculations.

Germanium detectors are mandatory because of their high energy resolution. However, the resolution rises with decreasing the shaping time of the electronics. Actually, counting rates are limited typically to 10^4 Hz, which means that two consecutive γ rays must be separated by several tens of μs to be recorded correctly.

This makes no problem with a stable target at WNR (Los Alamos) where the beam has a high frequency (0.6 MHz) so that all γ rays of any origin are randomly distributed over the bursts. On the other hand, because of this high frequency the flight path has to be short (20 m) to minimise the overlap between neutrons from consecutive bursts, and no time selection is possible. Thus the counting rate for radioactive targets is due much more to their activity than to the reaction. At Gelina, which has an intermediate frequency (800 Hz) and where the neutrons are produced by bremsstrahlung, the shaping time is at the origin of a variable dead time at neutron energies above 1 MeV, because even at 200 m the γ flash is observed in a large fraction of bursts and comes only a few μs before the high energy neutrons. At n_TOF, two consecutive burst are separated by 2 to 14 s, and the flight path is about 185 m. Our first tests at this facility show that the Ge detector sees an intense γ emission at time 0 in almost all bursts, while the γ rays corresponding to (n,xn) reactions appear at 2 to 6 μs.

The method we are investigating is based on 12 or 14 bit digital electronics to increase the acceptable counting rate, and on an externally reset preamplifier to lower the sensitivity to the γ-flash. We present here our methodology, and the tests performed so far.

The methodology

The following steps must be checked:

- The expected transition must be clearly separated. The feeding of a level depends on the structure of the nucleus. Lines with energies close to that of the interesting one may come from transitions between other levels in the same nucleus, from material hit by the beam or from the background.
- A good resolution must be obtained to separate the line from other ones and to enhance the signal/noise ratio with respect to the background due γ rays from different origin, but also from Compton scattering of higher transitions. It must be obtained for instantaneous counting rates of several hundreds of kHz. The acquisition system must be able to handle and store the data flow.
- The γ flash must not block the charge collection in the detector nor saturate the preamplifier.

These points can actually be checked only with a beam. To check them most efficiently, it is preferable to look for the best conditions to test each one separately. This has led us to go to different places where these conditions could be matched.

Measurement of an energy spectrum at 45 MeV in Louvain-la-Neuve

The Cyclotron in Louvain-la-Neuve produced a very intense (10^6 neutrons/s) and quasi-monoenergetic beam at 45 MeV using the ^{7}Li(p,n)^{7}Be neutron production reaction. This energy corresponds to the maximum of the (n,5n) cross-section on the W isotopes. The planar HPGe detector was placed 12 cm from a 0.5 mm thick ^{nat}W sample, and at 2.5 m from the ^{7}Li target. At this distance, the beam had a diameter of about 4 cm. The electronics and the acquisition system were conventional. The spectrum obtained in 3 hours is shown in Figure 1. One recognises easily the $2^+ \rightarrow 0^+$ and $4^+ \rightarrow 2^+$ transitions in five isotopes of W. The ^{178}W is due to almost 100% to the (n,5n) reaction on ^{182}W. Since the continuous component of the beam was not separated during this test from the mono-energetic one, the other lines can be due to (n,xn) reactions with different x values. The $4^+ \rightarrow 2^+$ transitions appear stronger than the $2^+ \rightarrow 0^+$ ones because the self-absorption is less important at 200 keV than at 100 keV.

It is quite encouraging to see clearly the lines despite the strong γ background due to the neutron source and also despite the mixing of 4 isotopes in the sample and the absence of selection of the mono-energetic part. Further tests are planned with this selection and a Th sample.

Application of the 12 bit flash ADC for (n,n'γ) reaction in Geel

Gelina produces a white beam decreasing rapidly in intensity above a few MeV. The coaxial HPGe detector recorded γ rays emitted by a ^{58}Ni sample placed at 200 m from the neutron source. The signal from the preamplifier was directly connected to a 12 bit 100 MS/s flash ADC. The data have been stored during 3 hours on the hard disk of the PC, and analysed off line.

The analysis is based on a convolution of the sampled signal and a mathematical function. The resulting function is a trapezoid, [5] which means that the signal with a very long decreasing tail is transformed in a finite one. The energy is given by the height of the trapezoid. The method corrects actually also the ballistic effect in a very elegant way. The most important result is shown in Figure 2. The line at 1.454 MeV corresponds to the decay of the first level in ^{58}Ni. It is seen with a resolution of 3 keV, which is comparable to what can be obtained with conventional electronics. But for this resolution to be obtained it is sufficient that two consecutive trapezoids are separated, so that much higher counting rates are possible.

Figure 1. **Zoom on two regions of the energy spectrum of γ rays emitted by (n,xn) reactions on ^{nat}W**

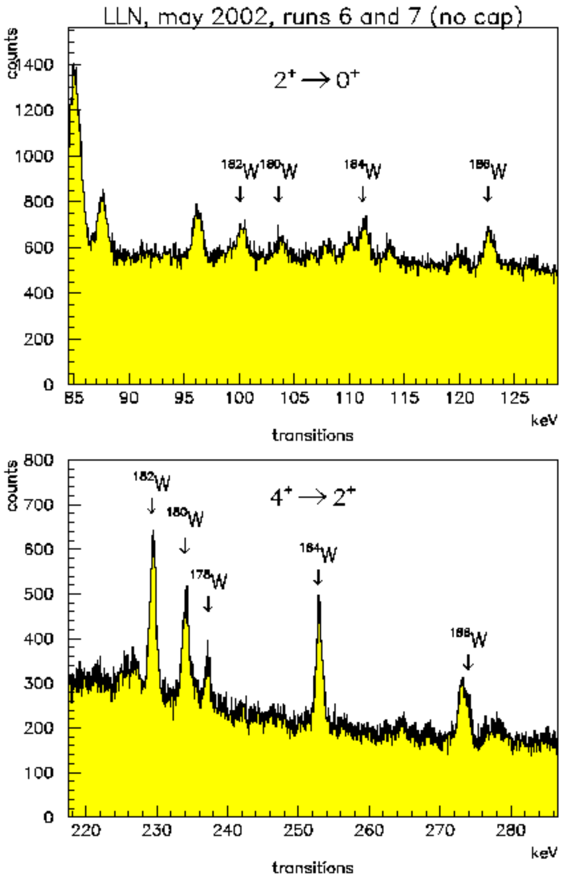


Figure 2 shows also the presence of two other lines, due to the natural activity of ^{40}K (1.460 MeV) and to another transition (1.448 MeV) in ^{58}Ni. The presence of this latter line implies that the resolution must be good enough to separate it from the 1.454 MeV line. With large volume detectors this can be obtained in the present stage of the method only with parameters of the trapezoid which imply a separation between two consecutive γ rays – and hence between the γ flash and the first γ – which does not yet allow reaching the highest neutron energies.

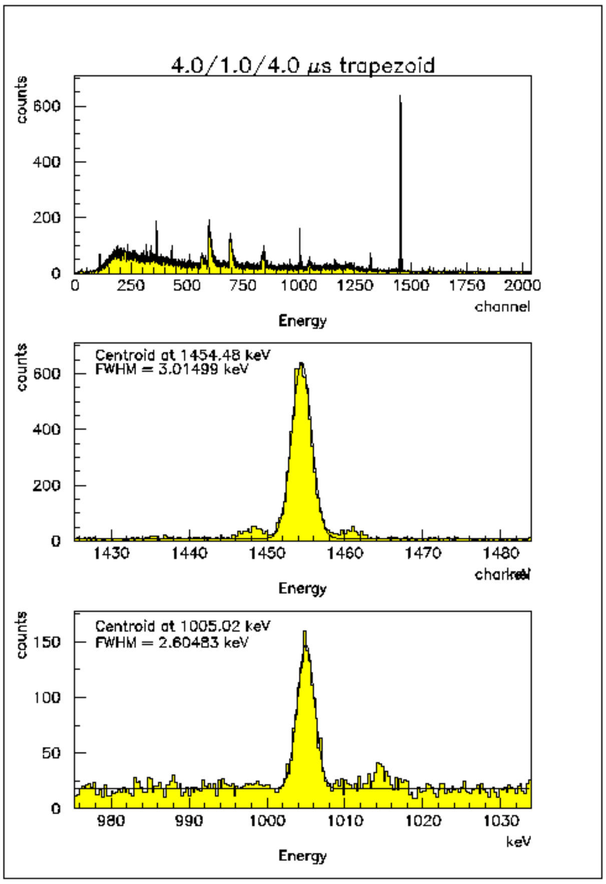
Utilisation of an external reset preamplifier at n_TOF

A first test had been performed in June 2001, i.e. when a strong muon background was present in the experimental area. Then, even at a large distance from the beam, the planar HPGe detector was blinded for 100 µs by the intense γ production at time 0, and recovered its full efficiency only after 10 ms.

A new test has been performed this summer when this background had been significantly reduced. During this test, the detector was placed at about 40 cm from the beam line in order not to disturb the running capture measurement. To monitor its efficiency, a strong Cs source was placed in front of it. It was equipped with a new pre-amplifier which can be reset externally by the signal delivered by the accelerator or internally. [5] The acquisition was performed again with the 12 bit flash ADC. The characteristics of the preamplifier were chosen so that its dynamics allowed the flash

ADC to record with the full 12 bit resolution one γ ray of 1 MeV or, for example, five γ rays of 200 keV. Only the delay between the accelerator signal and the reset procedure was remotely adjustable. We have taken data by varying the delay of the external reset systematically, and with the internal reset. Their analysis has only started. Figure 3 shows two events among a few we have examined individually. In the first one, as expected, the preamplifier has been reset and several γ rays have been recorded, their energy being given by the steps in the voltage. A zoom on the second one shows that a γ ray was recorded at time 40 µs, and could apparently have been detected at a shorter time. The delay was adjusted so that the γ flash would have appeared at time 8 µs. This result is encouraging, since it shows that we have some possibility to drop the effect of the γ flash. However, it is not demonstrated that a good resolution and a stable efficiency are obtained after a few µs. The analysis of the data is in progress, and new measurements are foreseen.

Figure 2. **Energy spectrum of the ^{58}Ni(n,n'γ) reaction: full (top) and zooms (middle and bottom)**

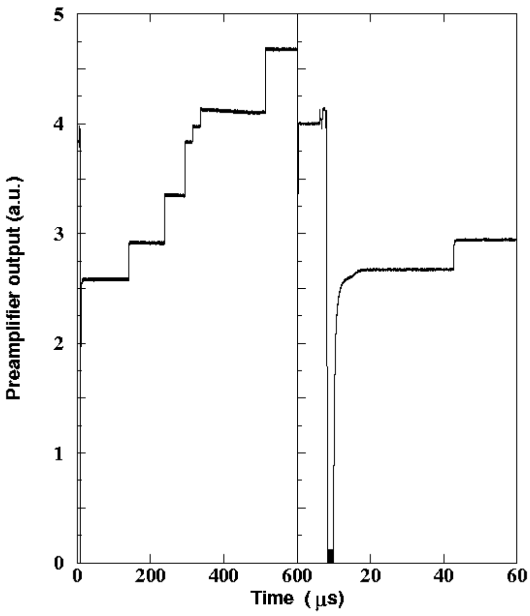


Conclusion

Several significant progresses have been realised: the possibility to use HPGe detectors at various neutron beams without rapid damage has been demonstrated. In the case of a ^{nat}W sample bombarded by a 45 MeV neutron beam, the spectrum is easily readable even down to 100 keV γ energy. A method to analyse data delivered by a 12 bit flash ADC has been developed, allowing reaching a good energy resolution even in the case of a coaxial detector where the ballistic effect is more important than in a planar one. A preamplifier with external reset has been used and its ability to lower the impact of the γ flash has been tested. This latter point has to be analysed quantitatively.

The main problem remains nevertheless the γ rays emitted at time 0, since one is interested in γ rays emitted only a few µs later. At Gelina, this is due to a γ flash which has already been dropped as much as possible. Thus only an improvement of the analysis method can allow going further. The data taken at n_TOF have still to be analysed before any conclusion can be drawn. It is not yet evident that reset preamplifiers are the solution, especially if the intensity of the time 0 emissions can still be dropped.

Figure 3. **Output of the externally reset preamplifier**
The detector measures several γ rays after the reset (left part).
A γ ray is recorded about 40 μs after the γ flash (right part).



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