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Accuracy of the pulse height weighting technique for capture cross-section measurements

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The direct method of determination of neutron capture cross-sections requires to count the number of γ-ray cascades generated after the capture process. This can be achieved with a large 4π detector of efficiency close to 100 % for detecting all the γ-rays in the cascade. Alternatively [1] one could use a detector registering only one γ-ray per capture event, i.e. a detector with small detection efficiency but in such a way that this efficiency is proportional to the photon energy: $\varepsilon_\gamma = kE_\gamma$. In this case the efficiency for detecting the cascade would be proportional to the cascade energy E_c and independent of the cascade path:

$$\varepsilon_c \approx \sum_j \varepsilon_{\gamma_j} = kE_c \tag{1}$$

The proportionality of the efficiency with the energy can be achieved through the manipulation of the detector response R_{ij} by the introduction of a pulse height dependent weighting factor W_i to be applied to each registered count.

The smooth (polynomic) behaviour of the weighting factor can be determined by least squares fit from a number of γ-ray responses in the energy range of interest (up to 10 MeV):

$$min \left(\sum_j \sum_i W_i R_{ij} - kE_{\gamma_j} \right)^2 \tag{2}$$

Obviously the accuracy of the method depends strongly on the accuracy with which the responses can be determined. At the nTOF facility, C_6D_6 liquid scintillator detectors will be employed to measure capture cross-sections for a variety of targets using the pulse height weighting technique. The goal is to achieve a high accuracy (a few percent uncertainty in the measured cross-sections) and this issue has to be carefully examined.

Historically, and due to the difficulty to obtain mono-energetic γ-ray sources in the energy range of interest, the detector responses were initially obtained by

Monte Carlo simulations. It was found later that there was a serious discrepancy between the result obtained by this method and the one obtained from transmission measurements for the well-known resonance at 1.15 keV in ^{56}Fe. After thorough investigations it became clear that the problem was originating in the Monte Carlo simulated response distributions.

This conclusion was arrived at mainly, after careful measurements at Geel [2] of mono-energetic γ-ray responses. The method employed was the coincidence technique for two-gamma cascades populated in (p,γ) resonance reactions in light nuclei. Subsequently [3] the measurements were repeated with a detector set-up similar to the one employed in the (n,γ) measurements. The extracted experimental weighting function giving a cross-section in agreement with the standard transmission value for the 1.15 keV resonance in ^{56}Fe, was adopted for the capture measurements. However it was also recognized that the cause for the discrepancy between the Monte Carlo simulated response and the measurement was probably due to the big influence of the materials surrounding the source (other than de detecting medium) producing secondary radiation. This cast some doubts on the universality (or even validity) of the experimental weighting function determined for the (p,γ) set-up when employed for the (n,γ) measurements. In order to truly take into account the systematic differences of the various target/detector set-ups only the Monte Carlo method is practicable.

At Oak Ridge [4] the Monte Carlo method was further investigated and it was found that the EGS4 [5] code gave a satisfactory result for the 1.15 keV resonance in ^{56}Fe measured with their experimental set-up. They were not able however [3] to produce the same result when applied to the Geel set-up.

We have decided to re-investigated this issue more carefully. In particular whether the differences between Monte Carlo and measurement could be due to insufficient detail in the description of the measuring set-up or rather due to a poor implementation in the Monte Carlo code of the relevant physical processes in the generation/interaction of the secondary radiation.

The simulation package GEANT3 [6] was chosen and was used to investigate extensively the response of the detector set-up described in Ref. [3] in the photon energy range 1.2-8.4 MeV. The main results of this study [7] can be summarized as follows:

- The shape of the measured response distributions is well reproduced by the simulation. The absolute value of the efficiency is well reproduced at the higher energies but there is a tendency to overestimate it at low energies (18 % at 1.2 MeV). This result is not understood since at low energies one expects the Monte Carlo simulation to work better.

- At high energies the contribution to the detection efficiency of the dead

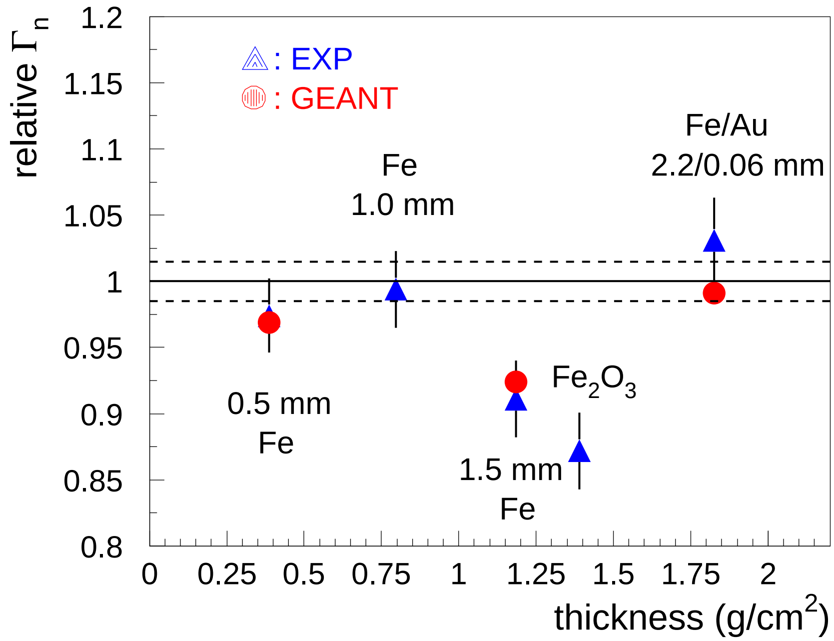

Figure 1: Comparison of measured (Ref. [8]) and simulated neutron width for the 1.15 keV resonance in ^{56}Fe obtained with the pulse height weighting technique for various sample thicknesses and compositions. The values are normalized to the transmission value.

materials is close to 40 %. The contribution of the detector dead material is negligible as compared with the (p,γ) target backing (0.3 mm Ta).

The validity of the experimental (p,γ) weighting function for the capture measurements was investigated by G. Fioni [8] by comparing the result obtained for the 1.15 keV resonance in ^{56}Fe using different sample thicknesses and compositions. In order to be able to compare with these results a realistic simulation of the capture process would be necessary. Therefore a computer program was developed to generate "realistic" cascade events by the Monte Carlo method. For each nucleus a known low-energy level scheme can be defined consisting in a complete set of levels with known spin-parity and branching-ratios (obtained from evaluated data files, for example). At higher energies and up to the resonance state, the statistical model of the nucleus is used to generate a level scheme. Levels of appropriate spin-parity are generated from a level density formula (giving the average level spacings) by introducing fluctuations of the Wigner type. The γ-ray intensities are generated from the Giant Resonance (GR) model (Axel-Brink hypothesis) by introducing fluctuations of the Porter-Thomas type. The conversion electron process is also taken into account. Appropriate parameters for both level densities and GR can be defined for each nucleus.

In Figure 1 it is shown the comparison of the simulated experiment with the measurement for different samples. On one hand the dispersion of the experimental values shows the limitation of the experimental (p,γ) weighting function applied to the capture measurements. On the other hand the fact that the simulation reproduces the behaviour of the experimental points is a strong evidence for the accuracy of the Monte Carlo simulations.

All this confirms the necessity of using the appropriate weighting function for each specific (n,γ) set-up, which can only be obtained by Monte-Carlo simulations. The accuracy of the simulations should be verified with a set of selected capture measurements on well known resonances. The measurements should be chosen to enhance the systematic effects of the weighting function on the extracted cross-section. This can be achieved selecting resonances with very different decay patterns, that is, with different average γ-ray cascade multiplicities (μ_γ) and energies. The proposed measurements include: the 16.2 keV ($\mu_\gamma = 1.9$) and the 30.4 keV ($\mu_\gamma = 1.0$) resonances in ^{207}Pb ($S_n = 7.367$ MeV), the 1.15 keV resonance ($\mu_\gamma = 3.2$) in ^{56}Fe ($S_n = 7.646$ MeV), the 4.9 eV resonance ($\mu_\gamma = 4.8$) in ^{197}Au ($S_n = 6.512$ MeV), the 5.2 eV resonance in ^{109}Ag ($S_n = 6.809$ MeV) and the first resonances ($\mu_\gamma = 4.0$) in ^{238}U ($S_n = 4.806$ MeV).

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