A BaF_2 Detector Array for Neutron-Capture γ-Rays

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Submitted to Nucl. Instr. Meth. A

The neutron time-of-flight system at ELBE will produce neutrons in the energy interval E_n = 50 keV$-$10 MeV, where there is a need for neutron cross section measurements for transmutation, fission and fusion reactor applications [1].

For measurements of neutron-capture γ-rays, a scintillation detector array covering up to 96 % of the total solid angle is being built from 42 BaF_2 crystals, each 19 cm long, having a hexagonal cross section with an inner diameter of 53 mm. Two adjacent inner rings of 12 crystals each are surrounded by an outer ring of 18 crystals. They are read out by fast, UV sensitive Hamamatsu R2059 photomultiplier tubes [2], able to measure both the slow and the fast component of the scintillation light, enabling pulse-shape discrimination to separate photon signals from intrinsic α-particle background. A fast digital data acquisition system based on the Acqiris DC282 digitiser [3] is under development.

The efficiency ε of the BaF_2 array due to (n,γ) reactions in a target of 1 cm^3 (7.87 g) of ^{56}Fe has been simulated. It depends on two mechanisms:

(1) The detailed behavior of the γ-cascades following neutron capture. A Monte Carlo code developed at FZD [4] was used to simulate cascades from capture of S-neutrons in ^{56}Fe by exciting levels with spin $\frac{1}{2}$ in ^{57}Fe. The excitation in ^{57}Fe was selected from the range $E_X = 7.6 - 15$ MeV, corresponding to capture of neutrons with energies $E_n = 0.0 - 7.4$ MeV. The γ-ray multiplicity and the individual γ-ray energies E_γ were determined in each cascade.

(2) The interactions in the crystals of the emitted γ-rays. Energy deposition tables for γ-ray transport in the array were created using MCNP5, where monoenergetic photons of energy E_{tab} were emitted isotropically from the ^{56}Fe target in steps of 0.5 MeV, up to $E_{tab} = 15$ MeV. The photons were traced through the setup, providing a step-by-step account of all interactions until final absorption or escape. This was done for 90000 γ-rays for each energy and resulted in a table containing the energy deposited in the 42 BaF_2 crystals in a (90000 $\times$ 42) array. The sum energy of all 42 entries for a γ-ray starting with energy E_γ may be anywhere between zero and E_γ, depending on how much energy was lost along the track (which may span over one or more crystals).

The calculation of ε proceeded by selecting a γ-ray with energy E_γ from a cascade and identifying the energy deposition table with E_{tab} closest to E_γ. One of the 90000 events was chosen by random, and the energy deposited in each of the 42 detectors was obtained by multiplying the entries with the scale factor E_γ/E_{tab}. This was done for all γ-rays in the cascade, giving the total energy. By repeating the process for all cascades, the instrumental multiplicity m, the energy distribution of the detected cascades, and ε were obtained. The calculation can be performed with several threshold requirements: a minimum energy E_{thr} deposited in each hit BaF_2 crystal, a minimum total energy E_{THR} in the array, and a minimum multiplicity m_{thr}. Thereby a comparison can be made with a real situation where, e. g., background reduction may call for coincident signals in at least two detectors.

Fig. 1 shows the response for neutrons in the range $E_n = 0.0 - 7.4$ MeV with (i) no condition, (ii) $E_{thr} \geq$ 300 keV combined with $E_{THR} \geq 7.6$ MeV, and (iii) $E_{thr} \geq 300$ keV plus $m_{thr} \geq 2$. In case (ii), only events above the neutron separation energy are studied, where the high threshold may allow also for $m = 1$ events. In (iii), coincident signals in at least two detectors are utilised instead of a high threshold on the total energy. The efficiencies are (i) $\varepsilon = 0.91$, (ii) $\varepsilon = 0.53$, and (iii) $\varepsilon = 0.67$.

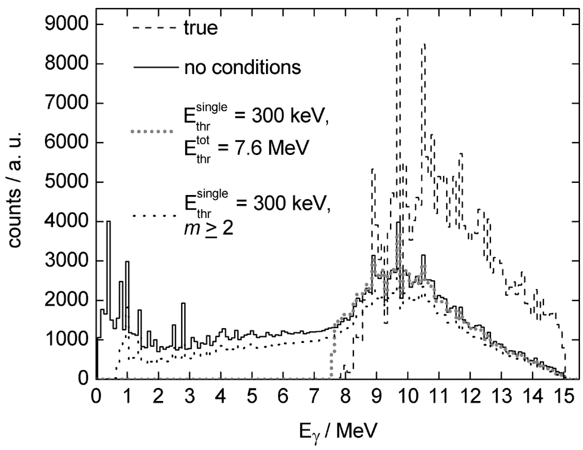

Fig. 1 *Total cascade energy (dashed line), and energy detected by the BaF_2 array under conditions indicated.*

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[2] http://www.hamamatsu.com

[3] http://www.acqiris.com

[4] G. Rusev, Ph.D. thesis, TU Dresden (2007)

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