Scintillator optimization for JET gamma-ray diagnostics

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Gamma-ray diagnostics of magnetically confined plasmas investigated in the Joint European Torus (JET) tokamak provide information on runaway electrons (fast electrons that often appear during plasma disruptions), fusion products and other fast ions due to nuclear reactions on fuel ions or main plasma impurities such as carbon and beryllium. The energy and spatial distributions of runaway and fast ions in plasma are measured in JET with the Gamma Cameras, equipped with a 2D detector array. The array comprises 19 CsI:Tl photodiodes with a diameter of 20 mm and a thickness of 15 mm [1].

The CsI:Tl scintillator has a reasonable energy resolution and high photon detection efficiency. However, due to the comparatively long scintillation decay time, around 1000 ns, spectrometry with MHz count rates is not feasible. Since heavy scintillators, like $LaBr_3$:Ce with Z_{eff}=45 with, a density of 5.06 g/cm^3 and a decay time around 20 ns, are now available for gamma-ray diagnostics, the possibility of replacing CsI:Tl crystals by the $LaBr_3$:Ce is being considered. To find the geometrical dimensions for the $LaBr_3$ scintillator which are optimal for measurements in the energy range 1-6 MeV, Monte Carlo simulations were performed with the Geant4 code [2]. A fixed diameter of the $LaBr_3$ detector equal to 20 mm and an energy resolution of 4% were assumed in the simulations. 10^6 parallel gammas with an energy of 4.4 and 6.0 MeV were incident on the scintillator surface. The 4.4 MeV gamma line is emitted in the reaction

$$^{9}Be + \alpha \rightarrow {}^{13}C \ {}^{n} \ {}^{12}C^{*} \ {}^{\gamma\ 4.44MeV} \ {}^{12}C_{\ g.s.}$$

whereas gammas with an energy of 6.13 MeV are observed in the reaction induced by neutrons on oxygen, ie.

$$^{16}O + n \rightarrow {}^{16}N + \rho, {}^{16}N \ {}^{\beta} \ {}^{16}O^{*} \ {}^{\gamma\ 6.13MeV} \ {}^{16}O_{\ g.s.}$$

In Fig. 1 the simulated gamma-ray spectra for the $LaBr_3$ scintillator with a thickness equal to 5 and 25 mm for 4.4 MeV gammas are shown. The positions of the full energy peak (FEP), single escape peak (SEP) and double escape peak (DEP) are indicated by arrows.

To find the optimal thickness of the scintillator, we take a figure of merit (FoM) equal to the ratio between the DEP intensity for the 4.4 MeV gamma ray, located at 3.4 MeV, and the number of events in the background over the same energy range produced in the detector by 6.0 MeV gammas.In Fig. 2 (left) the spectra obtained for a scintillator with a thickness of 5 mm irradiated by gammas with energies of 4.4 (upper) and 6.0 MeV (lower) are compared. In the right part of Fig. 2 such a comparison is shown for a scintillator with a thickness of 25 mm.

In Table 1 the simulation results for scintillators with a thickneses from 5 to 28 mm are presented showing that the optimal scintillator thickness is around 25 mm for the FoM defined above.

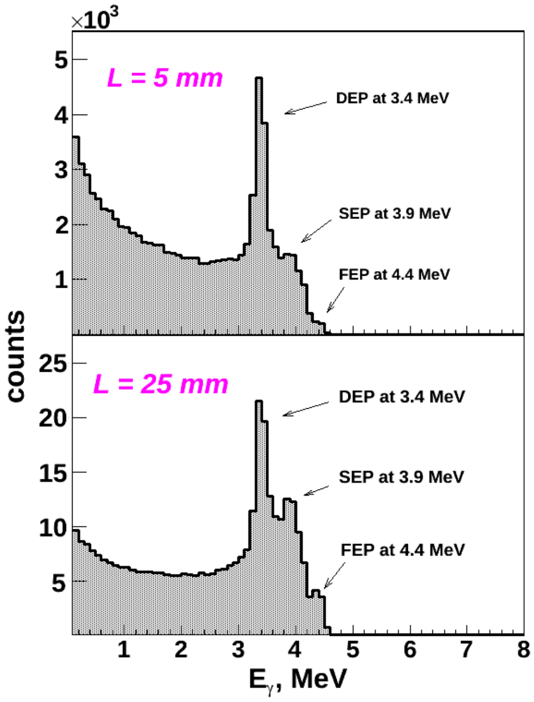

Fig. 1. Monte Carlo simulated gamma-ray spectra for a $LaBr_3$ scintillator obtained for 4.4 MeV gamma rays incident on a crystal with a thickness of 5 mm (upper) and 25 mm (lower).