WPJET4 Gamma Camera Upgrade (GCU)

D08	Simulations and optimization of the detector geometry: scintillator crystals+photodectors

The DT-experiment in 1997 has shown that direct measurements of confined alpha particles are very difficult. Alpha-particle studies require a significant development of dedicated diagnostics. JET has now an excellent set of confined and lost α-particle diagnostics. However, in order to take full benefit from the future extensive DT campaign in 2017, a number of diagnostic upgrades are necessary, as stated in the "Work Plan for the implementation of the fusion roadmap in 2014-2018", see *GCU Project Management Plan* and references therein. Among these necessary upgrades, the gamma ray camera plays an important role as a very useful diagnostic tool for the study of confined α-particles as well as fast ions. The information provided by the upgraded gamma-ray camera, namely gamma ray spatial emissivity energy resolved, will complement the high resolution spectroscopy measurements provided by KM6S and KM6T spectrometers along radial and oblique line of observation, respectively. The gamma ray emission spectra of Gamma Camera are associated with specific reactions among fast ions or fusion alphas with impurities, e.g., ^{9}Be(α, nγ)^{12}C, and thus reconstruct the energy. From these data it is possible to measure the spatial distribution/redistribution of the fast ions and fusion alphas in selected ranges of their energy and to follow their evolution in time.

The energy and spatial distributions of fast ions in plasma are now measured in JET with the Gamma Camera, equipped with a detector array. The array comprises 19 CsI:Tl with a diameter of 20 mm and a thickness of 15 mm coupled to photodiodes. CsI:Tl crystals are characterised by a comparatively long scintillation decay time, about 1000 ns.

From a diagnostic point of view a high power D-T plasma represents a rather harsh environment. For operating the Gamma Ray Camera diagnostic at the high D-T neutron fluxes expected in the next high-power D-T campaign on JET and to improve its spectroscopic capability specific hardware improvements are needed. In particular, it is proposed to enhance the existing spectroscopic and count rate capability by replacing the 19 CsI detector with new faster and better energy resolution detector modules, e.g., $CeBr_3$ or $LaBr_3$:Ce detectors with a scintillation decay time about 20 ns. This is a challenging upgrade due to available space for detectors and shielding. The new detector must be able to sustain count rate in excess of 500 kHz and energy resolution equal or better than 5% at 1.1 MeV. New detector material should not contain oxygen to avoid unwanted background due to a reaction on oxygen. For both $LaBr_3$ and $CeBr_3$ scintillators, light yield is high and comparable, about 6-7×10^4 photons/MeV.

The $CeBr_3$ scintillator was found to fulfil low noise measurement conditions. It shows 30 times reduction in internal activity in comparison with $LaBr_3$. The $CeBr_3$ scintillator has a similar energy resolution, sensitivity and decay time as the $LaBr_3$ scintillator. Moreover, the $CeBr_3$ scintillator seems to be more resistant for gamma radiation than $LaBr_3$. A 1 kGy dose of gamma radiation deteriorates the yield of $LaBr_3$ by ~10% and worsens its energy resolution from 3.0 to 3.8%, while is almost negligible for $CeBr_3$.
$CeBr_3$ may also be more resistant to neutron radiation because of lower neutron capture cross section in Ce (~12 mb) than in La (~100 mb) at E_n ~30 keV [1-2]. These features make $CeBr_3$ an interesting alternative for JET plasma applications in spite of the excellent spectroscopic performances of $LaBr_3$ scintillator.

It is important to underline that the space available for detectors is limited: a new setup (scintillator + photodetector) must be fixed in a cylinder with a diameter of 35 mm and a length of 35 mm.

At NCBJ we performed both measurements and Monte Carlo simulations to find optimal detector geometry for gamma-ray spectroscopy measurements in the camera.

The energy spectra recorded with 3 $CeBr_3$ samples under irradiation of PuBe source emitting 4.4 MeV gamma-rays are presented in the left part of Fig. 1. The full energy peak (FEP) at 4.4 MeV is recorded only for 2 largest samples. Besides FEP, the single escape peak (SEP) and double escape peak (DEP) are observed at energies of 3.9 MeV and 3.4 MeV, respectively. For the smallest sample, only DEP is registered by the scintillator due to a low probability of 511 keV quanta absorption.

The right part of Fig. 1 shows the response of the tested $CeBr_3$ samples to PuC source that emits 6.1 MeV gamma-rays. The peaks corresponding to the detection of 6.1 MeV gamma-rays are substantially less intense. There are two reasons:

- the stopping power for 6.1 MeV is smaller,
- the intensity of our PuC source is much smaller compared to PuBe source (lower integrals despite longer measurement live time).

Measurements done with PuC source do not show any peaked structures in the region-of-interest (RoI) that is important for the GCU project, i.e. between 3.4 MeV (DEP) and 4.4 MeV (FEP), marked with vertical dashed lines in Fig. 1.

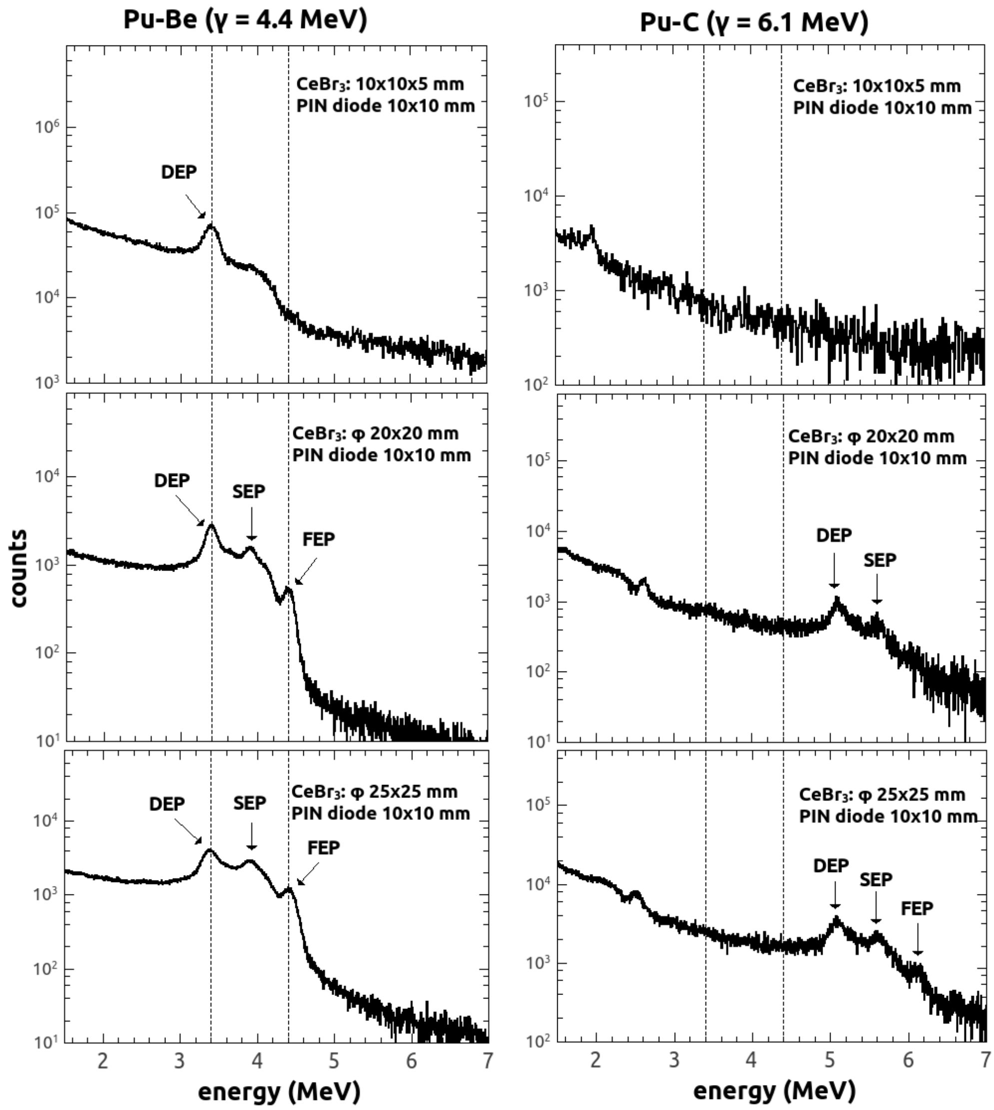

Fig. 1. Comparison of gamma spectra from PuBe and PuC sources for $CeBr_3$ scintillators: 10×10×5 mm, Ø20×20 mm, Ø25×25 mm, coupled to 10×10 mm PiN-diode. Dashed vertical lines are limiting the GCU region-of-interest.

To find geometrical dimensions for the scintillator which are optimal for measurements in the energy range 1-6 MeV, the Monte Carlo simulations were performed with the Geant4 code. An energy resolution of 4% was assumed in simulations. The 10^6 parallel gammas with energy of 4.4 and 6.0 MeV were incident on a scintillator surface.

As an example, in Fig. 2 gamma spectra obtained from Monte Carlo simulations are shown for scintillators with dimensions, as described in the figure caption.

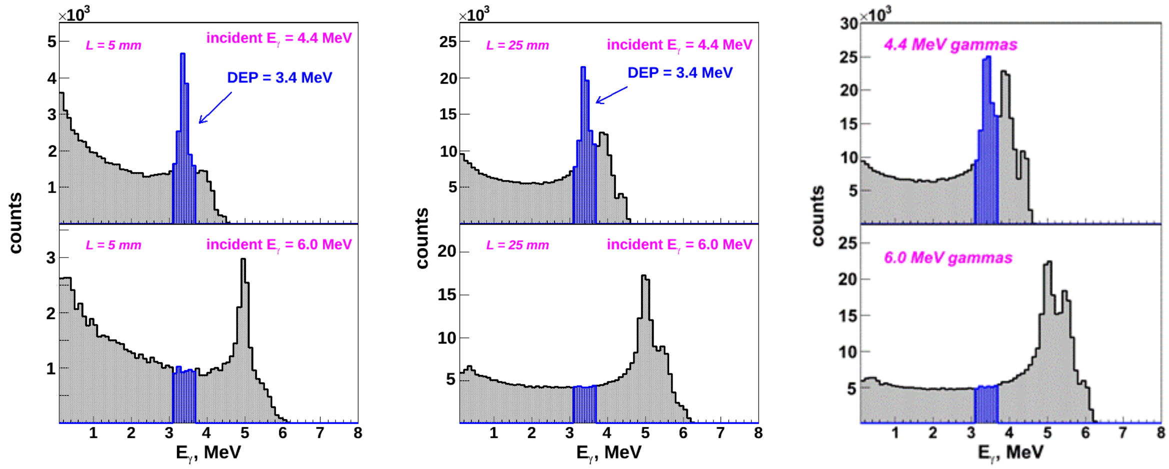

Fig. 2. In the left part, spectra obtained for a scintillator with a diameter of 20 mm and a thickness of 5 mm irradiated by gammas with energies of 4.4 (upper) and 6.0 MeV (lower) are compared. In the central part, such a comparison is shown for a scintillator with a a diameter of 20 mm and thickness of 25 mm. In the right part, the scintillator has dimensions of 35×35 mm.

To find an optimal thickness of the scintillator, a figure of merit (FoM) equal to a ratio between a DEP intensity for 4.4 MeV gamma-ray, located at 3.4 MeV, and a number of events in the background, at the same energy range produced in the detector by 6.0 MeV gammas, is considered. The simulation results for scintillators with a thickness from 5 to 28 mm show that the optimal scintillator thickness is around 25 mm for FoM defined above.

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This scientific work was partly supported by Polish Ministry of Science and Higher Education within the framework of the scientific financial resources in the years 2015-2017 allocated for the realization of the international co-financed project.
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.