Deliverable D10.2

WP10 – JRA04 – INDESYS
Innovative solutions for nuclear physics detectors

MS116 Characterization of light production, propagation and collection for both organic and inorganic scintillators
D10.2
R&D on new and existing scintillation materials:
Report on the light production, propagation and collection for both organic and inorganic scintillators

One of the key points in the design and construction of large and complex detection systems based on scintillation detectors is the knowledge of the response function to incident radiation of interest. The response function depends on how well is known the interaction processes of incident particles and the light production and transport processes involved in scintillation materials. When detectors are used primarily for spectrometry, an optimum pulse height resolution is required. The resolution is mainly influenced by the statistical fluctuation of the number of photons produced in the detector, the efficiency of the transportation to the photocathode and the geometrical effects of the light collection. These effects are very important in large-area detectors where a light guide has to be used to couple scintillator with a smaller photo-sensor.

The light response of inorganic scintillators for gamma rays has been studied based on simulations of light propagation in different detectors using GEANT4 code. The light, produced by gamma rays of 1 MeV emitted at two different points, have been simulated for two detectors: cubic $LaBr_3$ crystal (2”x2”x2”) and phoswich detector $LaBr_3$ (2”x2”x2”) + NaI (2”x2”x6”). In the one case gamma rays were emitted into the center of the forward crystal wall and in the other into the left side position.
The obtained light response for the cubic $LaBr_3$ crystal (2”x2”x2”) presented in Fig. 1 showed the light output dependence on the interaction point. The achieved different light distributions for both irradiation points indicated the possibility of obtaining precise gamma energy deposit information by the usage of segmented photodetector.

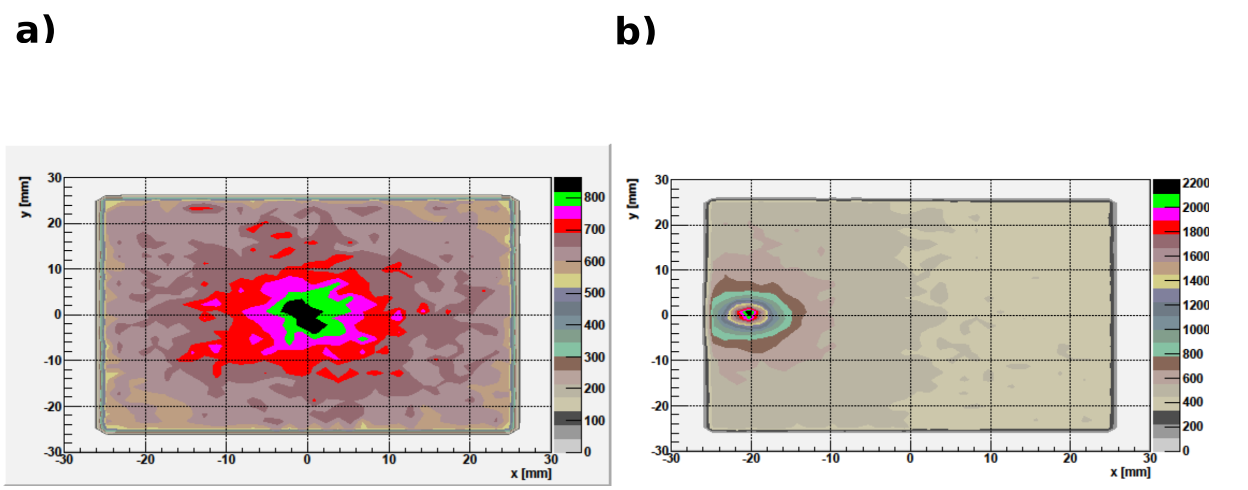

Figure 1. Distribution of scintillation light produced by absorption of 1 MeV gamma ray, measured on back side of cubic 2”x2”x2” $LaBr_3$ crystal. The gamma ray was emitted: a) - into the center of the $LaBr_3$, b) - into left side of the crystal (point x,y = [-2 cm, 0]).

As a result of similar simulation performed for phoswich detector, composed of 2”x2”x2” $LaBr_3$ attached to 2”x2”x6” NaI no dependence on the interaction point has been gained (see Fig. 2), indicating that there is no possibility to get information of the energy deposit position by measuring the scintillation light distribution for phoswich detector. Such information depends mainly on length of detector and is lost due to longer path of light from the gamma interaction point to the photodetector.

a) **b)**

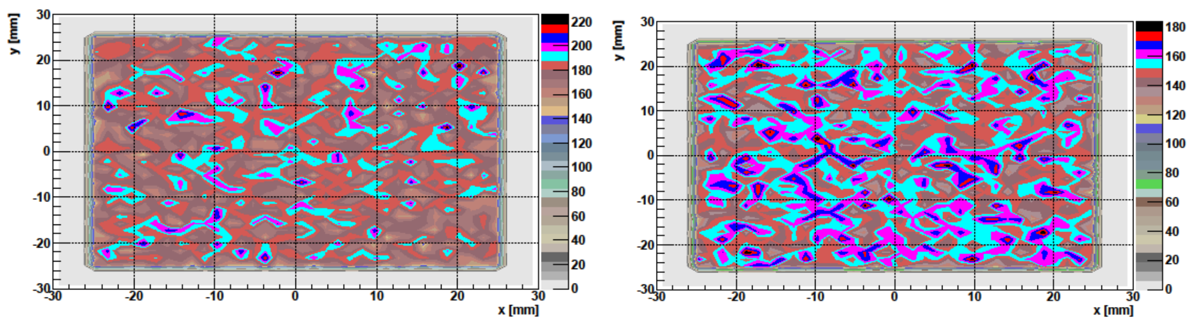

Figure 2. Distribution of scintillation light measured on back side of phoswich detector (2”x2”x2” $LaBr_3$ + 2”x2”x6” NaI), produced by absorption of 1 MeV gamma ray emitted: a) - into the center of the $LaBr_3$, b) - into left side (point x,y = [-2 cm, 0]).

In the context of simulation of the light generation, transport and collection in the CSI(Tl) crystals another simulation a package based on Geant4, called R3BSim (developed within the Workpackage SiNURSE) has been used.

The possibilities in Geant4 for the surface finish with the goal of understanding the light propagation inside a CsI scintillator and the reflectivity were investigated. The simulations were performed for extremely long crystals (up to 22 cm and 2x3 cm2 surface entrance). The adequacy of including a scintillator light guide and its effect on the final light collection was explored. Different surface finishes (ground-front-painted and polished-back-painted) were used to investigate the effects of light guide geometry of the crystals influence on the number of photons detected. Different generators were also used; gammas and photons, given both the same results. As the example, the results of simulations for 18 cm long CsI(Tl) crystal and different angles of the light guide are shown in the Fig. 3. The main conclusion of the work is that for large angle of the light guide, the amount of photons collected is reduced. The explanation is that they are reflected back into the crystal and some of them lost in these long paths. The results of this work proved that this kind of simulation is a powerful tool extremely useful in the design of “non standard” geometry crystals.

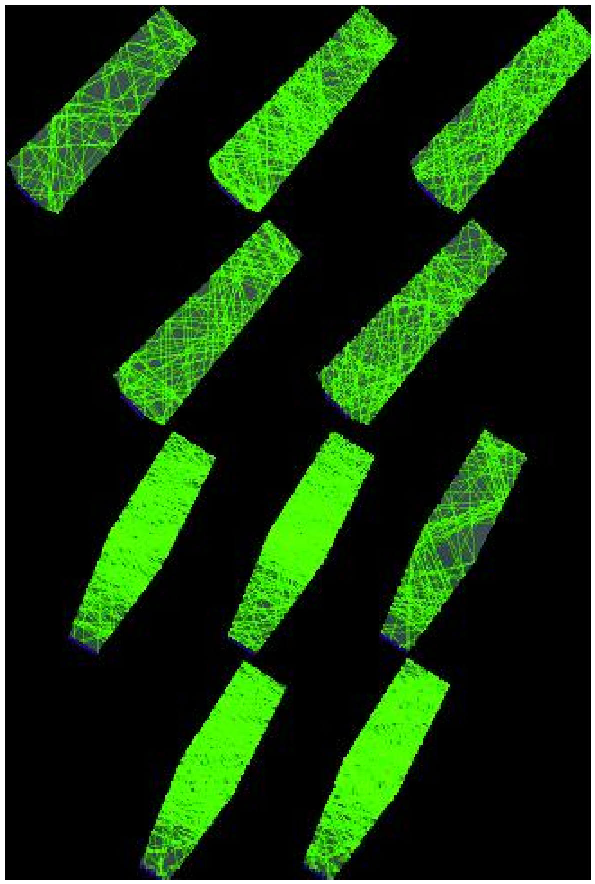

Figure 3. Graphic result of the simulation for 18cm long CsI(Tl) crystals with a light guide angles ranging from 20- 80 degrees. In all cases the light propagation of ten photons inside the crystal is shown.

With the aim to optimize the design of large-area organic scintillation detector array for neutron spectrometry, Monte Carlo simulation tools based on the GEANT4 package have been developed and validated experimentally. GEANT4 includes standard physics models for particle interaction, light production and photon transport. However, an incomplete description of some relevant processes has been identified. In fact, the high precision neutron model G4NeutronHP lacks of nuclear data related to inelastic reactions induced in ^{12}C. Based on the state-of-art simulation code NRESP7, we have improved the GEANT4 high precision neutron model by providing the same physical models and nuclear data (cross sections and angular distribution taken from ENDF/B-VII.0) for $^{12}C(n,\alpha)^{9}Be$ and $^{12}C(n,n')3\alpha$ reactions. Simulations of the response function to neutron of energies in the range up to 14 MeV have been performed with both codes. An excellent agreement is observed in the middle and high energy region of the response functions for energies higher than 8 MeV while small discrepancies are still present at the very low energy region.

On the other hand, an extensive work has been performed in order to improve and verify GEANT4 packages concerning the optical transport processes inside scintillation assemblies, models for boundary processes like GLISUR and UNIFIED have been validated and some bugs related with Lambertian reflection fixed. The influence of the geometrical shape, the type of reflective surface, the presence of a light guide and the optical properties of materials on the light collection efficiency and uniformity have been evaluated with GEANT4 codes. The work of Schölermann and Klein was taken as a reference and the GEANT4 code have been validated by calculating identical geometries under the same physical conditions with excellent agreement.

- Effect of the detector shape in the light collection. A series of different detector container geometries with squared, hexagonal and circular transversal section have been evaluated. All cells were defined with the same transversal section and thickness. The results showed that the collection efficiency converges to the cylindrical container one as the transversal area and the number of corners in the shape increases due to the lower number of Lambertian collisions experienced by the photons before reaching the window. The squared and hexagonal shapes favoured more compact arrangement of the modules. The simulations also confirm that tubular like position sensitive detectors show a worse light collection.

- Reflectivity of the coating. The collection efficiency has been studied for simplified detector geometry: an organic scintillator active volume enclosed in an aluminium container with the internal walls coated with diffuse reflector or polished surface and coupled to a quartz glass window. The use of diffuse reflector paint increases the collection efficiency compared to the polished finishing of the aluminium container internal walls.

- Light guide. The effects of the size and surface coating on the locus-dependent light collection have been studied for different reflectivity of the boundaries. It has been observed that a totally coated or polished light guide results in large locus-dependent light collection efficiency. In addition, a partial coating with diffuse reflector has become the most efficient way to solve such dependency. The thickness of the light guide plays also a role in the absolute light collection efficiency is achieved. A trade-off between size and coating pattern should be applied for optimal performance.

The developed GEANT4 code has been applied to optimize the design of a large organic liquid scintillator BC501A cell of 20 cm diameter and 5 cm thickness. After an extensive simulation work performed on different parameters the following conclusions have been drawn. Cylindrical shape and diffuse reflector wrapping optimize the light collection efficiency. In order to couple the largest available 130 mm diameter photomultiplier, a light guide fitting the diameters of the scintillator and the photocathode is needed. A conical light guide of 3 cm thickness with external surface totally covered with diffuse reflector paint optimizes the homogeneity of the light collection versus the interaction position of incident particle within a variation of 10% between the center and the edge of the scintillator surface.