Functional Materials 16, No.1 (2009)

Fringe effects in large-area scintillation detectors

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Received November 20, 2008

The light reflection conditions near the crystal fringes are known to differ from those in the sample middle part due to additional reflections from the butt surfaces. Such effects may be insignificant (as, for example, in most standard spectrometric detectors) but may be of importance in image visualization systems (as gamma cameras). In this work, the light yield inhomogeneities near the butt surfaces of gamma camera detectors are studied. Seven types of the crystal surface treatment and the reflecting coating materials are considered.

Известно, что вблизи краев кристалла условия отражения света отличаются от таковых в средней части образца из-за дополнительных отражений света от торцевых поверхностей. Такого рода эффекты могут быть несущественными (как, например, для большинства стандартных спектроскопических детекторов), но в случае систем для визуализации изображений (гамма камера, например) могут играть существенную роль. В работе исследуются неоднородности светового выхода вблизи торцевых поверхностей детекторов для гамма камер. Рассматриваются семь вариантов обработки поверхности кристалла и выбора материала светоотражающих покрытий.

The use of large-area scintillation detectors is among the most common ways to visualize images in scientific and medical application fields (SPECT cameras) [1]. In such cases, the optimum detector design is defined by two main factors: the physical homogeneity of the scintillation crystal and the minimization of fringe effects associated with the light reflection specific features at the crystal butts. The geometric causes of such fringe effects is illustrated in Fig. 1. It is seen that at the crystal butt, a fraction of light reflected from the side surface may return to the crystal or leave it. This effect gives rise to the light yield inhomogeneity that must be manifested to the greatest extent near the side butts (fringes) of the scintillator. At the same time, it is known [2–4] that a certain roughness of the scintillator surface and/or the use of various light-reflecting coatings may influence considerably the light collection character in the crystal.

The aim of this work was to determine the causes of the light yield inhomogeneity at the crystal butts and to develop the fringe effect control methods for large-area scintillators. In particular, the calculations

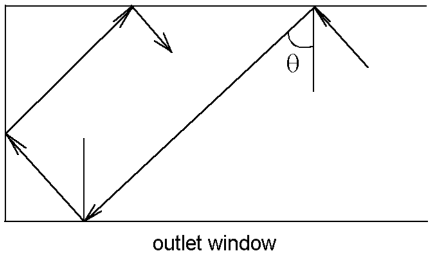

Fig. 1. Scheme of light beam reflection at a crystal butt.

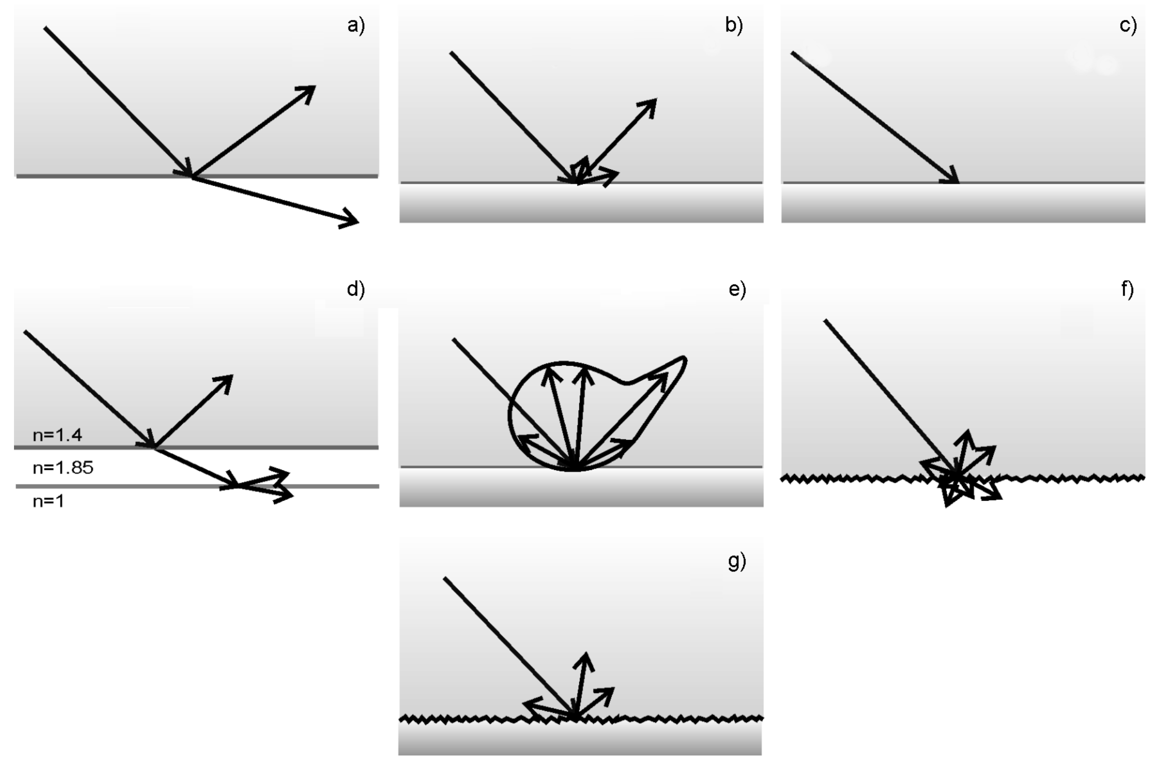

Fig. 2. Light reflection schemes from butts at various treatments and the reflector configurations: (a) case of a mirror semi-transparent surface; (b) reflection towards the crystal volume from a mirror crystal surface with a totally reflecting surface coating; (c) no reflection from the blackened surface (black body approximation); (d) case of totally reflecting coating out of contact with the crystal surface; (e) case of a roughened crystal surface in optical contact with white reflector; (f, g) case of roughened surface in absence of any reflector (f) and with a reflector at the crystal surface (g).

and experiments were made using NaI(Tl) single crystals being typical scintillators in the diagnostic SPECT systems.

Simulation of light collection conditions at the crystal butt and potentialities of the "fringe effect" control. The fringe effects are insignificant as a rule in bulk spectrometric detectors (where the crystal height ration to its transversal dimensions is 1–3). However, in the image visualizing systems (SPECT), such effects may be of a significant importance, because even small homogeneity deviations should compensate the errors in the scintillation flash coordinate reconstruction using the Anger algorithm. Thus, the suppression of fringe effects by optimizing the light collection conditions near the crystal butt is of great importance along with the electronic methods of the signal correction.

In this work, under consideration are seven options of the crystal surface treatment and the light-reflecting coating material selection that influence substantially the light collection. In this case, the Monte-Carlo simulation of the light collection coefficients at the butts of a scintillation crys-

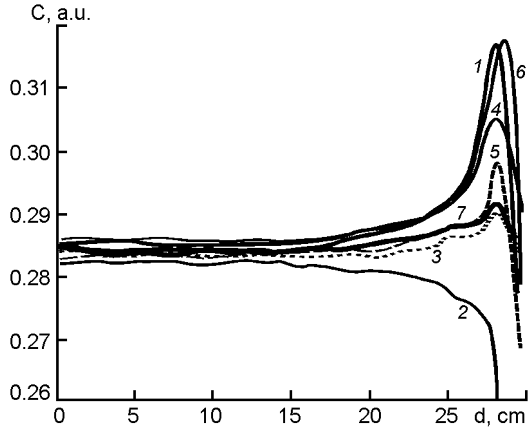

Fig. 3. Light collection coefficient as a function of the distance from the crystal butt (point 30 cm) at various treatments of the crystal surface: (*1*) reflecting MgO shell; (*2*) black reflector on the crystal butt; (*3*) polished reflector-free surfaces; (*4*) polished surfaces with white reflector (Tyvec); (*5*) roughened reflector-free surfaces; (*6*) roughened surfaces with white reflector (Tyvec); (*7*) the crystal surface coated with a transparent light guide with refractive index 1.4.

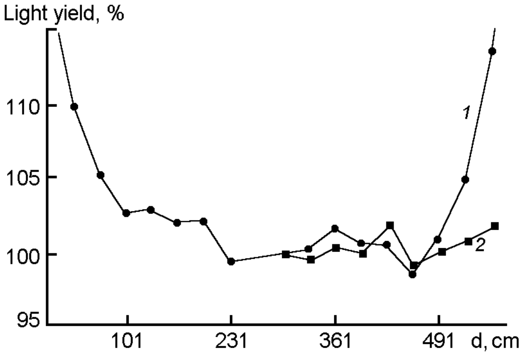

Fig. 4. Light yield profile over the detector area: (*1*) the surface treatment according to calculation 6 (Fig. 3); (*2*) that according to calculation 2 (Fig. 3).

tal is a very effective way to estimate the fringe effect value. Such calculations have provided a high efficiency and reliability of the forecasting both for halide scintillators [2, 3, 5] and oxide [3, 6] ones. As a rule, however, such calculations were carried out for standard type detectors [2, 3, 5] or long-length ones [3, 7], while there are only few works concerning the detectors with a crystal large cross-section/thickness ratio. In the calculations, used was the PARALLELOGRAM model of CFlash algorithm proved to be reliable in the simulation of alkali halide scintillators [5]. The cases considered are presented schematically in Fig. 2. The simulation results are shown in Fig. 3.

Experimental data on the light yield value distribution along a large-area detector screen. In experiments, a NaI(Tl) crystal of 590×470×9.5 mm^3 size glued to a 17 mm thick glass light guide. Such a sandwich is an analogue of a detector for medical gamma camera. To measure the light yield, a Hamamatsu R1306 PMT combined with a spectrum analyzer and collimated with a ^{57}Co source centered at the side opposite to the PMT. Scanning of the source and measuring system along the crystal-light guide assembly made it possible to measure the light yield both at the central and periphery areas of the crystal. In Fig. 4, shown are the experimental data for two cases.

It is to note that to provide the light yield measurements immediately at the butt of a scintillation crystal, the light guide should overlap the crystal as is shown in Fig. 5 (left). Therefore, the experimental data must include a contribution from the light guide that somewhat deteriorates the fringe effect measurement accuracy immediately at the crystal butt. At the same time, the light collection simulation for such a sandwich in the cases 1 and 2 (Fig. 4) shows that the light guide contribution to the light collection coefficient decrease is small (0.285 to 0.24), the signal drop shape at the crystal butt being the same. Fig. 5 presents the case of the reflection at $R = 0.95$ and that of total absorption of light exiting through the butt, $R = 0$.

Thus, the experimental and calculated data have been shown to coincide rather well, thus confirming the correctness of the model and parameters used to the light collection calculation. The light yield inhomogeneity at the crystal butts can be reduced by blackening of the butt, however, the total number of registered photons is reduced in this case. The size increase of the light guide overlapping the crystal butt provides some compensation of the fringe effects. It is to note that in this case, an additional possibility arises to control the exiting light distribution by a special treatment of the light guide butt.

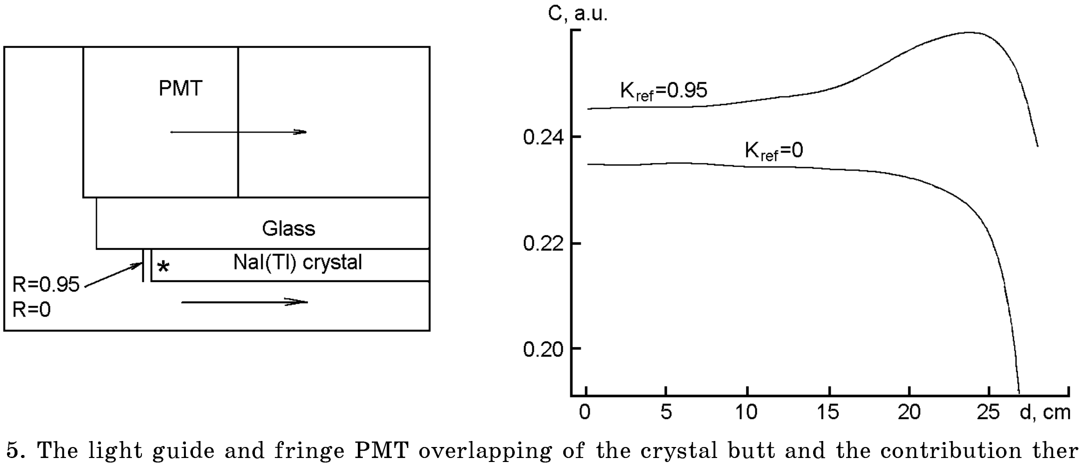

Fig. 5. The light guide and fringe PMT overlapping of the crystal butt and the contribution thereof to the light yield distribution at the butt of a large-area detector.

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Крайові ефекти у сцинтиляційних детекторах великої площини

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Відомо, що поблизу країв кристала умови віддзеркалення світла відрізняються від середньої частини зразка завдяки існуванню додаткових віддзеркалень світла від торцевих поверхонь. Такі ефекти можуть бути несуттєвими (як, наприклад, для більшості стандартних спектрометричних детекторів), але у випадку систем візуалізації зображень (гамма камера, наприклад) можуть відігравати суттєву роль. У роботі досліджуються неоднорідності світлового виходу поблизу торцевих поверхонь детекторів для гама камер. Розглядаються сім варіантів обробки поверхні кристалау та вибору матеріалу світловідбиваючих покриттів.