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Effective Luminescence Efficiency and spectral matching of a Cerium Fluoride Crystal Scintillator with various optical sensors

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INTRODUCTION & AIM

- The aim of this study was to examine the effective luminescence efficiency (ELE) and the spectral matching of a 10×10×10 mm^3 Cerium Fluoride (CeF_3) single crystal scintillator with various optical sensors [1].
- While numerous investigations have shown that CeF_3 crystals have non-proportional response to gamma rays, they have been already successfully used in high-rate calorimetry, including Large Hadron Collider's High-Luminosity phase experiments.
- However, the scintillation response of CeF_3 has not been systematically examined in the energy range covering medical imaging applications.

METHOD

Measurements were performed with a CPI Inc. CMP 200 DR, X-ray generator and X-ray tube IAE SpA model RTM90HS, in the range 60–150 kVp and 63 mAs.

20 mm Al was added in addition to the inner filter of the X-ray tube, to simulate attenuation from a human chest.

The ratio of the light energy flux emitted by the examined sample, normalized by the X-ray exposure rate can be expressed as the absolute luminescence efficiency [1]:

$$AE = \eta_A = \frac{\dot{\Psi}_\lambda}{\dot{X}} = \left(\frac{i_{elec}}{S\eta_p \alpha_s c_g}\right)\dot{X}^{-1} \quad (1)$$

In equation (1) $\dot{\Psi}_\lambda$ is the light energy flux (output signal) in units of μW m^{-2}. $\dot{X}$ is the exposure rate (mR s^{-1}). i_{elec} is the current produced by the electrometer in pA and S denotes the surface of the crystal, excited by X-rays (mm^2). The peak sensitivity of the photocathode (η_p) is expressed in units of pA/W. α_s is the spectral matching between the light source (in this case crystal) to the spectral response of the optical sensor (in this case the photocathode). Finally, the geometric light collection efficiency (c_g) has a value of 15.6. The units of the luminescence efficiency is EU=(μW m^{-2})/(mR s^{-1}).

If the AE is reduced by the spectral matching factor (α_s) (denoting the percent of the light produced by the scintillator which is within the same wavelength range with the optical response of a light sensor), then the effective luminescence efficiency (ELE) is derived [1].

$$EE = \eta_{eff} = \eta_A \alpha_s \quad (2)$$

The ELE was calculated for various optical detectors, often used in medical applications, while the spectrum of CeF_3 was obtained from manufacturer data [2].

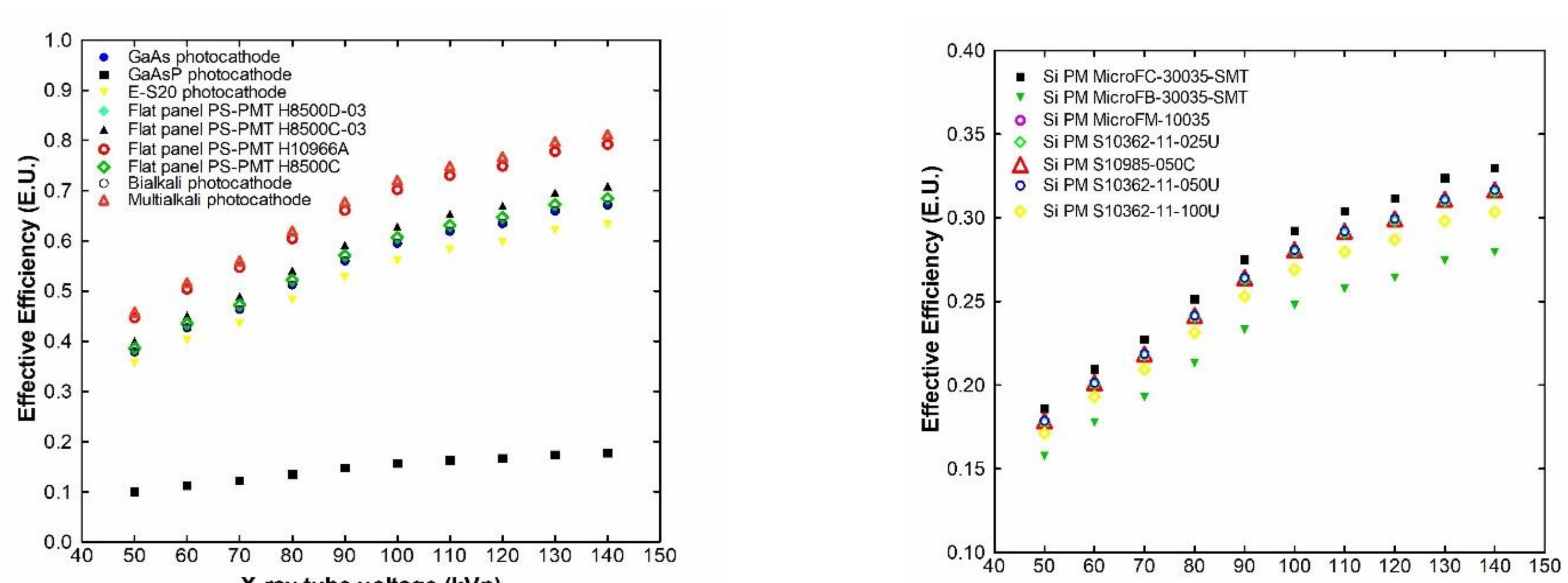

Figure 2. ELE of CeF_3 with photocathodes (**a**) and silicon PMTs (**b**).

RESULTS & DISCUSSION

Figures 2 and 3 show calculated ELE values with X-ray tube voltage.

Figure 2 shows grouped spectral responses of photocathodes (Figure 2a) and silicon photomultipliers (Figure 2b), whereas Figure 3 shows grouped spectral responses of CCDs (Figure 3a) and CMOS (Figure 3b).

ELE is maximized for multialkali photocathodes and flat panel position sensitive photomultipliers, since in these cases most of the emitted light from CeF_3 scintillator can be adequately collected by the detectors.

The combination of the multialkali photocathode with CeF_3 results in effective efficiency values reduced by a 2.58% compared to the absolute efficiency values at 140 kVp. In the case of the combination of CeF_3 with the gallium arsenide photocathode, the corresponding absolute efficiency reduction is 24.26% at 140 kVp.

Typical ELE values for single crystal scintillators, already integrated in medical imaging systems range from: 3 EE for BGO (used for example in the GE Discovery IQ scanner, GE Healthcare, Milwaukee, Wisconsin, US) [3], 5 EE for GSO:Ce (Philips Gemini GXL PET/CT, Philips Medical Systems, Eindhoven, Netherlands) [4], 8 for LYSO:Ce (Philips Gemini TF PET/CT, Philips Medical Systems, Eindhoven, Netherlands) [5] to 12 for LSO:Ce (Siemens Biograph TruePoint PET/CT, Siemens Healthineers, Forchheim, Germany) [6,7].

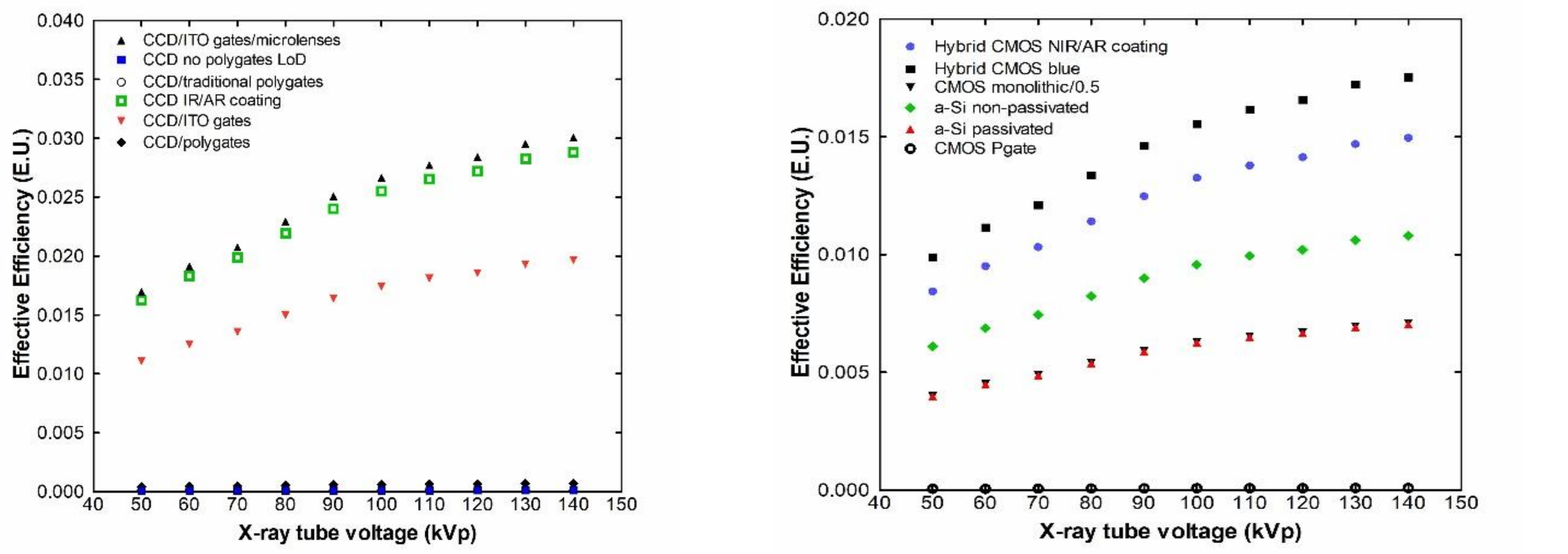

Figure 3. ELE of CeF_3 with CCDs **(a)** and CMOS **(b)**.

CONCLUSION

At the examined energy range the resulted values are considered low compared to typical materials used as X-radiation to light converters, thus it could not be used in radiological applications covering this energy range. It is possibly worth studying CeF_3 crystal at higher energies, considering that the luminescence efficiency did not reach the maximum value at 150kVp (maximum energy of the medical X-ray tube).

FUTURE WORK / REFERENCES

1. Ntoupis, V.; Michail, C.; Kalyvas, N.; Bakas, A.; Kandarakis, I.; Fountos, G.; Valais, I. Luminescence Efficiency and Spectral Compatibility of Cerium Fluoride (CeF_3) Inorganic Scintillator with Various Optical Sensors in the Diagnostic Radiology X-Ray Energy Range. *Inorganics* **2024**, *12*, 230, doi:10.3390/inorganics12080230.
2. CeF_3 - Cerium Fluoride Scintillator Crystal | Advatech UK Available online: https://www.advatech-uk.co.uk/cef3.html (accessed on 2 May 2024).
3. Ponti, E.D.; Crivellaro, C.; Morzenti, S.; Monaco, L.; Todde, S.; Landoni, C.; Elisei, F.; Musarra, M.; Guerra, L. Clinical Application of a High Sensitivity BGO PET/CT Scanner: Effects of Acquisition Protocols and Reconstruction Parameters on Lesions Quantification. *Current Radiopharmaceuticals 15*, 218–227, doi:10.2174/1874471015666220107100200.
4. Sathiakumar, C.; Som, S.; Eberl, S.; Lin, P. NEMA NU 2-2001 Performance Testing of a Philips Gemini GXL PET/CT Scanner. *Australas Phys Eng Sci Med* **2010**, *33*, 199–209, doi:10.1007/s13246-010-0016-6.
5. Surti, S.; Kuhn, A.; Werner, M.E.; Perkins, A.E.; Kolthammer, J.; Karp, J.S. Performance of Philips Gemini TF PET/CT Scanner with Special Consideration for Its Time-of-Flight Imaging Capabilities. *Journal of Nuclear Medicine* **2007**, *48*, 471–480.
6. Jakoby, B.W.; Bercier, Y.; Watson, C.C.; Bendriem, B.; Townsend, D.W. Performance Characteristics of a New LSO PET/CT Scanner With Extended Axial Field-of-View and PSF Reconstruction. *IEEE Transactions on Nuclear Science* **2009**, *56*, 633–639, doi:10.1109/TNS.2009.2015764.
7. Valais, I.; David, S.; Michail, C.; Konstantinidis, A.; Kandarakis, I.; Panayiotakis, G.S. Investigation of Luminescent Properties of LSO:Ce, LYSO:Ce and GSO:Ce Crystal Scintillators under Low-Energy γ-Ray Excitation Used in Nuclear Imaging. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **2007**, *581*, 99–102, doi:10.1016/j.nima.2007.07.037.