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3.6.1: Imaging System Analysis and Modeling

IMAGE TRANSFER CHARACTERISTICS OF EUROPIUM ACTIVATED SCINTILLATORS FOR MEDICAL IMAGING APPLICATIONS.

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Abstract - **Image transfer characteristics (MTF, DQE) of Y_2O_2S:Eu, Y_2O_3:Eu, and YVO_4:Eu image receptors were evaluated. These materials were used in the form of laboratory prepared screens. MTF was experimentally determined by the square wave response method and theoretically evaluated by a diffusion equation model. DQE was calculated using experimentally determined optical data of the scintillators. Light spectra were measured and their compatibility to the spectral sensitivity of various photodetectors was calculated. The MTF and DQE of Y_2O_2S:Eu were better than those of Y_2O_3:Eu, which was superior to YVO_4:Eu. The spectral compatibility of the three scintillators was very good to excellent (0.7 to 0.95), being better than that of some commercially used scintillators.**

I. INTRODUCTION

Several photodetectors employed in various medical imaging applications, such as films in laser imagers, Si photodiodes in CT detectors, CCD arrays in digital radiographic systems, or photocathodes used in image intensifiers and photomultipliers, exhibit high sensitivity to red light. However, some of these photodetectors are usually coupled to scintillators emitting in the green or blue region of the electromagnetic spectrum, causing optical signal losses. On the other hand, there are scintillator materials activated with trivalent europium ion (Eu^{3+}) emitting red light, which is very well matched to the spectral sensitivity of the above mentioned red sensitive photodetectors. These red scintillators have been used in non medical applications, such as color TV screens, but have not been employed in commercial medical imaging systems. The purpose of this study is to investigate the suitability of three such scintillators, namely Y_2O_2S:Eu, Y_2O_3:Eu, YVO_4:Eu, for use as medical image receptors. The following image transfer characteristics of each phosphor material were studied: a/the Modulation Transfer Function (MTF), expressing image sharpness and spatial resolution, and b/the Detective Quantum Efficiency (DQE), giving the signal to noise ratio squared (SNR^2), which is transfer from the input to the output of an imaging system. Additionally, the spectral compatibility between the light spectrum of these scintillators and the spectral sensitivity of some red sensitive photodetectors was assessed by evaluating the spectral matching factor.

II. METHODS.

The scintillating materials were used in powder form to prepare screens by sedimentation with coating thickness ranging from 20 to 180 mg/cm^2. MTF was determined by the square wave response function (SWRF) method [1], [2]. The screens were placed in contact with a red sensitive film (Agfa Scopix LT 2B) and a square wave test pattern (Type 53) with line pairs (lp) ranging between 2.5 and 100 lp/cm. The screens were then exposed to 70 kVp X-rays and the resulting images were digitized by a MICROTEC ScanMaker IIsp (24-bit color, 1200x1200 dpi) CCD scanner. Image brightness profiles were obtained along 64 lines perpendicular to the test pattern lines. The SWRF was determined by averaging these profiles for each screen-film combination. The MTF was then calculated by the formula [1]

$$MTF(f)=\frac{4}{\pi}\left[\frac{SWRF(f)}{f}+\frac{SWRF(3f)}{3f}-\frac{SWRF(5f)}{5f}+..\right] \quad (1)$$

where f is the fundamental spatial frequency of the test pattern. The MTFs of the screens were also calculated using formulas derived from the theoretical model of Swank based on diffusion theory[3].

The DQE [3] was calculated at zero frequency:

$$DQE(0)= A_Q(\mu,T) \,.\, A_S(\mu, s, r, a) \quad (3)$$

where A_Q is the X-ray quantum detection efficiency, expressing the fraction of incident X-rays that are detected by the screen material, μ is the X-ray mass attenuation coefficient of the scintillating material, T is the screen coating thickness, A_S is the statistical factor, describing the statistical optical pulse height distribution emitted by the screen [3] and calculated using optical parameters s, a, r, found as described in previous studies [2],[4].

The spectral matching factor was determined by:

$$a_S = \int_{\lambda_1}^{\lambda_2} S_P(\lambda)S_D(\lambda)d\lambda \Big/ \int_{\lambda_1}^{\lambda_2} S_D(\lambda)d\lambda \quad (4)$$

where S_P is the scintillator spectrum measured by a monochromator (Oriel 7240) and S_D is the spectral sensitivity of the photodetectors [4].

III. RESULTS

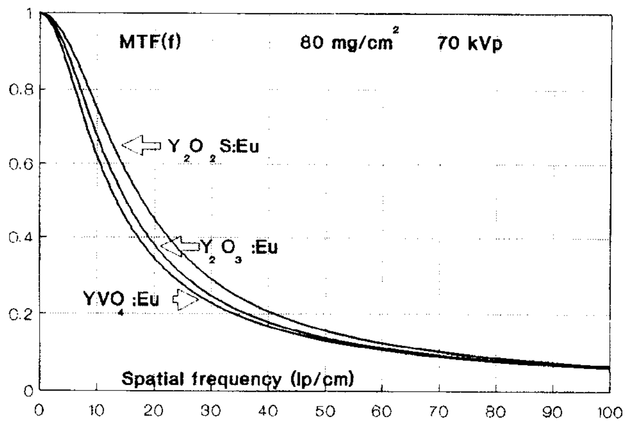

Fig. 1. MTF of three scintillator screens.

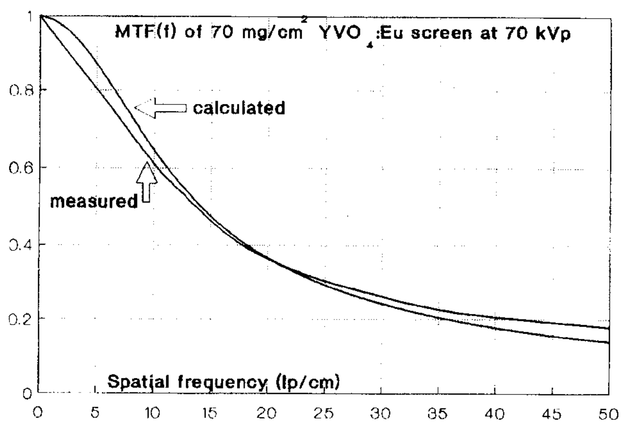

Fig. 2. MTF measured Vs calculated of YVO_4:Eu.

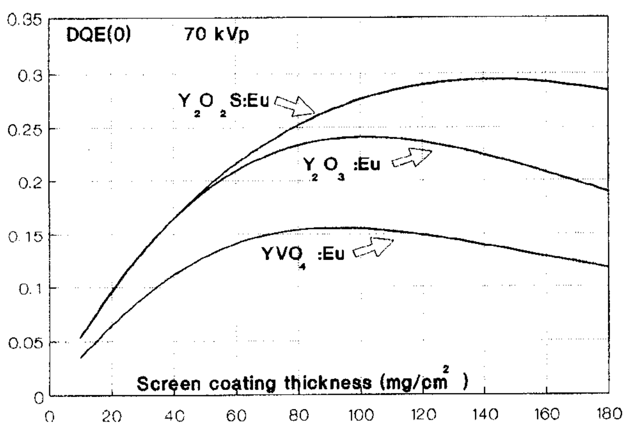

Figure 3. DQE Vs screen thickness.

The MTFs Y_2O_2S:Eu screens were found slightly better than those of the other scintillators, especially in the low to medium spatial frequency region; this is demonstrated in Fig. 1 for 80 mg/cm^2 screens. Fig.2 gives a comparison between measured and calculated MTFs. DQE(0) was higher for the Y_2O_2S:Eu screens as shown in Fig. 3. The Y_2O_3:Eu scintillator was also found to attain relatively high DQE(0) values in the thin to medium thickness range. The spectral matching factors for the three scintillators ranged between 0.9 to 0.95, when combined with red sensitive films or with GaAs or S-25 photocathodes, and between 0.65 - 0.7 when used with Si photodiodes and CCD arrays.

IV. DISCUSSION

The MTFs corresponding to the three materials employed in this work were not found to differ significantly. In the high spatial frequency region, which determines the spatial resolution, all MTFs were practically identical. In the low to medium frequency range the MTF of the Y_2O_2S:Eu screen was found superior, indicating better image sharpness. This difference may be attributed to the superior intrinsic physical properties of this material: X-ray absorption, conversion efficiency, optical scattering. Same reasoning holds for DQE(0); Y_2O_2S:Eu scintillator was superior to Y_2O_3:Eu, which in turn was better than YVO_4:Eu. The spectral matching factors of the three red light emitting scintillators were found to be better than those of green-blue emitting scintillators, such as Gd_2O_2S:Tb, Y_2O_2S:Tb, or La_2O_2S:Tb usually employed in X-ray imaging. This signifies reduced signal losses for the red light scintillators.

IV. CONCLUSION

The image transfer characteristics of Y_2O_2S:Eu scintillator were superior to those of Y_2O_3:Eu which in turn were better than the corresponding characteristics of YVO_4:Eu. The spectral matching of the three scintillators to common photodetectors was very good to excellent.

V. REFERENCES

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