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PROGRAM AND EXTENDED ABSTRACTS

MODELING QUANTUM NOISE IN RADIOGRAPHIC PHOSPHOR SCREENS

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Introduction

Screen noise results mainly from spatial statistical fluctuations in the number of x-ray photons absorbed by the intensifying screen. Generally speaking noise depends upon the incident x-ray spectrun and the intrinsic conversion efficiency of the screen. Theoretical models for predicting quantum noise of medical imaging detectors based on scintillating screens have been developed [1,3]. These models takes into account the exposure conditions (photon energy), screen characteristics (screen coating thickness, type of scintillator) and scintillator optical properties (absorption and scattering of emitted light). Noise is evaluated in terms of the spatial frequency dependent Noise Power Spectrum (NPS), which is depended upon the optical properties of the phosphor material. We have continued and present in this paper the aforemention work with the inclusion of characteristic radiation production and absorption within the phosphor material.

Description of the model

During this work certain assumptions have been made: *(i)* The screen is considered to be divided into N layers of thickness t. *(ii)* The phosphor grains are assumed to have spherical shape, *(iii)* The escape of characteristic radiation is considered and treated as an autonomous source of noise involving the entire energy spectrum, with probability equal to that of the probability of production of K x-rays for every energy. In the production of characteristic radiation only the high Z element of the phosphor material is considered. *(iv)* The characteristic photons are assumed to be emitted isotropicaly in a solid angle of 4] radians. *(v)* Auger electrons, k, and L x-rays are assumed to be absorbed at the interaction site. *(vi)* It was assumed that all light quanta have the same energy which was measured experimentally (average energy).

In order to implement assumption *(ii)* the noise due to absorption of primary radiation and the noise due to absortion of characteristic radiation has been treated separately. For the former case

the equation for NPS is being previously reported as [3,4] :

$$QNPS(u,E,T)= \int_0^E f(E)A_Q(E)m^2(E)\int_0^T X(t,E)\left[G(u,t)\right]^2 dtdE \qquad (1)$$

where: QNPS stands for quantum noise power spectrum, T is the phosphor thickness, E is the energy corresponts to the high voltage of the tube, $A_Q(E)$ is the fraction of incident x-ray quanta with energy between E and E+dE that is absorbed in the phosphor, $f(E)$ is the x-ray intensity incident on the screen, $m(E)$ is conversion gain of screen: number of light quanta produced per absorbed absorbed x-ray of energy E, $X(t;E)$ is the fraction of x-rays absorbed with energy between E and E+dE which do so in a thin layer, dt, at depth t in the screen, $G(u,t)=G(0,t)MTF(t;u)$, where MTF is the Modulation Transfer Function of the screen given as a function of depth (t) and frequency (u) [5,6] and G(0,t) is the fraction of light photons created in a thin layer at depth t in the screen that escape to the output.

In order to evaluate the latter noise source the following interaction scheme has been implemented. *(i)* An x-ray fluence distribution, f(E) with energy betweem E and E+dE is in normal incidence at a phosphor screen of thickness T. *(ii)* Characteristic radiation is produced with probability depending of the fluence energy. A fraction of the k x-rays will interact in the screen and a part of them will be absorbed. *(iii)* k x-rays will interact at different depths t, with the phosphor grains in the screen. The number of k x-ray quanta of energy $E_{k,ıı}$ produced in depth i t and absorbed by the grains in a thin layer at j t, is described by $q_j(Eki)$. *(iv)* The absorbed x-ray energy is partially converted into optical photons. The total number of light quanta produced from all the interacting x-ray quanta and absorbed in that elementary layer, is $m(E_K)$. $q_j(Eki)$. *(v)* The emitted light is propagating and interact in all directions. The fraction of it that finally escape to the output is $G_k(0,t)$. *(vi)* Those light quanta that do escape will be spread over the output. This process is characterized by $G_k(u,t)$, where index k denotes the origin of these light photons, (characteristic absorption).

Absorption of characteristic radiation

If an interaction occurs at depth i t in the phosphor material then at a point P characteristic radiation is created, and the energy that is carried away by the K photons equals to k_i [7]. The K photons are isotropically emitted from point P with a solid angle 4ı. If the solid angle is divided into 2m solid angle elements Ω_r , r=1 to 2m. The amount of energy that photons emitted by this angle and interact in a layer positioned at j t is defined as $Y_{r,i,j}(E_{ki},\ t,\ \Omega_r)$. Considering every solid angle elements and the total screen thickness, the total energy that is absorbed within the layer positioned at j t equals to:

$$q_j(E_k) = \sum_{i=1}^{N-1}\sum_{r=1}^{m} Y_{r,i,j}(E_{ki}, \Delta t, \Delta\Omega_r) \quad (2)$$

It is a known fact that the variance var(E) of the output signal (i.e the light photon emitted from an intensifying screen) equals (assuming Poisson distribution in the absorption and of x-rays as well as to the gain) to [4]:

$$QNPS(u,E,t) = \mathrm{var}(u,E,t) = q(E,t)\cdot\left[m(E)\cdot G(E)\right]^2 \quad (3)$$

where q(E) is the x-ray energy absorbed in a screen of thickness t and $m(E).G(u,t,E_L)$ is the average number of light photons emitted from a screen per absorbed x-ray. If we take into account the total screen thickness as well as the entire energy spectrum that irradiates the screen and by utilizing eq2 we derive the equation which gives the correction for the escape and absorption of characteristic x-rays only:

$$QNPS_k(u,E,T) = \int_0^E m^2(E_k)\int_0^T q_j(E_k)\left[G_k(u,t)\right]^2 dt dE \quad (4)$$

The total Noise Power Spectrum due to quantum mottle is obtained by the sum of (1) and (4)

$$NPS(u,E,T)_{total} = QNPS(u,E,T) + QNPS_k(u,E,T) \quad (5)$$

Results and Discussion

A set of ZnSCdS:Ag screens covering a range of surface densities (20mg/cm^2 to 130mg/cm^2) was prepared by sedimentation in our laboratory. The screens were put in close contact with the film and irradiated. Images were digitized by a MICROTEC Scanmaker II SP (24-bit color, 1200x1200 dpi) CCD scanner. NPS was experimentally derived by means of the FFT of the autocorrelation function.

The model previously introduced is a function of the optical parameters of the scintillator, that is n_C which is the intrinsic conversion efficiency and η the reciprocal diffusion length which characterize optical absorption. The value of n_C for this material was taken as 0.209. The value η was found by fitting the experimental results as 35 cm^2/g . This value exceeds fitted values previously reported (33.9cm^2/g) [4]. It indicates higher optical absorption but this is to be expected because of the k-edge correction which accounts for higher energy absorption in the layer.

In figure 1 a comparison between theoretical prediction (solid lines) and experimental results (dots) of the total NPS normalized at zero frequency is demonstrated. It should be noted that for low surface densities the agreement is not that satisfied as in bigger densities because the model does not comply with the assumption for the solution of the Boltzman equation [3]. Nevertheless it can be seen that higher surface densities demonstrates reduced noise transfer characteristics for the same exposure conditions due to higher efficiency in the absorption of X-rays.

In figure 2 the small difference in noise transfer characteristics between a screen of surface density of 80mg/cm^2 and one of 120mg/cm^2 is indicated. This marks the 80mg/cm^2 screen as an optimum surface density for this energy region. This deduction is useful in phosphors manufacture and can be used to optimize image quality. Furthermore this deduction can be utilized inversely. That is use the model to find the optimum irradiation conditions for a given phosphor material.

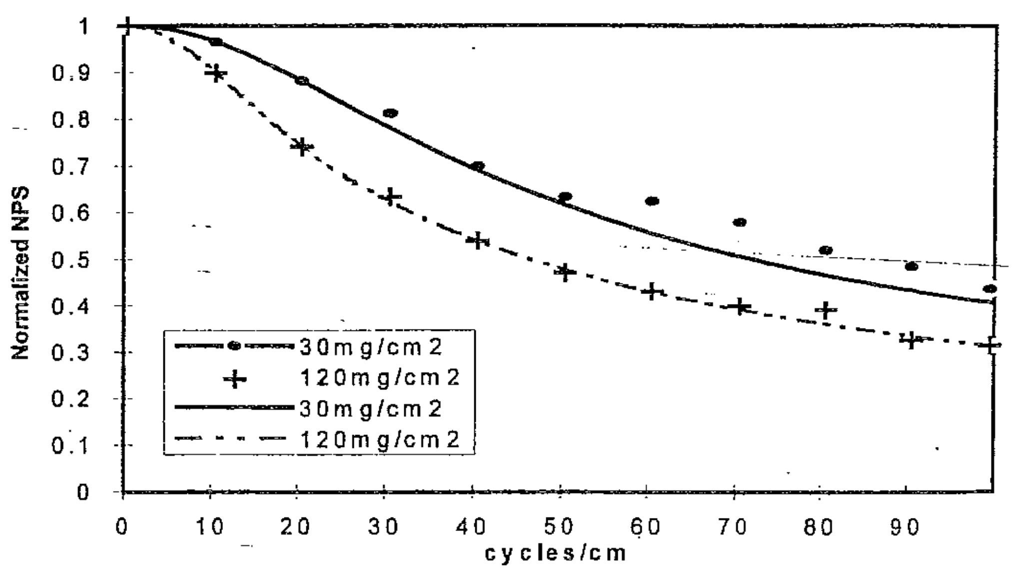

Figure 1. Normalized Noise Power Spectra of two ZnSCdS:Ag screens (30mg/cm^2 and 120mg/cm^2) irradiated at 70 kVp. The solid lines represent the theoretical (fitted) curves and the dots experimental results.

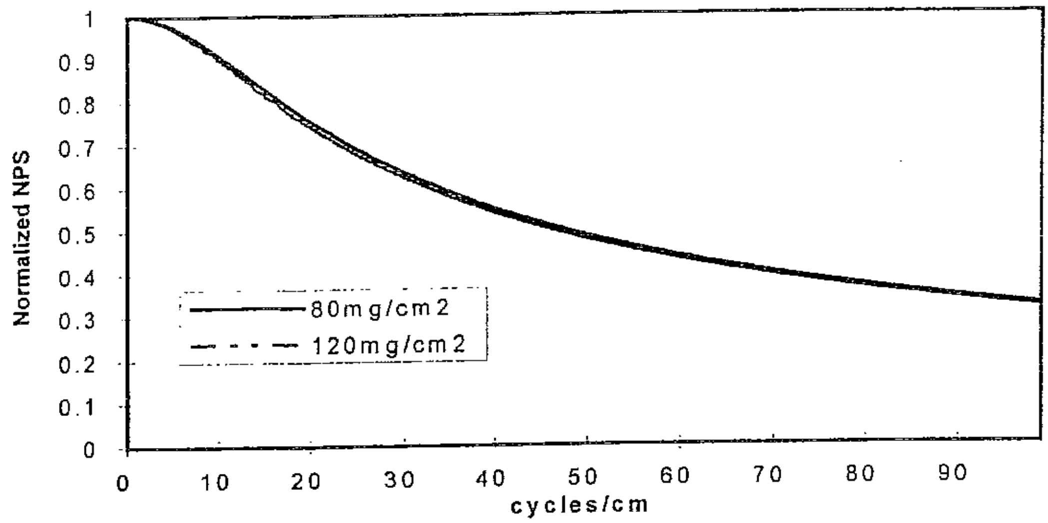

Figure 2. Normalized Noise Power Spectrum of a 80mg/cm^2 (upper curve) and a 120mg/cm^2 (lower curve) screen for a 70 kVp X-ray.

Conclusion

A model correcting the noise transfer characteristics, for the k-edge production and absorption in phosphor materials has been proposed. This model can be used alone to estimate the optimum screen characteristics which would assure optimum diagnostic information or could be used to evaluate irradiation conditions and exposure limits of currently used materials, thus provoke possible patient re-examinations. In that way image quality can be improved and patient dose can be decreased.

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