Unity Energy Response Using CaSO4:DY/Teflon

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***Abstract*—This study investigates the possibility of achieving unity energy response using the very sensitive CaSO4:Dy/Teflon thermoluminescent detector at photon energies below 100 keV. Accurate measurements for the energy responses were carried-out using ultra thin, 3 micron thick, TLD discs with average grain size of about 3μm. The present work shows that the experimental reduction factor for the 15 % phosphor loading with average grain size of 3 μm is in good agreement with the calculation based on the cavity theory but at grain size of 1.0 μm. This indicates that the cavity theory is underestimating the real experimental reduction factor in the energy response. The present work expect that unity energy response can be achieved with grain size of about 1 μm.**

***Index Terms*— Cavity Theory, Energy Response, Particle Size, Photon Energy.**

I. Introduction

In the study of radiation effect on human, there are special circumstances in which dosimeters having unity response (energy independent), good spatial resolution, and high sensitivity are required. This permits measurement to be made over cellular dimensions. The use of radiations for treatment of cancer is well established and widespread. A large number of hospitals have radiotherapy facilities. For accurate measurement of exposures to patients, a sensitive tissue equivalent dosimeter is needed. Among many types of thermoluminescent detectors (TLD), $CaSO_4$:Dy is one of the most sensitive, although it has a major disadvantage that its energy response is a complex function of both photon energy and phosphor grain size (Chan and Burlin, 1970; Pradhan and Bhatt, 1970; Driscoll and McKinlay, 1981; Pradhan and Bhatt, 1982; Silva 1989; Carlson, et al., 1990; Kasa 1990; Hemandez and Rivera Et Al., 2012). According to the cavity chamber theory (Chan and Burlin, 1970), if a detector such as a TLD placed inside a medium of different properties, the energy response (***L***) of the detector becomes a complex function of the energy lost by the electrons and that is imparted by the interaction of photons with the TLD (Karali, et al., 2009; Olko, et al., 2006), which is given by;

$$L = \frac{D_m}{D_c} = dS_{m,c} + (1-d)\left(\frac{\mu_{en}}{\rho}\right)_{m,c} \quad (1)$$

Where, D_m & D_c are the radiation dose in the medium and in the cavity, d is a weighting factor, function of the cavity size, $S_{m,c}$ is the electron stopping power ration of the medium to the cavity, and $\left(\frac{\mu_{en}}{\rho}\right)_{m,c}$ is the photon mass energy absorption coefficient ratio of the medium to the cavity. The weighting factor (d) is defined as;

$$d = \frac{1-e^{-\beta L}}{\beta L} \quad (2)$$

Where, β, is the electron attenuation coefficient and is related to the electron range through;

$$e^{-\beta R} = 0.01 \quad (3)$$

It was shown that the weighting factor (d**)** decreases from one to zero with increasing cavity size.
For small cavity, energy absorption by photon interaction in the cavity becomes very small.

$$d \sim 1 \quad and \quad (1-d) \approx 0 \quad (4)$$

Therefore, the response equation reduced to;

$$L \approx S_{m,c} \quad (5)$$

As cavity size increased;

$$d \sim 0 \quad and \quad (1-d) \approx 1 \quad (6)$$

Therefore, the response equation reduced to;

$$L = \left(\frac{\mu_{en}}{\rho}\right)_{m,c} \quad (7)$$

Calculation of the energy response was carried out according to the cavity theory for phosphor having large grain size, 5 μm grain size, and for 1.0 μm grain size.

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We believe that reducing grain size can control the energy response of the TLD at photon energies below 100 keV.

II. Material and Method

The aim of this work is to achieve unity energy response using a very sensitive CaSO4:Dy/Teflon detector at photon energies below 100 keV. This can be done by varying phosphor grain size and the percentage loading of the phosphor in Teflon. CaSO4:DY powder of grain size $\sim 75\ \mu m$ is re-treated by milling and sieving in our laboratory to achieve average grain size of 3.0 μm. Two TLD rode having phosphor loading of 30% and 15% by weight were manufactured by incorporating the TLD phosphor into a Teflon powder, heated, and molded into a TLD rod. Slices of pre-selected thickness of 3 μm TLD discs are cut by means of microtome. At the beginning the micro-discs are soft and difficult to handle. This problem is overcome by sandwiching the discs between two micro-slide glasses in an oven at a temperature of 280 ^{0}C for two hours. The micro-discs become rigid and more easily to be handled with vacuum tweezers. Direct measurement of the thickness of the micro-discs with a standard digital micrometer yields values of $3 \pm 0.5\ \mu m$. The thickness is also checked using a Mercer digital metric gauge unit type 122D. An average value of $3\ \pm 0.5\ \mu m$ is assumed for all discs.

The radiation beam was directed perpendicularly to the surface of an approximately cylindrical phantom of Teflon plastic, see Fig. 1.

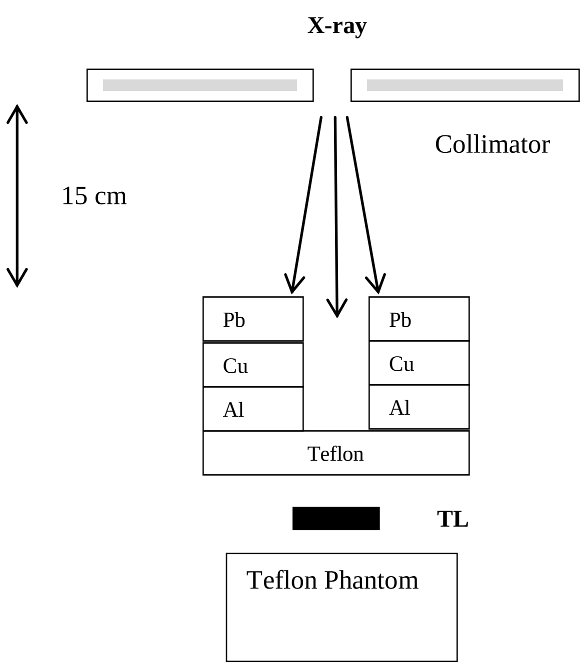

Fig. 1. The irradiation arrangement to measure the energy response.

The entrance field, symmetrically situated on the phantom surface, was 1.0 cm diameter and was defined by means of a special mask made of, lead, copper, aluminum, and Teflon. The mask was arranged so that the material nearest to the detector was the material with the lowest k-edge. Thus, the incident spectrum progressively degenerated to negligible proportions in the graded absorber. Thus, the incident spectrum progressively degenerated to negligible proportions in the graded absorber. The micro discs were placed on the top of the Teflon phantom.

Measurements of the energy response were carried-out using 90 discs for both phosphor loadings using filtered x-ray spectra having effective energies from 30 keV to 80 keV. The effective energy was checked using the half-value-layer method. All discs are irradiated with 0.1 Gy photon dose. The discs light out-put were normalized to that for Co-60 gamma source energy.

III. Results and Discussion

Fig. 2 shows the calculated and the measured energy response of CaSo4:Dy surrounded by Teflon material. The average grain size in the present experimental work is 3 µm.

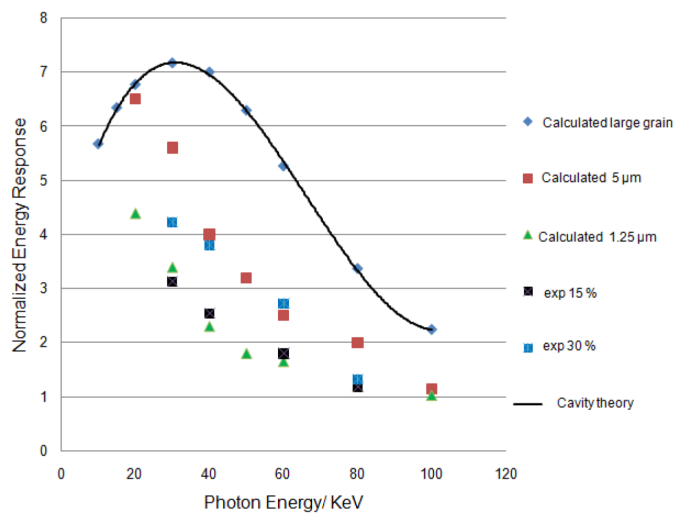

Fig. 2. The energy response of CaSO4:Dy/Teflon normalized to Co^{60} energy.

It is shown from the figure that the experimental energy response for the 15 % loading is in good agreement with the cavity theory calculation for the 1.0 µm grain size.

Cavity theory usually based on the assumption of single crystal of CaSO4:Dy surrounded by Teflon which is not the case in practice. In practice, large crystal is crushed to very small sized crystals, but small crystals tend to agglomerate and stick with each other by electrical forces developed during milling and sieving. Therefore, decreasing the percent phosphor loading in the TLD rode helps to separate the small grain from each other. Extra reduction in the energy response is therefore expected if the experimental problem can be overcome. Fig. 3 shows the reduction factor in the energy response for both phosphor loadings at different photon energies.

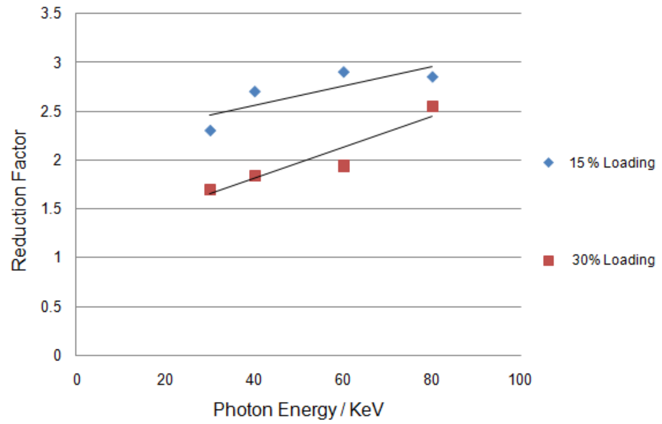

Fig. 3. The experimental reduction factor in the energy response of CaSO4:Dy/Teflon at different photon energies and phosphor loadings.

It is observed that the reduction factor for the 15% phosphor loading is greater than that for 30% phosphor loading, and this reduction increases with increasing photon energies.

Table I shows the measured energy response with its standard error compared with the cavity theory calculations at different x-ray qualities.

TABLE I

THE MEASURED AND CALCULATED ENERGY RESPONSE OF CASO4:DY/TEFLON AT DIFFERENT PERCENT LOADING AT DIFFERENT EFFECTIVE PHOTON ENERGIES

Photon Energy (keV)	Calculated (Large grain)	Calculated (5 μm)	Calculated (1.25 μm)	Experimental ± SD 15 % loading	Experimental ± SD 30% loading
10	5.68				
15	6.35				
20	6.78	6.5	4.6		
30	7.18	5.6	3.3	3.13±0.3	4.22±0.35
40	7.01	4.0	2.5	2.54±0.32	3.80±0.35
50	6.30	3.2	1.8		
60	5.25	2.5	1.5	1.8±0.31	2.7±0.30
80	3.37			1.18±0.25	1.32±0.30
100	2.24	1.37	1.3		

IV. CONCLUSION

From the above discussion one can conclude that calculations based on the cavity theory are underestimating the real experimental energy response, and the general trends of the calculation agree with the experiment but with higher energy response value. Therefore Unity energy response can be achieved with grain size of about 1 μm.

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