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Radiation attenuation properties of shields containing micro and Nano WO3 in diagnostic X-ray energy range

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► ***Original Article***

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ABSTRACT

Background*:** It has recently been shown that the particle size of materials used for radiation shielding can affect the magnitude of radiation attenuation. Over the past years, application of nano-structured materials in radiation shielding *has attracted attention* world-wide. The purpose of this study was to investigate the shielding properties of the lead-free shields containing micro and nano-sized WO3 against low energy x-rays. ***Materials and Methods*:** The radiation shields were constructed using nano and micro WO3 particles incorporated into an EPVC polymer matrix. The attenuation coefficients of the designed shields were evaluated for low energy x-rays (diagnostic radiology energy range). ***Results*:** The results indicate that nano-structured WO3/PVC shields have higher photon attenuation properties compared to those of the micro-sized samples. ***Conclusion: Our experiment clearly shows that the smaller size of nano-structured WO3 particles can guarantee a better radiation shielding property. However, it is too early to draw any conclusion on the possible mechanisms of enhanced attenuation of nano-sized WO3 particles.

Keywords: *Radiation, attenuation, micro, Nano, WO3, in diagnostic radiology, X-ray.*

INTRODUCTION

Over the past decades nanotechnology has enabled us to create a wide variety of life-changing products. This technology is also currently used for production of multipurpose radiation shields. Since the discovery of X-rays and radioactivity, flexible lead-based radiation shields have been widely used in radiology departments. Currently, the shielding design of X and g facilities, protective equipments and clothing is mainly based on lead materials. However, recently there has been a great deal of concern expressed about the toxicity of lead (1). In addition the heaviness of the lead would cause back strain, and orthopedic injuries in radiation workers who wear the lead aprons for long durations (2-5). Therefore production of environmentally-friendly lead-free radiation shields with less weight compared to conventional lead-based shields is a challenging issue in diagnostic radiology and nuclear medicine (6-11). Different investigations have been performed to obtain the properties of aprons made by combining elements with different K absorption energies, i.e. copper, tin, barium, tungsten, antimony, yttrium, and lead (5, 6, 9, 12). Recently the use of Nanoparticles in the design of lead-free radiation shields have been investigated (13). Protective materials with Nano particles have shown to have good mechanical properties to be used in developing radiation shields (1, 13-15). The size and concentration of Nano-particles used in making radiation shields are two important factors affecting the radiation attenuation properties of the protective materials (1, 13, 16). The purpose of this study is to design nano and micro-structured shields using WO3 particles incorporated in EPVC polymeric matrix, and to compare the radiation shielding properties of nano and micro-sized shielding materials.

MATERIALS AND METHODS

Flexible sheets of WO3 were produced in a poly vinyl chloride (EPVC) polymeric matrix. In this experiment, the nano and micro-structured shields with the purity of +99% were constructed using WO3 particles incorporated in EPVC polymeric matrix with 20%, 50% and 60% of mass proportions. The grain sizes of nano particles used in construction of the shields were 20 to 100 nm, while the average micro WO3 particle size was less than 20 µm. The scanning electron microscope (SEM) image of the nano-sized WO3 powder is shown in figure 1.

The X-ray attenuation measurements were performed for tube voltages between 40 kVp and 100 kVp at 128 mAs (filtration of 1.5 mm Al). X-ray beam was generated by a Shimadzu diagnostic digital radiography machine with a tungsten anode tube powered by a three-phase generator. The X-ray transmission measurements were carried out by a calibrated solid state dosimeter (R100B model, Barracuda, Germany). The transmitted X-ray beam intensity (I) was measured by placing the samples at the distance of 28cm from the detector. The experimental set up used for measurement of the X ray intensity after the shields is shown in figure 2. The relative X-ray transition (δ) was obtained using equation 1.

$$\delta = \frac{\left[\left(\frac{I}{I_0}\right)_{micro} - \left(\frac{I}{I_0}\right)_{nano}\right]}{\left[\left(\frac{I}{I_0}\right)_{nano}\right]} \times 100 \qquad (1)$$

The mass attenuation coefficient of the nano and micro-sized particles were then obtained from (I/I_0) values. The relative mass attenuation coefficient values were obtained using the following equation.

$$m = \frac{\left[\left(\frac{\mu}{\rho}\right)_{nano} - \left(\frac{\mu}{\rho}\right)_{micro}\right]}{\left[\left(\frac{\mu}{\rho}\right)_{micro}\right]} \times 100 \qquad (2)$$

RESULTS

The effect of the increase in weight fraction of nano and micro-sized WO3-PVC composite with thickness of 1±0.2 mm on relative X-ray transition (δ) for different X-ray tube voltages of 40, 50, 70, 80, and 100kv is shown in figure 3.

According to figure 3, there exists no observable difference in relative X-ray transition

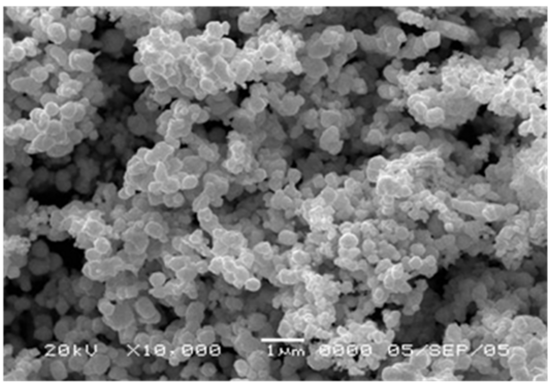

Figure 1. The SEM image of the nano-WO3 powder.

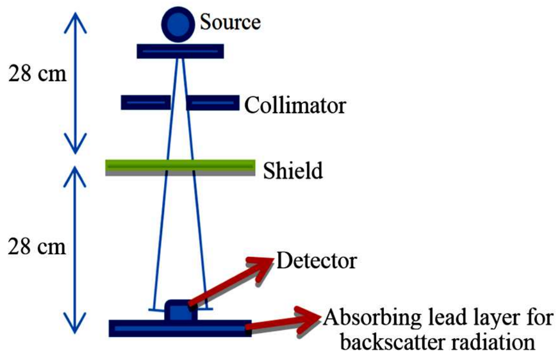

Figure 2. The experimental setup used for measurement of the radiation intensity transmitted through the samples.

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(δ) for 20% weight percentage of both nano and micro-sized WO3 incorporated to EPVC for voltages of 80 kv. For voltage of 100 kv, all samples showed the same behavior.

For 40, 50, and 70 kv, the X-ray transitions (δ) for samples with 50%, and 60% nano-sized WO_3 are at least 21% of the δ with micro-sized partcles.

The maximum relative X-ray transitions (δ) for samples with nano-sized WO3 relative to micro-sized WO3 were observed in 70 kv for 60% weight percentage of WO3. In voltage of 70 kvp, which is near the k edge of the tungsten, the average X-ray transition of the X-ray are more than other voltages, for all samples with 20% and 60% weight percentage, this is because of the fact that the X-ray attenuation increase in the energies equal to the k-edge of the elements. The total photon attenuation in shields decreases by increasing the photon energy. Therefore it can be concluded that the maximum differences in photon attenuation between Nano and micro-structured samples are observed for 40, 50, and 70 kvp. Such differences are more observed for samples containing 50 and 60% weight percentage of WO3.

Figure 4 compares the relative values of the mass attenuation coefficient (m) for voltages of 40, 50, 70, 80, and 100 kv for samples with all mass percentages. The figure indicates that the maximum increase in the mass attenuation coefficient is observed at 70kvp and for the samples with 60% mass percentage of WO3. The results show that the samples containing Nano-sized particles can attenuate the 70 kvp beam better than samples with micro-sized wo3, while for higher energy beams, i.e. 80 and 100 kvp, the rate of increase in mass attenuation coefficient decrease and thus the mass attenuation become almost similar.

The radiation dose measured after the samples are compared for different photon energies in figures 5 and 6. According to figure 5, for tube voltage (kVp) of 40 kV, the Nano-structured shields with 20, 50, and 60% weight percentage of WO_3, reduce the dose 12.15, 27.64, and 34.72% compared to micro-structured shields. Figure 6 indicates that for tube voltage of 100 Kv, the dose reductions due to Nano-shields with 20, 50, and 60% WO_3 content were found to be 0.79, 2.11, and 2.98%. The maximum dose reductions were found to be 41.27% at 70kVp for samples with 60% weight percentage of WO3. According to the figures, for low kVps, the samples containing Nano-particles can reduce the dose significantly more than the micro-structured samples, while for higher energies, i.e. 80 and 100kvp, no considerable difference is observed for Nano and micro-structured samples.

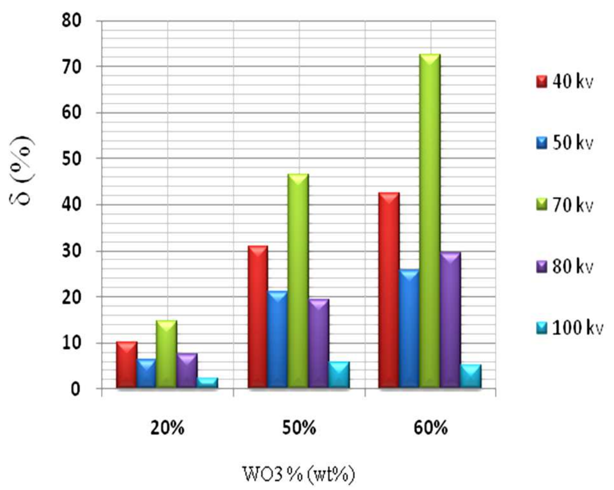

Figure 3. The percentage difference between the X-ray transmission of nano and micro-structured samples, (δ), as function of WO_3 weight percentage for different X-ray voltages.

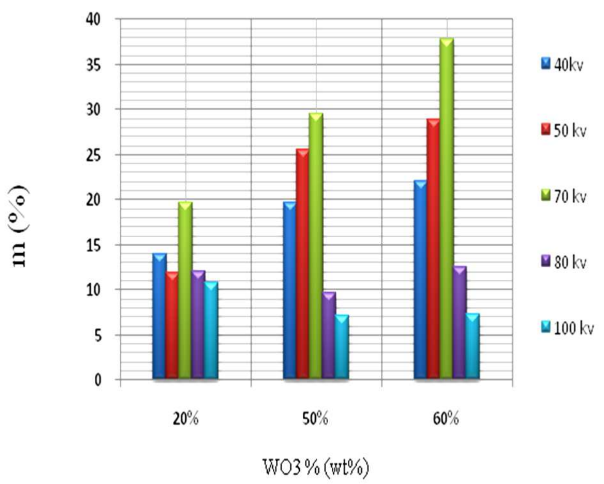

Figure 4. percentage difference between the mass attenuation coefficients (m/ρ) of nano and micro-structured samples, (m), as function of WO_3 weight percentage for different X-ray voltages.

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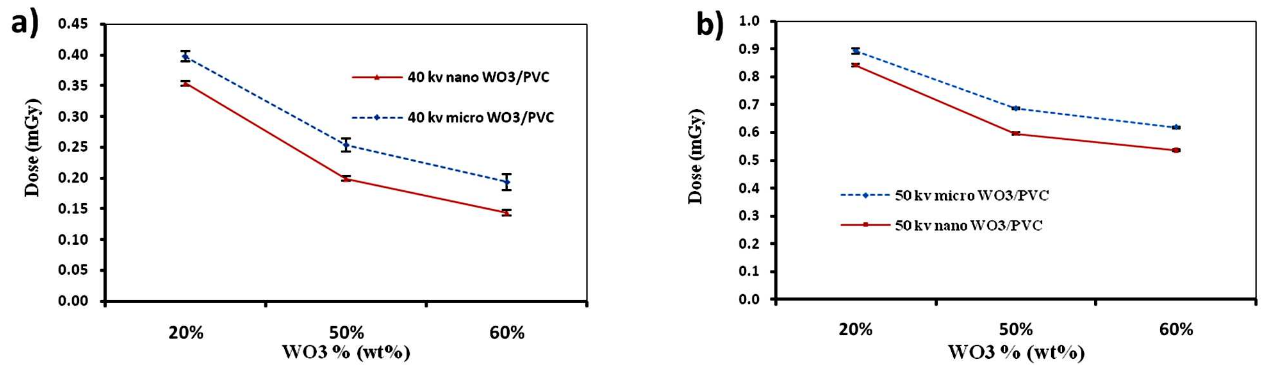

Figure 5. The dose measured after the micro and nano- structured shields with 1.1 cm thickness as a function of the weight percentage (wt %) of WO_3 for (a) 40 kV and (b) 50 Kv X-ray beam.

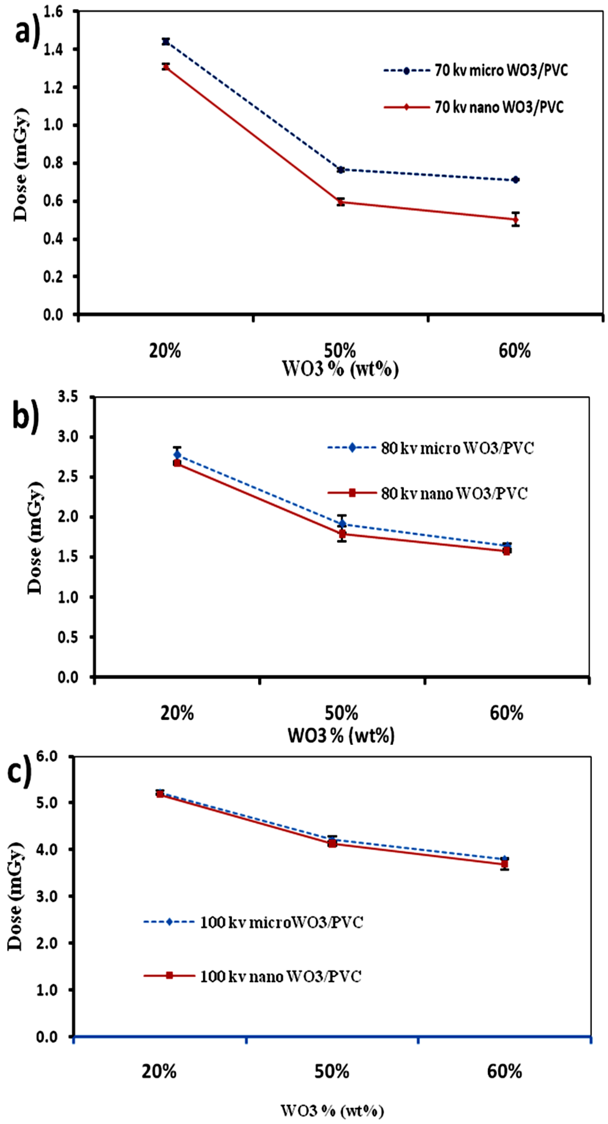

Figure 6. The dose measured after the micro and nano-structured shields with 1.1mm thickness as a function of the weight percentage (wt %) of WO_3 for (a) 70 kV (b) 80 Kv, and c) 100kV X-ray beam.

DISCUSSION

The X-ray beam attenuation by nanostructured and microstructured materials has been investigated inthis study. The results of this study show that the 80, and 100 kvp X-ray beams lead to an almost unchanged dose after passing through both nano and micro-structured samples. While, for beams with 40, 50 and 70 kVp, the values of the dose after Nano-structured samples are less than the dose after micro-structured samples for all concentrations. The results also indicate that the Nano-structured WO_3/PVC samples have greater absorption low energy X-ray photons compared to the samples produced with micro-structured WO_3/PVC.

According to the results the nanostructure-based shields can reduce the radiation dose significantly in comparison with the micro-structured ones with the same proporsion of WO_3/PVC. Because of the smaller sizes of the Nano particles, the crackle is blocked more efficiently. Light, non-lead, and safer shields for use in diagnostic radiology, can be constructed using suitable weight percentage of Nano-WO_3 powder.

Conflict of Interest: *Declared none.*

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