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X-ray spectroscopy applied to the study of the radiation transmission through nanomaterials

Espectroscopia de raios x aplicada ao estudo da transmissão de radiação através de nanomateriais

Roseli Künzel and Emico Okuno

Instituto de Física da Universidade de São Paulo (USP) – São Paulo (SP), Brazil.

Abstract

In this study, we compare the energy absorbed by nanostructured and microstructured materials as a function of the x-ray beam energy and material concentration. For this purpose, we used CuO microparticles, with a mean particle size of about 56 μm, and nanoparticles with size in the range 10 – 100 nm. These particles were separately incorporated into a polymeric resin in proportions of 5% and 30% relative to the resin mass. Plates with about 5x5 cm² in area and uniform thickness were produced for each material. The x-ray generator was a Philips, model MG 450, with a tungsten anode tube. Measurements were performed for beams generated at 25, 40 and 100 kV tube voltages. Data were registered with an Amptek XR-100T-CdTe detector. Results show that nanostructured materials absorb more radiation than the microstructured ones for both material concentrations in the resin. For example, for a 5% particle concentration and material thickness of (6.0±0.2) mm, the difference between air kerma values is about 16% for 25 kV, 8% for 40 kV and about 2% for 100 kV.

Keywords: nanoparticles, microparticles, oxides, x-rays.

Resumo

Neste trabalho, comparamos a absorção da radiação por materiais nanoestruturados e microestruturados em função da energia do feixe de radiação e da concentração de partículas na amostra. Com esse propósito, utilizamos micropartículas de CuO, com tamanho médio de partícula de aproximadamente 56 μm, e nanopartículas com tamanho na faixa de 10 – 100 nm. Essas partículas foram incorporadas separadamente a uma resina polimérica em proporções de 5% e 30% com relação à massa da resina. Para cada material foram produzidas placas com área de aproximadamente 5 x 5 cm² e espessura uniforme. Os feixes de raios X foram emitidos por um equipamento da marca Philips, modelo MG 450, dotado de um anodo de tungstênio. As medições foram realizadas para feixes gerados com diferença de potencial de 25, 40 e 100 kV. Os dados foram registrados com o detector XR-100T-CdTe da marca Amptek. Os resultados obtidos mostram que o material nanoestruturado absorve uma maior parcela da radiação quando comparado ao microestruturado para as duas concentrações de partículas de CuO na resina estudadas neste trabalho. Por exemplo, para o caso da concentração de 5% de partículas de CuO na resina, para uma amostra com espessura de (6,0±0,2) mm, a diferença entre os valores de kerma no ar é aproximadamente 16% para 25 kV, 8% para 40 kV e 2% para 100 kV.

Palavras-chaves: nanopartículas, micropartículas, óxidos, raios X.

Introduction

Nanomaterials are defined as those materials whose structural elements have dimensions from 1 to 100 nm[1]. The chemical and physical properties of many conventional materials can change for the same compound in the nanostructured form[1]. These materials can be lightweight, flexible and can also exhibit enhanced mechanical performance providing interesting possibilities for structural applications[1,2]. Currently, nanoparticles are widely investigated for several technological applications, including diseases diagnostics, tumor treatment procedures and design of lead-free radiation protection devices[3-5].

Traditionally, radiological protection of the operating personal under clinical interventional procedures is based on lead personal protective equipment (PPE). These lead protection devices are relatively heavy, and the toxicity of these materials is also an environmental issue[6]. In this way, new materials are being investigated in order to produce lead-free radiation protection devices[4,6-8]. The study of the properties of radiation absorption by nanomaterials could provide an alternative in order to replace lead garments for use in the clinical routine[4,6].

In this work, we compare the x-ray attenuation by nanostructured and microsctrutured materials. For this purpose, CuO particles, both with nanosize and microsize,

Corresponding author: Roseli Künzel – Instituto de Física da Universidade de São Paulo – Rua do Matão, Travessa R – CEP: 05508-090 – São Paulo (SP), Brasil – E-mail: roselikunzel@gmail.com

were separately incorporated in a polymeric resin in proportions of 5% and 30%. X-ray spectra were measured for beams generated at 25, 40 and 100 kV tube voltages.

Materials and methods

In this work, CuO nanoparticles with grain size in the range between 10 and 100 nm, produced by the Brazilian Industry Nanum, and CuO microparticles (Vetec Química Fina, Brazil) with 56 μm average particle size were incorporated, separately, to a polymeric resin in proportions of 5% and 30%, relative to the resin mass. Plates with about 5×5 cm^2 in area and uniform thickness were produced for each material. Plates with thickness (6.0±0.2) mm were produced with 5% CuO powder (nanosized and microsized) + 100% resin. In the case of 30% CuO powder + 100% resin, plates with (10.3±0.3) mm were produced for both nanosized and microsized materials.

The x-ray beams were emitted by a Philips equipment MG 450 model, connected to a constant potential generator. This tube has a 2.2 mm thick Be window with a fixed tungsten anode tube (22° anode angle). The radiation beams were registered by using a XR-100T-CdTe detector (Amptek, Inc., Bedford, MA) with 9 mm^2 nominal active area and 1 mm nominal thickness. Output pulses were processed by a digital pulse processor PX4 Amptek system. This equipment has a 100 μm Be window and is cooled by Peltier cells. A tungsten collimator with 1000 μm aperture and 2 mm thickness was used in front of the detector. The alignment between the focal spot and detector was carried out with a laser device. Figure 1 presents a schematic setup of the experimental arrangement used in the measurement of the transmitted radiation through the above described materials. X-ray beams were emitted at 25, 40 and 100 kV tube voltages. The energy calibration of the spectrometer was performed using the measured spectra of γ-rays and x-rays emitted by ^{241}Am, ^{133}Ba and ^{152}Eu radioactive sources.

Primary and transmitted x-ray spectra through the materials were corrected for all possible partial interactions of photons with the detector active layer[9].

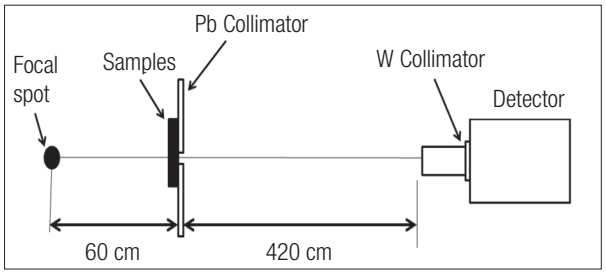

Figure 1. Illustration of the experimental setup used in the spectra measurements.

Results and discussion

Figure 2 presents the corrected primary x-ray spectra measured at 25 and 40 kV tube voltages; Figure 3, at 100 kV tube voltage. The primary x-ray spectra were measured using only the 4 mm Be filtration. The x-ray spectra measured at this condition shows the L and K characteristics of X-rays emitted by the tungsten anode.

Figures 4 to 6 compare the x-ray spectra absorbed by microstructured CuO and nanostructured CuO separately incorporated to a polymeric resin in a proportion of 5% relative to the resin mass. The thickness of the plates was 6.0 mm. According to these Figures, the nanostructured material absorbs more low energy photons when compared to the microstructured material. The air kerma value calculated at 25 kV, illustrated in Figure 4, is about 16% higher for the microsized material when compared with the nanosized one. Figure 5 also reveals a higher absorption by the nanosized material for low energy photons. The

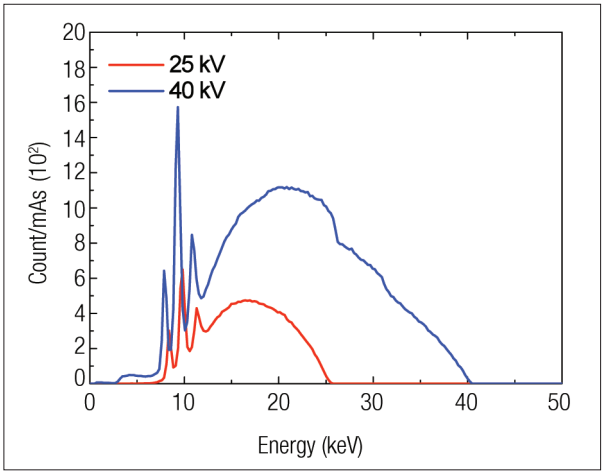

Figure 2. Primary x-ray spectra measured at 25 and 40 kV tube voltages.

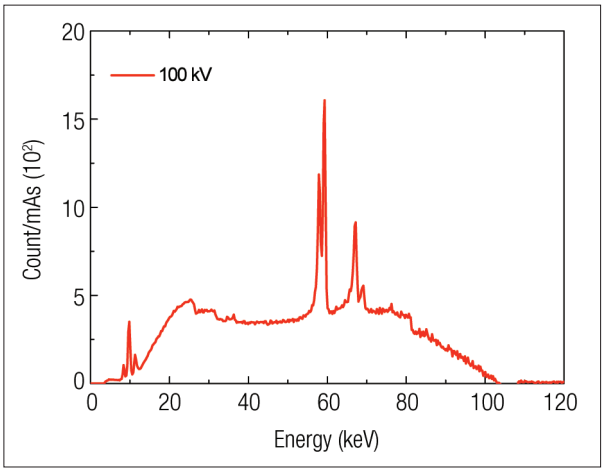

Figure 3. Primary x-ray spectra measured at 100 kV tube voltages.

difference in the air kerma value for the x-ray beam generated at 40 kV tube voltage is about 8%. On the other hand, the difference in the air kerma value for the x-ray beam generated at 100 kV tube voltages, illustrated in Figure 6, is only 2%.

Figure 7 compares the x-ray attenuation for samples produced with the separate incorporation of 30% CuO nanoparticles or microparticles in a polymeric resin. Both samples have (10.3±0.3) mm thickness. Results show that the nanostructured material absorbs about 5% more radiation than the microsctructured one.

The difference observed in the x-ray absorption by nanostructured and microstructured materials is attributed in the literature to the particle size effect[7]. As the particle size decreases, the number of particles increases. Considering the material used in this work, one microparticle is equivalent in scale to about 600 nanoparticles. Therefore, the distribution of the nanoparticles in the resin is different of that presented by the microparticles, resulting in a more uniform dispersion in the resin. This effect can be responsible for the higher absorption of the low energy x-ray photons by the nanostructured CuO material when compared to the same proportion of CuO material but with microsized particles.

Conclusion

In this work, we present results of the x-ray absorption by nanostructured and microstructured materials

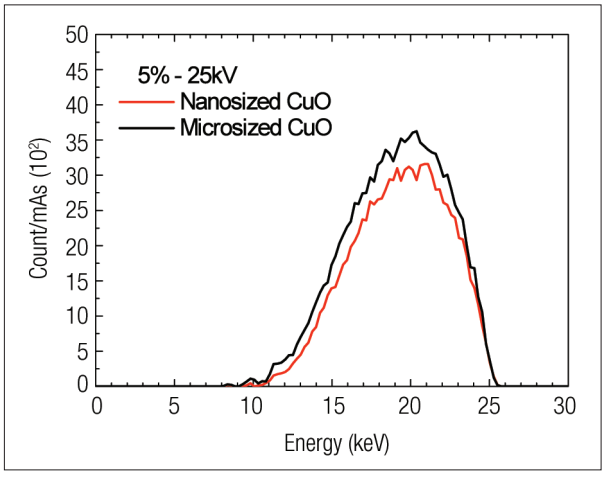

Figure 4. Comparison of a 25 kV x-ray spectra transmitted through 6.0 mm of a sample with 5% nanosized CuO+100% resin (red line) and 6.0 mm of 5% microsized CuO+100% resin (black line).

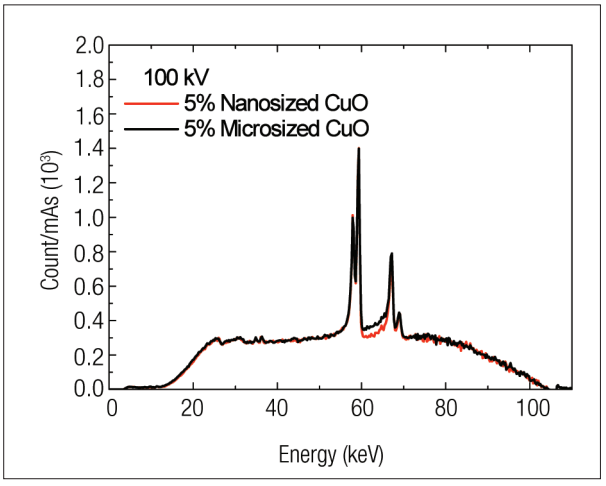

Figure 6. Comparison of a 100 kV x-ray spectra transmitted through 6.0 mm of a sample with 5% nanosized CuO+100% resin (red line) and 6.0 mm of 5% microsized CuO+100% resin (black line).

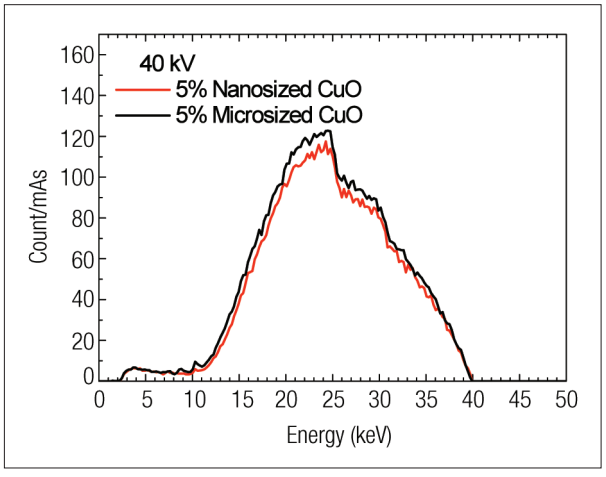

Figure 5. Comparison of a 40 kV x-ray spectra transmitted through 6.0 mm of a sample with 5% nanosized CuO+100% resin (red line) and 6.0 mm of 5% microsized CuO+100% resin (black line).

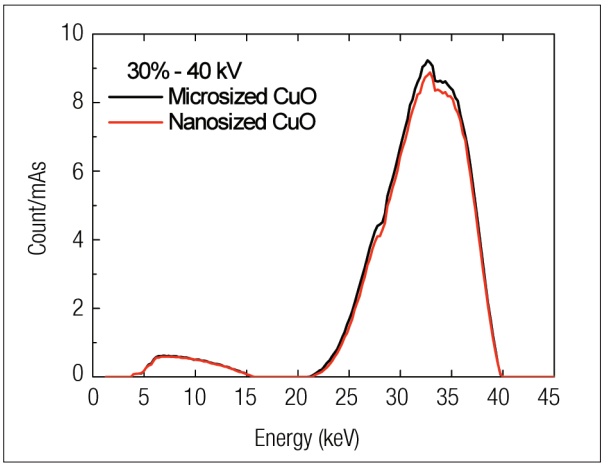

Figure 7. Comparison of a 40 kV x-ray spectra transmitted through 10.3 mm of a sample with 30% nanosized CuO+100% resin (red line) and 10.3 mm of 30% microsized CuO+100% resin (black line).

incorporating 5% and 30% of CuO powder to a polymeric resin. For the same material concentration, sample thickness and x-ray beam energy, the parameter that changes from the microstructured to the nanostructured sample is the particle size and consequently the quantity of particles. Results show that, for the materials concentrations studied in this work, the difference between the x-ray attenuation by nanostructured and microstructured materials is only evident for low energy x-ray beams. For the same material concentration and thickness, the radiation absorption is higher for the nanostructured material when compared with the microsctrutured one for low energy x-ray photons. On the other hand, for higher energy x-ray beams, namely those generated at 100 kV tube voltages, the influence of the particle size on the x-ray absorption is not evident.

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References

1. Poole Jr C, Owens FJ. Introduction to nanotechnology. New York: Wiley-Interscience; 2004.
2. Lines MG. Nanomaterials for practical functional uses. Journal of Alloys Compounds. 2008;449:242-5.
3. Cho SH, Jones BL, Krishnan S. The dosimetric feasibility of gold nanoparticle-aided radiation therapy (GNRT) via brachytherapy using low-energy gamma-/x-ray sources. Phys Med Biol. 2009;54(16):4889-905.
4. Haber FE, Froyer G. Transparent polymers embedding nanoparticles for x-rays attenuation. Journal of the University of Chemical Technology and Metallurgy. 2008;43(3): 283-90.
5. Hainfeld JF, Slatkin DN, Focella TM, Smilowitz HM. Gold nanoparticles: a new X-ray contrast agent. Br J Radiol. 2006;79(939):248-53.
6. Scuderi GJ, Brusovanik GV, Campbell DR, Henry RP, Kwon B, Vaccaro AR. Evaluation of non-lead-based protective radiological material in spinal surgery. Spine J. 2006;6(5):577-82.
7. Botelho MZ, Künzel R, Okuno E, Levenhagen RS, Basegio T, Bergmann CP. X-ray transmission through nanostructured and microstructured CuO materials. Appl Rad Isot. 2011;69(2):527-30.
8. Taylor EW. Organics, polymers and nanotechnology for radiation hardening and shielding applications. SPIE. 2007;6713(671307):1-10.
9. Künzel R, Herdade SB, Costa PR, Terini RA, Levenhagen RS. Ambient dose equivalent and effective dose from scattered x-ray spectra in mammography for Mo/Mo, Mo/Rh and W/Rh anode/filter combinations. Phys Med Biol. 2006;51(8):2077-91.