Novel paint design based on nanopowder to protection against X and gamma rays

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ABSTRACT

Background: Lead-based shields are the standard method of intraoperative radiation protection in the radiology and nuclear medicine department. Human lead toxicity is well documented. The lead used is heavy, lacks durability, is difficult to launder, and its disposal is associated with environmental hazards. The aim of this study was to design a lead free paint for protection against X and gamma rays. **Materials and Methods:** In this pilot st we evaluated several types of nano metal powder that seemed to have good absorption. The Monte Carlo code, MCNP4C, was used to model the attenuation of X-ray photons in paints with different designs. Experimental measurements were carried out to assess the attenuation properties of each paint design. **Results:** Among the different nano metal powder, nano tungsten trioxide and nano tin dioxide were the two most appropriate candidates for making paint in diagnostic photon energy range. Nano tungsten trioxide (15%) and nano tin dioxide (85%) provided the best protection in both simulation and experiments. After this step, attempts were made to produce appropriate nano tungsten trioxide-nano tin dioxide paints. The density of this nano tungsten trioxide-nano tin dioxide paint was 4.2 g/cm^3. The MCNP simulation and experimental measurements for HVL (Half-Value Layer) values of this shield at 100 kVp were 0.25 and 0.23 mm, respectively. **Conclusions:** The results showed the cost-effective lead-free paint can be a great power in absorbing the X-rays and gamma rays and it can be used instead of lead.

Keywords: Lead-free shields, new radiation shields, nano metal powder, nanopowder, radiation protection, X and gamma rays

INTRODUCTION

Lead shields are used in medical facilities to protect the workers and patients from unnecessary radiation exposure from diagnostic radiology procedures.[1-3] Lead and some of its alloys are generally the most cost-effective shielding materials to protect against the effects of gamma and X-rays. The properties of lead that make it an excellent shielding material are its density, high atomic number, level of stability, ease of fabrication, high degree of flexibility in application, and availability.[4] Unfortunately, lead may present an insidious health hazard to pediatric patients because of the lead dust that is readily removed from the surface of lead objects in the Nuclear Medicine and Radiological departments. Although the density of lead dust is high, it may still become airborne, contaminate floors and other nearby work surfaces, and be inadvertently inhaled or ingested.[5]

The adverse health effects of lead exposure in children and adults are well documented.[6-10] There are also reports on the need for corrective measures due to corrosion of lead sheets when lead is used for structural shielding.[11] Based on the above mentioned facts, production of environmentally friendly non-toxic lead-free radiation shields which provide less weight compared to conventional lead-based shields remains a challenging issue in radiation protection.[12] The use of lead free shields has been associated with some unexpected problems such as being efficient only at a limited tube-voltage range.[13,14] Efforts have been made

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globally for finding new materials and designs for production of lead-free radiation shields.[15,16]

According to the above reports there are environmental issues with its disposal secondary to its known toxicity. In this study, we designed a new non-lead paint based on nano metal powder. The purpose of this pilot study is to construct a paint that can be applied everywhere and with such as non-toxic, light weight and high absorbency properties.

MATERIALS AND METHODS

This pilot study had two phases. In the first phase, we studied a wide variety of nano metal compounds which potentially could be appropriate radiation shields against X and gamma ray. MCNP4c (Monte Carlo N-Particle Transport Code System) was used to model the attenuation of X-ray photons in paints with different percentages of nano-materials and varied designs.[17] Photon absorption rates was simulated with MCNP4C CODE of Monte Carlo software and tally F_4 and F_5. The experimental set-up used in our simulation was based on the RAD 60 X-ray tube (Varian medical Systems, CA) material composition and target dimensions. We used the point detector tally measure of photon flux at a point (unit is photons/cm^2 or MeV/cm^2), which is normalized to be per starting particle. The X-ray beam is produced as electrons slowdown in the anode; encounter some attenuation in the anode material depending on the anode angle and the beam direction. The tube voltage was considered 100 kVp. The 6.5×10^8 photon was transported in each program running and transported X-ray from the layers was obtained. Their curves were provided with SPSS v. 19 software. Area under the curve was indicated to the intensity of transported X-ray and the best composition was selected by comparing these curves.

In the next step, different nano metal powders were dispersed in epoxy paints to assess their attenuation properties. In this regard, the attenuation of poly-energetic X-rays emitted by a diagnostic CPI (CMP200 with Varian tube) X-ray machine was measured under good geometry conditions. Dose rates were measured using a Farmer type ion chamber (Wellhöfer, Model FC65-G, made in USA. Ngas/(NxAIon) (cGy/R): 0.854, Sensitive volume: 0.65 cm^3, Sensitivity (nom.): 0.21 nC/cGy) and a Wellhöfer DOSE-1 electrometer [Figures 1 and 2].

RESULTS

In this study, we found nano tungsten trioxide and nano tin dioxide were two most appropriate candidates for radiation shielding and they were selected in order to produce the absorber paint. A mixture of nano tungsten trioxide (15%) and nano tin dioxide (85%) provided the best protection in both simulation and experiments. Radiation intensity after passing through various layers of paint is shown in Table 1 using MCNP modeling. The highest attenuation was obtained in combination of two non-lead metals (15% nano tungsten trioxide and 85% nano tin dioxide). The attenuation of lead shields was much lower than that of the non-lead paint layer. The densities of nano lead and nano tungsten trioxide-nano tin dioxide paints were 4.79 and 4.16 g/cm^3, respectively. HVL values were measured by passing radiation through a layer of 2 mm thickness of nano tungsten trioxide (15%) and nano tin dioxide (85%) powder in epoxy paint matrix [Table 2]. HVL measurement was done based on beer lambert law. HVL values were measured by passing the radiation through a layer of 2 mm thickness of nano lead powder in grease matrix which is presented in Table 3.

In the next stage, attempts were made to produce appropriate nano tungsten trioxide-nano tin dioxide epoxy paints which could be used for preparation of shielding garments. The density of this nano tungsten trioxide-nano tin dioxide paint was 4.2 g/cm^3. The MCNP simulation value for HVL of this shield was 0.28 mm at 100 kVp. On the other hand, narrow beam absorption measurements indicated a HVL of 0.23 mm.

DISCUSSION

As the results showed a combination of the nano tungsten trioxide (15%) and nano tin dioxide (85%) provided the best radiation shielding property in both simulation and experiments. This experiment guides to the manufacturing of the appropriate epoxy paint as the matrix and different nano metal powders as the absorbent elements. There are many rich mines of tin and tungsten in Iran, the production cost of this paint is economic. The cost-effective lead-free paint produced in this study with features such as non-toxic, resistant to erosion, lightweight and

Figure 1: Farmer type ion chamber (Wellhöfer, Model FC65-G)

Figure 2: The Wellhöfer DOSE-1 electrometer used in study

Table 1: MCNP results of radiation intensity after passing from shields with different compositions

100 kVp	I	I0	I/I0	% metals	% metals in epoxy paint	Density (g/cm³)
1	4.47×10^{-07}	7.71×10^{-06}	0.058	15 Nano WO_3, 85 Nano SnO_2	13.02 Nano WO_3 73.78 Nano SnO_2	4.16
2	5.31×10^{-07}	7.71×10^{-06}	0.069	100 WO_3	86.8 Nano WO_3	5.64
3	5.62×10^{-07}	7.71×10^{-06}	0.074	35 Nano $WO_{3,}$ 65 Nano SnO_2	30.38 Nano $WO_3$56.42 Nano SnO_2	4.41
4	5.39×10^{-07}	7.71×10^{-06}	0.071	28.5 Nano WO_3, 71.5 Nano SnO_2	24.74 Nano WO_3 62.06 Nano SnO_2	4.34
5	6.01×10^{-07}	7.71×10^{-06}	0.073	25 Nano WO_3, 75 Nano SnO_2	21.7 Nano $WO_3$65.1 Nano SnO_2	4.29
6	6.86×10^{-07}	7.71×10^{-06}	0.076	100 Nano SnO_2	86.8 Nano SnO_2	3.77
7	7.24×10^{-07}	7.71×10^{-06}	0.090	100 Nano Pb	86.8 Nano Pb	4.79

MNCP: Monte carlo N-particle

Table 2: The HVL determination by measuring the radiation intensity after passing a layer of 2 mm thickness of nano epoxy paint

2 mm 39.6% nano WO_3, 47.74% nano SnO_2, 13.2% epoxy paint			
100 kVp	I	I0	I/I0
1	0.012	2.47	0.005
2	0.009	2.47	0.004
3	0.014	2.47	0.006
4	0.019	2.47	0.008
5	0.017	2.47	0.007
6	0.014	2.47	0.006
7	0.009	2.47	0.004
8	0.017	2.47	0.007
9	0.019	2.47	0.008
Average	0.014444	2.47	0.006111

HVL: Half-value layer

Table 3: The HVL determination by measuring the radiation intensity after passing a layer of 2 mm thickness of lead powder in the grease matrix

2 mm 86.8% nano Pb, 13.2% grease			
100 kVp	I	I0	I/I0
1	0.039	2.44	0.016
2	0.043	2.44	0.018
3	0.036	2.44	0.015
4	0.039	2.44	0.016
5	0.041	2.44	0.017
6	0.036	2.44	0.015
7	0.031	2.44	0.013
8	0.041	2.44	0.017
9	0.036	2.44	0.015
Average	0.038	2.44	0.01577

HVL: Half-value laye

with widely applicable on the equipment and walls radiology and nuclear medicine sections, offers effective radiation protection in a diagnostic energy range. Due to its main properties such as low density, high atomic number, level of stability, ease of fabrication, high degree of flexibility in application, and availability, lead has been introduced as a popular radiation shield. However, lead contamination at superfund sites presents a threat to human health and the environment and according to US Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), lead is the second substance of the top 20 hazardous substances list. This pilot study helps scientists to substitute nano materials for radiation protection against X and gamma radiation in Nuclear and Radiological department.

CONCLUSION

The layers made of nano tungsten trioxide (15%) and nano tin dioxide (85%) in an epoxy paint matrix could be considered as a non-toxic, resistant to erosion, lightweight and with widely applicable on the equipment and walls substitute for conventional lead shields.

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The new designed paint has been registered in the Iranian Intellectual Properties and Technology Institute as an invention (reference No. 79340).

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