Design of a Novel Shield of Nuclear Medicine with New Alloy

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Abstract

Background: protecting patients and healthcare workers from harmful ionizing radiation, has been an important concern. Due to high efficacy, for many years lead has been used as the best choice for this purpose. Lead has been always considered as a traditional choice to protect both workers and patients from any unnecessary exposure to ionizing radiation. Recently there has been a great deal of concern expressed about the toxicity of lead. The aim of this study was to design a novel shield of nuclear medicine with different alloy as a desire replacement for traditional lead base protectors.

Methods: A combination of Cadmium, Bismuth, Lead (only 15%) and Copper were selected by studying of metals and calculation of metals' HVL by Monte Carlo N-Particle Transport Code (MCNP4C) modeling.

Results: The results of the tests were evaluated and determined that the designed shield reduces considerably the received dose by a thousand times and this alloy with 2mm thickness is equivalent with 20mm traditional lead shield.

Conclusion: This novel shield with a much less lead produced in this study is considerably safer and offer effective protection in diagnostic energy ranges and may replace the traditional lead-based protectors.

Key Words: ionizing radiation, lead-base protectors, cadmium, bismuth

Introduction

Exposure limits in recent years have changed by learning more about the biological effects of ionizing radiation and alterations in social attitude which advised to limit radiation exposure. The concept of tolerable dose was considered in the 1930s; the dose that radiation worker could be continuously exposed to without showing acute lethal effects such as skin erythema. In the early 1950s, the emphasis was on long-term effects. Maximum radiation from allowable dose was defined in order to minimize the risk and became acceptable on average for a person(1).

As usage of radioactive materials spread, providing a portable effective shield for protection of operating personnel became vital. Gamma rays is emitted in all sides and due to great powers of penetration, high energy gamma radiation will not be completely blocked by shields, while lower energy levels can be safely blocked (2). The most hazardous radiations are gamma rays, x-rays, and neutron particles. If a shield can be effective toward these types of radiation, there would be a negligible hazard from other types. An effective shield should induce sufficient attenuation of the radiation intensity caused by a particular installation to a tolerable level. Lead density, high atomic number, high level of stability, ease of fabrication, high degree of flexibility in application, and its availability has rendered lead an excellent shielding material. High levels of ionizing radiations from radioactive substances are dangerous for living organisms, including human kind. The first people that worked with X-rays and radioactive substances clearly observed that these substances can cause burns or scarring and there is a possibility of chromosomal mutation and subsequent cancer even at low levels (3). In some cases, the easiest way to reduce the amount of radiation exposure to people who are working in this field is putting a shield between the source of radiation and individual. Lead has always be considered as a traditional choice for the radiological protection. It has long been used in radiology departments to protect both workers and patients from any unnecessary exposure to ionizing radiation (4-6). Recently a great concern about the toxicity of lead has been expressed and the need of transition from flexible lead protectors to environmentally friendly nontoxic lead-free shields has been proposed by many scientists (7-10). Recently, Mortazavi and colleagues were able to build a lead-free protective shield; Tapron which mainly practical in diagnostic radiology (11). The aim of this study was to produce a novel lighter shield with lesser lead and better protection effects.

Materials and Methods

Energy threshold must be controlled and managed was obtained by calculating the maximum energy emitted from the vials, syringes and radioactive waste in nuclear medicine and immunology sectors. Energy threshold in ideal conditions was between 1 to 1000 mCi which is relatively at high dose range. An alloy (2 mm thickness) of Cadmium (40%), Bismuth (40%), Lead (15%) and Copper (5%) wired with Nichrome (1 mm thickness) (an alloy of nickel and chromium) were selected by studying of metals. Calculation of the amount of protection to reduce the dose and metals' HVL (Half Value Layer) were done by Monte Carlo N-Particle Transport Code (MCNP4C) modeling. Then between the two layers of alloy, a carbon based polymeric layer (4 mm thickness) of the mentioned heavy metals was placed (combination of used metals in the context of a carbon polymer material that increases protection several times). Dimensions and exact location of the source were simulated based on the actual size. The number of studied particles in the simulation was considered 80 million in order to reduce the statistical error. Source energy was defined as 662 KeV in the input file and F1 Tali was used in order to calculate the integral of the intensity based on the studied surface. Desired Tali was calculated at a distance of 1 meter from the shield with the assumption that no one would be closer to the shield for a long time. Moreover, program was calculated once again in case there is not any protection against mentioned source. To compare and illustrate the impact of shield, the output was measured at a distance of 1 meter.

Results

In the screening step of the study, Cadmium (40%), Bismuth (40%), Lead (15%) and Copper (5%) found to be the most appropriate compound for radiation shielding in a diagnostic gamma energy range. This alloy was considered with 2 mm thickness. Geometry of the desired system was plotted by MCNP4C modeling. Radiation intensities after passing from shield using MCNP modeling was $5.172\times10^{-4}\pm0.0049$ while without shield was $4.860\times10^{-1}\pm0.0001$ as seen the shield reduces the received dose by a thousand times (Table 1). This alloy with 2mm thickness is equivalent with 20mm traditional lead shield.

Table 1: MCNP4C results of radiation intensity without shield and after passing shield.

Used geometry	**Radiation intensity ± Error**
Without shield	$4.860\times10^{-1} \pm 0.0001$
With shield	$5.172\times10^{-4} \pm 0.0049$

Discussion

When there is a risk of exposure with harmful amounts of radionuclide, personal protective equipment (PPE) should be worn. The type of PPE depends on the quantity, type, and nature of the radiation and health care facility design. As we try to increase the protection level of shields, the inevitable result is weight increase and flexibility reduction which leads to inability to use shielded attire. Because of the penetrating ability of the radiation used in nuclear medicine, shielding is necessary. The most important role of a protecting shield is preventing rays penetration. Density of shield material has the most important role in preventing penetration of rays. Currently, the densest available substance is lead. Lead and some of its alloys are generally the most cost-effective shielding materials to protect against the effects of γ- 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. Hence, generally lead products show smooth surfaces that lead to contamination risk reduction and therefore, less radioactive hazard (12). In portable shielding systems that low weight and volume are two important factors, selection of lighter materials may adversely affect the protective property of the shield. Recently there has been a great concern expressed about the toxicity of lead and human lead toxicity is well documented (13-15). Lead is a systemic toxicant with no known beneficial biological function and, for several endpoints, no identified threshold of toxicity. The fetus, children, pregnant and elderly are particularly susceptible to some of the toxic effects of Pb (16). Owing to this reality, there is a necessity for transition from conventional lead protectors to environmentally friendly non-toxic lead-free shields.

In this study a specific combination of Cadmium (40%), Bismuth (40%), Lead (15%) and Copper (5%) wired with Nichrome as a novel alloy with a slight amount of lead compared to the traditional lead-based protectors introduced as a possible suitable replacement. Moreover, the carbon based polymeric layer of Cadmium, Bismuth and Lead that is placed in the middle of the two layers of mentioned alloy increases protection several times. It should be noted that the presence of copper in the alloy increases its protection to some extent. In addition, the extra weight of lead aprons results in low back pain and neck pain among radiologists and cardiologists in the long term. Likewise, Lead based protectors, protective shields for radioiodine vials in particular, are very heavy and long-term moving of them results in plenty of adverse physical effects. However, the designed nuclear medicine shield in this study is significantly lighter in comparison with lead based shields as a result of less lead usage and considerable thinner thickness. Compared with lead based protectors, the present new shield is so flexible that can be easily customized into arbitrary shapes. Moreover, this new alloy is environmentally friendly and can be recycled conveniently. Therefore, the designed shield can be considered as an elastic, resistant to erosion, environmentally friendly, lightweight substitute for conventional lead shields.

Conclusion:

This novel shield with a much less lead produced in this study is considerably safer and offer effective protection in diagnostic energy ranges and may replace the traditional lead-based protectors.

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Conflict of Interest: The authors report no conflict of interest.

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