

An Investigation to Determine an Optimum Protective Garment Material in Nuclear Medicine

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ABSTRACT

Aim: The aim of this study is to find an optimum material to protect garment for protection against ⁹⁹Tc^m radionuclide.

Materials and Methods: Monte Carlo simulation code was applied to investigate radiation attenuation of 13 shielding materials including: Ba, gray Sn, white Sn, Sb, Bi, Bi₂O₃, BaSO₄, Sn/W, Sb/W, Pb and W with thicknesses of 0.5 and 1 mm to determine an optimum protective garment material in nuclear medicine against ⁹⁹Tc^m. Furthermore, the dose enhancement on the staff body was investigated for shielding materials such as tungsten and lead.

Results: The findings of the simulations show that the maximum and minimum attenuation obtained with thicknesses of 1 mm W and 1 mm BaSO₄ were 96.46% and 14.2%, respectively. The results also demonstrate that tungsten does not cause any dose enhancement on staff body but this is not true for lead. Tungsten provides the highest radiation attenuation without dose enhancement on the body of staff.

Conclusion: Among materials evaluated, tungsten is the optimum material and it can be applied for the design of protective garment for nuclear medicine staff against ⁹⁹Tc^m.

Keywords

Nuclear Medicine, Monte Carlo Simulation, ⁹⁹Tc^m, Protective Garment

Introduction

Diagnosis and treatment in nuclear medicine are based on the use of various radionuclides [1]. Gamma emitters have the most application among radionuclides in nuclear medicine [2-3]. Concerns have raised over protection against gamma radiation. As soon as a radionuclide is administered to a patient, the patient will be converted to a dangerous source of ionizing radiation for everyone, particularly for nuclear medicine staff [4].

Studies have revealed that the highest dose related to cancers and genetic effects has been received by nuclear medicine staff [5]. The staff need to reduce their exposure by increasing their distance from the radiation source and using of lead aprons. The use of lead aprons is certainly selective because it does not yield the same protective effect for various radionuclides [6]. However, it seems that the use of lead aprons is the major step in the implementation of As LowAs Reasonably Achievable

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(ALARA) policy. According to ALARA, all protective actions should be applied to reduce radiation exposure [7]. Protective garments are applied to reduce the exposure of nuclear medicine staff. Currently, protective garments with lead equivalence thicknesses of 0.25 to 0.5 mm are available [5, 8-9].

There are different ideas about application of lead aprons in nuclear medicine. Deb et al. [10] stated that a lead apron with lead thickness of 0.5 mm did not reduce dose against $^{99}\text{Tc}^{\text{m}}$ source significantly [10]. Twaite et al. [11] advised that the use of lead aprons is useful in high dose radiation in nuclear medicine [8, 11]. The topic that causes much concern for nuclear medicine staff is that they wear lead aprons designed for the protection against x-ray due to different energies of x-rays and gamma-rays; it is not likely to provide considerable protection against gamma-rays in nuclear medicine with available lead protective garments [8]. In fact, the photoelectric effect is the dominant interaction in the application of lead aprons in radiology against low energy x-rays (with maximum spectrum of 150 keV and average energy of 50 keV), while for gamma radiation in nuclear medicine, their energies and even their interactions with materials are different and Compton effect is predominant with relatively high energy sources.

Young [6] stated that the efficiency of lead aprons with lead equivalent thickness of 0.5 mm was less than 65% for $^{99}\text{Tc}^{\text{m}}$ [6]. It is not effective because nuclear medicine staff are exposed continuously by radioactive patients and sources; there is a stochastic probability for carcinogenic and genetic effects of radiation. Additionally, studies showed that a material with high atomic number leads to dose enhancement at tissue in the vicinity of the irradiated tissue of body [8, 12-13].

Despite widespread use of radiopharmaceuticals, there are few advances regarding staff radiation protection. Few studies have been carried out to investigate non-lead shields

against the radiation emitted by radionuclides used in nuclear medicine. Among various radionuclides, this study is performed for $^{99}\text{Tc}^{\text{m}}$ radioactive source. $^{99}\text{Tc}^{\text{m}}$ is commonly used in nuclear medicine examinations, being utilized in over 80% of nuclear medicine procedures [14]. Its half-life is 6.02 hours and decays via beta decay (with 2% probability) or internal conversion (with 98% probability). The primary gamma emission is a 140 keV photon [15].

This study aims to introduce a number of non-lead materials for shielding of nuclear medicine staff against $^{99}\text{Tc}^{\text{m}}$ to provide a material with higher attenuation and without dose enhancement in body.

Materials and Methods

In this study, MCNPX Monte Carlo code (version 2.4.0) was applied to simulate the interactions of photons and matter. A simulation program should be validated before its application. To validate simulation, a lead shield with thickness of 0.5 mm was simulated and then the results of the simulations were compared with the results of experimental dosimetry for the lead shield with the same set-up. The criterion for acceptability of a simulation is type-A uncertainty in the statistical simulation calculations which should be less than 5%, that is defined permissibly in the MCNP manual [16]. Moreover, the acceptable criterion to validate the simulation is considered less than 5%, based on the percentage difference between the results of two methods of simulation and dosimetry.

After validation, the simulation with phantom was carried out and percentage attenuation was obtained for non-lead shielding materials and lead including: Ba, gray Sn, white Sn, Sb, Bi, Bi_2O_3 , BaSO_4 , Sn/W, Sb/W, Pb and W with thicknesses of 0.5 and 1 mm against gamma-rays of 140 keV emitted by $^{99}\text{Tc}^{\text{m}}$ source. Furthermore, simulation without phantom was carried out for lead and shields that pro-

vide more attenuation than lead does. Then, simulation for the cases of with and without phantom were compared for these shields and lead to investigate dose enhancement on the body of staff who wear these shields. It can be realized which a shield causes dose enhancement in the vicinity of body inappropriately. Furthermore, the acceptable criterion for the simulation was an uncertainty of less than 5% that is based on MCNPX manual [16].

Validation of MCNP Simulation

MCNP Monte Carlo code (version 2.4.0) was applied to simulate the interactions of photons with matter. A $^{99}\text{Tc}^m$ source emitting 140 keV photon was simulated in a spherical shape with 0.2 mm radius. An air dosimeter was simulated in the form of a cylinder with 1 cm radius and 1 cm height at 50 cm distance from the $^{99}\text{Tc}^m$ source. An environment of air was considered around the source and dosimeter.

In the simulation, an air cell with dimensions of $50 \times 30 \times 0.05 \text{ cm}^3$ was simulated [8]. In another simulation to simulate the lead shield with thickness of 0.5 mm, the material cell was defined as lead instead of air with the same thickness of 0.05 cm, other dimensions were optional (Figure 1). F6 tally was used to calculate the energy deposited per unit mass (MeV/g). The number of photons transported was 109 in each simulation. The energy cut-off for electrons and photons was 10 keV. The simulations were performed by a server computer with a 1.7 GHz Intel mobile processor having 7 cores and 16.00 GB Random Access Memory (RAM). The results of the simulations were obtained in terms of deposited dose inside the dosimeter. Afterwards, the percentage attenuation was calculated through the following equation:

$$\text{Attenuation (\%)} = 100 \times (1 - I/I_0) \quad (1)$$

where I and I_0 are deposited doses in the dosimeter with and without lead shielding, respectively.

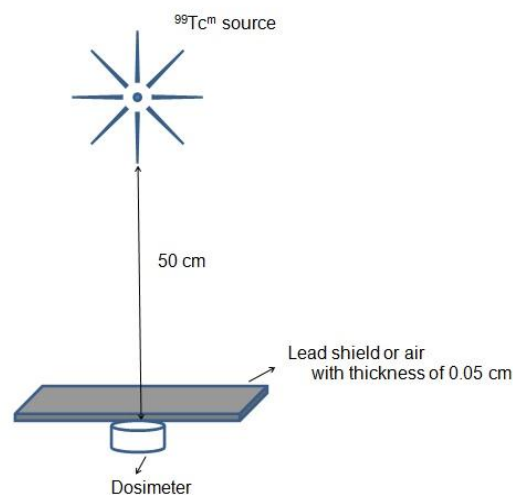


Figure 1: Set-up used in the simulation method. This figure is schematic and is not to a real scale

In the dosimetric set-up, a calibrated model of Gamma Scout peripheral dosimeter (made in Germany) capable to measure over 0.01-1000 $\mu\text{Sv/h}$ range, was applied to measure the dose rate beyond the lead apron. The dosimeter was calibrated by Karaj Secondary Standards Dosimetry Laboratory (SSDL) in Iran. In the dosimetric set-up, a plastic syringe containing 1 mCi of $^{99}\text{Tc}^m$ hung from a stand was considered as a source. Its activity was measured by a dose calibrator (Initial Calibrated Blank (ICB) model; Alfa Aesar company, Avocado, Lancaster, the United States). The dosimeter was positioned at 50 cm distance from the source in the horizontal direction and the reading of the dosimeter was recorded. Then, a lead shield with lead equivalent thickness of 0.5 mm was hung from a stand while the dosimeter was positioned to stick behind the lead shield at the same distance of 50 cm away from the source (Figure 2). Later, the reading of the stand dosimeter was recorded. The dosimetry was repeated three times and each reading was recorded for 20 seconds in the nuclear medicine Department of Imam Reza Hospital in Kermanshah, Iran. In general, staff

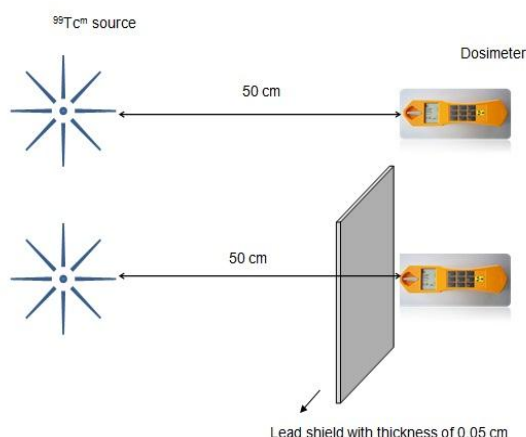


Figure 2: Set-up used in dosimetry method. This figure is schematic and is not to a real scale.

spend about 120 seconds near a $^{99}\text{Tc}^m$ source at a distance of 50 cm. Then, their averages were considered as the reading of the dosimeter. The percentage attenuation was calculated through equation (1), the difference in this case is that I and I_0 herein are dosimeter reading per unit time ($\mu\text{Sv/h}$) with and without lead shielding, respectively.

Furthermore, the percentage attenuation obtained from the dosimetry was compared with the attenuation from the simulation. The criterion for acceptability of simulation is type A uncertainty of less than 5%, based on MCNPX manual [16]. Additionally, the acceptable criterion to validate the simulation is considered as a discrepancy of less than 5%, based on the percentage difference between the results of two methods of simulation and dosimetry.

After validation of the simulation, original simulations were carried out based on the following steps:

The original simulations contain two geometries: the simulation with phantom and without it. In fact, the objective of this study is to investigate attenuation of non-lead and lead shields with thicknesses of 0.5 and 1 mm against $^{99}\text{Tc}^m$ source. Then, dose enhance-

ment of body of staff who wore these non-lead shields were compared with lead shields. Finally, the optimum non-lead material was introduced to protect staff against $^{99}\text{Tc}^m$.

Simulation with Phantom

In this step of the present study, MCNPX Monte Carlo code (version 2.4.0) was applied to simulate the deposited dose at different depths of a water phantom in a situation where each shield was placed on the phantom separately. A $^{99}\text{Tc}^m$ source emitting 140 keV photon was simulated in a spherical shape with 0.2 mm radius. A water phantom with dimensions of $50 \times 30 \times 20 \text{ cm}^3$ was simulated as an adult torso (Figure 3).

The phantom containing water was simulated, because water can be tissue equivalent and its simulation is easy. Furthermore, different materials were simulated as shields, including: Ba, gray Sn, white Sn, Sb, Bi, Bi_2O_3 , BaSO_4 , Sn/W, Sb/W, Pb and W with thicknesses of 0.5 and 1 mm. $^{99}\text{Tc}^m$ source was considered at a distance of 50 cm from the upper surface of the phantom. The simulations were performed by a server computer with a 7-core 1.7 GHz

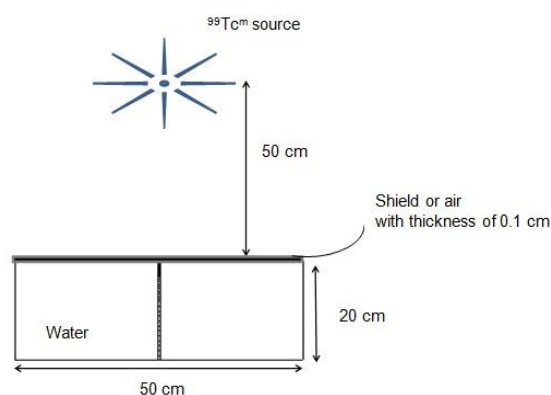


Figure 3: Set-up used in the with phantom case. In the simulation with phantom, the upper part on the phantom surface, shown in black color, is either air or the shield. This figure is schematic and is not to a real scale.

Intel mobile processor and 16.00 GB RAM. A set of various voxel sizes was considered in the phantom depth on the central radiation axis in Z direction in order to achieve the deposited dose values in different depths of the phantom with and without shields. The size of the first voxel in the water phantom under the shield was $0.5 \times 0.5 \times 0.01 \text{ cm}^3$. The selection of the voxel sizes was based on such a fact that they were changed in water phantom to provide high spatial resolution where the likelihood of dose enhancement exists. The reason to choose different voxel sizes was that small voxel sizes presented high spatial resolution, and larger voxel sizes gave low statistical uncertainty. The voxel sizes which were utilized are listed in Table 1. F6 tally was used to calculate the energy deposited per unit mass (MeV/g). The number of photons simulated was 10^9 in each simulation. The energy cut-off for both electrons and photons was 10 keV. The time needed to run each simulation program by the server computer was 240 hours. Dose changes versus depth of phantom in the cases of with and without shields were plotted by Microsoft Excel 2007 software. The percentage attenuation of the shields was calculated through the equation (1); the difference is that here I and I_0 represent deposited dose in the first voxel of the phantom with and without the shield, respectively.

Table 1: Voxel dimensions on the central radiation axis in Z direction (phantom depth).

Number of voxels	Thickness of voxels (cm)
6	0.01
10	0.1
10	0.2
10	0.5
11	1.0
1	0.94

Presenting deposited doses at different depths of staff body was a good reason to choose this geometry for calculations, particularly skin, when staff wear these shields, they are exposed to $^{99}\text{Tc}^m$. To show the deposited dose in units of Gy, the deposited energy in the body of staff in terms of MeV/g was converted to absorbed dose by the application of unit conversion factors and the activity of $^{99}\text{Tc}^m$ source.

Simulation without Phantom

This set-up of simulation was similar to the phantom, but an air dosimeter was simulated instead of a water phantom (Figure 4). MCNPX Monte Carlo code (version 2.4.0) was applied to simulate the interactions of photons and matter. A $^{99}\text{Tc}^m$ source emitting 140 keV photon was simulated in a spherical shape with 0.2 mm radius. An air dosimeter was simulated in the form of a cylinder with 1 cm radius and 1 cm height at 50 cm distance from the $^{99}\text{Tc}^m$ source. In this simulation, an air cell with dimensions of $50 \times 30 \times 0.05 \text{ cm}^3$ was

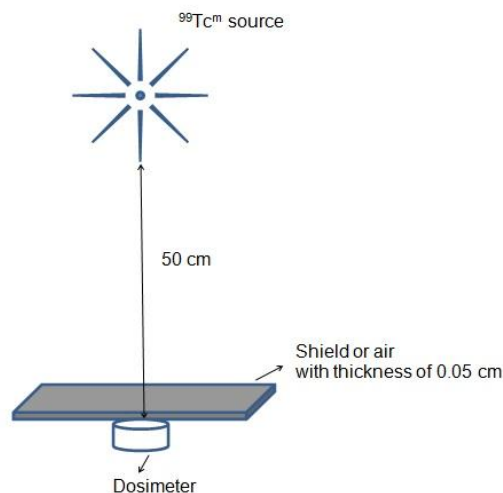


Figure 4: Set-up used in the without phantom case. This figure is schematic and is not to a real scale.

simulated. For the simulation of lead shield and the tungsten shield with thickness of 0.5 mm, the material cell was defined as lead and tungsten instead of air with the same thickness of 0.05 cm. Other dimensions were optional (Figure 4). F6 tally was used to score the energy deposited per mass (MeV/g). The number of photons simulated was 10^9 in each simulation. The energy cut-off for both electrons and photons was 10 keV. The simulations were performed by the same computer as mentioned before. The results of the simulations were obtained by scoring the deposited dose in the dosimeter. The percentage attenuation of shields was calculated through equation (1), the difference is that here I and I_0 are deposited doses in dosimeter with and without shield, respectively.

Finally, the results of the simulations with and without a phantom were compared for the two shields (lead and tungsten), that provide the highest radiation attenuation to introduce the optimum material as the shield to be worn by staff against $^{99}\text{Tc}^m$.

Results

Validation of Monte Carlo Simulation

Attenuation obtained for lead shield with thickness of 0.5 mm using simulation and dosimetry methods were 64.73% and 65%, respectively.

Comparing Simulations with and without Phantom

Figure 5 shows the dose on the central radiation axis on Z direction in phantom depth ($0 < Z < 20$ cm). The maximum and minimum dose changes were obtained in the phantom surface with thicknesses of 1 mm W shield and 0 mm shield, respectively.

Figure 6 shows the percentage attenuation which was obtained from 13 simulated shields by the calculation of the deposited dose in the

first voxel (0.005 cm depth) in the water phantom. The maximum and minimum attenuation was obtained with thicknesses of 1 mm W and 1 mm BaSO_4 ; they were 96.46% and 14.21%, respectively.

Figure 7 illustrates percentage attenuation which was obtained by lead and tungsten shields with and without phantom. In the simulation without phantom, tungsten provides the same percentage attenuation compared with the phantom case; however, this is not true in the case of lead. Lead shield provides lower attenuation in the vicinity of phantom.

Discussion

In this study, percentage attenuation was obtained for non-lead and lead shields with thicknesses of 0.5 and 1 mm against 140 keV gamma-rays emitted by $^{99}\text{Tc}^m$ source (Figure 6). Furthermore, the dose enhancement on the body of staff was investigated in the presence of two shields with high radiation attenuation—such as tungsten and lead. In validation of the simulation, percentage attenuation obtained from lead shield with thickness of 0.5 mm are very close in simulation and dosimetry. The difference is 0.57%, which is acceptable. The uncertainty in this study in dosimetric method might be related to radiation contaminations received by the dosimeter due to the existence of other radioactive sources that were used in the nuclear medicine Department of Imam Reza Hospital. of other radioactive sources that were used in the nuclear medicine Department of Imam Reza Hospital. This study was carried out in the nuclear medicine department. Furthermore, the dose obtained by dosimeter by lead shield with thickness of 0.5 mm was 4.21 $\mu\text{Sv/h}$, which is less than the legal dose (0.025 mSv/y). The legal dose was calculated by the following equation through dose limit of 50 mSv/y [17] by assuming 50 working weeks per year, 5 working days per week, 8 hours per day, and time work used was routine for nuclear medicine staff.

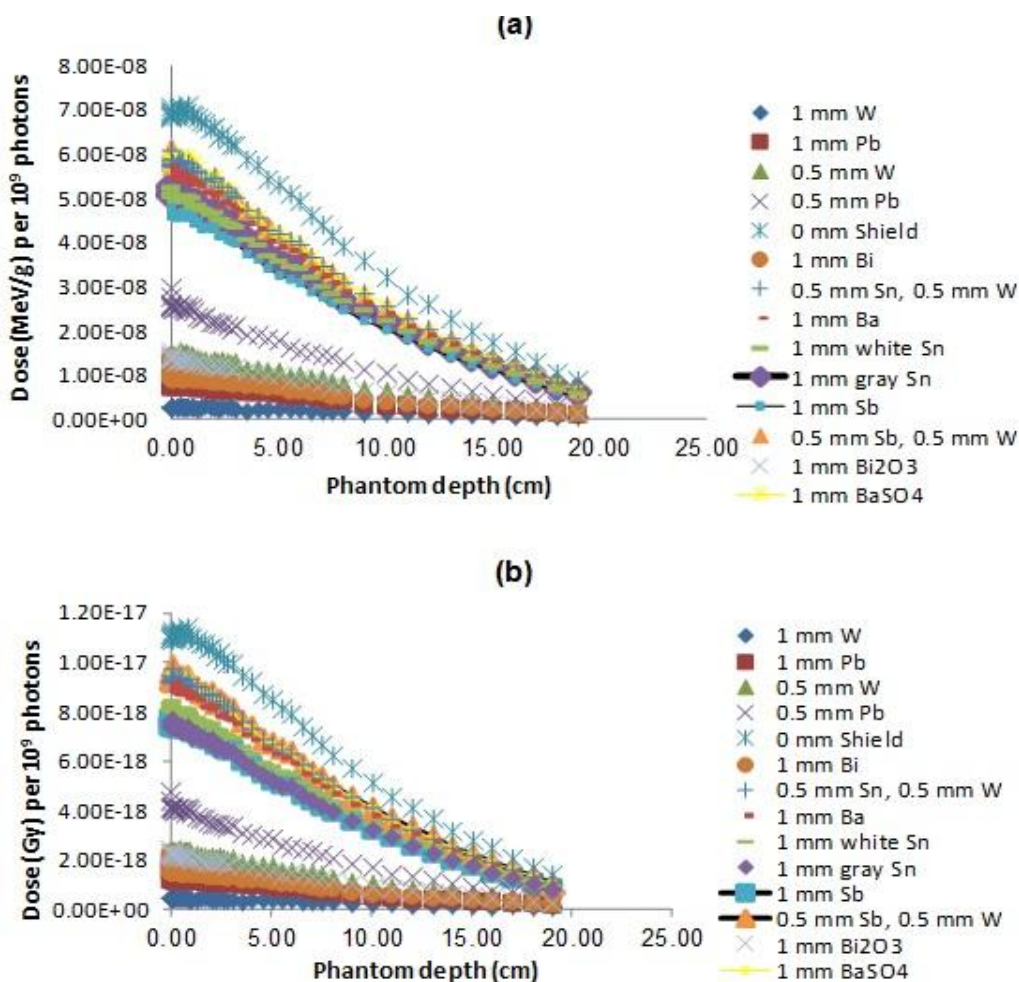


Figure 5: Dose changes on the central radiation axis in Z direction in phantom depth ($0 < Z < 20$ cm); in terms of (MeV/g) (a); and in terms of (Gy) (b). Note that the error bars are not seen clearly on the figure and it is due to the low percentage uncertainty which is ranging between 1%-2%.

Legal dose = annual dose limit (mSv/y) / (No. of weeks per year \times No. of days per week \times No. of hours per day) (2)

In a similar study, using dosimetry method, Young [6] showed that lead aprons with lead equivalent thickness of 0.5 mm provided attenuation of 64.5% against $^{99}\text{Tc}^m$. In the present study, this quantity was found to be 65% using dosimetry and 64.73% using simulation. The results of this study agree with Young's study with differences equal to 0.5% and 0.23% from the dosimetry and simulation

methods, respectively.

Based on the simulation in the presence of a shield, the dose enhancement is observed on the surface of phantom. It seems to be due to the absorption of low-energy photons, the secondary electrons are produced on the phantom's surface. These electrons are generated by the interactions of 140 keV photons emitted by $^{99}\text{Tc}^m$ with air and shield atoms. Furthermore, the dose reduced with increasing the penetration of high-energy photons at the depths of the phantom. Due to the interaction

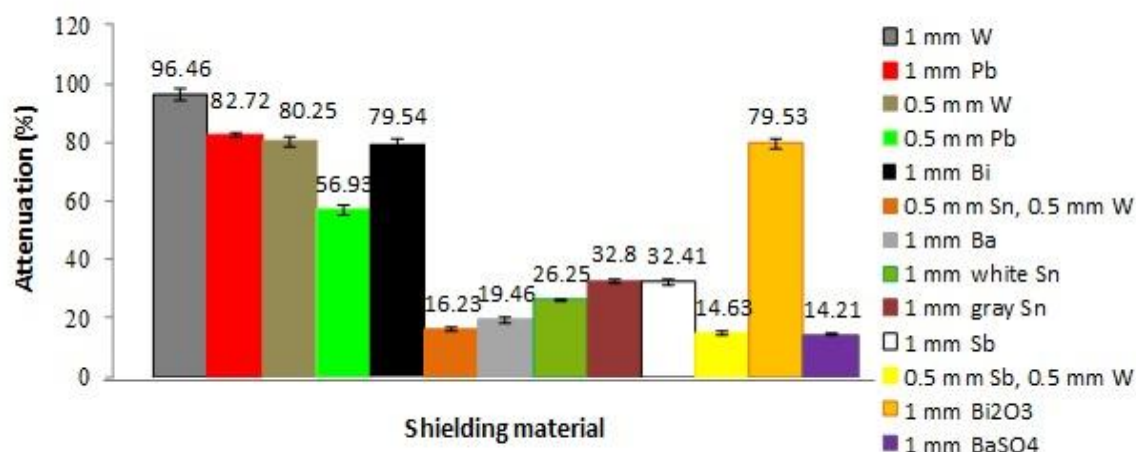


Figure 6: Percentage attenuation (%) obtained for 13 shielding material cases in the simulation with phantom.

of photons with atoms of the phantom, a reduction in photon intensity occurs (Figure 5).

In the case of simulated single layer shields of Ba, gray Sn, white Sn, Sb and BaSO₄, results show that they provide attenuation ranging from 14.2% to 32.8%. It is due to the predominance effect of Compton scattering at 140 keV photon emitted by ⁹⁹Tc^m, and the application of low density materials does not significantly provide attenuation, and their application is not recommended for ⁹⁹Tc^m (Figure 6).

In the case of simulated single layer shields of 1 mm W, 1 mm Pb, 0.5 mm W, 1 mm Bi and 1 mm Bi₂O₃, it can be expressed that they provide attenuations ranging from 79.54%-96.46%. This is also due to predominance of Compton scattering by 140 keV photons, and the application of higher density materials provides higher attenuation. Therefore, they significantly reduce the dose in the phantom, indicating that they are suitable shields against 140 keV photons emitted by ⁹⁹Tc^m (Figure 6).

In the case of simulated shield of 0.5 mm

Pb, it can be stated that it provides attenuation of 56.93%. It is due to the predominance of Compton scattering at 140 keV photon energy, and the application of lead provides intermediate attenuation because lead (11.34 g/cm³) demonstrates relatively lower density than other higher density materials such as tungsten (19.25 g/cm³) (Figure 6).

On the other hand, for simulated double layer shields such as Sb/W and Sn/W, it can be concluded that they provide attenuation of 14.6 and 16.2%, respectively. These results show that there is dose enhancement in the water phantom, mainly due to the application of double layer shields, and more secondary electrons are produced in these shields. Thus, they are not considered more suitable shields than lead shield against ⁹⁹Tc^m, consequently, they are not suitable for protection against ⁹⁹Tc^m (Figure 6).

Comparing the results of simulations in the cases of with and without phantom shows that between lead and tungsten shields with thickness of 0.5 mm, shields which use tungsten

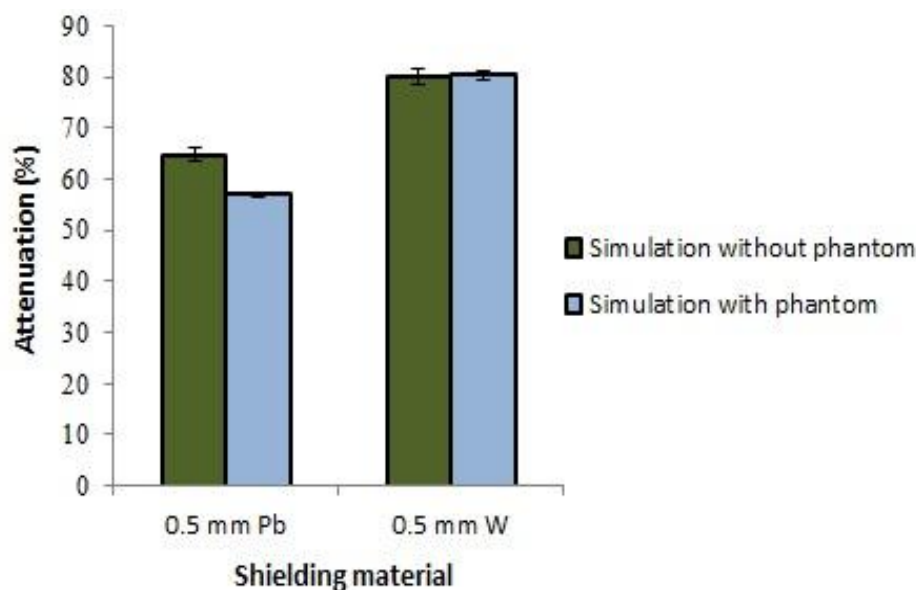


Figure 7: Comparing attenuations of simulated shields of lead and tungsten against $^{99}\text{Tc}^m$ in the simulations with and without phantom.

(with the same attenuation (80%)) are more suitable than lead ones so as to be worn by staff. The reason might be Compton scattering that is predominant at 140 keV photon emitted by $^{99}\text{Tc}^m$ (Figure 7). Although tungsten has a lower atomic number ($Z = 74$) than lead ($Z = 82$) and bismuth ($Z = 83$), its high density compensates for this shortage. Tungsten, with a higher density than lead (19.25 g/cm^3 versus 11.34 g/cm^3), provides more attenuation than lead in the same thickness. Furthermore, not only in the presence of tungsten, dose enhancement is not observed on the surface of body of staff, but also a dose reduction of about 0.18% is seen. It is due to high density of tungsten by which more 140 keV photons are attenuated, and low-energy photons are absorbed in the body of staff. However, in the case of lead, due to less density than tungsten, a number of 140 keV photons and attenuated photons pass from lead shields and they are absorbed in the body of staff; dose enhancement is seen on the surface of phantom (Figure 7).

In a similar study, Fog and Collins [8] concluded that attenuation of protective garments with thickness of 0.5 mm lead equivalence at depths of 1 mm and 2 cm in the phantom was 50% approximately for $^{99}\text{Tc}^m$. In this study, attenuation of 0.5 mm lead was obtained as 64% at 1 mm depth and 68% at 2 cm depth of the phantom. The difference in data is about 18% in two studies that is major, partly because Fog and Collins considered materials with different layers under lead shields such as plastic veneer attached to the lead shield, thickness of underclothing staff, epidermis layer and torso of body containing water. Since more secondary electrons are produced in torso of staff, lower attenuation in depths of phantom was seen. Furthermore, they considered dose profile. In the current study, dose changes were investigated at the depth of phantom, and only torso of staff was considered under the lead shield. Radiation passing through the lead shield is absorbed at depths of water phantom. In this study, the shielding effect is directly in-

investigated in the vicinity of body and it can be realized which shields cause dose enhancement in the vicinity of body inappropriately. In future studies, it is suggested that this work is performed for other common sources in nuclear medicine such as ^{131}I radionuclide.

Unlike materials with high atomic numbers such as lead ($Z = 82$) and bismuth ($Z = 83$), tungsten with a lower atomic number ($Z = 74$) provide the highest attenuation against $^{99}\text{Tc}^m$. It is due to its high density (19.25 g/cm^3). Furthermore, tungsten has advantages and disadvantage compared to lead. One advantage of tungsten is its high density that it provides high attenuation against 140 keV gamma radiations emitted by $^{99}\text{Tc}^m$. It has mechanical strength, machinability and corrosion resistance [18]. It is also resistant to breakage [18], unlike lead that is fragile and very soft [19]. It is important that tungsten is safer than lead due to its less risk which is related to exposure [18]. It is economical because of high density [18]. There is not a need for tungsten to be replaced each year due to cracking and brittleness such as lead shields. Furthermore, tungsten with thickness of 0.5 mm provides the attenuation equal to 1 mm of lead, without dose enhancement at the surface of phantom. Disadvantages of tungsten include: it is expensive and heavy, and it is not easily available compared with lead in various countries but China is enriched regarding its tungsten resources; it can import tungsten worldwide [18]. Totally, the advantages of tungsten are more than its disadvantages. In addition to high attenuation, weight of a shield is an important factor for its usage by staff. Therefore, here two shields of lead and tungsten with thickness of 0.5 mm are compared together with the estimated weights. Such shields are considered with a shape of a rectangle with dimensions of length, width and thickness of 10, 5 and 0.05 cm. Thyroid gland have the estimated length and the width. Densities of lead and tungsten are 11.34 g/cm^3 and 19.25 g/cm^3 , respectively.

The volume and weight of each shield can be calculated easily if there are the length, width, height and mass density of the shield with a cubic form.

Results demonstrate that the mass of lead shield and tungsten with thickness of 0.5 mm are 28.35 and 48.12 g, respectively. Tungsten shield group is heavier than lead shield with mass difference of 19.77 g. Additionally, masses calculated for lead and tungsten shields with thickness of 1 mm, are 56.70 and 96.25 g, respectively. Tungsten with thickness of 0.5 mm (48.12 g) is lighter than the lead with thickness of 1 mm (56.70 g). Furthermore, it provides similar attenuation (80.25%) compared to lead with thickness of 1 mm (82.72%). For having the same attenuation, it can be used from tungsten with less mass and thickness than a lead shield.

Conclusion

Different materials with high atomic numbers such as lead and bismuth, and also tungsten with a lower atomic number provide the highest attenuation against $^{99}\text{Tc}^m$. Furthermore, tungsten with thickness of 0.5 mm provides similar attenuation compared to lead with thickness of 1 mm against $^{99}\text{Tc}^m$.

This hypothesis is accepted in this study that presence of lead in the vicinity of body causes dose enhancement on the body surface but it is not true in the case of tungsten. Tungsten is an optimum material to design protective garments against $^{99}\text{Tc}^m$ in nuclear medicine. It is a reality that tungsten is a heavy metal and expensive. To reduce the weight and price of a tungsten garment, using small-scale tungsten shields for the protection of radiosensitive organs such as thyroid gland and gonads can be a good idea. To overcome its low flexibility, powder tungsten can be used instead of tungsten sheet. It seems that tungsten with thicknesses of 0.5 and 1 mm with radiation attenuation of 80.25 and 96.46% is the best choice in order to shield of thyroid for staff against $^{99}\text{Tc}^m$.

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Conflict of Interest

None Declared.

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