Automatic winder shielding materials focused on shape of the shielding using Monte Carlo N-particle

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Abstract. Automatic winder is a device that can be controlled using a remote controller which can be operated from a distance. It is equipped with electronic component like battery, raspberry pi and mechanical component such as gear, motor, and drive cable. This device will be used to perform radiographic testing which highly exposed to the gamma radiation. Front surface of the automatic winder is an area that receive high dose rate, thus proper shielding needs to be considered to protect component inside the automatic winder. In this study, two type of shapes were selected to be installed at the front surface of the winder housing. By using Monte Carlo N-Particle, increase the thickness of depleted Uranium from 1 mm, 3 mm, 5 mm, 7mm, 9 mm and 11 mm will reduce the dose rate received to the automatic winder. When comparing the shape, it shows that hemisphere shape gives better shielding compared with rectangular shielding.

1. Introduction
Gamma radiation is classified as electromagnetic (EM) radiations beside any other EM radiations such as radio waves, infrared radiation, ultraviolet radiation, X-rays and microwaves [1][2]. Gamma radiation has been utilized in various sectors for example, in medicine (radiotherapy), industry (sterilization and disinfection) as well as the nuclear industry. Shielding against gamma radiation is very crucial because it could cause skin, blood and eye disorders to human being who exposed to the radiation [3]. Therefore, different types of shielding materials have been manufactured depending on the applications in order to provide necessary protection to the radiation worker and their surrounding environment [4].

In finding an appropriate shielding material for certain application, the weight, space and cost of the shielding materials have become the main concerns among the researchers around the globe. In principle, materials comprised of high-atomic number (Z) and high-density elements are good candidates to be used as effective gamma shields due to their high probability of interactions and larger energy transfer with gamma rays [1]. Materials used for Gamma radiation should be highly dense such as concrete and Lead [5]. Although the low-density materials can also be considered in reducing the intensity of Gamma radiation, but the higher-density materials are more effective [6]. The sufficient installation of high-quality Gamma radiation shielding material is required to reduce the risks of excessive gamma exposure.
Automatic Winder is a device that can be controlled using a remote controller which can be operated from a distance. It is equipped with electronic components like battery, raspberry pi and mechanical components such as gear, motor, and drive cable. This device will be used to perform radiographic testing which highly exposed to gamma radiation. In this study, two parameters were considered in order to protect the Automatic Winder from malfunction which is type and thickness of the shielding material. Monte Carlo N-Particle Transport Code (MNCP) has been used to optimize shielding material for industrial radiography Automatic Winder in this study. Three types of shielding used in the study were Lead, Tungsten, and depleted Uranium.

Lead has a good physical property that makes a fantastic shield property against a gamma-ray in nuclear medicine. The main advantage of using a Lead shield is because of its compactness due to its density [7][8]. However, it is dangerous to health because of its toxicity and the dust particles that formed on the surfaces of Lead objects [8]. Moreover, the Lead physical property such as strength and hardness are not suitable for the hard environment. However, Lead is a common radiation shielding material for radiation protection [6]. Tungsten has a high gamma attenuation property, but it does not possess the chemical toxicity associated with lead [9]. Thus, Tungsten has many advantages therefore it is one of the most important materials for nuclear applications. Furthermore, Tungsten composite materials are used in high gamma radiation shielding applications because of their high density and favorable mechanical properties. One-third less Tungsten material has the same effectiveness at absorbing energy compared with lead and it can provide compact shielding without compromising the attenuation characteristics [1]. From [10] there is an equation that provides the relationship between ambient dose equivalents with the thickness of shielding material. A case study by [11] indicates that the measured dose values approximately decrease exponentially with the increase of Lead thickness. Furthermore, the sensitivity measured of the ion chamber decrease with an increasing the Lead thickness as a result of decreasing the dose values, hence, the dose unpredictability increased at low dose values. Lastly, the objective of this study is to compare the ability of three different types of shielding material on gamma radiation and to study the effect of different shapes of shielding material in shielding gamma radiation.

2. Methodology
The basic algorithm of all Monte Carlo methods is the fundamental that is based on a stochastic component. Consequently, there is a wide variety of algorithms under the name Monte Carlo and used for very different applications from materials modelling to risk assessment in finance [12]. The first Monte Carlo method is attributed to Ulam and Metropolis, that was developed while working at the Los Alamos National Laboratory during the Manhattan project [13].

The Monte Carlo method that will be used throughout this study follows the kinetics of a series of events, known as the probabilities of occurrence, hence its name kinetic Monte Carlo (KMC). It was first used in the field of radiation damage by H. Heinisch in the early 90’s [14] and since then it has been applied to different types of metals, particularly iron, iron alloys [15][16] and Tungsten [17][18]. Monte Carlo simulations comprises of a branch of experimental mathematics that involves experiments with random numbers [19]. Differing from a physical experiment, Monte Carlo simulation uses random numbers to conduct many virtual experiments on the computer and then analyzes the results of the experiments on a statistical basis to draw the conclusions. The stochastic approach of Monte Carlo method favoured its application to address diffusion problems such as mass and heat transfer problems in material science [20][21].
The generation of structure for the cell card, surface card and data card were written in the input of MCNP as shown in Figure 1. The details for each equipment that are involved in the experiment are illustrated in code that was generated for MCNP software. The main equipment involved throughout the experiment were Automatic Winder, Gamma projector, radiation detector and the shielding materials. The arrangement of the equipment is shown in Figure 2.

2.1 Studies of gamma radiation level
The initial test conducted in this study was to look at the radiation levels at several different locations during the radiography test where it has been simulated using MCNP software. This test is important for identifying and comparing radiation levels at specific places to help build effective shielding. Although the test is a basic test in which the results could be anticipated beforehand, it is important to verify that the MCNP model produced is correct and working properly. Figure 2 shows the experimental set up where the radiation levels at locations a, b and c have been studied. The detector is located inside the automatic winder as shown in Figure 2 (b). It was predicted that the readings at location a will be...
zero while the readings at location b will be higher than location c due to the distance with the detector is shorter.

![Equipment arrangement](image)

**Figure 2.** Equipment arrangement.

### 2.2 Studies of different types and thicknesses

The MCNP model from the initial test has been used in this second test where a layer of shielding material was placed between the radiation source and the detector located at the inside of the automatic winder wall. In this study, the radiation location was only at position c as it was the longest exposure position during radiographic testing. Radiation level readings without shielding material that were carried out in the preliminary tests were used as controls. Then the Lead shielding material with a thickness of 1 mm was placed in the position as shown in Figure 2 and the readings of the detector with the radiation source at position c were recorded. The test was repeated with the thickness of the Lead shielding material raised to 11 mm with intervals of 2 mm. The tests were then repeated with the Tungsten and depleted Uranium shielding materials at the same thicknesses as the tests conducted on the Lead. All the readings were recorded and plotted in a graph.
2.3 Studies of shape of shielding material
Figure 3 shows the three shapes of shielding material that have been studied using the MCNP simulation method. The purpose of this study is to observe if the shape of the shielding material affects the ability to withstand the Gamma radiation. The shape 1 is a flat form. It is a common form which used as a control and a comparison of the other two forms that were tested. The shape 2 is vertically curved and the third shape is horizontally curved as shown in Figure 3.

![Figure 3. Three shape of shielding material studied.](image)

3. Result and discussion
In order to achieve two objectives of this study, MCNP has been used. From Figure 4, stage 1 is where the source secure in gamma projector equal to 0 Sv/hr. At stage 2, the source in the guide tube was 42 µSv/hr that just outside the gamma projector. The source at the end of the guide tube is 58 µSv/hr (stage 3).

![Figure 4. Intensity at different location during exposure.](image)

3.1 Studies of Gamma Radiation Level in Radiographic Testing.
There are three types of shielding used to find out this objective which are Lead, Tungsten, and depleted Uranium. Figure 5 shows that depleted Uranium is the best shielding material compared to Tungsten and Lead. The dose rate (µSv/hr) is decreasing due to the increase of shielding thickness, hence dose
rate ($\mu$Sv/hr) is inversely proportional to shielding thickness. As for depleted Uranium, the dose rate is decreasing from 35 ($\mu$Sv/hr) to 10 ($\mu$Sv/hr) following the increasing of the shielding thickness. In conclusion, depleted Uranium is the most effective shielding material on gamma radiation.

![Graph showing dose rate ($\mu$Sv/hr) versus the shielding thickness (mm) by different types of material shielding.]

3.2 Studies of shielding material of different types and thicknesses

Based on the result of objective one, depleted Uranium is the most effective shielding material on gamma radiation compared to Lead and Tungsten. Therefore, for this objective, the researcher tested the effect of different shapes of shielding using depleted Uranium. The shaped of shielding material tested for this objective are flat rectangular, vertically curve, and horizontal curve. Figure 6 shows that the vertically curved material shielded more gamma radiation compared to the horizontally curved shape. Flat rectangular is the less effective shape in material shielding compared with the other two. In conclusion, vertically curved is the most efficacy shape of the shielding material.
3.3 Studies of shielding material of different types and thicknesses

The results show that the shape of a shielding materials affects the ability. Figure 7 shows that curved shapes are more effective for filtering Gamma radiation, which have given lower dose rate readings as compared to the flat shape. Meanwhile, the comparison between shape 2 (vertically curved) and Shape 3 (horizontally curved) shows that shape 2 is more effective in filtering Gamma content.
4. Conclusion
This study concluded that among the three tested materials, depleted uranium proved to be the most effective shielding material of IR-192 gamma radiation, followed by tungsten and lead. For the second objective, it concluded that horizontally curved is the most efficacy shape of the shielding material. Followed that the vertically curved material shielded more gamma radiation compared to the flat rectangular shape.

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