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Effect of Collimator Thickness on Build-up Factor Value for γ-radiation Using Inferential Statistic

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Authors' contributions

This work was carried out in collaboration between all authors. Authors ST and GM designed the study and managed the analyses of the study. Author PPA performed the statistical analysis, wrote the protocol, wrote the draft of the manuscript and managed the literature. All authors read and approved the final manuscript.

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ABSTRACT

A study of the effect of collimator thickness on the build-up factor value for the γ-radiation source has been conducted. The γ-radiation source used is from Cesium-137. The materials used in this research are concrete and wood, each of which was divided into 6 cm and 9 cm thickness. Data retrieval is done using Vernier Interface with Logger Pro 1.8 application. The data obtained are 600 radiation counts for each material thickness. The data processing of the enumeration results using inferential statistics is done to analyze the thickness of the collimator to the build-up factor value. The effect of the thickness of some of these materials is important to determine the value of build-up factor.The result obtained from the calculation is the build-up factor value increases along with the increasing thickness of the collimator for all materials. It is obtained that the build-up factor value is influenced by the thickness of the collimator. The B value for 6 cm & 9 cm wood collimator are 12,3% and 59,83% respectively while for 6 cm and 9 cm concrete collimator are 36,88% and 72,95% respectively, from B reference. The study of the build-up factor will be very useful in its application to the manufacture of radiation shields.

Keywords: Build-up factor; Cesium-137; collimator thickness; γ-radiation; inferential statistic.

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1. INTRODUCTION

The study of photon interactions with materials such as mass attenuation coefficients, effective mass numbers, and build-up factors has grown tremendously in recent years along with increasing use of radioactive sources in medicine, Gamma-ray studies, radiation, and chemical physics. The interaction of photons relies heavily on the atomic number of materials, which have many applications in studies in the field of radiation and other areas that utilize the principle of the interaction of radiation with a material. The high number of atomic materials causes greater electron density in the atom, and increasing the probability of photon collisions in the material [1-6]. One of the events due to the interaction of photons with a material is scattering (Compton scattering) followed by secondary radiation derived from the scattering. The accuracy in determining the rate of radiation exposure depends on the total measurement of photons absorbed by the material. The calculation of energy absorbed in a medium needs to take into consideration the collided photons and uncollided photons.

The use of radiations in various applied fields of science leads researchers to find ways to reduce the main effects and side effects of radiation by using radiation shields [7]. Radiation safety can be evaluated from the materials used in the manufacture of radiation shields. The intensity of gamma rays that pierce a medium followed the Lambert-Beer law and was strongly influenced by three conditions: monochromatic rays, the thickness of the radiating absorbing material, and the beam geometry that arrives at the detector. If any of these three states are not met, then the law is invalid. Lambert-Beer's law would be valid if using a correction factor called build-up factor [8]. The study of the build-up factor has attracted researchers [9,10]. The build-up factor defined by the ratio of the total value of a certain radiation quantity at many points to the radiation value reaching a certain point without going through the collision [11,12]. Research on the value of build-up factor for gamma radiation source of some materials has been done such as concentrate material [13,14], gas [8], soil and ceramics [15,16].

This study will describe the results of research on the effect of thickness of collimator on build-up factor value. The materials used in the manufacture of this collimator are concrete and wood to obtain a good beam to determine the build-up factor value of the material variation and the thickness of the collimator.

2. METHODS

In solving the build-up factor problem, we use equation (1) [7]:

$$I = I_0 e^{-\mu x} \tag{1}$$

Equation (1) is called the Lambert-Beer equation. From equation (1), I is the intensity of radiation after entering the material, I_0 is the initial intensity of the radiation source. The value of x is defined as $\frac{t}{\rho}$ so that the equation becomes:

$$I = I_0 e^{-\left(\frac{\mu}{\rho}\right)t} \tag{2}$$

From equation (2), $\frac{\mu}{\rho}$ is mass attenuation coefficient, t is the value of mass/unit area (g/cm2). If I and I_0 have the same calculated values on the absorber thickness x (cm), the coefficient of attenuation (μ) can be searched by equation (3) [7]:

$$\mu = \frac{1}{x} ln\left(\frac{I_0}{I}\right) \tag{3}$$

In the *build-up factor* (B) calculation, equation (1) can be modified into equation (4) [7]:

$$I' = B I_0 e^{-\mu x} \tag{4}$$

So the B value is sought according to equation (5) [8,12,13]:

$$B = \frac{I'}{I} \tag{5}$$

The error value of B is obtained using (6):

$$\Delta B = \sqrt{\frac{SD_1^2}{n_1} + \frac{SD_2^2}{n_2}} \tag{6}$$

The value of SD is the standard deviation of the data and n is the number of data taken.

The set of tools used for measuring intensity using the collimator (I') that calculate with equation (4) is shown in Fig. 1(a), while for measuring radiation intensity without using collimator (I) calculate by using equation (1) shown in Fig. 1(b).

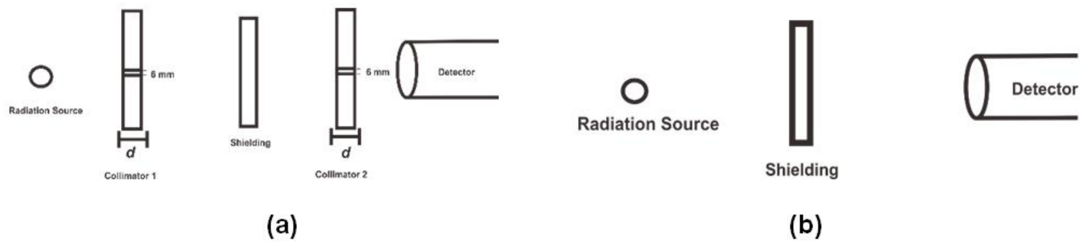

Fig. 1. (a) Measuring intensity using a collimator (b) Measuring radiation intensity without collimator

The model used to describe the random nature of the radiation count is the Poisson distribution defined by the equation:

$$P(x;\mu) = \frac{\mu^x e^{-\mu}}{x!} \tag{7}$$

$P\ (x;\mu)$ is the probable value of a normalized occurrence at a given time interval; x is the number of successful elements in the sample and μ is the average of the population. $P\ (x;\mu)$ is said to be normalized because when all the values of the probabilities that are summed will be close to 1.

The build-up factor was calculate by comparing the radiation intensity value using the collimator and the radiation intensity value without the collimator by using Eq. (5). The materials to be used for making collimators are concrete and wood which are each made with variations of length (***d***) 6 cm and 9 cm. Collimator hole was made with 6 mm diameter. The radiation source used in this study was Cesium-137 with activity 5 μCi and energy 662 keV. The radiation shield used was lead with a density area of 3,49 g / cm^2. The retrieval of radiation count data was done by using VERNIER interface with Logger Pro 1.8 application. The data obtained in the form of radiation counts within 12.000 seconds with the sampling time interval is every 20 seconds to obtain 600 radiation data. The data processing of the enumeration was conducted to analyze the relationship between material type, the thickness of collimator & radiation intensity using the statistical technique.

3. RESULTS AND DISCUSSION

Radiation measurement data were processed using *Microsoft Excel* to get the value for *t*-Test and Descriptive Test. Descriptive Test is used to find basic statistical data such as mean, standard deviation and others, while *t*-Test is used to find data of comparison result from two data groups. The sample of data processing that will be discussed is wood with thickness 6 cm and 9 cm and concrete with thickness 6 cm and 9 cm. The results of the Descriptive Test obtained for the radiation count from wood and concrete collimator shown by Table 1.

Based on Descriptive Test data for radiation data with collimator 6 cm and with collimator 9 cm for concrete and wood material obtained that the average value decrease along with increasing of thickness of collimator, so from the result stated that radiation intensity reaching detector Decreases as the thickness of the collimator increases. In addition to data from Descriptive Test, it is also necessary *t*-Test data to determine whether the data compared to differentiate or not. The comparable *t*-test data are between countless collimator and chips using wood and concrete collimators of 6 cm and 9 cm thickness respectively. Results from *t*-Test are shown by Table 2.

The values obtained from the *t*-Test for the 6 cm and 9 cm collimators in Table 2 explain that the *t*-Stat values for concrete and wood with thicknesses of 6 cm and 9 cm have values greater than *t* Critical. Based on the data that the value t Stat $\gg$ t Critical states that the comparable data are statistically differentiated. The purpose of this discrepancy is that the radiation intensity values received by the detectors without collimators and by using a collimator have different intensity values. The B value of the experimental results is obtained from the ratio between I and I' between the chips without the collimator and with which the collimator between one data and the other data is independent. B values for wood and concrete collimators with 6 cm and 9 cm are shown by Table 3.

The reference B value is obtained by logarithmic interpolation for an energy order of 0,5 MeV - 1 MeV. This energy range is used because the radiant energy emitted by radioactive Cesium-137 is 0,662 MeV. Based on the result of logarithmic interpolation obtained reference B equal to 1,22.

The effect of the thickness of the collimator on the build-up factor value shown in Table 3 gives information that as the thickness of the collimator increases, the build-up factor increases. The value of B is derived from the calculation using equation (5), while the value of ΔB is derived from equation (6). As defined by Harima [11] and Overcamp [12] which states that the value of B is defined as the ratio of the total value of a certain radiation quantity at many points to the radiation value reaching a certain point without going through the collision, this may explain why the value of B Increases with increasing thickness. Based on that definition, when the thickness increases then the path penetrated by the photon is longer so that during the trip to the photon detector will have many collisions. Interaction, when the photon passes through the material, produces a lot of scattering and by interacting the photon with the material causes the increasing number of photons. This increase in the number of photons is possible from non-colliding photons or from secondary photon scattering which reaches the detector. The B value of the experiments in this study has found that the value also depends on the thickness of the collimator and the collimator material. The B value increases with increasing of collimator thickness. It can be seen that the increase of collimator thickness caused the photons collide with the collimator and air materials will also increase so that the radiation depth and possibly increase the scattering of photons that reaches the detector. Based on Table 2, all values of experimental *B* results are greater than reference B. It is found that the collimator thickness has an effect on the measurement of build-up factor value. By comparing reference B and experimental B results, it is found that the percentage of B value increase for 6 cm and 9 cm wood collimator are 12,3% and 59,83% wood collimator while for concrete with 6 cm and 9 cm collimator thickness are 36,88% and 72,95% respectively. The B value of concrete is always higher than the wood for each thickness, it is because the concrete atom density value is greater than the wood. Increasing density of atoms will cause greater collisions in the material, hence the scattering will also occur along the collimator and produce greater accumulated radiation inside the detector.

The Poisson distribution for various variations of radiation count is shown in Fig. 2.

From Fig. 2 it was found that one of the distributions that can be used in the case of radiation is Poisson distribution. Each Poisson distribution graph for radiation counts without collimator, with 6 cm collimator and 9 cm collimator has different peak values. The peak value of the Poisson Distribution for radiation counts without collimator, with wood collimator 6 cm and 9 cm are 0.093595; 0,109883 and 0,131252 respectively while peak value for the count with concrete collimator with thickness 6 cm and 9 cm is 0,121543 and 0,137287 respectively. In addition to the peak value, the width of the Poisson distribution for each count representing the number of occurrences (Number of Count) also changes. Given the different values between peaks and wide changes of Poisson distribution, it can be seen that the collimator affects the magnitude of the radiation count value reaching the detector so that the creation of a good collimator becomes important in calculating the radiation intensity. Fig. 2 illustrates that by using a collimator, the intensity of the radiation becomes focused. The μ values of the Poisson Distribution for radiation counts without collimator, with wood collimator 6 cm and 9 cm are 18,03, respectively; 13,12 and 9,26 while μ values for count with concrete collimator 6 cm and collimator 9 cm respectively are 10,78 and 8,527 so it is obtained that with increasing of collimator thickness, μ value decreasing.

Table 1. Descriptive test for concrete and wood collimator

Material	Thickness	Mean	Standard error	Standard deviation
Wood	6 cm	13.11666667	0.145301419	3.559143351
	9 cm	9,265	0.127526	3.123732
Concrete	6 cm	10.78	0.138468449	3.391770459
	9 cm	8.5267	0.124419334	3,047638823

Table 2. *t*-Test for concrete and wood collimator

***t*-Test**	***t* Stat**	***t* Critical**
Without Collimator - Wood Collimator 6 cm	22,12300155	1,961986708
Without Collimator - Wood Collimator 9 cm	41,56174814	1,962090037
Without Collimator - Concrete Collimator 6 cm	33,30537774	1,962018236
Without Collimator - Concrete Collimator 9 cm	45,46458411	1,962115099

Table 3. Value of B for wood and concrete variation thickness

Material	**Thickness**	B	ΔB
Wood	6 cm	1,37	0,222092
	9 cm	1,95	0,210891
Concrete	6 cm	1,67	0,217683
	9 cm	2,11	0,209027

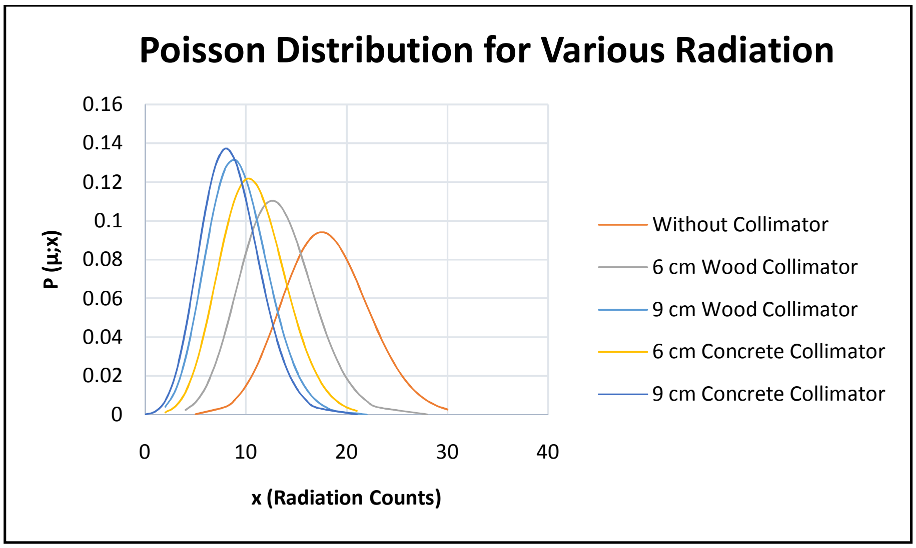

Fig. 2. Poisson distribution for various collimator thickness and material

4. CONCLUSION

The effect of collimator thickness on build-up factor measurement for Cesium-137 radiation source has been done using the statistical method. The result of this research is build-up factor value increases along with increasing of collimator thickness for both materials (concrete & wood) and also obtained that by using collimator, radiation count becomes increasingly focused. The B value for 6 cm & 9cm wood collimator respectively was 12,3% and 59,83% while for 6 cm and 9 cm concrete collimator respectively was 36,88% and 72,95% from B reference.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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