EFFECT OF COLLIMATOR ELEMENTS ON THE BEAM SPECTRUM AND KERMA IN GAMMA IRRADIATOR

PENGARUH UNSUR MATERIAL KOLIMATOR TERHADAP SPEKTRUM BERKAS DAN KERMA DI IRRADIATOR GAMMA

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ABSTRACT

EFFECT OF COLLIMATOR ELEMENTS ON THE BEAM SPECTRUM AND KERMA IN GAMMA IRRADIATOR*. In the development of low-medium energy photon calibration facilities we have simulated several types of gamma irradiator collimator materials with ISO 4037-1 design connected to the output beam spectrum and the resulting kerma. Four types of collimator material, namely Al, Fe, Pb, and WCu have been simulated with gamma radiation sources ^{241}Am, ^{57}Co, ^{137}Cs, and ^{60}Co. Simulations were carried out using the Monte Carlo method with the PHITS computer program. Based on the comparison of air kerma produced, collimators made from Al are suitable for gamma sources ^{241}Am, Fe material for gamma sources ^{57}Co, and Pb material for sources ^{137}Cs and ^{60}Co.*

Kata kunci*: dose, gamma spectra, collimator, Monte Carlo, PHITS.*

ABSTRAK

PENGARUH UNSUR MATERIAL KOLIMATOR TERHADAP SPEKTRUM BERKAS DAN KERMA DALAM IRRADIATOR GAMMA. *Dalam pengembangan fasilitas kalibrasi foton energy rendah-menengah telah disimulasikan beberapa jenis material kolimator pada irradiator gamma sesuai desain ISO 4037-1 yang dihubungkan dengan spectrum berkas dan KERMA yang dihasilkan. Empat jenis material kolimator yaitu Al, Fe, Pb, dan Cu telah disimulasikan dengan sumber gamma ^{241}Am, ^{57}Co, ^{137}Cs, dan ^{60}Co. simulasi dilakukan menggunakan metode Monte Carlo dengan program PHITS. Berdasarkan hasil perbandingan kerma udara yang dihasilkan maka disimpulkan bahwa kolimator berbahan Al cocok untuk sumber gamma ^{241}Am, material Fe cocok untuk sumber gamma ^{57}Co, dan material Pb cocok untuk sumber gamma ^{137}Cs dan ^{60}Co.*

Keywords*: dosis, spectrum gamma, kolimator, Monte Carlo, PHITS.*

INTRODUCTION

According to the Decree of the Head of Bapeten Number 01-P / Ka-BAPETEN / I-03 regarding the guidelines for dosing of radio diagnostic patients, in the operation of x-ray machine there is a need for verification of the calibration and the operating conditions of dosimetry and monitoring equipment. Good calibration requires a photon irradiator that produces a range of photon energy from the measuring instrument used. The suitability of the main conditions in calibration is energy. For this reason, in designing the calibration facility for x-ray measuring instruments, a gamma radiation source that produces the appropriate energy is required. In the design of low-medium energy photon irradiators, in addition to the availability of radiation sources, collimators are also needed to direct the output beam. The output beam from the radiation source is isotropic. Therefore, a collimator is needed to direct the beam only in the calibration position. Collimators are designed with certain shapes and use certain materials. The shape of the collimator is designed in such a way that it produces a cone beam with a beam diameter of 20 cm at a distance of 100 cm from the tip of the collimator. Figure 1 shows the collimator design in ISO 4037-1: 1996.

The design of the cylindrical tubular collimator is 213 mm long, 180 mm in diameter and inside is placed rings with a thickness of 15 mm at each distance of 20 mm. The ring hole diameters vary to form a minimum angle of 9.5 degrees. Several types of metals are used as collimators, including aluminum (Al), iron (Fe), lead (Pb), and tungsten-cooper (WCu). The choice of metal type is based on the ability of radiation absorption. At ISO 4037-1 1996, collimator material design still only uses WCu.

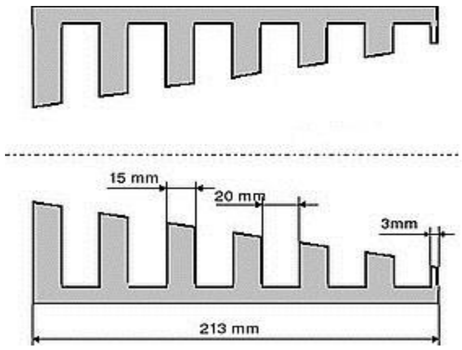

Figure 1. PTB collimator design is according to ISO 4037-1.

The irradiator is designed to produce a beam with a spectrum close to mono energy so that the radiation sources with the gamma mono-energy radiations are used. However, the use of metals as collimators will affect the beam spectrum. The interaction of gamma with the atoms of the elements in the collimator material can produce x-ray radiation. The appearance of secondary x-rays will change the shape of the collimator output beam spectrum. Characteristic and continuous x-rays resulting from the interaction of gamma with collimator will cause the resulting kerma dose calculation to be inaccurate. Therefore, it is important to choose the type of collimator material that produces the lowest additional radiation. The interaction of radiation with materials and the results of radiation from their interactions can be simulated using the Monte Carlo method with the PHITS computer program. The selection of materials in the collimator design can be done in a simulation. The effect of collimator material on the photon energy spectrum produced by the irradiator has not been widely simulated, for this reason, this paper will present the results of a collimator material design simulation using the PHITS computer program.

Determination of the energy spectrum of the ^{137}Cs irradiator and the dose of kerma associated with the collimator material and variation of the source distance using the Monte Carlo method is still limited [1]. Rodriguez et al. Used Monte Carlo with the PENELOPE program to determine the energy spectrum of gamma irradiators [2]. He found that no significant changes in the energy spectrum resulted from increasing the thickness of the material. Taneja et al used MCNP6 [3] to determine the energy spectrum of ^{137}Cs gamma irradiators with activities of 450 Ci and 5 Ci [4]. While W.S Bak, et al did the same thing but with FLUKA it was found that the difference at a distance of 5 m was only 1% [5]. Simulations are generally still carried out for the ^{137}Cs gamma source, while other gamma sources such as ^{241}Am, ^{57}Co, and ^{60}Co sources have not been carried out. For this reason, it is necessary to simulate changes in the spectrum and gamma irradiator kerma from the influence of collimator materials.

METHOD

Particle and Heavy Ions Transport System (PHITS) is a multipurpose computer program based on Monte Carlo to simulate the trip of particles and heavy ions in three dimensions with the order energy of 10^{-5} eV - 1 TeV [6]. The interaction of photons and electrons emitted from radioactive sources with collimator material is simulated to obtain the output in the form of a dose of kerma as a function of energy in the position of 100 cm from the tip of the collimator. To produce photon energies with a range from low to high generally use a radioactive source ^{241}Am, ^{57}Co, ^{137}Cs, and ^{60}Co. The types of materials used as collimators are Al, Fe, Pb, and WCu. The simulation is done through three stages: making input, running on a computer, and analyzing the output. The input consists of three parts including the geometry and collimator material, the definition of the radiation source, and the dose of the kerma.

Collimator

Nuklindolab has made two collimators with the geometries following ISO 4037-1 with aluminum and lead material with the appearance shown in Figure 2. The collimator was designed as part of a low-medium photon energy calibration facility using gamma beams from ^{241}Am, ^{57}Co, ^{137}Cs, and ^{60}Co according to ISO 4037-1 [7] recommendation. Di In Germany PTB as the primary calibration laboratory has used five sources namely ^{241}Am, ^{57}Co, ^{137}Cs, ^{60}Co, and ^{226}Ra [8]. The facilities at PTB use ^{241}Am, ^{57}Co, ^{137}Cs, and ^{60}Co for sources approaching a single energy, while the use of ^{226}Ra is as a source that approaches continuous energy [4]. The collimator is in a room with a length of 370 cm, a width of 270 cm, and a height of 300 cm. The space walls are made of 20-cm-thick concrete except the side of the beam that has a wall thickness of 50 cm. The position of the collimator 125 cm above the surface of the floor and the end of the collimator has a distance of 200 cm from the wall. The devices measuring radiation are placed in the center of the collimator and wall at a distance of 100 cm from the tip of the collimator. Geometry models and collimator materials were made as PHITS inputs. Figure 3 shows the collimator ring front view (a) and the side colimator ring geometry in the PHITS view (b). The collimator consists of three parts: the source buffer (1), container (2), and ring (3 and 4). The material for the three parts of the collimator is the same. In the simulation, there are four different types of collimator materials, namely Al, Fe, Pb, and WCu.

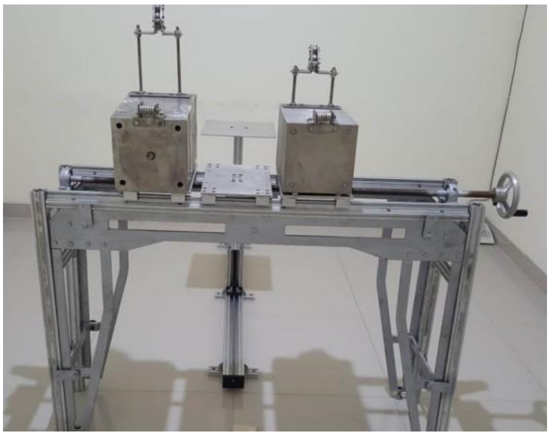

Figure 2. Collimator with Al and Pb.

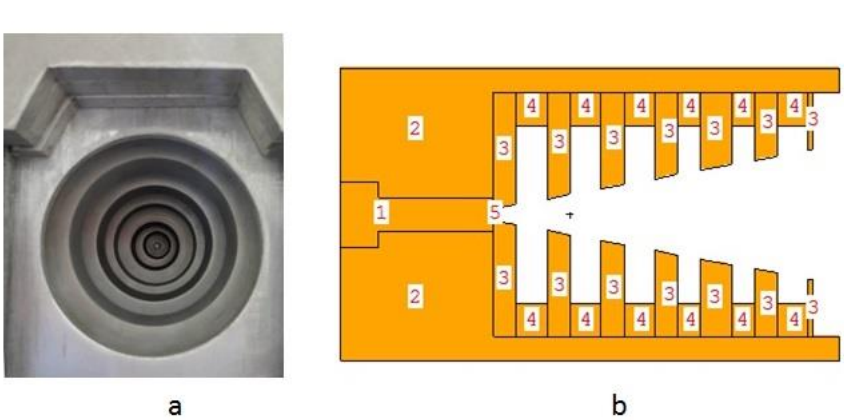

Figure 3. (a) Collimator ring front view and (b) Geometry collimator in PHITS.

Radiation sources

As a low-moderate photon energy calibration facility, an irradiator which produces the appropriate energy gamma is prepared. To obtain a low-medium gamma calibration curve, gamma transmitters with varying energy ranges in the range of 10 keV - 2 MeV are required. Among the sources that can be used are ^{241}Am, ^{57}Co, ^{137}Cs, and ^{60}Co. The ^{241}Am gamma radiation source is also an alpha radioactive transmitter, while the ^{57}Co, ^{137}Cs and ^{60}Co gamma radiation sources are also beta transmitters. The gamma energy from each of these radiation sources is shown in Table 1.

Table 1. Gamma energy of irradiator sources.

No.	Source	Gamma energy (KeV)	Yields (%)
1.	^{241}Am	59	36
2.	^{57}Co	14	9.5
		122	85.6
		136	10.6
3.	^{137}Cs	662	85
4.	^{60}Co	1174	100
		1333	100

The gamma photons produced ^{241}Am (59 keV) represent the energy range of 10-100 keV; gamma of ^{57}Co (122 keV) represents the energy range of 100-500 keV; ^{137}Cs (652 keV) represents the energy range of 500-1000 keV; and the gamma energy of ^{60}Co (1174 keV and 1333 keV) represents energy ranges of 1000 - 2000 keV. The cylindrical source is in stainless capsules. The source is placed inside the collimator. Radiation is emitted in an isotropic direction. The gamma radiation source ^{241}Am of 300 mCi activity is inside the G22 capsule of stainlees material with a diameter of 15 mm and a thickness of 6 mm. The ^{137}Cs gamma radiation source activity of 201 mCi and ^{60}Co 5 mCi are inside the P03 capsule of stainless steel material with a diameter of 6 mm and 8 mm thick.

KERMA

The simulations using PHITS are carried out to obtain air kerma or kerma dose as an energy function at a position of 100 cm from the front end of the collimator. In its calculations, PHITS uses tally t-track to get photon flux results in volume. The photon flux is then converted into a kerma dose using the multiplication factor of flux to dose conversion. The factor for flux to dose conversion can use ICRP-74 data or ICRP-116 by interpolation in logarithms. Yet, based on the calculation of Hae Sun Jeong, et al stated that for calculating the dose of kerma it is recommended to use a factor of flux to dose conversion using ICRP-74 data [10].

RESULTS AND DISCUSSION

PHITS input for Al, Fe, Pb, and WCu collimators has been made with four sources of gamma radiation. PHITS input is run using a computer with an Intel core i5- 2.3 GHz, 4 GB RAM, and Windows 8.1 operating system. Gamma dose as a function of energy is calculated at 100 cm position. The time taken for the computer to run the input to get a 1% statistical error is 20 minutes. The cross section of photon interaction data in the PHITS calculation is used by the JENDL-4 library.

The results of the simulation of the kerma dose rate distribution from gamma sources ^{241}Am in collimators made from Al, the width of the kerma beam at the measurement position of 100 cm, and the distribution of kerma rates in the room are shown in Figure 4. The collimator design, according to ISO 4037-1, is quite good in directing beam so that it can produce a beam at a distance of 100 cm with a diameter of 40 cm. The beams at a distance of 100 cm will then be used for low-medium photon calibration. With a gamma source of ^{241}Am 300 mCi and a collimator using Al the material produces a kerma rate in the room ranging from 0.1 - 1 μSv/h and in the position of 100 cm 830 μSv/h.

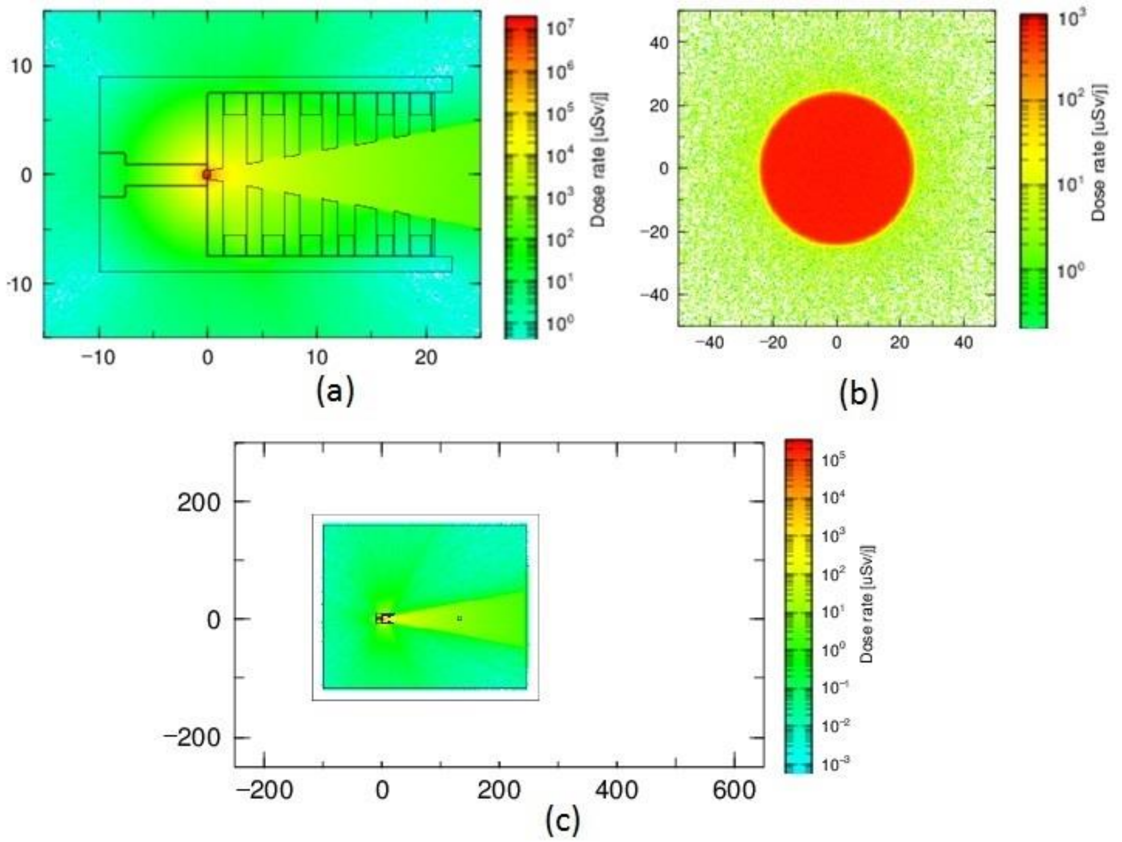

Figure 4. (a) Distribution of kerma dose rate on Al collimator with ^{241}Am source, (b) Field size of beam at 100 cm, dan (c) Distribution af air kerma in the room.

The effect of collimator on the dosage of the beam bundle output can be seen in changes in the gamma spectrum of the beam compared to the initial spectrum of the radiation source. The choice of material for the collimator will be based on the shape of the output gamma spectrum which is closer to the initial spectrum form of the radiation source. The PHITS program simulates gamma interactions from radiation sources with collimator material, and calculates the output beam flux as a function of energy. The results of the simulation of the shape of the collimator output beam with several types of material are shown in Figure 5.

Figure 5 shows the shape of the ^{241}Am gamma spectrum between the initial form of the source and the shape of the collimator output beam. The difference is quite significant in the output of collimators using WCu material. Several energy peaks emerge as a result of the interaction of the source photon with the atomic shell of the constituent elements that produce characteristic x-rays. From the spectrum comparison between collimators with different materials, it appears in gamma sources with quite large energy, such as ^{57}Co, ^{137}Cs, and ^{60}Co. The peak with 80 keV in Pb collimator appears. The peak is a fluorescence x-ray due to the Pb atomic electric photo effect. There are also peaks around the energy of 200 keV for sources of wide ^{137}Cs and ^{60}Co where the peak is the result of the Compton effect. The relationship between gamma energy and scattering was investigated by Hossain, et al., by simulating and measuring an energy beam of ^{137}Cs 662 keV, and it was found that the energy of the gamma rays decreased with the angle of scattering[11]. The scattering fraction is different for gamma energy, beam angle, and collimator material, where the material with large atoms will give a small scatter fraction. Bourgoisa and N. Comte found that the scattering fraction for air was higher by a factor of 5 compared to steel[12]. Other simulation results show that the scattering is also by the material and the angle of scattering[13,14].

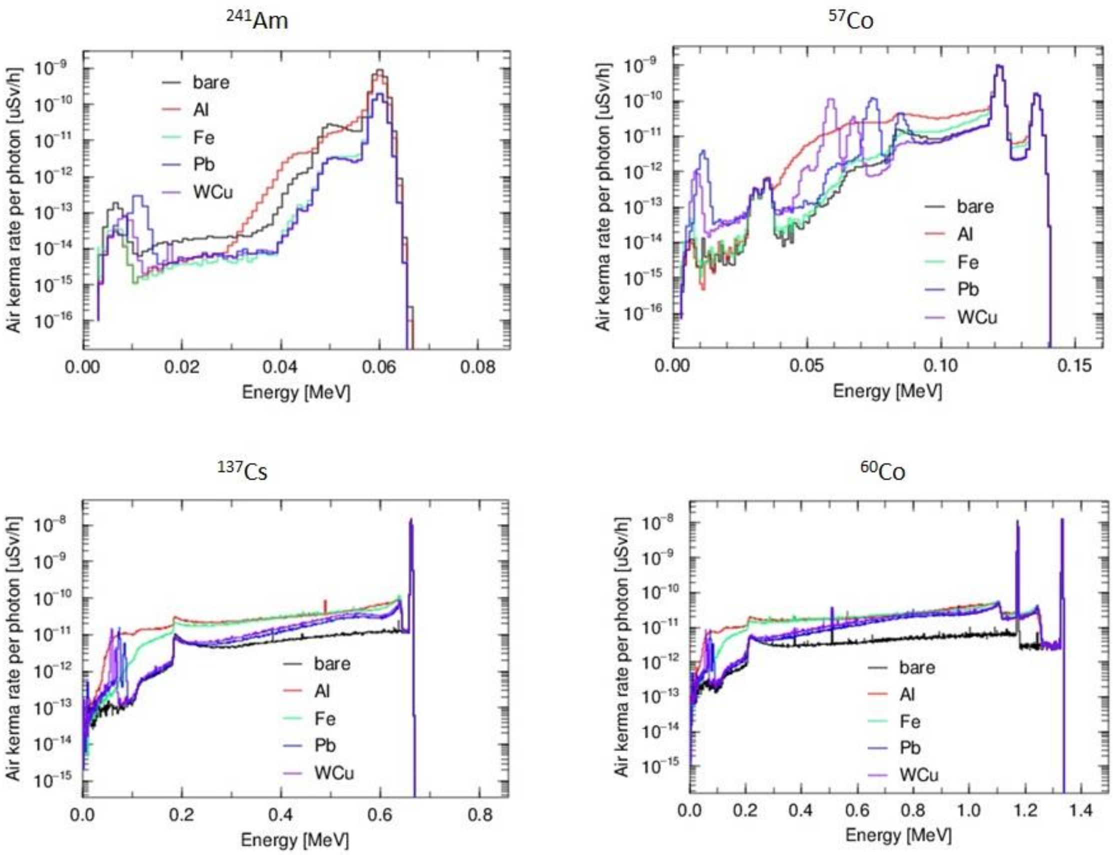

Figure 5. Gamma spectra of each collimator materials.

Table 2. Air kerma from each collimator material.

No.	Source	Air kerma (uSv/h) per photon				
		Bare	**Colli. Al**	**Colli. Fe**	**Colli. Pb**	**Colli. WCu**
1.	^{241}Am	2.87E-09	2.08E-09	6.18E-10	5.62E-10	5.66E-10
2.	^{57}Co	3.99E-09	5.86E-09	4.41E-09	4.57E-09	4.44E-09
3.	^{137}Cs	5.19E-08	6.69E-08	6.48E-08	5.64E-08	5.80E-08
4.	^{60}Co	9.30E-08	1.14E-07	1.15E-07	1.06E-07	1.08E-07

The presence of these characteristic x-ray energy peaks changes the kerma dose value in the output beam. This will disrupt the accuracy of the kerma dose calculation. In Figure 5 is the form of the energy spectrum of the output beam photons, while in Table 2 it is shown the release of the kinetic energy of photons in the air (air kerma) from the output beam. Based on the simulation results of the air kerma dose at a position of 100 cm from the tip of the collimator as shown in Table 2 shows that the gamma source ^{241}Am is more suitable to use Al collimator. The value of air kerma dose from gamma source ^{241}Am with Al collimator is approaching bare condition (without collimator). Meanwhile, gamma source ^{57}Co is more suitable to use Fe collimator, and gamma source ^{137}Cs and ^{60}Co are more suitable to use Pb collimator. The collimator material that is "suitable" here is the one that gives the least scatter, i.e. from its lowest air kerma value. As shown in the Table, the use of collimators made from Fe, Pb, and WCu for ^{57}Co, ^{137}Cs and ^{60}Co sources provides an additional dose of kerma. For example, the dose of kerma at 100 cm from the Pb collimator for the ^{137}Cs source gives an increase of 8.7%. These results were also obtained in the calculation of Samer et al at 9%, so the consequence was they added a 5.54 cm thick Pb plate to reduce it [4]. For distances above 1 m, Alex F. Bielajew, et al., succeeded in correcting the distance factor against the correct dose as a function of the distance squared using simulation and measurement to localize the factors that influence that it is concluded that the analysis lies at 0.5% for a distance of 1 - 7 m [15,16].

CONCLUSION

The Monte Carlo method with the PHITS program has been used well to simulate the interaction of photons with collimator material with the aim of choosing the right type of collimator material. It has been simulated the interaction of photon output sources ^{241}Am, ^{57}Co, ^{137}Cs, and ^{60}Co with four types of collimator material namely Al, Fe, Pb, and WCu. The simulation results show that collimator made from Al is suitable for gamma source ^{241}Am, Fe material for gamma source is ^{57}Co, and Pb material for source is ^{137}Cs and ^{60}Co.

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