SIMULATION OF BEAM COLLIMATOR FOR NEUTRON RADIOGRAPHY USING MONTE CARLO METHOD

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ABSTRACT

One of the major component in neutron radiography is a collimator that is used to collimate the neutron in parallel beam with less gamma ray contamination and high thermal neutron flux. The collimator consists of seven components and the interest component is an aperture as it is used to prevent the thermal neutron from entering the beam except through the center hole. In this study, the collimator design was taken from radial beam port at NR facilities at ANM with the collimation ratio is 46.4. In order to increase the collimation ratio, optimization of the aperture component has been done on four different material and 1-5 cm diameter parameters. The optimization of apertures shows that the cadmium with 1 cm diameter yields the thermal neutron flux at the collimator inlet and outlet with 1.78 $x10^3$ n cm^{-2} s^{-1} and 5.90 $x10^2$ n cm^{-2} s^{-1} while the gamma ray contamination was 10.7 μSv hr-1. The optimization succeed to produce high L/D ratio however the thermal flux was low and the gamma contamination was higher than original design but satisfied the ICRP 74 condition for radiation worker.

ABSTRAK

Kolimator merupakan salah satu komponen yang memainkan peranan yang penting dalam radiografi neutron dimana ia digunakan untuk menghasilkan pancaran neutron yang kurang kontaminasi sinar gamma dan fluence neutron yang tinggi. Kolimator mengandungi tujuh komponen dan aperture merupakan komponen yang digunapakai untuk menghalang thermal neutron daripada memasuki pancaran neutron kecuali melalui lubang tengah di aperture komponen tersebut. Kajian ini mengunakan reka bentuk kolimator yang digunapakai di radial beamport dengan L/D iaitu 46.4 di kemudahan NR di ANM. Nisbah L/D boleh ditingkatkan dengan pengoptimuman aperture dimana empat jenis bahan yang berbeza dan 1-5 cm diameter untuk aperture telah dimanipulasikan. Selepas pengoptimuman, cadmium dengan diameter bernilai 1 cm menunjukkan flux yang memasuki aperture ialah 1.78 $\mathrm{x}10^3$ *n* cm^{-2} *dan flux yang keluar ialah 5.90* $\mathrm{x}10^2$ *n* cm^{-2} s^{-1} *bersama dengan sinar gamma 10.7 μSv hr-1. Pengoptimuman berjaya meningkatkan L/D ratio tetapi flux yang terhasil adalah lebih rendah dan tinggi sinar gamma jika dibandingkan dengan reka bentuk asal tetapi memadai dengan syarat yang telah ditetapkan oleh ICRP 74 untuk pekerja sinaran.*

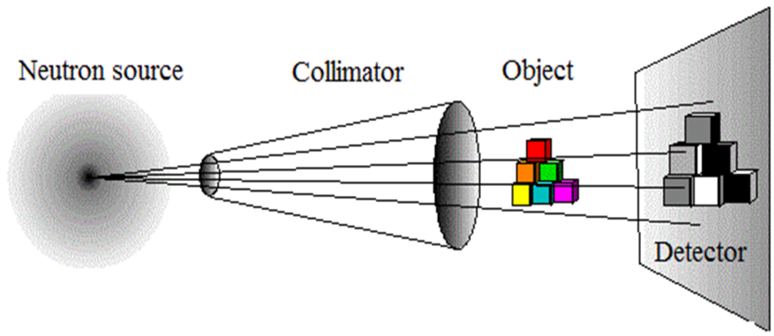
Keywords: Neutron radiography, collimator, aperture

INTRODUCTION

Neutron radiography (NR) is an imaging technique that is widely used in industry, medical, explosive inspection and others that required non-destructive testing (NDT) tools. Neutron is a highly penetrating particles as it is a neutral component of the atomic nucleus and thus it has a capability to pass through heavy element better [1]. Nowadays, many industries and sciences like nuclear industry, material science and engineering, aerospace demanded to use NDT tools for quality assurance and due to that improvement in NR is necessary [2]. There are three major components in NR method which are the neutron source, collimator and the imaging process system as shown in Figure 1 [3]. Generally, neutron source can be produced in three way from accelerator, a radioisotope or nuclear reactor [4]. The collimator is a component that extract the neutron beam with flux intensity on the image plane to obtain a better neutron radiographic resolution [5]. The best design of collimator are depending on the collimation ratio (L/D), the beam divergence, the gamma content, and the neutron flux and also materials selection [6]. While for the imaging process system or detector, the uses of charge couple device (CCD) camera were widely used for real time exposure. In Malaysia, NR facility only available at Agensi Nuklear Malaysia (ANM) and are currently being upgraded in order to reduce the exposure time and produced better image resolution [7].One component that required for major improvement is a neutron collimator. The collimator itself contain seven component that are typically included some or all of it which were the illuminator, beam filters, aperture, gamma shielding, collimator walls, clean up plates and filling gas.

Figure 1: Neutron radiography components

In this study, a radial collimator design has been adopted from NR facility at ANM and used to simulate the design with the aims to evaluate the neutron flux intensity and gamma dose rate. Furthermore, this study will



optimize one of the collimator component which is the aperture that is functionally to prevent any thermal neutrons from entering the beam except through the center hole in order to collimate the neutron to form a conical beam [6]. The simulation using MCNPX will used 5 Ci of 241Am-Be as a neutron source due to this collimator will be installed at the radial beam port which has low thermal neutron intensity available if compare to tangential beam port. The aperture component will be manipulated on its material and diameter in order to obtain large L/D ratio with high thermal neutron flux and low gamma ray content [8]

EXPERIMENTAL AND INSTRUMENTATION

The materials selection and diameter plays a major role in optimizing the aperture in order to limit the neutron beam to only passing through the center hole of the aperture because the beam produced at the image plane will be uniform and parallel beam [8]. The collimation ratio (L/D) will affected when varied the diameter. Figure 2 illustrate the simulation model of collimator adopted from NR facility by using MCNP.

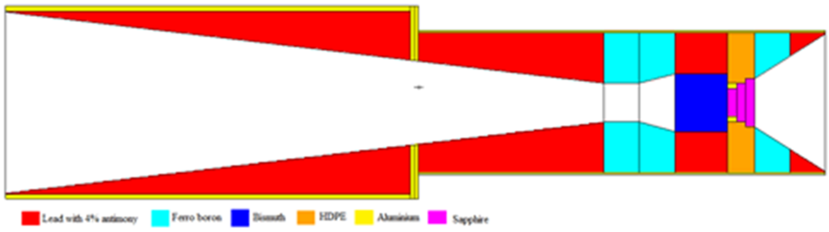


Figure 2: VisedX of collimator for MCNP simulation.

According to Figure 2, the design consists of 7 different materials used in order to produce high thermal neutron flux and low gamma ray content at the end of the collimator. The simulation required the neutron sources and this study used point sources of 241Am-Be with the activity of 1 Ci (37 GBq). Since the collimator is design to install at the low thermal neutron source, the 241Am-Be is suitable to be used for simulation. Two manipulative parameters used are the materials selection and the diameter in order to optimize the aperture. The simulation will start with varying the four materials selected with high neutron absorption cross section which are Boral (B_4C +Al), boron carbide (B_4C), cadmium (Cd) and borated polyethylene so that thermal neutron can be shielded from entering the beam and pass through aperture diameter [8]. Then after choosing the best materials, the diameter will be varied from 1cm to 5cm of the aperture.

MCNP Method

This simulation of the collimator was done by using $1x10^8$ of neutron particle history (NPS=100,000,000) in order to obtain an accuracy of < 2% in F4: n p and F2:n p tally. The tally used are to calculation the flux on the surface of aperture (surface 25), the estimated track length of particle flux (n cm^{-2} s^{-1}) along the collimator and the flux-to-dose conversion factor according to ICRP 74.

RESULT AND DISCUSSIONS

Table 1 shows the comparison between neutron flux at the surface of aperture (Surface 25) and materials. From the simulation result, Cd has the lowest thermal neutron flux about $3.27x10^8$ n cm^{-2} s^{-1} while Borated polyethylene has the highest neutron flux which is $8.28x10^{10}$ n cm^{-2} s^{-1} at the aperture component. Since the function of aperture is to limit the amount of thermal neutron entering the aperture except through the center hole, thus from this simulation, Cd is the most suitable materials because the absorption of the neutron inside Cd is less thus the remaining flux will enter the center hole without further interact with cadmium.

Table 1: The result of aperture and thermal flux at each materials.

Materials	Aperture Flux (n cm^{-2} s^{-1})	Outlet Thermal Flux (n cm^{-2} s^{-1})
Ferro boron	4.24x10^{9}	3.05x10^{4}
Boral	1.67 x10^{9}	2.84 x10^{4}
B4C	2.71 x10^{9}	3.12 x10^{4}
Cadmium	**3.27** x10^{8}	**8.28** x10^{3}
Borated	8.28 x10^{10}	2.40 x10^{5}

As the Cd materials yields the lowest flux at the entrance of aperture (surf=25), thus it is used as aperture material to determine the optimize diameter. However, changes in diameter will directly altered the L/D ratio. The diameter parameter can be used to enhance the amount of neutron intensity and produce better image resolution for the radiographed object. Table 3.2.2 shows the specification of the modification on the L/D ratio.

Based on Table 2, the thermal flux at surf=25 was increases as the diameter increase, but the collimation ratio were decreases. According to Dinca *et al.*, (2005), to obtain a larger number of neutron, the collimator requires large aperture entrance but smaller aperture entrance will gives bigger L/D ratio. This hypothesis can be accepted as in this study, smaller diameter of 1 cm increase the L/D ratio while the bigger diameter of 5 cm yields high neutron flux which was 3.27 x10^{8} n cm^{-2} s^{-1} at the aperture entrance. However, the studies from Husin Wagiran *et al.*,(2009) stated that the optimization of aperture diameter could not be done by increasing the diameter only but it also depends on the flux produce at image plane. Therefore, by observing the flux at the collimator outlet shown in Figure 3, as the diameter increases from 1-5 cm, the flux at the collimator outlet also increases from 5.90 x10^{2} n cm^{-2} s^{-1} to 8.28 x10^{3} n cm^{-2} s^{-1}.

Table 2: L/D ratio for different diameter

Diameter (cm)	L/D	Thermal Flux (n cm^{-2} s^{-1})		Dose Rate (μSv hr-1)
		Aperture (Surf=25)	Outlet (cell=3)	
1	**212.00**	**1.78E+3**	**5.90E+2**	**10.7**
2	106.00	3.23E+7	1.17E+2	12.1
3	70.67	7.27E+7	1.77E+3	38.5
4	53.00	1.83E+8	3.70E+3	45.6
5	42.40	3.27E+8	8.28E+3	56.0

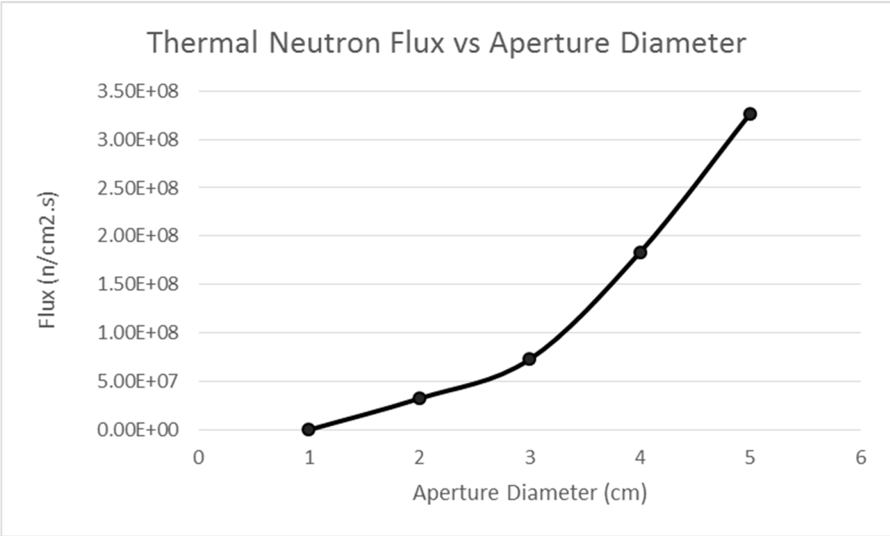


Figure 3: Graph of thermal neutron versus varied diameter

CONCLUSION

As a conclusion, the simulation has shown that the best material selection and diameter after optimization using ^{241}Am-Be on original design is cadmium with 1 cm diameter aperture. The thermal neutron flux and gamma ray contamination were evaluated where both enter the collimator with 1.78E+03 n cm^{-2} s^{-1} and 1.07E+01 μSv hr^{-1}. After the optimization, the collimation ratio were succeed to increase but the thermal flux obtained were decreases to 5.90E+02 n cm^{-2} s^{-1} with small reduction for gamma ray contamination of 10.7 μSv hr^{-1} which can be accepted for radiation worker to work with this collimator design.

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