Vol. **132** (2017) *ACTA PHYSICA POLONICA A* No. 3-II

Special issue of the 3rd International Conference on Computational and Experimental Science and Engineering (ICCESEN 2016)

Calculations of Temperature Rise in Al, Cu and Fe Photon Collimators for 8–32 MeV Photon Beams

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We have focused on temperature changes in the collimator at the TARLA bremsstrahlung photon facility. One of the important parameters during the design of an ideal collimator, especially for high-energy photons, is temperature rise in the collimator material. For this purpose, energy deposition in the collimator materials was simulated using the FLUKA Monte Carlo code. Depending on energy deposition values, temperature rise in the collimator materials of Al, Cu and Fe was calculated for photon beams with 8–32 MeV energies.

DOI: 10.12693/APhysPolA.132.1168
PACS/topics: 07.05.Tp, 02.70.Uu, 29.17.+w

1. Introduction

Devices that interact with high-energy particle beams (such as collimators, radiators, beam dumps) in the accelerator centers may become damaged over time due to exposure to excessive radiation. Therefore, when these devices are designed, the parameters such as energy deposition, heat load and pressure that occur on the devices are determined in advance by simulation codes [1, 2]. Thus, the damage that the radiation can induce in the materials used, is crucial for the devices. Because the photons produced in the radiator of the TARLA (Turkish Accelerator Radiation Laboratory at Ankara) bremsstrahlung photon facility [3] directly interact with collimator, the estimation of the damage, especially at entrance of the collimator, is important.

When a solid target interacts with the accelerated particle beam, the energies of the particles are deposited on the material [4]. Ionization losses after interaction between the photon beam and the collimator cause energy deposition and temperature rise in the collimator material [5]. This energy deposited on the collimator material varies depending on the type of the material and the energy of the beam. For effective and long-lasting use of the collimator, it is important to know this energy deposition and temperature rise in advance. Especially at very high energy, the temperature rise on the collimator is even more important. To prevent failure of the collimator, the temperature of the collimator should be below the ultimate temperature limits [6]. Therefore, while choosing the collimator material, the mechanical and chemical strength of the material should be taken into account.

We made this study as a preliminary study for calculating the temperature rise in Al, Cu and Fe collimators, caused by the bremsstrahlung photon beam with 8–32 MeV energies at TARLA bremsstrahlung photon facility and to predict if there will be any damage of the collimator. The energy values deposited on the collimator were calculated by FLUKA simulation code.

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2. Materials and methods

2.1. Photon collimator

Collimator in a bremsstrahlung photon facility provides transport of produced bremsstrahlung photon beam from accelerated electron beam to the experimental field and focus on the target, on which experiment has to be performed. In this study, using FLUKA code we have designed cone geometry with an entrance radius of 0.25 cm and exit radius of 1.4 cm to be used as a collimator geometry. The geometry of the outer part of the collimator was designed as a cylinder with a radius of 6 cm (Fig. 1). As shown in the Fig. 1, the cylinder has a cone-shaped tunnel drilled in it. The model was oriented along the z direction in FLUKA. The inside of the collimator was set as vacuum environment, and the collimator materials were set as Al, Cu and Fe.

At the TARLA bremsstrahlung photon facility, bremsstrahlung photons with energy up to 80% of the energy of electrons, which come to the radiator, can be obtained [7]. For this reason, the simulations were carried out with the approach of producing photons with 8, 16, 24 and 32 MeV energies from 10, 20, 30 and 40 MeV energy electrons, respectively.

2.2. Energy deposition and temperature rise

In this study, interactions of photon beam and collimators made of aluminum, copper and iron were simulated using FLUKA Monte Carlo code, which is used in calculations of particle transport and interactions of particles with matter [8]. In these simulations the energy deposition on the collimator materials was calculated. The simulations were run by making three cycles for 10^6 photons.

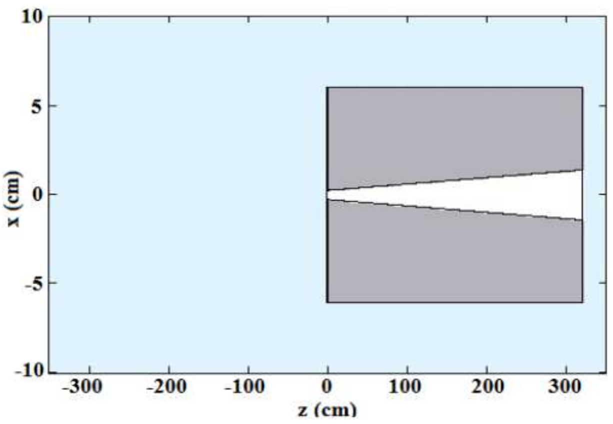

Fig. 1. The geometry of collimator in FLUKA.

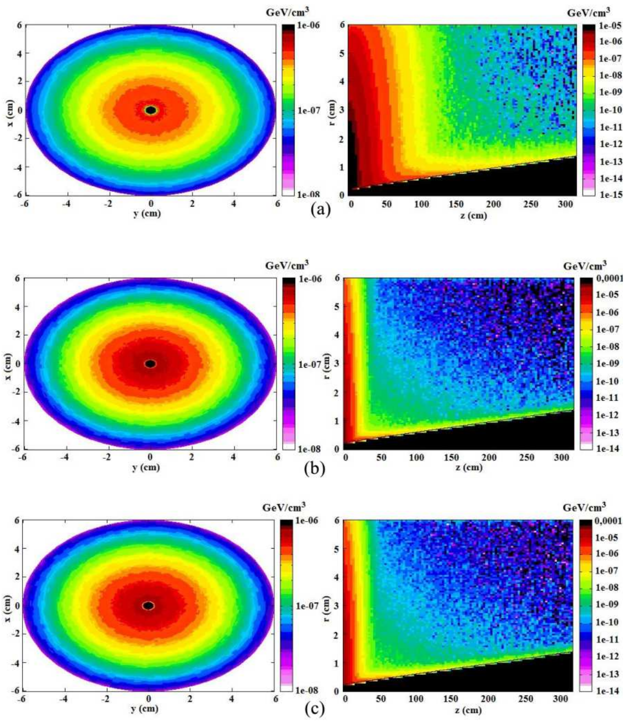

Fig. 2. Energy deposition distribution on (a) Al, (b) Cu, (c) Fe collimator for 8 MeV photon energy.

Energy deposition distribution in R-φ and R-z planes for Al, Cu and Fe collimators, for the lowest (8 MeV) and the highest (32 MeV) possible energy photon beam are shown in Figs. 2 and 3.

Figures 2 and 3 show that the highest energy deposition is in the collimator entrance zone. It is seen from figures that when moving away from centre of the collimator the deposited energy decreases.

Values of deposited energy for Al, Cu and Fe collimators for four different photon energies are given in Table I.

When the results in Table I are examined, the smallest energy deposition is observed for Al collimator and the maximum deposition is observed for Cu collimator. As the photon beam energy increases, the deposited energy also increases.

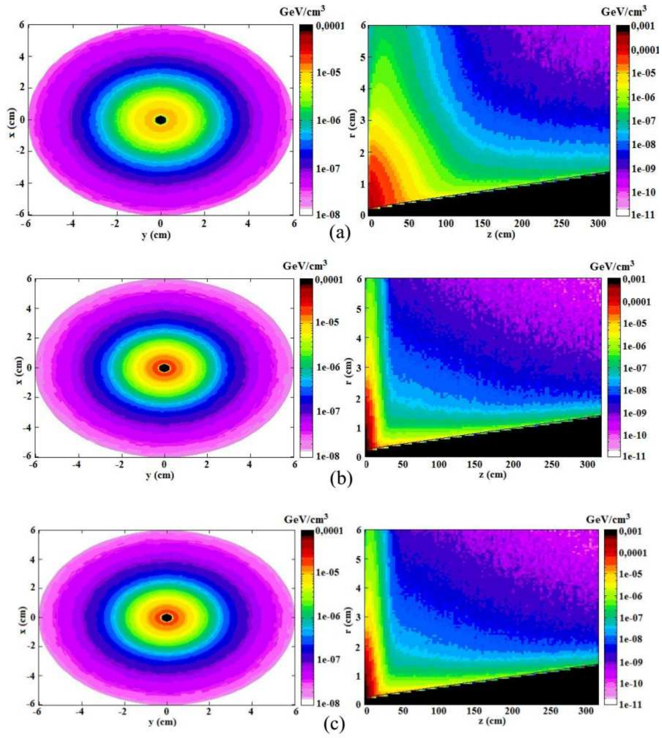

Fig. 3. Energy deposition distribution on (a) Al, (b) Cu, (c) Fe collimator for 32 MeV photon energy.

TABLE I

The energy deposition on Al, Cu, Fe collimators for various photon energies.

Collim.	Energy deposition [GeV/cm^3]			
Mater.	8 MeV	16 MeV	24 MeV	32 MeV
Al	6.34×10^{-3}	1.43×10^{-2}	2.14×10^{-2}	2.80×10^{-2}
Cu	7.34×10^{-3}	1.54×10^{-2}	2.30×10^{-2}	3.04×10^{-2}
Fe	7.28×10^{-3}	1.54×10^{-2}	2.29×10^{-2}	3.02×10^{-2}

The temperature change of any material depends on amount of energy deposited on the material as follows [1]

$$\Delta T = \frac{\Delta Q}{m c_v}, \quad (1)$$

where ΔQ is the energy deposition on the collimator material [J], m is the mass [kg] and c_v is the heat capacity [J/(kg K)]. Heat capacity of Al, Cu and Fe is given in Table II [9]. Values of temperature rise were calculated for each material and this values are given in Table III per photon.

When the energy of the photon beam increases, it is shown that there is alteration of temperature rise in the collimator in Table III and the highest temperature increase occurs in Al collimator. As these values of temperature rise are compared with the melting point (Table II) of the collimator materials, this increase is found to be very small.

TABLE II

Some features of the materials used in the collimator simulations

Collimator material properties	Al	Cu	Fe
Melting point [°C]	660.32	1084.62	1538
Melting point [K]	933.47	1357	1811
Heat capacity [kcal/(kg °C)]	0.22	0.092	0.108
Heat capacity [kJ/(kg K)]	0.91	0.39	0.45

TABLE III

Temperature rise induced in Al, Cu and Fe collimators for various photon energies.

Collimator	Temperature rise ($\times 10^{-13}$K)			
Materials	8 MeV	16 MeV	24 MeV	32 MeV
Al	4.225	9.532	14.280	18.692
Cu	3.439	7.232	10.778	14.208
Fe	3.365	7.105	10.586	13.943

3. Conclusions

In this study we have focused on the temperature rise of the collimator material, to determine the most suitable collimator material. The energy deposition on collimator materials of Al, Cu and Fe by photon beam with 8–32 MeV energy was simulated using FLUKA code (Table I). These values were used to calculate the temperature rise of the collimators. The temperature rise for each collimator material and each photon beam energy were calculated using Eq. 1 (Table III). As a result, it has been found that the highest temperature rise occurs in Al collimator, however these values are very small when compared to the melting points (Table II) of the materials. For this reason, it is understood that the temperature change is an observable parameter in this energy range for Al, Cu, Fe materials.

Acknowledgments

This work has been supported by State Planning Organization of Turkey under project number of DPT2006K-120470 and Suleyman Demirel University Foundation Unit (BAP) with the project number 3407-D2-12.

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