

Modeling of x-ray attenuation on SS316 metal

by Fajar Arianto

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Modeling of x-ray attenuation on SS316 metal foam shielding using MCNPX

E Hidayanto, W S Budi and F Arianto

Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia

Email: ekohidayanto@fisika.fsm.undip.ac.id; wahyu.sb@fisika.fsm.undip.ac.id; ariantofajar@gmail.com

Abstract. The use of lead plates as shielding to X-ray radiation has the disadvantages of being heavier and not environmentally friendly when compared to other materials. Currently, metal foam technology is developed that is expected to be close to the ability of lead plate as a radiation shielding that is lighter and environmentally friendly. This research was conducted by modeling SS316 stainless steel plates and foams for the thickness of 5-40 mm, the diameter of 2, 3, and 4 mm at an energy of 0.1, 0.662, and 1 MeV. The metal plate and foam modeling were carried out using the program of Monte Carlo N-Particle eXtended (MCNPX). Calculation of X-ray attenuation from the modeling results shows that SS316 stainless steel performance both in the form of plates and metal foams is almost equivalent to pure lead. From these results, it can be concluded that metal foam technology is expected to be a lighter and environmentally friendly lead-in radiation retaining material.

1. Introduction

The radiation containment system in the radiology room in the hospital is a crucial part. The system functions as a barrier to the scattering of radiation energy produced by the X-ray machine so that it does not directly affect the radiation officers or the families of patients waiting outside the radiology room. Radiation containment systems in radiology rooms are generally made of concrete and lead plates. But this radiation-based retaining system turned out to have weaknesses. The main disadvantages of these protective materials are their high density, poor engine capability, and low mechanical stability. Likewise, a radiation barrier made from lead has a weakness in weight and not environmentally friendly.

Research on the use of radiation retaining agents that are more effective than concrete and lead is continued to be carried out with current technological developments. It has been reported that barium enriched with concentrates exhibits excellent compressive strength and abrasion resistance as a barrier to X-ray radiation, proportional to lead [1]. Similarly, barium-based materials, such as silicon nitrate [2] and barium aluminum silicate for microstructure as composites [3, 4] can also increase the ability to restrain X-ray radiation. Composites of barium aluminum silicate, iron phosphate [5], titanium iron oxide [6], calcium, and magnesium contain iron and aluminum which can increase the ability of materials to prevent X-ray radiation.

One of the materials developed as a barrier to X-ray radiation is metal foam. The metal foam material is made of hollow metal balls that are embedded in a metal matrix. This metal foam material shows attractive attenuation properties with exceptional energy absorption properties, has mechanical properties, and the ability to protect secondary gamma rays as seen in metal foams from paraffin, boron



carbide materials [7, 8], and silicon rubber/paraffin [9]. Other types of metal foams from aluminum also show potential as a protective material with advantages in high energy absorption and excellent heat rejection ability [10].

The unique structure and characteristics of metal foam motivate the creation of other types of metal foam material by varying the parameters used such as percentage of material, the thickness of the material, and diameter of the hollow sphere. The variation of metal foam material parameters is performed to improve its physical quality, one of which is strength and increase the absorption of X-ray radiation. Therefore, it is necessary to explore further the feasibility of variations in metal foam material for X-ray radiation barrier applications.

6 Assessment of some parameters of the properties of materials can be carried out by modeling. The Monte Carlo N-Particle Transport Code (MCNP) is one that was developed to verify the accuracy of the observed material properties and the microstructure has been developed. Chen et al. Have developed MCNP modeling on steel-steel composite metal foam (S-S CMFs) and aluminum-steel composites (Al-S CMFs) with various ball sizes and matrix materials for nuclear and radiation environmental applications [11, 12]. Gedik and Baytas in 2015 have also examined metal foams made from SiC and Al₂O₃ [13].

1 In this study, the exploration of metal foam material as a radiation barrier is carried out by modeling using the Monte Carlo N-Particle eXtended (MCNPX) program. In modeling the metal foam material, the parameters varied are ball diameter, thickness, and energy used. The results of the calculation of the attenuation value of X-rays in metal foam material will be compared with the attenuation value of X-rays in the material retaining pure lead radiation, both in the form of metal foam and plates.

2. Experimental Methods

In the radiation barrier modeling system, metal foam material will be formed into plates like a radiation barrier in general. The variation of metal foam material specifications used in this study are cavity diameter 2, 3, and 4 mm stainless steel radiation retaining material (SS316) and pure lead, energy used is 0.1; 0.662; and 1 Mev, the thickness of the radiation barrier from 0.5 to 4 cm with the distance between the radiation source and the detector being 45 cm (according to Figures 1a and 1b). Metal foam modeling in this study was carried out using the Monte Carlo N-Particle eXtended (MCNPX) program which has several stages, namely designing the geometry, determining the surface boundaries, entering the required material data and parameters to be searched, running, and the calculation of the X-ray attenuation value using the absorbed dose value of the material. MCNP (Monte Carlo N-Particle) is a multipurpose calculation code for the transport of neutrons, photons and electrons that is continuous energy, generalized geometry, and time-dependent developed by Los Alamos National Laboratory, University of California United States [14]. Meanwhile, MCNPX is the result of the development of MCNP version five which has been equipped with several new features, one of which is the burn-up facility [15]. This program package also deals with electron transport, both the source of electrons and secondary neutrons that occur due to gamma-ray interactions. This system uses a nuclear data library from ENDF/B-VI. Using nuclide data from ENDF/B-VI, MCNPX will perform calculations and produce microscopic and macroscopic cross-sectional data from each metal foam material probabilistically to find absorbency dose values.

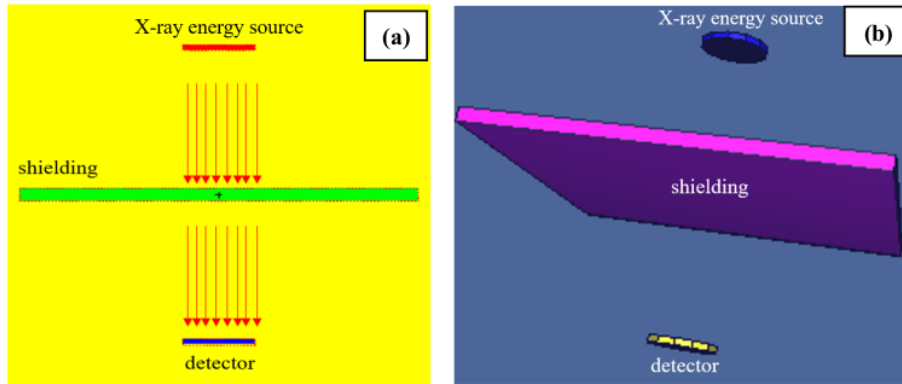


Figure 1. Research modelling in (a) 2D (b) 3D.

The calculation phase of the absorption dose begins with the preparation/creation of the input file using notepad ++ software. The MCNPX input file consists of three main parts, namely cell card, surface card, and data card. The cell card shows the number of cells or geometry sections to be made. The surface card contains the surface data involved in forming cells in this metal foam modeling, while the data card contains data about the specifications of the material used, X-ray energy, the position of the radiation detector, and other supporting parameters. Execution is carried out in a Windows system environment equipped with Total Commander. The MCNPX input file is run using the total commander to obtain dose data using the F6 tally. This study using an X-ray energy source directed at the radiation barrier in the form of metal foam. The study was conducted with variations in the rate of radiation doses without a radiation barrier to determine the initial dose coming out of the radiation source. Then the measurement of the dose rate is carried out using a radiation barrier. The radiation dose rate was measured using a radiation detector placed 22.5 cm from the location of the radiation barrier. The results of the MCNPX calculations for geometry will be presented in the form of images, while for the absorbed dose values in the variation of the thickness of the radiation barrier, the energy used, and the diameter of the hollow spheres will be processed into the graphical form using Microsoft Excel software.

3. Results and Discussion

Some data obtained from this study, the transmission value for variations in the thickness of the radiation barrier on the variation of source energy and the geometrical appearance of metal foam material. The geometry of the metal foam material modeling using MCNPX is presented in Figure 2. The white circle is the air cavity, and the green color is the metal.

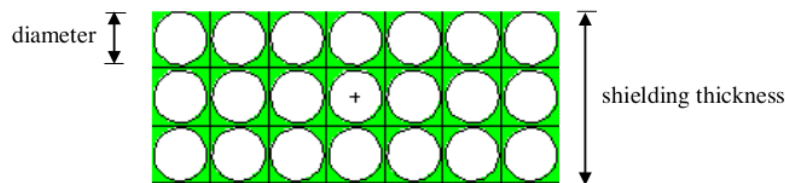


Figure 2. Metal foam material from MCNPX modeling.

In figure 2 which is a geometrical display of metal foam material from the MCNPX modeling results, it can be explained that the metal foam material in this study is SS316 stainless steel metal plates in which there are cavities with varying diameter sizes of 2, 3, and 4 mm. The purpose of the existence of

hollow spheres is to reduce the volume of metal material used, but it is expected that its ability to restrain X-ray radiation can approach the ability when shaped solid plates. The geometry display will then be used for the verification of the compiler material data card and the F6 tally calculation. The results of the F6 tally calculation in conditions without radiation retaining material will then be compared with conditions when there is radiation retaining material which is later to determine the transmission value. The calculation result of X-ray attenuation transmission starts at 0.1 MeV energy for variations in the diameter of metal foam material from 2 to 4 mm with a radiation barrier thickness of 0.5 to 4 cm (according to Figure 3).

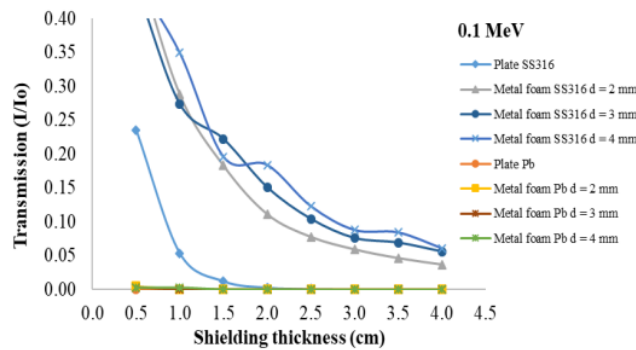


Figure 3. Relationship of changes in transmission value (I/I_0) to the thickness of the radiation barrier at the energy of 0.1 MeV.

In Figure 3 it can be analyzed that at 0.1 MeV energy, the transmission value of the SS316 plate is higher than the transmission value of the Pb plate. That is because Pb absorption is greater than SS316 stainless steel. Likewise, the transmission capability that occurs in metal foam conditions. However, it is interesting that the attenuation ability of metal foam conditions does not differ greatly with the ability to attenuate on the plate shape. This can be interpreted that the shape of metal foam which needs less material is still able to approach the ability to form plates. Ball cavity diameter affects the attenuation ability, the smaller the diameter of the ball cavity, the smaller the transmission value, which means the greater the attenuation value. The same phenomenon also occurs at 0.662 MeV and 1 MeV energy. The results of the calculation of transmissions at 0.662 MeV and 1 MeV energies are respectively presented in Figures 4 and 5.

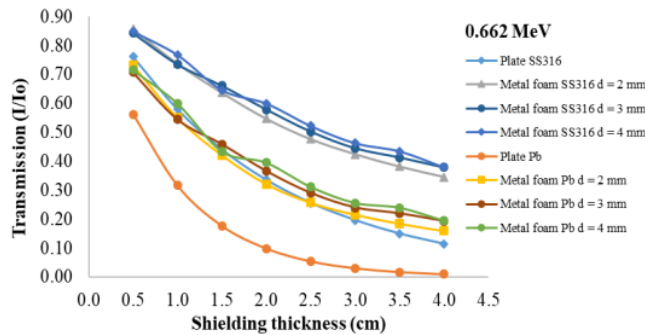


Figure 4. Relationship of changes in transmission value (I/I_0) to the thickness of the radiation barrier at the energy of 0.662 MeV.

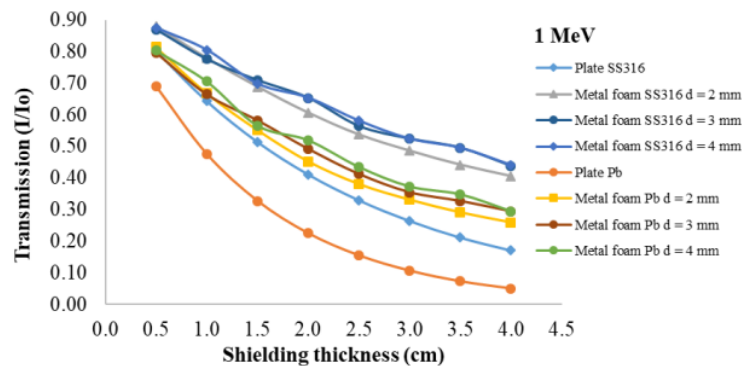


Figure 5. Relationship of changes in transmission value (I/I_0) to the thickness of the radiation barrier at the energy of 1 MeV

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The results of this study are consistent with previous studies conducted by Chen et al [11] for some radiation-retaining agents. It can be concluded that the ability to restrain radiation of metal foam made from stainless steel SS316 can approach the attenuation ability of a radiation barrier made from pure Pb.

4. Conclusions

SS316 metal foam technology has been successfully modeled using Monte Carlo N-Particle eXtended (MCNPX) which produces a material with attenuation capability close to that of the pure lead plate. Metal foam technology is expected as a lighter and environmentally friendly material so that in the future, can be used to replace the pure lead plates as radiation barriers.

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Acknowledgments

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