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Comparison Of Gamma Ray Shielding Strength Of Lead, Aluminium And Copper From Their Experimental And MCNP Simulation Result

Nwosu, O. B

Department of Physics and Industrial, Nnamdi Azikiwe University Awka, Anambra state, Nigeria
Email: bo.nwosu@unizik.edu.ng, Zigma02@yahoo.com

Abstract: Gamma ray shielding experiments and simulation of it with MCNP code was carried out with three metallic materials; Copper, Aluminium and Lead using 10mCi 0.662KeV Cs-137 gamma ray source. The study was to understand the attenuation strength of these materials in relation to one another; and the behaviour of the emergent photon intensities in relation to the thickness of the shield. These materials of different thicknesses were placed in turns behind the radiation source and the emergent radiation was counted using NaI (TI) detector. These arrangements were again simulated using MCNP4c codes and the results equally presented and compared with that from the experiment.It was discovered that photon shields, unlike those for charged particles, are governed by the exponential decay law and the flux of shielded photons is a complex mixture of scattered and unscattered photons; and that increase in the thickness of the absorber lowers the photo peak intensity detected.It was equally noticed that while only 0.6cm thickness of lead was required to reduce the gamma photon intensity to half of its original value, about 1.8cm of Copper and 3.6cm of aluminium was required to do the same work lead has done, showing lead as a far better absorber of gamma photon than copper and aluminium and can be used to shield against gamma ray; in turn, copper is a better absorber than aluminium. The relationship in the absorbing properties of these three materials in terms of their half thickness $\mathbf{th}^{1/2}$could be expressed thus:$\mathbf{th}^{1/2}_{lead}$ =1/3$\mathbf{th}^{1/2}_{copper}$ = 1/6$\mathbf{th}^{1/2}_{aluminium}$. Interesting to note isthe striking similarities between the two sets ofgraphs fromMCNP simulation and experiment.This goes to show the simulation work as veritable tool for modelling certain real life situations, and very useful in particles transport equations.

Keywords: Nuclear radiation shielding, gamma rays, MCNP simulation, linear attenuation coefficient

1.0 Introduction:

Shielding remains an important aspect of radiation physics. Radiation shielding is very pertinent in nuclear industries as well as in radioisotopes production and usage, and in particle accelerator facilities (NCRP, 1977). Materials for shielding gamma rays are typically measured by the thickness required to reduce the intensity of the gamma rays by one half (the half value layer{$\mathbf{th}^{1/2}$} or (HVL)(Kaplan, 1989,). When we make shielding calculations, we are more concerned amongst other things about the thickness of the material used in the shielding, the minimum thickness that could give us the maximum shielding from the emitting source, or even 99%. The knowledge of this thickness is an indication of the minimum thickness we have to use in order to ensure appreciable protection from that source.For each of the materials Lead, aluminium and copper used, the density of each is a known constant, our radiation source intensity (I_o) is known and it's constant throughout the experiment for each material, the attenuation constant at a certain emitting energy level is also known (Hubbell and Seltzer, 1995; Etherington, 1958). The only parameter varied here was the thickness of the chosen shield so as to find the emergent beam intensity for that thickness paying attention to see when our initial intensity have been reduced to half and the thickness at which this happened.Comparisons have been made between the shielding result from laboratory experiment and MCNP simulations. The shielding efficacy of the three metallic materials; Copper, Aluminium and Lead have equally been compared. The curves gotten from experimental results have been presented as well as the ones from MCNP simulations; these two results were then compared.

2.0 Shielding Experiment and its theoretical background:

The change in intensity of a photon in good geometry as expressed in (James, 2004; Morgan and Turner, 1967;Knoll, 2000etc) is usually expressed mathematically as a decreasing function with thickness of absorber;

$$-\frac{dI}{dx} = \mu I \qquad \text{..........................2.1}$$

μ is the constant of proportionality which is the total attenuation coefficient of the medium for the photon of interest and I is the photon intensity. The number or intensity I(x) of photon penetrating an absorber of thickness x can be found by rearranging and integrating

$$\int_{I_O}^{I(X)} \frac{dI}{I} = \int_{O}^{x} -\mu dx$$

$$\text{to yield}$$

$$Ln\, I(x) - Ln I_O = -\mu x$$

$$\text{or}$$

$$Ln\, I(x) = -\mu x + Ln I_O \qquad \text{................2.2}$$

This is an equation of straight line with a slope of $-\mu$ and a y-intercept(i.e with no absorber) of $\ln I_O$. This can be simplified by the law of logarithms to

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$$-Ln\frac{I(x)}{I_o}=-\mu x$$

And since the natural logarithm of a number is the exponent to which the base e is raised to obtain the number, this expression translates to

$$\frac{I(x)}{I_o}=e^{-\mu x}$$

$$I(x)=I_o e^{-\mu x} \qquad \text{..............................2.3}$$

Equation 2.3 is the exponential decay equation describing the intensity at a particular thickness(x) and is the main guiding equation for the experiment. I_o is the intensity of the incident beam, $I(x)$ is the intensity after traversing a distance x through the absorbing medium and μ the linear attenuation coefficient is the probability of interaction per unit distance in an absorbing medium.

2.1. Materials used in the experiment

This shielding experiment was carried out in the Olive lodge laboratory University of Liverpool. The materials used, their snapshots and brief descriptions are presented.

2.1.1 NaI (TI) detectors: This was used to count the gamma ray emitted from the source. It is shown in fig 1 below with cylindrical lead shield surrounding it.

Fig1: *The NaI (TI) detector with cylindrical lead shield surrounding it*

Photo peak is created when gamma ray interact in the scintillator via the photo electric effect; more on this can be found in (Knoll, 2000; Lilly, 2001).

2.1.2 Gamma ray source: 10mCi Cs-137

This was used to provide the needed gamma rays used in the experiment. The source has an activity of 324KBq,and emits gammaray of energy 0.662MeV.

2.1.3 Absorber materials used

Lead, aluminium and copper of various thicknesses shown on fig2 below was used as the absorber, and the linear attenuation coefficient μ of these shields are a known constant at certain emitting energy

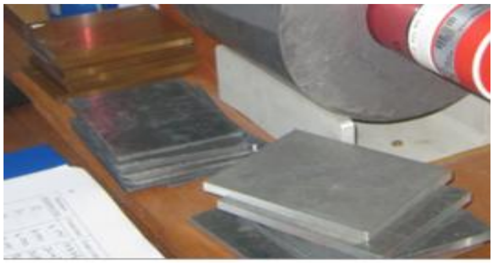

Fig2: *Various thickness of shielding material (Copper, Aluminium and Lead)*

(a) Lead
Linear Attenuation Coefficients of lead at 662KeV energy (μ) = 1.29 cm^{-1} (Etherington,1958)

(b) Aluminium,
Linear Attenuation Coefficients (in cm^{-1}) of aluminum at 662KeV energy (μ)0.21 cm^{-1}(Etherington, 1958)

(c) Copper,
Linear Attenuation Coefficients (in cm^{-1}) of copper at 662KeV energy (μ) = 0.67 cm^{-1} (Etherington, 1958)

2.1.4: The computer set-up:

The output from the detector was visualised and counted from the screen of the monitor as shown of fig3 below

Fig3 *The shield material, the NaI(TI) detector and the connections to the monitor*

2.1 Experimental set-up and results presentation:

These materials as described were arranged thus: the source- the shield material – the detector – connected to the out-put monitor. Each material was experimented with; the count rate against each thickness was tabulated and plotted out before moving onto the next metal. The result from each experiment(lead, copper, aluminium) have been presented here in tables1-3 and fig4-7.

2.2.1Copper absober

The experimental result obtained with copper showing decreasing photon intensity with increasing copper absober thickness has been shown on table 1 and fig.4

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Table1: *table of value for copper thickness against count rate*

Absorber Thickness(cm)	Count rate(Hz)
0.0	73.34
0.6	52.1
1.2	33.46
1.8	20.54

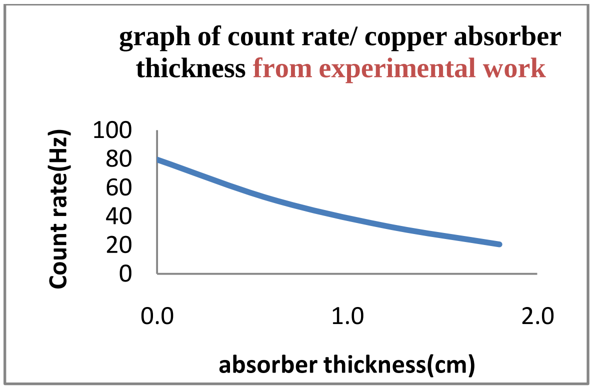

Fig4: *Exponential decrease of gamma photon count rate against copper thickness.*

2.1.2 Aluminiumabsorber

The experimental result obtained with aluminium showing decreasing photon intensity with increasing aluminium absober thickness has been shown on table 2 and fig.5

Table 2: *table of value for copper thickness against count rate*

Absorber thickness(cm)	Count rate(Hz)
0.0	73.34
0.6	66.62
1.2	57.49
1.8	52.21
2.4	44.49
3.0	37.83
3.6	34.53

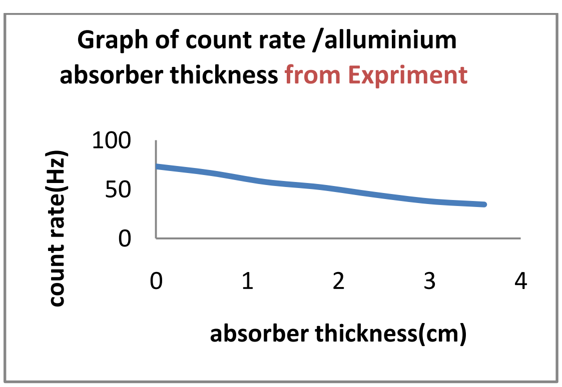

Fig5. *Exponential decrease in count rate against aluminium thickness*

2.2.3 Leadabsorber

The experimental result obtained with lead showing decreasing photon intensity with increasing lead absober thickness has been shown on table 3 and fig.6

Table 3: *table of decreasing count rate at increasing absober thickness.*

Absorber thickness(cm)	Count rate(Hz)
0.0	73.34
0.2	66.62
0.4	57.49
0.6	52.21

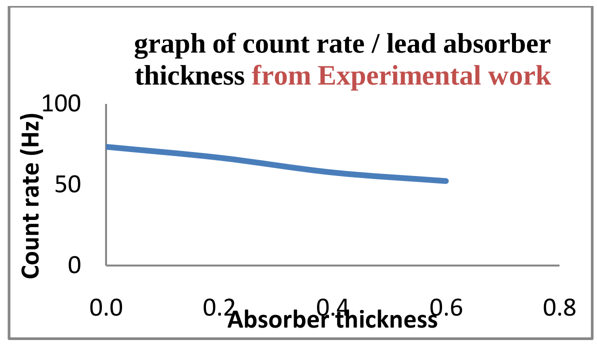

Fig5. *Exponential decrease of count rate with lead thickness*

The presented experimental results showed that the photo peak intensity which was always highest at 0 absorbers thickness, i.e. when no absorbing material was inserted (I_o) continues to decrease in intensity with increasing absorber thickness in each of the three materials. The graph also showed an exponential decrease in photon intensity as against increasing absorber thickness as has been theoretically predicted in (James, 2004; Morgan and Turner,1967;Knoll, 2000 etc

3.0 MCNP simulation and theoretical background

MCNP is an example of Monte-Carlo code like MCBEND, MONK, GEANT4. It is the general- purpose Monte Carlo N-Particle transport code that can be used to track for neutrons, photons and electrons. It uses a continuous – energy nuclear and atomic data libraries to treat three – dimensional configuration of materials in geometric cells bounded by first, second and third degrees (Andrew, 2000). The maximum line length in MCNP input file is 80 columns and it has a fixed structure that must be adhered to, if the programme is to give a reliable output. These are;the title card, Cell cards, Surface card, and Data cards. Each of these cards is defined using a series of commands containing parameters, starting each card on a new line. The important concepts that were followed in MCNP in-put files in this work include

Geometry (cells and surface): MCNP uses Cartesian axes of x,y,z and it's chosen arbitrarily.

- Cells card: used to define intersections, unions and complements of the regions bounded by the surfaces of our objects.
- Surfaces card: Defined by supplying coefficients to the analytic surface equations; with a combination of planes, spheres and cylinders we can construct simple geometric shapes as done here. To plot this geometry we use the command mcnpip n=filename (Andrew, 2000).
- **Source definitions card:** defined by using the source definition command (sdef card), which carries some parameter like
- Pos; for x, y, z position of our point source.
- Erg; which define the energy of the emitted particle, with energy distribution d1.
- **Tallies card (F's cards)**: This is used to specify the type of information we want to obtain from the MCNP simulation, like particle current, flux, energy etc .
- **Material specification Card**: Defines the isotropic composition of the materials in the cells and the cross section library to be used.
- Specific time we want the programme to run is usually set with the command ctme= 120. To run MCNP file we command as follows: mcnpixrz n=filename. When this computer time has elapsed, it will display 3 additional output files, but the one with the tag "o" has the output of our tallies from which we consider the particle flux against the set distance. (Andrew,2000; Oak Ridge National Laboratory 1966).

3.1 Simulation result presentation.

The result of the simulation work done with the three absorbers of different thickness each has been presented on tables4-6 and fig6-8

3.1.2Simulation with Copper absorber

Table4: *Decreasing photon intensity against increasing absorber's thickness*

Absorber Thickness(cm)	Photo pk int.
0.0	2.43E-02
0.6	1.97E-02
1.2	1.53E-02
1.8	1.15E-02

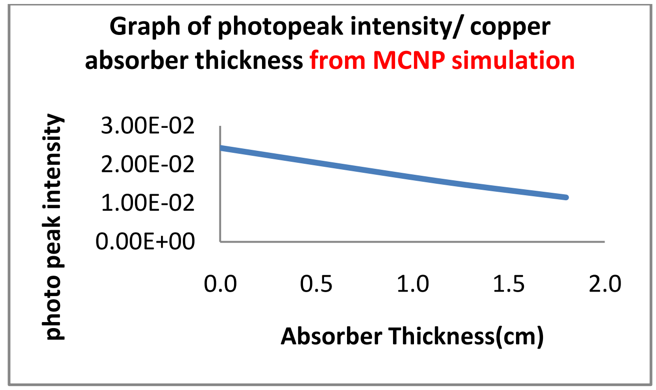

Fig6 *Exponential decay of photon intensity with increasing absorber thickness*

3.1.2Simulation with Aluminium absorber

Table5: *decreasing photon intensity against increasing absorber's thickness*

Absorber Thickness(cm)	Photo pk int.
0.0	2.71E-02
0.6	2.30E-02
1.2	1.90E-02
1.8	1.51E-02
2.4	1.16E-02
3.0	8.75E-03
3.6	6.49E-03

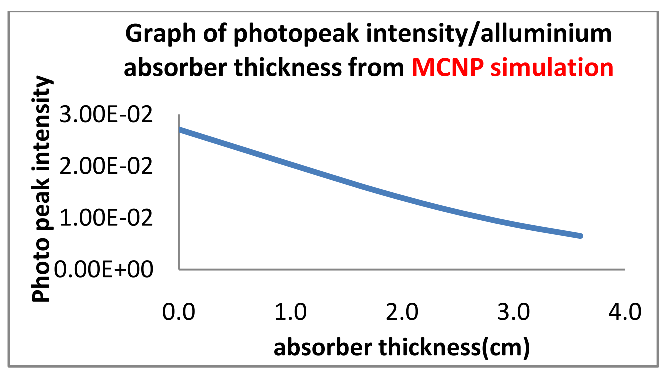

Fig7 *Exponential decay of photon intensity with increasing absorber thickness*

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3.1.3Simulation with Lead absorber

Table6: *decreasing photon intensity against increasing absorber's thickness*

Absorber Thickness(cm)	Photo pk int.
0.0	2.18E-02
0.2	1.76E-02
0.4	1.46E-02
0.6	1.20E-02

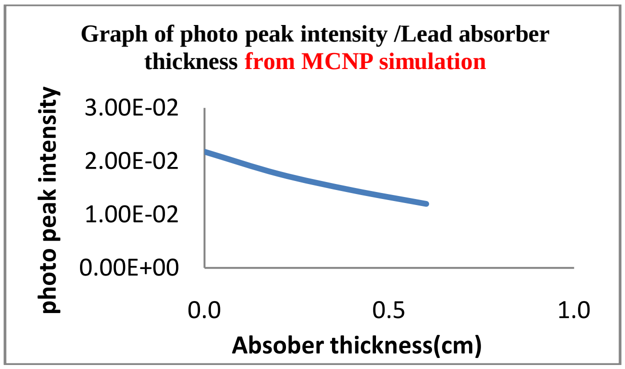


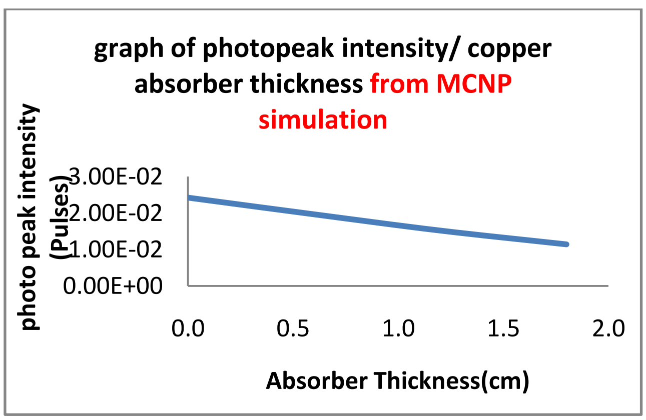
Fig7 *Exponential decay of photon intensity with increasing absorber thickness*

4.0 Results discussion

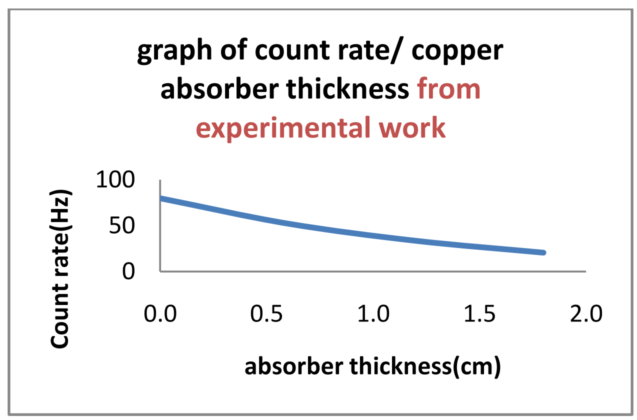
It has been observed that each pair of the three graphs has a similar behaviour, in that the photo peak intensity is inversely proportional to the absorber thickness in an almost exponential form. As the absorber's thickness increases, the photo peak intensity decreases; conversely as you reduce the absorber's thickness, the photo peak intensity increases. This isimaginable, since the absorber is to shields, absorbs or reduces the number of photons going into the detector, then the more you increase its thickness the more it does this work and the lesser the photons that get to the detector and then the lower the number of counted photons.The exponential relationship for photon absorption suggests that, theoretically, complete absorption of beam of photon radiation never really occur, but in a practical sense exponential attenuation and absorption can be used to reduce most of the beam intensities to imperceptible levels.

4.1Experimental and MCNP simulation result comparison:

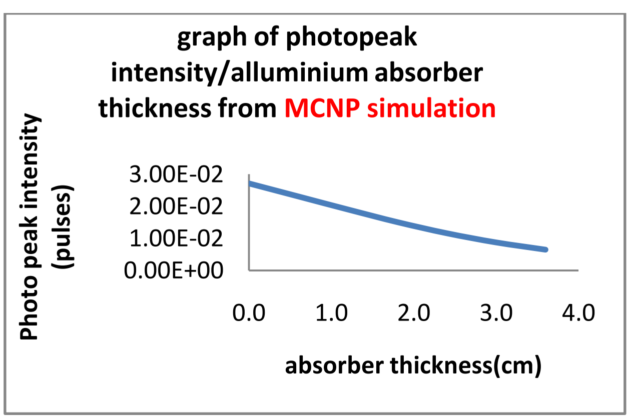
For comparison of the simulation work and the practical work, two sets of plots for each absorber material (copper, aluminium and lead) from the MCNP simulation work and the practical work have been juxtaposed here in fig8(a-c) for easy visualisation.



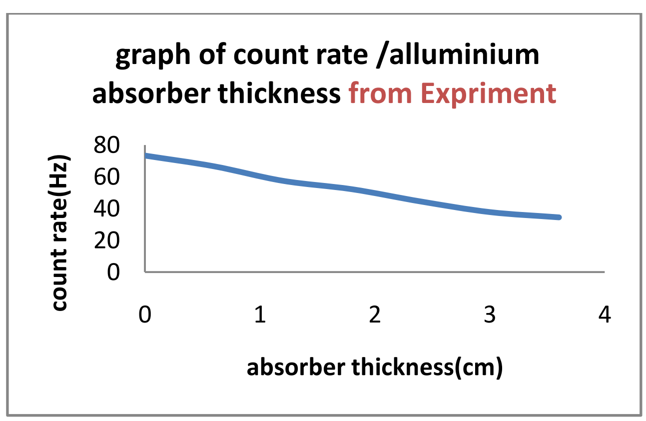
A1:graph from MCNP simulation(Copper).



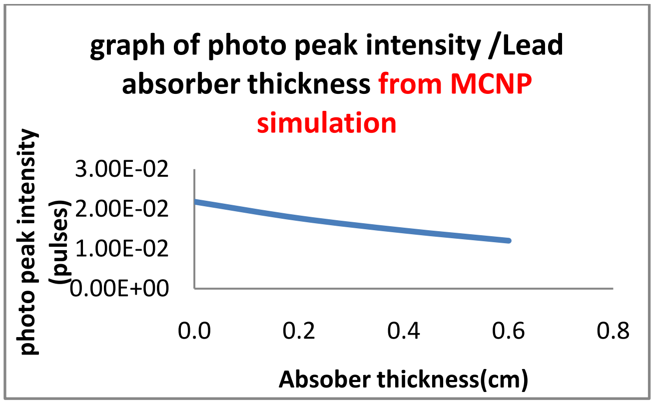
A2: Graph from the laboratory experiment (Copper)



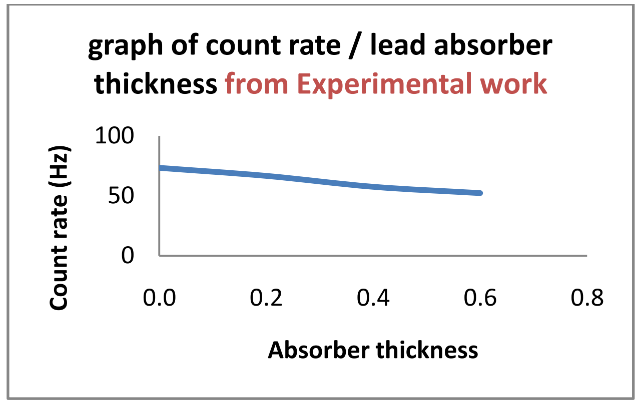
B1.Graph from MCNP simulation (Al.).



B2. Graph from the laboratory experiment (Al)



C1Graph from MCNP simulation (Lead).



C2: Graph from the laboratory experiment (Lead)

Figure 8 *a-c graphical display of MCNP and laboratory shielding work using three materials*

4.2 Absorber's properties compared:

From a distance, the graphs of these three absorbing materials (Lead, Aluminium and Copper) look very similar, but on a closer look, one will identify a striking and important differences amongst these three materials especially lead. While only 0.6cm thickness of lead is required to reduce the gamma photon intensity or photo peak to half of its original value, about 1.8cm of Copper and 3.6cm of aluminium is required to do the same work that lead has done. This then goes to show that lead is a far better absorber of gamma photon when compared to Copper and aluminium and can be used to shield against gamma ray. in turn, copper is a better absorber than aluminium. Hence from personal perspectives and deductions, if $\mathbf{th}^{1/2}$ is taken as the half thickness, then the relationship in the absorbing properties of these three materials in terms of their half thickness could be expressed thus:

$$\mathbf{th}^{1/2}{}_{lead} = 1/3\mathbf{th}^{1/2}{}_{copper} = 1/6\mathbf{th}^{1/2}{}_{aluminium}$$

In conclusion, MCNP simulation is a veritable tool for modelling certain real life situations, and very useful in particles transport equations.The above graphs have also shown that out of the three materials, lead is a better shield because it requires just a few thicknesses of it to cut down the photon intensity to half its original value, then followed by copper and aluminium being the least.

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References:

[1] Andrew Boston; Introduction to MCNP-the Monte Carlo transport code Olive Lodge LaboratoryPp 20-40 2000

[2] Etherington, H; Nuclear Engineering handbook, McGrawl –Hill book companyInc.pp 7-61: 7-111, 1958

[3] Hubbell, J. H., Seltzer S. M., Tables of X-Ray Attenuation Coefficients and MassAbsorption Coefficients 1 keV to 20 MeV for Elements Z = 1 to 92 and 48 Additional Substances of Dosimetric Interest, NIST, Gaithersburg, MD.pp 30-50,1995

[4] James E M, 2004. Physics for Radiation Protection: A Handbook; WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim. 116- 220pp 20-100

[5] Kaplan M.F, Concrete Radiation Shielding, John Wiley & Sons, New York, USA pp 50-120' 1989

[6] Knoll G F, Radiation detection and measurements; third edition; John Wiley and sons Inc.pp 711-721, 2000.

[7] Lilley J,.Nuclear physics principles and application; John willey& sons; pp4-200; 2001

[8] Morgan, K. Z., Turner J. E., Principles of Radiation Dosimetry, JohnWiley , New York.Pp 15-30,1967

[9] NCRP, Radiation Protection Design Guidelines for 0.1–100 MeV Particle AcceleratorFacilities, 1977(Report No. 51, National Council on Radiation Protection and Measurements, Bethesda, MD).

[10] Oak Ridge National Laboratory Radiation Shielding and Information Center1966,(Report 10, Oak Ridge, TN).