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Monte-Carlo Simulation and Measurement Of Gamma Ray Attenuation in Concrete

Joshua Pondo & Dr. Nadir Hashim

Kenyatta University-Kenya

THE PRESENTATION OUTLINE

1. Introduction

2. The Measurement

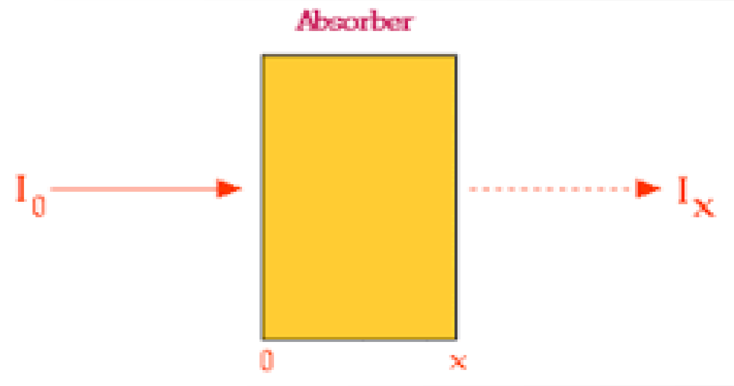
3. GEANT4-Based Simulation

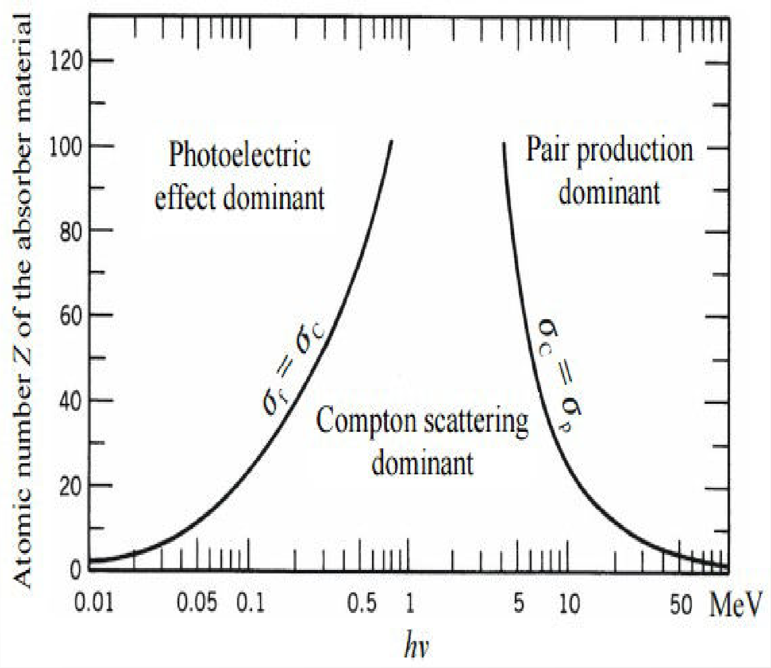
4. Analysis

4. Conclusions

INTRODUCTION
The background information

- Gamma ray attenuation is the reduction in gamma ray intensity as it passes through a material.
- This is mainly via the processes
  i. Photoelectric effect.
  ii. Compton effect.
  iii. Pair production.
- These processes predominates in different photon energy ranges as shown alongside.





Studied Attenuation Parameters

- Linear attenuation coefficient
- Half Value Layer
- Mean Free Path
- Mass attenuation coefficient

The background information

- Gamma ray attenuation studies: experimental and theoretical
- Theoretical approaches: Monte Carlo simulation, Analytical
- Monte Carlo simulation:
  - Statistical approach of deriving a macroscopic solution to a problem by the use of random numbers.
  - Involves random sampling of probability distribution functions that describe the problem.
- Some particle transport simulation codes: EGS, MCNP and FLUKA, GEANT4

GEANT4 APPLICATION

High Energy Physics

Nuclear Physics

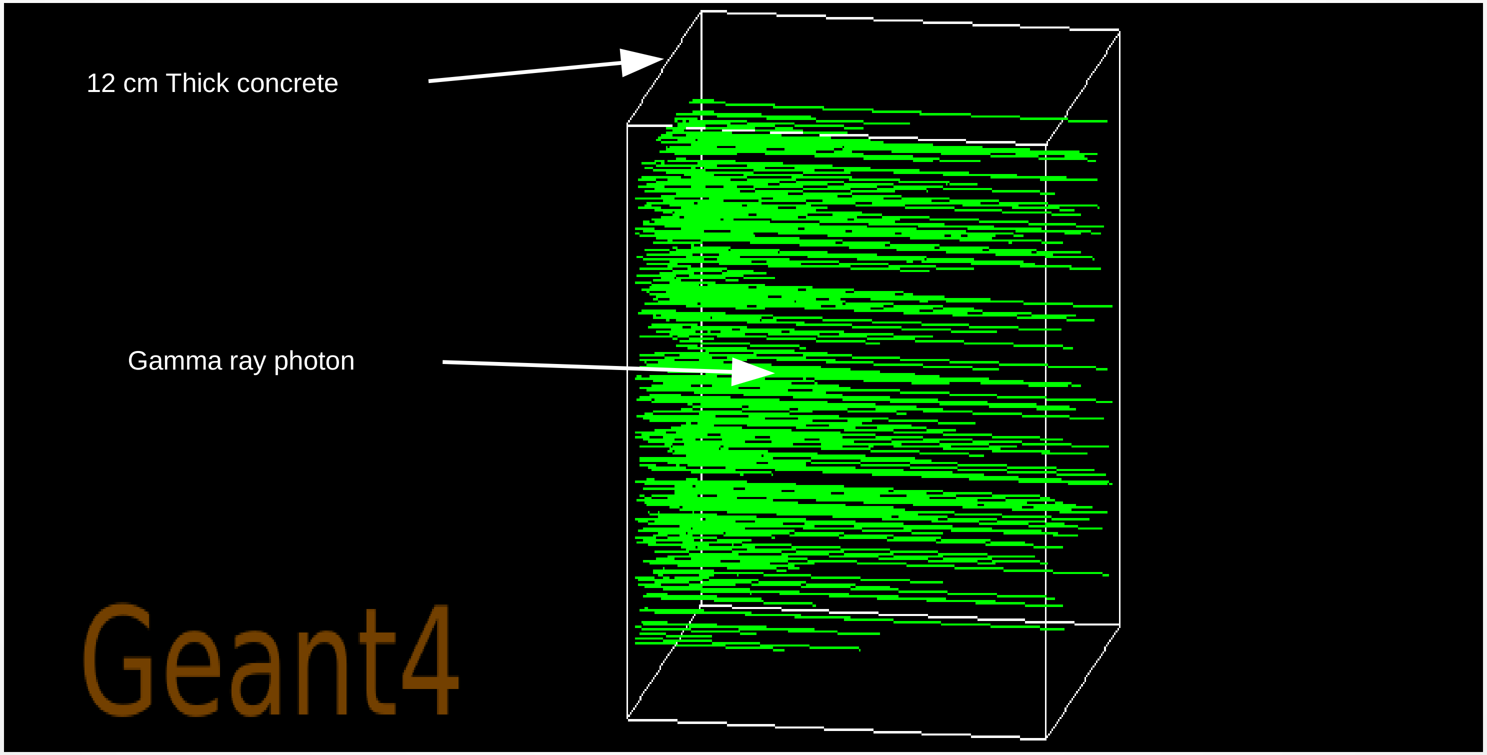
Accelerator Physics

Medical Physics

Space science

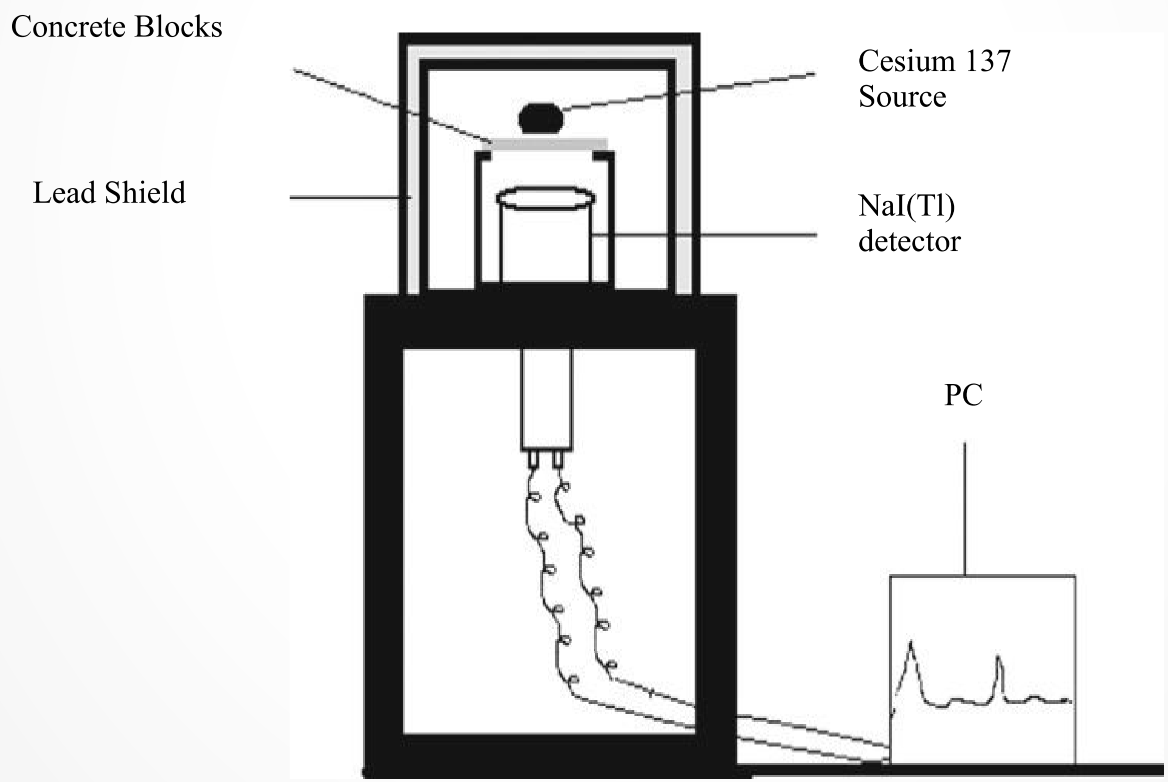
Sample GEANT4 run output

Define simulation parameters: Geometry, magnetic Field, particle Definition, generation and Tracking, the physics process involved, visualization etc



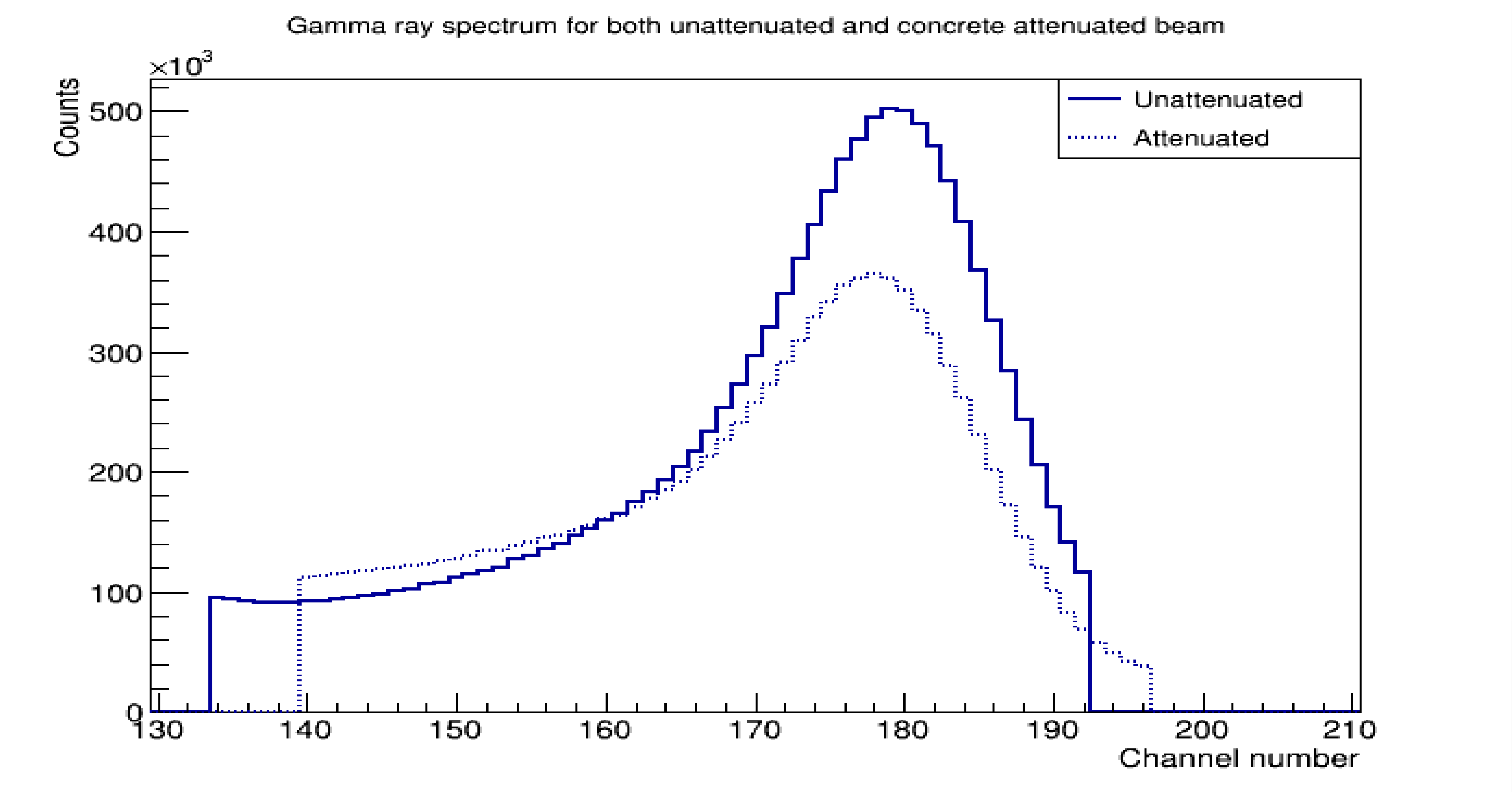
The Measurement

The narrow beam transmission method used for measurement



The Measurement

The following is the **spectrum** obtained from the NaI(Tl) at the ROI region for both attenuated and unattenuated gamma ray beam.



RESULTS AND DISCUSSION

Simulated and Measured Intensity variation with concrete Thickness

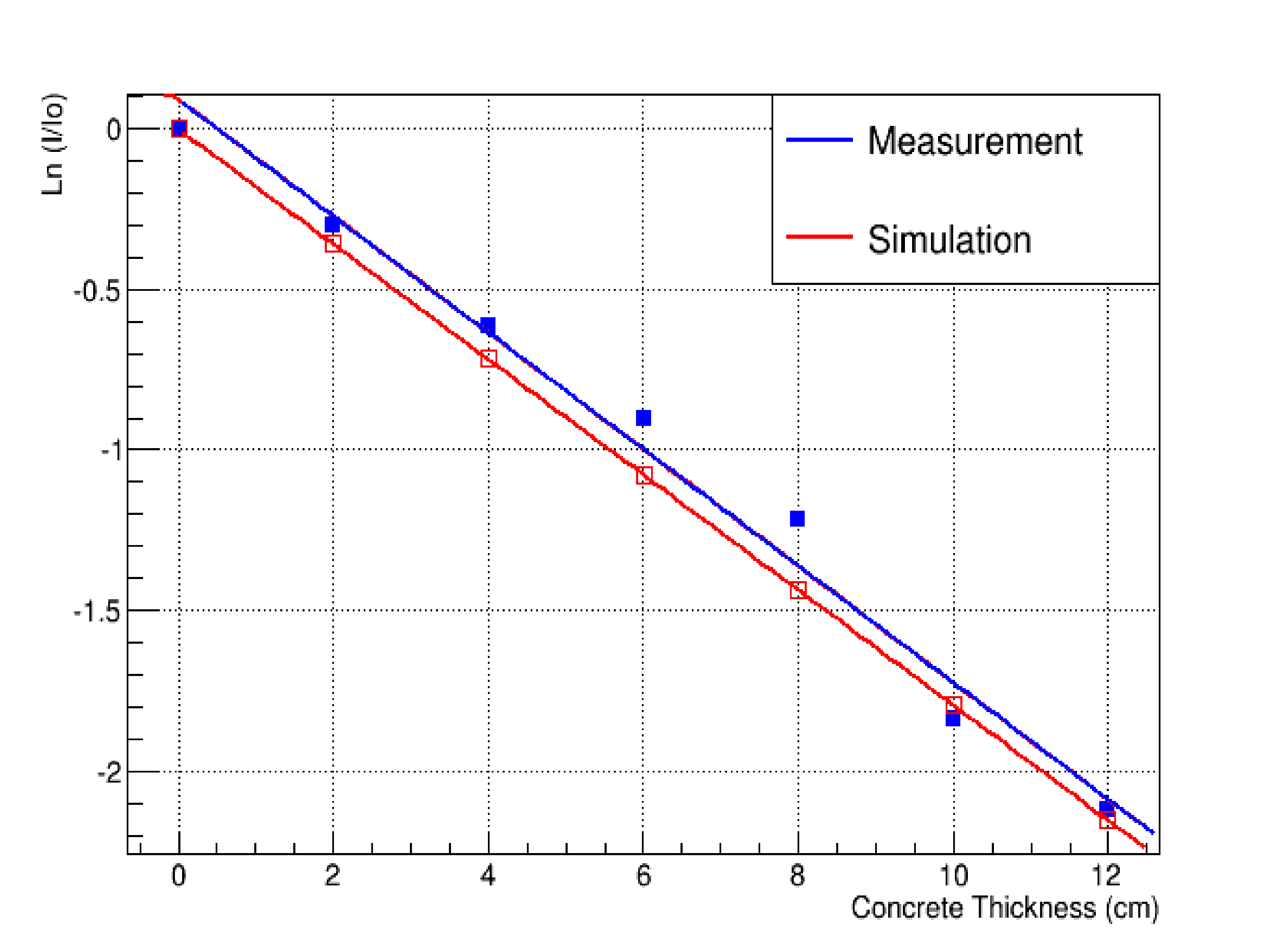
Concrete Thickness(cm)	INTENSITY (cpm)		Natural logarithm of (I/Io)	
	GEANT4 Simulation	Measurement	GEANT4 Simulation	Measurement
0.0±0.0	1168089	1168089±497	0.0000	0.0000±0.0006
2.0±0.2	814987	865861±445	-0.3600	-0.2993±0.0007
4.0±0.4	569724	632546±386	-0.7181	-0.6134±0.0007
6.0±0.6	397033	473300±340	-1.0791	-0.9034±0.0007
8.0±0.8	277608	345657±327	-1.4367	-1.218±0.001
10±1	194101	186341±234	-1.7946	-1.836±0.001
12±1	135849	140685±210	-2.1516	-2.117±0.002

The Linear Attenuation Coefficient

- This is the fraction of the incident photon beam intensity that a unit thickness of the material is able to absorb as the beam passes through it.
- We let I be the intensity of photons which pass through a thickness x of material, with Io the intensity of incident photon. The intensity of photons that interact in an additional thickness dx is -dI. We can write:
- $dI = -\mu I dx$ 2
- which when integrated and rearranged gives
- $I = I_o \exp(-\mu x)$
- or $\ln(I/I_o) = -\mu x$ 3
- where I=Transmitted Intensity, Io=Incident Intensity, x is the concrete thickness and μ is the Linear Attenuation Coefficient,
- The obtained value of μ was **0.179/cm** and **(0.182±0.006)/cm** from simulation and measurement respectively.

RESULTS AND DISCUSSION

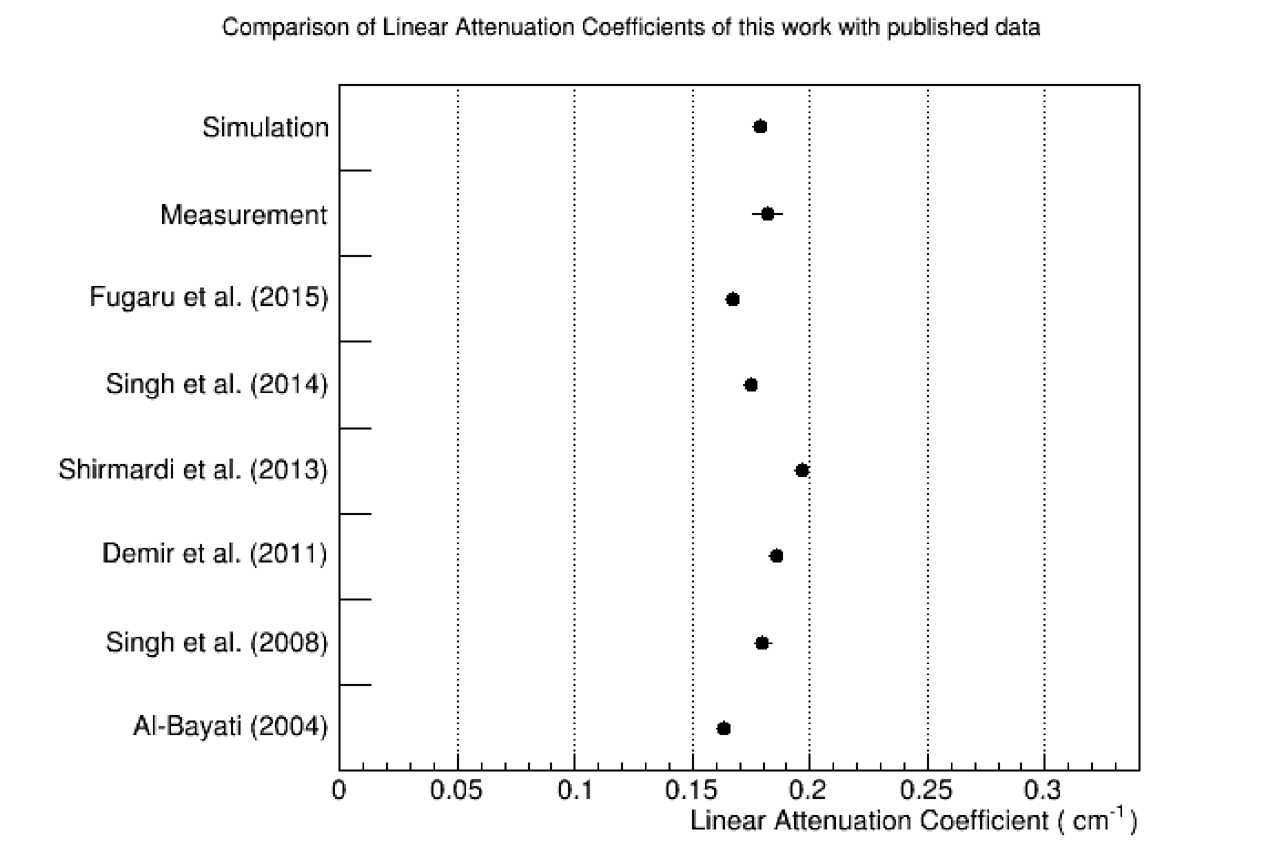
The simulated and measured Linear attenuation coefficient



RESULTS AND DISCUSSION

Comparison of obtained value of Linear attenuation coefficient of ordinary concrete for gamma rays of energy 662 keV with the published ones

This work in /cm		Published works in /cm					
Simulation	Measurement	Singh et al. (2008)	Demir et al. (2011)	Fugaru et al. (2015)	Al-Bayati (2004)	Singh et al. (2014)	Shirmardi et al. (2008)
0.179	0.182± 0.006	0.1799± 0.0034	0.1855± 0.0015	0.167	0.163	0.175	0.197



RESULTS AND DISCUSSION

The Half Value Layer

- **The Half Value Layer** is the thickness of the material that reduces the intensity of the gamma photon beam to half its original value.

- This is given by

  HVL = Ln2/μ 4

  where μ is the Linear Attenuation Coefficient.

- The Half Value Layer obtained in this work are presented below

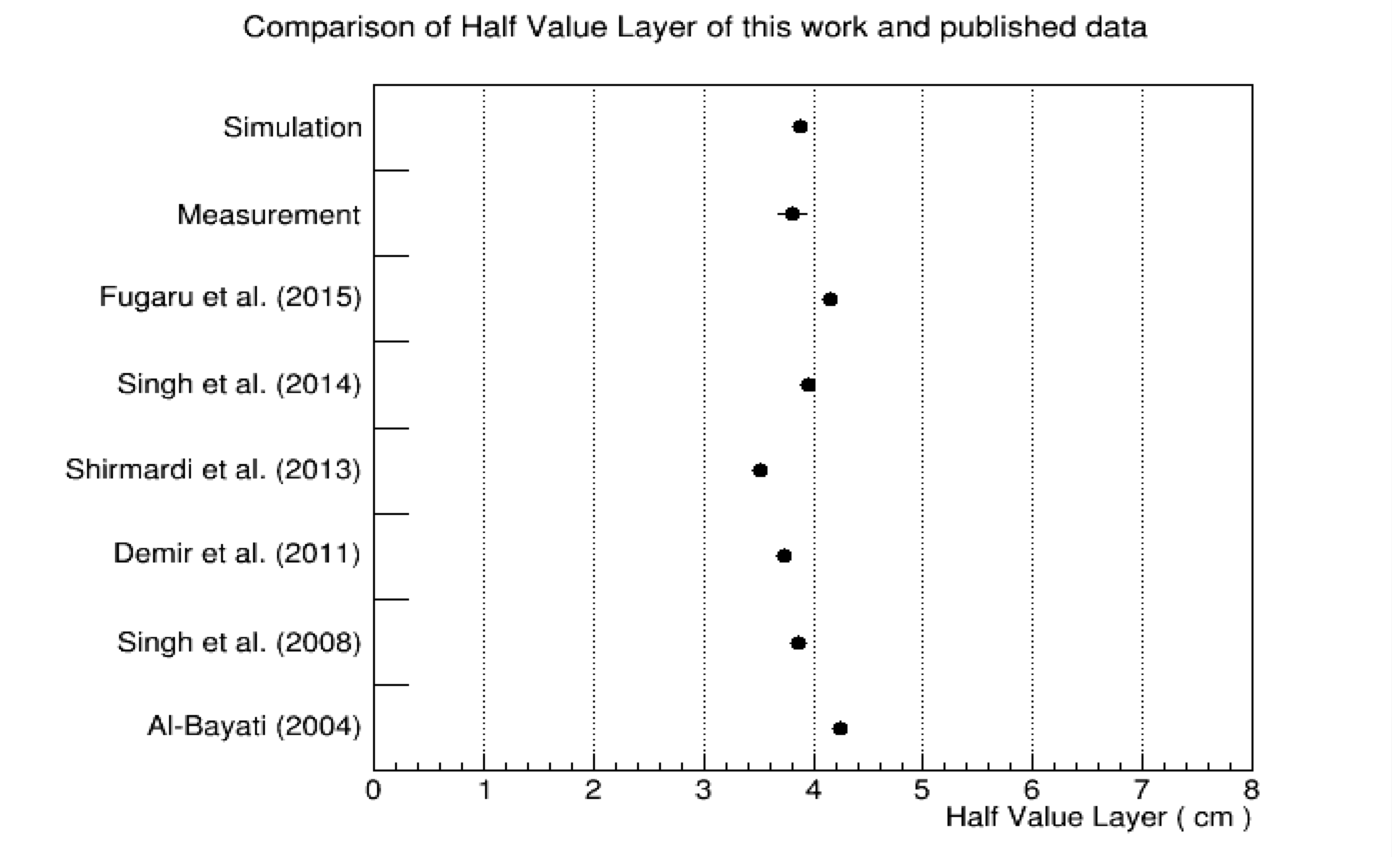
  H.V.L = (3.81±0.13) cm (Measurement)

  H.V.L = 3.87 cm (Simulation)

RESULTS AND DISCUSSION

Comparison of obtained value of the Half Value Layer of ordinary concrete for gamma rays of energy 662 keV with the published ones

This work in cm		Published works in cm					
Simulation	Measurement	Singh et al. (2008)	Demir et al. (2011)	Fugaru et al. (2015)	Al-Bayati (2004)	Singh et al. (2014)	Shirmardi et al. (2008)
3.87	3.81±0.13	3.853± 0.073	3.737± 0.030	4.15	4.25	3.96	3.52



RESULTS AND DISCUSSION

The simulated and the measured Mean Free Path

- **The Mean Free Path** is the average distance a single particle travels through a given attenuating medium before interacting. It is given by

$X_m = 1/\mu$ 5

where μ is the Linear Attenuation Coefficient.

- Using the above obtained values of linear attenuation coefficient, the Mean Free Path obtained in this work are presented below

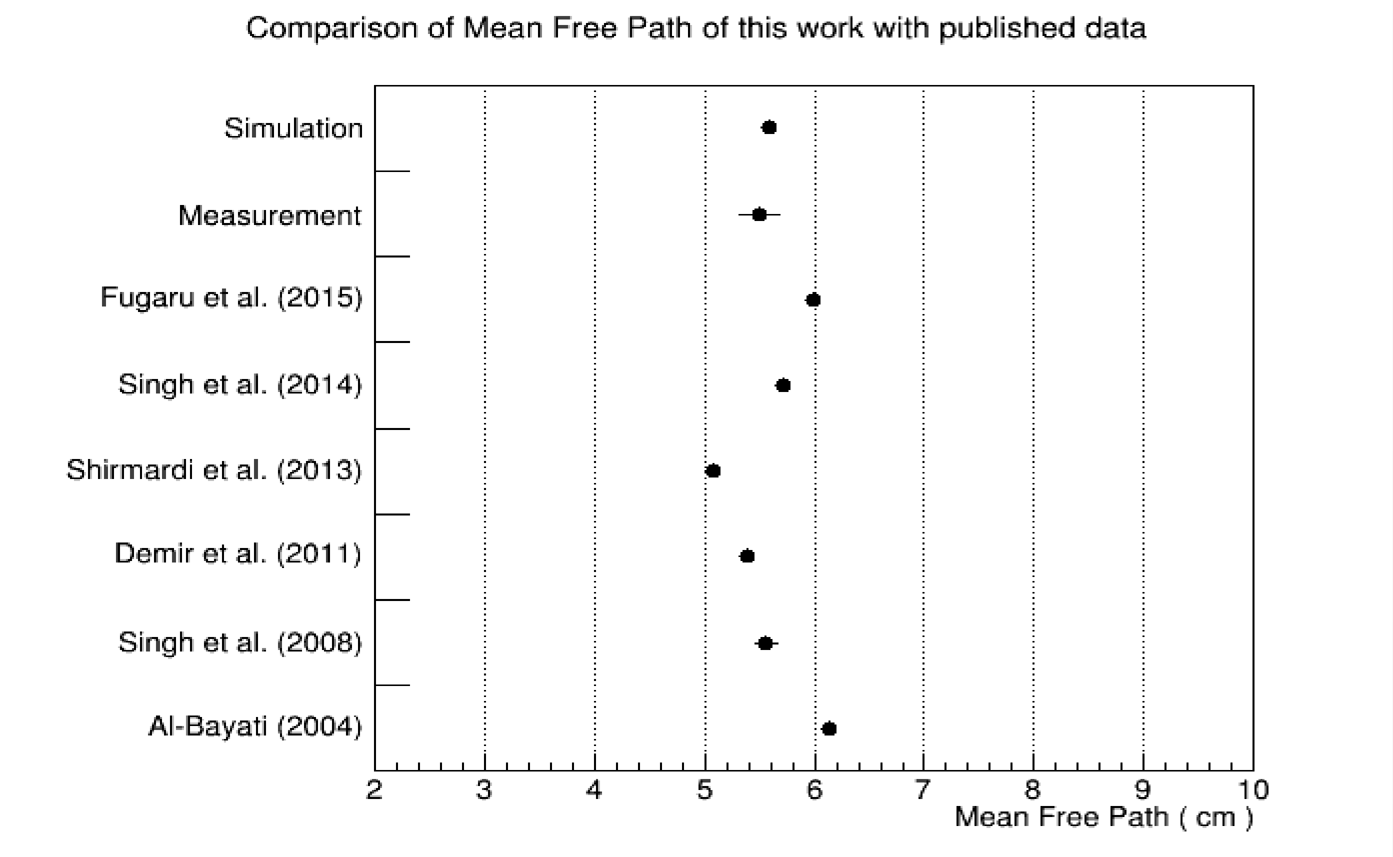
$X_m = (5.49 \pm 0.18)$ cm (Measurement)

$X_m = 5.59$ cm (Simulation)

RESULTS AND DISCUSSION

Comparison of the obtained value of Mean Free Path of ordinary concrete for gamma rays of energy 662 keV with the published ones

This work in cm		Published works in cm					
Simulation	Measurement	Singh et al. (2008)	Demir et al. (2011)	Fugaru et al. (2015)	Al-Bayati (2004)	Singh et al. (2014)	Shirmardi et al. (2008)
5.59	5.49±0.18	5.559± 0.105	5.391± 0.040	5.99	6.13	5.71	5.08



RESULTS AND DISCUSSION

The Mass Attenuation Coefficient

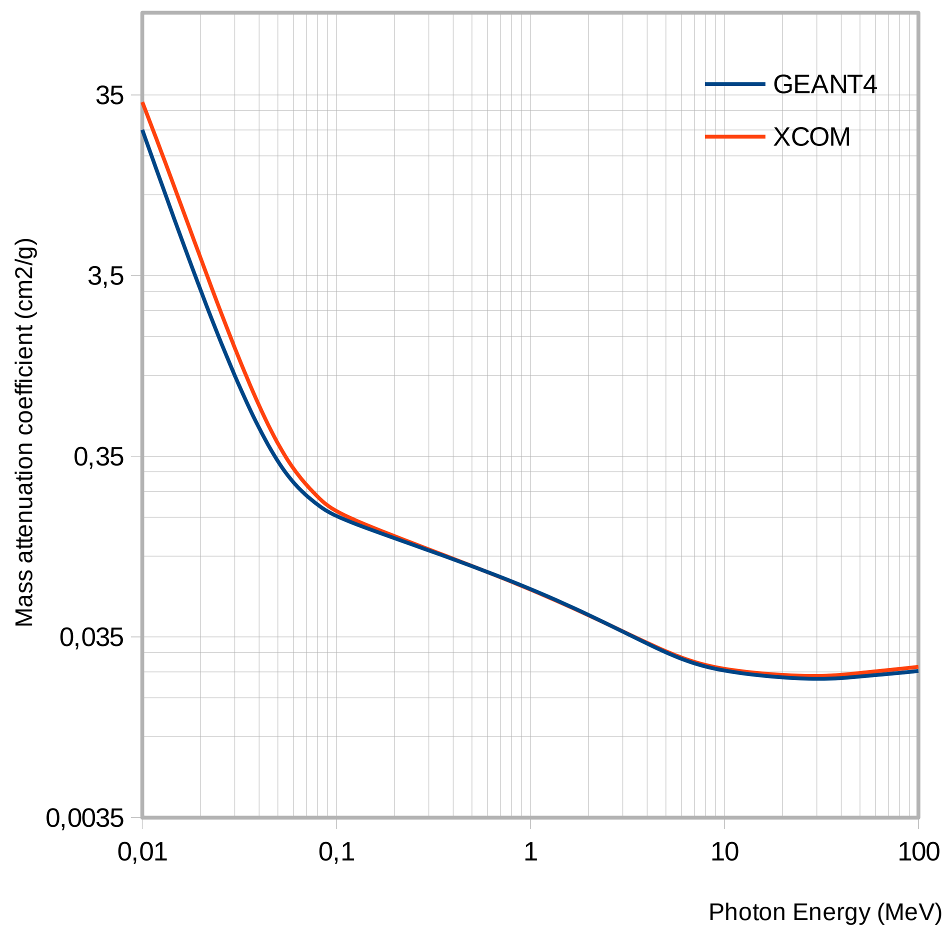
- This is the measure of a material ability to absorb or scatter electromagnetic radiation per unit of mass. This attenuation eliminates the density dependence of the material on gamma ray attenuation.
- GEANT4 and XCOM codes were used for its simulation.
- It corresponds to the sum of the mass attenuation coefficient from individual interactions as shown below.

$$\frac{\mu}{\rho}=\frac{\tau}{\rho}+\frac{\sigma}{\rho}+\frac{\kappa}{\rho} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Total Mass Attenuation Coefficient

ENERGY (MeV)	Total Mass Attenuation Coefficient(cm2/g)	
	GEANT4	XCOM
0.01	22.44	31.98
0.03	0.9787	1.391
0.06	0.2517	0.3005
0.08	0.1891	0.2094
0.1	0.1636	0.1742
1	0.06441	0.06402
5	0.02875	0.02914
10	0.0228	0.02331
30	0.02051	0.02129
50	0.02113	0.0221
80	0.02213	0.02328
100	0.02268	0.02391

Variation of the Total mass attenuation coefficient with energy.

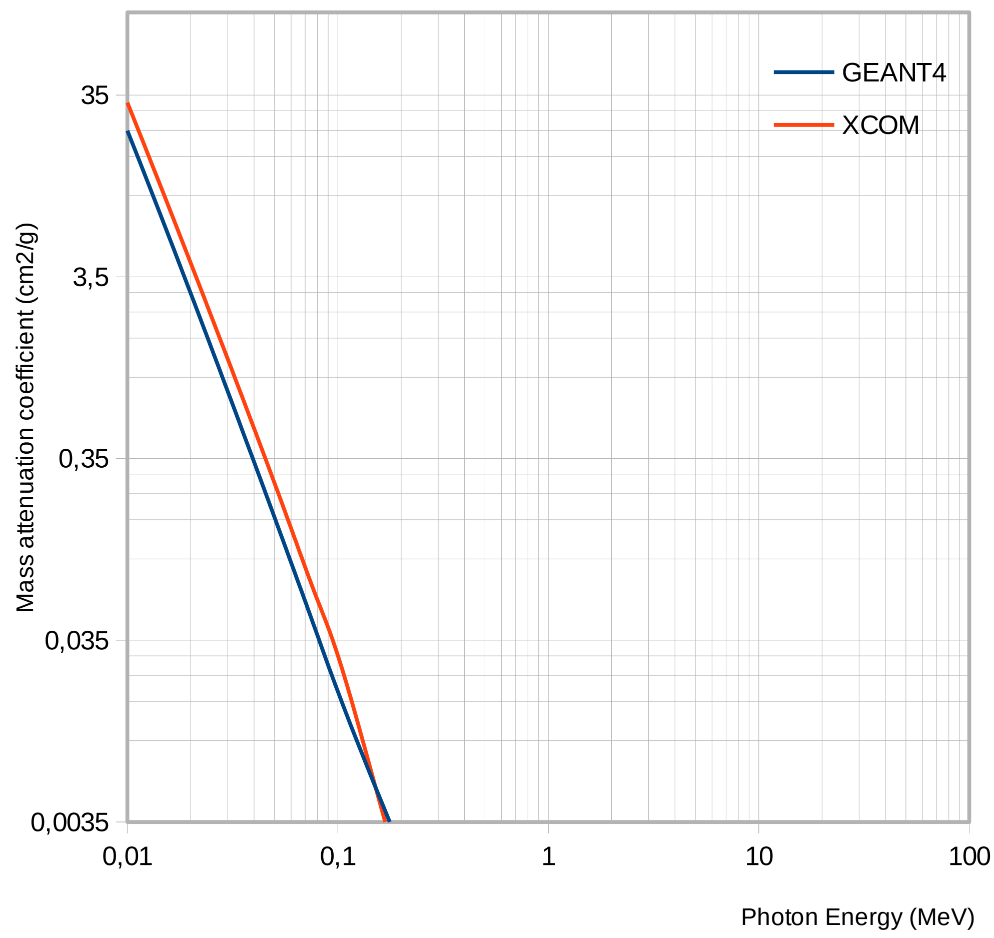


RESULTS AND DISCUSSION

Photoelectric Mass attenuation coefficient

ENERGY (MeV)	Photoelectric Effect(cm2/g)	
	GEANT4	XCOM
0.01	22.31	31.85
0.03	0.8189	1.234
0.06	0.09344	0.1442
0.08	0.03723	0.05831
0.1	0.01827	0.02883
1	0.00003	0.00005
5	0	0.00004
10	0	0.00002
30	0	0
50	0	0
80	0	0
100	0	0

Simulated Photoelectric Mass attenuation coefficient variation with energy for XCOM and GEANT4 codes.



Photoelectric Mass Attenuation Coefficient

Photoelectric Mass Attenuation Coefficient, τ/ρ is given by

$$\frac{\tau}{\rho}=\frac{N_A Z}{A}{}_a\tau \qquad \text{...................................} \; 7$$

Where N_A is the Avogadro's constant, Z is the atomic number, A atomic mass while ${}_a\tau$ is the total cross section per atom which is photon energy dependent as

$${}_a\tau \propto E^{-3} \; \text{...} \; 8$$

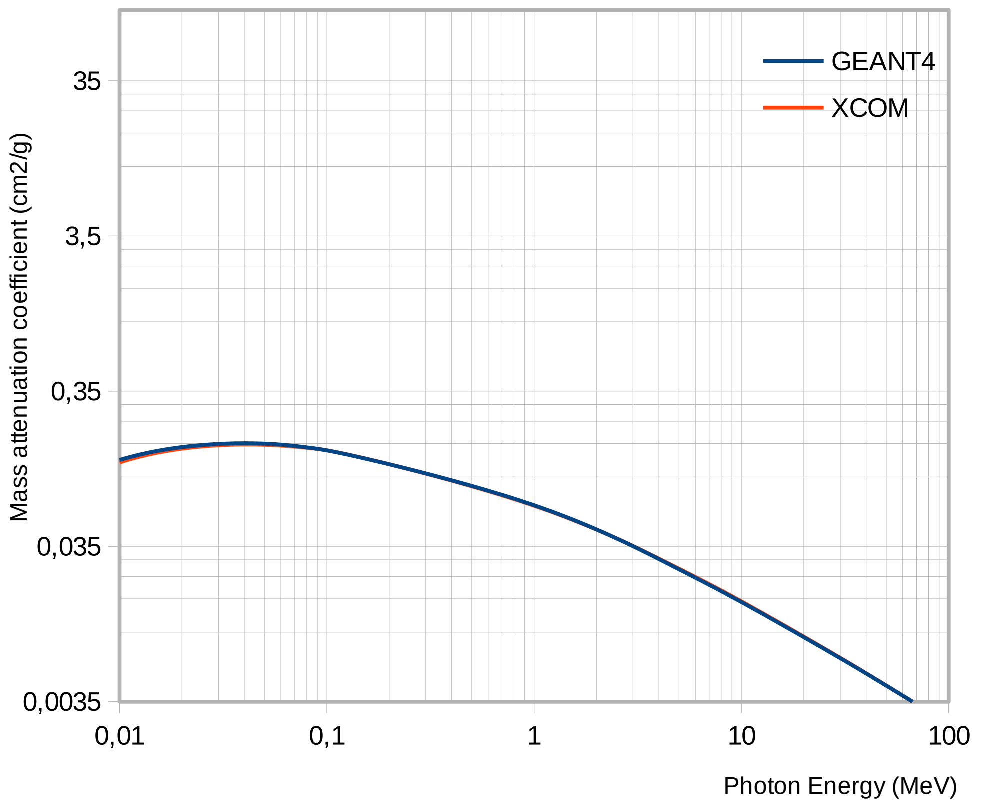
The obtain decrease in Photoelectric mass attenuation coefficient with energy is in agreement with both Attix (1986) and Podgorsak (2005) who observed that Photoelectric mass attenuation coefficient decreases with energy.

The disagreement at low photon energy is attributed to adoption of different cross section data sources by the codes.

Compton mass attenuation coefficient

ENERGY (MeV)	Compton Effect (cm2/g)	
	GEANT4	XCOM
0.01	0.1261	0.1216
0.03	0.1599	0.1569
0.06	0.1583	0.1563
0.08	0.1519	0.1511
0.1	0.1454	0.1454
1	0.06439	0.06398
5	0.02492	0.02515
10	0.01533	0.01549
30	0.006664	0.006699
50	0.004437	0.004444
80	0.003026	0.003019
100	0.002517	0.002506

The variation of Compton mass attenuation coefficient with photon energy



Compton Mass Attenuation Coefficient

Compton Mass Attenuation Coefficient, σ/ρ is given by

$$\frac{\sigma}{\rho} = \frac{N_A Z}{A} {}_a\sigma \quad \text{.................................... 9}$$

Where N_A is the Avogadro's constant, Z is the atomic number, A atomic mass while ${}_a\sigma$ is the total cross section per atom which is photon energy dependent as

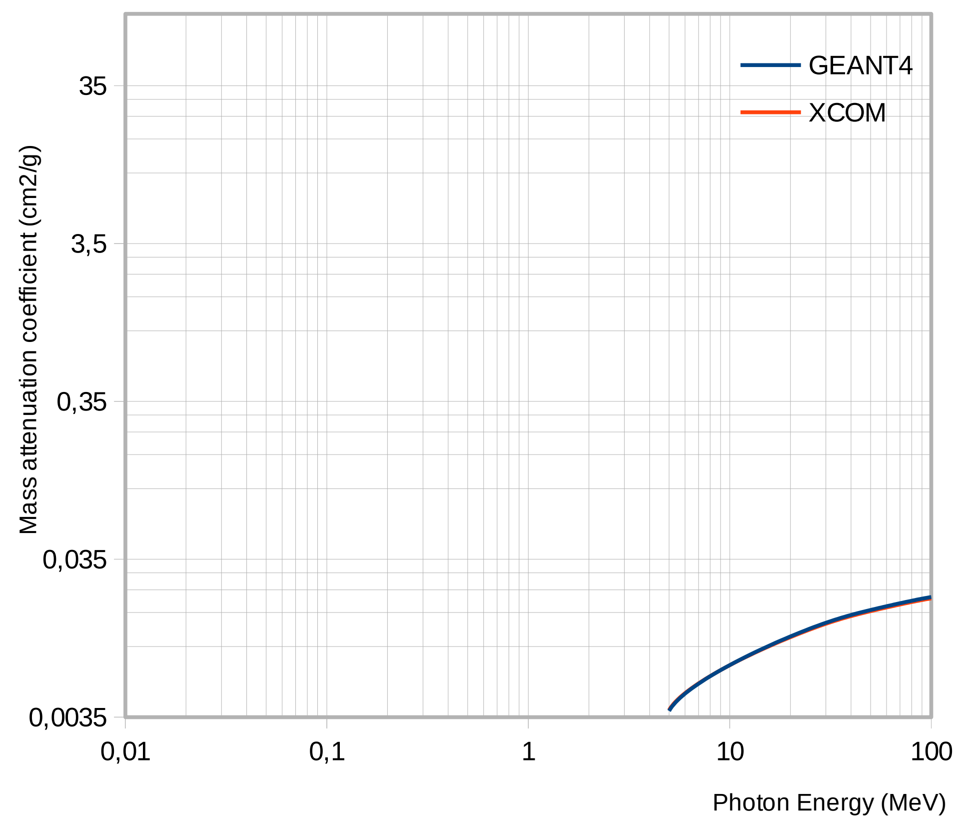
$${}_a\sigma \propto E^{-1} \quad \text{.. 10}$$

The obtain decrease in Compton mass attenuation coefficient with energy is in agreement with both Attix (1986) and Podgorsak (2005) who observed that Compton mass attenuation coefficient decreases with energy.

Pair production mass attenuation coefficient

ENERGY (MeV)	Pair-Production(cm2/g)	
	GEANT4	XCOM
0.01	0	0
0.03	0	0
0.06	0	0
0.08	0	0
0.1	0	0
1	0	0
5	0.003831	0.003881
10	0.007472	0.007462
30	0.01385	0.01365
50	0.01669	0.01641
80	0.0191	0.01875
100	0.02016	0.01976

The variation of Pair Production mass attenuation coefficient with energy



Pair production Mass Attenuation Coefficient

Pair production Mass Attenuation Coefficient, κ⁄ρ is given by

$$\frac{\kappa}{\rho}=\frac{N_A Z}{A} a\kappa \qquad \text{.................................. 11}$$

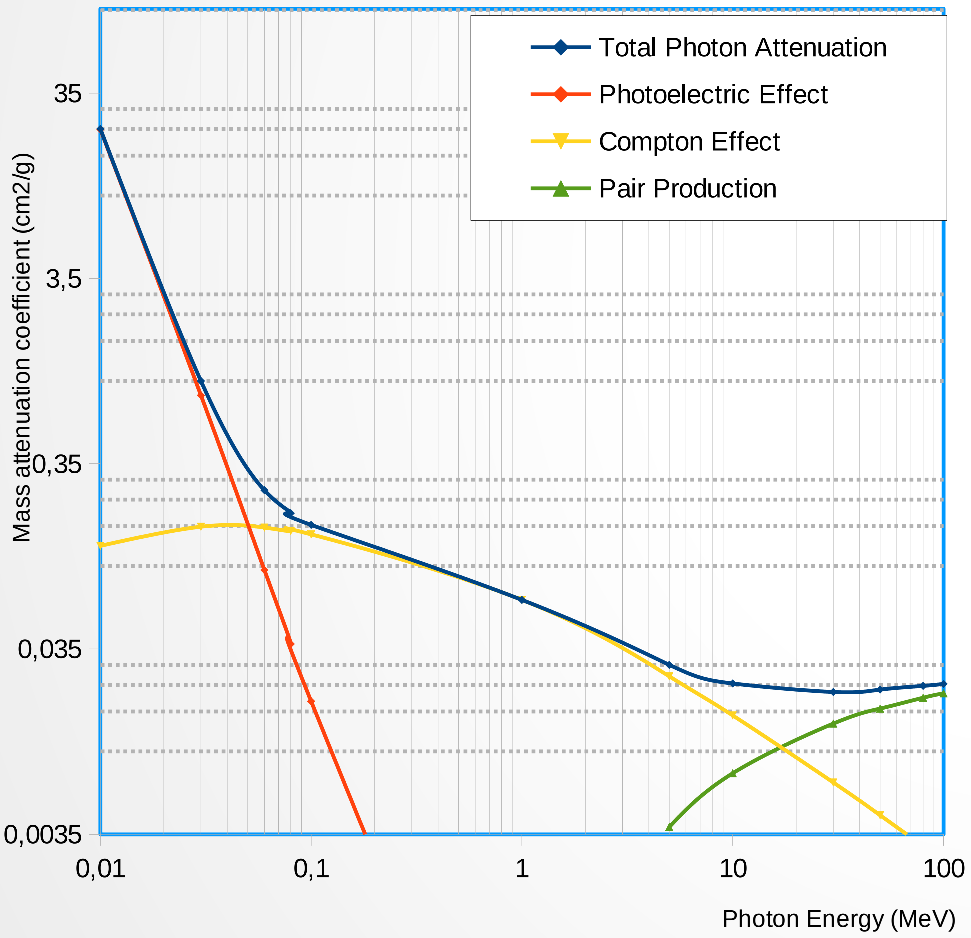
Where N_A is the Avogadro's constant, Z is the atomic number, A atomic mass while $a\kappa$ is the total cross section per atom.

It is a processes with a lower energy threshold given by the mass of an electron-positron pair, i.e 1.02 MeV

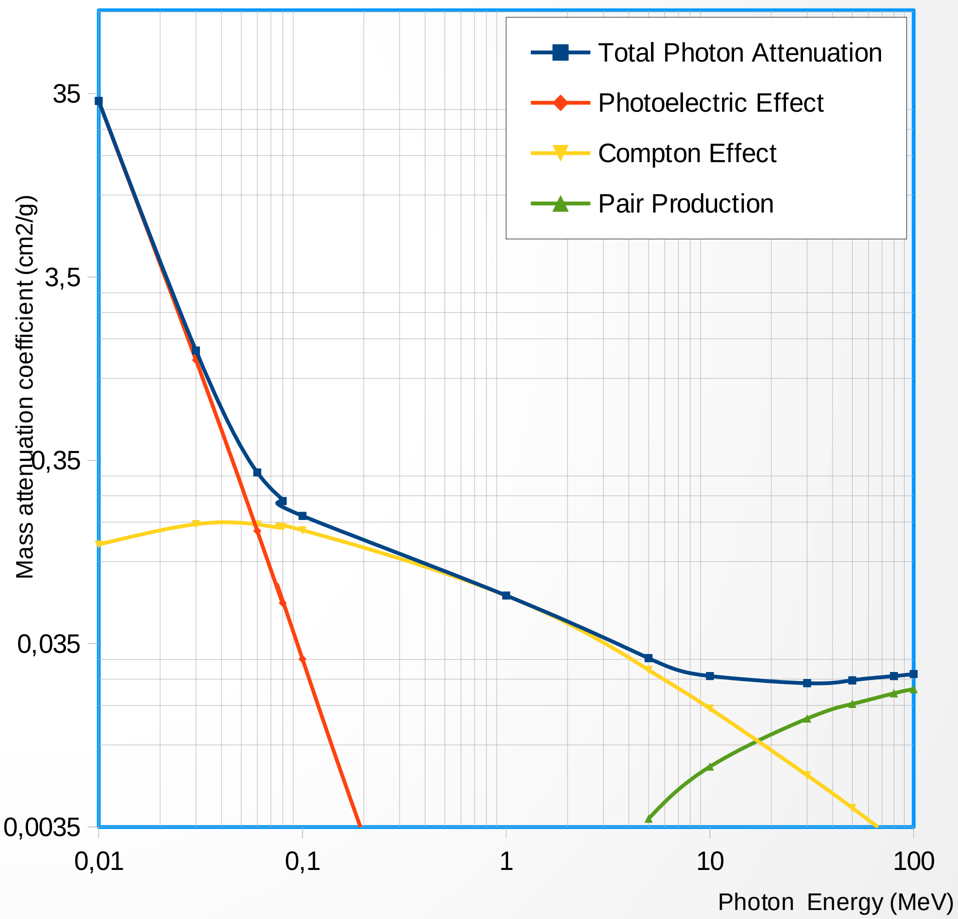
The obtain increase in Pair production mass attenuation coefficient with energy is in agreement with both Attix (1986) and Podgorsak (2005) who observed that Pair production mass attenuation coefficient increases with energy.

Mass attenuation coefficient

GEANT4



XCOM



CONCLUSIONS

The findings of this research showed that

1. From measurement, the attenuated fraction of intensity of gamma rays of energy 662 keV by ordinary concrete is (0.182±0.006) /cm while that from simulation is 0.179 /cm.

2. From measurement, the thickness of ordinary concrete that attenuates by half the intensity of gamma rays of energy 662 keV is (3.81±0.13) cm while that from simulation is 3.87 cm.

3. From measurement, gamma rays of energy 662 keV travels an average distance of (5.49±0.18)cm in ordinary concrete before interacting with it while from simulation it travels an average distance of 5.59 cm.

CONCLUSIONS

4. The GEANT4 Simulated and XCOM simulated variation of mass attenuation coefficient of ordinary concrete with gamma ray energy in the range of 10 keV to 100 MeV was found to be in agreement except for the photoelectric mass attenuation coefficient at lower energies. This was attributed to the use of different cross section data sources in GEANT4 and XCOM.

5. The research findings have validated the use of GEANT4 program for the study of gamma ray attenuation in matter.

Thank you very much...