2021 International Nuclear Atlantic Conference – INAC 2021
Virtual meeting, Brazil, November 29 – December 2, 2021

ISBN: 978-65-594-1256-3

Evaluation of mass attenuation coefficient of concrete sample for different traits

L. Bastos[1], T. Teixeira[1], H. Gama Filho[2], S. Calixto[3], M. Gonçalves[3], M. J. dos Anjos[2], R. Lopes[1], D. Oliveira[1]

[1] *luanfbastos@gmail.com, tamara.porfiro@coppe.ufrj.br, rlopes@coppe.ufrj.br, davifoliveira@coppe.ufrj.br*
Nuclear Instrumentation Laboratory/PEN/COPPE/UFRJ
hamiltongamafilho@hotmail.com, marcelin@uerj.br
Electronic Instrumentation and Analytical Techniques Laboratory/IF/UERJ
[3]*marcelogoncalves@ugb.edu.br, calixto.sebastiao.jr@gmail.com*
Geraldo di Biase University

1. Introduction

Concrete is a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate [1] and is widely used in different ways such as structural, filling and shielding. The use as shielding is important in nuclear installations and radiation therapy rooms due to the attenuation properties of the beams from nuclear reactions and to protect people from radiation.

The gamma transmission technique is a method used to determining the attenuation coefficient of different types of materials and elements and is based in the Beer-Lambert's law [2]. This technique employs a monoenergetic gamma ray source and a high-efficiency detector. Both devices are placed on the same horizontal plane and positioned at 180 degrees from each other. The transmitted intensities are recorded by the electronic components associated with the detector and can be displayed as an energy spectrum. This technique is widely used for calculating the attenuation coefficient of concrete samples [3-7]. The aim of this work is compare experimental and theoretical mass attenuation coefficient for concrete with different traits.

2. Methodology

The samples used in this study are sixty-three 100 mm x 50 mm (H x d) plugs, as determined in NBR 7215 standard [8], divided in three traits that are listed in table I. Density for each sample is also presented in table I. The IPT samples were prepared with standard sand as determined in NBR 7211 standard [9], the conventional samples were prepared using conventional sand that can be bought in any hardware store and the ART samples were prepared with artificial sand (gravel that can be classified as fine aggregate). It used a 40 MPa concrete and a water cementing rate of 0.48. Density was determined by the displacement technique. A glass beaker was filled up with distilled water and its density was determined by using an aluminum cylinder with known weight and volume and equation 1. After calculating the water density, the equation 2 was used to calculate the concrete density. In equation 1, M_{Al} is the aluminum weight in container filled up with water without touching its bottom and V_{Al} is aluminum volume. In equation 2, M_{air} is concrete mass in air, M_{water} is concrete mass in water container without touching its bottom and ρ is water density. Concretes samples were wrapped in plastic film to avoid penetration of water.

$$\rho_{H_2O} = \frac{M_{Al}}{V_{Al}} \tag{1}$$

$$\rho_{conc} = \frac{M_{air}}{M_{water}} \times \rho \tag{2}$$

Table I: Quantity of elements used in concrete samples.

Samples	Cement (g)	Standard Sand (g)	Conventional Sand (g)	Artificial Sand (g)	Density (g/cm^3)
IPT	642	1872	-	-	2,076
ART	642	-	-	1872	2,120
Conventional	642	-	1872	-	2,059

To determine the linear attenuation coefficient for the 662 keV energy peak, a gamma-ray transmission system consisting of a 2.24 GBq Cs^{137} radiation source, collimated with a cylindrical lead collimator of 5 mm in diameter and a 2 x 2 in NaI(Tl) scintillation detector, also collimated with a cylindrical collimator of 5 mm in diameter. The signals from the detector were processed by standard gamma ray electronics, consisting of a pre-amplifier, an amplifier and a multichannel analyzer for acquiring the energy spectrum.
The number of counts reaching the detector with and without the samples was recorded for the same counting live time of 300 s and the distance between the radiation source and the detector was 15 cm.
The mass attenuation coefficient (μ_m) was calculated following the Beer-Lambert's Law for a monoenergetic radiation beam, as shown in equation 3, were I_0 is the intensity recorded without the sample, I is the intensity recorded with sample, t is the thickness of sample and ρ is the sample density.

$$\mu_m = \frac{\ln(I_0) - \ln(I)}{t \times \rho} \quad (3)$$

To determine the composition of each trait, X-ray diffraction was used and the results are in table II. The samples were passed through a nylon mesh sieve with a 50 µm opening and the analysis was performed by a commercial benchtop equipment D2 Phaser from BRUKER. A voltage of 30 kV, a current of 10 mA, filter kβ of Ni, with a measurement time of 0.5 s, with an initial angle of 7º and a final angle of 70º at a step of 0.01º was used for the scan. With the elements defined, they were used into the XCOM platform to identify the attenuation coefficient. They were also inserted into an MCNP code that reproduced the system setup so that data could be validated. Fig. 1 shows the geometry used in MCNP simulation setup.

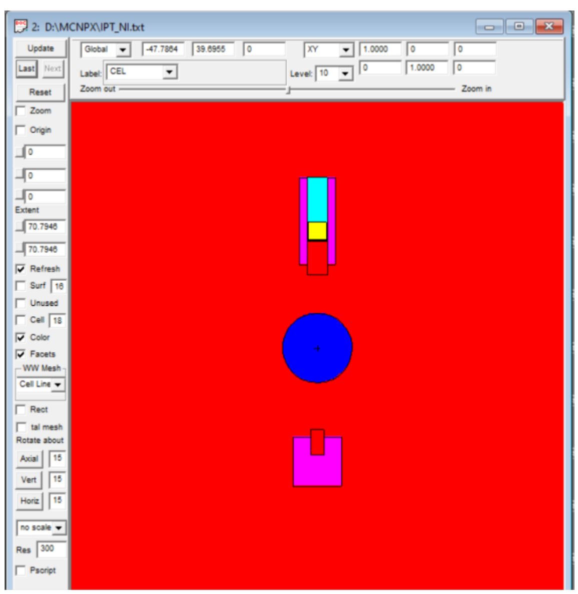

Fig. 1 Geometry setup used in MCNP

Table II: Elemental composition.

Compound	Chemical formula	ART (%)	IPT (%)	CON (%)
Quartz	O2Si	28,0	67,5	53,1
Calcite	CCaO3	3,1	6,9	12,9
Albite	AlNaO8Si3	28,3	7,9	-
Vaterite	CCaO3	6,1	10,4	12,0
Microcline	AlK0.89Na0.11O8Si3	23,4	-	21,1
Annite	Al3.156Fe1.624K0.928O12Si2.32	4,4	-	-
Organic Compound	C10H7NO3	3,7	-	-
Bassanite	CaHO4.5S	0,8	-	-
Anhydrite	CaO4S	1,9	-	-
Portlandite	CaH2O2	0,3	2,9	0,8
Berlinite	AlO4P	-	4,3	-

3. Results and Discussion

Table III compares the linear attenuation coefficient for the energy of 662 keV of experimental, XCOM and MCNP code and the absolute error and the relative error. Although the samples had different fine aggregates, they presented a similar value for the mass attenuation coefficient for 662 kV energy. The proximity of mass attenuation coefficients was expected when the density, which was presented in table I, is analyzed. Calculation of errors considered result found on XCOM platform as a theoretical reference. The biggest error found was for the experimental value of ART, but it is still considered a good parameter, as it is a relative error of only 5.3%. In this way, this work presents a good agreement between experimental setup, XCOM and MCNP.

Table III: Mass Attenuation Coefficient for experimental setup, XCOM and MCNP.

Samples	Mass Attenuation Coefficient (x10^{-2} cm^2/g)			Absolute Error		Relative Error	
	XCOM	Experimental	MCNP	Experimental	MCNP	Experimental	MCNP
ART	7.70	8.11	7.53	0.41%	0.17%	5.3%	2.21%
IPT	7.73	8.00	7.65	0.27%	0.08%	3.5%	1.03%
Conventional	7.72	8.06	7.74	0.34%	0.02%	4.4%	0.26%

4. Conclusions

The mass attenuation coefficient showed good agreement for the experimental setup and theoretical values. The three different traits didn't show any difference in attenuation of 662 kV photon. Furthermore, there is no difference in analyzed traits. Further studies are needed to indicate the best trait to be used without lost in mechanical capabilities.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. The authors also would like to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ) for their financial support.

References

[1] ASTM C125 - *Standard Terminology Relating to Concrete and Concrete Aggregates*, ASTM International, West Conshohocken, PA (2018).

[2] Knoll, G. F., *Radiation Detection and Measurement*, 3 ed., New York, John Wiley & Sons (1999).

[3] Salinas, I.; Conti, C.; Lopes, R., "Effective density and mass attenuation coefficient for building material in Brazil", *Applied Radiation and Isotopes*, v 64, pp 13-18 (2005).

[4] Akkurt, I.; Akyildirim, H.; Mavi, B.; Kilincarslan, S.; Basyigit, C., "Photon attenuation coefficients of concrete includes barite in different rate", *Annals of Nuclear Energy*, v. 37, pp. 910-914 (2010).

[5] Damla, N.; Baltas, H.; Celik, A., Kiris, E., Cevik, U., "Calculation of radiation attenuation coefficients, effective atomic numbers and electron densities for some building materials", *Radiation Protection Dosimetry*, v. 150 (4), pp. 541-549 (2012).

[6] Un, A.; Demir, F., 2013, "Determination of mass attenuation coefficients, effective atomic numbers and effective electron numbers for heavy-weight and normal-weight concretes", *Applied Radiation and Isotopes*, v. 80, pp. 73-77.

[7] Gokçe, H. S.; Ozturk, B. C.; Çam, N. F.; Andiç-Çakir, O., "Gamma-ray attenuation coefficients and transmission thickness of high consistency heavyweight concrete containing mineral admixture", *Cement and Concrete Composites*, v. 92, pp. 56:69 (2018).

[8] NBR 7215 - *Cimento Portland - Determinação da resistência à compressão de corpos de prova cilíndricos*, Associação Brasileira de Normas Técnicas (2019).

[9] NBR 7211 - *Agregados para concreto - Especificação*, Associação Brasileira de Normas Técnicas (2009).