NUMERICAL CALCULATION OF IONIZING RADIATION ATTENUATION CHARACTERISTICS FOR CONCRETE

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Summary: *This paper presents a method of numerical calculations of the total mass attenuation coefficient as one of the basic radiation characteristics of materials used for produced of concrete for a special purpose. Using the XCOM software, numerical calculations were made, and then the results between the mass attenuation coefficient values for the selected type of concrete with barite, for concrete which are a combination of steel with magnetite and steel with limonite, and for UHPC concrete with barite and nanosilica, are compared.*

Keywords: *concrete barite, concrete steel magnetite limonite, UHPC concrete nanosilica, gamma X radiation, total mass attenuation coefficients*

1. INTRODUCTION

Modern engineering technologies require a multidisciplinary approach in solving complex problems that arise in the selection of different types of concrete that could be used in the environment with levels of increased dose rate of gamma and X radiation. To build medical facilities with rooms for radiological diagnostics and radiotherapy and nuclear medicine, in special facilities where there are accelerators of nuclear particles in nuclear power plants with nuclear reactors as well as nuclear facilities for the storage of radioactive waste, used a special type of concrete that provide protection of X and gamma radiation. Barite aggregate is used to produce heavyweight concrete which application concerns radiation shielding in hospitals and nuclear facilities. The basic characteristics of ordinary concrete and heavy-weight concrete with barite were studied for the case of their use for shielding from gamma radiation [1, 2, 3]. In cost-benefit analysis the question is what are the radiation characteristics of different types of concrete, which could be used to protect against gamma and X rays [4, 5, 6]. The energy deposited the transmission factor and the mass attenuation coefficients in ordinary and barite concretes have been calculated with the photon transport Monte Carlo software.

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The numerical simulations results show that using barite as an aggregate in the concrete is one of the solutions for gamma ray shielding. Thereat, it is shown non-destructive method for determining the gamma radiation absorption characteristics of concrete [7]. In references [8, 9], one of the goals is to implement appropriate numerical calculations for obtaining the value of the total mass attenuation coefficient in the energy range 10 keV - 150 MeV of gamma and X radiation, and their dependence in the content of barite and nano-silica in UHPC concrete with specially defined mechanical properties. Nanosilica has a dominant influence on the improvement of the mechanical properties, and barite has a dominant influence on the characteristics that increase the absorption of ionizing radiation, i.e., improves the characteristics for protection against ionizing radiation. Investigations in these references [8, 9] is designed to, by simultaneously using different portions of the two materials, nano-silica and barite, in the composition of various types of concrete conduct tests on the ability to improve the mechanical properties and properties for the radiation protection of concrete.

In this paper, computer code XCOM [10] was used for the calculation of the total mass attenuation coefficients $(\mu/\rho)_{tot}$, which is an important factor for determination of the photon attenuation, as well as during research and testing of radiation protection properties [1-6] for different content of aggregates in concrete. Computer code XCOM operates on a method of combining the values of the existing database for effective cross section of physical processes accompanying the transport of photons through different materials. This means that there is a possibility to use data bases for coherent and incoherent scattering, photoelectric absorption, and pair production cross-sections for the different chemical structure of materials which enter into the composition of the concrete.

2. NUMERICAL METHODS

One of the most important characteristics of the concrete for protection against gamma and X radiation is its Total Mass Attenuation Coefficient $(\mu/\rho)_{tot}$.

Basic relations for engineering calculations the attenuation of exposure dose rate of ionizing radiation, which passes through the wall of concrete, can be displayed as:

$$X = X_0 \cdot \exp\left[-\left(\frac{\mu}{\rho} \right)_{tot} \cdot \rho d \right] \tag{1}$$

where X (C/kg s) and X_0 are intensity exposure rates behind and in front of the wall, where the wall thickness is d (m) and the density is ρ (kg/m^3). This Eq. (1) is consistent with the application of Bouguer-Lambert-Beer law for attenuation of the intensity of mono energetic photon radiation for the cases of penetration of the narrow beam of radiation through a concrete wall as a protective barrier.

The definition of Total Mass Attenuation Coefficient for mixture or compound is given by:

$$\left(\frac{\mu}{\rho}\right)_{tot} = \sum_j w_j \cdot \left(\frac{\mu}{\rho}\right)_j \tag{2}$$

where w_j and $(\mu/\rho)_j$ are the weight fraction and mass attenuation coefficient of the constituent element j.

The numerical calculations included two steps: 1. For each type of concrete from Tab. 1 its composition was determined in accordance with the nomenclature of chemical elements and chemical compounds, 2. Interactive use of the program XCOM [10], where the known composition of individual types of concrete determines the total mass attenuation coefficient depending on the change of energy photon radiation.
XCOM program enables to calculate interaction coefficients for the following processes: Compton (incoherent) and Rayleigh (coherent) scattering, photoelectric absorption, and pair production in the field of the atomic nucleus and in the field of the atomic electrons. The mean free paths between scatterings, between photo-electric absorption events, or between pair production events are the reciprocals of partial interaction coefficients. The total attenuation coefficient is equal to the sum of the interaction coefficients for the individual processes.

3. RESULTS AND DISCUSSION

Comparing radiation attenuation characteristics can determine which type of concrete best meets the requirements for protection against X and gamma radiation. In this way, appropriate preconditions for optimal cost-benefit analysis are created prior to the production of concrete for special purposes, because in addition to mechanical characteristics, radiation attenuation characteristics for different types of concrete are also considered. In our work, computer code XCOM was used for the calculation of the total mass attenuation coefficients for four different concrete types, which is specified in Table 1.
The dependence of values total mass attenuation coefficients on energy photon radiation is shown in the figure Fig. 1.

Table 1. Types of concrete for numerical calculations of the total mass attenuation coefficients with software code XCOM [10]

Mark	**Type of concrete**	**Density** (g cm^{-3})	**Material composition data in [reference]**
CB	Concrete, Barite (Type BA)	3.350	[11]
CMS	Concrete, Magnetite and Steel	4.640	[11]
CLS	Concrete, Limonite and Steel	4.540	[11]
B5n	Concrete, UHPC barite nanosilica 5%	2.830	[9]

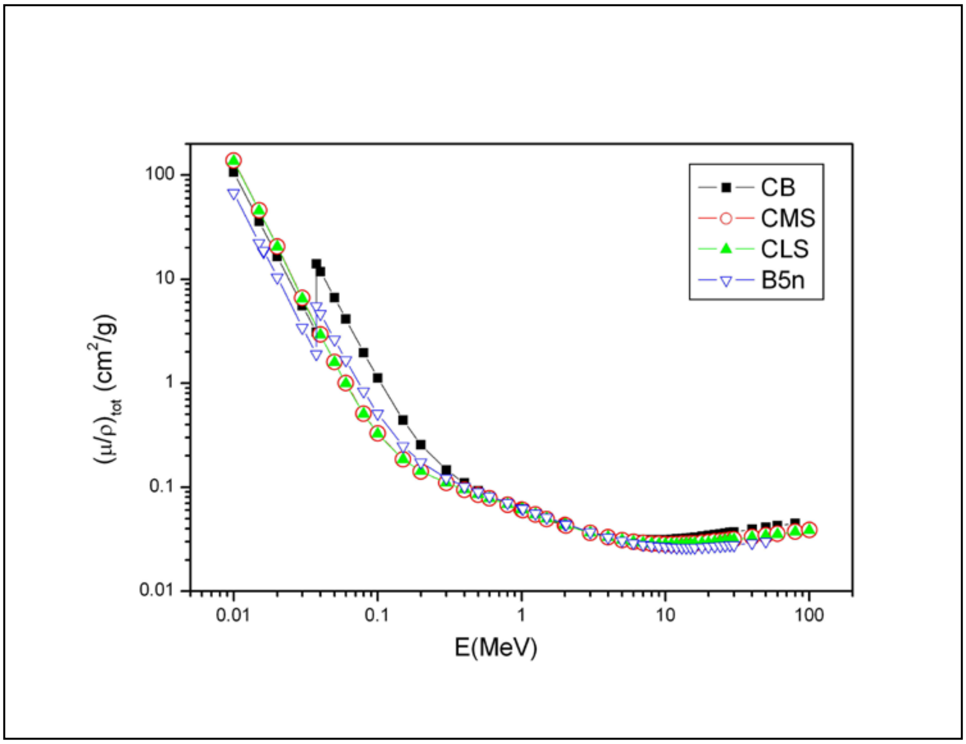

Figure 1. Total mass attenuation coefficients for four different concrete types

On the graphs Fig. 1, one can see, that total mass attenuation coefficients $(\mu/\rho)_{tot}$ has dependence of the photon energy (E): a) in three ranges for concrete types CMS and CLS, decreasing sharply at low energies (E<0.15 MeV), decreasing slightly in the middle range (0.15 MeV<E<6 MeV) and increasing slightly at high energies (E>6 MeV); b) in three ranges for concrete types CB and B5n, decreasing sharply in bottom range (10 keV<E<400 keV) with the sharp discontinuity around 30 keV, decreasing slightly in the middle range (0.4 MeV<E<6 MeV) and increasing slightly at high energies (E>6 MeV); c) in the energy range of 400 keV to 6 MeV values for the total mass attenuation coefficients are approximately the same for four different types of concrete. The results, which we have pointed out, are tied to different photon absorption mechanism for different energy range. The sharp discontinuities in energy dependence for total mass absorption coefficient are connected with the processes of the photoelectric absorption.

4. CONCLUSION

In this investigation, based on the results of the corresponding graphs for Total Mass Attenuation Coefficient $(\mu/\rho)_{tot}$ it can be concluded that in the range of energy of gamma and X radiation from 30 keV to 300 keV, concrete types CB and B5n with barite sand has greater protective power than concrete types CMS or CLS. Concrete type CMS with magnetite and steel has greater protective power than other three concrete types for the energy of gamma and X radiation E < 30 keV, while the concrete type CB is with better characteristics than other types of concrete for the attenuation of the radiation beam for photon energies greater than 30 keV. The results of this research point to the conclusion that before the concrete production of certain mechanical properties is approached, it is reasonable to apply the appropriate methodology with the numerical calculation of the basic absorption characteristic of the concrete for protection against gamma and X radiation.

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REFERENCES

[1] Yılmaz, E. et al: Gamma ray and neutron shielding properties of some concrete materials, *Annals of Nuclear Energy*, **2011.**, vol. 38, p.p. 2204–2212

[2] Juniora, T.A.A. et al: Mass attenuation coefficients of X-rays in different barite concrete used in radiation protection as shielding against ionizing radiation, *Radiation Physics and Chemistry*, **2017.**, vol. 140, p.p. 349-354

[3] Ouda, A.S.: Development of high-performance heavy density concrete using different aggregate for gamma-rey shilding, *Progress in Nuclear Energy,* **2015.**, vol. 79, p.p. 48-55
[4] Ling, T.C. et al: X-ray radiation shielding properties of cement mortar prepared with different types of aggregate, *Materials and Structures*, **2013.**, DOI 10.1617/s11527-012-9959-2
[5] Bashter, I.I. et al: Magnetite ores with steel or basalt for concrete radiation shelding, *Jpn. J. Appl. Phys.*, **1997.**, Vol. 36, Part 1, No.6A, p.p. 3692-3696
[6] Sarkawi, M.S. et al: Radiation shielding properties of ferro-boron concrete, *IOP Conf. Series: Materials Science and Engineering*, **2018.**, vol. 298, doi:10.1088/1757-899X/298/1/012037
[7] Stankovic et al: Gamma Radiation Absorption Charcteristics of Concrete with Components of Different Type Materials, *Acta Physica Polonica A*, **2010.**, Vol. 117, p.p. 812-816
[8] Jankovic et al: Effect of nano-silica and aggregate type on properties of ultra high performance concrete, *Proceedings of the 9th International Concrete Conference 2016 "Environment, Efficiency and Economic Challenges Challenges for Concrete"*, Dundee, Scotland, UK, **2016.**, p.p. 839-846
[9] Jankovic et al: The influence of nano-silica and barite aggregate on properties of ultra high performance concrete, *Construction and Building Materials,* **2016.**, vol. 126, p.p. 147-156
[10] Berger, M.J. et al: *XCOM: Photon Cross Section Database (version 3.1),* http://www.nist.gov/pml/data/xcom/index.cfm, NBSIR 87-3597. National Institute of Standards and Technology, Gaithersburg, MD, **2010.**
[11] Shultis J.K. and Faw, R.E.: *Radiation Shielding*, Prentice Hall, Englewood Cliffs, New Jersey, **1996.**

НУМЕРИЧКИ ПРОРАЧУН КАРАКТЕРИСТИКА БЕТОНА ЗА АТЕНУАЦИЈУ ЈОНИЗУЈУЋЕГ ЗРАЧЕЊА

Резиме: *У овом раду се приказује метод нумеричког прорачуна тоталног масеног атенуационог коефицијента као једног од основних радијационих карактеристика материјала од којих се производе бетони за специјалну намену. Применом софтвера XCOM урађени су нумерички прорачуни, а потом су упоређени резултати између вредности масеног атенуационог коефицијента за изабрани тип бетона са баритом, за бетоне који су комбинација челика са магнетитом и челика са лимонитом, као и за UHPC бетон са баритом и наносиликом.*

Кључне речи: *баритни бетон, бетон челик магнетит лимонит, UHPC бетон нано-силицијум диоксид, гама X зрачење, тотални масени атенуациони коефицијент*