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Fast gammametry for evaluation shielding concrete specimens

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ABSTRACT

Concrete truly is a building material. It can be used in many fields as building structures, shielding materials as concrete biological shield surrounding the reactor pressure vessel, radioactive waste cementation and even decorative objects. As a result, it is important to inspect some parameters of concrete structures. For achieving this aim, an industrial computed tomography (CT) system was designed and developed on the base of the first generation CT system. The CT scanner consists of a 50.8mm NaI(Tl) detector in diameter and a ^{137}Cs (30 mCi) radioactive source. The position of phantom was defined by three motors. The CT scans were taken out in one dimension and total count for each gammametry of concrete was 15 minutes. In this study, several concrete cylindrical specimens of various components were prepared. Internal structures of the specimens were considered using industrial gamma CT apparatus to compare homogeneous and linear attenuation coefficient (that has direct relation with total density and atomic number, etc). After that, the special software was prepared for determination of homogeneity and attenuation coefficient. Consequently, the greater homogeneity and density give the higher quality and durability especially for using in concrete shield surrounding the reactor pressure vessel.

Keywords: Concrete compositions, Fast gammametry, Homogeneous, Attenuation coefficient.

INTRODUCTION

Concrete truly is a green building material. It can be used in many fields as building structures, shielding materials as a concrete biological shield surrounding the reactor pressure vessel and even decorative objects [1,2]. Different factors may influence the concrete quality and durability. One of the factors is attenuation coefficient that determines concrete density and the other factor is homogeneity. As a result, it is important to inspect concrete structures and study these factors in concrete. Nuclear imaging systems, such as gamma computed tomography, are able to inspect and identify failures in concrete [3, 4, 5].

Tomography imaging consists of directing γ-rays onto an object from multiple orientations and measuring the decrease in intensity along a series of linear paths. This decrease is characterized by Beer's Law, which describes intensity reduction as a function of γ-ray energy, path length, and

linear attenuation coefficient of material. A specialized algorithm is then used to reconstruct the distribution of γ-ray attenuation in the volume being imaged [6]. In a gamma-ray transmission, I, of a mono-energetic radiation beam traversing a phantom of thickness is given by the following equation:

$$I = I_0 e^{-\int \mu \, dx} \qquad (1)$$

Where I_0 is the incident beam intensity of the radiation beam, dx is some different path length and μ is the function describing the linear attenuation coefficient in the imaged object [7,8].

Attenuation coefficient changes with effects of Raleigh, photoelectric, Compton and pair product. $\mu_{photoelectric}$ has a great dependence on the atomic number of the absorber, a primary reason for more attenuation which reduces by increasing incident photon energy (E_γ). $\mu_{Compton}$ is almost independent of atomic number (Z) and depends on the electron density [8]. Thus, the total attenuation coefficient increases as atomic number (Z) and density increase [8].

Also, the factor of homogeneity means having a uniform structure throughout that is the connotation of invariance. Homogeneity has an inverse direction with standard deviation (σ) and this factor decreases when homogeneity increases. The result σ is the square root of an unbiased estimator of the variance of the population from which n is counts per a constant time and $\bar{n}$ is average of counts in same time [9].

$$\sigma = \left[\frac{1}{m-1}\sum_{i=1}^{m}(n_i - \overline{n})^2\right]^{\frac{1}{2}} \qquad (2)$$

Also, m is the total measurements numbers.

Radioactive decay is a random process. Consequently, any measurement has statistical fluctuation ($\sigma_{statistical}$). These inherent fluctuations represent an unavoidable source of uncertainty in all nuclear measurements and often can be the predominant source of imprecision or error. The total standard deviation (σ_{tot}) is due to statistical fluctuation and ($\sigma_{non\ homogeneity}$).

MATERIALS AND METHODS

1. Concrete compositions

Several concrete specimens in cylindrical form, 74 mm in diameter and 148 mm in height were made (Fig. 1). The specimens consist of various compositions to consider the effect of them on concrete durability, attenuation coefficient and homogeneity.

Specimen A was made from stone powder and cement composition with 2:1 ratio. Specimen B was made from sandstone and cement compositions with 2:1 ratio. Specimen C was made from sandstone, sand and cements compositions as sand & sandstone 1:1 and sand & cement with 2:1 ratio. Specimen D was made from stone powder and cement in 1 ratio. Specimen E was made from stone powder, sandstone and cement with 1:1:1 ratio. Specimen F was made from stone powder & sandstone with 1:1 ratio and stone powder & cement with 1:2 ratio.

2. Apparatus and gammametry method

A single-source – single-detector gamma computed tomography (CT) scanner system was used in this study. In this system a NaI(Tl) detector 50.8mm in diameter was located opposite the center of the ^{137}Cs (30 mCi) source in 550 mm distance. The energy window for applied source

was selected 662±90 keV. Two cylindrical lead collimators were used for source and detector that source collimator produced the narrow beam in 2mm. The detector and the source were aligned by a point semiconductor laser. The position of sample was defined by motors. In each movement of gammametry , the concrete has the linear movement by 1mm step and counting time for each step is 10 seconds. Nuclear electronic system consists of a NaI(Tl) (2×2, 905-3 model, Eberline company), and a specialized multi channel analyzer (MCA, PSS-1, NSTRI, Tehran, Iran) consists of pre-amplifier, amplifier, high voltage (HV) and a data acquisition system. A universal written software can simultaneously read positions and steps, control the motors and MCA. After that, the special software was prepared for determination of homogeneity and attenuation coefficient. This software is able to select one sample as reference and compares other samples proportionately with it.

RESULTS AND DISCUSSION

Concrete specimens in cylindrical forms A, B, C, D, E and F were studied by one dimension gammametry. A standard polyethylene sample that has uniform homogeneity and define attenuation coefficient was scanned to observe linear attenuation coefficient tolerance and standard deviation due to statistical fluctuation (Fig. 2). The results showed that the tolerance for μ is about 1% and for $s_{tatistical}$ is 2% due to statistical fluctuation. In order to observe effective factors on concrete qualify, a reference sample (specimen A) was selected and other samples were compared proportionately with it. The results of homogeneity (standard deviation- STD) and attenuation coefficient were represented in Table1. In this Table, the assumed σ and μ of reference sample (specimen A) equals 100 and other samples were compared proportionately with it (Fig. 3). Total gammametry time is about 15 minutes that can be a symptom for fast gammametry.

The results show that the specimen C has the highest attenuation (μ) but is so non homogeneity. Also, standard deviation- STD (σ) for specimen D is the lowest. Homogeneity has an inverse direction with standard deviation (σ) and this factor decreases when homogeneity increases. Thus, the specimen D has the greatest homogeneity. The greater homogeneity and linear attenuation coefficient give the higher quality and durability. It is important to select a concrete shield surrounding the reactor pressure vessel. Therefore, this concrete must possess high attenuation coefficient and durability. The concrete E can be suitable for shielding.

Fig. 1. Concrete specimens in cylindrical form

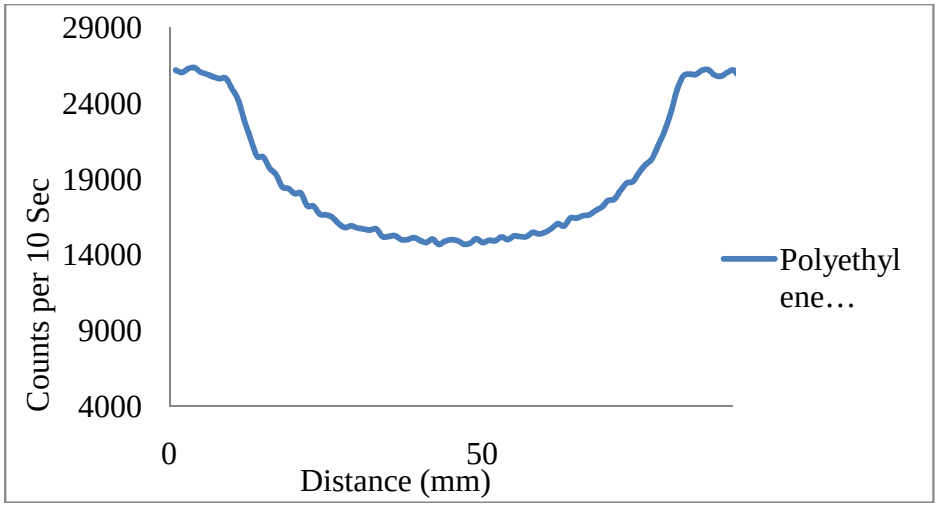

Fig. 2. The standard polyethylene phantom with uniform homogeneity and define linear attenuation coefficient for observing of statistical fluctuation and linear attenuation coefficient tolerance.

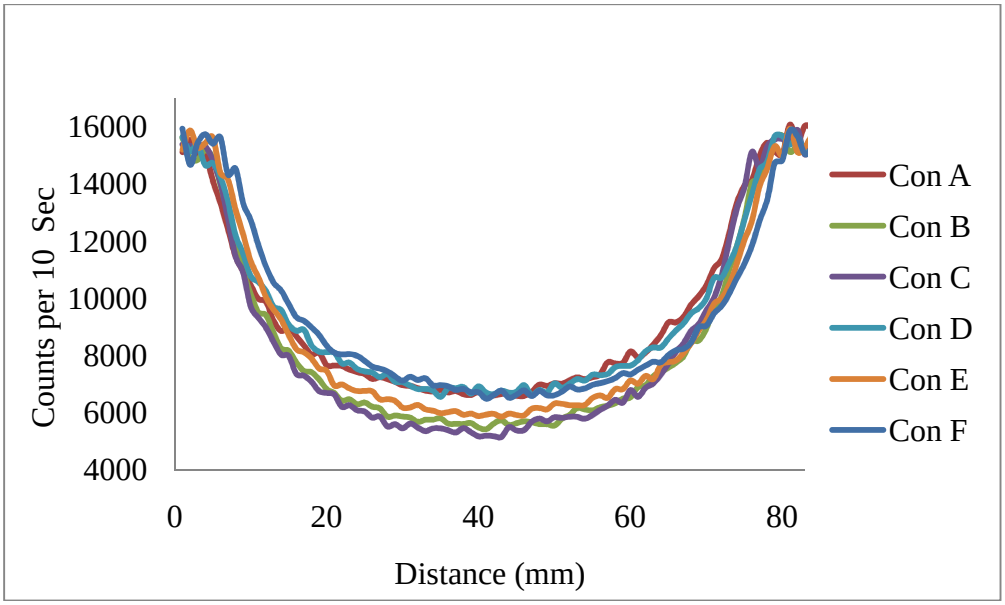

Fig. 3. The results of concrete specimens gammametry

Table1. The results of homogeneity σ (standard deviation- STD) and attenuation coefficient μ

Sample	Linear Attenuation Coefficient (μ)	Standard Deviation – STD (σ)
Concrete A	100.00 ±1%	100.00 ± 2%
Concrete B	121.31 ±1%	151.47 ± 2%
Concrete C	127.88 ±1%	165.45 ± 2%
Concrete D	100.76 ±1%	98.30 ± 2%
Concrete E	114.94 ±1%	103.09 ± 2%
Concrete F	100.31 ±1%	135.18 ± 2%

CONCLUSION

Gammametry using singe source-single detector is a simple and fast method for evaluation concrete shielding specimens and other propose. By this method can determine two main parameters (linear attenuation coefficient and homogeneity) for different component concert for

shielding purpose. Also, for same component concrete can determine relative density. In industrial scale for production of concert can use from portable version of single source-single detector gammametry system in arbitrary location.

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