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Dependence of Attenuation of Ionizing Radiation on Compression and Dimension of Geologic Material (An Application to X-ray Shielding)

[1]J.A. Adegoke and [2]O.G. Olowomofe

[1,2]Physics Department, University of Ibadan, Ibadan, Nigeria.

Abstract: Search for alternative materials required for shielding ionizing radiation has being on the increase for some period of time. Lead which is widely used is expensive, therefore researches has to be carried out on other materials. Clay has been suggested but it is not as effective as lead in shielding ionizing radiation. This work therefore studies the compression of clay samples at different pressures and thicknesses, so as to improve its shielding ability in the attenuation of ionizing radiations. The research work was on pure clay material and studied their effectiveness as radiation shielding material. The samples were made in bricks and their linear attenuation coefficients were measured at two different X-ray energies of 60keV, 10 mA and 120 keV, 15 mA. The samples were compressed at a pressure of 875Nm^{-2}, 1750 Nm^{-2}, 2625 Nm^{-2}, 3500 Nm^{-2}, and 4375 Nm^{-2}, for thicknesses of 1.0cm, 1.5cm, 2.0cm, 2.5cm,and 3.0cm. The result obtained shows that as the thicknesses increases, the linear attenuation increases which is in conformity with Lambert beer's equation. The attenuation coefficient obtained shows increase in value when compared to ordinary clay samples that were irradiated without compression.

Key words: Ionizing radiation, attenuation coefficient, thickness, intensity and compression.

INTRODUCTION

The factor that determines the physical and chemical properties of soil at any given location have been under study for the past decades. There are different kinds of rocks minerals, plants, geological materials, and other vegetation from which the soil is originally formed and these play important roles in determining the physical structure and also the chemical structure of the soil. (Guggenheim *et al.,* 1995). Soil is a mixture of minerals (e.g. clay, quartz) water, air and living organisms. It is composed of organic components, mainly from plants and from the decomposition of the many tiny life forms that inhabits the soil, the inorganic components that are principally the products of rocks and minerals which have undergone chemical and natural processes and disintegration by weather (Birkeland, 1984).

Clay is a naturally occurring material, composed of primarily of fine grained minerals which show plasticity through a variable range of water content, and which can be hardened when dried or fired. Clay deposits are mostly composed of clay minerals (phyllosilicates minerals), minerals which impact plasticity may also be a part of clay (Guggenheim *et al.,* 1995).

From prehistoric times, clay has been indispensable in architectures, in industry and in agriculture. Thousands of years BCE the cuneiform script was written on clay tablets with a blunt reed called a stylus (Ehlers, *et al.,* 1982). Clay is used as a building material, it is used in the form of brick, either sun- dried or fired. Clays are also of great industrial importance e.g. in the manufacture of tile for wall and floor coverings, and of pipe for drainage and sewage. The less absorbent bentonites are used chiefly in the oil industry, e.g. as filtering and deodorizing agents in the refining of petroleum (Grim, 1986). Clay is also of high domestic importance, e.g. in the manufacture of cooking pots and other cooking utensils.

Clay or concrete material has been discovered to be effective as shielding material for ionizing radiations; Russian scientist has used clay to protect their body while working with nuclear material.

Sources of ionizing radiation have been in existence for technological ages. The natural sources and the artificial sources are the major sources of these radiations. These ionizing radiations have found applications in different facets of human endeavour which include medicine, research, industry and agriculture (Mann, 1988). In all these areas of applications the use of radiation sources has been found to produce a lot of benefits. The principle that summarises this, called ALARA, states that radiation doses to persons involved in the use of ionizing radiation must be As Low As Reasonable Achievable (IAEA, 1973a).

Generally the ALARA principles are ensured by (I) Minimizing the time an individual spend around radiation sources. (ii) Staying far away from the radiation sources. (iii) By shielding the sources away from individuals and (iv) A combination of all the three approaches or any two of them. It is however known that the most effective of the approaches is shielding, and to its disadvantage it is the most expensive. The idea therefore has been to find materials that can be used as shielding material at minimal cost. A shield is a physical entity interposed between a source of ionizing radiation and an object to be protected such that the radiation level at the position of that object is reduced.

Corresponding Author: O.G. Olowomofe, Physics Department, Uiversity of Ibadan, Ibadan, Nigeria.
E-mail: waleography@hotmail.com

Lead is the most widely and effective material used as radiation shield because of its high density, large atomic number, high resistance to chemical corrosion and ease to fabricate. However lead is not common and is very expensive hence there is a limitation to its availability as radiation shield. Uranium is another excellent radiation shield material because of its high density, however, it is highly active chemically and oxidizes when expose to air in addition to being difficult to fabricate. Concrete is another versatile and widely active material because it is easy to fabricate, and relatively inexpensive, however because of its ability to lose its hydrogen content, its ability as a radiation shielding material is greatly reduced (Chilton *et al.,* 1984).

Search for alternative materials required for shielding ionizing radiation has being on increase for some period of time, Lead which is widely used is expensive, therefore researches has to be carried out on other material. Clay has been suggested as alternative material (Alam *et al.,* 2001), but it is not as effective as a shielding material as lead. Its vast usage in technical industry, architecture, and construction industry, couple with its ability to absorb radiation and the fact that it is common, inexpensive, non-toxic, easy to fabricate than lead and concrete mentioned above makes it relevant in shielding ionizing radiation.

Several works have been carried out in determining the radiation shielding ability of clay and some soils used for building in Bangladesh(Salinas *et al.,* 2005) and Brazil(Alam, *et al.,* 2001). This work aims to study the shielding characteristics of pure clay-brick sourced from Seven different location in Ekiti state south-western Nigeria and to relate its attenuation coefficient to different thicknesses and pressures. It also evaluates the changes in physical structure and state of the clay due to compression of the clay brick to shield ionizing radiation.

Theoretical Background:

Radioactivity has been defined as the spontaneous disintegration of atomic nuclei by the emission of sub atomic particles called alpha particles and beta particles and those of electromagnetic rays called X-rays and gamma rays. It can also be defined as the spontaneous emission of ionizing radiations by radioactive materials. It was found out that radioactive elements are more concentrated sources of energy than had been known before. (Pattison, 1999)

Energy emitted from a source is generally referred to as radiation. Radiation can be categorised as ionizing and non- ionizing radiation. The greatest important of the two is the ionizing radiations. All emission from radioactive sources is ionizing in nature and can radiate energy. Radiations have been a subject of study for the past decades.

Radiation measurements are possible because of interaction of radiation with matter. Generally, radiation interaction with matter involves transfer of energy from radiation to the matter which it transverses .Dunn, (1957) reported that for most radiation shielding, photon energies of 10 keV to 10 MeV are important. For this energy range, the photoelectric effect, pair production, Compton scattering mechanisms of interaction predominates over all others. Our choice of 60 keV to 120 keV in this project work is still within this range. Of these three, the photoelectric effect predominates at lower photon energies.

In Compton Effect, an incident photon is scattered when it collides with a loosely bound orbital electrons in the outermost shell. This leads to the reduction of the energy of the photons from hf to hf'. The change in energy results in change in frequency and increase in wavelength of the photon from λ to λ' while the orbital electron is scattered at a different angle □ and the electron energy is almost equal to $hf - hf'$. This energy that is deposited in a material can be calculated by applying the conservative principle for energy and momentum and it is given by the equation below:

$$E_k = E_r\left[\frac{(E_r/m_oc^2)(1-\cos\theta)}{1+(E_r/m_oc^2)(1-\cos\theta)}\right] \tag{1}$$

Where m_o= momentum of the electron, E_r =Energy of the electron:

C = Speed of light

This scattering can therefore have a value in the continuous range of zero to $E_{\max}$. This explains the continuous distribution of pulse heights termed Compton plateau in gamma spectroscopy.

Absorption of ionizing radiation can be defined as the taking up of energy by matter. Absorption results in reduction in the amount of energy available to allow a body to do work. (Dendy *et al.,* 2000) The energy, in the process, is not lost but is converted to internal energy within the absorbing medium. Dark coloured bodies absorb more thermal energy from radiations than light coloured or white bodies. The rate of absorption of T, where T is the temperature difference (T^4). The rate of absorption is also dependent on the amount of exposed surface area; the larger the area, the greater the absorption. The following equations show this relationship (Dendy *et al.*, 2000).

$$\frac{dA}{dt} = K(T_m - T_E)^4 = KT^4 \tag{2}$$

where T = $T_m - T_E$ and

$$\frac{dA}{dt} = \sigma A_s$$

Combining the two equations, we have:

$$\frac{dA}{dt} = \varepsilon A_s (T_m - T_E)^4$$

Where the constants K and σ are contained in the constants ε.

T_m= Temperature of the medium, T_E = Temperature of the body, As= Surface area,

σ= surface charge, $\frac{dA}{dt}$ = Rate of Absorption.

The absorption of ionizing radiation is related to the intensity of the radiation and obeys the inverse square law.

$$I \alpha \frac{1}{d^2} \tag{3}$$

Where I is the intensity and d is the thickness of the absorber.

This means that the closer the material that will absorb the ionizing radiation to the source, the higher the absorption rate.

There are several methods available for detecting ionizing radiation. Some of these includes (i) Ionization chamber, Geiger Muller counters and Scintillation counters, (ii) Cloud chambers and bubble spark (visualized detection), and (iii) Thermoluminence dosimeter (TLD). And film badges (Dosimeter.) the ionization chamber is of most interest to this study because it allows wide range measurement of ionization current which gives an output signal that is a linear function of the amount of radiation detected with a precision of better than 0.1% (Mann *et al.*, 1988) and also being the only standard dosimeter available for use at the SSDL of NIRPR, University of Ibadan as at time of measurement and is therefore described in detailed below: Irradiation is the process by which a body is exposed to radiation. The exposure may be deliberate or accidental. Irradiation was the process used in this research work.

Attenuation is the reduction in the amplitude of a signal or radiation. When radiation is scattered by a medium, there is a change in direction of the radiation. Radiations are sometimes attenuated exponentially by transmission through a medium. Attenuation is the opposite of amplification and is measured in decibels (Dunn, 1957).

The attenuation of parallel beam of radiation photon is given according to the Lambert-Beer equation as:

$$I = I_o \ell^{-\mu x} \tag{4}$$

Where I_o is the incident intensity of the photon, I is the transmitted intensity of the photon, x is the thickness of the absorbing medium and μ is the linear attenuation coefficient. This equation relates the intensity of radiation photons at a specified energy after attenuation coefficient, I to that without attenuation at the same energy I_o, under a good geometry collimator conditions. A block diagram of the passage of radiation photon through shield is shown below:

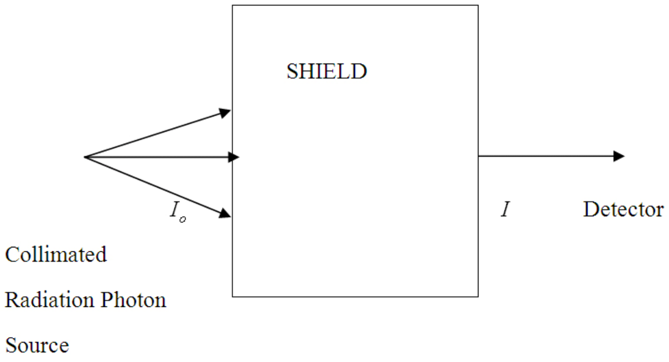

Fig 2.1: A block diagram of attenuation of a beam of radiation photons under good geometry condition.

MATERIALS AND METHODS

Clay sample were collected from four major location in Ekiti State (i) Isan Ekiti where three clays from three different locations namely Turoo, orudi and Aradee are usually mixed at equal proportion(sample A) and the three samples identified as (sample B, C, D) for making pots,.(ii) Ara Ijero Ekiti (sample E) where the clay is used in pots making (iii) Ire Ekiti (sample F) where the clay is predominantly used for block making and consequently a fancy block factory was sited at the location, and (iv) Orin Ekiti(sample G) where we have red clay deposit mostly used for building construction.

Samples were wrapped separately with a polythene bag to avoid contamination with other soil samples, this is to maintain the properties and identity of the sample at all stages of sample preparation. The apparatus used includes clay soil samples, a metallic cylinders (of diameter 2.7cm), AC Hydraulics (compressor) of capacity , 16 tons, Mettler weighing device (Maximum weight =310g, Minimum weight = 0.5g, 0.01g, deionised water , oven (at 110°C) furnace (at 1000°C), Meter rule , X-ray ionization chamber, two collimators, and. A PTW UNIDOS digital type.

These experiments were set up first at the Ceramics department of the Federal Institute of Industrial Research, Oshodi, Lagos (FIIRO) and National Institute of Radiation Protection Agency (NIRPR), University of Ibadan. Firstly deionised water was obtained and was used to mix the soil sample to form a paste. This was done in a dry container and was measured accordingly as shown in table 4.1. The measured soil samples were poured into the metallic ocylinders, one after the other, and were compressed by the Hydraulics to different thicknesses at different pressures. The compressed samples were allowed to air dry for a day before being transferred to the oven which is at 110°C. The samples were allowed to oven dry for a day after which they were fired at 1000°C in a blast furnace. These set of samples were reweighed after firing for the values of weight W_3 (g). The samples were also coded just after compression for easy identification. the samples were rearranged to thicknesses x= 1, 2, 2.5, 3.0, centimeters for the different pressures $P=875 \times 10^4$, 1750×10^4, 2625×10^4, 3500×10^4, $4375 \times 10^4 N/m^2$ respectively. The set up was carried out at the Secondary Standard Dosimetry Laboratory (SSDL) of the National Institute of Radiation Protection Agency (NIRPR), University of Ibadan. It consisted of two linear collimators: one at the front of the ionization chamber and another for the X-ray source. A PTW UNIDOS Electrometer was employed to record the counting in the control room. The x-ray machine is the source of radiation, ionization chamber detected the amount of radiation transmitted through sample while the lead collimator was employed to produce radiation beam of narrow geometry. The clay brick was placed; between two collimators each of aperture of 1.2mm at a distance of 100cm from the x-ray source .Figure 3.0 shows the experimental setup of the samples to be irradiated.

The Hopewell design Inc. X-ray machine was first preconditioned for about 30 minutes. The reason for this is to allow the machine to attain the operational temperature and voltage for good emissions of electrons having been left unused for a period of 5 days. The preconditioned was applied subsequently during the periods taken for the counting.

The counting process involves the measurement of the direct flux from the source, which was first taken without placing any sample between the X-ray source and Ionization chamber and also counting was recorded when lead block was placed in between the detector and ionization chamber, this was later subtracted from each other for the background reading of the flux (Io) which is taken as the intensity of the direct flux. Samples were subsequently placed between the X-ray source and the detector at linear collimator geometry. X-ray source of energies 60KeV and 120KeV were irradiated on each samples for 30 seconds by this procedure the intensity of the direct(I_o) and the transmitted (I) flux were determined and the counting was recorded by the electrometer.

Fig. 3: Functional diagram of the counting assembly.

Plate 3.0: Experimental setup consisting of a collimated ionization chamber, a collimated X-ray source and the sample to be irradiated at the middle

Plate 3.1: Samples compressed at different pressures for different thicknesses.

The linear attenuation coefficient was determined from the measured transmitted intensity from X-ray fluxes on the thicknesses of each of the compressed clay samples. All the samples show that as the photon energy increases, there is corresponding increase in the intensity of radiation on each samples that were irradiated. This is in agreement with general trend reported in literature review by (Dendy *et al.,* 1999).

RESULTS AND DISCUSSION

The linear attenuation coefficients calculated for all the samples at energies of 60keV, 10mA and 120keV, 15mA are shown in Table 1. It shows that the average attenuation for samples A ,B, C, D, E, F and G at a particular thickness and energies shows considerable reduction in intensity between 1750Nm^{-2} and 4375Nm^{-2} of pressure applied in compressing the samples. The results show that attenuation increases as both thickness and pressure increase. This is in conformity with Lambert beer's equation.

Table 1 shows that as the pressure increases, the attenuation coefficient increases with decrease in intensity at both photon energy used. This indicates that the clay material responds to compressibility from increased pressure used in compressing the clay soil. This also indicates that attenuation factor of the same thickness of clay sample varies at different pressure and energy. From the observation discussed above, it can be said that the changes in structure due to increase pressure of compression coupled with the physical nature of the material is responsible for the response of the samples to the reduction in intensity of the X-ray radiation. (Salinas *et al.,* 2006).

It was also observed that as we increase the pressure, the attenuation coefficient for the various thicknesses increases, continuously with increasing thickness. This is as a result of increase in density due to the applied pressure on the soil sample.

Generally, it was observed that as the thicknesses increases the linear attenuation increases minimally for all the samples as the pressure applied increases. This indicates that the attenuation coefficient depends on the rate at which a clay sample is compressed and as the intensity of penetration increases the attenuation coefficient reduces in value.

Table 1:

Thickness(Xcm)	Pressure(Nm^{-2})	60keV, 10Ma	Attenuation(µ) 120keV,15Ma
1	875	0.149	0.0805
	1750	0.1848	M0.137
	2625	0.2378	0.1782
	3500	0.3095	0.238
	4375	0.3276	0.2762
1.5	875	0.2227	0.1515
	1750	0.2373	0.2001
	2625	0.2487	0.2437
	3500	0.3034	0.2814
	4375	0.339	0.3197
2	875	0.2324	0.2091
	1750	0.2927	0.2824
	2625	0.3064	0.3023
	3500	0.3317	0.309
	4375	0.3571	0.3231
2.5	875	0.2479	0.264
	1750	0.3046	0.2975
	2625	0.3107	0.2975
	3500	0.3394	0.3232
	4375	0.376	0.3236
3	875	0.2484	0.3538
	1750	0.334	0.301
	2625	0.3128	0.3122
	3500	0.349	0.3354
	4375	0.3655	0.3832

Conclusion:

Linear attenuation coefficient of compressed clay samples from seven different locations in south western Nigeria has been determined. The results obtained for all the samples show that the intensity of radiation reduces as the thickness of compression increases with increase in pressure, which is in agreement for a shielding material to radiation. Consequently, its attenuation coefficient increases which shows corresponding decrease in attenuation between thicknesses 2.5 cm and 3.0 cm and pressures 1750 Nm^{-2} to 4375 Nm^{-2}. This can be said to be due to increase in compression at high pressure and large thickness as observed. Therefore for an improved shielding effectiveness of this material, larger thicknesses of the brick is required as noticed during the course of this work especially between 3cm to 3.5cm thickness samples, which shows significant response to shielding.

Also, compression and corresponding firing at a high temperature of the clay samples show significant high reduction in the weight of the samples after compression and firing as compared to when it is not dried and fired. Its response to compressibility and slight difference in value from increase pressure shows the materials rigidity in structural strength thus making it suitable as shield for ionizing radiations.

REFERENCES

"Radiation Dosimetry: X-Rays Generated at Potentials of 5 to 150KV", ICRU Report 17, 1960. International Commission on Radiological Protection, Pergamon, Oxford.

500F (288C)" in *Effects of Radiation on substructure and Mechanical Properties*

Alam, M.N., M.M.H. Miah, M.I. Chowdhury, 2001. Attenuation coefficients of soils and some building materials of Bangladesh in the energy range 276-1332KeV. *Appl. Radiat. Isot*., 54: 973-976.

Chilton, A.B., J.K. Shultis and R.E. Faw, 1984. Principles of Radiation Shielding, New Jersey Prentice-Hall, Inc;

Dendy, P.P. and B. Heaton, 2003. Physics for Diagnostic Radiology, (2nd ed). Bristol and Philadelphia: Institute of Physics Publishing.

Dunn, W.W., 1957. Transmission of Fast Neutrons Through Aluminum, Iron and Lead, - *Thesis*, Air Force Institute of Technology, *Armed Services Technical Information Agency*, 124760.

Ehlers, Ernest G. and Blat Harvey, 1982. Petrology, ligneous, Sedimentary, and Metamorphic. San Francisco: W.H freeman and company ISBN 0-716-1279-2.

Guggenheim, Stephen and R.T. Martin, 1995. Definition of clay and clay mineral: Journal. Report of the AIPEA nomenclature and CMS nomenclature committees (http//www.clays.org/jounal/archive/volume.pdf).

Halliday/ Resnick/ walker, 2001:1986. Fundamentals of physics, sixth edition. John Wiley and sons, Inc. New York.

Hubbel, J.H., 1982. Photon mass attenuation and energy absorption coefficients from 1KeV to 20MeV. *Int.. J. Appl. Radiat. Isot*., 33: 1269.

Hubell, J.H., S.M. Seltzer, 1997. Tables of x-ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients (Versions 1.03), (Online) Available: http://physics.nist.gov/xaamdi(2004,July 26). National Institute of Standards and Technology, Gaithersburg, MD.

Institute of Building Technology and the Central Laboratory for Radiological Protection, 1995. Building Materials. Warszawa, Poland; *ITB and CLOR*: Instruction number 234: PL - 03 - 194 Building. Macdonald and Evans Ltd.

Mann, W.B., 1988. Radioactivity Measurements: Principle and Practice. England.

Price, B.T., C.C. Horton and K.T. Spinney, 1957. *Radiation Shielding*, Pergamon,Elmsford, N.Y., pp: 199-193.

Radiation Protection and Measurements, Washington, D.C., 1976.

Radiation Protection: Recommendations of the International Commission on Radiological Protection, Adopted 1965. ICRP Publication 9, Pergamon, Elmsford,N.Y., 1966,1969, 3-4. Recommendation of the International Commission on Radiological Protection(1977). ICRP Report 49). Oxford Pergamon Press.

Salinas, I.C.P; Conti, C.C; Lopes, R.T. (2006). Effective density and mass attenuation coefficient.