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Studies on relaxation length and half-thickness of some rock samples using gamma radiation

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ABSTRACT

Relaxation lengths of different types of rock were measured using gamma radiation from a ^{60}CO source. Results show that limestone has the highest relaxation length of 20.000 cm, while sandstone has the least relaxation length of 8.850 cm. Half-thickness was determined for each rock sample. Results also show limestone with the highest value of half -thickness as 13.860 cm, while sandstone has the least half -thickness of 6.133 cm. Densities of rock were also measured. Mass attenuation coefficient was determined for each rock sample. With the proper choice of the thickness of rock sample from theoretical evaluation, it was observed that sandstone with thickness of 280 cm almost completely attenuate gamma ray energy in the range 0.1 Mev to 1.836 Mev.

INTRODUCTION

Rocks that constitute the earth's crust consist essentially of assemblages of various minerals. They can be broadly classified, depending upon their mode of origin, into three major divisions: the sedimentary, metamorphic and igneous rocks. Rocks within each of the major divisions are classified partly by the shape and size of the individual particles, which make up the rock and partly by the rock-forming minerals that are present in significant amounts. These rocks can be quarried into different sizes for road construction as well as in the construction of dwelling places. They can also be used to shield radiations from nuclear sources.

There are a lot of industrial uses of gamma irradiation such as food preservation, sterilization of medical devices, pharmaceutical products and packaging materials, improvement of mechanical, electrical and thermal properties of plastics. Such ionizing radiation combined with nuclear wastes from nuclear bomb testing, volcanic eruptions, nuclear power plants could increase the sources of gamma radiations in our environment. From recent studies, it was observed that our environment has been contaminated by some radioactive fallouts[1,2]. Exposure to gamma radiation may be harmful. Gamma rays are the most penetrating of all natural radiations and are best absorbed by dense materials.

Since attenuation depends on the density of the material as well as on other property[3], very dense materials (such as lead) are very expensive. Therefore, there is need to investigate our local materials for use as protective shields and coatings that could attenuate some of these radiations. Gamma radiations from cobalt-60 have already been used in measuring the density of

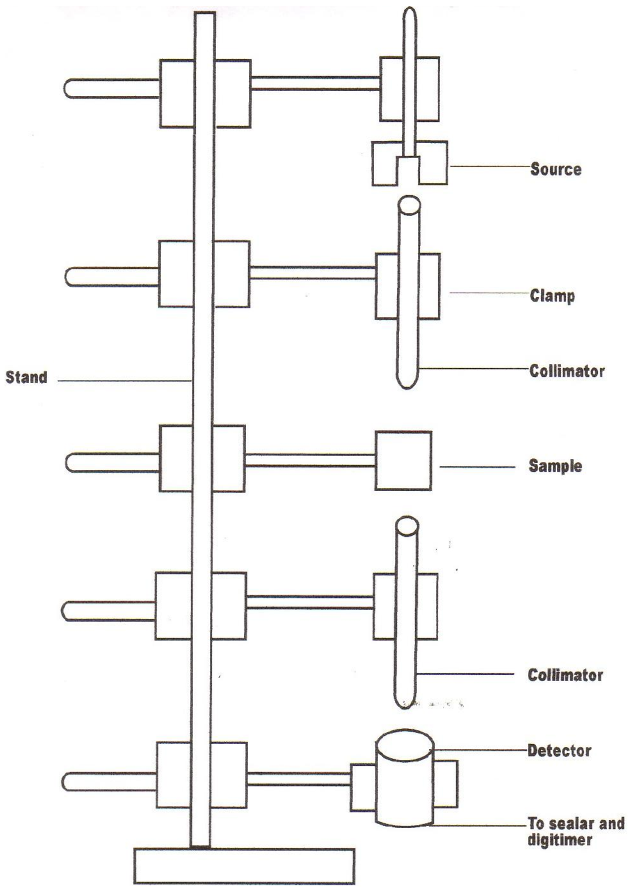

Figure 1 : Experimental setup

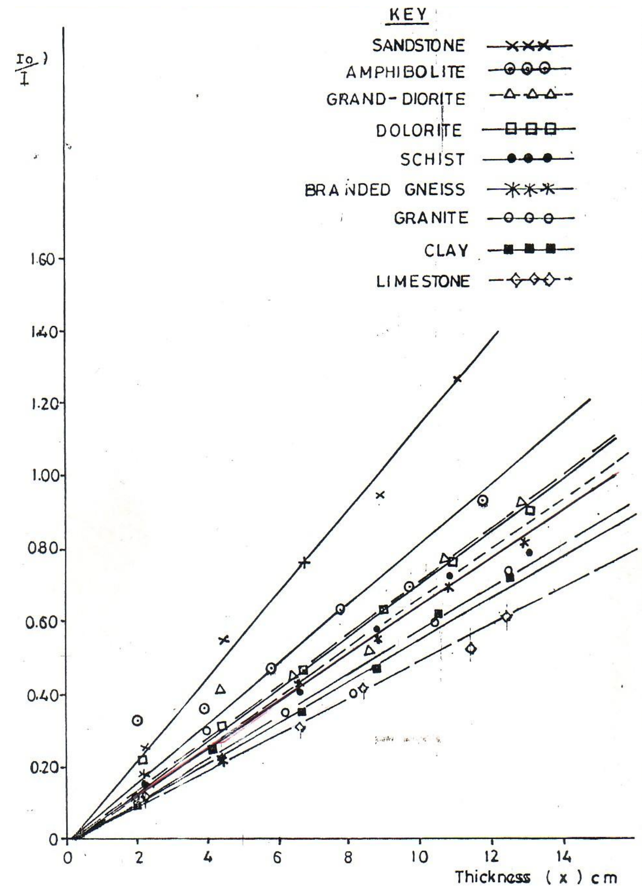

Figure 2 : A plot of ln(Io/I) against thickness

rocks and various other materials[5,6]. Recently, Akpabio et al.[7] and Akpabio et al.[8] developed models for Relaxation length and Half-thickness of wood using gamma radiation technique. In this investigation, the same gamma radiation from cobalt -60 has been used in determining the relaxation length and half-thickness of different types of rock.

FORMULATION OF THE PROBLEM

Three main processes attenuate gamma radiations in rocks: Photo effect, Compton (also known as Compton Debye) effect and pair production. When gamma radiation of intensity I is incident on a rock of thickness X, the attenuation of gamma radiation in the rock substance is given by the relationship[4,9].

$$I = I_0 e^{-\mu X} = I_0 e^{-X/R_1} \quad (1)$$

where I_0 is the intensity of the beam before passing through a material of thickness X; I, is the intensity after passage through X, μ is the attenuation coefficient and R_1 is the relaxation length.

The attenuation of gamma rays by different gamma-absorbers may also be expressed in terms of a quantity called the half-thickness, $X_{1/2}$ (i.e. the thickness of absorber needed to reduce the intensity to half its initial value)[10],

such that $I = \frac{1}{2} I_0$

Eq. (1) may be written as, $\ln (I_0/I) = \mu X$ **(2)**

Such that $\ln 2 = \mu X_{1/2}$ and $X_{1/2} = 0.693/\mu$ **(3)**

On plotting In (I_0/I) against X from eq. (2), the attenuation coefficient for each rock sample is determined and likewise the relaxation length.

MATERIALS AND EXPERIMENTAL

Materials

In this investigation, nine different rock samples were used. Six of the rock samples among which include Amphibolite; Schist; Branded Gneiss; Dolorite; Granite and Grand-diorite, were collected from Strabag Quarry in Netim Village of Akamkpa Local Government Area in Cross River State, Nigeria. Limestone and Sandstone were obtained from Urban Local Government Area also in Cross River State, Nigeria, while clay rock was taken from the ravine in University of Uyo compound in Akwa Ibom State, Nigeria.

Rock cutting machines with diamond coated blade; Model 16 SSP Serial 16 SSP 7626 and Model CS1O thin section cut-off saw (Logic Tech. Ltd. Scotland) were used for cutting each rock sample into six rectangular blocks with thickness ranging between 2.0cm and 13.2 cm. Cobalt -60 (5 μC_i) gamma source model P66 340/8, Geiger Muller (GM) tube detector and scalar counter/timer model P67520/4 were used in measuring the relaxation length of the rock samples.

Experimental method

The experimental set up for the determination of relaxation length by gamma radiation was as described earlier in some previous studies[7,11,12]. The set up comprised a GM tube and a scalar counter/timer. Two steel collimators of equal diameters and thickness arranged axially between the source and sample and between sample and detector reduced the primary and secondary gamma-rays to narrow beams as shown in figure 1. The sample was irradiated from the top by narrow beam of gamma-rays. Counting time was fixed at 30 minutes and average background corrected activity obtained from the total count. Counting was repeated twice for each sample and average count rate taken.

The number of counts for the transmitted intensity of the gamma radiations, I of each sample (of varying thickness) was taken for the same time duration of 30 minutes. The same procedure was used for all the different rock samples. At each instance, the count rate without sample was measured before each sample was introduced. The bulk densities were also determined by conventional methods.

RESULTS AND DISCUSSION

The radionuclide content of rocks is a complicated function of their geochemical history; which varies considerably among the various types, certain generalization can be made that derive from extensive geological investigations. For example; the radioactivity in igneous rocks is related to the quantity of silicates, being highest in acidic varieties and lowest in the ultra basic rocks (e.g. dunites). Igneous rocks generally exhibit higher radioactivity than sedimentary rocks, while metamorphic rock have concentrations typical of the unmetamorphosed rocks from which they are derived certain sedimentary rocks, including some shales and phosphate rocks are highly radioactive, while other types notably limestone and various evaporates (e.g. halite, anhydrite and gypsum) are quite low in radio nuclide content[13].

TABLE 1 : Experimental results for the relaxation length, half-thickness, density and mass attenuation coefficient of the rock samples

Rock sample	Density (gcm^{-3}) ρ ±0.011	Relaxation length R_l (cm)	Half-thickness $X_{1/2}$ (cm)	Mass attenuation coefficient (cm^2g^{-1}) ±0.002
Sandstone	3.358	8.850±0.067	6.133±0.023	0.034
Amphibolite	2.832	12.195±0.083	8.451±0.024	0.029
Grand-Diorite	2.800	14.085±0.045	9.761±0.012	0.025
Dolorite	2.716	13.889±0.044	9.625±0.012	0.027
Schist	2.713	14.925±0.047	10.343±0.012	0.025
Branded gneiss	2.472	15.385±0.044	10.662±0.011	0.026
Granite	2.400	17.241±0.042	11.948±0.011	0.024
Clay	2.031	17.544±0.038	12.158±0.009	0.028
Limestone	1.749	20.000±0.033	13.860±0.007	0.029

The relaxation length for each rock samples is obtained from eq. (2) by the plotting of In (1_0/I) against X. The respective relaxation length, mass attenuation coefficient and half-thickness for the different rock samples are presented in TABLE 1.The variation in attenuation of gamma radiation with thickness X of the different rock samples are as obtained in figure 2.

The attenuation of gamma radiation may also be expressed in terms of a quantity called, the half-thickness. It will be obvious from TABLE 1, which shows the variation of half-thickness ($X_{1/2}$) with density (ρ); that as the density of the rock sample increases, the half value thickness decreases. This means that, attenuation is indirectly proportional to the density. It is observed that the mass attenuation coefficient is nearly constant (TABLE 1) for the investigated rock samples. The result conforms to what is found experimentally as presented by Littlefield and Thorley[10].

Attenuation depends on several factors, some of which include bulk density and size of the particles.

TABLE 2 : Computed gamma ray attenuation for rock sample (Sandstone)

Source	Gamma ray energy (Mev)	Gamma ray energy attenuated (nev)
	0.100	2
^{132} Ba	0.302	5
^{132} Ba	0.356	6
^{22} Na	0.511	9
^{132} Cs	0.662	12
^{54} Mn	0.835	15
^{92} Y	0.898	16
^{60} Co	1.173	21
^{22} Na	1.273	23
^{60} Co	1.332	24
^{94} Y	1.836	33

Moreso; closely packed particle materials have high bulk density and corresponding low pore spaces, while loosely packed particle materials have large pore spaces. Hence, lower porosity enhances retardation factors between the solid particles. This lowers the penetration of gamma rays in the material, thus high bulk density particles attenuate or scatter more radiation than the low-density particles[10,11]. This implies that materials with heavier particles have lower values of relaxation length and half-thickness. Therefore, sandstone contains closely packed particles that can attenuate or scatter gamma radiations, while Limestone contains loosely packed particles.

Uwah and Rosenberg[14] carried out Instrumental Neutron Activation Analysis (I NAA) to determine sixteen trace elements: Na, K, Mn, Sm, La, Fe, Tn, Sc, Co, Ba, Rb, Br, Sb, U, Cs and Ta in some rock samples from Ugep in the lower Benue region of Nigeria. Most of the rock samples for this investigation were also obtained from the lower Benue region. They concluded that, there is evidence of preferential enrichment of Th with respect to U in the rock samples of the areas. Likewise, Ba concentration in these rocks is higher than normal. On the whole, these concentrations (U and Ba) are not high enough to infer possible mineralization. Hence, there was no anomalous concentration that would have adversely affected our result for this study.

Leaching of radio nuclides from underground nuclear repositories or toxic substances from landfills and their migration in the surrounding environment are critical points in environmental research[15]. Since retardation factors[16] of the rocks surrounding the repository determine the geological safety barriers, we have computed the thickness of a typical rock sample (Sandstone following the results of TABLE 1) that will completely attenuate gamma ray in a given energy range 0.1 Mev to 1.836 Mev. The result of our computation is presented in TABLE 2. The list of standard sources and their gamma ray energies were obtained from Holmberg and Rieppo[4], while 0.1 Mev was included to complete the range. From the Table, we can observe that sandstone of 280cm thick almost completely attenuate gamma ray energies in the given range. This implies that Sandstone with thickness more than 280cm could completely attenuate gamma ray in a given energy range.

CONCLUSION

From our experimental results we conclude that limestone has the highest relaxation length and half-thickness value of 20,000cm and 13.860cm respectively. While, sandstone has the least relaxation length and half-thickness of 8.850cm and 6.133cm respectively. The results also indicate considerable potential for the mass attenuation coefficient of rock, which can guide construction engineer on the type of rocks to select for the construction of accommodation in gamma invasive areas.

Since relaxation length and half thickness value of rock samples depend on density, it implies that there are suitable physical parameters that can be determined and used to identify rock samples. Theoretically evaluated attenuation values of TABLE 2 for gamma ray energies in a given range suggest that, rock sample such as Sandstone with thickness more than 280cm could completely attenuate gamma ray energies. However, this research is open for further investigation as only a few rock samples among the numerous rocks were used for this work.

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