

COMPARATIVE STUDY ON ATTENUATION AND SCATTERING OF γ -RAYS THROUGH SEDIMENTARY AND IGNEOUS ROCKS

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ABSTRACT The attenuation and scattering coefficients of gamma-rays of different energies in two sedimentary and two igneous natural rocks; siltstone, conglomerate, andesite and felsite respectively, and also in compressed powdered samples of the same four rocks, were studied. The effects of particle size (grain diameter d mm) and sample density, ρ , with radiation energy (E) ranging from 0.36 to 1.33 MeV, were investigated. The results showed an inverse proportionality between the linear attenuation coefficient μ and both d and E , also we found that μ has a direct proportionality with the sample density, ρ . The side scattering coefficient, ϕ , is directly proportional to both d and E , but at the same time ϕ has an inverse proportionality with the sample density ρ .

KEYWORDS Sedimentary rock, Igneous rock, Attenuation coefficient, Side scattering coefficient

INTRODUCTION

With the extensive applications of radioactive materials, it is necessary to look for efficient absorbers appropriate for shielding. The propagation of gamma-rays through gabbro and troktolite have been investigated in a previous paper^[1]. The object of the present experiment is to study the attenuation and scattering of gamma-rays of different energies through absorbers composed of natural rocks and compressed powdered samples for the same four rocks under study.

This paper describes a series of experiments undertaken by us to investigate some transmission properties of gamma-radiation through two sedimentary and two igneous natural rocks "siltstone, conglomerate, andesite and felsite respectively" and compressed powdered siltstone, conglomerate, andesite and felsite. we also present a comparative study of attenuation and scattering of gamma-rays through sedimentary and igneous rocks. The most important quantity characterizing the penetration and diffusion of gamma-radiation in extended matter is the attenuation coefficient μ which depends on the photon energy E and atomic number Z of the medium^[2]. Hence we are primarily interested in evaluating μ as well as the side scattering of radiation for different gamma-energies and different grain diameters of the materials under investigation, i. e., natural rocks and compressed powdered siltstone, conglomerate, andesite and felsite.

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1 EXPERIMENTAL DETAILS

1.1 Preparation of samples

Compressed samples of local rocks in the form of powdered siltstone, conglomerate, andesite and felsite in the form of circular discs 3 cm in diameter, and also discs of the same local natural rocks were used in this investigation. The powder was prepared by grinding the four rocks, sieving it through a standard set of sieves: 0.18, 0.16, 0.10, 0.09, 0.08, 0.071 and 0.056 mm, then the sieved samples were pressed with a hydraulic compressor under 35 ton/cm² to thicknesses ranging from 0.85 to 1.93 cm.

1.2 The sources, detector, collimator and scaler

Three sources of gamma-radiation have been used: ⁶⁰Co, ¹³⁷Cs and ¹³³Ba. Each source is housed in its own lead container. The radiation is confined to a narrow beam by a lead collimator having a small hole.

A Geiger-Müller counter was used in this experiment as the detector, which has the following characteristics: (a) end window tube; (b) glass envelope; (c) mica window of thickness 5 mg/cm²; (d) cathode-copper film layer; (e) input window diameter 20 mm and (f) operating voltage 750 V.

Our collimator is a hole with 8 cm in length and 1 cm in diameter bored through a cubic lead block having an edge of 8 cm. This is followed by a similar block containing a narrow bored hole with 7 mm diameter, and the two lead blocks are arranged such that the two bored holes are aligned with the source to give a narrow collimated beam with reasonable intensity. The collimator thickness allows for the absorption of radiation scattered out of the beam inside the collimator so that the scattered radiation does not emerge in the room.

Linear attenuation coefficients (μ) of gamma-rays in siltstone, conglomerate, andesite and felsite in compressed and natural forms for the different sources have been calculated from the relation

$$I = I_0 \exp(-\mu x) \quad \ln \frac{I_0}{I} = \mu x \quad \text{or} \quad \log \frac{I_0}{I} = 0.4343 \mu x \quad (1)$$

Linear attenuation coefficients of siltstone, conglomerate andesite and felsite were determined from the linear graphed relation between $\log(I_0/I)$ and x , where I_0 represents the initial intensity of radiation when the absorber thickness is zero, I is the intensity of transmitted radiation through the absorber which has x cm thickness then μ also can be calculated by dividing the slope of the straight line resulting from the last relation by 0.4343.

The mass attenuation coefficient μ/ρ can be calculated by dividing the linear attenuation coefficient μ by the density of the absorbing material as follows

$$\mu/\rho = \frac{\text{cm}^{-1}}{\text{g/cm}^3} = \text{cm}^2/\text{g}$$

The relaxation length (or mean-free-path, mfp) can be calculated from the definition relaxation length = 1/linear attenuation coefficient.

To determine the side scattering coefficients, the detector was fixed at a certain distance from the sample's edge (2 cm) and directed perpendicular to the direction of the incident beam. Then different measurements were taken along the extension of the sample by varying the thickness of absorber. In this experiment siltstone, conglomerate, andesite and

felsite were investigated as shielding materials, where silicon is the predominant essential constituent element, see tab 1^[3]. Fig. 1 is a schematic diagram for our good geometry absorption and side scattering arrangement.

Tab 1. The chemical composition for four rocks /%

Chem. comp.	Siltstone	Conglomerate	Andesite	Felsite
SiO ₂	55.64	71.5	54.20	74.57
Al ₂ O ₃	14.44	10.4	17.17	12.58
Fe ₂ O ₃	5.62	4.4	3.48	1.3
H ₂ O	5.54	—	0.86	0.66
CaO	4.69	3.5	7.92	0.61
CO ₂	3.80	—	—	—
MgO	2.93	2.9	4.36	0.11
K ₂ O	2.87	3.6	1.11	4.3
FeO	1.25	1.2	5.29	1.02
Na ₂ O	1.21	2.0	3.67	4.13
TiO ₂	0.69	0.3	1.31	0.17
P ₂ O ₅	0.17	—	0.28	0.07
MnO	—	0.2	—	0.05

2 RESULTS AND DISCUSSION

2.1 Linear and mass attenuation coefficients and relaxation length

If n_0 is primary photons per second n is photons per second passes normally through a foil containing N atoms/cm³. The attenuation of the photon beam is described by a simple exponential law with a linear attenuation coefficient μ .

$$\frac{n}{n_0} = \exp (-\mu x)$$

Linear attenuation coefficients (μ) of gamma-rays in siltstone, conglomerate, andesite and felsite in compressed and natural forms for different sources ⁶⁰Co, ¹³³Ba and ¹³⁷Cs have been calculated by two different methods:

First: graphically from the attenuation curves by using equ. (1).

Second: by using the least square method and its results. we obtain a good agreement with the results obtained by application of the above linear graphic relation.

We mentioned for example the application of the least square method on one

case for siltstone using the source ⁶⁰Co at grain diameter 0.095 mm as follows in table 2. The mass attenuation coefficients μ/ρ were evaluated for the three radiation sources.

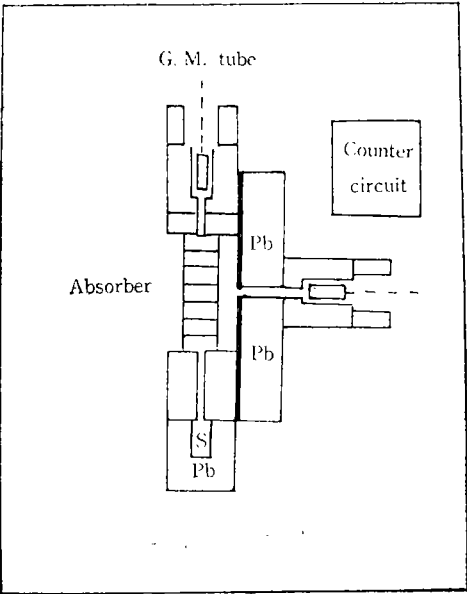


Fig 1. Schematic diagram for good geometry absorption and side scattering arrangement.

Fig 2 and 3 show the variation of μ/ρ and the relaxation length, λ , as a function of the grain diameter (d) for siltstone and andesite.

It's possible to see that μ/ρ varies linearly with d according to the equation

$$\mu/\rho = -ad + k \quad \text{for } 0.0635 \leq d \leq 0.17 \text{ mm} \tag{2}$$

Tab 2. Shows a sample calculation for the attenuation coefficient using the method of least square values for the averaging process on one case for siltstone using the source ^{60}Co at grain diameter 0.095 mm

x/cm	$x-\bar{x}$	$(x-\bar{x})^2$	I	log I	$(\log I - \log \bar{I})$	$(x - \bar{x})(\log I - \log \bar{I})$
1.11	-2.915	8.497	900	2.9542	0.07526	-0.21939
2.35	-1.675	2.805	830	2.9191	0.0401	-0.06716
3.46	-0.565	0.319	801	2.9036	0.02465	-0.01393
4.81	0.785	0.616	763	2.8825	0.00354	0.00278
5.92	1.895	3.591	670	2.8261	-0.05291	-0.10026
6.50	2.475	6.125	577	2.7612	-0.11781	-0.29157
$\Sigma \ 21.953$			$\Sigma \ -0.68653$			
$\bar{x} = 4.025$			$\bar{I} = 756.8$		$\log \bar{I} = 2.87898$	

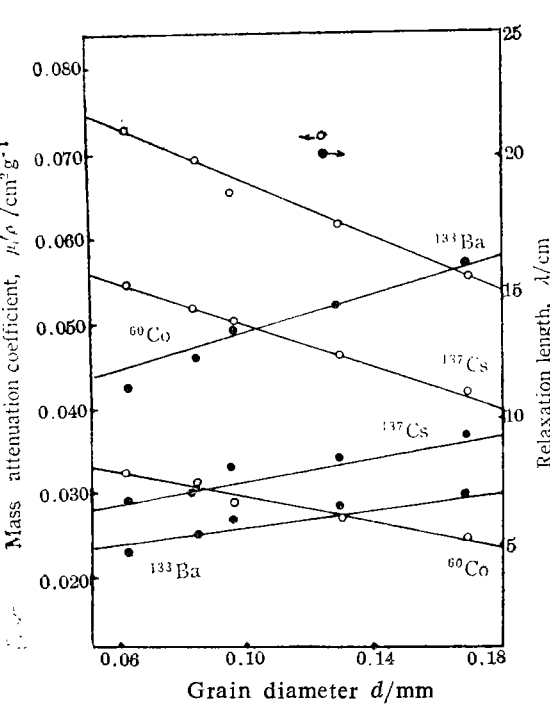


Fig 2. Variation of mass attenuation coefficient μ/ρ and the relaxation length λ as a function of the grain diameter d for siltstone

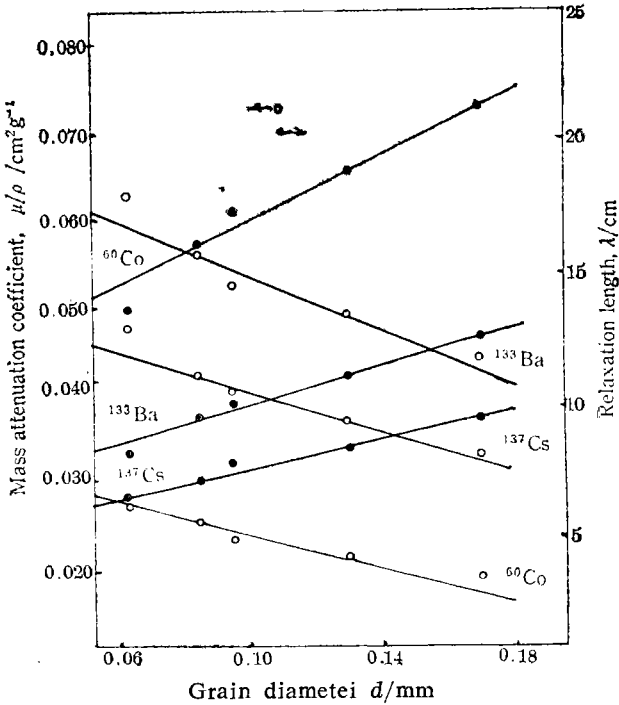


Fig 3. Variation of mass attenuation coefficient μ/ρ and the relaxation length λ as a function of the grain diameter d for andesite

where a represents the rate of change of μ/ρ with d , and k is a constant which depends on the kind of absorber. The figures show also that the relaxation length, λ , increases linearly with d according to the following empirical formula^[4]

$$\lambda = Ad + K \quad \text{for } 0.0635 \leq d \leq 0.17 \text{ mm} \tag{3}$$

where A represents the rate of change of λ with d and k is a constant which depends on the kind of absorber, the variation of μ/ρ and λ were studied with the variation of ρ . The obtained values of μ/ρ and λ are plotted in fig. 4 and 5 for siltstone and andesite. It is seen that μ/ρ increases linearly with ρ in the energy range of interest according to the following empirical formula:

$$\mu/\rho = bp + c \quad \text{for } 0.0635 \leq d \leq 0.17 \text{ mm} \tag{4}$$

where b represents the rate of change of μ/ρ with ρ and c is a constant which depends on the kind of absorber. On the other hand the relaxation length decreases linearly with ρ according to the following empirical formula:

$$\lambda = -B\rho + c \quad \text{for } 0.0635 \leq d \leq 0.17 \text{ mm} \tag{5}$$

where B represents the rate of change of λ with ρ and c is a constant which depends on the kind of absorber.

As the powder gets finer (i.e., d gets smaller) the density, ρ , increases, and the number of scattering centers increases causing more elimination of photons from the incident beam, hence more attenuation. The comparisons between the mass attenuation coefficients and relaxation length for four rocks are made, tabel 3 and 4 show this for two rocks only as example.

$$\text{slope} = \frac{\Sigma(\log I - \log \bar{I}(x - \bar{x}))}{\Sigma(x - \bar{x})^2} = 0.031409$$

$$\mu = \text{slope } 2.303 \text{ cm}^{-1} \quad \mu = 0.07233 \text{ cm}^{-1}$$

this value equals approximately the experimental result which we have obtained from curves, equal 0.07309 cm^{-1} .

Tab 3. Measured values of effective mass attenuation coefficients and relaxation lengths for conglomerate with different radiation source energies

Grain diameter d/mm	Density ρ /g cm ⁻³	⁶⁰ Co		¹³⁷ Cs		¹³³ Ba	
		1.33 MeV	1.17 MeV	0.661 MeV		0.36 MeV	
		μ/ρ /cm ² g ⁻¹	λ /cm	μ/ρ /cm ² g ⁻¹	λ /cm	μ/ρ /cm ² g ⁻¹	λ /cm
0.17	2.368	0.02550	16.56	0.04286	9.85	0.05688	7.42
0.13	2.420	0.02742	15.07	0.04612	8.96	0.05997	6.89
0.095	2.460	0.02860	14.21	0.04815	8.44	0.06268	6.49
0.085	2.500	0.03030	13.20	0.05272	7.59	0.06750	5.93
0.063	2.640	0.03260	11.62	0.05495	6.89	0.07317	5.18

Tab 4. Measured values of effective mass attenuation coefficients and relaxation lengths for felsite with different radiation source energies

Grain diameter d/mm	Density ρ /g cm ⁻³	⁶⁰ Co		¹³⁷ Cs		¹³³ Ba	
		1.33 and 1.17 MeV		0.661 MeV		0.36 MeV	
		μ/ρ /cm ² g ⁻¹	λ /cm	μ/ρ /cm ² g ⁻¹	λ /cm	μ/ρ /cm ² g ⁻¹	λ /cm
0.17	2.345	0.01995	21.38	0.03356	12.71	0.04454	9.57
0.13	2.396	0.02200	18.97	0.03706	11.26	0.04921	8.48
0.095	2.406	0.02360	17.61	0.03970	10.47	0.05269	7.89
0.085	2.447	0.02443	16.73	0.04152	9.84	0.05637	7.25
0.063	2.575	0.02820	13.77	0.04757	8.16	0.06313	6.15

2.2 Side Scattering Measurements

The radiation field at a point in space rot emefrom the source can be divided into two components. The first component is the uncollided or the unscattered photons that

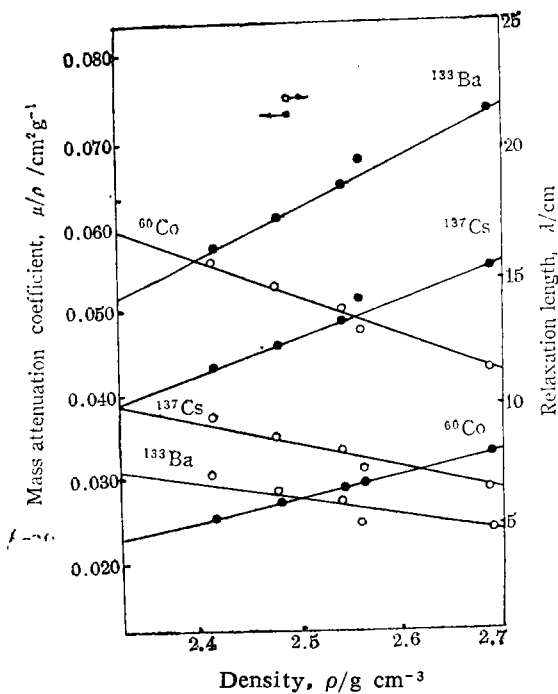


Fig 4. Variation of mass attenuation coefficient μ/ρ and relaxation length λ as a function of density ρ for Siltstone

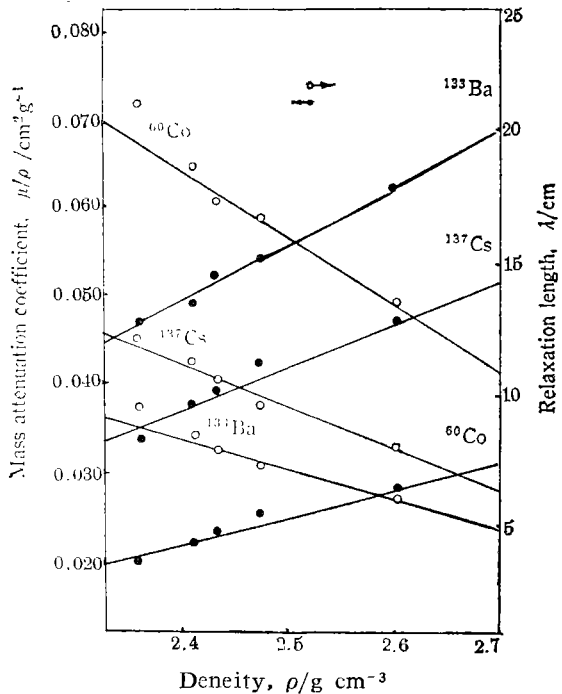


Fig 5. Variation of mass attenuation coefficient μ/ρ and relaxation length λ as a function of density ρ for Andesite

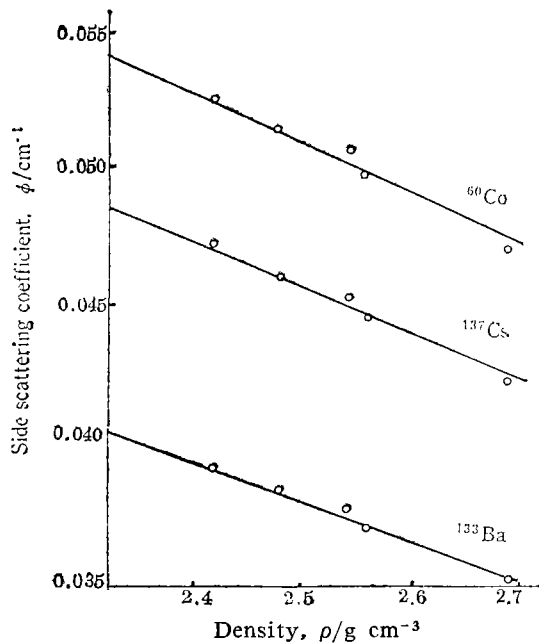


Fig 6. Variation of side scattering coefficient ϕ as a function of density ρ for Siltstone and for the three radiation sources

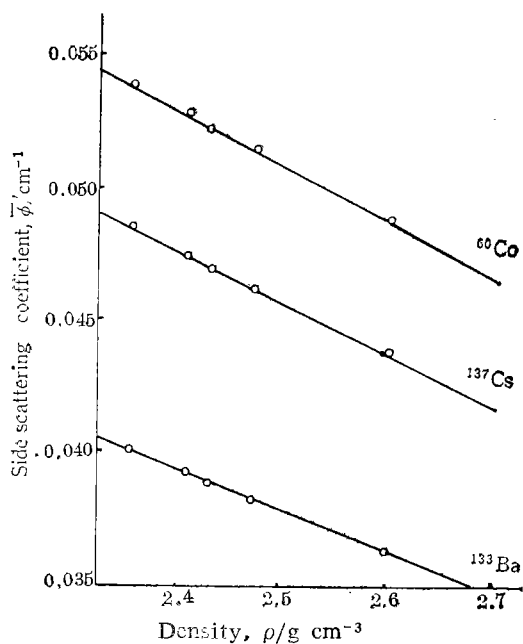


Fig 7. Variation of side scattering coefficient ϕ as a function of density ρ for Andesite and for the three radiation sources

arrive at the point without having undergone any interaction with the transported medium. The second component is composed of the collided or scattered photons. These have undergone one or more interactions resulting in changes of direction or energy or both.

To measure the scattered radiation, the detector was placed perpendicular to the incident radiation at a distance of 2 cm from edge of the samples. The detector was moved parallel to the extension of the sample. Measurements were taken at equal steps 1cm apart. The detector was moved in a circular plane around the sample discs at 45° intervals, then we took the average value of the measured side scattering. Three different parameters were investigated: (a) the effect of photon energy on side scattering using three different sources (^{60}Co , ^{137}Cs , ^{133}Ba), (b) the density of the absorber and (c) the effect of the sample material. As in the case of compressed powdered gabro and tricktolite^[1], the scattered to primary radiation ratio (I_s/I_0) was found to decrease exponentially along the extension of the absorber. Hence the empirical formula for side scattering

$$I_s = I_0 \exp(-\phi z) \quad (6)$$

was verified experimentally in case of siltstone, conglomerate, andesite and felsite for ^{60}Co , ^{137}Cs and ^{133}Ba sources as shown in fig 6 and 7. The figures show that ϕ decreases linearly with the density (ρ) of the absorber according to the derived equation^[5].

$$\phi = -E\rho + F \text{ for } 0.635 \leq d \leq 0.17 \text{ mm} \quad (7)$$

where E represents the rate of change of ϕ with ρ and F is a constant which depends on the kind of absorber, also ϕ increases as the energy of radiation increases for the same density in the energy range of interest.

Fig 8 and 9 show the relation between the side scattering coefficient ϕ and the grain

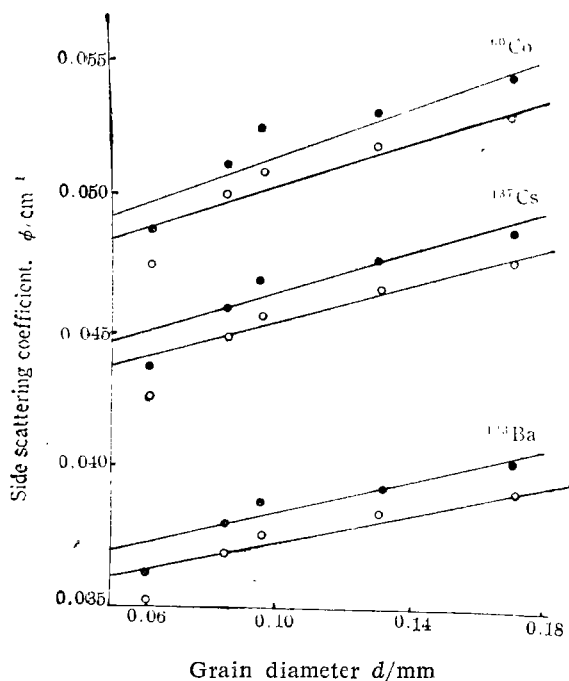


Fig 8. Relation between the side Scattering coefficient ϕ and the grain diameter d for the three radiation sources
(○) siltstone (△) conglomerate

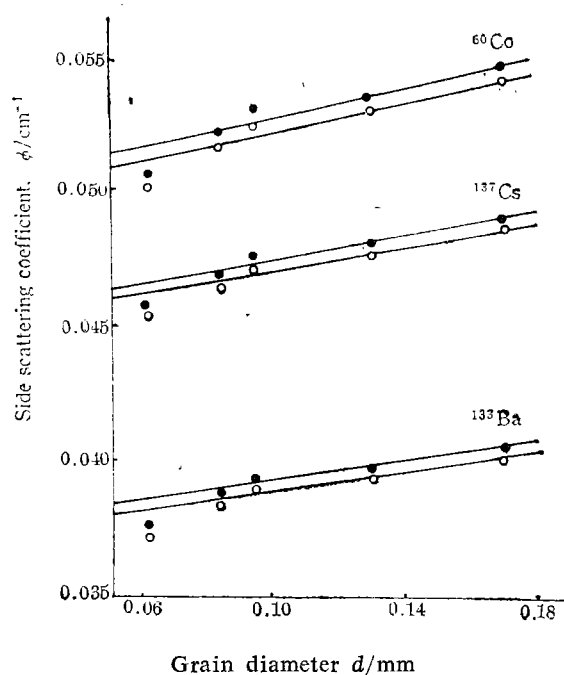


Fig 9. Relation between the side scattering coefficient ϕ and the grain diameter d for the three radiation sources

diameter (d) for siltstone and andesite and for the three radiation sources. It can be seen that ϕ varies linearly with d according to the equation:

$$\phi = ed + f \quad 0.0635 \leq d \leq 0.017 \text{ mm} \quad (8)$$

where e represents the rate of change of ϕ with d , and f is a constant which depends on the kind of absorber. Fig 6 and 7 show the relation between the side scattering coefficient (ϕ) and density of the absorber for siltstone and andesite. From the fig 8 and 9 we found that ϕ increases linearly with increasing both grain diameter " d " and the photon energy of source E .

2.3 Comparative Study on Attenuation and Side Scattering of Gamma-Rays in Sedimentary and Igneous Rocks

There are noticeable small differences in attenuation and side scattering coefficients (μ , ϕ) for sedimentary and igneous rocks. We find that sedimentary rocks have attenuation coefficients greater than that in igneous rocks, but at the same time the side scattering coefficients of sedimentary rocks is smaller than that in igneous rocks. The differences in (μ , ϕ) for sedimentary and igneous rocks can be attributed to the following

(1) The two sedimentary rocks under investigation (siltstone and conglomerate) have densities greater than those of two igneous rocks under our study (andesite and felsite).

(2) The percentage content of iron compound (Fe_2O_3) in the two sedimentary rocks is greater than that in the two igneous rocks.

(3) The percentage content of sodium oxide (Na_2O) in the two sedimentary rocks is smaller than that in the two igneous rocks.

Not only does the attenuation coefficient, μ , depend on the photon energy, E , and the atomic number, z , of the absorber medium, but also the side scattering coefficients are directly proportional to the photon energy, E , and inversely proportional to the atomic number, z .

3 CONCLUSION

Our main purpose of the present work is to investigate the use of indigenous and inexpensive materials as gamma-ray shielding. For this we used ground samples from some sedimentary and igneous rocks, namely, siltstone, conglomerate, andesite and felsite with different grains size by using standard sieves with different diameters as 0.18, 0.16, 0.10, 0.09, 0.08, 0.071 and 0.056 mm. All our rocks samples were pressed at 35 tons/cm², to form tablets 3 cm in diameter, thickness ranging from 0.85 to 1.93 cm. The gamma sources used were of energies ranging between 0.36 and 1.33 Mev (^{60}Co , ^{137}Cs and ^{133}Ba).

We experimentally determined both the linear and mass attenuation coefficients for each specimen using three sources graphically and using the least squares methods. Our results showed a decrease in radiation intensity logarithmically with the increasing shield thickness. Also we observed an increase in the attenuation coefficients when using specimens with small grains diameters, this may be attributed to multiple scattering that leads to increase in open paths of rays inside the larger grain samples.

The study of the relation between absorption coefficient and material type showed higher attenuation coefficients for siltstone and conglomerate than for andesite and felsite.

Finally it was possible to study the side scattering of gamma-rays using each of the three sources individually and it was found that attenuation coefficients as well as side scattering are dependent on powder grain size. Empirical formulas were used to fit the results. The attenuation and scattering coefficients for the four natural rocks approximate those

for the compressed samples, which have the smallest grain size in this paper. We found that the relative (to Pb) absorption for siltstone, conglomerate, andesite and felsite as natural rock equal 19.56%, 18.33%, 16.74% and 15.37% respectively and as compressed samples which has smallest mean grain diameter (0.063 mm) equal 17.79%, 17.48%, 14.89% and 14.74% respectively. the relative (to Pb) absorption is defined as the percent ratio of the linear attenuation coefficient of gamma-rays for rock to the linear attenuation coefficient of gamma-rays for lead for the same radiation source ^{60}Co , and the relative (to Pb) scattering ratio for siltstone, conglomerate, andesite and felsite as natural rocks equal 388.6%, 405.5%, 412% and 417.5% respectively and as compressed samples which has smallest mean grain diameter (0.063 mm) equal 420.1%, 430.8%, 435.3% and 440% respectively for the same radiation source ^{60}Co . We conclude that the rocks here studied could be used gamma-ray shielding.

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沉积岩和火成岩对 γ 射线的吸收及散射的比较研究

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摘要 介绍沉积岩(Siltone 和 Conglomerate)和火成岩(andesite 和 felsite)的 γ 射线的衰减系数与散射系数的测量方法和测量结果。四种材料均制成颗粒粗细不同的粉末,在制成样品。颗粒的尺寸有: 0.17、0.13、0.095、0.085、0.063 mm 五种。同时也测量上述品种的天然岩石的衰减系数与散射系数。使用 ^{60}Co 、 ^{137}Cs 、 ^{133}Ba 等 γ 射线源,能量在 0.36 到 1.33 MeV 范围。详细地研究了线性衰减系数 μ , 质量衰减系数 μ/ρ 、弛豫长度 $1/\mu$ 及侧边散射系数 ϕ 与颗粒直径 d 、样品密度 ρ 和 γ 射线能量是 E 的关系。发现线性衰减系数与 d 和 E 成反比与 ρ 成正比,而侧边散射系数与 d 和 E 成正比但与 ρ 成反比。比较此两大类岩石的 μ 和 ϕ 差异的原因。实验的结果认为这些材料可用于屏蔽 γ 射线。

关键词 沉积岩,火成岩,吸收系数,边散射系数