The Effect of Water Contents in Concrete as the Radiation Shielding Material

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ABSTRACT

The shielding performance of heavy concrete for neutrons and gamma rays was measured experimentally and compared with theoretical predictions. It was found that the hydrogen content in concrete sensitively determined the neutron shielding performance. On the contrary, the gamma ray shielding performance was easily predicted, if the density of concrete and its rough ingredients were given. The shielding performance of heavy concrete can be predicted more accurately, if the hydrogen atom density is carefully analyzed. A very preliminary results to analyze hydrogen atoms using the neutron capture gamma ray will also be discussed.

1 INTRODUCTION

Concrete is widely used to shield both gamma rays and neutrons to keep radiation level low in environment. As heavy concrete is the mixture of cement, heavy aggregates, and water, there would exist some fluctuation of the shielding performance for neutrons and gamma rays due to several reasons. They are the fluctuation of sizes of aggregates and spatial inhomogeneity of water contents in heavy concrete. In the present experiment, the shielding performance of heavy concrete for both gamma rays and neutrons were measured taking into account these fluctuation and inhomogeneity. The measurements of transmitted neutrons and gamma rays through concrete slabs were conducted, which is a very standard transmission experiment. The results were compared with the direct simulation calculation based on the atom density obtained by the chemical analysis.

The neutron shielding performance of heavy concrete depends sensitively on the degree of water content (Oishi et al. 1989). Therefore, the hydrogen atom density is very important to design safe but economical concrete shield.

This in mind, a simple method to analyze hydrogen atoms is proposed and being explored. This method based on the comparison of the capture gamma ray intensity of H and some other elements, for example Ca, Si, etc. The results obtained so far are promising, but the agreement of the hydrogen density with the chemical analysis is still very poor. Some results will also be discussed in the present paper.

2 EXPERIMENT

2.1 Transmission experiment

The standard gamma ray and neutron transmission was conducted for the four heavy concrete samples having the densities, 4.0, 3.5. 3.0 and 2.3 g/cc. In Table 1, the weight densities of ingredients are shown for each concrete sample. These densities were measured when concrete was mixed. The water contents in the table was obtained by comparing weights measured under the completely dry condition and the shielding experiment was conducted. The dimensions of samples are shown in Fig. 1.

(1) Gamma ray transmission experiment

The experimental layout of the gamma ray transmission experiment is shown in Fig. 2. The gamma ray sources in the present experiment were Co-60 and Cs-137 of about 2 mCi each. The energy spectra of transmitted gamma rays were measured for gamma rays having 1.33 MeV and 1.17 MeV from Co-60, and 0.66 MeV from Cs-137. From the measured attenuation of these gamma rays, the linear attenuation coefficients were obtained for various heavy concrete samples. The energy spectrum of gamma rays was measured with an NaI scintillation counter and a pulse hight analyzer.

(2) Neutron transmission experiment

In Fig. 3, the conceptual layout is shown for the neutron transmission experiment. The neutron source used in the present experiment was Cf-252 which emits about 10^9 neutrons per second. A neutron rem counter was used to measure the rem converted dose rate of neutrons transmitted through concrete samples.

2.2 Analysis of hydrogen atom density by neutron captrue gamma rays

By capturing neutrons, specific gamma rays are induced for elements which are contained in heavy concrete. Some of the specific gamma rays for the main elements are listed in Table 2. If, the intensity of gamma rays induced by hydrogen atoms and other elements, for instance Ca, are measured and at the same time the atomic number density of Ca is known, the atomic number density of hydrogen can be obtained,

$$N_H = \frac{C_H \, N_{Ca} \, \varepsilon_{Ca} \sigma_{Ca} A_{Ca}}{C_{Ca} \, \varepsilon_H \, \sigma_H \, A_H} ,$$

where N's stand for the atomic number densities, C's for intensties of specific gamma rays, ε's for detector efficiencies for each gamma rays, σ's for thermal neutron capture cross sections and A's for branching ratios for measured gamma rays.

A very preliminary measurements of capture gamma rays are measured for several heavy concrete samples. The layout of the experiment is shown in Fig. 4. Neutrons from TRIGA-II reactor (100 kW) were used as the incident neutron source to heavy concrete, and capture gamma rays were measured with a Ge detector with a 4000 channel pulse hight analyzer.

3 EXPERIMENTAL RESULTS AND THEIR EVALUATION

3.1 Transmission experiments

(1) Gamma ray transmission experiments

Examples of the measured transmitted gamma ray spectra are shown in Fig. 5 for 10 cm thick concrete samples and Co-60 source. It is clearly seen that, as the densities of concrete becomes higher, the intensity of transmitted gamma rays becomes weak. The linear attenuation coefficients can easily obtained from these data. In Table 3, the calculated linear attenuation coefficients based on the ingredients obtained by the chemical analysis are compared with experimental results. The maximum error between two coefficients is found to be the factor 1.16, which indicates, as gamma ray shielding performance of heavy concrete is concerned, the atomic density obtained by the chemical analysis can be used as the basic data for shielding design.

(2) Neutron transmission experiments

In Table 4, the count rates of a neutron rem counter are compared between the experiment and the calculation. The ratios of the calculation and the experiment (C/E values) are also shown in the same table. The calculation was performed with the two dimensional radiation transport code, DOT3.5 (Mynatt et al 1973), and BUGLE-80 (Roussin 1980) as the cross section library. The same ingredients of concrete which was used in gamma ray calculation was utilized tentatively. Generally speaking, agreement between the experiment and the calculation is good, being the C/E between 0.68 and 1.14.

It was again confirmed in the present experiment that the shielding performance of heavy concrete depends, very sensitively, on the density of hydrogen atom. For example, 1 % change of hydrogen atom density will cause 25 % change of the count rate of a rem counter for 40 cm thick heavy concrete (4.0 g/cc). In Table 5, the changes of transmitted dose rates are listed, when water contents of heavy concrete are changed.

As for the shielding performance, it was found that the neutron attenuation coefficient of heavy concrete having density of 4.0 g/cc and thickness of 40 cm is larger, by factor 4, than the ordinary concrete (2.3 g/cc) of the same thickness.

3.2 Analysis of hydrogen atom density by neutron capture gamma rays

An example of the gamma ray spectra from heavy concrete irradiated by neutrons is shown in Fig. 5. It is clearly seen that specific capture gamma rays are measured, and each peaks are identified. However, the calculated atomic number density of hydrogen atoms does not agree with one by chemical analysis. The reason of the discrepancy is being explored. The discrepancy may be caused by inadequate treatment of back-ground gamma rays. A new series of the experiment is being planned with improved geometry.

4 CONCLUSIONS

4.1 Transmission experiments

(1) Gamma ray transmission experiments

The gamma ray shielding performance of heavy concrete can be predicted using the ingredients obtained by the conventional chemical analysis and the most important factor is the total density of concrete samples.

(2) Neutron transmission experiments

The accurate predictions of the neutron shielding performance is achievable, if one can use the accurately analysed ingredients of concrete. The hydrogen atom density is most important among densities of other elements.

4.2 Analysis of hydrogen atom density by neutron capture gamma rays

The experiment was conducted and the specific capture gamma rays of neutrons from several elements in heavy concrete were successfully measured. The peaks of gamma rays clearly correspond to several elements of heavy concrete, including hydrogen atoms. Quantitative agreement of number density of hydrogen atoms with chemical analysis is still poor. However, with new experimental arrangement, this agreement will be improved.

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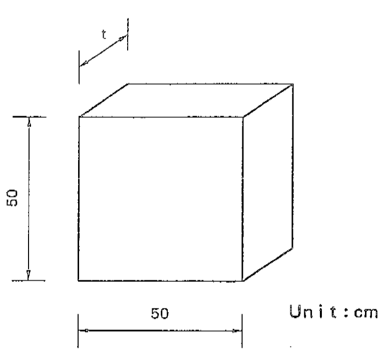

Fig. 1 Dimensions of Concrete Samples

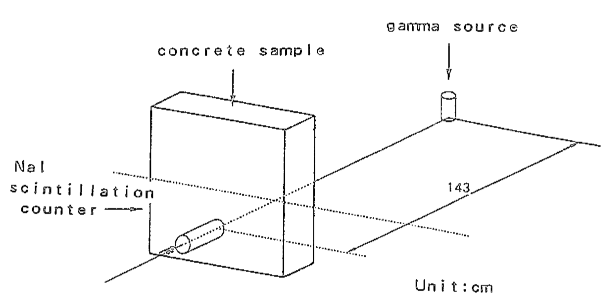

Fig. 2 Conceptual Layout of the Gamma Ray Transmission Experiment

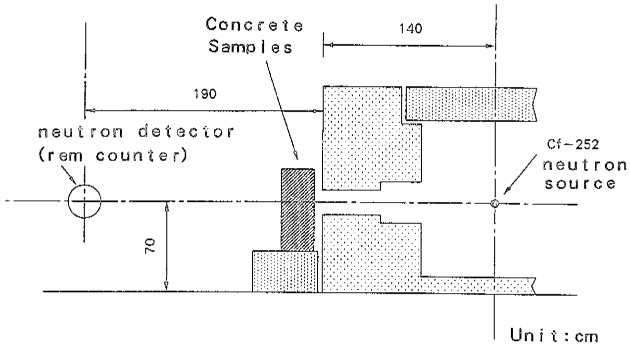

Fig. 3 Conceptual Layout of the Neutron Transmission Experiment

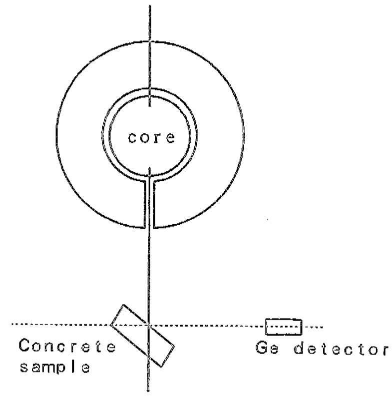

Fig. 4 Conceptual Layout of Capture Gamma Ray Experiment

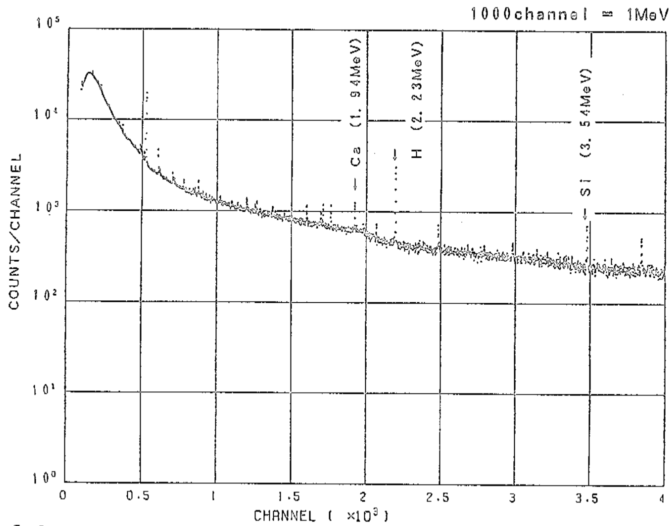

Fig. 5 Gamma Ray Spectra from Heavy Concrete with Pure Ge-detector (Ordinary Concrete NO. 4)

Table 1 Concrete Properties

sample	concrete sample			
	No. 1 ρ=4. 0	No. 2 ρ=3. 5	No. 3 ρ=3. 0	No. 4 ρ=2. 3
density (g/cm)	4. 0	3. 5	3. 0	2. 3
fine aggregates (Kg/m³)	1699	1632	913	879
coarse aggregates (Kg/m³)	1856	1754	1727	1030
cement (Kg/m³)	273	302	302	302
water content (%)	2. 46	2. 35	4. 60	5. 00

Table 2 Specific Capture Gamma Ray Properties of Elements

Element	Thermal Neutron Capture Cross Section, (barns)	Gamma Ray Energy, (MeV)	Absolute Gamma Ray Intensity (%)
H	0. 332	2. 23	97. 0
Si	0. 16	3. 54	64. 0
Ca	0. 44	1. 94	99. 2

(*) Thermal neutron capture cross section is for natural elements

Table3 Comparison of Linear Attenuation Coefficients between Experiment and Chemical Analysis

Unit: 1/cm

gamma ray energy (MeV) \ sample	concrete sample							
	No. 1 ρ=4. 0		No. 2 ρ=3. 5		No. 3 ρ=3. 0		No. 4 ρ=2. 3	
0.662	0.3041 / 0.3207±0.021	0.95	0.2956 / 0.2950±0.0065	1.00	0.2450 / 0.2579±0.011	0.95	0.1902 / 0.1976±0.0088	0.96
1.17	0.2322 / 0.2230±0.0194	1.04	0.2259 / 0.2020±0.017	1.12	0.1876 / 0.1612±0.012	1.16	0.1460 / 0.1294±0.0029	1.13
1.33	0.2176 / 0.1993±0.0110	1.09	0.2117 / 0.1916±0.0035	1.10	0.1758 / 0.1504±0.010	1.16	0.1368 / 0.1206±0.0002	1.13

①	③
②	

①: caluculation based on chemical analysis ($\mu = \sum_i \rho_i \cdot \mu_i$)
②: estimation based on present experiment
③: ①/②

Table4 Comparison of Neutron Rem Counter Count Rates between Experiment and Calculation

Unit: cps

thickness (cm) \ sample	concrete sample							
	No.1 ρ =4.0		No.2 ρ =3.5		No.3 ρ =3.0		No.4 ρ =2.3	
5	25.56 / 22.41	1.14	25.68 / 24.51	1.05	26.16 / 28.52	0.92	30.06 / 28.86	1.04
10	8.86 / 8.13	1.09	8.96 / 8.009	1.12	9.48 / 10.00	0.95	12.47 / 12.12	1.03
20	1.24 / 1.125	1.10	1.27 / 1.201	1.06	1.49 / 1.750	0.85	2.55 / 2.614	0.98
30	0.201 / 0.220	0.91	0.211 / 0.208	1.01	0.272 / 0.3559	0.76	0.603 / 0.633	0.95
40	0.0372 / 0.055	0.68	0.0399 / 0.0486	0.82	0.0557 / 0.0788	0.71	0.157 / 0.187	0.84

①	③
②	

①: calculated (cps)
②: measured (cps)
③: C/E

Table 5 Rem Counter Count Rate Change for 1% Change of Hydrogen Atom

unit: %

concrete thickness (cm)	concrete sample			
	No. 1 ρ=4. 0	No. 2 ρ=3. 5	No. 3 ρ=3. 0	No. 4 ρ=2. 3
5	4. 3	4. 4	3. 3	2. 6
10	8. 5	8. 2	6. 1	4. 1
20	15. 7	15. 2	11. 6	7. 9
30	21. 9	22. 6	15. 9	11. 4
40	28. 0	31. 0	20. 8	15. 0