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Gamma Ray Shielding from Saudi White Sand

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Abstract: This study is a comparison of gamma ray linear attenuation coefficient of two typs of shielding materials made of Saudi white and red sand. Each shield was consisted of one part of cement two parts of sand in addition to water. Different thicknesses were tested. The concentrations of all elements in each shield material were determined by Inductively Coupled Plasma Mass Spectrometer (ICP-MS). The results obtained from the ICP-MS were used in MCNP4B (Monte Carlo N-Particle Transport Computer Code System) [1] to calculate the attenuation coefficient. The theoretical (MCNP4B) and the experimental calculations were found to be in a good agreement. In the casw of the largest thickness used, 28cm, the gamma ray intensity passing through the white sand shield was approximately half of the intensity obtained through the red sand shield. The average linear attenuation coefficients were found to be 0.17cm^{-1} and 0.15cm^{-1} for white and red sand shields respectively. The study shows that white sand is better for attenuating gamma ray compared to the red sand.

Keywords: white & red sand, MCNP4B, ICP-MS, gamma ray, attenuation coefficient

1. Introduction

Gamma shielding is more effectively performed by materials with high atomic mass number and high density [2]. One such material is lead [3], which has a disadvantage of its low melting point. Iron is used for higher and lower energies. Iron is selected based on structural, temperature, and economic considerations. Water can be used but it is a poor absorber of gamma radiation, thus large amounts are required. Concrete is a good gamma attenuator as a general shield material. Concrete is strong, inexpensive, and adaptable to different types of construction.

The major objective of this work is to compare the gamma ray shields made of Saudi red and white sand. Saudi Arabia has a huge amount of these two kinds of sand. The white sand concrete is much better in all characteristics than the red one. An extensive study has documented that the white sand blocks is harder than red sand blocks [4].

It is one of our national issues to look into the possible improvement in gamma attenuation by using the white sand concrete to extend the commercial values of this kind of sand.

2. Shielding Preparation

Two kinds of shielding materials made of Saudi white and red sand. Each shield was consisted in two parts of sand to one parts of cement in addition to water. In order to obtain good workability and allow development of the maximum strength possible, the shielding ingredients must be thoroughly mixed. The mixing was done by machine. A typical mixer (a paddle mixer with tilting drum) was used. Mixing time was around five minutes. A shorter mixing time may result in nonuniformity, poor workability, low water retention and less desired air content. A too long mixing time may adversely affect the air content of shield made with air-entraining cement [5]. A 30x30 cm molds were made of plastic with different heights (thicknesses). Different thicknesses were made 4, 8 and 16cm. Using these three shielding, different thicknesses were tested 4, 8, 12(4+8), 16, 20(4+16), 24(8+16) and 28(4+8+16) cm.

3. Experiment Setup

The experiment was arranged as shown in Figure 1, where the studying shield was mounted in the middle of distance between the gamma source and the detector. The gamma radiation emitted from the source (^{137}Cs with activity around 102 mCi) was collimated using lead blocks so that the radiation beam was guided to the detector through about 55cm^2 windows in the lead shield.

The distances between the source, the detector and the studying shield were selected so that the dead time of the detector was in the range of 0.52 to 3.58%.

The attenuation coefficient was calculated using the relation:

$$I = I_0 e^{-\mu x}$$

where: I is the measured attenuated gamma ray intensity, I_o is measured initial intensity (no studying shield), μ is attenuation coefficient factor and x is the shield thickness.

The gamma ray spectrum was acquired for a real time of 420 sec for each measurement which was reasonably enough to obtain a good pulse height distribution. Counts under the peak (0.661 Mev) spectrum area were used to calculate the attenuation coefficient factor of both studying shields (see Table 1).
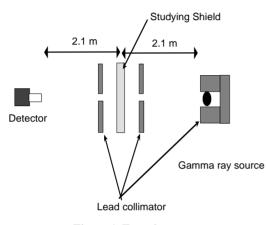

Figure 1. Experiment setup

Table 1. The counts rate obtained from the experiment

RED Shield				
Thick. (cm)	Area under the peak (R1)	Area under the peak (R2)	Average (R1+R2)/2	Coeff
0	244757	245089	244923	
4	136996	136771	136883.5	0.145
8	74181	74230	74205.5	0.1493
12	41793	41728	41760.5	0.1474
16	22764	22307	22535.5	0.1491
20	12592	12643	12617.5	0.1483
24	6846	6893	6869.5	0.1489
28	3857	3824	3840.5	0.1484
Attenuation Coefficient Average				0.1481
White Shield				
0	244757	245089	244923	
4	121246	120933	121089.5	0.1761
8	65292	65431	65361.5	0.1651
12	32166	32318	32242	0.169
16	17249	17144	17196.5	0.1660
20	8526	8602	8564	0.1677
24	4463	4464	4463.5	0.1669
28	2157	2277	2217	0.1680
Attenuation Coefficient Average				0.1685

4. Theoretically

A simulation of the experiment was done using MCNP4B. The geometry was described as shown in Figure 1. The source was described as a point source ^{137}Cs with one energy 0.661 Mev. The source was assumed as an isotropic. Point detectors were used to find out the gamma intensity at the detector window.

Samples from the studying shield were tested to measure the densities (see Table 2), and to find out the concentrations of the elements in the studying shield materials. ICP-MS was used to find the concentrations of the elements in the white and red shield materials.

5. Use of ICP-MS for Elemental Determination of the Studying Shield

Accurately weighed portion (0.2–0.3g) of the dried sample was transferred to a TEFLON digestion tube (120mL) and 10.0 mL of the acid mixture (HNO_3/HF/HCl, 3:1:1) was introduced. The tube was sealed and the sample was digested inside a microwave oven (Milestone ETHOS 1600) following a heating program shown in Table 3. After being cooled to ambient temperature, the tube was opened; the inside of the lid was rinsed with distilled and de-ionized water (DIW) and the mixture heated on a hotplate (120℃) for 30 min. to drive off HF and HCl. The resulting digest was filtered in a graduated plastic tube using 1% HNO_3 for washing and made up to 30.0mL mark. For ICP-MS measurement the clear digest so obtained was diluted 10 times incorporating 10 μgL^{-1} solution of ^{103}Rh. In general, samples were prepared in a batch of six including a blank (HNO_3/HF/HCl) digest [6–8].

Table 2. Density measurements for both shields materials

Red		
Weight gm	Volume cm^3	Density g/ cm^3
15.6493	8	1.9561625
11.7517	6	1.958616667
19.7258	10	1.97258
Average		1.962453056
White		
Weight gm	Volume cm^3	Density g/ cm^3
18.3513	8.5	2.158976471
12.1144	6	2.019066667
11.1688	5	2.23376
Average		2.137267712

Table 3. Microwave heating program used for dissolution of the concrete samples

Step	1	2	3	4
Power (W)	250	400	650	250
Time (min)	10	10	10	10

High purity water (DIW) (Specific resistivity 18 MΩ. cm⁻¹) obtained from a Millipore Milli-Q water purification system was used throughout the work. HNO_3, HF and HCl used for sample digestion were of Suprapure® grade with certified impurity contents were purchased from Merck, Germany. A multi-element standard (Merck -VI) containing 30 elements with certified concentration values or laboratory made multi-element standard (6-elements) was used as the external standard during ICP-MS measurements. The Standard Reference Material (SRM), IAEA-SOIL-7 was purchased from the International Atomic Energy Agency, Vienna. It was used for quality assurance conformation.

The analysis is performed by a Perkin-Elmer Sciex Instruments multi-element ICP-MS spectrometer, type ELAN6100, equipped with a standard torch, cross flow nebulizer and Ni sampler and skimmer cones.

The ELAN provides a unique semi quantitative method called Total Quant. This technique enables one to determine the concentration of up to 81 elements in a sample in a single measurement. Determination can be performed without using a series of standards, the use of standards is recommended to adjust the ELAN for improved accuracy. Calibration is achieved using just a few elements distributed throughout the mass range of interest. The calibration process is used to update internal response data that correlates measured ion intensities to the concentrations of elements in a solution. In this work a multi elements standards supplied by Perkin-Elmer was used to calibrate the system. The semi quantitative analysis results of the white shield and the read shield are shown in Table 4.

The moisture content of the white sand shield and the read sand shield was measured using moisture analyzer MA50 system from Sartorius. It was found to be 2.4% and 1.95% respectively.

6. Results and Discussion

The MCNP4B was run for enough time to approach an error less than 5%. A waiting factor, which equal to one, was used in the MCNP4B. The output of MCNP4B and the results from the measurements were shown in Table 5. Figure 2 shows the count rate vies shielding thickness for both types of shielding made from red and white sand, experimentally and theoretically.

The attenuation coefficient for the two kinds of shielding were calculated and then plotted as a function of the shield thickness for each case. (See Figure 3).

The results show a clear improvement in the gamma attenuation coefficient in the case of white sand.

During the preparation of the shield it was observed that water is floated on the surface of the red shield mold. Also from the moisture measurements, it was found that

Table 4. Elemental composition of red sand shield and white sand shield

Ele.	White shield %	Red shield %	Ele	White shield %	Red shield %
C	0.002	0.003	Cr	0.002	0.001
Na	0.0467	0.053	Mn	0.008	0.007
Mg	0.094	0.087	Fe	0.329	0.316
Al	0.239	0.12	Sr	0.025	0.017
S	0.101	0.056	Ba	0.003	0.003
K	0.173	0.221	Ce	3.344	1.006
Ca	4.33	2.179	H	0.371	0.317
Ti	0.002	0.001	O	49.88	52.17
V	0.003	0.002	Si	41.05	43.44

Table 5. The attenuation coefficients for both red and white shield

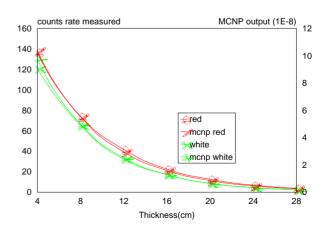| **Red**				
Thick. (cm)	Peak area	MCNP4B	Attenuation	
			Meas.	MCNP
0	244923	1.96E-07		
4	136883.5	1.04E-07	0.1455	0.1596
8	74205.5	5.52E-08	0.1493	0.1584
12	41760.5	2.95E-08	0.1474	0.1579
16	22535.5	1.59E-08	0.1491	0.1572
20	12617.5	8.50E-09	0.1483	0.1569
24	6869.5	4.62E-09	0.1489	0.1562
28	3840.5	2.50E-09	0.1484	0.1558
Ave.			0.1481	0.1574
White				
0	244923	1.96E-07		
4	121089.5	9.81E-08	0.1761	0.1733
8	65361.5	4.97E-08	0.1651	0.1717
12	32242	2.52E-08	0.169	0.1709
16	17196.5	1.29E-08	0.166	0.1703
20	8564	6.55E-09	0.1677	0.1699
24	4463.5	3.43E-09	0.1669	0.1687
28	2217	1.74E-09	0.168	0.1688
Ave.			0.1684	0.1705

Figure 2. The obtained count rates experimentally and theoretically.
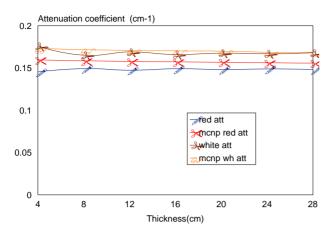
Figure 3. The calculated attenuation coefficients experimentally and theoretically

the white sand shield is higher than the red sand shield on moisture contents; this mean water was absorbed more in the white sand than in the red sand. More water causes the increasing of the reaction between the cement and the sand, and reducing the temperature, which reduce the amount of cracking inside the shield [5]. This causes the shield solidity. This may explain the improvement of the gamma attenuation coefficient of the white shield [9].

The theoretical (MCNP) and the experimental calculation were found to be in good agreement. At the largest thickness, 28cm, the gamma ray intensity passing through the white sand shield was approximately half of the intensity obtained in the case of the red sand shield. The average linear attenuation coefficient for the shield made of white sand is 0.17cm^{-1} and that from red sand is 0.15cm^{-1}.

7. Conclusions

The study concludes that white sand is better for attenu-

ating gamma ray compared to the red sand especially for large thickness.

The theoretical (MCNP) and the experimental calculation were in good agreement with each other.

We recommended using the white sand in the concrete shield to attenuate gamma ray.

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