Neutron and Gamma Radiation Dose Transmission Measurements for New Refractory Heavy Concrete Samples Including MgO-Cr_2O_3-Fe_2O_3

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Abstract - Radiation is used in the industry, medicine and especially nuclear power plants, etc. In the nuclear energy plant is working at the very high temperatures due to fission reactor concepts and fast neutron spectra so high resistance temperature materials have an important role in the shielding studies. To be used as radiation shielding in the nuclear power plants, in this study five different concentration new refractory heavy concrete samples have been designed and produced. Natural MgO-Cr_2O_3-Fe_2O_3 have been used in production of the samples. Mixing ratios have been determined by Monte Carlo simülation program Geant4 code. Fast neutron total macroscopic cross section has been calculated by Geant4 code. Moreover neutron absorbed dose measurements have been carried out by using average 4.5 MeV energy ^{241}Am-^{9}Be fast neutron source BF_3 gas detector. Gamma radiation the mass attenuation coefficient (MACs), mean free path (MFPs) and half-value layer (HVL) have been calculated at the 0.1-15 MeV energy range by VinXCom software. High temperature resistance of the samples has been tested at 600-1100 ^{0}C. The results have been compared with paraffin, conventional concrete and hematite heavy concrete. According to these reference samples, the new refractory heavy concrete samples have the high absorption ability for both fast neutron and gamma radiation. Thus, this new samples can be used to shielding studies radiation applications.

Index Terms—Heavy concrete; gamma; neutron cross section; Geant 4 Monte Carlo code

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1 INTRODUCTION

RADIATION is commonly used in many fields such as energy, medicine, military, agriculture, environment, space, mine and laboratory researches. The increasing need for energy necessitates the establishment of new nuclear power plants.

During these applications may be leaking radiation and if good a protection from radiation is not provided, it will cause hereditary damage to living tissues [1-2]. So, good shielding material must be used according to radiation type and energy. A lot of materials are used for shielding radiation, one of them is heavy concrete.

Heavy concrete have unit weight ranging from about 2.9 and 6 g/cm3 while unit weight of conventional concrete varied between 2,2 and 2,45 g/cm3 [3]. Heavy concretes can produced by adding various materials such as iron ore minerals, slags, ore minerals, natural rocks in various densities to conventional concrete. Many of heavy concrete has been produced for this aim.

A new type heavy concrete has been produced using waste lead and zinc slag for gamma radiation shielding and it was compared to conventional concrete, this concrete has been reported to absorb better gamma radiation [4]. Heavy concrete plates have been produced containing barite mineral at different thicknesses and mass reduction coefficients have been calculated for different energies for X-rays. It is pointed out, the barite mineral important additive has been determined for radiation shielding [5]. Red mud-based new radiation-resistant concrete has been produced by using a lot of synthetic aggregate such as Barium silicate (sanbornite), barium iron titanium silicate (bafertisite), barium aluminum silicate, iron titanium oxide (pseudorutile), barium titanate, barium iron titanium oxide, barium aluminum oxide and magnetite materials. Then gamma radiation shielding parameters have been calculated [6]. Heavy concretes used in nuclear power plants, concrete

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can become hot when exposed to neutron and gamma radiation and as a result of this warming, the water in the concrete evaporates and cracks form on the surface of the concrete, radiation may leaks from these cracks [7]. Radiation and high temperature resistant new heavy concrete samples have been produced by using chrome ore ($FeCr_2O_4$), hematite (Fe_2O_3), titanium oxide (TiO_2), aluminum oxide (Al_2O_3), limonite [FeO (OH) nH_2O], siderite ($FeCO_3$), barite ($BaSO_4$), nickel oxide (NiO) materials and alumina cement. Then neutron and gamma radiation shielding parameters have been determined [8]. By adding some metal or metal oxides into the concrete, the radiation absorption ability can be increased. Different types heavy concrete samples have been produced by adding nano and tungsten oxide (WO_3) particles in concrete. It has been reported that as the proportion of tungsten oxide (WO_3) in concrete increases, the gamma radiation retention capacity increases [9]. In this present study, four different type new refractory heavy concrete samples were produced which contain natural $MgO-Cr_2O_3-Fe_2O_3$ and it was calculated shielding parameters for fast neutron and gamma radiation.

2 EXPERIMENTAL PROCEDURES

2.1Materials and sample preparation

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Three different aggregates such as chromite, hematite and magnesia were used in the study. Chromite and hematite from the Kayseri City, Yahyalı District (in Turkey) and magnesia minerals is from the Meram (Konya, Central Turkey) were supplied. The maximum particle size of aggregate was determined at 16 mm in production. All of the new concrete samples mass composition percentage ratios were determined with Monte Carlo simulation program Geant4 code [10]. Mixing ratios of samples, attenuation coefficient, total macroscopic cross-sectional values were selected to be high for neutron and gamma radiation. To the determined ratios, cement and aggregates were mixed for 10 minutes in a dry form until homogeneous with the aid of a mixer. When the mortar reaches the desired shape a preformed molds of 10x3 cm was poured. It was left to be dry at room temperature. The percentages of the materials used in the concrete production are given in the Table 1.

TABLE 1
WEIGHT FRACTIONS OF THE CONCRETE TYPES

Mineral	**NTHC1 (ρ=4.20 g/cm^3)**	**NTHC2 (ρ=4.025 g/cm^3)**	**NTHC3 (ρ=4.015 g/cm^3)**	**NTHC4 (ϱ=4.0 g/cm3)**
Porlant Cement	15	10	10	10
Water (H_2O)	10	15	15	15
Chromite ($FeCr_2O_3$)	25	35	45	55
Hematite (Fe_2O_3)	40	30	20	10
Magnesia (MgO)	10	10	10	10

NTHC: New type heavy concrete

2.2 Neutron radiation transmission

Total macroscopic cross section has been calculated theorical for neutron essential shielding parameters. Total macroscopic cross section which essentially shielding parameters has been calculated theoretical for neutron with Monte Carlo simülation program Geant4 code. The total macroscopic cross section (∑) expresses interaction such as scattering, absorption, capture, fission, etc. between neutron radiation and target material. The total macroscopic cross section (∑) expresses interaction such as scattering, absorption, capture, fission, etc. between neutron radiation and target material. It is can be calculated as follows considering the microscopic cross-section and the atomic number.

$$\sum = N\sigma \tag{1}$$

$$N = \frac{\rho}{A} N_A \tag{2}$$

N; atomic density in the target material, ϱ; density of the target material, NA; the number of Avogadro.

$$\Sigma \text{ Total} = \Sigma \text{ scattering} + \Sigma \text{ absorption} + \Sigma \text{ capture} + \Sigma \text{ fission} + \ldots \tag{3}$$

Neutron equivalent dose rate measurements were carried out, for this ^{241}Am/Be neutron source which emits neutrons an average energy of 4.5 MeV and BF_3 gas detector was used. The schematic arrangement of experimental set up and measuring system used in the present study are shown in Fig. **1.**

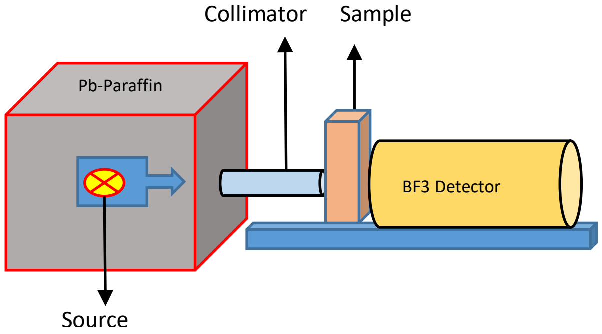
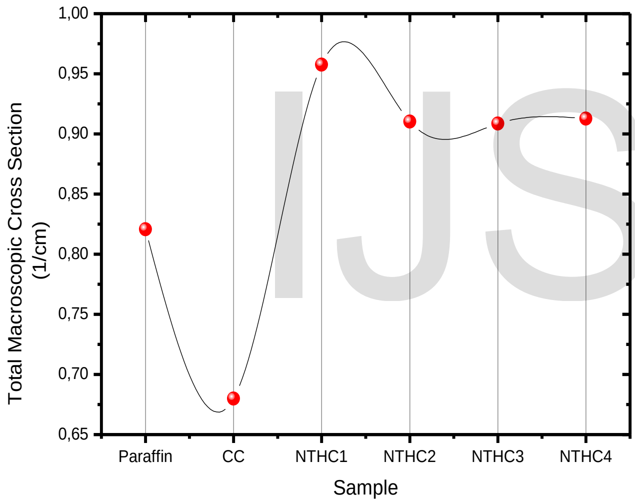


Fig. 1. Experimental geometry.

3 RESULTS AND DISCUSSION

3.1 Neutron attenuation properties

Total macroscopic cross section has been calculated for Fast neutron 4.5 MeV energy by Geant4 code and results give in Figure 2.



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(*CC:* Conventional concrete, *NTHC:* New type heavy concrete)

Fig. 2. Total macroscopic cross sections values of samples for 4 cm thickness.

From the results in Figure 2, it can be seen that the 4.5 MeV Neutron Total Macroscopic Cross Sections (cm^{-1}) values of the all NTHC samples are higher than the paraffin and normal concretes taken as reference samples. The higher this value, the better the ability of the material to absorb neutron radiation.

Experimentally dose measurement was carried out and obtained results are given Table 2.

TABLE 2
EQUIVALENT DOSE RATES BY EXPERIMENTS

Sample code	**Absorbed equivalent dose rates (μSv/h) by the samples**	**Absorbed dose percentage of samples (%)**
Paraffin	0.4703	38.95
CC	0.3011	24.93
NTHC 1	0.8072	66.85
NTHC 2	0.7901	65.43
NTHC 3	0.7857	65.03
NTHC4	0.7604	62.97

The dose of 1.2074 (μSv/h) emitted from the source was absorbed paraffin (38.95 %), conventional concrete (24.93 %), NTHC1 (66.85 %), NTHC2 (65.43 %), NTHC3 (65.03 %) and NTHC4 (62.97 %) of the dose. According to the results, all NTHC samples have perfect shielding ability, but NTHC1 is much better than others. This is due to the fact that, the structure of Fe_2O_3 contains more chrome the other samples.

3.2 Gamma-ray attenuation properties

In the present study, it has been calculated the gamma-ray shielding parameters of the all NTHC samples in the energy range between 0.015 and 15 MeV. The calculated results compared with conventional concrete and Hematite heavy concrete. Table 3. and shows the comparison of mass attenuation coefficients (MACs). It is clearly seen that the MACs of the NTHC are higher than the conventional concrete and Hematite heavy concrete in all calculated energies.
It is the average distance (MFP) at which energy of a known gamma ray can travel without any interaction in the material. This is parameter important for gamma ray hielding study. If the materials have low mean free path, it is have radiation shielding performance is high. As shown in Table 4, MFP of the NTHC are low than the conventional concrete and Hematite heavy concrete in all calculated energies. In addition to, half value layer (HVL) was calculated of the samples and the results were presented in the Table 5. The half-thickness value is the thickness of the material required to reduce the intensity of the gamma ray incident on any material in half. This value is low indicates that the material has good gamma-ray absorption power. Acoording to Table 5, HVL of the NTHC are low than the conventional concrete and Hematite heavy concrete in all calculated energies.

TABLE 3

MASS ATTENUATION COEFFICIENT (cm^2/g) VALUES of SAMPLES

Energy (MeV)	NTHC1	NTHC2	NTHC3	NTHC4	CC	Hematite heavy concrete
0.015	28.2722	28.0882	27.9041	27.72	7.0538	21.5363
0.02	12.6914	12.5988	12.5063	12.4138	3.1052	9.6598
0.03	4.0775	4.0446	4.0117	3.9788	1.0476	3.1238
0.04	1.8546	1.8394	1.8242	1.8089	0.5415	1.4425
0.05	1.0391	1.0309	1.0227	1.0146	0.3585	0.8257
0.06	0.6713	0.6663	0.6613	0.6563	0.2752	0.5474
0.08	0.3713	0.3691	0.3668	0.3645	0.2043	0.3192
0.1	0.2592	0.258	0.2567	0.2555	0.1745	0.2328
0.15	0.1664	0.1659	0.1655	0.165	0.1428	0.1591
0.2	0.136	0.1357	0.1355	0.1352	0.1271	0.1333
0.3	0.1099	0.1097	0.1096	0.1094	0.1086	0.1095
0.4	0.0962	0.0961	0.096	0.0959	0.0968	0.0964
0.5	0.0871	0.087	0.0869	0.0868	0.0882	0.0874
0.6	0.0801	0.08	0.08	0.0799	0.0814	0.0806
0.8	0.07	0.07	0.0699	0.0698	0.0714	0.0705
1	0.0628	0.0628	0.0627	0.0627	0.0642	0.0633
1.5	0.0512	0.0511	0.0511	0.051	0.0523	0.0515
2	0.0443	0.0443	0.0443	0.0442	0.0451	0.0446
3	0.0367	0.0366	0.0366	0.0366	0.0367	0.0367
4	0.0325	0.0325	0.0325	0.0325	0.032	0.0324
5	0.03	0.03	0.03	0.03	0.0289	0.0297
6	0.0284	0.0284	0.0284	0.0284	0.0269	0.0279
8	0.0266	0.0266	0.0266	0.0266	0.0244	0.0259
10	0.0257	0.0257	0.0257	0.0257	0.0229	0.0248
15	0.0251	0.0251	0.0251	0.0251	0.0212	0.0238

(***CC:*** Conventional concrete, ***NTHC:*** New type heavy concrete)

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TABLE 4
MEAN FREE PATH (cm) VALUES OF SAMPLES

Energy (MeV)	**NTHC1**	**NTHC2**	**NTHC3**	**NTHC4**	**CC**	**Hematite heavy concrete**
0.015	0.0087	0.0088	0.0089	0.009	0.0616	0.0186
0.02	0.0195	0.0197	0.0199	0.0201	0.14	0.0414
0.03	0.0606	0.0614	0.0621	0.0628	0.415	0.1281
0.04	0.1331	0.1351	0.1365	0.1382	0.803	0.2773
0.05	0.2376	0.241	0.2435	0.2464	1.2128	0.4844
0.06	0.3678	0.3729	0.3766	0.3809	1.5797	0.7307
0.08	0.6649	0.6732	0.679	0.6858	2.128	1.2531
0.1	0.9525	0.9631	0.9702	0.9786	2.4913	1.7179
0.15	1.4838	1.4972	1.5052	1.515	3.0457	2.5144
0.2	1.8159	1.8307	1.8387	1.8492	3.4197	3.0015
0.3	2.2474	2.2642	2.2728	2.2842	4.0028	3.6523
0.4	2.5654	2.5841	2.5934	2.606	4.493	4.1473
0.5	2.8362	2.8567	2.8668	2.8805	4.9318	4.5748

0.6	3.0816	3.1038	3.1145	3.1293	5.3389	4.9648
0.8	3.5249	3.5501	3.5624	3.5791	6.0852	5.6726
1	3.9291	3.9572	3.9708	3.9894	6.772	6.3199
1.5	4.8253	4.8597	4.8763	4.899	8.3168	7.7615
2	5.5698	5.6094	5.6283	5.6545	9.6461	8.9732
3	6.7355	6.7828	6.8052	6.8362	11.855	10.9086
4	7.5873	7.64	7.6646	7.699	13.606	12.3623
5	8.2175	8.2737	8.2995	8.3359	15.0199	13.471
6	8.6818	8.7405	8.7671	8.8048	16.1599	14.3135
8	9.2776	9.339	9.366	9.4049	17.8483	15.4525
10	9.5971	9.6592	9.6858	9.7246	18.9795	16.1192
15	9.8529	9.9144	9.9395	9.9771	20.4913	16.796

TABLE 5

HALF VALUE LAYER (HVL) VALUES of SAMPLES

Energy (MeV)	**NTHC1**	**NTHC2**	**NTHC3**	**NTHC4**	**CC**	**Hematite heavy concrete**
0.015	0.0061	0.0061	0.0062	0.0063	0.0427	0.0129
0.02	0.0135	0.0137	0.0138	0.0140	0.0971	0.0287
0.03	0.0420	0.0426	0.0430	0.0436	0.2877	0.0888
0.04	0.0923	0.0936	0.0946	0.0958	0.5566	0.1922
0.05	0.1647	0.1670	0.1688	0.1708	0.8407	0.3358
0.06	0.2549	0.2585	0.2611	0.2640	1.0949	0.5065
0.08	0.4609	0.4666	0.4707	0.4754	1.4750	0.8686
0.1	0.6602	0.6676	0.6725	0.6783	1.7268	1.1908
0.15	1.0285	1.0378	1.0433	1.0501	2.1111	1.7428
0.2	1.2587	1.2689	1.2745	1.2817	2.3704	2.0805
0.3	1.5578	1.5694	1.5754	1.5833	2.7746	2.5316
0.4	1.7782	1.7912	1.7976	1.8063	3.1143	2.8747
0.5	1.9659	1.9801	1.9871	1.9966	3.4185	3.1710
0.6	2.1360	2.1514	2.1588	2.1691	3.7007	3.4413
0.8	2.4433	2.4608	2.4692	2.4809	4.2180	3.9319
1	2.7235	2.7429	2.7523	2.7652	4.6940	4.3806
1.5	3.3446	3.3685	3.3800	3.3958	5.7647	5.3798
2	3.8607	3.8881	3.9013	3.9194	6.6861	6.2197
3	4.6687	4.7015	4.7170	4.7385	8.2173	7.5613
4	5.2591	5.2956	5.3127	5.3366	9.4309	8.5689
5	5.6959	5.7349	5.7528	5.7780	10.4110	9.3374
6	6.0178	6.0585	6.0769	6.1030	11.2012	9.9214
8	6.4307	6.4733	6.4920	6.5190	12.3715	10.7109
10	6.6522	6.6953	6.7137	6.7406	13.1556	11.1729
15	6.8295	6.8722	6.8895	6.9156	14.2035	11.6421

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4 CONCLUSION

In the present work, we were produced, four different type heavy concrete samples (NTHC) and equivalent absorbed dose measurement was carried out for fast neutron radiation. It is determined that of all NTHC samples high ratio absorbed dose. In addition, by Monte Carlo Simulation Geant4 code we have calculated the total macroscopic cross section (TMCS), of samples theoretically. Obtained total macroscopic cross section results were compared with paraffin and conventional concrete. It is found that the total macroscopic cross section (TMCS) value of new type heavy concrete were higher than on paraffin and conventional concrete. The calculated mass attenuation coefficients (MAC), half value layer (HVL) and mean free path (MFP) by Vin Xcom software, results compared with conventional concrete and hematite heavy concrete. According to the results are founded that all new type heavy concrete samples have high radiation shielding ability than conventional concrete, hematite heavy concrete for both fast neutron and gamma radiation. Therefore, these new type heavy concrete samples for radiation safety in research laboratory, in nuclear reactors, in shelters and radiation therapy centers can be used.

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