ISSN NO. 2320-5407

Journal homepage:http://www.journalijar.com
Journal DOI:10.21474/IJAR01

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Attenuation Coefficient of Reactive Powder Concrete Using Different Energies.

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Manuscript Info

Manuscript History:

Received: 12 May 2016
Final Accepted: 19 June 2016
Published Online: July 2016

Key words:
Attenuation coefficient, gamma energy source, beta energy source, reactive powder concrete.

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Abstract

Linear and mass attenuation coefficient of reactive powder concrete (RPC) sample (of compressive strength equal to 70 Mpa) using beta particles and gamma ray with different energies have been calculated as a function of the absorber thickness and energy. The attenuation coefficient were obtained using NaI(Tl) energy selective scintillation counter with $^{90}Sr/^{90}Y$ beta source having an energy rang from (0.546-2.274) MeV and gamma ray energies (0.569, 0.662, 1.063, 1.17 and 1.33) MeV . The attenuation coefficient usually depends upon the energy of radiations and nature of the material. The result represented in graphical forms. Exponential decay was observed. It is found that the capability of reactive powder concrete to absorber beta particles and gamma ray without any significant reduction in the compressive strength of the sample. That's mean it is useful to choice this sample for radiation shielding of gamma and beta raywith low thickness.

Introduction:-

Beside nuclear facilities (nuclear reactors and particle accelerators), with the increasing use of radiation in medicine, the provision of adequate protection remains an important concern [1–3]. The effectiveness of the shielding material is determined by the interactions between the incident radiation and the atoms of the absorbing medium. The interactions which take place depend mainly upon the type of radiation, the energy of the radiation, and the atomic number of the absorbing medium.

Most important characteristic of a material protection is its ability in attenuation of gamma radiation. In general, heavy materials have higher ability in attenuation of gamma-rays.

One of the most widely used materials in reactor shielding is concrete; it is basically, a mixture of cement, sand, coarse aggregates and water. It is cheap, easy to prepare in different compositions, and easy to form and to use in construction works. Radiation shielding concrete can be used to attenuate both neutron and gamma rays. The photon interaction with the matter depends on the incoming photon energy and the density of the shielding material. The concrete shielding properties may vary depending on the material components of the concrete [4].

The attenuation coefficient is an important parameter characterizing the penetration and diffusion of rays in composite materials, and the accurate values linear attenuation coefficient of beta and gamma rays for various media especially composite materials are useful for dosimeter, radiation shielding to choice the suitable type of material to adequately stop various forms of radiations, as well as for many nuclear physics experiments [5]. The attenuation coefficient usually depends upon the energy of radiations and nature of the material [6]. The attenuation coefficient of beta by composite were investigated by Pujol et al. [7]. Also, measurements on attenuation coefficients and range energy relation of beta particles for various absorber at different energies have been reported by various workers as Rocca et al. [8] and Mahajan [9]. The effects of different parameters and energies on the attenuation coefficient for cement and concrete samples were discussed in several studies as in refs. [10-15].

This work aims to evaluate the performance of reactive powder concrete composite in attenuating gamma ray and beta particles. In this work the absorption of gamma ray and beta particles in different thickness of reactive powder concrete are studied and measured the linear and mass attenuation coefficient as a function of the energy and absorber thickness. Beta-particles and gamma ray intensities behind the samples with different thickness have been measured. Measurements have been carried out using a collimated beam of pure beta source $^{90}Sr/^{90}Y$ with energy (0.546-2.274) MeV and Cs-137, Co-60 and Bi-207 gamma sources with energies (0.569, 0.662, 1.063, 1.17 and 1.33) MeV. The leakage beta-particles and gamma ray intensities behind the samples have been carried out by using sodium iodide crystal NaI(TI) scintillation detector of dimension 2”×2”. The incident and transmitted intensities were determined for fixed preset time at 1000 sec in each measurement.
The attenuation of radiation expressed as:

$$I=I_0\exp(-\mu x) \quad \text{………(1)}$$

where I_0 is the number of particles of radiation counted during a certain time duration without any absorber, I is the number counted during the same time with a thickness x of absorber between the source of radiation and the detector and μ is the linear absorption coefficient. This equation may be cast into linear form,

$$\log I=\log I_0-\mu x \quad \text{……….(2)}$$

$$\mu= (1/x) \log (I_0/I) \quad \text{……….(3)}$$

The unit of μ is cm^{-1}
The mass absorption coefficient, μ_m defined as,
$\mu_m= \mu/\rho$
μ_m is measured in cm^2/gm and ρ is particle density of absorber in gm/cm^3.

Material and Methods:-

Absorber materials:-

The materials used to prepare the reactive powder concrete samples as absorber with different thicknesses of this work are:

- **Cement:-**

An Ordinary Portland Cement (Type–I), Tassluga, was used for all specimens. The results of chemical analysis and physical test are shown in **Table 1** and **Table 2**, respectively. The results of both chemical and physical test were compared with Iraqi Specification No. 5 / 1993 [16].

- **Fine Aggregate:-**

Al-Ukhaider sand of (0.6 mm) maximum size was used as fine aggregate in concrete mixes for all specimens. Sieve analysis of the used sand is shown in **Table 3** both with the limit of Iraq Specification No. 45/1993 [16]**,** while the physical properties are shown in **Table 4**. According to the limit of Iraq Specification the used sand can be classified as Zone 4.

- **Water:-**

Tap water was used for both mixing and curing process. **Table 5** shows the chemical analysis of the used water both with the limit of ASTM C 1602/C 1602M-04 [17]specification.

- **Silica Fume:-**

Silica fume conformed to EN 13263, product of Sika, was used as an additives (pozzolanic material) to produce the HPC for all specimens. The chemical composition and ASTM C1240-03 [18] requirements of silica fume are listed in **Table 6** and **Table7**.

- **Superplasticizer**

A new generation of modified polycarboxylic ether that complies with ASTM C494-05 [19] types A and F (GLENIUM51) was the superplasticizer that used as a superplasticizer to modify the workability of high strength concrete .**Table 8** gives the technical description of GLENIUM51.

Table 1. Chemical composition of cement.*

No.	Compound Composition	Chemical Composition	% Weight	Iraqi Specification No. 5 / 1993
1	Silica	SiO_2	20.28	---
2	Alumina	Al_2O_3	5.00	---
3	Iron Oxide	Fe_2O_3	3.44	---
4	Lime	CaO	63.80	---
5	Magnesia	MgO	2.33	5 (max)
6	Sulfate	SO_3	2.4	2.8 (max)
7	Insoluble residue	I.R	1.27	1.5 (max)
8	Loss on ignition	L.O.I	3.00	4.0 (max)
9	Tricalcium aluminates	C_3A	0.58	---
10	Lime saturation factor	L.S.F	0.93	0.66 – 1.02
11	Tricalcium alumina ferrite	C_4AF	Not available	---
12	Tricalcium silicate	C_3S	Not available	---
13	Dicalcium silicate	C_2S	Not available	---
14		Fe_2O_3- Al_2O_3	Not available	---

*All the test were conducted by the National Center of Laboratories and Researches (Baghdad).

Table 2. Physical properties of cement.*

No.	Physical Properties	Test Result	Iraqi Specification No. 5 / 1993
1	Specific surface area (Blaine Method) m^2/kg	392	230 (min)
2	Setting time (Yicale's Method) Initial time setting : (hour: mint) Final time setting : (hour: mint)	 2:25 3:50	 00:45 (min) 10:00 (max)
3	Autoclave Expansion %	0.08	0.80 (max)
4	Compressive Strength, Mpa 7 days 28 days	 21.41 27.81	 15.00 (min)\ 23.00 (min)

*All the test were conducted by the National Center of Laboratories and Researches (Baghdad).

Table 3. Grading of the fine aggregate.

Sieve size (mm)	%Passing by Weight	Limit of Iraqi Specification No. 45 / 1993			
		Zone 1	Zone 2	Zone 3	Zone 4
10	100	100	100	100	100
4.75	100	90-100	90-100	90-100	95-100
2.36	100	60-95	75-100	85-100	95-100
1.18	100	60-90	55-90	75-10	90-100
0.60	81.6	30-70	35-59	60-79	80-100
0.30	41.4	5-34	8-30	12-40	15-50
0.15	7.8	5-20	0-10	0-10	0-15
$75x10^{-3}$	0	5 max			

Table 4. Physical properties of the fine aggregate.*

No.	Physical Properties	Test Result	Iraqi Specification No. 45 / 1993
1	Specific gravity	2.63	---
2	Sulfate contained %	0.30	0.5 (max)
3	Absorption	0.6	---

*All the test were conducted by the National Center of Laboratories and Researches (Baghdad).

Table 5. Chemical analysis of used water.*

No.	Chemical Test	Standard Unit	Results	ASTM C 1602/C 1602M-04
1	TSS	ppm	< 0.1	----
2	TDS	ppm	417	2000
3	Sulfate	ppm	0.2	3000
4	Chloride	ppm	50	1000
5	PH	---	7.2	(4.5-8.5)
6	Turbidity	NTV	4.81	---

*All the test were conducted by the Sanitary Laboratory/Civil Engineering Dept. /Baghdad University.

Table 6. Chemical composition of silica fume.*

No.	Compound Composition	Chemical Composition	% Weight
1	Silica	SiO_2	92.03
2	Alumina	Al_2O_3	0.18
3	Lime	CaO	0.70
4	Iron Oxide	Fe_2O_3	1.10
5	Magnesia	MgO	2.10
6	Sulfate	SO_3	0.85
7	Loss on ignition	L.O.I	3.78

*All the test were conducted by the S. C. Geological Survey and Mining.

Table 7. Chemical requirements of SF according to ASTM C1240-03.

Chemical Composition	Test Result	Limit of ASTM C 1240-03
Silica (SiO_2), min	92.03	85.00
Loss on ignition (L.O.I) , max	3.78	6.00

Table 8. Technical description of GLENIUM51*.

Form	Viscous liquid
Color	Light brown
Relative density	1.1
PH	6.6
Viscosity	128 +/- 30 CPS
Transport	Not classified as dangerous
Labelling	No hazard label required

*Data sheet of the Manuscript.

Table 9. Details of the adopted mix.

Mix Proportion (kg/m^3)				
Water	Cement	Sand	SP	SF
360	910	960	160	230

Casting and Curing of Reactive Powder Concrete Samples

Eight standard cubes of (50x50x50) mm side length were casted using the adopted mix of reactive powder concrete. The process of mixing was similar to the one recommended by ACI Committee Report 544. All the dried materials were mixed well to get homogeneous composition after that (75 % of water amount + 50 % of superplasticiser) were added to the dry composition with additional mixing foe approximately five mints. The residual liquid quantity (25 % of total water + 50 % of superplasticiser) were added with further mixing until the mixture is met.

Water curing was used for 28 days after which three cubes were tested (dry surface) to evaluate the compressive strength

Experimental setup:-
The experimental arrangement with the electronic configuration is schematically shown in Fig.1. The assembly was placed in lead castle. Energy calibration was performed using a set of standard gamma sources.

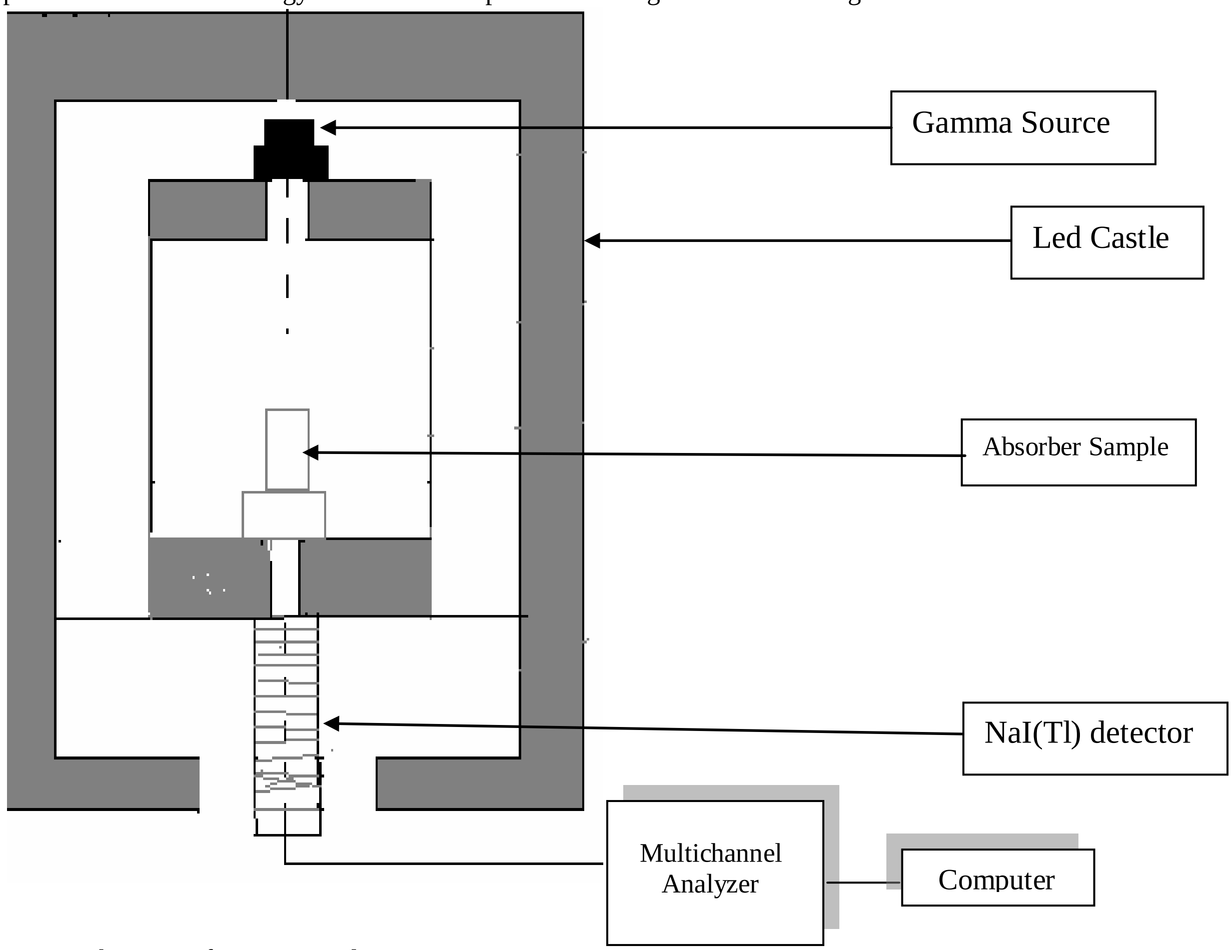

Fig.1: Schematic of experimental setup

Determination of beta-particles range
The range of beta-particles, for energy range $0.01 \leq E \leq 2.5$ MeV can be approximated by Baker and Katz [10] :

$$R(kg.m^{-2}) = 4.12\ E^{n}\ (MeV) \qquad \ldots\ldots\ldots\ldots(4)$$

where $n = 1.265 - 0.0954 \ln E_{max}$
E_{max} is the maximum beta-particles energy in MeV and R is the range of beta-particles in $kg.m^{-2.}$

Therefore, when the thickness of the attenuator is above the rang of beta-particles the transmitted particles would be nearly stopped, for concrete, sheet of thickness0.5 cm, which is sufficient to stop all beta particles from $^{90}Sr/^{90}Y$.

Results and Discussion:-
Experimental values of the logarithmic absorption of gamma ray as a function of samples thickness d (i.e. path length) in cm were shown in figures (2 to 6). It is clear that the intensity decrease with increase the thickness of the samples. The slope of the absorption graph gives the experimental gamma-ray linear attenuation coefficient of the absorber concrete in terms of cm^{-1}.

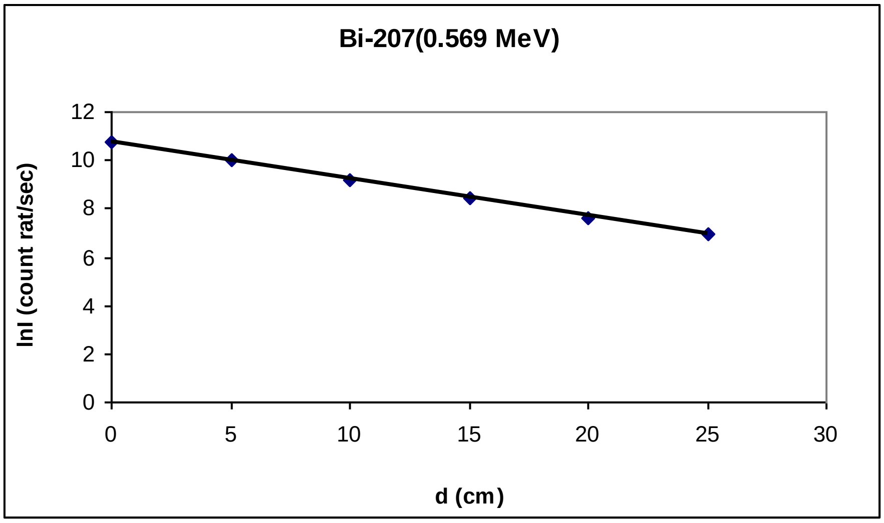

Fig. (2): The logarithmic absorption of gamma ray as a function of the sample thickness in cm.

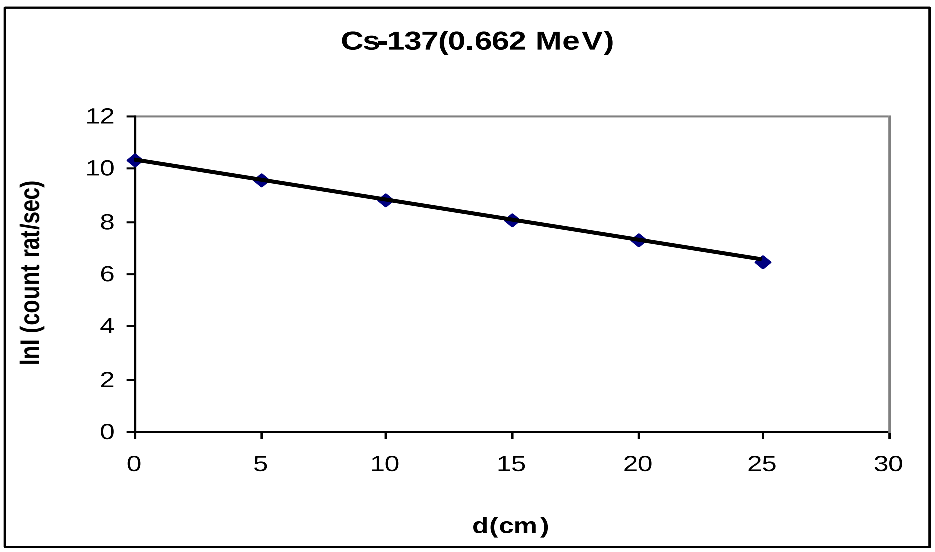

Fig. (3): The logarithmic absorption of gamma ray as a function of the sample thickness in cm.

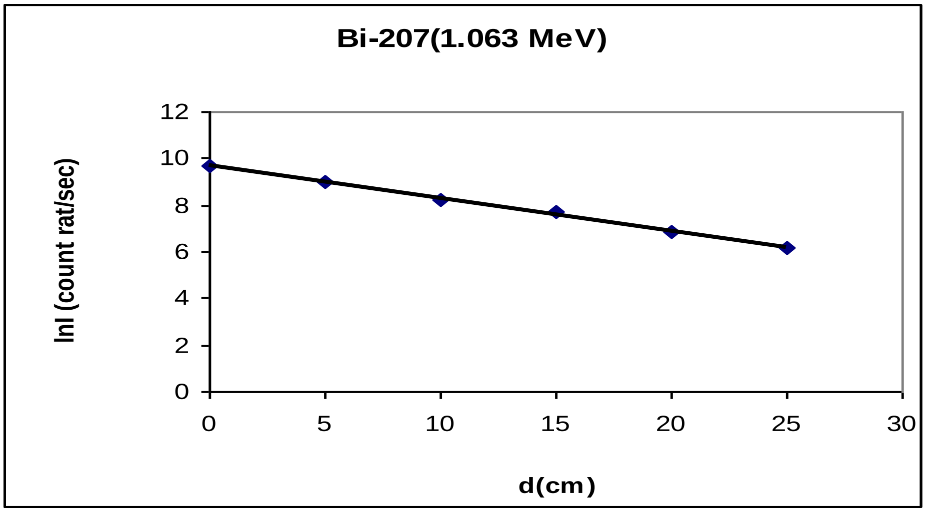

Fig. (4): The logarithmic absorption of gamma ray as a function of the sample thickness in cm.

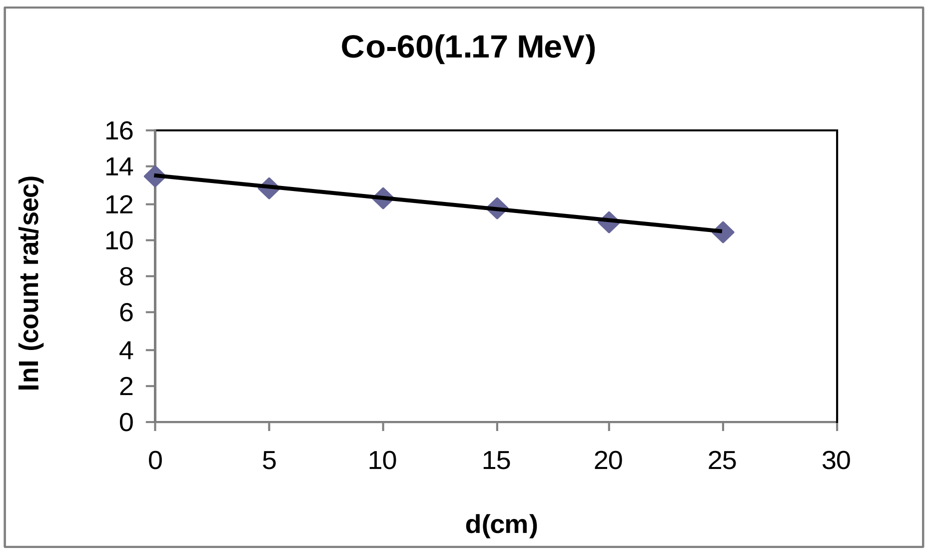

Fig. (5): The logarithmic absorption of gamma ray as a function of the sample thickness in cm.

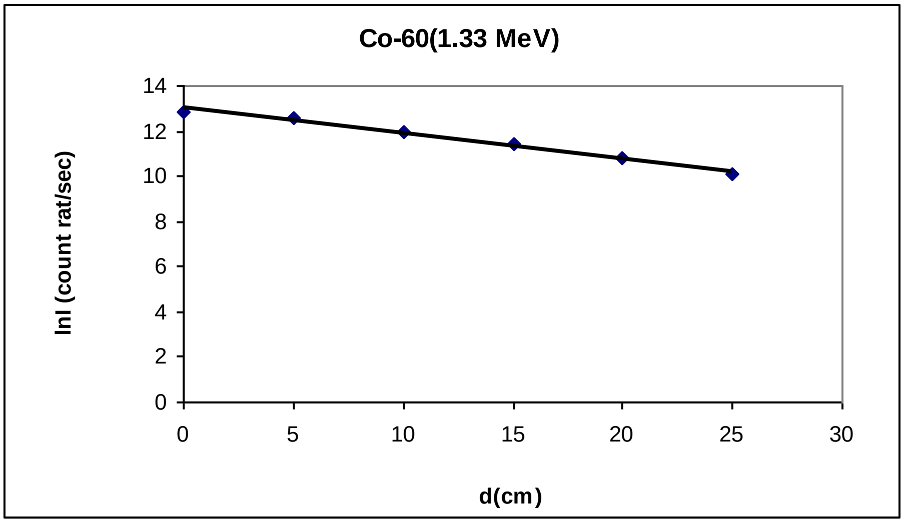

Fig. (6): The logarithmic absorption of gamma ray as a function of the sample thickness in cm.

The linear attenuation coefficient (μ) for the sample obtained from equation (3) and plotted as a function of energy in MeV as shown in figure (7). It is found that the linear attenuation decrease with increase energy. The values of mass attenuation coefficients (μ_m) for gamma energies (0.569, 0.662, 1.063, 1.17 and 1.33) MeV were found to be (0.07, 0.069, 0.059, 0.055 and 0.051) $cm^2.g^{-1}$, respectively. These values give the conclusion that the μ_m values decreases as energy increased. Another useful concept is the half-value thickness, $X_{½}$, which is the value of the absorber thickness that will reduce the intensity by a factor of 2. It has been found ranging from 4.5 cm to 6 cm depending on the values of the energies above.

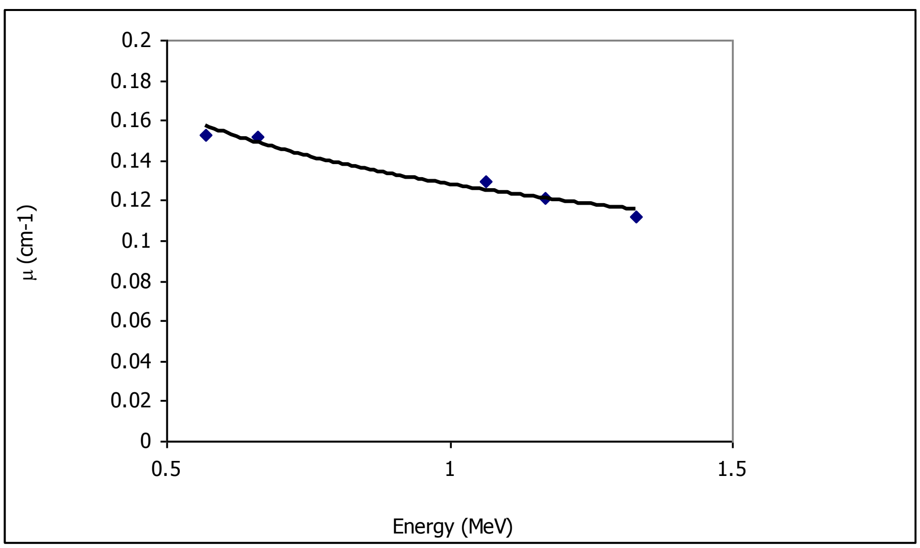

Fig. (7): Linear attenuation coefficient (μ) of gamma ray as a function of the sample thickness in cm.

Also, beta particles are attenuated in an absorption medium by the various interaction processes, primarily through ionization and radiative energy losses.

The absorption spectra for beta particles without and in different thickness of absorber from 5 to 25 cm was shown in Fig.8. It is clear that the intensity of beta decrease with increase the thickness of the absorber.

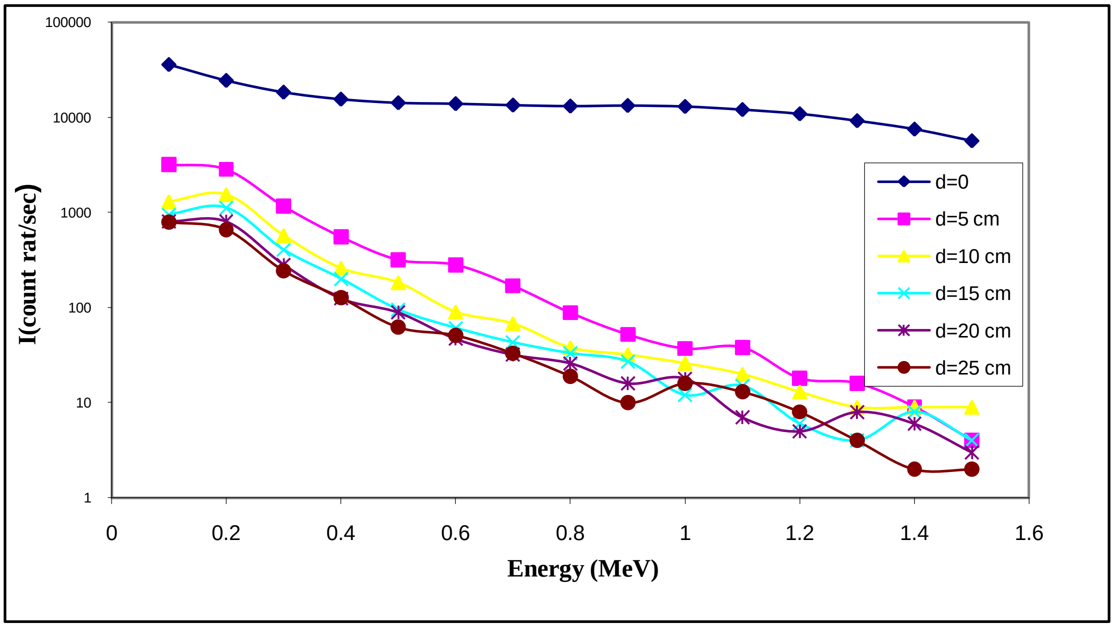

Fig. (8): Absorption spectra for beta particles in different thickness in cm

Linear attenuation coefficients of beta particle of energy range 0.1-1.5 MeV for different thickness of concrete composite obtained from eq.3 are shown in figures (9) and (10) as a function of energy and thickness, respectively. It is shown that linear attenuation increase with increase energy and decrease with increase the thickness of absorber. Also, these values with mass attenuation coefficients of beta particle are given in Table (9).It is shown that the mass attenuation decrease with increase the thickness of absorber and increase with increase energy.

Tabel 9: Linear and mass attenuation coefficients for different thickness of reactive powder concrete composite.

Thickness	d=5cm		d=10cm		d=15cm		d=20cm		d=25	
E(MeV)	μ cm^{-1}	$μ_m$ cm^2/g	μ cm^{-1}	$μ_m$ cm^2/g	μ cm^{-1}	$μ_m$ cm^2/g	μ cm^{-1}	$μ_m$ cm^2/g	μ cm^{-1}	$μ_m$ cm^2/g
0.1	0.483	0.221	0.331	0.152	0.241	0.110	0.189	0.086	0.152	0.069
0.2	0.430	0.197	0.276	0.126	0.205	0.094	0.170	0.078	0.144	0.066
0.3	0.551	0.253	0.346	0.159	0.254	0.116	0.208	0.095	0.172	0.079
0.4	0.662	0.304	0.408	0.187	0.274	0.125	0.217	0.099	0.193	0.088
0.5	0.759	0.348	0.434	0.199	0.333	0.153	0.253	0.115	0.217	0.099
0.6	0.779	0.357	0.503	0.231	0.361	0.165	0.284	0.130	0.224	0.102
0.7	0.874	0.401	0.528	0.242	0.382	0.175	0.301	0.138	0.240	0.110
0.8	1	0.459	0.584	0.268	0.398	0.182	0.311	0.142	0.261	0.119
0.9	1.108	0.509	0.602	0.276	0.413	0.189	0.335	0.153	0.287	0.131
1	1.171	0.538	0.621	0.285	0.465	0.213	0.358	0.164	0.267	0.122
1.1	1.151	0.528	0.639	0.293	0.445	0.204	0.372	0.170	0.273	0.125
1.2	1.280	0.588	0.672	0.308	0.499	0.229	0.384	0.176	0.288	0.132
1.3	1.270	0.583	0.692	0.318	0.515	0.236	0.352	0.161	0.309	0.142
1.4	1.344	0.617	0.672	0.308	0.456	0.209	0.356	0.163	0.329	0.151
1.5	1.450	0.666	0.644	0.295	0.482	0.221	0.376	0.172	0.317	0.145

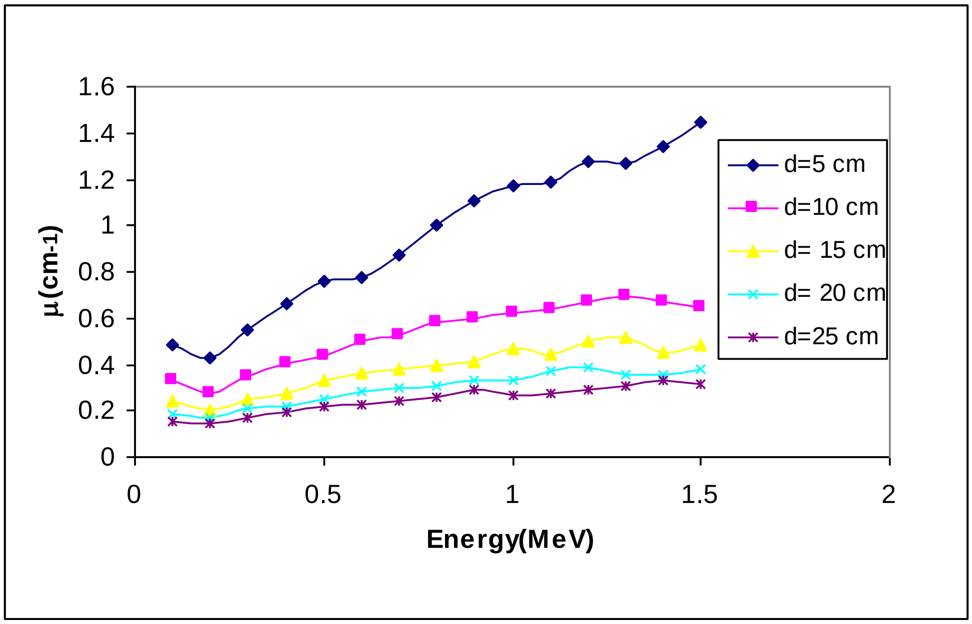

Fig. (9): Linear attenuation coefficient (μ) as a function of beta energy for different thickness d in cm.

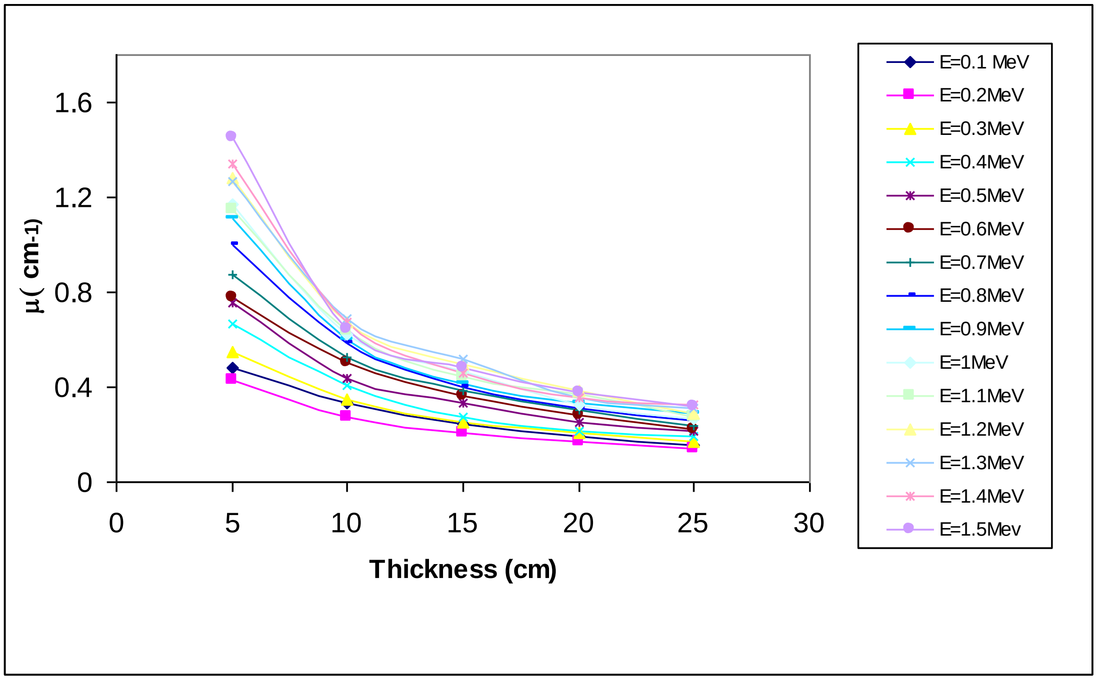

Fig. (10): Linear attenuation coefficient (μ) as a function of thickness for different energy of beta

Conclusion:-

The aim of this work was to investigate the performance of low weight materials for shielding gamma ray and beta particles. The attenuation of radiation can be achieved using a wide range of materials and understanding the basic principles involved in the physical interaction of radiation with matter that can help in the choice of shielding for a given application.

The resultsof this research indicated that the thickness affected on the absorption of the energy. The thickness of the sample does really influence the energy that penetrating the sample.

It is clear that the intensity decrease with increase the thickness of the reactive powder concrete samples. For gamma ray, it is found that the linear and mass attenuation coefficient decrease with increase energy. For beta particles, the linear attenuation increase with increase energy and decrease with increase the thickness of absorber. These results improved the capability of reactive powder concrete to absorber gamma ray and beta particles. That's mean it is useful to choice this sample for radiation shielding of gamma and beta raywith low thickness with no significant reduction in the compressive strength.

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