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EXPERIMENTAL INVESTIGATION OF GAMMA RADIATION SHIELDING CHARACTERISTICS FOR DIFFERENT ABSORBING MATERIALS

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Abstract

Gamma radiation shielding characteristics such as linear attenuation coefficient, mass attenuation coefficient, half- value layer ,Tenth Value thickness and Build up factors.; for different types of materials were measured using gamma energy. Measurements performed using a GM Tube Assembly. The radio activities of the emergent radiation were measured, when each of these materials were placed between a detector and radioactive source. Results show that Attenuation coefficient decreases with increase of gamma energy, and attenuation coefficient increases with increase of density and shows significant variation for different materials. Attenuation coefficient depends on the energy of incident photons and the nature of the material. On behalf of Build up factor Iron was found to be the second Best absorber.

Keywords - Attenuation Coefficient, Buildup factor, Gamma Radiation, GM Counter Assembly, Different Absorbing Materials. Iron the second best absorber.

INTRODUCTION

Studies on interaction of gamma radiation have been the subject of interest for the last several decades. Study of gamma-ray interaction has made profound impact in the fields of atomic physics, radiation physics, material science, environmental science, biology, health physics, agricultural, cancer therapy and forensic science etc. The mass attenuation coefficient is a measurement of how strongly a chemical species or substance absorbs or scatters light at a given wavelength, over a unit mass of material. With the development of technology, human health has started to be exposed extra radiation and this can damage human cell (01-05). In order to be protected from radiation three different methods are commonly used. Those are time, distance and the shielding. The latter one is the most important method in which shielding materials become important. Attenuation coefficient is an important parameter for study of interaction of radiation with matter that gives us the fraction of energy scattered or absorbed from different absorbing materials like Lead, Aluminium, Iron, Marble, and Glaze tile, Concrete, Mud and Sea Foam. These have a variety of uses; they can be used as packaging materials and as efficient heat insulator in various interior spaces and furniture works. They can also be used to shield radiation from nuclear sources. In its many applications, these materials may be used as it is or after suitable chemical modification intended to tailor the material properties to those desired in the end-product. Besides the use of these materials and new composite materials in building and furniture, they may also extensively used as a source of fiber for pulp and paper and as a source of chemicals for new materials and applications (06-10). In order to fully understand the properties and behavior of these materials when subjected to physical, chemical and biological processes, there is need for future research. This information is very important for the development of new applications of these materials, their composites and derived materials. Gamma radiation from radio nuclides, such as K40,Th232 and U238 series and their decay products, represents the main external source of irradiation to the human body (Auwal et al, 2011).There are many useful applications of gamma ray such as radiotherapy, medical tracer and sterilization. Thus it is important to investigate its some properties such as radiation shielding. For this purpose the attenuation coefficients of eight different materials samples have been measured. For this investigation, gamma energy range from 0.511MeV to 1.332MeV was used to determine the gamma radiation shielding characteristic such as linear attenuation coefficient, mass attenuation coefficient, half- value layer etc; of eight types of materials.

MATERIALS AND METHODS

1. MATERIALS

For the accomplishment of this research project entitled “Comprehensive study of interaction of gamma radiations having diagnostic energy range with various shielding materials”, the following materials are required

Syringes, Source Container Shielding, cotton, Collimators, for the well collimate or narrow beam., Source of $I^{131,}$ Source of $Tc^{99m,}$ Stop Watch, Wood stand, Meter rod, to measure the distance between Detector and Source, Vernier calipers, for accurate measurement of absorber’s or material’s thickness ,Screw Gauge, for accurate measurement of absorber’s or material’s thickness, Gloves, for radiation protection in Lab., Lab coat, for radiation protection in Lab., Personal Computer, having up to date operating system i.e., Windows XP, MS Office and SPSS 11.0 version along with film badges, survey meters, dose calibrators and complete GM Counter assembly as per recommendations of International Standards.

ABSORBER KIT

- Lead (8 slices had thickness 0.16, 0.21, 0.24, 0.33, 0.50, 0.69, 0.92 and 1.25 cm) .
- Aluminium (9 slices had thickness 0.04, 0.07, 0.09, 0.09, 0.12, 0.16, 0.2, 0.24 and 0.32 cm)
- Iron (9 slices had thickness 0.16, 0.16, 0.16, 0.48, 0.64, 0.64, 0.64, 0.64 and 0.48cm)
- Marble (8 slices had thickness 1.44, 1.31, 1.4, 1.43, 1.35, 1.38, 1.34 and 1.35 cm)
- Glaze tile (8 slices had thickness 0.69, 0.69, 0.69, 0.69, 0.69, 1.38, 1.38 and 2.07cm)
- Concrete (7 slices had thickness 1.36, 1.19, 2.02, 2.09, 1.86, 1.92 and 1.99 cm)
- Mud (9 slices had thickness 1.98, 2, 3.95, 4.01, 3.86, 4.06, 4.07, 3.72 and 4.05)
- Sea Foam (8 slices had thickness 1.19, 1.21, 1.35, 1.34, 1.6, 1.49, 1.63 and 1.87 cm).

The thickness of lead, concrete, marble, glaze tile, mud and sea foam was determined with the help of Venire calipers and thickness of aluminum and iron was measured with aid of screw gauge.

Figure:- 01 Absorber Materials

Figure:-02 Source and Source containerlead shield

2. METHODS

- Point source formation

The process of point source formation of I^{131} with 364 keV was done at Hot Lab-II of Punjab Institute of Nuclear Medicine (PINUM). I^{131} was radioactive element that produces artificially in nuclear reactor as bi-product. It was used for thyroid uptake studies and for treatment of thyrotoxicosis and differentiated carcinoma of thyroid. Tc^{99m} with gamma ray energy of 140 keV and half life 6 hours was radioisotope that was most commonly used in nuclear medicine department. It was produced in a generator from the parent Mo^{99}, a beta emitter with half life of 66 hours. The procedure of point source of Tc^{99m} was done at hot lab-I of Punjab Institute of Nuclear

Medicine (PINUM). The Several steps was done related to both point source formation i.e., I^{131} and Tc^{99m} , which were listed below –

01. Wear lab coat and Gloves; pinned the film badge on coat.

02. Take cotton swab and make ball of diameter approximately 3-4 mm.

03. With the help of syringe inject the liquid I^{131} from the lead shielded vial.

04. Eject one or two drops of liquid I^{131} on to cotton ball and this cotton ball is places in a small separate vial.

05. With the help of dose calibrator measure the activity or exposure of point source and placed in a small separate vial for further experimental work.

06. Place the point source vial in a lead source container and measure the activity with the help of survey meter, note that the counts are equal to the background counts then the source was ready.

- In Good or narrow-beam geometry usually require that the beam be collimated with a narrow aperture at the source so that only a narrow beam of photons was directed onto the absorber [Fig 3.8]. This minimizes the probability that photons would strike neighboring objects e.g., the walls of room and scatter toward the detector. Matching collimation on the detector helps to prevent photons that were multiple scattered in the absorber from being recorded. In addition, it was desirable to place the absorber about halfway between the source and the detector.

01. Switch on the power supply of GM tube and electrometer; set the electrometer at 400 V because the GM tube was work properly at this voltage. Record counts of 60 seconds (1 minute) time duration without placing the source, absorber and collimator in front of GM tube. These counts are referring to as background counts. For similar time duration take more two readings and calculate the mean.

02. The distance between the source and GM tube (detector) was adjust to 35 cm and fixed for all the observations. A highly collimated beam was generated by placing the collimator in front of source and (detector) GM tube. Record three observations for same time duration, calculate the mean and subtract the background counts from result. After subtraction we get the value of I_o i.e., the gamma radiation intensity at zero absorber thickness.

03. Placed the one slice of any absorbing material and record the observations as above for same time duration and distance between Source and detector.

04. Determined the Half Value Layer (HVL) by extrapolation graphs.

Calculate the Tenth Value Layer, Linear attenuation coefficient μ_l, Mass attenuation coefficient μ_m and mean free path, mfp (X_m) by using the formulas for each absorber materials.

$$\mathbf{I = I_o e^{-\mu x}}$$

I is the gamma radiation intensity transmitted through an absorber of thickness x.
I_o is the gamma radiation intensity at zero absorber thickness.
x is the absorber thickness
μ_l slope of absorption curve - linear attenuation coefficient.

$$\mathbf{TVT = 3.32 \times HVT} \qquad \mu_m = \mu_l / \rho \qquad X_m = 1 / \mu_l$$

Under the condition of bad (poor) geometry, i.e., for a broad beam or for a very thick shield, a significant number of photons may be scattered by the shield into the detector, or photons that had been scattered out of the beam may be scattered back in after a second collision. All the experimental observation method is same as the good geometry for all absorber materials slices only the experimental arrangement is different which is given in [03,04].

STATISTICAL ANALYSIS

Different procedures of statistical analysis (SAS, 1995) were used to analyze the data. The data was analyzed through computer by using SPSS.

Figure:-03 Good or Narrow Beam Geometry

Figure:-04 Bad or Broad Beam Geometry

RESULTS AND DISCUSSIONS

Attenuation coefficient depends on the energy of incident photons and the nature of the absorbing Material. Mass attenuation coefficient obtained from dividing the linear attenuation coefficient with density. Attenuation coefficient decreases with increasing energy and attenuation coefficient increases with increasing density of the material and finally build up factor was calculated and compared for different materials under investigation, our findings showed that the half value layer was that thickness that decreased the intensity to half. Tenth value layer was thickness of absorbing materials that decreased the photons transmitted beam intensity by a factor of 10. For lead calculated HVL was 0.1 cm and TVL was 0.21 cm in GG for photons of 365 keV but it was observed that the values were increased when only geometry was changed. In BG HVL was 0.15 cm and TVL was 0.50 cm. When we changed the photons energy 140 keV, HVL was also changed 0.09 cm, TVL was 0.30 cm in GG and HVL was 0.13 cm, TVL was 0.43 cm in BG. After lead iron gave very good results, in case of gamma photons of 364 keV HVL was 0.21 cm, TVL was 0.21 cm in GG and HVL was 0.29 cm, TVL was 0.96 cm in BG. For gamma photons of 140 keV HVL was 0.16 cm, TVL was 0.53 cm in GG and HVL was 0.2 cm, TVL was 0.66 cm in BG. The HVL and TVL were also calculated for absorbing materials. Aluminum, marble, concrete, glaze tile and mud.

The maximum values of linear attenuation coefficient and mass attenuation coefficient excluding lead was of iron in all geometries of medium for gamma photons of 364 keV and 140kev. Linear attenuation coefficient reflects the absorptivity of the absorbing material. The mass attenuation coefficient depends on atomic number Z and photon energy. Mean free path was the average distance traveled by a photon in the absorber before experiencing an interaction. So the minimum value of mean free path was observed in case of iron that proved better shielding against gamma photons. The comparison of buildup factors is given in the following tables (02K 01-02K 07.

Table 2K 01

Calculation of the buildup factor for lead absorbing material

Thickness of lead absorber (cm)	**Buildup factor, B**	
	I^{131}	**Tc^{99m}**
0	1.190	1.168
0.16	1.525	2.218
0.37	1.691	3.340
0.61	1.658	1.946
0.94	1.175	1.414
1.44	2.000	2.071
2.13	2.500	3.000

Table 2K 02

Calculation of the buildup factor for iron absorbing material

Thickness of iron absorber (cm)	**Buildup factor, B**	
	I^{131}	**Tc^{99m}**
0	1.092	1.347
0.16	1.235	1.461
0.32	1.112	2.074
0.48	1.227	1.719
0.96	1.180	1.284
1.6	1.524	1.500
2.24	2.073	4.143

3.05	4.000	4.750
4.3	5.000	11.000

2.88	3.088	4.500
3.52	3.028	7.000
4	16.600	5.000

Table 2K 03

Calculation of the buildup factor for aluminum absorbing material

Thickness of aluminum absorber (cm)	**Buildup factor, B**	
	I^{131}	**Tc^{99m}**
0	1.337	1.689
0.04	1.299	1.664
0.13	1.281	1.931
0.2	1.382	1.955
0.29	1.446	1.906
0.41	1.342	1.970
0.57	1.353	1.910
0.77	1.401	1.944
1.01	1.400	1.969
1.33	1.376	2.663

Table 2K 04

Calculation of the buildup factor for Marble absorbing material

Thickness of marble absorber (cm)	**Buildup factor, B**	
	Tc^{99m}	**Tc^{99m}**
0	1.167	1.143
1.44	1.356	1.064
2.75	1.285	1.083
4.15	1.391	1.132
5.58	1.644	1.342
6.93	1.925	1.197
8.31	2.607	1.164
9.65	3.733	1.226
11	45.000	1.283

Table 2K 05

Calculation of the buildup factor for Concrete absorbing material

Thickness of concrete absorber (cm)	**Buildup factor, B**	
	I^{131}	**Tc^{99m}**
0	1.014	1.014
1.36	1.097	1.088
2.55	1.078	1.236
4.57	1.045	1.171
6.66	1.184	1.233
8.52	1.122	1.244
10.48	1.189	1.130
12.36	1.200	1.488

Table 2K 06

Calculation of the buildup factor for glaze tile absorbing material

Thickness of glaze tile absorber (cm)	**Buildup factor, B**	
	I^{131}	**Tc^{99m}**
0	1.196	1.049
0.69	1.121	1.186
1.38	1.262	1.070
2.07	1.201	0.974
2.76	1.188	1.096
3.45	1.062	1.088
4.83	1.020	1.176
6.21	1.018	0.836
8.28	1.198	0.695

Table 2K 07

Calculation of the buildup factor for mud and absorbing material

Thickness of mud absorber (cm)	**Buildup factor, B**	
	I^{131}	**Tc^{99m}**
0	1.024	1.199
1.98	1.089	1.245
3.98	1.140	1.157
7.93	1.285	1.764
11.94	1.252	2.567
15.8	1.321	1.526
19.86	1.816	2.125
23.93	2.296	2.750
27.65	3.267	4.500
31.7	5.400	2.500

Fig 05: Comparison of Half value layer, HVL (cm) for different absorbing materials, when gamma sources were I^{131} and Tc^{99m} in GG and BG

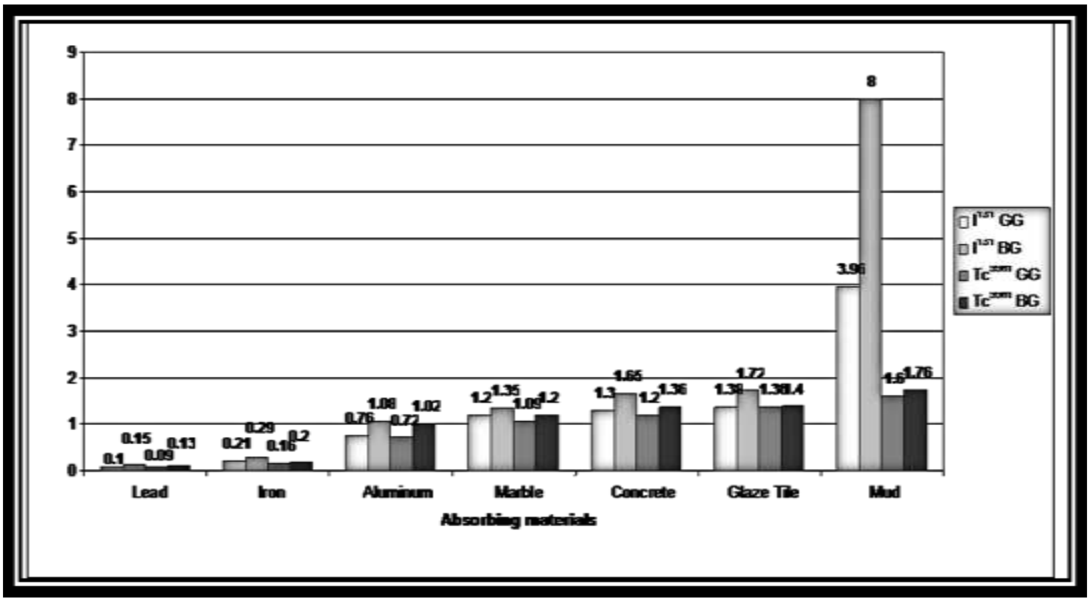


Fig 06: Comparison of Tenth value layer, TVL (cm) for different absorbing materials, when gamma sources were I^{131} and Tc^{99m} in GG and BG

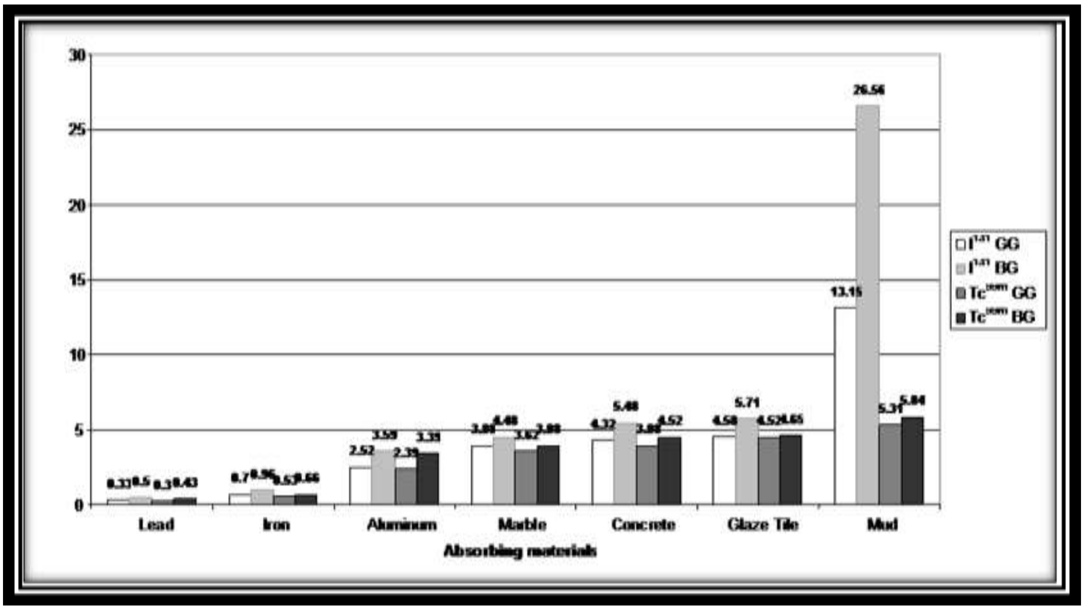


Fig 07: Comparison of Linear attenuation coefficient,μ (cm^{-1}) for different absorbing materials, when gamma sources were I^{131} and Tc^{99m} in GG and BG

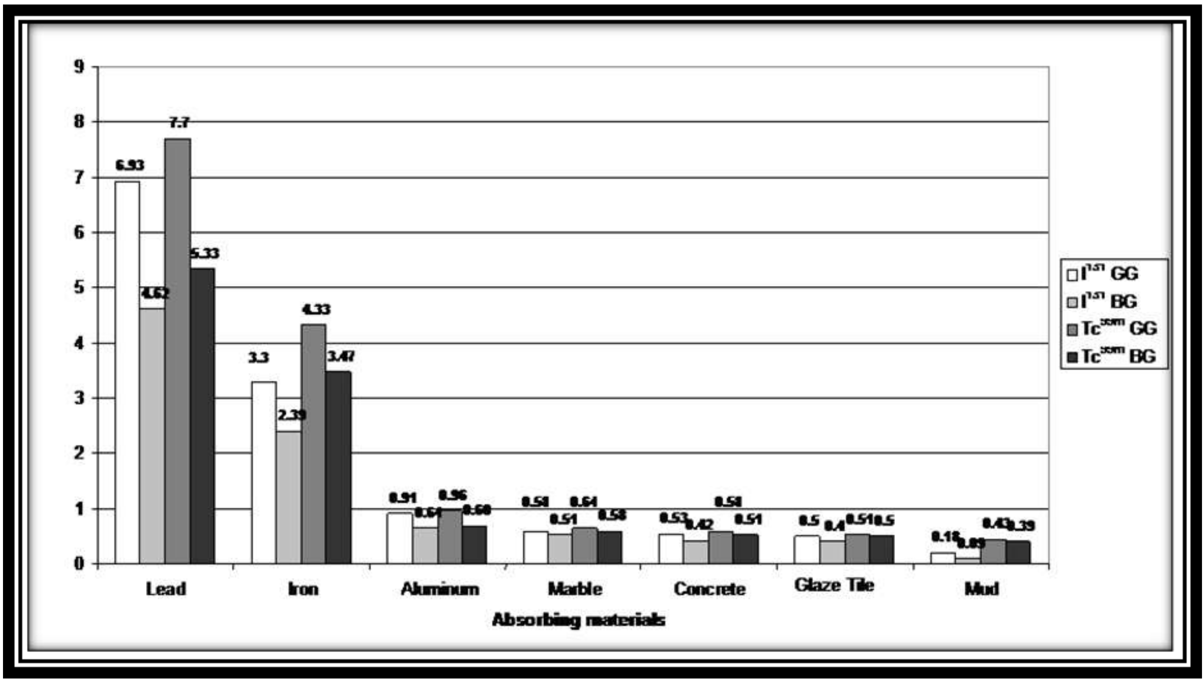


Fig 08: Comparison of Mass attenuation coefficient,μ_m (cm^2/g) for different absorbing materials, when gamma sources were I^{131} and Tc^{99m} in GG and BG

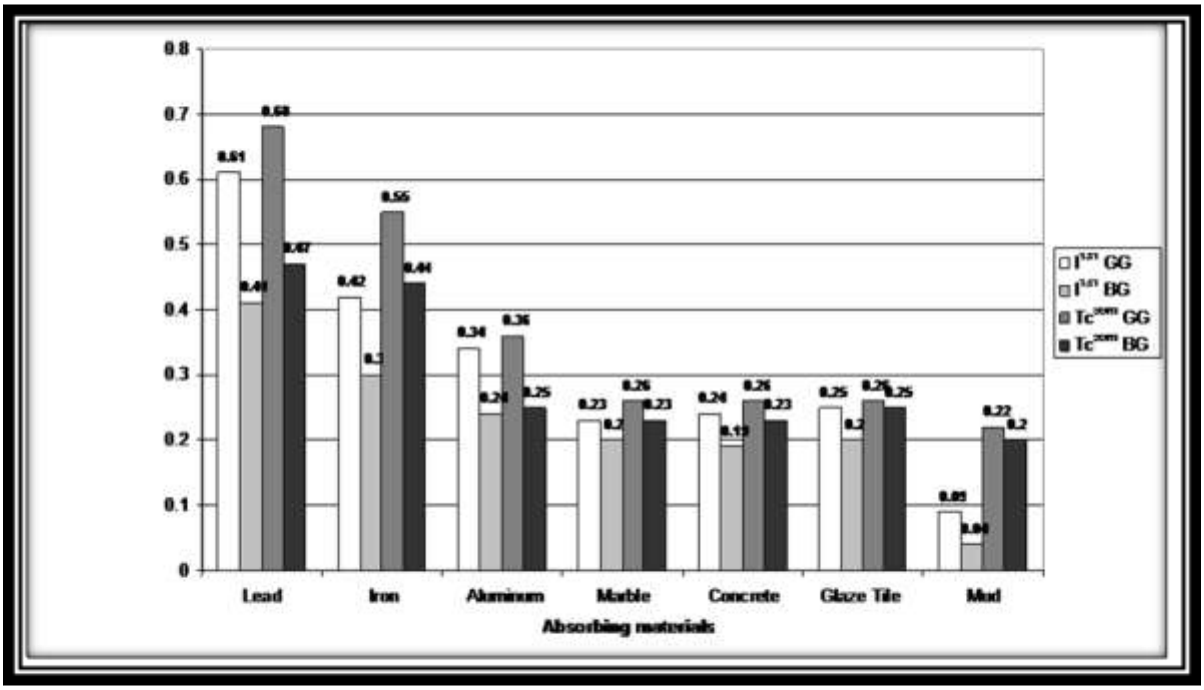
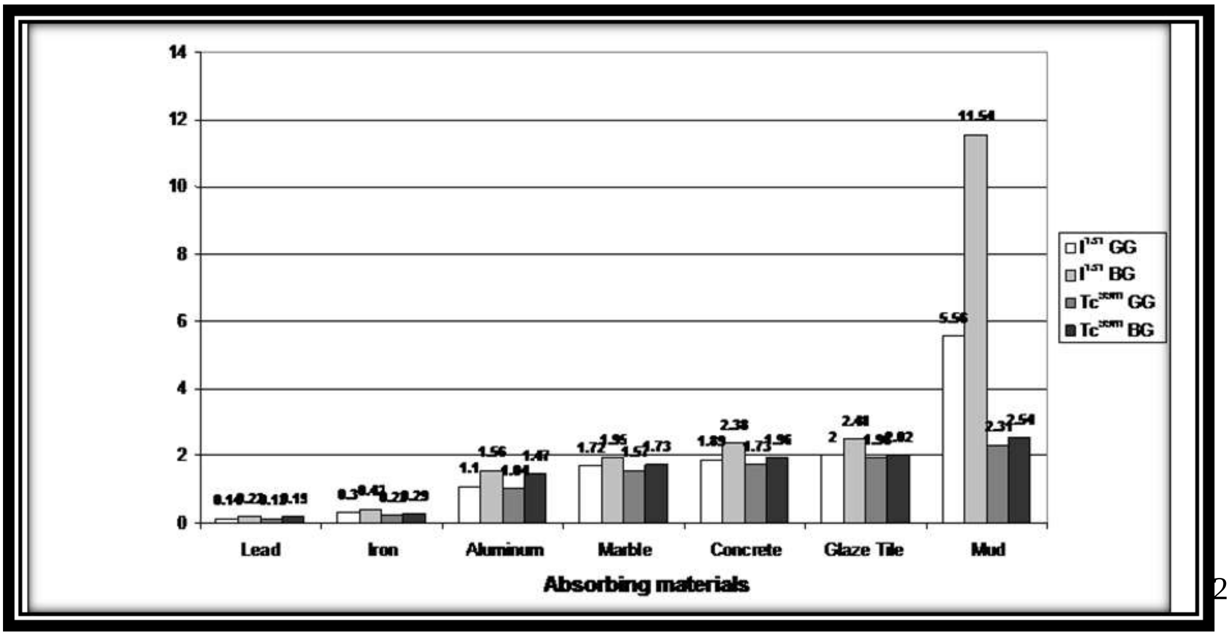


Fig 09: Comparison of Mean free path (cm) for different absorbing materials, when gamma sources were I^{131} and Tc^{99m} in GG and BG



We had observed that change in the intensity attenuation in GG and BG was due to the arrangement of the experimental shelf. Buildup factor in all absorbing materials are almost increasing gradually by increasing the thickness of the absorbing material. From these results it was concluded that iron was the most suitable material for attenuation of gamma radiations after lead. It is cheap than lead and easy to fabricate. Iron can be use in making syringe shielding, iron aprons and iron gowns for handling and injecting radioactivity. Other materials tungsten, gold and uranium, but they have disadvantages of high cost and difficulties in fabrication

DISCUSSION

In recent years, lead has been recognized as a source of environmental pollution; this includes lead use for radiation shielding in radiotherapy. We looked for a new material that could be a lead substitute. We chose a material composed of tungsten and resin. We compared the attenuation coefficient of the material with those of lead and Lipowitz's metal, and found the material has a higher attenuation coefficient than the other two. The material may be used as a substitute for lead because it is easy to fabricate and friendly to the environment (11-15). In present study economic shielding was tested and the result of iron absorbing material was best after lead. It is easy to fabricate and friendly to environment. The only disadvantage was the corrosion on the surface of iron slices due to moister of air. This problem can be solved by applying synthetic enamel on open surfaces of shielding. The linear attenuation coefficients μ (cm^{-1}) and total mass attenuation coefficients (μ/ρ) ($cm^2\ g^{-1}$) of γ-rays for barite, marble and limra have been calculated using the XCOM program (Version 3.1) at energies from 1 keV to 300 MeV. The calculated results were compared with the estimation coefficients (μ/ρ) based on the measured total linear attenuation coefficients (μ) (Akkurt *et al.*, 2004). Paper deals with the energy generation within shielding materials when single energy photons of 1.43 and 2.75 MeV, emitted from V^{52} and Na^{24} disc source respectively penetrate single layer shields of Al, Fe, Pb and graphite. The calculation is carried out using the buildup factor method. A comparison has been made in order to estimate the percentage of energy saving for each photon energy and shielding material. Also the theoretical and experimental build up factors, used for the energy generation calculation, are presented. The theoretical scalar flux, calculated using the Monte-Carlo code SAM-CE, was applied for the theoretical build up factor calculation. The scalar flux measured directly in experimental facilities was used for the experimental build up factor calculation.

In present study the HVL (cm), TVL (cm), linear attenuation (cm^{-1}), mass attenuation coefficient (cm^2/g) (16-20) and mean free path (cm) of lead, iron, aluminium, marble, concrete, glaze tile, mud and sea foam were calculated and results are compared from data of experiments performed during the course of this project. Buildup factor for each slice of every absorbing material was also calculated experimentally (Fig. 05-09).

As for as the shielding material itself is concerned, density and thickness go hand in hand in reducing radiation intensity. If a material is 1 cm thick with a density of 10 gm/cm^3 were placed between the source and a detector, it would have the same stopping power as a material 10 cm thick having a density of 1gm/cm^3 placed similarly. For this reason, unit of density thickness have become accepted in gram per square centimeter as (gm/cm^3 × cm = gm/cm^3 × 1/cm^{-1} = gm/cm^2). Densities also change when materials assume different physical states, and yet their atomic numbers remains the same. A good example of this is water which has an effective atomic number of 7.4 but assumes different densities depending on its physical states… whether ice, liquid or vapor. The results of sea foam were showed that (Table 16A-B) gamma photons (I^{131} and Tc^{99m}) intensity was not reduced by using the thickness 11.69 cm. But in case of mud slices the intensity was decreased by increasing the thickness of mud slices. It was observed that at 4.3 cm thickness of lead absorbing material, the activity was approximately equal to the background counts of the medium. When mud slices was used to attenuate the same activity of 364 keV and 140 keV gamma photons it was observed that at 31.7 cm thickness intensity was equal to background counts. As result it was concluded that atomic structure of the absorbing material was very important to attenuate the gamma photons of any energy (21-30).

As observed that the absorbing materials sequence pattern was same in case of Tc^{99m} and I^{131} i.e., lead, iron, aluminum, marble, concrete, glaze tile and mud. For different photons sources the value of HVL may be differ but the sequence was same as observed in case of Tc^{99m} and I^{131} when detecting system was GM counter. So it was suggested that attenuation of gamma intensity was depends on the shielding materials, gamma photon source i.e., Tc^{99m} or I^{131} and the geometry of the medium i.e., Good or narrow beam geometry or Bad beam geometry. It was concluded that the material that had high density and low value of mean free path showed the maximum value of attenuation of the gamma photons (31.36).

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