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Assessment of Radiation Shielding Property of Heavyweight Concrete Incorporating Hematite Iron Ore

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ABSTRACT

The aim of this research is to produce and assess the property of heavyweight concrete which could be used to shield photon radiation. The shielding capacity is achieved by incorporating a denser aggregate into the concrete mixture. The concrete is prepared by partially substituting basalt aggregate with hematite ore. Five concrete mixtures with varying content of hematite aggregate per total volume of coarse aggregate (0%, 25%, 50%, 75% and 100%) are produced in the laboratory. Three concrete slabs with a dimension of 200*200 mm sides and 100mm thickness are prepared as a representative for each concrete mixture. The photon radiation shielding property of the concrete samples is evaluated using two separate experiments. In the first experiment Cesium-137 is used as a gamma radiation source and radiation survey meter was used to measure the intensity of radiation passing through the shield. In the second experiment Cobalt-60 is used as a radiation source and a combination of ionization chamber and an electrometer is used to measure the dose. The result of the experiments showed that radiation shielding property of the concrete increase with an increase in hematite content. For a Cesium-137 source with a radiation intensity of 0.64 µSv/hr at 1 m in straight line, the linear attenuation coefficient of the samples increased from 0.023 $\frac{1}{cm}$ for normal concrete with no hematite to 0.127 $\frac{1}{cm}$ for concrete with 100% hematite coarse aggregate. For Cobalt-60 with energy 1.25 MeV, the linear attenuation coefficient of the samples increased from 0.135 $\frac{1}{cm}$ for normal concrete with no hematite to 0.196 $\frac{1}{cm}$ for a concrete with 100% hematite coarse aggregate. Generally, heavyweight concrete which is made of hematite is found to be good for gamma radiation shielding purpose.

KEY WORDS: Heavyweight concrete, hematite ore, radiotherapy, radiation shielding, linear attenuation coefficient, radiation survey meter, ionization chamber, electrometer, Cesium-127, Cobalt-60.

1. INTRODUCTION

Radiation energy is used in different sectors of industry in modern civilization. The health sector, commercial sector, and defense sectors are some of the major industries that are known to utilize radiation energy. Ionization radiation, the most common form of radiation, is used in health institutions for various purposes. The primary use of ionization radiation in medicine is for: imaging, treatment of cancer, blood irradiation and sterilization of single use medical devices (Ahmed, 2007). There is no argument whether ionization radiations are essential or not in medicine. Ionization radiations are vital part of modern-day medicine. But with the benefits, there comes a price to be paid. Besides the numerous benefits that come from the application of radiation technology, sometimes accidents occur in the process of attaining and use of radioactive source. The dangerous radiations emanated from radioactive sources can affect the human body, on occasions causing lethal damages (Akkurt, 2010). Hence, radiation shielding is a vital area of science applied to prevent the leakage and exposure of harmful radiation to the surrounding environment. The fundamental nature of the shielding is to attenuate or shield the harmful and unwanted rays from exposure to users who work with them or close to their sources.

The purpose of radiation shielding is to reduce the effective equivalent dose from a linear accelerator to a point outside the room to a sufficiently low level (American Concrete Institute, 2002). To these end, engineers, physicists, and scientists are engaged in a continuous researches to control and reduce the level of radiation exposure from ionizing radiation sources. A variety of alternative construction materials are used for shielding radiation energy. Radiotherapy rooms are constructed using lead, steel, ordinary concrete, earth, wood, and polystyrene. All these materials have pros and cons. Lead plates cost more in comparison to other shielding materials, are relatively neutron transparent, difficult to work with, and require supporting structure. Concrete is usually used for radiation shielding purposes because of its relative cheapness and ease of construction (American Society for Testing and Materials, 1997). The traditionally used ordinary concrete requires considerable thickness in the range of 1.5-3 m to attenuate radiation from high energy radioactive sources. The walls, especially the primary barriers, take up large portion of the building space. In urban areas where this health institutions are locate a limitation of free space exists (Biggs, 2010). On the other hand, heavyweight concrete eliminates most of the above stated shortcomings of radiation shielding materials. Therefore, understanding of the design, construction, and property of heavyweight concretes is vital.

Nevertheless, heavyweight concrete such as hematite concrete are not used widely in the construction industry. The lack of comprehensive scientific studies on the various types of heavyweight concretes is one of the reasons for the underutilization of the materials. The correlation between hematite content and radiation shielding capability of concrete is not clearly understood by designers and construction professionals. Considering the above views, one important question may arise. Do we know the relationship between the amount of hematite and shielding capacity of concrete? This research is conducted to produce a heavyweight concrete by partial replacement of basalt coarse aggregate with hematite ore and investigate the radiation shielding capability.

Radiation Concepts

Radiation is a discharge and transference of energy throughout space. The roaming energy is originated from different sources and the source determines the inherent characteristic of the radiation. Radiation energy can originate naturally from unstable atoms which have an unbalanced number of neutrons and protons and artificially formed using special machines like diagnostic X-ray machines, nuclear-weapons and nuclear power production (Bushong, 2017). Radiation can be classified into two major categories based on their ability to ionize matter. Consequently, radiations are classified as Ionizing and non-ionizing depending on the ability to hit electrons out of their orbits and giving the atom a positive charge (Ahmed, 2007; Bushong, 2017). Ionizing radiation is capable of knocking electrons out of their orbits around atoms and giving the atom a positive charge (CNSC, 2012; EPA 2012). Ionizing radiations are further classified into: X-rays and gamma rays (James, 2013). Whereas, non-ionizing radiation has energy lower than the ionization potential of atoms and therefore cannot ionize matter. Generally, non-ionizing radiations are not hazardous to the human body Examples of non-ionizing radiation are visible light, infrared, radio waves, microwaves, and sunlight (EPA, 2012).

Benefits of Photon Radiation in Medicine

The phenomenon of radioactivity and radiation were discovered more than 100 years ago. Since then developments in technology and superior understanding of its effects on the body have made radiation an integral part of contemporary medicine (Kaplan, 1989). Ionizing radiation has two important uses in medicine: diagnosis and therapy. The most common benefit of ionizing radiation is for Diagnostic (imaging) purpose. X-ray imaging allows physicians to identify tumors with respect to the normal anatomical structure of the patient (Kildea, 2010). In diagnostic nuclear medicine, radiopharmaceuticals which emit γ rays are used to give a picture about the examined organ (Lawrence, 2008; Li, 2011). Therapeutic

Application is a delivery of a prescribed dose of radiation to tumors (malignant cells)(Merril and Thomas, 1997). Radiotherapy uses high energy ionizing radiation to shrink tumors and kill cancer cells. For that purpose x-ray, gamma ray, and charged particles are used for cancer treatment (Kildea, 2010).

Biological Aspects of Radiation Protection

Since 1942 the biological effects of ionizing radiation to humans has been studied extensively. The studies have shined a light on the numerous biological effects that are associated with the exposure of living organism to ionizing radiation (EPA, 2012; Podgorsak, 2010). Biological effects of ionizing radiation can be classified into two broad categories: Acute effects and Delayed effects (Shrimpton, 2001). Acute effects are caused when a huge dose of whole-body radiation is received rapidly or when the exposure is received largely in the first few days (Podgorsak, 2010). The symptoms of acute radiation injury can be seen as early as a few hours after exposure (Akkurt et. al, 2010). Nausea would occur at doses less than 1 Gray (Gy) and for a dose range of 4 to 5 Gy about 50% of the exposed individuals are expected to die. When the whole-body dose approaches 10 Gy, the fatalities would reach 100% (Akkurt et. al., 2010; Turner, 2007). Delayed effects of radiation may not manifest for several years after the exposure. The effects can result either from enormous doses or from relatively small exposures repeated over an extended period of time. The delayed effects can manifest in the exposed individual or in the offspring of the exposed individual. Variation in eye or hair color, serious deformity, crippling disease, and premature death, cancer, cataract, development of abnormalities in fetus and Growth retardation are some of the common delayed effects in humans (Podgorsak, 2010, Turner, 2007).

Radiotherapy Machines

The machines most commonly used for radiotherapy are the linear accelerator (LINAC) and Cobalt-60 therapy units (Melissa,2008). British Journal of Radiology (BJR) Supplement No. 11 (BJR #11) and Supplement No. 17 (BJR #17) megavoltage (MV) define energy levels of common LINAC machines. The energy definition as per BJR #11 is used for shielding calculation. However, most of the LINACS are marketed at the high energy or BJR #17 (Table 1).

Table 1: LINAC energy levels as per BJR #11 and BJR #17

BJR #11 MV	4	6	10	15	18	20	24
BJR #17 mV	4	6	10	16	23	25	30

A traditional LINAC treatment room/bunker comprises: a primary barrier, secondary barrier, maze, door and shielding for HVAC. A Plan view showing the directions of primary beam and secondary beam, primary and secondary barrier, maze, and door for a typical radiotherapy room is shown in figure 1 below.

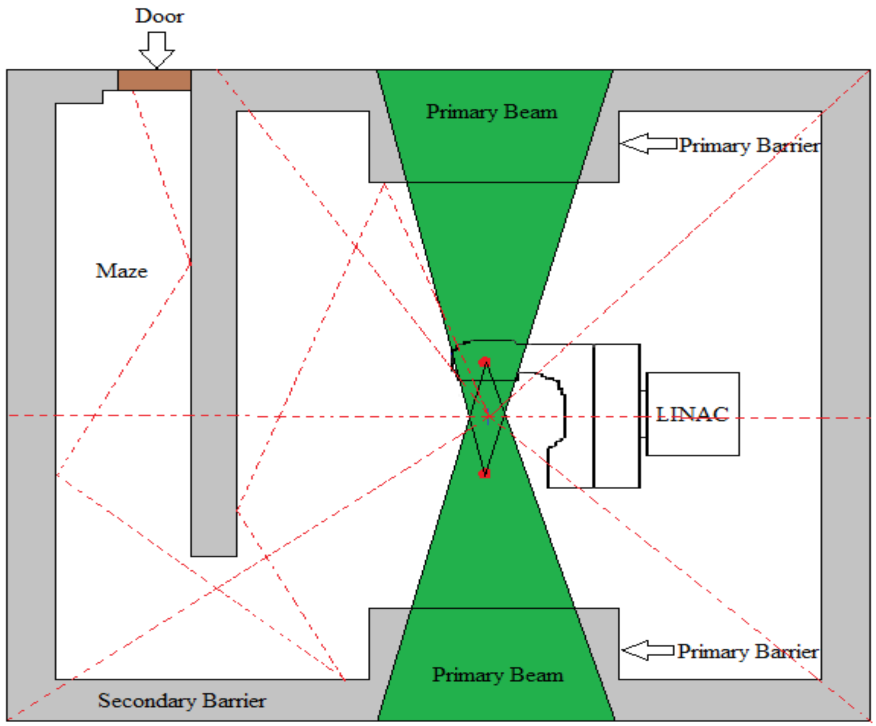

Figure 1: A Plan view showing the directions of primary beam and secondary beam, primary and secondary barrier, maze, and door [16].

The applicable energy range for radiotherapy treatment varies from 1.25 MV to 24 MV. In radiotherapy facilities LINACs or cobalt-60 therapy units are employed and the radiation source is usually incorporated into a support that rotates in a single plane around the patient. The horizontal axis rotation is referred to as the isocenter axis. The isocenter is the volume defined by the intersection of the isocenter axis and the axes of rotation of both the patient couch and the collimator of the radiation unit and is typically close to the center of the treatment room (Biggs, 2010).

Photon Radiation Shielding

Radiation shield is a physical barrier placed between a radiation source and the object to be protected so as to reduce the radiation level at the position of the object (UNSCEAR ,2008). The purpose of radiation shielding design in medical radiotherapy installations is to limit radiation exposures to members of the public and employees to an acceptable level (Biggs, 2010). Radiation transmission relationship is used to determine the amount of thickness of a material required to attenuate radiation for a specified energy level.

Figure 2 portrays the basic principle of radiation shielding; an absorber/shield protects an individual at a distance d from the radiation source. Io is the initial photon intensity, I(x) is the photon intensity after passing through an absorber of thickness x in narrow-beam geometry, and μ (cm^{-1}) is the total attenuation coefficient.

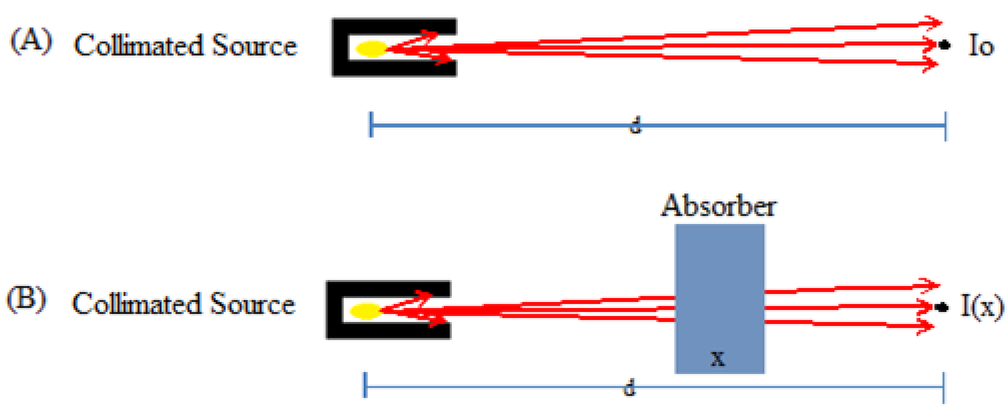

Figure 2: Diagram depicting (A) initial photon intensity and (B) photon intensity passing through an absorber (Melissa, 2008)

Photon Attenuation Coefficient: Linear attenuation coefficient is the sum of the probabilities of interaction per unit path length by each of the three scattering and absorption processes: photoelectric effect, Compton Effect, and pair production. Linear attenuation coefficient has dimensions of inverse length (1/cm). The values of μ is obtained with collimated narrow beams of monoenergetic photons incident on the different absorbers with a detector placed behind each absorber such that scattered photons are not detectable. Attenuation of photon radiation by different absorbing materials under narrow beam condition satisfies the Beer Lambert equation (equation 1).

$$I(x) = I_0 e^{-\mu x} \qquad \text{Eqn. (1)}$$

Half-Value Layer: is the thickness of absorber required to decrease the intensity of a beam of photons to one-half its initial value. The HVL is expressed in units of distance. Like the attenuation coefficient, it is photon energy dependent. The half-value layer can be calculated using the simple calculation depicted in equation 2 below.

$$\text{HVL} = x_{1/2} = \frac{ln2}{\mu} = \frac{0.693}{\mu} \qquad \text{Eqn. (2)}$$

The tenth-value-layer: is the thickness of absorber required to decrease the intensity of a beam of photons to one-tenth of its original value . The tenth-value layer (TVL) is calculated by the formula shown in equation 3.

$$\text{TVL} = x_{1/10} = \frac{ln10}{\mu} = \frac{2.3026}{\mu} \qquad \text{Eqn. (3)}$$

Concrete Technology in Radiation Shielding

Concrete is one of the most versatile and widely produced construction materials in the world. Concrete is a manmade building material that exhibits similar properties with stone. Besides providing structural strength, concrete can also be used to deliver a good radiation shielding structures. There are two major types of radiation shielding concrete: Ordinary concrete and Heavyweight concrete. Ordinary concrete is usually considered to have a density of 2.35 gcm^{-3}. It is commonly used in the construction of structural components in buildings and infrastructures. Heavyweight concrete is used in the construction of radiation shielding walls in nuclear reactors, radiotherapy rooms and industrial irradiation and laboratories. Heavyweight has a density of >2.35 gcm^{-3} (Biggs, 2010). The concrete obtains this kind of density due to the incorporation of heavyweight aggregates with specific gravities higher than 2100 kg/m^3 in the concrete mix. Heavyweight aggregates that are introduced into the concrete mixture help to improve the radiation shielding capability of the concrete.

Aggregates for Producing Heavyweight Concrete

Aggregates used for the production of heavyweight concrete are classified into two major groups. The first group is minerals, rocks and synthetic materials that have high specific gravity. Heavyweight aggregates are classified in to two groups: iron mineral ores and barium minerals. The most common iron ore mineral ores include Hematite, Magnetite and Ilmenite. Hematite is the most common iron ore mineral exploited for the production of iron all over the world. Hematite has a chemical formula of Fe_2O_3 and is a non-magnetic iron mineral. Hematite in its pure form has a hardness of 5 to 6 on Mohs' scale, and a specific gravity of 5.26. The color varies from bright red to dull red to steel gray. Hematite ores can be used as aggregates to produce a dense concrete capable of shielding radiation. The barium minerals are Barite and Ferrophosphorus. The second group consists of minerals and synthetic glasses that contain considerable amount of boron. The commercially important sources of boron are principally sodium, calcium, and magnesium borate precipitates. Whereas Boron- Frit glasses are clear, colorless, synthetic glasses produced by fusion and quenching used in making ceramic glazes.

Mix Design for Heavyweight Concrete

Mix design is the process of selecting the proportions of cement, water, fine and coarse aggregates and sometimes cement replacement materials and admixtures to produce an economic concrete mix with the required concrete properties..

Heavyweight concrete for radiation shielding can be proportioned using the ACI Method of absolute volumes developed for normal concrete.

2. MATERIALS AND METHODS

Raw Materials for Heavyweight Concrete Production

Hematite aggregate is used to partially substitute basalt coarse aggregate to produce heavyweight concrete. The hematite ore is obtained from Northern Amhara Region, Wag-Himra special zone, Sekota woreda, Tsemera kebele. Tsemera kebele is located about 20 km north of Sekota town. The Tsemera hematite obtained has a dull reddish color. Hematite ore is prepared as an aggregate by manually crushing the ore using Sledgehammers/ Mallets. Basalt Coarse Aggregate is the other coarse aggregate used. The basalt aggregate is acquired from one of the local aggregate producers/suppliers in Akaki area (Addis Ababa). The sand used is “Meki” sand and it is obtained from a local distributer in Addis Ababa City. The cement used in all the concrete mixtures is 52.5 N Normal Portland cement. The cement manufactured at Dangote cement factory is used in the experimental investigation. The water used for concrete is clean and free from dirt or organic matter. The water source is the Addis Ababa Water and Sewage Authority potable water line. Before preparing the mix design, enquiry on the major physical properties is conducted on the coarse aggregates and fine aggregate (sand) to ensure conformity to international standards. The result of the physical tests is incorporated in the design of the concrete mixtures. The physical properties of the sand, basalt and hematite used in the experiment are summarized on Table 2.

Table 2: Physical Properties of Hematite Aggregate

Properties	Sand	Basalt	Hematite
MSA (mm)	4.75	25	25
Dry Rodded Unit Weight (Kg/ $m^{3)}$	-	1630	2608.8
Bulk specific gravity (OD)	2.55	2.74	3.74
Bulk specific gravity (SSD)	2.56	2.77	3.78
Apparent specific gravity	2.57	2.81	3.88
Absorption, %	0.34	0.93	1.0
Moisture Content %	1.32	3.13	1.49
Fineness Modulus (FM)	2.89	-	-

Heavy Weight Concrete Mix Design

A concrete mixture with compressive strength of 30 MPa is designed for this research experiment. 30 MPa is chosen because of the common use of the specified type of concrete for Radiotherapy room walls and slabs in the construction industry. Two groups of concretes are produced: the experimental group and control group. The experimental group is prepared by substituting Basalt coarse aggregate with varying percentage of hematite ore aggregate. Concrete with 25%, 50%, 75%, and 100% of hematite ore contents per total volume of coarse aggregate are produced. However, the control group is a normal concrete produced with same cement content, and water to cement ratio as the experimental group. Table 3 shows the water, cement, sand, and coarse aggregate proportions for the five mixture groups.

Table 3: Mix detail for C 30 Grade Concrete mixtures for unit m^3 with varying percentage of hematite by volume of coarse aggregate

Mix Code	Cement (Kg)	Water (Kg)	Sand (Kg)	Aggregates (Kg)	
				Basalt	Hematite
CG	409	179	627	1200	-
EG25	409	179	627	997.2	465.6
EG50	409	179	627	664.8	931.2
EG75	409	179	627	332.4	1396.8

EG100	409	179	627	-	1862.4

Casting of Concrete Samples

For the radiation attenuation test, concrete samples with sides 200*200 mm and thickness (D) 100 mm are prepared accordingly. A sum total of 15 samples for the radiation attenuation test are prepared. After depositing concrete into molds, it is compacted right away. A table vibrator is used to consolidate the concrete mixtures. Following casting, the concrete samples are allowed to set inside the molds. After 24 hours are passed the concrete samples are removed from the molds (de-molded). The de-molded concrete samples are cured at room temperature in a curing tank. The test samples are cured for 14 consecutive days. Then, the cured samples are subjected to a series of experimental investigations.

Design of the Research Experimental

Experiment One: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on essential concrete properties.

Fresh concrete density: The density (unit weight) of the freshly mixed concrete is determined in accordance with ASTM C 138. The density of fresh concrete samples is determined by way of dividing the net weight of the concrete with volume of the measure used. The density is expressed in grams per cubic centimeter.

Hardened concrete density: A digital balance and a ruler are used to determine the hardened concrete density. First, the dimension of the concrete samples is measured by means of ruler and the volume is calculated. Then, the weight of the concrete samples is measure by a digital balance. Finally, the density of the concrete samples is determined by dividing the weight with volume of the samples. The density is articulated in grams per cubic centimeter. Equation 4 depicts the simple formula employed to calculate the density of the concrete samples.

$$D_{sample} = \frac{W_{sample}}{V_{sample}} \qquad \text{Eqn. (4)}$$

Experiment Two: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on photon radiation shielding property of concrete using Cesium-137 isotope.

The Gamma radiation shielding investigation using Cesium-137 isotope is carried out at The Ethiopian Radiation Protection Agency.

Photon attenuation coefficient (μ): coefficient of radiation attenuation is one of the most important factors required to perform shielding calculation. The value of μ for the shield/Absorber is determined using the radiation transmission Beer Lambert (equation 1) discussed previously.

Two important devices are used to conduct the experimental investigation for determining the Photon attenuation coefficient (μ): Cesium-137 isotope and radiation survey meter. The Cesium-137 isotope serves as radiation emitting source and the radiation survey meter is employed to measure the maximum intensity of radiation emanating from the Cesium-137 Isotope at 1 m from the source.

The initial photon intensity (I_0) and the photon intensity after passing through the absorber/shield ($I(x)$) are determined using the transmission obtained by directing a collimated narrow beam of gamma radiation from a cesium-137 source. Initial photon intensity (I_0) is determined first before placing concrete samples between the survey meter and the radiation source. Then, the photon intensity after passing through the absorber/shield ($I(x)$) is measured by placing the concrete samples with thickness 100 mm in between the Cesium-137 source and radiation survey meter.

The survey meter and the Cesium-137 radiation source are arranged in straight line 1 m from one another. The initial photon intensity and the photon intensity after passing through the absorber/shield are obtained at the same time and under the same experimental conditions. Finally, photon attenuation coefficient (μ) is calculated by inserting the variables (I_0 and $I(x)$) into the Beer Lambert equation. Figure 3 demonstrates the experimental setup arranged to determine the initial photon intensity and the photon intensity after passing through the absorber/shield.

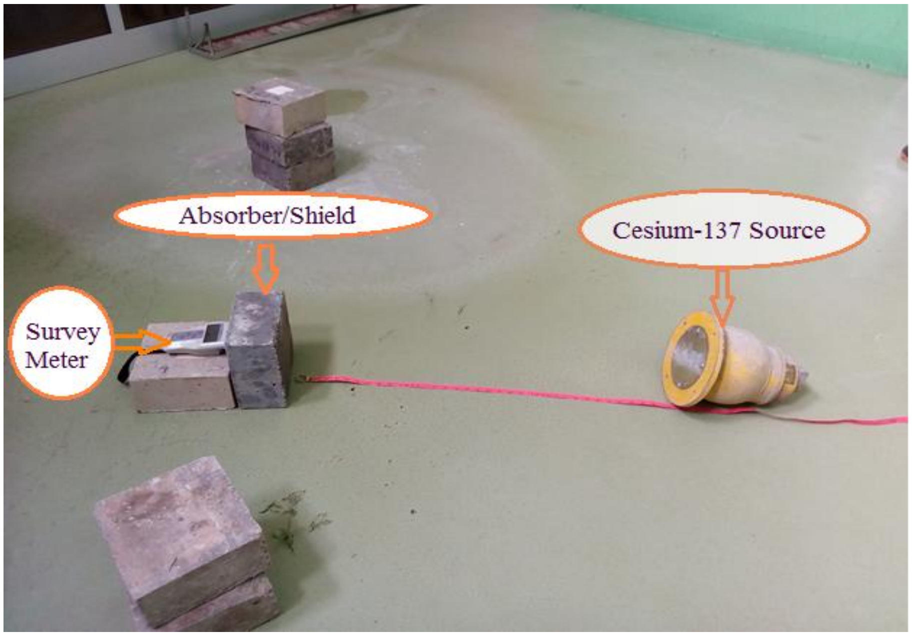

Figure 3: Measuring the radiation intensity of a collimated narrow beam passing through an absorber/ shield placed at a distance of 1 meter from a Cs-137 source

Half-Value and Tenth-Value Layers: the effectiveness of the radiation shielding is described in terms of the half value layer (HVL) or the tenth value layer (TVL) of a material. The HVL is the thickness at which an absorber will reduce the radiation from Cesium-137 isotope to half, and the TVL is the thickness at which an absorber will reduce the radiation to one tenth of its original intensity. The HVL and TVL are expressed in units of distance (cm). The HVL and TVL values are calculated using equation 2 and 3 respectively as discussed previously.

Experiment Three: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on photon radiation shielding property of concrete using Cobalt-60 isotope.

The concrete slabs are exposed to Co-60 source under controlled conditions in the Cobalt-60 Teletherapy rooms of Addis Ababa University, Tikur Anbessa Hospital-Radiotherapy Department. An ionization chamber connected with n electrometer is used to measure the ambient radiation dose. An average of three independent measurements was taken as the representative value of the specific mix.

Photon attenuation coefficient: the value of the photon attenuation coefficient (μ) for the shield/Absorber is obtained by directing collimated narrow gamma rays from the Cobalt-60 Teletherapy Machine onto the different absorbers/samples with an ionization chamber placed behind each absorber. The photon attenuation coefficient (μ) of the concrete samples is calculated by inserting the measured values of the Initial Exposure Rates and the Exposure Rates after passing through the absorber/shield obtained from the experiment into equation 1 (Beer Lambert Eqn.).

Figure 4 shows the experimental setup for measuring the radiation intensity of collimated narrow gamma rays generated from Co-60 Teletherapy Machine.

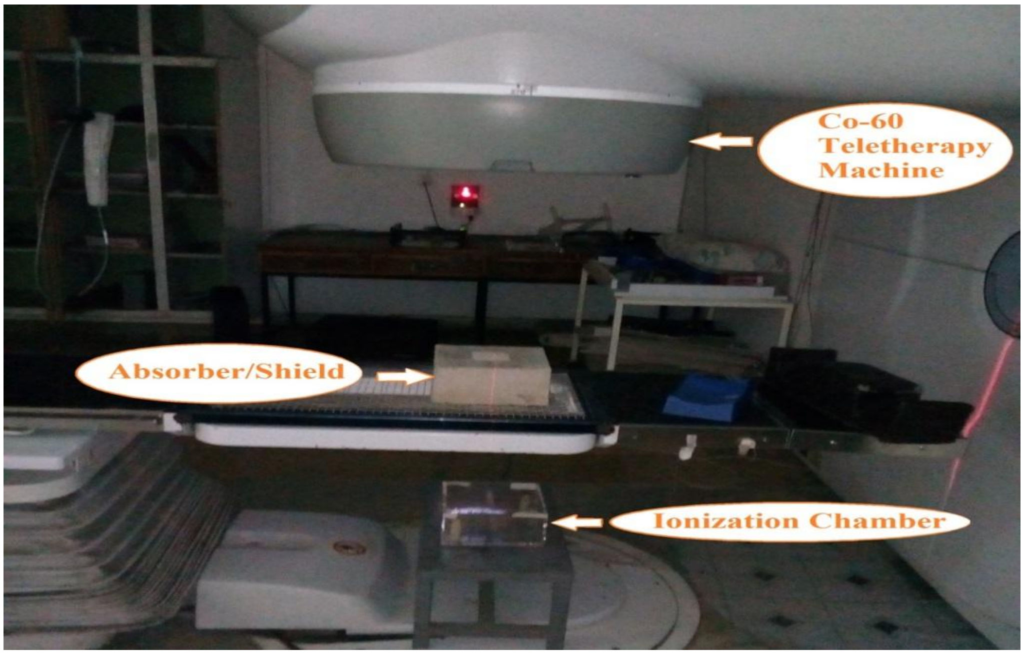

Figure 4: Measuring the radiation intensity of collimated narrow gamma rays generated from Co-60 Teletherapy Machine

In order to keep the alignment between the line of radiation transfer and the center line of the absorbers/ concrete samples, a laser beam is employed to locate the center of the samples and align the center with the line of radiation flow. An Ionization Chamber which is connected with an Electrometer is used to measure radiation dose and current produced. Ionization chamber is the most widely used type of dosimeter for precise measurements, such as those required in radiotherapy.

When Gamma radiation is emitted from the Co-60 Teletherapy Machine, it passes through the absorber/shield and hit an Ionization Chamber placed directly behind the concrete samples. The ionization chamber for the research is filled with 1 cm^3 of air. The gamma radiation that hit the ionization chamber will ionize the air and liberate ion pairs. The ionized gas acts like an electric field and movement of ion pairs are measured as a current, which is proportional to exposure rate. Accordingly, the current produced by the ionization process is measured using electrometer and expressed in Microcoulomb (μC). The magnitude of charge or current measured from ionization chambers is estimated from the fact that an exposure of 1 Rontgen (R) generates a charge of $\approx 3\times10^{-10}$ C in 1 cm^3 of room-temperature air at a pressure of 1 atm.

Half-Value and Tenth-Value Layers: the half value layer (HVL) and the tenth value layer (TVL) of the shielding materials required to reduce the radiation to half and one tenth of the original value are used to describe the efficiency of the absorber/shielding material. The HVL and TVL are expressed in units of distance. The two values are calculated by introducing photon attenuation coefficient (μ) into equation 2 and equation 3, respectively.

3. RESULTS AND DISCUSSION

Experiment One: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on Density of Concrete

According to the measurements carried out, the lowest fresh concrete density is recorded for the normal concrete (CG) with a measured density of 2.36 gcm^{-3}. The succeeding concrete mixes with 25%, 50% and 75% hematite replacement, showed an increase in fresh concrete density. The maximum fresh concrete density is obtained from EG100 which is made by replacing 100% of basalt aggregate with hematite coarse aggregate. A fresh concrete density of 3.35 gcm^{-3} is obtained for EG100. Therefore, the fresh concrete density increased with the rise in hematite content.

The second parameter assessed concerning concrete density is the hardened concrete density. Based on the experiment, it is evident that the 28^{th} day hardened density for the concrete samples showed an increase with the rise in the percentage of hematite content. The maximum hardened concrete density of 3.29 gcm^{-3} is achieved for the mixture with 100% hematite content. The average density of the hardened concrete samples for each mix is shown in the Figure 5.

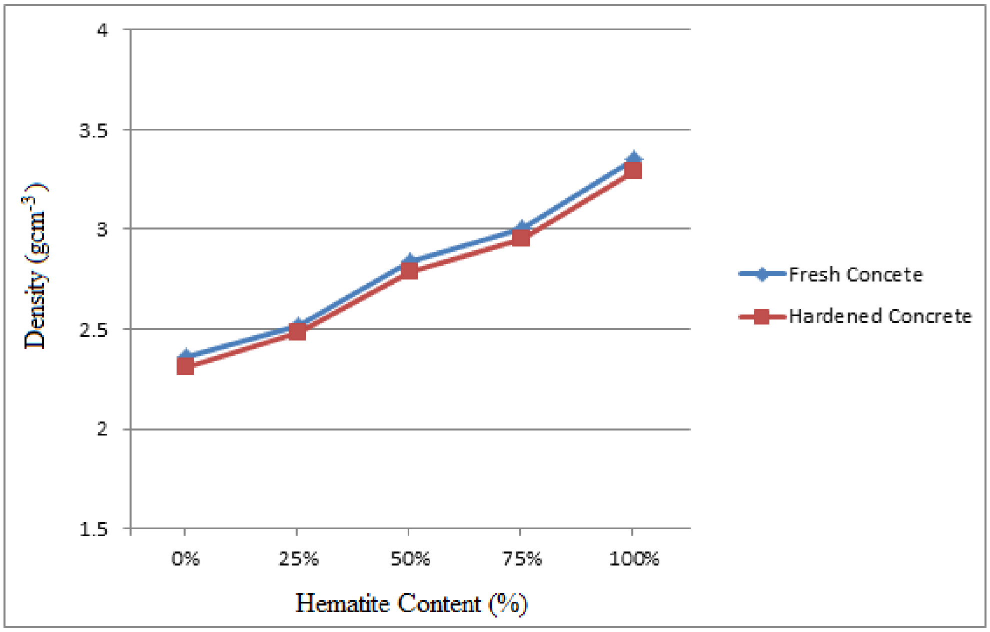

Figure 5: Effect of hematite ore on the density of concrete

Discussions and Interpretations of the Results

Based on the experimental results, three trends concerning concrete density are identified. Both fresh and hard concrete density increased with an increase in the percentage of hematite content. The density of concrete is found to be directly proportional to the percentage of hematite aggregate. The highest density is recorded for the concrete group with 100% hematite ore as a coarse aggregate. The increase in the density is attributed to heavy density of Fe (iron) which is the major compound in hematite ores.

Heavyweight concrete is usually considered to have a density of >2.35 g/cm^3 (Biggs,2010). Therefore, based on the NCRP 151 definition, mix CG (0% hematite) is categorized as a normal weight concrete. Mix EG25, EG50, EG75, and EG100 with hematite contents of 25%, 50%, 75%, and 100% respectively can be classified as heavyweight concretes.

Experiment Two: Assessment of the effect of partial substitution of Basalt Aggregate with Hematite Ore on Gamma Radiation Shielding Property of Concrete Using Cesium-137 Isotope.

Linear attenuation coefficient (LAC): the Cesium-137 source which is used in the experiment has an average maximum intensity of 0.64 µSv/h at a straight distance of 1 meter away from the source. Hence, average maximum intensity of 0.64 µSv/h is taken as the initial photon intensity (I_0). The experimental result shows that the maximum photon intensity after passing through the absorber of thickness 100 mm decreased with an increase in the percentage of hematite content in the concrete samples.

By inserting the measured initial photon intensity I_0 and the photon intensity after passing through the absorber I(x), and thickness of the shield (100 mm) into radiation transmission equation the Linear Attenuation Coefficient (LAC) of the concrete samples for the five mix groups is determined. The Linear Attenuation Coefficient (LAC) of the concrete samples increased with an increase in the percentage of hematite content. The rise in unit weight of the concrete specimens increased the linear attenuation coefficient value. The lowest LAC is obtained for sample CG (ordinary concrete): 0.023 $\frac{1}{cm}$. Whereas, the highest LAC value is attained for EG100: 0.127 $\frac{1}{cm}$. Table 3 shows the average maximum photon intensity after passing through a shield for the five mixture groups.

Table 4: Relationship between Hematite content and the average maximum photon intensity after passing through a concrete shield of thickness 100mm

Mix Code	**Hematite Content (%)**	**Unit weight (g/cm^3)**	**Average Max. Intensity I(x) (µSv/hr)**	**Linear Attenuation Coefficient (1/cm)**
CG	0	2.31	0.51	0.023
EG25	25	2.48	0.48	0.029
EG50	50	2.79	0.39	0.050
EG75	75	2.95	0.30	0.076
EG100	100	3.29	0.18	0.127

Half-Value (HVL) and Tenth-Value Layer (TVL): the half-value and tenth-value layer showed a substantial decrease when the amount of hematite incorporated in the concrete is increased. Using the Control Group (0% hematite) as a reference, the required HVL and TVL decreased as follows: 21.09% for EG25% (25% hematite), 54.18% for EG50 (50% hematite), 70.03% for EG75 (75% hematite), and 82.12% for EG100 (100% hematite).

Therefore, EG100 which is a shield made of 100% hematite aggregate gives the optimum shielding of gamma radiation emitted from a Cesium-137 isotope. The required HVL and TVL for the concrete sample with 100% hematite decreased by 82.12% relative to the Control group (0% hematite). Figure 6 shows the correlation between hematite content and half-value and tenth-value layer of the concrete samples.

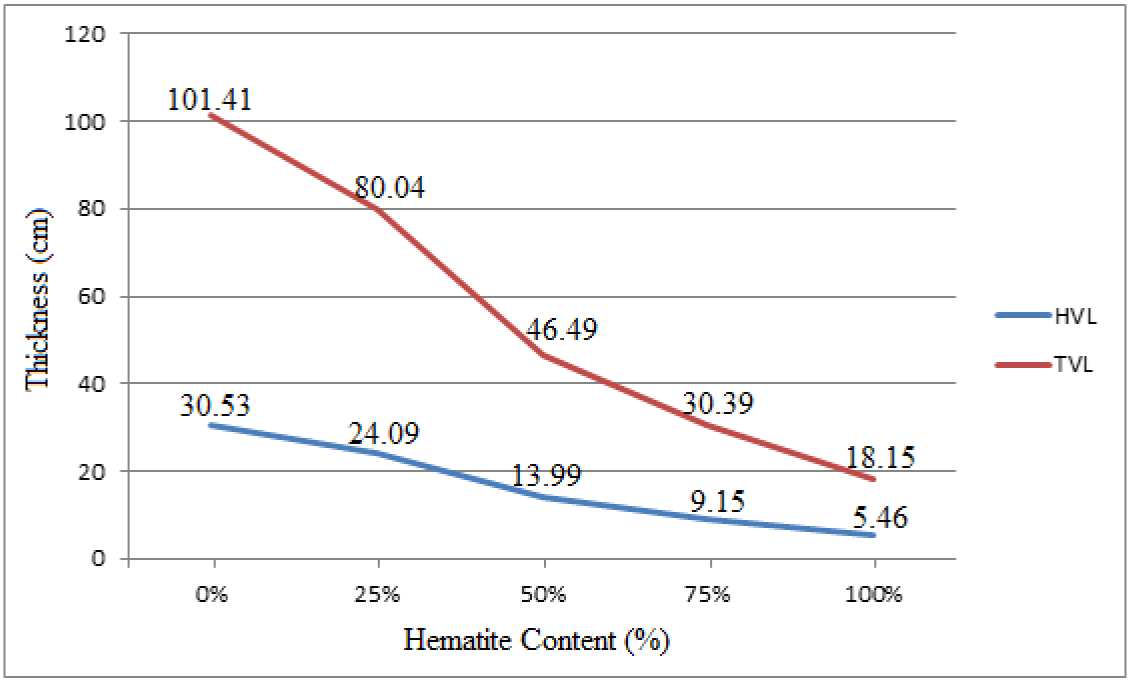

Figure 6: Effect of hematite on HVL and TVL

Discussions and Interpretations of the Results

Two important points are observed from the experiment. The first point is the rise in linear attenuation with an increase in the percentage of hematite in the concrete samples. The increase in the LAC value can be credited to the high atomic number of iron (Fe) which is the major component of hematite aggregate. Hematite which is composed mainly of iron oxide has a higher combined atomic number than the traditional concrete making materials. The attenuation coefficient is dependent on the particular absorber medium and the photon energy (the material as well as the energy of the radiation). At any specific energy the values of linear attenuation generally increase as the Z (atomic number) of the absorber increases. Because of the high-Z effect heavyweight concrete, made of hematite, increases the effectiveness as a photon shield.

The second point is the decline in the half value and tenth value layers. The HVL and TVLs decreased with an increase in the percentage of hematite aggregate in the concrete samples. The reason behind the phenomenon is that, the density of hematite is higher than densities of other concrete ingredients. Increasing the density of the absorber/medium increased the linear attenuation coefficient. Additionally, HVL and TVLs are inversely proportional to linear attenuation coefficient. Therefore, an increase in attenuation coefficient decreases the HVL and TVLs. Based on the results, it can be concluded that increase in hematite content decrease the thickness of shield required to reduce the original radiation intensity into half and tenth of its original value.

Experiment Three: Assessment of the effect of partial substitution of Basalt Aggregate with Hematite Ore on Gamma Radiation Shielding Property of Concrete Using Cobalt-60 Isotope.

Linear attenuation coefficient (LAC): the initial Exposure (X_0) is measured without the absorbers. When the Co-60 machine emits gamma rays at a straight line distance of 1 m from the ionization chamber, an average charge of 3.654E-09 C is recorded from the Electrometer. Using the charge-exposure relationship, an average charge of 3.654E-09 C corresponds to an exposure of 12.18 R in 1 cm^3 of air. Hence, the initial photon exposure (X_0) is 12.18 R.

The photon exposure after passing through the absorber (X_x) is found by placing an absorber of thickness 100 mm in between the radiation source and the ionization chamber. The average charge in air produced by the Cobalt-60 radiation in the ionization chamber after passing through an absorber showed a decrease with an increase in the hematite content of the shielding concrete samples. A maximum average charge of 9.52E-10 (exposure of 3.17 R) is produced using sample CG (0% hematite) as a shield and a lowest charge of 5.12E-10 (exposure of 1.71 R) is produced when using EG100 (100% hematite) as a shield. Table 4 presents the relation between hematite content and the average exposure (R) after passing through a shield.

By substituting the initial exposure (X_0), photon exposure after passing through an absorber (X_x), and thickness of the concrete samples (100 mm) into Beer Lambert equation, the values for the linear attenuation coefficient of the concrete specimens is calculated. The linear attenuation coefficient increase with the rise in hematite content of shielding material/samples. The lowest linear attenuation coefficient of 0.135 $\frac{1}{cm}$ is obtained for sample CG (0% hematite). For the subsequent mixtures the linear attenuation coefficient increased corresponding to the rise in hematite content. The highest linear attenuation coefficient value of 0.196 $\frac{1}{cm}$ is obtained for sample EG100 (100% hematite concrete). Using CG (0% hematite) as a reference, the LAC of the succeeding mixtures increased as follows: 2.88% for EG25 (25% hematite), 10.6% for EG50 (50% hematite), 18.67% for EG75 (75% hematite) and 31.12% for EG100 (100% hematite). Table 4 presents the effect of hematite content on linear attenuation coefficient.

Table 5: Average maximum photon exposure (R) after passing through a shield

Mix	Hematite	Unit weight	Average	Exposure	Linear

Code	Content (%)	(g/cm^3)	Charge (C)	(R)	Attenuation Coefficient (1/cm)
CG	0	2.31	9.52E-10	3.17	0.135
EG25	25	2.48	9.06E-10	3.02	0.139
EG50	50	2.79	8.10E-10	2.70	0.151
EG75	75	2.95	6.95E-10	2.32	0.166
EG100	100	3.29	5.12E-10	1.71	0.196

Half-Value and Tenth-Value Layers: the half-value layer and tenth-value layers are computed by inserting the linear attenuation coefficient into their respective formula. With the increase in linear attenuation coefficient both the half-value layer and tenth-value layers decreased tremendously. Figure 7 shows the decrease in half-value layer and tenth-value layers due to rise of linear attenuation coefficient in the succeeding mixture groups.

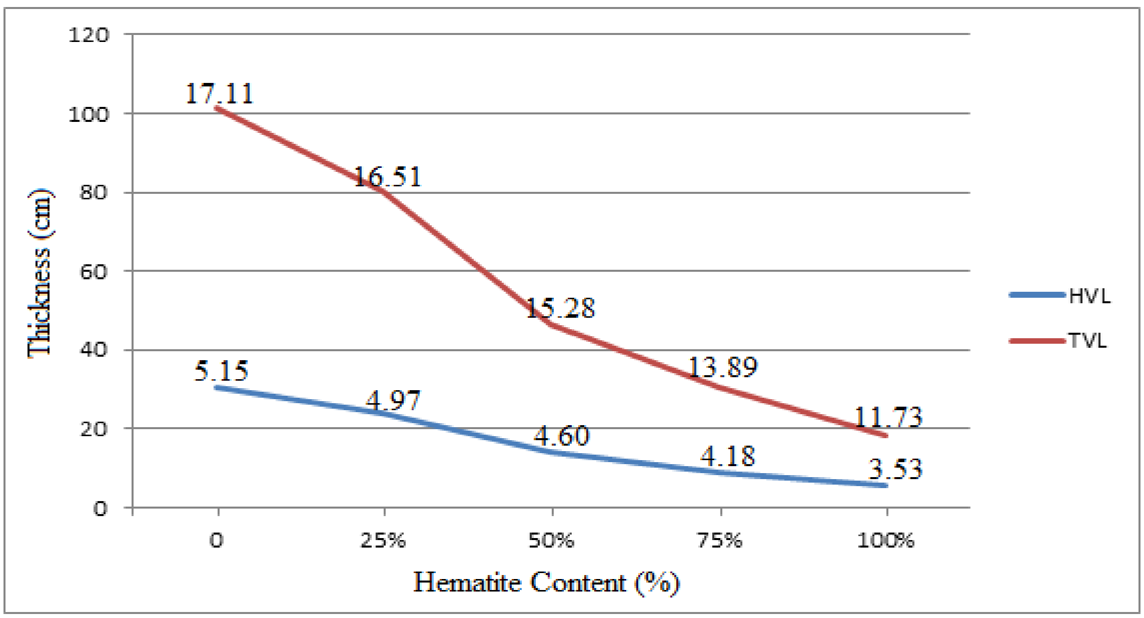

Figure 7: Relationship between hematite content of concrete and the HVL and TVL

Taking the control group (0% hematite) as a reference the HVL and TVL of the experimental groups decreased as follows: 3.51% for EG25 (25% hematite), 10.70% for EG50 (50% hematite), 18.82% for EG75 (75% hematite) and 31.44% for EG100 (100% hematite).

Discussion and Interpretation of the Results

The experimental outputs depict that the linear attenuation coefficient of the concrete samples increase with an increase in hematite content. The highest attenuation coefficient is obtained for sample EG100 (100% hematite). This indicates that, the high atomic number of iron (Fe) which is the major component of hematite increase the attenuation coefficient of the concrete samples.

Consequently, the rise in linear attenuation coefficient in turn decreased the required half-value layer and tenth-value layers. The reason behind is the inverse relationship that exists between attenuation coefficient and HVL and TVLS. This indicates that it is possible to decrease the required half-value layer and tenth-value layers of shield material by incorporating hematite aggregate into the concrete mixes.

According to the results, 100% hematite content concrete provides the optimum HVL and TVL. Therefore, the concrete with 100% hematite is the optimum mix ratio and lesser thickness of the material is required to shield the Co-60 radiation.

4. CONCLUSIONS

The major conclusions are stated as follows:

1. The bulk specific gravity of the hematite ore is 3.78. The specific gravity of hematite iron ore in its pure form is 5.26. Therefore, the hematite ore has considerable amount of impurities.

2. Density of concrete increase with hematite content, both in fresh and hardened states. Maximum density of concrete is achieved for total replacement of hematite with basalt aggregate. It is possible to produce heavyweight concrete with fresh concrete density up to 3.35 gcm^{-3} using sekota/ tsemera hematite ore.

3. The Linear Attenuation Coefficient (LAC) of the concrete samples increased with an increase in the percentage of hematite content. The rise in unit weight of the concrete specimens increased the linear attenuation coefficient value. The increase in linear attenuation coefficient indicated an increase in radiation shielding potential.

4. Half-value and tenth-value layer of concrete is inversely proportional to amount of hematite. The half-value layers and tenth-value layers which are inversely correlated with the linear attenuation coefficient decreased with the increase in the hematite content of the concrete specimens. This shows that incorporation of hematite in concrete mixtures reduces the thickness of the material required to reduce the photon radiation level to half and one-tenth of the original value. This in turn demonstrates the capacity of concrete with hematite contents to shield gamma rays effectively.

5. Concrete/ shield made of 100% hematite aggregate gives the optimum shielding of gamma radiation emitted from a Cesium-137 and Co-60 isotope. The required HVL and TVL for the concrete sample with 100% hematite decreased by 82.12% relative to the Control group (0% hematite).

The main contribution of this research is in enhancing the understanding of the correlation between hematite content and gamma radiation shielding property of concrete. The research indicated that with the increase in hematite content the linear attenuation coefficient of the concrete samples increased. The rise in linear attenuation reduced the thickness of material required to reduce the original intensity of the radiation to half and one-tenth of the original value (HVL & TVL). This phenomenon clearly indicated that the rise in hematite content increased the gamma radiation attenuation coefficient of the shielding materials. The maximum attenuation coefficient is recorded for EG100 (100% replacement of basalt with hematite). Therefore, 100% replacement of basalt with hematite aggregate is found to produce samples with highest capacity to attenuate/shield gamma radiation.

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