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Gamma-Rays Absorption Studies of Garnet series of Gemstones at 1 Kev to 100 GeV: Theoretical Calculation

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Abstract: - Mass attenuation coefficients and partial photon interactions have been calculated theoretically at incident photon energy 1 Kev to 100 GeV for garnet series of gemstones (Grosaularite (GS1), Pyrope(GS2), Spessarlite(GS3), Almandine(GS4), Uvarovite(GS5) and Androdite(GS6) using XCOM software [1]. The values of these parameters have been found to change significantly with incident photon energy and composition of the garnet series of gemstones. Half value layer (HVL) and tenth value layer (TVL) has also been calculated; whose lower value reveals the good shielding ability for gamma rays. Hence it is concluded that GS4 shows the maximum shielding effectiveness and also GS6 and GS3 seem to have good radiation shielding. It is also analyzed that our calculated mass attenuation coefficient of NBS concrete by the present method are in excellent agreement with standard values given by ANSI/ANS-6.4.3 data.

Keywords: - *Gemstones, Half value layer, Mass attenuation coefficients, and Tenth value layer.*

I. INTRODUCTION

Radiation protection is necessary, because radiation is all around us, in the air, the water, the food we eat. It causes us to feel unwell, and it can contribute to the eventual onset of disease. That's why we need effective ways of protecting ourselves from this bombardment. And nature has provided a ready-made solution. Gemstone and noble metal combinations in jewelry are far superior technology for protection from radiations. Gems need to be worn in contact with the skin, and the larger the surface area in contact the better.

In today's world, irradiation is routinely used to color a number of gemstones. The process by which irradiation changes color is fairly straightforward. Radiation causes electrons to be knocked off some atoms, leaving them free to be absorbed by others. This has the effect of creating "color centers" which in turn alter the light-absorbing pattern of the gemstone and by extension its color. Generally it is gamma rays from radioactive elements such as cobalt which labs use to irradiate gemstones. Gamma rays leave no residual radioactivity. Radium by contrast, does and is hence dangerous to human health[2].

Garnet series gem stones are good materials which are at low cost and easily available and protect from radioactive radiations. The study of absorption of gamma rays in the gem stones has become an interesting and exciting field of research. The photon mass attenuation coefficients are the basic quantities required in determining the penetration of X-rays and gamma photons in matter [3]. The mass attenuation coefficient (μ/ρ) is a measure of probability of interaction that occurs between incident photons and matter per unit mass per unit area. The knowledge of mass attenuation coefficients of X rays and gamma photons in biological, chemical and other important materials is of significant and practical interest for industrial, biological, agricultural, defence and medical applications [4]. Accurate values of photon mass attenuation coefficients are required to provide essential data in diverse fields such as nuclear diagnostics (computerized tomography), nuclear medicine, radiation protection, radiation dosimetry, gamma ray fluorescence studies, radiation physics, shielding, security screening and etc[5].

The mass attenuation coefficient values of partial photon interaction processes such as photoelectric effect, Compton scattering, pair production and total are available in the form of software package XCOM from Berger and Hubbell [6, 7] by substituting the chemical composition/weight fraction of compound/mixture, the mass attenuation coefficient of the shielding materials will be generated in the energy range 1 Kev - 100 GeV [8]. Hubble are published tables of mass attenuation coefficients and the mass energy absorption coefficients for 40 elements and 45 mixtures and compounds for 1 keV to 20 MeV in 1982.Hubbell and Seltzer replaced these tables in form of tabulation for all elements having $1 \leq Z \leq 92$ and for 48 additional substances for dosimetric interest [9]. The reports on attenuation coefficients measured by researchers reported [8-19] for different energies for various samples in solid, liquid, stones and alloys.

ANSI/ANS-6.4.3 (1991) standard has been administratively withdrawn in August 2001, but the work is in progress for updating this much used standard by a working group chartered in 2007 by the American Nuclear Society (ANS). Recently, a study has been made for the purpose of updating gamma-ray mass attenuation coefficients for high-*Z* engineering materials that are presented in the current ANS standard [3].This prompted us to study the mass attenuation coefficient (μ / ρ) of garnet series of gemstones. Recently we studied the measurement of total and partial mass attenuation coefficients of oxide glasses [10]. The research paper on mass attenuation coefficients measured by researchers reported [11-18] for different energies for various samples in solid, liquid, stones and alloys.

In the present work, the Total and partial mass attenuation coefficient have been calculated for garnet series of gemstones for all photon interactions (coherent, incoherent, photoelectric, pair production and total photon interaction [with coherent]) in the energy range 1 KeV - 100 GeV. The variations of Total and partial mass attenuation coefficient with energy are shown graphically for the all photon interactions.

The chemical formulae, refractive index and specific gravity of garnet series of gemstones (Grosaularite (GS1), Pyrope(GS2), Spessarlite(GS3), Almandine(GS4), Uvarovite(GS5) and Androdite(GS6) are as shown in Table1. are taken from (19).

II. INTERACTION OF RADIATION WITH MATTER RAYS

Nuclear radiations (α, β, γ-rays) have been used for a long time and serious accidents leading to confirmed and suspected deaths of persons arising from direct and indirect effects of radiations have occurred. In different applications of radiations it is observed that, over-exposure is harmful and under-exposure is ineffective. Gamma rays and ultraviolet radiations, for instance, produce electrons through the well-known mechanism of photoelectric, compton and pair production[20].

2.1 Photoelectric (PE)

In this process, gamma rays is completely absorbed by an atom. The photon energy is transfer to the inner orbit of an electron (usually from the K shell), which is then eject from a atom. An electron from the outer atomic orbit subsequently fills the inner orbital space, with consequent liberation of energy.This energy may manifest as X- rays. This ejected electron will travel with energy equivalent to the energy of the photon less that binding energy of the electron to the atom, and will undergo further interactions with other atoms. The photoelectric effect is the greatest in the case of low photon energies of less than 100 Kev, or in matters with high atomic numbers.

2.2 Compton Scattering (CS):

Interaction between a high energy photon and a free of loosely bound electron will lead to diversion of the photon, and a consequent of the energy, the lost energy is transferred to the electron which will travel with an energy equal to the energy loss by photon. The scattered photon may then undergo subsequent absorption by either the photo electric effect or Compton effect. Compton absorption is most important in the cases of photons with high energies of 100 Kev to 10 MeV.

2.3 Pair Production (PP)

Pair production is the simultaneous formulation of a electron and positron as a result of interaction between electromagnetic radiation of sufficient energy greater and equal of 1022 Kev and the field of an atomic nucleus of the atom. After being slowed down the electron and positron recombine, resulting in the production of two 511 Kev gamma rays (annihilation radiation).

III. THEORY

3.1 Calculation of Mass Attenuation Coefficient

The absorption coefficient of gem stones is dependent on its content and gamma - ray energy. This work describes a study of content dependence on measurements of attenuation of gamma - radiation at gamma-ray energy of gem stones .The attenuation of gamma rays expressed as:

$$I = I_o \exp(-\mu x) \qquad (1)$$

Where Io 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 the linear form,

$$\log I = \log I_o - \mu x$$

i.e.

$$\mu x = \log (I_o/ I)$$

$$\mu = (1/x) \log (I_o/I) \qquad (2)$$

The mass absorption coefficient of gem stones, μ_m defined as,

$$\mu_m = \mu/\rho \qquad (3)$$

Where, μ_m is the mass attenuation coefficient and ρ is the density of gem stones. The unit of μ is cm^{-1} and that of μ_m is cm^2/gm.

3.2 Calculation of half value layer (HVL) and tenth value layer (TVL)

Half –value layer (HVL) is the thickness of the attenuator that reduces the intensity of photon beam to half of its original value (I_0), i.e. (½) I_0 and is given by

$$HVL = \frac{0.693}{\mu}$$

also, the tenth-value layer, TVL, is defined as the thickness of the attenuator that reduces the photon beam intensity to one tenth of its original value (I_0), i.e. $(1/10)I_0$.

$$TVL = \frac{2.303}{\mu}$$

The HVL and TVL are expressed in units of distance (cm).Since, the linear attenuation coefficient varies with photon energy, HVL and TVL are also energy dependant quantities.

IV. RESULT AND DISCUSSION

4.1 Mass attenuation coefficient of selected materials as a function of chemical composition and incident photon energy:-

The results of the present investigation are shown graphically in figs. 1-6, where μ is given as a function of incident photon energy in all photon interaction processes. In the present work, the effect of chemical formulae of chosen gem stones on μ and the variations of μ with incident photon energy for all interactions are discussed in the following paragraphs.

Variation of total mass attenuation coefficients of all gem stones of garnet series with incident photon energy (MeV) for all types of interaction process is studied from fig. 1. Mass attenuation coefficient (μ) for the total photon interaction processes is initially high and decreases sharply with increase in incident photon energy up to 100 keV. Above 100 Kev the rate of decrease of μ (total) with incident photon energy is less and above 25 MeV μ (total) increases slightly with further increase in incident photon energy. This behavior is due to dominance of different interaction processes in different incident photon energies i.e. below 100 Kev photo electric process is dominant, from 100 Kev to 25 MeV Compton scattering and above 25 MeV pair-production process is dominant. It is also clear in fig. 1 that the gem stone GS6, contains a higher percentage of heavy element such as calcium and iron, has higher values of μ(total) in lower energy region and high energy region where as it is slightly lower in middle energy region as compared to other gem stones.

The above observations of fig. 1 can also be extended to the other figures (2-6) in which the effect of chemical formulae of chosen gem stones on μ is investigated for partial photon interactions (photo-electric effect, coherent and incoherent scattering, pair production in the electric field, and pair production in the nuclear field) for same choosing gem stones. From fig. 2, it is observed that the value of μ (photo) decreases rapidly with increase in incident photon energy for all the selected materials. It may due to reason that photo-electric cross-section varies inversely with incident photon energy as $E^{3.5}$. In the lower energy region values of μ(photo) of all the gem stones are almost same but as the incident photon energy increases there is considerable increase in difference of values of μ(photo) of all the gem stones as μ(photo) is further strongly dependent on atomic number of interacting materials as z^{4-5}.

In figs. (3,4) it is observed that the values of μ(incoh.) firsly increases with increase in incident photon energy and after 40 Kev values of μ(incoh.) decreases where as the values of μ(coh.) decrease sharply with increase in incident photon energy for all chosen samples. This decrease in values with increase in incident photon energy may be due to the reason that μ(coh.) and μ(incoh.) is inversely proportional to incident photon energy E. The variations in the values of μ(coh.) due to chemical composition is low but it is almost same in case of incoherent scattering. From the above results it is interpreted that decreasing rate of values of μ(photo) with incident photon energy is higher than μ(incoh.) decreasing rate. And the variation in μ(photo) due to chemical composition can be seen clearly which is not significant in case of μ(incoh.). Above results clearly explain the variation of μ(total) below 4 MeV in fig. 1.

The variation of μ for pair production in electric field and nuclear fields are shown in figs 5-6 respectively. In both cases, the values of μ(pp) increases slightly with increase in incident photon energy up to 400 MeV but beyond this incident energy the values of μ(cpp) remains almost constant. It may be due μ(pp) is directly proportional to logE. For pair production in the nuclear field, the values of μ(pp) of chosen samples show significant variation (fig. 6) but slight variation is observed for μ(pp) in the electric field (fig. 5). It may be due to pair production in nuclear field is Z^2 dependent, whereas the Z dependence of pair production in the electric field is almost linear. In the high incident photon energy range, the variation is observed in μ(total) (fig. 1) is because of Z^2 – dependence of the pair production in the nuclear field.

4.2 HVL and TVL as a function of incident photon energy

Figs. (7-8) explain the dependence of radiation shielding on HVL and TVL for all selected samples. It is concluded from the fig. that values of HVL and TVL increases sharply in the energy region of 1 Kev to 100 Kev whereas increasing rate is comparatively lower in the energy region of 100 Kev to 20 MeV and beyond this incident photon energy the HVL and TVL values tends to remain constant. Moreover, the sample which has low value of HVL and TVL has good radiation shielding for gamma rays than other samples. Using HVL and TVL for the selected samples, it is concluded that GS4 shows the maximum radiation shielding and also GS6 and GS3 seem to have good shielding effectiveness.

4.3 Standardization of the procedure

In order to check the reliability of present method, values of mass attenuation coefficient of NBS concrete calculated using XCOM program are compared with mass attenuation coefficient of NBS concrete values given by ANSI/ANS-6.4.3 data[21] for energies ranging from 1 Kev-100 GeV. From fig. 9 it can be analyzed that our calculated mass attenuation coefficient of NBS concrete are in excellent agreement with standard data. This gives confidence in our results for the garnet series of gemstones.

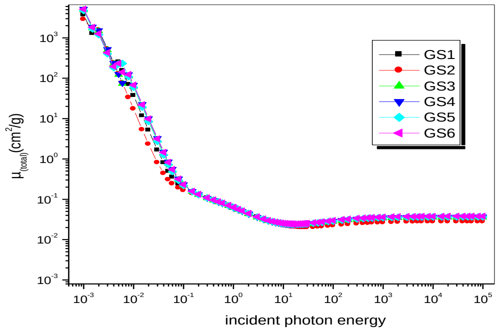

Fig.1: Variation of total mass attenuation coefficients of all gem stones of garnet series with incident photon energy (MeV) for all types of interaction process

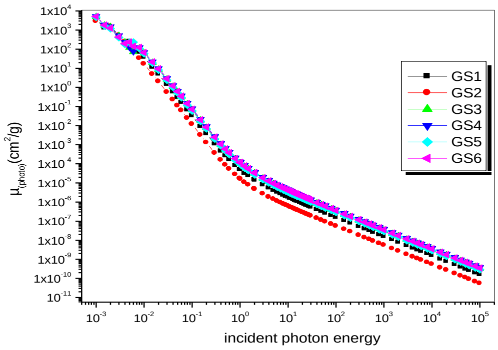

Fig.2: Variation of mass attenuation coefficients of all gem stones of garnet series with incident photon energy (MeV) for photo electric absorption.

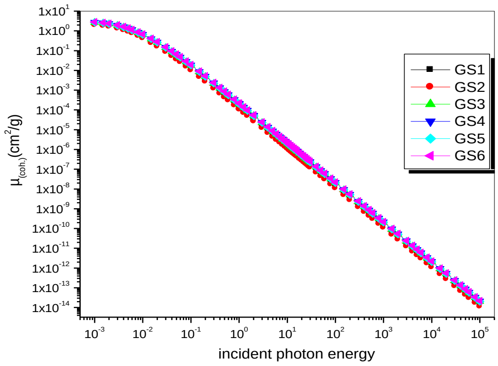

Fig.3: Variation of mass attenuation coefficients of all gem stones of garnet series with incident photon energy (MeV) for coherent scattering

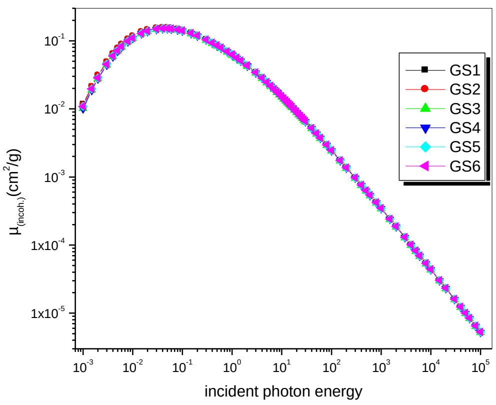

Fig.4: Variation of mass attenuation coefficients of all gem stones of garnet series with incident photon energy (MeV) for incoherent scattering.

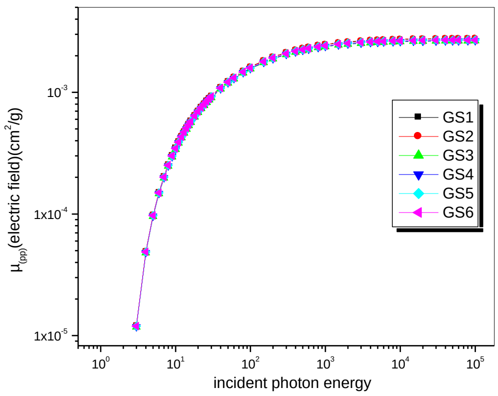

Fig.5: Variation of mass attenuation coefficients of all gem stones of garnet series with incident photon energy (MeV) for pair production in the electric field

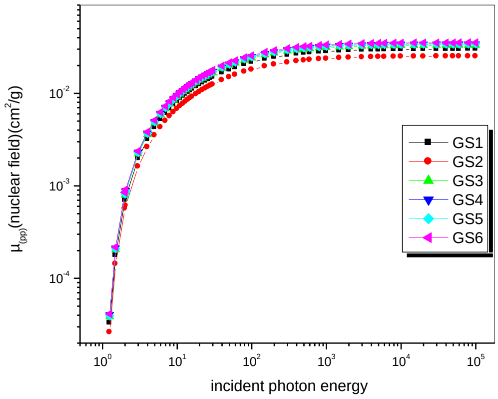

Fig.6: Variation of mass attenuation coefficients of all gem stones of garnet series with incident photon energy (MeV) for pair production in the nuclear field

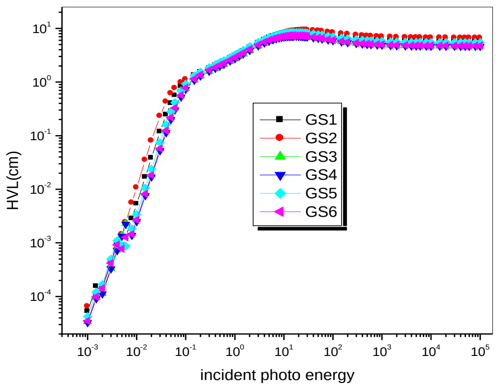

Fig: 7. Comparison of half value layer of all the samples for chosen energy range

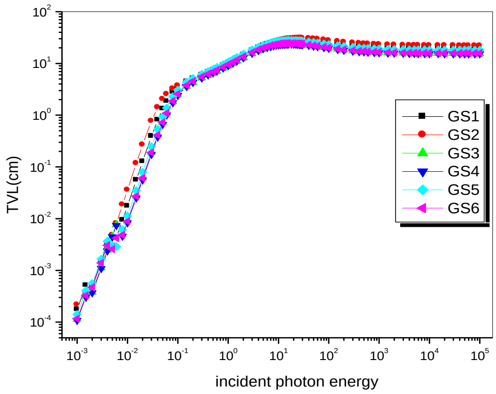

Fig: 8. Comparison of tenth value layer of all the samples for chosen energy range.

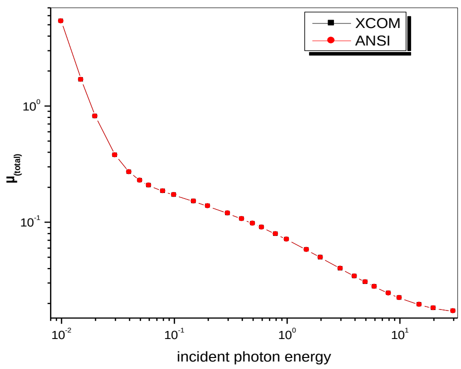

Fig. 9. Comparison between ANSI data base and present work with respect to the calculated values of mass attenuation coefficient for NBS concrete at energy range 1 Kev-100GeV.

Table 1: Chemical formula , Refractive index and Specific gravity of gem stones[19].

Garnet Series	Chemical Formula	Refractive index	Specific gravity
Grosaularite (GS1)	$Ca_3Al_2(SiO_4)_3$	1.735-1.763	3.4-3.7
Pyrope(GS2)	$Mg_3Al_2(SiO_4)_3$	1.705-1.760	3.7-3.8
Spessarlite(GS3)	$Mn_3Al_2(SiO_4)_3$	1.794-1.814	4.0-4.3
Almandine(GS4)	$Fe_3Al_2(SiO_4)_3$	1.766-1.830	3.9-4.2
Uvarovite(GS5)	$Ca_3Cr_2(SiO_4)_3$	1.838	3.4-3.5
Androdite(GS6)	$Ca_3Fe_2(SiO_4)_3$	1.865-1.940	3.8-3.9

V. CONCLUSION

- Mass attenuation coefficient (μ) of chosen samples for the total photon interaction processes is high initially and decreases rapidly with increase in gamma photon energy up to 100 keV. After 100 keV the variation of μ with incident photon energy is less and above 25 MeV μ increases slightly with increase in photon energy. This behavior is due to dominance of different interaction processes in different incident photon energies i.e. below 100 keV photo electric process is dominant up to 100 keV after that Compton scattering up to 25 MeV and pair-production process is dominant above 25 MeV. Mass attenuation coefficient is helpful for detail study in shielding effectiveness of different types materials /mediums.
- The gem stone GS6, contains a higher percentage of heavy element such as calcium and iron, has higher values of μ(total) in lower energy region and high energy region where as it is slightly lower in middle energy region as compared to other gem stones.
- Using HVL and TVL for the selected samples, it is concluded that GS4 shows the maximum radiation shielding and also GS6 and GS3 seem to have good shielding effectiveness.

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REFERENCES

[1] M. J.Berger and J.H. Hubbell, XCOM: Photon Cross-Sections Database, Web Version 1.2, National Institute of Standards and Technology, Gaithersburg, MD20899, USA, 1987/1999, http://physics. nist.gov /xcom (Originally published as NBSIR 87-3597"XCOM: Photon Cross Sections on a Personal Computer").

[2] Gemstone Treatments Heating and Irradiation Article by A.M. Zagoritis GG 4th November 2011, Lapigems Gem company (1974).

[3] Vipan Kumar, Kulwinder Singh Mann, S. R. Manohara, Gurdeep Singh Sidhu Investigations on some low Z alkali minerals as gamma ray shields, International Journal of Latest Research in Science and Technology ISSN (Online):2278-5299,Vol.1,Issue 4 :Page No.324-333 ,November-December (2012)

[4] Shivraj G. Gounhalli, Anil Shantappa, S. M. Hanagodimath, Studies on mass attenuation coefficient, effective atomic numbers and electron densities of some narcotic drugs in the energy range 1KeV - 100GeV. IOSR Journal of Applied Physics (IOSR-JAP) ISSN: 2278-4861. Volume 2, Issue 4 (Nov. - Dec. 2012), PP 40-48.

[5] Shivalinge Gowda, S Krishna veni, T Yashoda, T Kashoda, T K Umesh and Ramakrishna Gowda. Photon mass attenuation coefficients, effective atomic numbers and electron densities of some thermoluminescent dosimetric compounds. PRAMANA,Indian Academy of Sciences Vol. 63, No. 3 journal of physics, September 2004, pp. 529-541.

[6] N Singh , K.J Singh, K Singh and H Singh, Comparative Study of Lead Borate and Bismuth Lead Borate Glass Systems as Gamma-Radiation Shielding Materials, Nuclear Instruments and Methods in Physics Research, Section B ,225,2004, 305-309.

[7] S Singh, A Kumar, D Singh, K Singh and G.S. Mudahar, Barium-Borate-Flyash Glasses:As Radiation Shielding Materials, Nuclear Instruments and Methods in Physics Research, Section B ,226 ,2008,140-146.

[8] P. Limkitjaroenporn, J. Kaewkhao, W. Chewpraditkul and P. Limsuwan, Mass Attenuation Coefficient and Effective Atomic Number of Ag/Cu/Zn Alloy at Different Photon Energy by Compton Scattering Technique, Procedia Engineering, 32, 2012, 847 – 854.

[9] K Singh ,H Singh ,V Sharma , R Nathuram ,A Khanna ,R Kumar , S.S Bhatti and H.S Sahota, Gamma-Ray Attenuation Coefficients in Bismuth Borate Glasses, Nuclear Instruments and Methods in Physics Research, Section B, 194, 2002, 1-6.

[10] S.Gupta and G.S. Sidhu, Measurement of total and partial mass attenuation coefficients of oxide glasses: A radiation field, International Journal of Modern Engineering Research (IJMER) ISSN: 2249-6645, Vol. 3, Issue. 6, Nov - Dec. 2013 , pp-3830-3835.

[11] Vishwanath P. Singh and N.M. Badiger A Comprehensive study on gamma-ray exposure build-up factors and fast neutron removal cross sections of fly-ash bricks. Journal of Ceramics Volume 2013, Article ID 967264, 13 pages,

[12] P. Limkitjaroenporn, S. Tuschareon, J. Kaewkhao, J. Park, H.J. Kim. Mass attenuation coefficients and related parameters of citrine at different gamma rays energy using compton scattering technique, Science and Engineering Symposium 4th International Science, Social Science, Engineering and Energy Conference 2012, I-SEEC 2012 Proceeding - Science and Engineering (2013) 503–511.

[13] Pravina P Pawar and Govind K Bichile journal of chem..and Pharma.Research 2012, 4(1) :59-66

[14] Vandana A. Tupe , P. P. Pawar, D. R. Shengule and K. M. Jadhav, Measurements of mass and linear attenuation coefficients of γ- rays of photons for Ni in the energy range 360-1330 Kev. Journal of Chemical and Pharmaceutical Research, ISSN : 0975-7384 CODEN(USA) : JCPRC52012, 4(8):4032-4037.
[15] Chaudhari L. M. and Girase S.B. Determination of adulteration in milk samples by attenuation coefficient using nuclear technique. Archives of Applied Science Research, ISSN 0975-508 XCODEN (USA) AASRC9 2013, 5 (2):255-260.
[16] C C Ferreira, R E Ximenes , C A B Garcia, J W Vieira, A F Maia Total mass attenuation coefficient evaluation of ten materials commonly used to simulate human tissue. International Conference on Defects in Insulating Materials, IOP Publishing, Journal of Physics: Conference Series 249 (2010) 012029.
[17] Chikkappa udagani, Gamma ray attenuation study with varying moisture content of clay brick, International Journal of Engineering Science Invention ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726 www.ijesi.org Volume 2 Issue 7,July. 2013, PP.35-38.
[18] Julio Heredia Carmona, Oscar Díaz Rizo, Experimental and Monte Carlo determination of mass absorption coefficients for 90 SR/ 90 Y beta particles in organic compounds. NUCLEUS, NO. 45, 2009, pp. 26-31.
[19] A Handbook of precious stones by Rao bahadur Dr. L.A.N. Iyer, J.N. Tata professor of geology, Patna university (01-05-1947).
[20] Khairul Zaman and Haji Mohd. Dahlan, Physical Methods, Instruments and Measurements, Vol 4.
[21] Report ANSI/ANS.6.4.3. 1991, Gamma-ray Attenuation Coefficients and Buildup Factors for Engineering Materials, American Nuclear Society, La Grange Park, Illinois.