PRAMANA — journal of physics
© Indian Academy of Sciences
Vol. 67, No. 3
September 2006
pp. 501–506

Simulated mixed absorbers and effective atomic numbers for γ attenuation

K KARUNAKARAN NAIR[1], N RAMACHANDRAN[2], K K ABDULLAH[3] and K M VARIER[4,*]
[1]Department of Physics, MES College, Ponnani 679 586, India
[2]Department of Physics, MPMMSN Trust College, Shoranur 679 523, India
[3]Department of Physics, Farook College, Calicut 673 632, India
[4]Department of Physics, University of Calicut, Malappuram 673 635, India
[*]Corresponding author. E-mail: kmvarier@gmail.com

MS received 1 March 2005; revised 20 April 2006; accepted 23 June 2006

Abstract. The total γ-ray interaction crosss-sections on mixed absorbers were determined at 662 keV with a view to study the effective atomic numbers for γ-ray absorption under narrow beam good geometry set-up. The measurements were taken for the combination of metallic absorbers like aluminium, copper, lead and mercury and also for the simulated absorbers by rotating the targets. ORTEC HPGe and NaI(Tl) detectors were used for detection of γ-rays.The experimental results compare favourably with theoretical values derived from XCOM package and suggest the usefulness of the concept of effective atomic numbers and the utility of the rotating absorbers technique.

Keywords. γ-rays; γ attenuation; simulated mixed absorbers; effective atomic numbers; rotating absorber; XCOM.

PACS Nos 32.80.-t; 32.90.+a

1. Introduction

The concept of Z dependence of photon interaction has many applications in radiation studies and other fields involving radiation transport through materials. The effective atomic number has proved to be a convenient parameter for interpreting the γ-ray attenuation by a given medium. A compound or a mixture may be considered as a single element with an effective atomic number Z_{eff} given by [1]

$$Z_{\text{eff}} = \left(\sum_i f_i Z_i^{m-1} \right)^{1/(m-1)}, \tag{1}$$

where Z_i is the atomic number, index m depends on the particular interaction process being considered and f_i is the fractional content by weight of the ith element in the absorber combination, with $\sum_i f_i = 1$.

To characterize photon interactions, different effective atomic numbers have to be used for different individual processes over an extended energy range. The exponents need not only vary with energy, but also become different at a given energy as the elemental composition changes.

In view of the extensive use of the radioactive sources in medicine, agriculture, industry etc., the study of photon–atom interaction (attenuation and absorption coefficients) in different materials has gained importance in recent years. Since these interactions involve various compounds with different compositions, the effective atomic numbers $Z_{\rm eff}$ for the total and partial γ-ray interactions in compounds are equally important. A number of investigations on effective atomic numbers for total and partial photon interactions have been reported in the literature. These include both theoretical [2–11] and experimental [12–26] studies covering a wide range of γ energies from a few keV up to several GeVs. The experimental investigations have mostly concentrated on measurements of γ-ray attenuation coefficients. There have also been two studies [27,28] wherein the ratio of elastic-to-inelastic scattering has been utilized for deriving the effective atomic number for a few compounds. Various types of mixtures like metallic alloys, compounds as well as other composite materials including biological tissues, polymers, cements etc. have been subjected to similar studies.

In the present work, a different approach has been adopted for studying the effective atomic numbers. We have tried to simulate composite (mixed) absorbers of varying effective atomic numbers by combining elemental absorbers in different ratios by weight. The same have been subjected to γ-attenuation studies at 662 keV in order to derive the corresponding effective atomic number values for total photon interactions. Two different techniques have been used for obtaining the simulated composite absorbers. The details are presented in the following sections.

2. Experimental method

The 662 keV γ-rays for the measurements have been obtained from a 0.5 mCi ^{137}Cs source supplied by BARC, Mumbai. A well-defined narrow beam geometry in a vertical set-up was used for the attenuation measurements. The lead, aluminium and copper absorbers were in the form of square sheets of dimensions 5 cm $\times$ 5 cm and thickness of 0.1 mm, 1 mm and 1 mm respectively. In the case of mercury, a 5 ml glass beaker was used for keeping the liquid absorber. The absorber thickness in this case was varied by taking different volumes of the liquid in the beaker. The mercury level was measured by a precision traveling microscope. Measurements were made for various absorber thicknesses of the pure elemental absorbers and for various combinations of these absorbers. Such combinations were obtained by stacking the individual absorbers one over the other in the vertical narrow beam geometry.

Suitable numbers of absorber sheets were kept above the beaker containing the appropriate volume of mercury for making the combination of mercury with the other absorbers. It is assumed that such combinations simulate a true mixture with a uniform composition as far as γ-ray interactions are concerned.

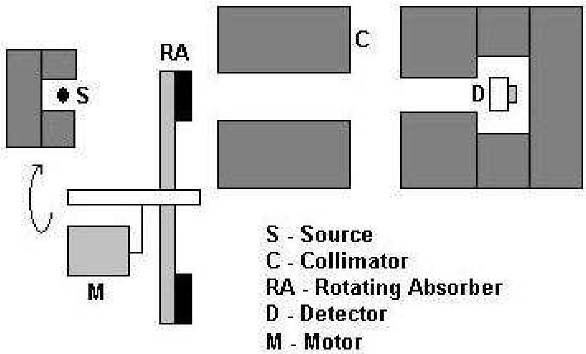

Figure 1. Schematic diagram of the experimental set-up for narrow beam geometry γ-attenuation measurements using rotating targets.

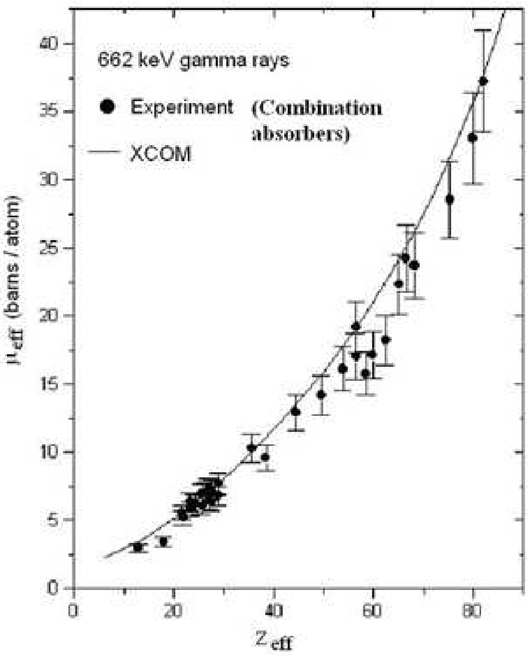

Figure 2. Variation of the total interaction cross-section vs. the effective atomic number for total interaction.

A circular disc of 20 cm diameter is fabricated using Hylum sheet for the rotating absorbers experiments, depicted in figure 1. Provision is made to fix absorbers at four positions on the disc. The arrangement to place absorbers is such that two positions are at opposite ends of the diameter. Suitable arrangements are made to fix the absorbers tightly on the disc. The disc is mounted on the shaft of a 1/8 hp AC motor such that the plane of the absorber is always perpendicular to the γ-ray beam. The speed of the motor is regulated by a UJT-controlled SCR circuit.

The control circuit is fabricated such that the speed of the motor is constant and it is monitored using an opto-electronic arrangement. The absorbers are taken in the form of sheets of 1 mm thickness each and fastened onto the disc. The disc is rotated about an axis passing through its center such that each elemental absorber comes in position between the source and the detector, one after the other, thus simulating a mixture absorber.

A 2″ × 1″ (Harshaw) NaI(Tl) detector mounted on a RCA 6810A PMT was used in some of the measurements for detecting the γ-rays transmitted through the absorbers. For the remaining part of the studies, an ORTEC HPGe detector has been used. The output of the pre-amplifier is fed to an ORTEC 571 amplifier and then to a CAMAC-based data acquisition and analysis set-up, consisting of a kinetic CAMAC crate and controller, a 4k Quad ADC supplied by Electronics Division, BARC, Mumbai, and a PC via an interface card. The data acquisition and analysis were carried out using FREEDOM software [29]. This Linux software had been developed at the Inter University Accelerator Centre, New Delhi, for online data acquisition for accelerator-based experiments using CAMAC data acquisition hardware and also for online as well as offline data analysis. It has event-by-event data recording capabilities utilizing coincident detector signals. There is provision for spectrum fitting involving Gaussian peaks (with or without tailing) and polynomial background. The software presents a very user friendly graphical user interface (GUI) which is completely menu-driven.

The attenuation coefficients have been calculated from the plot of logarithm of the transmitted intensities vs. the absorber thickness. The extracted values of the

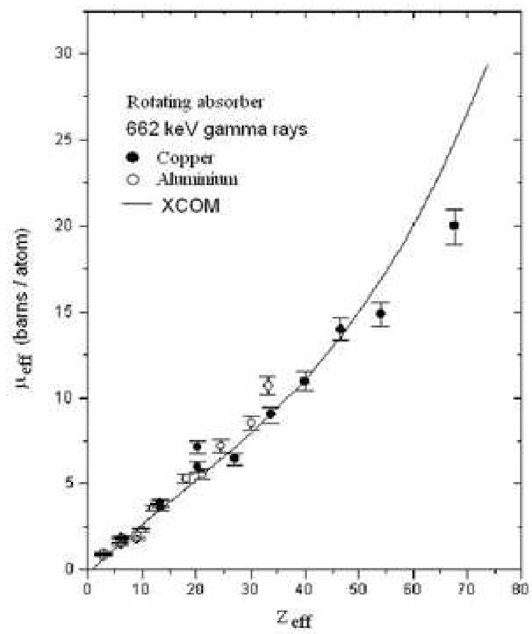

Figure 3. Photon cross-sections vs. effective atomic number using rotating targets.

attenuation coefficients in cm^2/g have been converted to effective total interaction cross-sections in barns/atom. By a similar procedure, theoretical values were extracted using the XCOM package [30,31]. This package is a computer program and data base, developed by Berger and Hubbell. It can be used to calculate theoretical photon cross-sections for scattering, photoelectric absorption and pair production, as well as total attenuation coefficients, in any element, compound, or mixture, at energies from 1 keV to 100 GeV. It utilizes a vast data base for all elements from hydrogen to fermium.

The effective atomic number of the absorber is calculated as per eq. (1).

3. Results and discussions

The experimental values for the total γ-interaction cross-sections are plotted in figure 2 for the first set of measurements by means of the solid points vs. the effective atomic number for the total interaction. Theoretical XCOM values for the mixtures are plotted as solid curves. The results with the rotating absorbers are shown separately in figure 3. There is good agreement between the experimental values and the XCOM results both for the combination absorbers as well as the rotating absorbers.

4. Conclusions

The good agreement between the present experimental results and the theoretical estimates based on XCOM suggest the usefulness of the concept of effective atomic numbers for γ-ray interaction as also the utility of the rotating absorbers technique.

References

[1] J H Hubbel, *National Bureau of Standards Report NSRDS* (1969) vol. 29

[2] Shivaramu, R Vijayakumar, L Rajasekharan and N Ramamurthy, *Radiat. Phys. Chem.* **62**, 371 (2001)

[3] N Koc and H Ozyol, *Radiat. Phys. Chem.* **59**, 339 (2000)

[4] Shivaramu and V Ramprasath, *Nucl. Instrum. Methods in Phys. Res.* **B168**, 294 (2000)

[5] S Guru Prasad, K Parthasaradhi and W D Bloomer, *Radiat. Phys. Chem.* **53**, 449 (1998)

[6] G S Bhandal and K Singh, *Appl. Radiat. Isotopes* **44**, 505 (1993)

[7] G S Bhandal and K Singh, *Appl. Radiat. Isotopes* **44**, 929 (1993)

[8] G S Bhandal and K Singh, *Appl. Radiat. Isotopes* **44**, 1231(1993)

[9] Gurmel S Mudahar, Makhan Singh and Gurbakhash Singh, *Appl. Radiat. Isotopes* **42**, 509 (1991)

[10] O Icelli, S Erzeneoglu, I H Karahan and G Cankaya, *J. Quant. Spectrosc. Radiat. Transfer* **91**, 485 (2005)

[11] S Gowda, S Krishnaveni and R Gowda, *Nucl. Instrum. Methods in Phys. Res.* **B239**, 361 (2005)

[12] S S Hiremath and G C Chikkur, *Ind. J. Pure Appl. Phys.* **31**, 855 (1993)
[13] D V Krishna Reddy, K Suresh Babu and S Chandralingam, *Can. J. Phys.* **63**, 1421 (1985)
[14] K Parthasaradhi, *Ind. J. Pure Appl. Phys.* **6**, 609 (1968)
[15] A Perumallu, A S Nageswara Rao and G Krishna Rao, *Can. J. Phys* **62**, 464 (1984)
[16] S Chandralingam, K Suresh Babu and D V Krishna Reddy, *Ind. J. Phys.* **A58**, 285 (1984)
[17] T K Kumar and K V Reddy, *Rad. Phys. Chem.* **50**, 545 (1997)
[18] C R Murthy, A S R Rao and G K Rao, *Appl. Radiat. Isotopes* **51**, 335 (1999)
[19] G S Bhandal, I Ahmed and K Singh, *Appl. Radiat. Isotopes* **43**, 1185 (1992)
[20] O Ielli and S Erzeneolu, *J. Quant. Spectrosc. Radiat. Transfer* **85**, 115 (2004)
[21] G Nayak, M G Vijaya and K Siddappa, *Radiat. Phys. Chem.* **61**, 559 (2001)
[22] S B Dagli and A F Baytas, *Radiat. Measurements* **37**, 253 (2003)
[23] K Singh, H Singh, V Sharma, R Nathuram, A Khanna, R Kumar, S S Bhatti and H S Sahota, *Nucl. Instrum. Methods in Phys. Res.* **B194**, 1 (2002)
[24] O Icelli, S Erzeneoglu, I H Karahan and G Cankaya, *J. Quant. Spectrosc. Radiat. Transfer* **91**, 485 (2005)
[25] G Kaur, K Singh, B S Lark and H S Sahota, *Radiat. Phys. Chem.* **58**, 315 (2000)
[26] K Parthasarathi, A Esposito and M Pellicioni, *Appl. Radiat. Isotopes* **43**, 1481 (1992)
[27] S Manninen, T Pitkanen, S Koikkalainen and T Paakari, *Appl. Radiat. Isotopes* **35**, 93 (1984)
[28] S Manninen and S Koikkalainen, *Appl. Radiat. Isotopes* **35**, 965 (1984)
[29] B P Ajithkumar and E T Subramanyam, *FREEDOM* – Unpublished internal report – Inter University Accelerator Centre, New Delhi, India (1995)
[30] M J Berger, J H Hubbel, S M Seltzer, J S Coursey and D S Zucker, *XCOM: Photon cross section database* (version 1.2), (Online). National Institute of Standards and Technology, Gaithersburg, MD. Available at http://physics.nist.gov/xcom (2003, April 17)
[31] M J Berger and J H Hubbel, *XCOM: Photon cross sections on a personal computer*, Program manual, Centre for Radiation Research, National Bureau of Standards MD20899 (1990)
M J Berger and J H Hubbel, *XCOM version 3.1 – NIST Standard Reference Data Base* (1999)