ISSN 0020-4412, Instruments and Experimental Techniques, 2021, Vol. 64, No. 2, pp. 318–320. © Pleiades Publishing, Ltd., 2021.

LABORATORY TECHNIQUES

A Different Method to Determine the Gamma-ray Linear Attenuation Coefficient

Elif Ebru Ermis[a,*], and Cuneyt Celiktas[b]

[a] *Izmir Tinaztepe University, Vocational School of Health Services, Medical Imaging Techniques Department, Buca, Izmir, 35400 Turkey*

[b] *Ege University, Faculty of Science, Physics Department, Bornova, Izmir, 35100 Turkey*

**e-mail: elermis@hotmail.com*

Received July 28, 2020; revised August 14, 2020; accepted August 17, 2020

Abstract—Gamma-ray linear attenuation coefficient values of Pb, Fe and Al absorber materials were investigated. A fast coincidence timing measurement spectrometer was used for this purpose differently from other traditional spectrometers. A solid point ^{22}Na positron source was utilized for the annihilation radiations. Obtained results were compared with those of XCOM program and literature values.

DOI: 10.1134/S0020441221010097

INTRODUCTION

As it is known, gamma-ray attenuation coefficient of an absorber material is a crucial parameter especially in gamma radiation shielding. For this purpose, a large number of studies for determining the gamma attenuation coefficients of various materials such as dental materials [1], glass [2–4], concrete [5] and solutions [6] etc. have been introduced in the literature.

If a monoenergetic gamma photon beam with I_0 intensity collides with a target of thickness x, the number of photons passing through the target, $I(x)$, is given by

$$I(x) = I_0 \exp(-\mu x), \quad (1)$$

where μ – is the linear attenuation coefficient of the target material. This quantity changes with the atomic number and density of the material.

Logarithm of both sides of the above equation gives

$$\ln I(x) = \ln I_0 - \mu x. \quad (2)$$

The slope of the graph of natural logarithm of the intensity versus target thickness gives the linear attenuation coefficient.

A coincidence measurement is used to detect certain types of radiation, to accept the pulses from a single type of particle, to choose the particles coming from a specific direction, and to eliminate the undesirable events. Timing coincidence means register two events simultaneously with a timing procedure out of a large group of events [7].

The objective of the presented work is to investigate and suggest a different method that can be described as fast coincidence timing method for determining gamma-ray linear attenuation coefficients of the materials differently from the traditional slow energy method [8].

MATERIALS AND METHODS

A solid point ^{22}Na source with the activity of ~5 μCi was used. It was positioned 3 cm far away from the detectors i.e. amidst of both detectors.

Two cylindrical plastic scintillation detectors that have Saint Gobain BC-420 type plastic scintillators (2 inch diameters and 2 inch heights) combined with Hamamatsu R1828-01 type photomultiplier tubes (PMTs) were utilized. The outputs of the detectors were connected to fast timing preamplifiers *P*. Their outputs were sent to constant fraction discriminators CFD through timing filter amplifiers TFA. The latter provide noise reduced and amplified signals. Positive outputs of the CFD were forwarded to universal coincidence unit *U* to generate a coincident signal for linear gate *LG* to perform its input. Fast negative outputs of the CFD were connected to time to amplitude converter *TAC* for its "start" and "stop" inputs. This device generates a timing output that is proportional to the time interval between its "start" and "stop" signals. The output of the *TAC* was sent to *LG* to trigger it via its "enabled" input. Thus, *LG* gave a coincidence output triggered by timing signals. *LG* output was finally connected to a counter which can be adjusted its recording time by a timer (Ti). The experimental setup was shown in Fig. 1.

Pb, Fe and Al absorber materials with the dimensions of 10 × 10 cm were used to determine their atten-

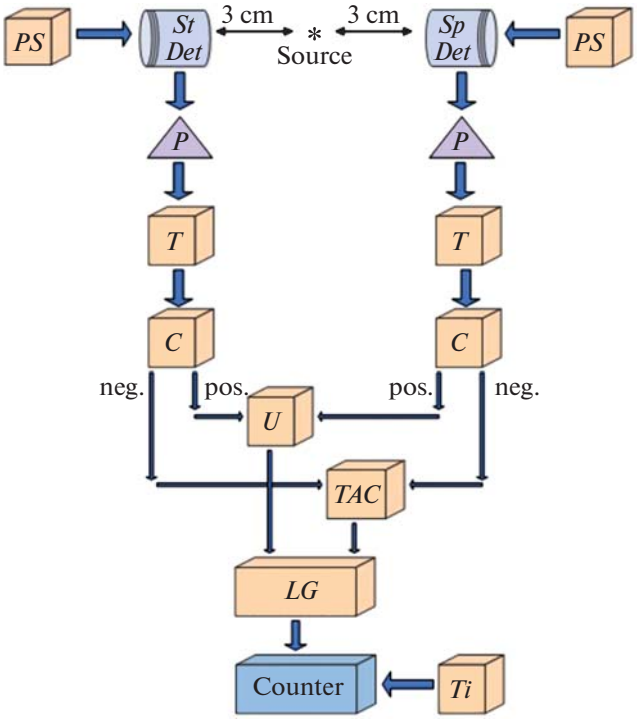


Fig. 1. Experimental setup. *PS* – power supply; *St Det* – start detector; *Sp Det* – stop detector; – preamplifier; *T* – timing filter amplifier; *C* – constant fraction discriminator; *U* – universal coincidence; *TAC* – time to amplitude converter; *LG* – linear gate; *Ti* – timer.

uation coefficients. These materials were chosen in particular to test the performance of the setup through high, middle and low density-materials.

The absorber materials in increasing thicknesses from 0 to 1 cm with the increments of 0.1 cm (i.e. each absorber has 1 mm thickness) were placed between the source and the stop detector to generate a timing output by the *TAC*. Each measurement with the acquisition time of 60 s was repeated three times for each absorber thickness. Background counts were also recorded three times in the same acquisition time and then averaged. As in the conventional method, each measurement was then subtracted from the averaged background counts. Finally, mean value of the determined attenuation coefficients for each material was calculated according to Eq. (2) and tabulated.

Constant fraction discrimination timing method was followed in the presented coincidence setup. In constant fraction timing method, the input signal to the constant fraction shaping circuitry is delayed, and a fraction of the undelayed pulse is subtracted from input signal. A bipolar timing pulse is generated, and its zero-crossing is detected and used to produce an output logic pulse [9]. Further information about the method can be found in the literature [7, 10, 11].

The timing method will ensure the detection of annihilation photons only and prevent the chance

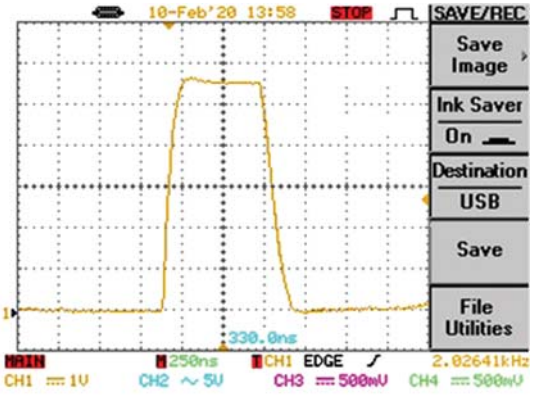


Fig. 2. *LG* output signal shape.

coincidences by this way, enhancing the detection performance. This is the main conception for the presented setup.

The signal shape of LG output can be seen in Fig. 2. The coincidence spectrum was also given in Fig. 3 when a multichannel analyzer (MCA) was connected to LG output instead of the counter. It can be stated from this figure that the presented setup succeeded in recording the coincident events only.

RESULTS AND DISCUSSION

Gamma-ray linear attenuation coefficients of materials wanted to be determined using a different method in this work. For this, unlike the traditional ones that use slow energy signals, a coincidence measurement setup which utilized from the fast timing signals was used.

Experimental coefficient values were determined from Eq. (2). In addition, these coefficient values were also calculated by XCOM [12] program for the comparison of the experimental values.

Whole results obtained from experiment and XCOM were compared with the literature values as seen in Table 1.

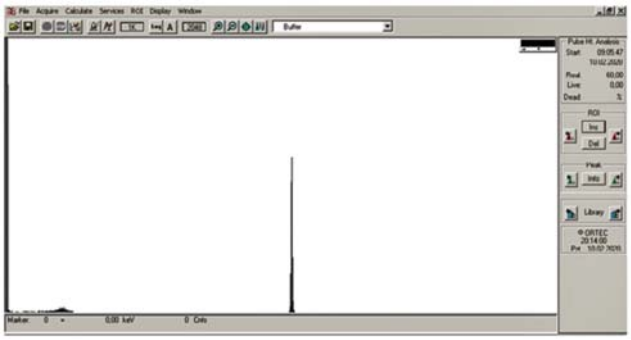


Fig. 3. MCA spectrum of *LG* output.

Table 1. Comparison of the obtained linear attenuation coefficients for 511 keV-energy gamma photons

Material	Density, g/cm^3	Linear attenuation coefficients, cm^{-1}		
		Experimental	XCOM [12]	Literature (for 500 keV) [13]
Pb	11.34	1.6376 ± 0.0081	1.6466	1.6443
Fe	7.87	0.6380 ± 0.0183	0.6422	0.6501
Al	2.70	0.2228 ± 0.0025	0.2244	0.2268

According to the obtained results in the Table, it can be concluded that the introduced timing coincidence setup was successful in determining the gamma-ray linear attenuation coefficient. The advantage of this setup, in addition, was the fact that the setup accepted only annihilation photons by discarding the any type of radiation such as background, scattered, backscattered etc. through a time of flight measurement.

Consequently, it was revealed that the gamma-ray linear attenuation coefficient of an absorber material could be determined through a different method by the presented study.

ACKNOWLEDGMENTS

This work was supported by TUBITAK, the Scientific and Technological Research Council of TURKEY under project number 116F324.

REFERENCES

1. Abbasova, N., Yüksel, Z., Abbasov, E., Gulbicim, H., and Tufan, M.C., *Results Phys.,* 2019, vol. 12, p. 2202. https://doi.org/10.1016/j.rinp.2019.02.068
2. Saeed, A., El-shazly, R.M., Elbashar, Y.H., Abou El-azm, A.M., El-Okr, M.M., Comsan, M.N.H., Osman, A.M., Abdal-monem, A.M., and El-sersy, A.R., *Radiat. Phys. Chem.,* 2014, vol. 102, p. 167. https://doi.org/10.1016/j.radphyschem.2014.04.032
3. Waly Al-Sayed, A., Fusco, M.A., and Bourham, M.A., *Ann. Nucl. Energy,* 2016, vol. 96, p. 26. https://doi.org/10.1016/j.anucene.2016.05.028
4. Al-Hadeethi, Y., Sayyed, M.I., and Tijani, S.A., *Nucl. Eng. Technol.,* 2019, vol. 51, p. 2005. https://doi.org/10.1016/j.net.2019.06.014
5. Shams, T., Eftekhar, M., and Shirani, A., *Constr. Build. Mater.,* 2018, vol. 182, p. 35. https://doi.org/10.1016/j.conbuildmat.2018.06.032
6. Chaudhari, L.M. and Teli, M.T., *Appl. Radiat. Isot.,* 1996, vol. 47, p. 365. https://doi.org/10.1016/0969-8043(95)00305-3
7. Tsoulfanidis, N., *Measurement and Detection of Radiation,* New York: Taylor & Francis, 1995.
8. Celiktas, C., *Ann. Nucl. Energy,* 2011, vol. 38, p. 2096. https://doi.org/10.1016/j.anucene.2011.05.015
9. Bedwell, M.O. and Paulus, T.J., *IEEE Trans. Nucl. Sci.,* 1979, vol. NS-26, no. 1, p. 442. https://doi.org/10.1109/TNS.1976.4328245
10. Leo, R.W., *Techniques for Nuclear and Particle Physics Experiments,* Berlin, Heidelberg: Springer, 1987.
11. Knoll, G.F., *Radiation Detection and Measurement,* New York: John Wiley and Sons, 2000.
12. National Institute of Standards and Technology (NIST). https://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html.
13. Grodstein, G.W., *X-Ray Attenuation Coefficients from 10 keV to 100 MeV, National Bureau of Standards Circular 583, AD-A278 139,* Washington, DC: National Bureau of Standards, 1957.

SPELL; OK