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Research Article

Experimental determination of the energy levels of ^{159}Gd via photonuclear reaction

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Abstract

In this study, the energy levels of ^{159}Gd are measured within the framework of the photonuclear reaction. For this aim, bremsstrahlung photons of 18 MeV endpoint energy produced by a clinical linear accelerator are used. The gamma photons emitted from the unstable ^{159}Gd nucleus are counted by using a high purity Germanium detector. The energy levels are determined with gf3 and ROOT spectrum analysis programs. The experimental results have been compared with the NUDAT database

Keywords: Photonuclear reaction; Gamma rays spectroscopy; Germanium detector.

1. Introduction

The aim of nuclear reactions is to understand properties and interactions of nuclei in the field of nuclear physics. Nuclear reactions consist of different forms such as elastic scattering, inelastic scattering, transfer reaction, breakup, photonuclear reaction. Nowadays the scope of nuclear physics studies with the advances in the technological fields has been expanded and opened the horizons to new work. In this context, photonuclear reaction has attracted attention in examining the structure of the nucleus. Photonuclear reaction is an interaction between nucleus and photon and is commonly used to measure the energy levels of nuclei which contain important information for the understanding of nuclear structure. The photonuclear reactions have been induced by a bremsstrahlung photon beam produced by a linac (Boztosun et al. 2015). The bremsstrahlung is the emission of a photon with deflection of an electron by an atomic nucleus.

Recently, the clinical linear accelerator (cLINAC) has began to play an important role in photonuclear reaction experiments and has been used to measure the energy levels of nuclei. In this way, ^{197}Au(γ,n)^{196}Au phtonuclear reaction by using a cLINAC was carried out by Mohr et al. (2007). They reported that the cLINAC is a perfect photon source in photonuclear experiments. Afterwards, to measure the subsequent transition energies and half-lives of zinc isotopes, Boztosun et al. (2014; 2015) have used the cLINAC. They expressed that the cLINACs need to apply for different nuclei when considered the number of the cLINACs which are increasing every passing day. With this goal, in the present study, we choose ^{159}Gd radionuclide to study the energy levels with the aid of the cLINAC.

Gd is founded as compound (salt) form in nature (Muljadi 2011). As seen from Fig. 1, Gd has seven stable isotopes. These isotopes are ^{152}Gd (0.205%), ^{154}Gd (2.23%), ^{155}Gd (15.10%), ^{156}Gd (20.60%), ^{157}Gd (15.70%), ^{158}Gd (24.50%) and ^{160}Gd (21.60%) (Abdullaeva et al. 2015). It has a high neutron absorption and ^{155}Gd and ^{157}Gd isotopes have the greatest neutron capture cross sections (Abdullaeva et al. 2015).

Figure 1. Ground and isomeric state information for Gd (NUDAT).

Therefore, it is used as protection material from the radiation in neutron radiography and nuclear reactors. ^{159}Gd isotope has been used in nuclear medicine research. Soares et al. (2010) showed that the ^{159}Gd radionuclide can be considered as a potential antitumor radionuclide. ^{159}Gd nucleus, $J^{\pi} = 3/2^{-}$, is an isotope of Gd element. The half life of ^{159}Gd is 18.59 h (Soares et al. 2010) and it is known as a radionuclide decays a beta and gamma (Moralles et al. 1995). The main energy for gamma state is 363.54 keV. Moreover, different studies on ^{159}Gd can be found in literature (Granja et al. 2004; Cantone et al. 2000; Reich 2012).

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In this work, our aim is to determine the energy levels of ^{159}Gd product nucleus formed with photonuclear reaction performed by using a photon beam of 18 MeV end point energy produced from a clinical linear accelerator. With this goal, we measure experimentally the energy levels of ^{159}Gd nucleus. Then, we compare our results with NUDAT database which is obtained from Nuclear Data Sheets (NUDAT).

In the next section, we give the experimental details. In Section 3, the result and discussions of the experiment are presented. Section 4 is devoted to summary and conclusions.

2. Experimental Details

The irradiation of sample in the present experiment has been carried out by using the cLINAC available at the Akdeniz University Nuclear Sciences Application and Research Center. The cLINAC is a standard and up-to-date Elekta TM Synergy TM accelerator (Elekta Digital Accelerator 2003). It can be evaluated as a source of photons. The obtained bremsstrahlung photons are collimated and flattened with several filters, resulting in a uniform forward focused photon beam. The cLINAC used in the experiment is shown in Fig. 2.

Figure 2. Philips SLI-25 clinical linear electron accelerator of Elekta TM Synergy TM.

For the experimental process, Gd element has been placed 58 cm away from the tungsten converter. In Fig. 3, this event is presented. Photonuclear reaction has been conducted with sufficient energy bremsstrahlung photons obtained by using the cLINAC.

The irradiation time of the sample is about 35 min. Then, the sample was placed into the detector established at the Physics Department of Akdeniz University. The detector used in this work is a high-purity germanium detector (HPGe). It is a p-type, coaxial, electrically cooled HPGe detector, placed in a well-shielded cavity. The shield is 10 cm thick lead with an inner surface covered by a 2mm copper foil to reduce the Pb X-rays generated in the Pb shielding. The HPGe detector used is a gamma-ray spectrometer from AMETEK-ORTEC (GEM40P4-83) with 40% relative efficiency and resolution of 768 eV FWHM at 122 keV for ^{57}Co source and 1.85 keV FWHM at 1332 keV for ^{60}Co source (Maestro 2012).

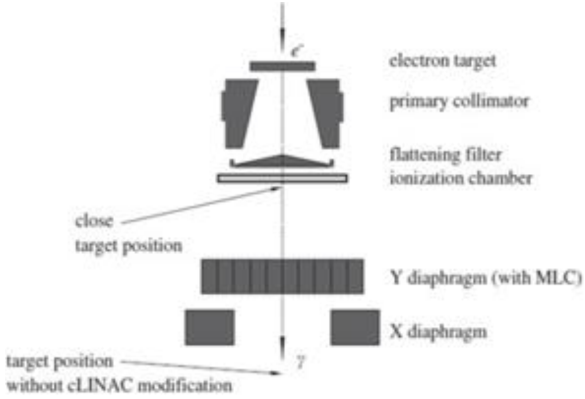

Figure 3. The schematic view of the photon beam production for the cLINAC used in the present experiment (Boztosun et al. 2014).

It is connected to a set of Nuclear Instrumentation Modules consisting of ORTEC preamplifier, bias supply, spectroscopy amplifier, analog-todigital converter and a computer. Data acquisition has been carried out with MAESTRO32 software. During the counting, spectra have been automatically recorded at regular time intervals.

3. Result and Discussions

In the present study, the experimental data of ^{159}Gd nucleus at bremsstrahlung end point energy of 18 MeV were acquired by using HPGe detector system. The spectrum analysis was carried out using the gf3 Radware gamma spectroscopy software (Radford 2000). In Table 1, all the gamma energy levels of ^{159}Gd were listed with the error values which consist of statistical and systematic errors. Statistical error represents uncertainty in photopic position and energy calibration. Systematic error arises from the difference between before and after the calibration due to the slip occurring in the channels during the experiment. While systematic error is dominant especially for strong several peaks, in many cases statistical error is dominant. Details regarding the calculation procedure of the measurement errors can be found in Boztosun et al. (2015). The fit of 363.535 keV energy as an example of spectrum has been shown in Fig. 4.

Table 1. Gamma-ray energies obtained in the decay of ^{159}Gd in comparison with NUDAT.

Element	Product Nucleus	Our results (keV)	Error values of our results	NUDAT (keV)	Error values of NUDAT
		210.730	0.021	210.783	0.003
		226.044	0.008	226.0406	0.0018
		237.263	0.041	237.341	0.005
		290.244	0.011	290.2865	0.0025
		348.256	0.010	348.2807	0.0018
Gd	^{159}Gd	363.535	0.010	363.5430	0.0018
		536.761	0.056	536.78	0.18
		580.753	0.015	580.808	0.006
		617.479	0.018	617.615	0.008
		854.822	0.044	854.947	0.020

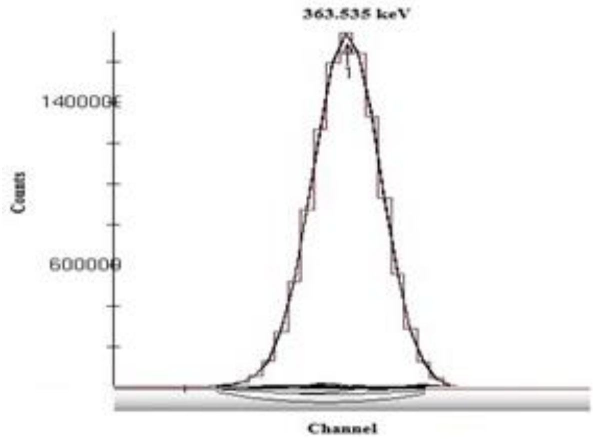

Figure 4. Gamma-ray spectrum of 363.535 keV energy of photonuclear reaction performed by using bremsstrahlung photons of 18 MeV endpoint energy.

We have measured ten different transitions of ^{159}Gd. When compared NUDAT database developed by the National Nuclear Data Center (NNDC) in Brookhaven National Laboratory, a harmony between our energies and the literature has been obtained. Generally, it has been observed that the error values of NUDAT are smaller than the error values of our results. However, it has been seen that our error value for 536.761 keV are slightly smaller than NUDAT database.

4. Summary and Conclusions

The experimental study was undertaken to measure energy levels of ^{159}Gd radionuclide. With this goal, a photonuclear reaction with a Gd element has been performed via the bremsstrahlung photons with an endpoint energy of 18 MeV sufficiently energetic. Thus, energy transitions of ^{159}Gd have been measured. The results have shown a good agreement with NUDAT database. In addition to this, it has been observed that our error value for 536.761 keV are slightly better than NUDAT database.

Finally, we should state that the experiment performed under this work is the study of the convenience of a medical linac as distinct from the previous studies. We think that to see the potentials of clinical linacs in the analysis of different nuclei would be very interesting and useful for both the experimental and theoretical nuclear physics when the clinical linacs increasing with each passing day in developing countries have been considered.

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