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HALF-LIVES OF ^{47}Sc ISOTOPE FROM PHOTONUCLEAR REACTIONS

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Abstract. *In order to understand atomic nuclei, photonuclear reaction is an important tool. Photons are used to induce the reactions. The use of bremsstrahlung photons generated from a medical linear accelerator is practical for performing these types of reactions. In this study, the 18 MeV endpoint energy bremsstrahlung photons have been used for activating a titanium target. By analyzing the gamma spectrum, the half-life of the* ^{47}*Sc isotope has been determined to be 3.5626 days. The result is very close to the present literature values of 3.3492 days.*

Key words: *Photonuclear reaction, clinic linac, bremsstrahlung, titanium, half-life*

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1. Introduction

Photon-induced nuclear reactions are referred to as photonuclear reactions. These reactions have a great importance in nuclear physics [1-4]. After bombarding the target with high-energy photons, the excited target nucleus decays by emitting nucleons or photons. If the particle being emitted is a neutron (proton), the reaction is a photo-neutron (proton) reaction. Judging from the Q-value of the reaction, a two-neutron (proton) emission, alpha emission, the emission of more particles or the emission of combinations of particles is also possible. Experimental studies on these reactions began in 1934 [5]. The advantages of photonuclear reactions include simultaneous determination of multiple elements, no time-consuming chemical separation procedure, minimal (if any) destruction of the sample, and excellent penetrating power of the photons into the sample [6]. The photonuclear data can be used in nuclear physics for the determination of nucleon binding energy, identification of nuclear levels and nuclear deformations. These data are also important for dosimetry, calculation of the absorbed dose, radiation protection, designing radiation shielding, and activation analyses, including archaeological and forensic science, material analysis, medical science, environmental science, geological science, and meteoroid analysis [7-11]. Also, there are numerous examples of using photonuclear reactions to determine half-lives of certain isotopes [12-26].

2. Experiment

Irradiation and residual activity measurement are the two steps in the experiment. The Elekta TM Synergy TM medical linear accelerator of Akdeniz University Research and Application Center in Turkey has been used for the activation of the titanium target. The primary electron beam generated by a gun with 50 keV energy is accelerated into a copper cavity by 3 GHz radio frequency with about 5MW peak power. The average electron current was about 30 μA at 18 MeV electron energy. The electrons in the beam hitting the tungsten target are stopped and bremsstrahlung photons are produced.

The natural titanium target consists of a mixture of five stable isotopes ^{46}Ti, ^{47}Ti, ^{48}Ti, ^{49}Ti and ^{50}Ti with 8.25%, 7.44%, 73.72%, 5.41% and 5.18% natural abundances, respectively (Table 1). The target was placed 58 cm away from the source. It was bombarded with bremsstrahlung photons with 18 MeV endpoint energy. The irradiation time was 1 hour. The neutron separation energies for ^{46}Ti, ^{47}Ti, ^{48}Ti, ^{49}Ti and ^{50}Ti isotopes are about 13.2, 8.9, 11.6, 8.1 and 10.9 MeV, respectively. The proton separation energies are 10.3, 10.5, 11.5, 11.4 and 12.2 MeV, respectively. Because of the sufficient activation energies from the photons, both the photoneutron reaction (γ,n) and the photoproton reaction (γ,p) are possible. Two-neutron or proton separation reactions are not possible since the energy values exceed the 18 MeV maximum energy.

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Table 1. Abundance and separation energy information for Ti isotopes

Isotope	Natural abundance (%)	Neutron separation energy (MeV)	Proton separation energy (MeV)
^{46}Ti	8.25	13.2	10.3
^{47}Ti	7.44	8.9	10.5
^{48}Ti	73.72	11.6	11.5
^{49}Ti	5.41	8.1	11.4
^{50}Ti	5.18	10.9	12.2

The total counting time was about 74.3 hours. An HPGe (AMATEK-ORTEC (GEM40P4-83)) p-type coaxial detector with electrical cooling system was used for the measurement. The relative efficiency of the detector was 40%. The FWHM values were 0.77 keV for 122 keV of ^{57}Co and 1.85 keV for 1332 keV of ^{60}Co. The detector system was connected to the bias supply, an amplifier, an ADC (analog-to-digital converter) and a computer. The detector was placed into a 10 cm thick lead shield. The inner surface of the shield was covered by a 2 mm thick copper foil in order to protect the detector from X-rays arising in lead. The standard calibration sources (Na-22, Mn-54, Ba-133, Cs-137, Co-57 and Co-60) were used for the energy calibration of the detector. The analyses were performed offline. The gamma-ray spectrum obtained after irradiation is shown in Fig.1.

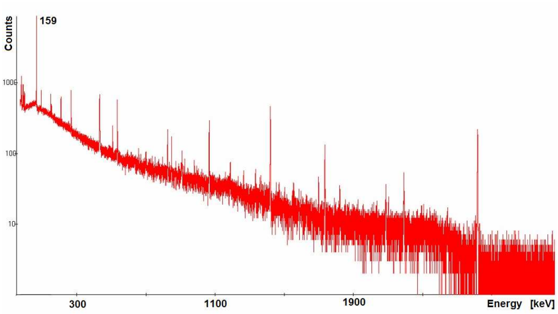

Figure 1. Gamma spectrum of photonuclear reaction performed on titanium target

3. Results and Discussion

Analyses were done to determine the half-lives of the products by using the RadWare package [27]. After the activation of the target, the ^{47}Sc isotope was generated by photoproton reaction shown as:

$$^{48}Ti + \gamma \longrightarrow {}^{47}Sc + p$$
$$^{47}Sc \longrightarrow {}^{47}Ti^{*} + e + \upsilon \qquad (1)$$
$$^{47}Ti^{*} \longrightarrow {}^{47}Ti + \gamma$$

The stable ^{48}Ti isotopes in the target absorb bremsstrahlung photons and emit protons producing unstable ^{47}Sc, which, in turn, beta decays into ^{47}Ti. With the biggest probability (I=68.4%), ^{47}Sc nucleus goes to the first excited level (7/2-) of ^{47}Ti nucleus. ^{47}Sc can also transition directly into the ground state (5/2-) of ^{47}Ti with I=31.6%. The 159.4 keV energy peak arising from 7/2- to 5/2- transition in ^{47}Ti nucleus was analyzed. The peak net area was measured for 74.3 hours in order to extract the half-life information of the parent nucleus. The standard exponential decay equation was used for fitting the experimental data (see Fig.2) and finding the half-life of ^{47}Sc:

$$N(t)=N_0\,(1-e^{-\lambda t}) \qquad (2)$$

Here, N_0 is the limiting maximum number of counts achieved after a sufficiently long time, λ is the decay constant, t is time and N is the counts in the peak at a given time. The unknown parameter is λ to obtain half-life information. According to the fit results, N_0 and λ values are obtained as 98157.2965 (273.917) and 2.2519×10^{-6} (7.51×10^{-9}) s^{-1} with errors in parenthesis, respectively. By using the formula $T1/2=ln2/\lambda$, the half-life value of 3.5626 (9) days was determined for ^{47}Sc. The adopted literature value is 3.3492(6) days [28]. The change in the 159 keV peak counts is shown in Fig.2.

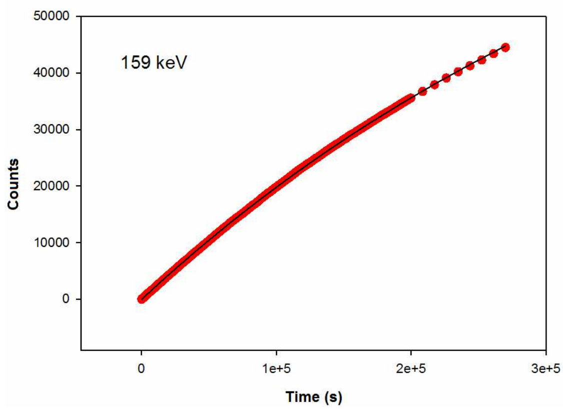

Figure 2. The growth curve obtained from 159 keV peak

4. Conclusion

The half-life of the ^{47}Sc isotope was determined from the decay of the stable ^{47}Ti isotope created after a photonuclear reaction with bremsstrahlung photons. The growth curve of ^{47}Sc was fitted by using the standard exponential decay equation. The half-life of the ^{47}Sc isotope has been determined as 3.5626 days. The result is close to the present literature values of 3.3492 days. The aim was not only to obtain a more sensitive and accurate half-life value, but also to show the usefulness of the method and equipment in the determination of the half-lives of the isotopes.

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REFERENCES

1. C. Segebade, H.P. Weise and G.J. Lutz, *Photon Activation Analysis*, Berlin, Germany: Walter de Gruyter and Co., 1987
2. K. Strauch, "Recent Studies of Photonuclear Reactions," *Ann. Rev. Nucl. Sci.*, vol. 2, pp. 105-128, Dec. 1953
3. *IAEA-TECDOC-1178, Handbook on Photonuclear Data for Applications Cross-Sections and Spectra*, Nuclear Data Section, IAEA, Vienna, Austria, 2000.
4. M. Schumacher, "Photonuclear reactions," *J. Phys. G: Nucl. Phys.*, vol. 14, Suppl., pp. S235-S255, Dec. 1988
5. J. Chadwick and M. Goldhaber, "A Nuclear Photoeffect: Disintegration of the Diplon by –Rays," *Nature*, vol. 134, pp. 237-238, Aug., 1934
6. J. Green, S. Zaijing, D. Wells and H. Maschner, "Using Photon Activation Analysis to Determine Concentrations of Unknown Components in Reference Materials," in *Proceed. AIP*, vol. 1336, 2011, pp. 497-501
7. Y.O. Lee, T. Fukahori and J. Chang, *J. Nucl. Sci. Tech.*, Evaluation of Photonuclear Reaction Data on Tantalum-181 up to 140MeV," vol. 35, no. 10, pp. 685-691, 1998
8. Z.J. Sun, D.P. Wells, C. Segebade, H. Maschner and B. Benson, "A Provenance Study of Coffee by Photon Activation Analysis," *J. Radioanal Nucl. Chem.*, vol. 296, no. 1, pp. 293-299, Apr. 2013
9. K. Wagner, W. Gorner, M. Hedrich, P. Jost and C. Segebade, "Analysis of Chlorine and Other Halogens by Activation with Photons and Neutrons," *Fresen. J. Anal. Chem.*, vol. 362, no. 4, pp. 382-386, Oct, 1998
10. M.S. Johnson et al., "Applications of Photonuclear Physics for International Safeguards and Security," *Int. Conf. Nucl. Data Sci. Tech.*, Jeju Island, South Korea, Apr.2010, pp. 1-4
11. Z. Randa, J. Kucera, J. Mizera and J. Frana, *J. Radioanal. Nucl. Chem.*, "Comparison of the Role of Photon and Neutron Activation Analyses for Elemental Characterization of Geological, Biological and Environmental Materials," vol. 271, no. 3, pp. 589-596, Mar. 2007
12. F.D. Schupp, C.B. Colvin and D.S. Martin Jr., "Photonuclear Reactions of Gallium and Arsenic with 70-Mev Bremsstrahlung," *Phys. Rev.*, vol. 113, no. 4, pp. 1095-1098, 1959
13. I. Boztosun, et al., "The Results of the First Photonuclear Reaction Performed in Turkey: The Zinc Example," *Turk. J. Phy.*, vol. 38, pp. 1-9, 2014
14. K. Lindenberg et al., *Phys. Rev. C*, Half-Lives of Au, Hg, and Pb Isotopes from Photoactivation," vol. 63, no. 4, 2001
15. W.L. Bendel, J. McElhinney and R.A. Tobin, "Photoneutron Reactions in N, O, F, Cu, Ag, and In," *Phys. Rev.*, vol. 111, no. 5, pp. 1297-1302, Sep. 1958
16. Y. Oka, T. Kato and N. Sato, "The Yields of Photonuclear Reactions in Titanium and Vanadium with Bremsstrahlung up to 60 MeV," *B. Chem. Soc. Jap.*, vol. 42, no. 2, pp. 387-393, 1969
17. Y. Oka, T. Kato, K. Nomura and T. Saito, "Gamma-Ray Spectrometric Study of the Photoactivation Products with 20 MeV Bremsstrahlung," *J. Nucl. Sci. Tech.*, vol. 4, no. 7, pp. 346-352, 1967
18. M.J. Berger and S.M. Seltzer, "Bremsstrahlung and Photoneutrons from Thick Tungsten and Tantalum Targets," *Phys. Rev. C,* vol. 2, no. 2, pp. 621-631, 1970
19. S.S. Belyshev, et al., "Studying Photonuclear Reactions Using the Activation Technique," *Nucl. Instrum. Meth. A*, vol. 745, pp. 133-137, May 2014
20. F. Dulger, S. Akkoyun, T. Bayram, H. Dapo and I. Boztosun, "Energy Levels and Half-Lives of Gallium Isotopes Obtained by Photo-Nuclear Reaction," *J. Phys: Conf. Ser.*, vol. 590, no. 1, 2015
21. P. Mohr, S. Brieger, G. Witucki and M. Maetz, "Photoactivation at a Clinical LINAC: The ^{197}Au(γ, n) ^{196}Au Reaction Slightly Above Threshold," *Nucl. Instrum. Meth. A*, vol. 580, pp. 1201-1208, 2007
22. M. Tatari, A.H. Ranjbar, "Design of a Photoneutron Source Based on 10 Mev Electrons of Radiotherapy Linac," *Ann. Nucl. Ener.*, vol. 63, pp. 69-74, Jan. 2014
23. M. Roig, V. Panettieri, M. Ginjaume and A. Sanchez-Reyes, "Photonuclear Isotope Characterization of a Siemens KDS 18 MV Linac Head," *Phys. Med. Biol.*, vol. 49, no. 14, pp. N243-N246, June 2004
24. J.H. Chao, et al., "Using Medical Accelerators and Photon Activation to Determine Sr/Ca Concentration Ratios in Teeth," *Appl. Radiat. Isot.*, vol. 67, no.6, pp. 1121-1126, June 2009
25. T. Fujibuchi, et al., "Estimate of Photonuclear Reaction in a Medical Linear Accelerator Using a Water-Equivalent Phantom," *Prog. Nucl. Sci. Tech.*, vol. 2, pp. 803-807, 2011
26. A. Alfuraih, M.P.W. Chin and N.M. Spyrou, "Measurements of the Photonuclear Neutron Yield of 15 MV Medical Linear Accelerator," *J. Radioan. Nucl. Chem.*, vol. 278, no. 3, pp. 681-684, Dec. 2008
27. I. Boztosun et al., "Photonuclear Reactions with Zinc: A Case for Clinical Linacs," *Eur. Physical J. Plus*, vol. 130, pp. 185-195, Sep. 2015
28. ORNL, Oak Ridge (TN), USA, *RadWare*. Retrieved from: http://radware.phy.ornl.gov/
29. T. W. Burrows, "Nuclear Data Sheets for A = 47," *Nucl. Data Sh.*, vol. 108, no. 5, pp. 923-1056, May 2007