New Physics: Sae Mulli, DOI: 10.3938/NPSM.65.1252
Vol. 65, No. 12, December 2015, pp. 1252∼1257

A Study on a Method for Measuring the Alpha Emitters from ^{242}Cm in Neutron Capture Reactions of ^{241}Am

Liu Dong · Jong-Kwan Woo*
Medical Physics Laboratory, Department of Physics, Jeju National University, Jeju 63243, Korea

Seoktae Koh
Department of Physics Education, Jeju National University, Jeju 63243, Korea

Se Byeong Lee
Proton Therapy Center, National Cancer Center, Goyang 10408, Korea

(Received 17 September 2015 : revised 20 October 2015 : accepted 20 October 2015)

The reaction rate of neutron capture reaction of ^{241}Am can be evaluated through measurements of the alpha (α) particles from ^{242}Cm. However, alpha spectrometry requires the adjustment of samples into a chemically-isolated form to prevent or reduce interferences due to α emitted by multiple α-emitting nuclides. To avoid the need for a complex chemical separation process, we propose a new method for detecting the α emitted from ^{242}Cm. In this method, a filter device is employed to absorb the α emitted from ^{241}Am and its products, but not the α emitted by ^{242}Cm. In order to determine the thickness of the filter, we used a Monte Carlo program to calculate the penetration depths of the α particles of interest and of unrelated α particles for various thicknesses of the filter. The calculation results suggested that a 25.75 μm thick aluminum absorber is an ideal filter. With this filter, the α's emitted from ^{242}Cm can be measured by using ordinary detectors, and the accuracy of measurement made by using high-resolution semiconductor detectors can be increased.

PACS numbers: 95.30.Jx, 29.25.-t, 96.25.Tg
Keywords: Neutron capture reactions rate, α emitter, Monte Carlo method

I. INTRODUCTION

As we know, the reaction rate of neutron capture reaction of ^{241}Am can be evaluate using accurate neutron capture cross sections in conjunction with the flux of neutron. However, the data of the neutron capture cross section of ^{241}Am from different reported measurements are conflicting and the discrepancies between the various data reported recently reach 20∼30% [1]. This suggested that a directly measurement method is necessary to obtain the accurate reaction rate of neutron capture reaction of ^{241}Am.

Fig. 1 shows the partial section of decay path of ^{241}Am under thermal neutron irradiation. From Fig. 1, it can be seen that ^{241}Am creates ^{242}Am in 90% branching ratio and ^{242m}Am in 10% branching ratio by thermal neutron capture (In the case of the fast neutron capture, the branching ratios are 85 % for ^{242}Am and 15% for ^{242m}Am) [2]. ^{242}Am with a half-life 16 hours, has two decay models: β^- decay that leads to ^{242}Cm (82.7% branching ratio) and electron capture which lead to ^{242}Pu (17.3% branching ratio). ^{242}Cm decays with a half-life of 160 days to ^{238}Pu with an alpha (α) emission. Considering the decay models, half-life and the emitters of the radionuclide, the α particles from the ^{242}Cm are ideal emitters that used to evaluate the reaction rate of ^{241}Am.

*E-mail: w00jk@jejunu.ac.kr

During alpha spectrometry measurement the energy of some alpha particle on any physical medium between radionuclide and detector is absorbed. To reduce the effect, which causes characteristic asymmetry in the alpha peak, the samples should be counted in a vacuum and they must be as thin as possible to avoid the self-absorption. In addition, a more concern is that α particle from the decay of ^{241}Am and some produced nuclides would affect the measurement of objective α particles. In regard to this, to minimize interferences between multiple alpha emitting nuclides, the interest alpha emitting nuclide ^{242}Cm must be chemically separated before analysis. The chemical separation used to isolate the nuclide of interest usually include coprecipitation, liquid-liquid extraction, ion exchange, and extraction chromatography. In some cases, two or more of these methods are combined. In order to account for the inevitable loss of the sample during separation, a known quantity of a specific isotope or tracer-radiochemical yield determinant is added to the sample [3]. Therefore, in order to measure the alpha emitters from ^{242}Cm, the complex chemical separation is necessary and the measurement results mainly depend on the separation of nuclides.

In regard to this, a new detection method of the α emitter from ^{242}Cm is proposed in this study. In this method, a filter device in a detector is employed to absorb the α emitters from ^{241}Am and its products except from ^{242}Cm. By using this method, the unrelated α particles could be absorbed. Therefore, the α particles emitted from ^{242}Cm could be measured using low resolution detectors without any chemical separation process.

II. METHOD

1. Principle

From the Fig. 1, it can be seen there are three nuclides with an extra-long half life: ^{237}Np, ^{242}Pu and ^{234}U. The decay properties of above three nuclides are summarized in Table 1. It can be seen that α particles are emitted during the decay processes of these nuclide. However, these nuclides have an extra-long halt life, and the energy of α emitters from these nuclides is much lower than the energy of α emitters from ^{242}Cm. Therefore the α emitters from these 3 nuclides and their products (daughter nuclides) could not lead to the significant effects to the measurement of α emitters from ^{242}Cm. Therefore we do not consider the α emitters from these nuclides in this study.

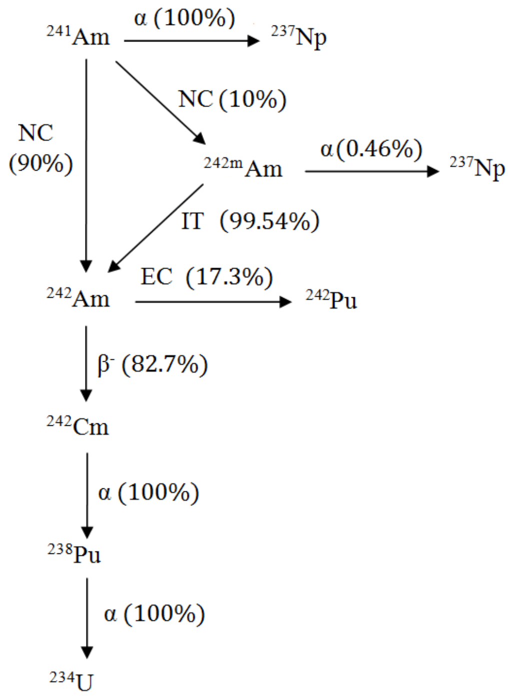

Fig. 1. The partial section of decay path of ^{241}Am under thermal neutron irradiation.

Except above three nuclides, the α particles emitted by other nuclides are able to affect the measurement result of α emitter from the decay of ^{242}Cm. These nuclides include: ^{241}Am, ^{242m}Am and ^{238}Pu. The summary of decay properties of these nuclides and ^{242}Cm with their half-life, Branching Ratio of α Decay, and Energy of α particle are shown in Table 2.

Undergo the irradiation of neutrons, the activity of ^{241}Am in irradiated materials is much higher than the activity of ^{242}Cm, ^{242m}Am and ^{238}Pu due to the low product rate of ^{242}Cm, ^{242m}Am, and ^{238}Pu, especially in the case of low neutron flux. Therefore, in the view of activity (flux of α emitters), it can be seen that the α emitter with energy of 5.486 MeV from the decay of ^{241}Am may lead to the primarily effects to the measurement of the α particles from the decay of ^{242}Cm. In addition, form energy perspective, the α emitters with energy of 5.499 MeV from ^{238}Pu is the most similar to α emitters with energy of 6.069 MeV from the decay of

Table 1. The nuclides with α emitters and an extra-long half-life in decay path of ^{241}Am undergo the neutron irradiation [4,5].

Nuclide	Half-Life	Branching Ratio of α Decay	Energy of α Particle (MeV)
^{237}Np	2.14×10^6a	100%	4.788 (47.6%) 4.774 (18.1%) 4.769 (14.4%)
^{242}Pu	3.76×10^5a	100%	4.902 (76.5%) 4.856 (23.5%)
^{234}U	2.14×10^5a	100%	4.773 (71.4%) 4.723 (22.4%)

Table 2. The Nuclides with α emitters and a modest half-life in decay path of ^{241}Am undergo the neutron irradiation [4,5].

Nuclide	Half-Life	Branching Ratio of α Decay	Energy of α Particle (MeV)
^{241}Am	432.2 a	100%	5.486 (85.1%) 5.443 (13.3%) 5.388 (1.0%)
^{242m}Am	152 a	0.46%	5.408 (0.01%) 5.205 (0.4%) 5.140 (0.03%)
^{242}Cm	163 d	100%	6.112 (74.1%) 6.069 (25.9%)
^{238}Pu	87.7 a	100%	5.499 (70.91%) 5.456 (28.98%)

^{242}Cm. Because the α emitters with energy of 5.499 MeV from ^{238}Pu is higher than the α emitters with energy of 5.486 MeV from the decay of ^{241}Am, the 5.449 MeV is selected as the highest energy point of the unrelated α emitters. Therefore, if the α emitters with energy of 5.499 MeV can be absorbed by a filter, then the other unrelated α emitters cannot penetrate the filter.

Fig. 2 shows the absorption principle of filter. The α emitters from the decay of ^{242}Cm may penetrate the filter and would be detected by a detector. The α emitters with energy lower of equal to 5.449 MeV from decay process of other nuclides could not penetrate the filter and would be absorbed by the filter.

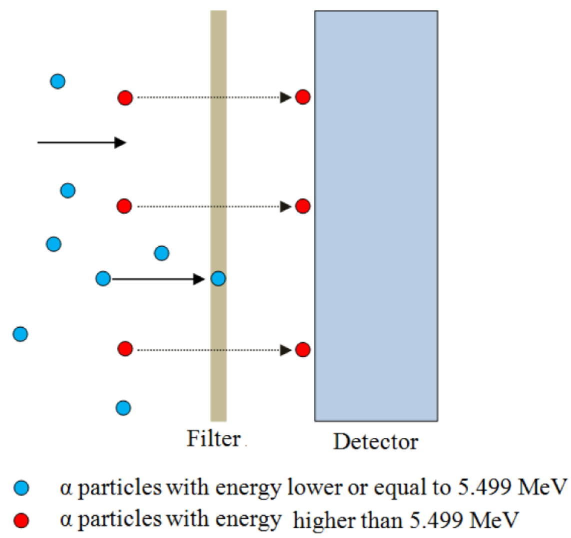

Fig. 2. (Color online) The schematic diagram for the filter used to absorb the unrelated α emitters.

2. The Determine of Thickness of Filter

Considering the short range of α particles in matter, in this design, the filter is processed into the foil and thereby metal materials are the more suitable than non-metal materials due to their physical properties. Moreover, the metal materials with lower atomic number are demonstrated that may lead to less secondary radiation. There are two reasons. First, the nuclei of lighter elements contain fewer neutrons, so a few secondary neutrons can be created during interaction process. Second,

Table 3. The penetration rates of α particles with two typical energy in corresponding aluminum absorber.

	Number of Incident Ions	Number of Penetrated Ion	Penetration Rate
5.486 MeV α Particles in 24.54 μm Absorber	100000	60745	60.75%
5.499 MeV α Particles in 24.54 μm Absorber	100000	72415	72.42%
6.069 MeV α Particles in 28.30 μm Absorber	100000	78888	78.89%
6.112 MeV α Particles in 28.30 μm Absorber	100000	95601	95.60%

the nuclei of light elements have a smaller nuclear charge, the interaction between α particles and materials product less photons from bremsstrahlung and less secondary electrons due to pair production [6]. Therefore, in this study, the aluminum is employed as the absorbed materials of filter.

In order to accurately measure the reaction rate of neutron capture reaction of ^{241}Am. The unrelated α emitters should be absorbed by the filter completely and the α emitters from the decay of ^{242}Cm could penetrate the filter and be detected by detector as much as possible. This means the thickness of absorber materials should be longer than the range of the unrelated α particles and shorter than the range of α particles from the decay of ^{242}Cm. Therefore the thickness of the aluminum absorber in the filter is the key of this measurement method.

In this study, the range of α particle in a aluminum absorber is calculated using the Stopping and Range of Ion in Matter (SRIM) program. SRIM is a Monte Carlo program used to simulate the interaction of ions and matter. It includes two modules: Stopping and Rang (SR) and Transport of Ions in Matter (TRIM). SR can be used to produce tables of stopping powers, range and straggling distributions for any ion at any energy in any elemental target. TRIM is a comprehensive Monte Carlo program used to simulate the interaction of ions and matter which accept complex targets made of compound materials with up to eight layers, each of different materials and calculate both the final 3D distribution of the ions and also all kinetic phenomena associated with the energy loss of the ions.

By using SR code, it can be calculated that the mean projected ranges for α particles with energy of 5.499 MeV and 6.069 MeV are about 24.54 μm and 28.30 μm respectively. However above projected ranges are mean range, in another word, some α particles with energy of

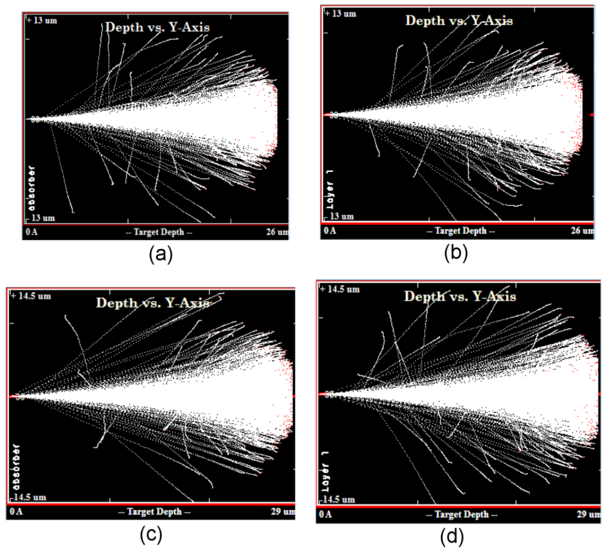

Fig. 3. (Color online) Interaction schematic diagram about the α particles and aluminum absorber plotted using TRIM code. (a) 5.499 MeV α particles into 24.54 μm Aluminum, (b) 5.485 MeV α particles into 24.54 μm Aluminum Absorber Absorber, 6.069 MeV α particles into 28.30 μm Aluminum Absorber, and (d) 6.112 MeV α particles into 28.30 μm Aluminum Absorber.

5.499 MeV may penetrate the aluminum absorber with the thickness of 24.54 μm. Also, the α particles with energy of 6.069 MeV may be absorbed by the aluminum absorber with thickness of 28.30 μm. To confirm above conclusion, the penetration rate (number of penetrated ion / number of incident ions) of α particles with energy of 5.499 MeV and 5.486 MeV in the aluminum absorber with thickness of 25.54 μm as well as the penetration rate of α particles with energy 6.069 MeV and 6.112 MeV in aluminum absorber with thickness of 28.30 μm are calculated using TRIM code. Fig. 3 shows the schematic diagram of the interaction of α particles and aluminum absorber plotted by TRIM. The simulation results about penetration rates from TRIM calculation are summarized in Table 3.

From Table 3, it can be seen that in the case of 24.5 μm absorber, the penetration rate of 5.486 MeV α par-

Table 4. The penetration rate of α particles with 5.499 MeV in aluminum absorber with various thickness (The number of incident ion in simulation is 100000).

Thickness of Al Absorber (μm)	Penetration Rate
24.54	72.42%
24.75	41.20%
25.00	10.14%
25.25	1.01%
25.50	0.40%
25.75	0.00%

ticles is 60.75% and the penetration rate of 5.499 MeV α particles is 72.42%. This means that a large amount of α particles may penetrate the absorber and affect the detection results of α emitters from the decay of ^{242}Cm. In the case of 28.3 μm absorber,the penetration rate of 6.069 MeV α particles is 78.89%, the penetration rate of 6.112 MeV α particles is 95.60%, in another word, many α emitters from the decay of ^{242}Cm cannot penetrate the absorber and be detected by detector. In order to get the ideal measurement results, we want the penetration rate of α particles with 5.499 MeV and 5.486 MeV in aluminum absorber is null and the penetration rate of α particles with 6.069 MeV and 6.112 MeV in aluminum absorber is 100%. Therefore, the simulation results suggested that the suitable thickness should be thicker than 24.5 μm and thinner than 28.3 μm is necessary. For this reason, we calculated the penetration rates of α particles with 5.499 MeV and α particles with 6.069 MeV into aluminum absorber with various thickness using TRIM code.

III. RESULTS AND DISCUSSION

Table 4 shows the simulation results about the penetration rate of α particles with 5.499 MeV in aluminum absorber with various thickness. From Table 4, it can be seen that when the thickness of aluminum absorber reach to 25.74 μm, the penetration rate of incident α particles is null, that means no α particles with energy equal to or lower than 5.499 MeV could penetrate the absorber.

Table 5 shows the simulation results about the penetration rate of α particles with 6.069 MeV in aluminum absorber with various thickness. The results suggested that the penetration rate of α particles reach to 99.21% when the thickness of aluminum absorber is equal to 27.50 μm. With the reduction of thickness, the penetration rate is increase. When the thickness is 25.75 μm, the penetration rate is hit 99.83%. Considering the straggling effects of range, the penetration rate for large amount of particles is impossible to reach to 100%, and the penetration rate of incident α particles in 5.499 MeV is null in the case of 25.75 μm. Therefore, it can be concluded that the 25.75 μm is the ideal thickness for absorber.

Table 5. The penetration rate of α particles with 6.069 MeV in aluminum absorber with various thickness (The number of incident ion in simulation is 100000).

Thickness of Al Absorber (μm)	Penetration Rate
28.30	78.89%
28.00	96.02%
27.75	98.59%
27.50	99.21%
27.25	99.51%
27.00	99.59%
26.75	99.68%
26.50	99.73%
26.25	99.75%
26.00	99.81%
25.75	99.83%

To confirm the justification of the absorber with the thickness in 25.75 μm, the penetration rate of α particles with 4.486 MeV and 6.11 MeV are calculated. The simulation results suggested that in the case of aluminum absorber with 25.75 μm, the penetration rate of α particles with 4.486 MeV is also null while the penetration rate of α particles of 6.11 MeV is 99. 88%. Therefore, it confirmed that the 25.75 μm is an appropriate thickness to aluminum absorber.

IV. CONCLUSION

In this study, we proposed a method to measure the accurate reaction rate of neutron capture reaction of ^{241}Am through measure the α particles emitted from the decay of ^{242}Cm without chemical separation process of multiple alpha emitting nuclides. In this method, a filter device is employed in a detector to absorb the α emitters from ^{241}Am and its products but except ^{242}Cm. In order to determine the thickness of the absorber in the filter, the TRIM code is used to calculate the penetration rate objective α particles and unrelated α particles in various thicknesses aluminum filter. The calculation results suggested that 25.75 μm aluminum absorber is an ideal thickness. By using this absorber, the penetration rates of unrelated α particles is null while the penetration rates of two kinds of α particles from ^{242}Cm are 99.83% and 99.88%, respectively. Through using this filter, even though without the chemical separation processing of alpha emitting elements, the measurement of α particles emitted from ^{242}Cm could be measured using a cheap ordinary detector without high resolution. For high resolution semiconductor detectors, the distraction from unrelated α emitter will be eliminated and the measurement results thus will be more accurate.

ACKNOWLEDGEMENTS

This work was supported by the research grant of the Jeju National University in 2012.

REFERENCES

[1] S. Nakamura, M. Ohta, H. Harada, T. Fujii and H. Yamana, J. Nucl. Sci. Technol. **44**, 12 (2007).

[2] V. Berthou, C. Degueldre and J. Magill, J. Nucl. Mater. **320**, 1 (2003).

[3] L. M. L. Nollet and F. Toldra, *Handbook of Food Analysis, Third Edition - Two Volume Set* (CRC Press, Boca Raton, 2015), p. 407.

[4] Laboratoire National Henri Becquerel, http://www.nucleide.org/DDEP_WG/DDEPdata.htm (accessed July. 19, 2015).

[5] National Nuclear Data Center-Brookhaven National Laboratory, http://www.nndc.bnl.gov/nudat2/ (accessed July. 18, 2015).

[6] J. H. Adams Jr., D. H. Hathaway, R. N. Grugel, J. W. Watts and T. A. Parnell, NASA/TM-2005-213688, 2005.