Nuclear Instruments and Methods in Physics Research B 266 (2008) 4855–4861

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Thermal neutron capture cross sections for the $^{152}Sm(n,\gamma)^{153}Sm$ and $^{154}Sm(n,\gamma)^{155}Sm$ reactions at 0.0536 eV energy

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ARTICLE INFO

Article history:
Received 21 June 2008
Received in revised form 23 July 2008
Available online 8 August 2008

Keywords:
Thermal neutron
0.0536 eV energy
Cross section
Sm_2O_3
Activation technique

ABSTRACT

The neutron capture cross sections for the $^{152}Sm(n,\gamma)^{153}Sm$ and $^{154}Sm(n,\gamma)^{155}Sm$ reactions at 0.0536 eV neutron energy were measured using an activation technique based on the TRIGA Mark-II research reactor, relative to the reference reaction $^{197}Au(n,\gamma)^{198}Au$. The activity was measured nondestructively using gamma-ray spectroscopy. Our measured values at this neutron energy are the first ones and are compared with $1/v$ based evaluated cross sections reported in the ENDF/B-VII and JENDL-3.3 libraries. The measured value for the $^{152}Sm(n,\gamma)^{153}Sm$ reaction is 0.28% lower than JENDL-3.3 and 0.48% higher than ENDF/B-VII. Our value for the production of ^{155}Sm is about 3% and 2.3% higher than the evaluated value with ENDF/B-VII and JENDL-3.3 at 0.0536 eV, respectively.

1. Introduction

Samarium is a rare earth element with great importance as (i) a neutron absorber (^{149}Sm and ^{152}Sm) in nuclear reactors and a component in nuclear reactor control rods and (ii) in nuclear medicine for therapeutic purposes. The ^{153}Sm radioisotope is a β^- emitting radioisotope used for tumor therapy and bone pain palliation due to its high local beta dose per disintegration and suitable half-life (46.5 h). This radionuclide is produced via the $^{152}Sm(n,\gamma)^{153}Sm$ reaction in a nuclear reactor. Additionally, ^{153}Sm has recently been used in insect ecology (insect behavior such as dispersal) as an ingested marker and detected using neutron activation analysis (NAA) because the high detection sensitivity [1]. Knowledge of the thermal neutron cross section of the $^{152}Sm(n,\gamma)^{153}Sm$ reaction is important because the neutron activation cross section data are used in the production of ^{153}Sm and may also be used in other studies related to the interaction of neutrons with matter.

Various energies of neutrons are available in a reactor. The energy dependence of the capture cross section must be known for proper estimation of radioactivity, radiation safety etc. The available libraries evaluate cross sections using $\sigma = \text{const.} \times 1/v$ law and a cross section at 0.0253 eV. The neutron capture cross section at other energies other than the average energy 0.0253 eV in the thermal region is useful to check data evaluation libraries.

Accurate measurements of neutron capture cross sections for most nuclides are currently necessary for the calculations of neutron transport, assessments of reactor safety, investigations of high-burn-up core characteristics, decay heat power predictions and for nuclear transmutation studies. However, the present status of experimental data for neutron capture cross sections is still inadequate both in quality and in quantity. Therefore, it is important to perform precise measurements of capture cross sections for those nuclides.

Few authors have reported thermal neutron capture cross sections on ^{152}Sm and ^{154}Sm at a neutron energy of 0.0253 eV and large discrepancies are present among them. In these references, mixed neutron beams of thermal and epithermal energies were used for activation [2–9]. They corrected the activity due to the epithermal neutrons by the Cd cut-off energy technique, which is very complex and includes large uncertainty in the measured cross section.

Recently, we have opened a new arena by utilizing the radial piercing beam port of the TRIGA Mark-II research reactor for determination of neutron capture cross sections at a rare energy (0.0536 eV) in the thermal region using the NAA technique. The present work was undertaken to measure thermal neutron capture cross section of the $^{152}Sm(n,\gamma)^{153}Sm$ and $^{154}Sm(n,\gamma)^{155}Sm$ reactions at 0.0536 eV as a part of systematic studies on metals [10,11]. The measured values were compared with $1/v$ based evaluated cross sections reported in the ENDF/B-VII [12] and JENDL-3.3 [13] libraries. The values obtained will be useful to estimate

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doi:10.1016/j.nimb.2008.07.032

activity, optimization of medical isotope production and to check the model calculation and data evaluation.

2. Experimental techniques

2.1. Neutron source

The TRIGA reactor has four external neutron beam tubes, namely tangential, radial piercing, radial-1 and radial-2 beam ports. Neutrons from the radial piercing beam port are used for neutron activation. The neutrons coming out of the reactor are of various wavelengths. They are monochromatized before sending them to the target for irradiation. In order to obtain appropriate monochromatic beam characteristics, a mosaic monochromator in combination with soller collimators was used. The soller collimator has a strong impact on the resolution and the intensity of the primary beam.

Monochromatization can effectively be done by Bragg reflection from a Cu(200) monochromator using a suitable single crystal. The plane of Cu(200) single crystal ($5 \times 15 \times 1.2$ cm^3) was inclined in a position that a neutron beam of single wavelength $\lambda = 1.236$ Å was obtained, which corresponds to 0.0536 eV neutron energy. We have calculated the error on this neutron energy amounts to 0.5% (0.00026 eV).

A schematic cross sectional view of the arrangement for the monochromatization of reactor neutrons and the experimental set-up are shown in Fig. 1. The reactor neutrons (mixed energies) from the piercing radial beam port pass through a collimator with sufficient shielding to the monochromator, which is also surrounded with enough shielding as shown in Fig. 1. The monochromatic neutrons are reflected through a solar collimator (internal area: 5×5 cm^2) and then pass through another collimator (internal area: 1.6×5 cm^2) and finally hit the target. The polybron shielding ($50 \times 50 \times 20$ cm^3) with a hole of 1.6×5 cm^2 at the center position, which is the second collimator after monochromatization, was setup at the end of the solar collimator to reduce the neutron background level at the sample position and the observed background level was around 150 n cm^{-2} s^{-1}. It should be mentioned that the distance between the monochromator and the target sample was 141 cm.

2.2. Sample preparation

A powder sample of samarium oxide (Sm_2O_3; 99.99% purity) was used as a samarium target of natural isotopic composition. In nature, samarium occurs as seven isotopes, three of which are radioactive with extremely long half-lives. The isotopes and their natural occurrences are ^{144}Sm (3.1%), ^{147}Sm (15%), ^{148}Sm (11%), ^{149}Sm (14%), ^{150}Sm (7.4%), ^{152}Sm (27%) and ^{154}Sm (23%). The three naturally occurring radioactive isotopes and their half-lives are ^{147}Sm (110 billion years), ^{148}Sm (8000 trillion years) and ^{149}Sm (10,000 trillion years). Their extremely long half-lives make these three radioactive isotopes essentially indistinguishable from the stable (nonradioactive) isotopes.

The Sm_2O_3 powder was pressed with a pressure of 5 ton/cm^2 using a hydraulic press to prepare a pellet of 0.82 g with a diameter of 1.2 cm and thickness 0.16 cm. The pellet was sandwiched with two pure gold foils (25 μm thick and 8 mm diameter) for irradiation. Gold foils were used to measure the effective neutron flux using the ^{197}Au(n,γ)^{198}Au monitor reaction. Two gold foils of approximately same size and weight were attached at the front and back of the pellet to determine the neutron beam attenuation along the target.

2.3. Sample irradiation

The pellet was irradiated with a monoenergetic (0.0536 eV) collimated (1.6×5 cm^2) neutron beam of 1.85×10^5 n cm^{-2} s^{-1} for 2 h at the outer end position of the last collimator. It should be mentioned that the irradiation time of 2 h was selected by considering the maximum saturation activity of the short-lived radionuclide ^{155}Sm at the present experimental conditions. A cadmium-covered gold foil and bare aluminum foil was also irradiated to check the presence of epithermal and fast neutrons, respectively. No peaks were found for ^{198}Au and ^{24}Na [^{27}Al(n,α)^{24}Na] in the gamma-ray spectrum for the irradiated Cd-covered gold and bare

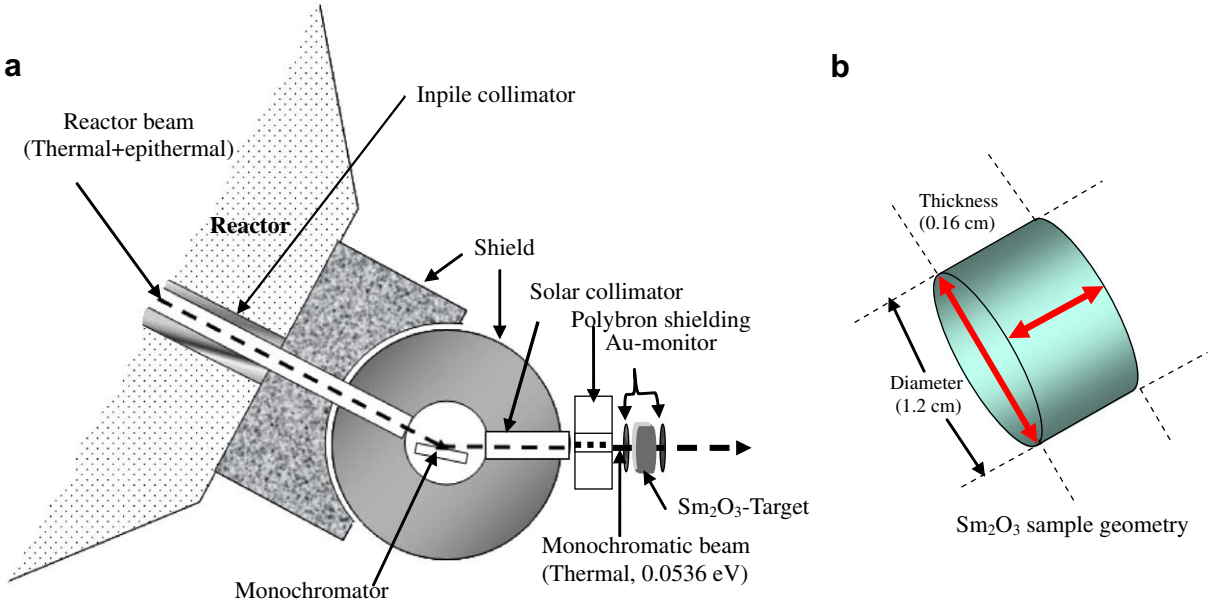

Fig. 1. Schematic view of monochromatic system and experimental arrangement for irradiation: (a) Cu(200) single crystal-$5 \times 15 \times 1.2$ cm^3; inner size of solar collimator-5×5 cm^2; inner size of second/final collimator (polybron shielding)-1.6×5 cm^2; distance between monochromator and the target sample is 141 cm and (b) sample geometry.