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Measurement of relative intensity of the discrete γ rays from the thermal neutron capture reaction ^{155,157}Gd(n,γ) using ANNRI detector (JPARC)

PRETAM KUMAR DAS *
Department of Physics, Okayama University, Okayama, 700-8530, Japan
E-mail: pretam.das86@s.okayama-u.ac.jp

K. HAGIWARA[1], **T. TANAKA**[1], **Y. YAMADA**[1], **I. OU**[1], **M.S. REEN**[1], **T. YANO**[3], **T. MORI**[1], **T. KAYANO**[1], **R. DHIR**[1], **Y. KOSHIO**[1], **M. SAKUDA**[1], **A. KIMURA**[2], **N. IWAMOTO**[2], **S. NAKAMURA**[2] **and H. HARADA**[2]
[1]*Department of Physics, Okayama University, Okayama, 700-8530, Japan*
[2]*Japan Atomic Energy Agency, 2-4 Shirakata Shirane, Tokai, Naka, Ibaraki 319-1195, Japan*
[3]*Department of Physics, Kobe University, Kobe.*

Abstract: We have measured the discrete γ rays from thermal neutron capture on enriched gadolinium targets (^{155}Gd and ^{157}Gd) using the ANNRI Germanium Spectrometer at JPARC. The photo-peak efficiencies were calibrated from 0.2 to 9 MeV using γ rays from the standard radioactive sources (^{60}Co, ^{152}Eu) and prompt γ rays from ^{35}Cl(n,γ) reaction. We have calculated the relative intensities of discrete γ rays from ^{157}Gd(n,γ) reaction. We found that our data are in fair agreement with the values published by NNDC (CapGam). We present the relative intensities of discrete γ rays from ^{155}Gd(n,γ) reaction measured for the first time.

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1. Introduction

We study the discrete γ rays produced from thermal neutron capture on gadolinium isotopes (^{155}Gd and ^{157}Gd). The experiment was performed using the Accurate Neutron Nucleus Reaction Measurement Instrument (ANNRI) Germanium spectromrter at JPARC-MLF. Gd is one of the rare nuclei which has a resonance in the thermal energy region in the neutron capture reaction. The resonance energy is 26.8 meV for ^{155}Gd and 31.4 meV for ^{157}Gd [1]. Gd has the largest thermal neutron capture cross-section among all the stable nuclei (60900 barns for ^{155}Gd and 254000 barns for ^{157}Gd) [1]. Gd(n,γ) reaction is used for neutron tagging to identify anti-electron neutrinos [2]. Recently, the Super Kamiokande (SK) is developing a Gd-loaded water Cherenkov detector "SK-Gd" for detection of anti-electron neutrinos ($\overline{\nu_e}$) [2, 3]. In that method, anti-electron neutrinos ($\overline{\nu_e}$) can be identified by coincidence of a prompt positron signal and a delayed γ-ray signal from the neutron capture on Gd. In this work, we present the measurements of the relative intensities of discrete γ rays from ^{157}Gd(n,γ) and ^{155}Gd(n,γ) reactions.

2. Experiment

The experiment (2014B0124) was conducted in December, 2014, using ANNRI detector [4]. The ANNRI detector is located at the beamline No.4 (BL04) in Material and Life Science Experimental Facility (MLF) [5]. The details of the ANNRI detector can be found elsewhere [4, 6]. The experimental conditions of the neutron beam and the detector were already explained elsewhere [6, 7]. For each detected γ-ray event, the pulse amplitude and the time interval between the trigger time (T) and each crystal hit (14 in total) are stored in the disk, only when at least one crystal has pulse height greater than 100 keV and none of surrounding BGO counters have pulse height greater than 100 keV. We used two kinds of enriched gadolinium oxide powder ($^{155}Gd_2O_3$ and $^{157}Gd_2O_3$). The isotopic composition of the targets is given in Table 1. The ANNRI detector was calibrated

Table 1: Isotopic composition of the targets

Material (Natural Abundance)	Isotopic composition (%)						
	^{152}Gd (0.2%)	^{154}Gd (2.18%)	^{155}Gd (14.8%)	^{156}Gd (20.5%)	^{157}Gd (15.7%)	^{158}Gd (24.8%)	^{160}Gd (21.9%)
$^{155}Gd_2O_3$	<0.02	0.50	91.90($\pm$0.3)	5.87	0.81	0.65	0.27
$^{157}Gd_2O_3$	<0.01	0.05	0.30	1.63	88.4($\pm$0.2)	9.02	0.60

using two radioactive sources (^{60}Co, ^{152}Eu) and prompt γ rays from ^{35}Cl(n,γ) reaction. We took data with target holder only to measure the background spectrum.

3. Analysis and Results

We analyzed the events with the neutron energy in the thermal energy between 4 meV and 100 meV, which is estimated by the time-of-flight (TOF) method [6]. The photo-peak efficiency was estimated from 0.2 to 9 MeV using γ rays from the standard radio-active sources (^{60}Co, ^{152}Eu) and prompt γ rays from ^{35}Cl(n,γ) reaction and it was compared with the Geant4 [8, 9] Monte Carlo (MC) simulation. The photo-peak efficiency of one Ge crystal from 0.2 MeV to 9 MeV is shown in Figure 1. It agrees with MC simulation within $\pm$7% accuracy.

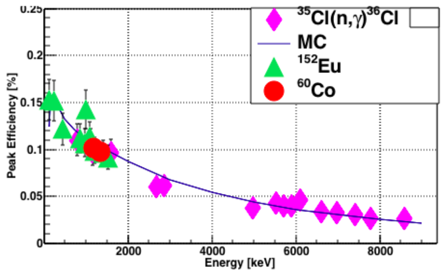

Figure 1: Photo-peak efficiency

We analyse only the relatively intense and isolated (discrete) γ-ray peaks. Single γ-ray spectrum from ^{155}Gd(n,γ) and ^{157}Gd(n,γ) reactions are shown in Figure 2 and Figure 3. Single γ-ray events are those in which only one Ge crystal is hit in an event. The peak area was evaluated by the summation of counts in the energy interval $[E_c - 3\sigma, E_c + 3\sigma]$, where E_c is the energy of the peak center and σ is the standard deviation of the γ-ray peak.

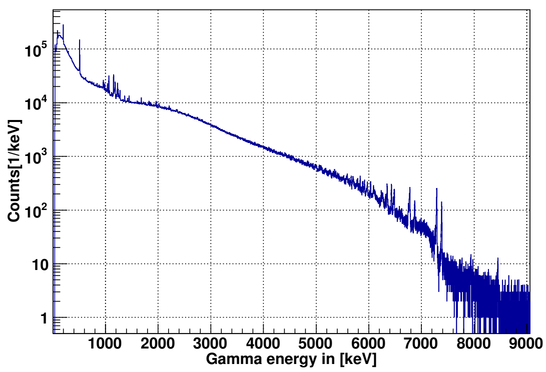

Figure 2: Single γ-ray spectrum from ^{155}Gd(n,γ) reaction

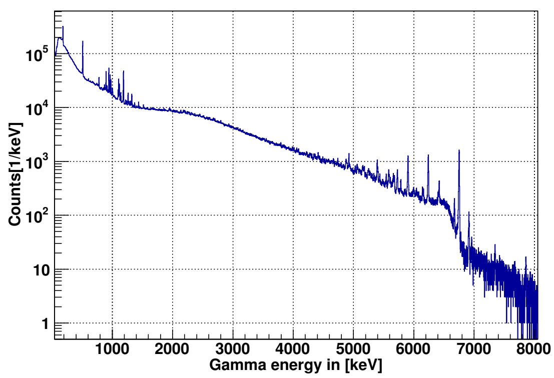

Figure 3: Single γ-ray spectrum from ^{157}Gd(n,γ) reaction

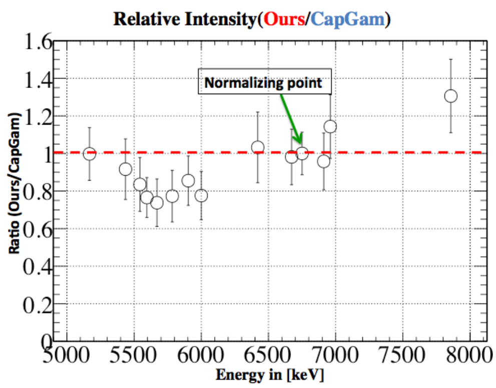

Figure 4: Ratio of relative intensities of prompt γ rays (Ours/CapGam) for ^{157}Gd(n,γ)

The ratio of the relative intensities of prompt γ rays for our ^{157}Gd(n,γ) data to those of NNDC (CapGam) values is plotted in Figure 4. New measurements of the relative intensities of discrete γ

rays from ^{155}Gd(n,γ) reaction are listed in Table 2. The value of the relative intensity is normalized to that of the 199-keV γ ray. The uncertainties in the table are statistical only.

Table 2: Relative Intensity of γ rays from ^{155}Gd(n,γ) reaction

Peak Energy (keV)	Relative Intensity, I_R (%)	Peak Energy (keV)	Relative Intensity , I_R (%)	Peak Energy (keV)	Relative Intensity , I_R (%)
199	100.00±0.275	1156	41.12±0.19	5660	1.20±0.08
296	6.24±0.17	1186	18.17 ±0.16	5836	0.72±0.06
625	3.38±0.13	1230	10.61±0.13	5918	0.79±0.07
780	3.16±0.15	1277	7.22 ±0.12	6034	1.46±0.08
840	3.36±0.13	1366	4.94±0.14	6348	2.19±0.07
897	1.61±0.14	1420	2.53±0.13	6429	2.54±0.08
959	7.54±0.13	1449	4.84 ±0.14	6481	1.43±0.08
969	5.70±0.12	1604	1.58±0.11	6870	0.75±0.05
988	5.06±0.12	1681	5.43 ±0.13	7288	3.54±0.08
1009	2.44±0.13	1962	6.97±0.15	7382	1.8±0.06
1039	11.38±0.15	2211	3.42± 0.15	8448	0.13±0.02
1065	23.59±0.15	5348	1.25± 0.084		

4. Summary

The relative intensities of the discrete γ rays from ^{155}Gd(n,γ) and ^{157}Gd(n,γ) reactions were measured with good accuracy. The photo-peak efficiency from 0.2 MeV to 9 MeV is understood well within $\pm 7\%$ accuracy. The comparison of the relative intensities of prompt γ rays for our ^{157}Gd(n,γ) data to those of NNDC (CapGam) values is found in good agreement. The relative intensities of discrete γ rays from ^{155}Gd(n,γ) have been measured for the first time. We plan to evaluate the systematic error in the relative intensity measurement due to the overlap of two γ rays in one crystal.

5. Acknowledgment

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