



High-resolution Measurements of Gamma-rays from Thermal-neutron Capture by ^{151}Eu and ^{153}Eu

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journal or publication title	CYRIC annual report
volume	2007
page range	1-5
year	2007
URL	http://hdl.handle.net/10097/44374

I. 1. High-Resolution Measurements of Gamma-Rays from Thermal-Neutron Capture by ^{151}Eu and ^{153}Eu

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Abstract: To accumulate the data for estimate activation of concrete in the nuclear power plant by neutrons, the cross-section for thermal-neutron capture by ^{151}Eu and ^{153}Eu is discussed. Europium oxide powder in natural abundance and enriched samples are irradiated by thermal neutrons from the 12-MeV AVF cyclotron together with Sc, Co and Au samples. The latter have been used to determine the neutron flux used, by their known neutron capture rates.

Introduction

The law of “clearance level” was enacted in 2007 as a part of the regulation law of nuclear plants, in order to exclude wastes, coming from e.g. nuclear power plant, from the regulation for radiation safety management when the radiation is smaller than “clearance level”. The radiation of concrete that composes a big part of the building structure of the nuclear installation is examined, and approved it’s radiation level by measurements and calculations, comparing these results with the clearance levels for each radioactive nuclide listed in the law.

The radiation levels of wastes are planned to determine by measurements. However, estimations by calculation are also applied when appropriate measurements are inaccessible. As such for the effective and safety enforcement of the law. Accumulation of the database of thermal-neutron capture-rate¹⁾ is essential as well as development of accurate and steady measurement-systems for low-level radiations.

For evaluation of radiation level of concrete by calculation, important radioactive nuclides are ^{152}Eu and ^{154}Eu , the half-life for which are, respectively, 13.542 and 8.593 y, formed by thermal neutron capture by ^{151}Eu and ^{153}Eu with larger capture cross-sections over several thousand barns. Note that an amount of ~several-ppm Europium is involved

in a soil. As illustrated in Figs. 1 and 2, amount of radioactive ^{152}Eu is known by measuring 1085.8-, 121.7825- and 344.3-keV γ -rays, while that of ^{154}Eu is done by the 123.07-keV γ -ray. As such, high-resolution γ -ray spectroscopy is required. Especially, resolving the two γ -rays with $E_\gamma = 121.7825$ and 123.07-keV is essential, indeed, and makes it possible to reduce the capture-cross section ratio $\sigma(^{153}\text{Eu})/\sigma(^{151}\text{Eu})$ by the Eu sample with natural abundance.

As illustrated in above photograph, activation by thermal neutrons has been carried out by those from an AVF cyclotron used for RI-production for PET works at Cyclotron and Radioisotope Center, Tohoku University.

Several samples, as listed in Table 1, have been simultaneously irradiated in order to estimate the neutron flux, since thermal neutron capture rates are much well known for these nuclides than those for $^{151,153}\text{Eu}(n,g)$. The neutron flux thus obtained by Au-experiments is estimated to be in the order of 10^4 (n/s.cm²). By several-days irradiation at the HM-12 compact cyclotron, 10 Bq/g radioactive Eu has been produced.

Gamma ray measurement

Gamma rays from activated samples have been analyzed with high-resolution HPGe detector in low-background surroundings with the iron shield-box made of RI-free steel sheet, used in battleship “MUTSU” over 60-years ago as illustrated in Fig. 4. Figure 5 shows the simple electric diagram for the gamma ray analyzing system. An sample of gamma ray analysis are illustrated in Fig. 6, together with the results of peak identification. Almost all prominent peaks, so far reported²⁻⁴⁾, have been found in Fig. 6.

Results

Typical gamma ray spectrum from the Eu sample is illustrated in Fig. 6. Since the residual nucleus ^{152}Eu , formed by the $^{151}\text{Eu}(n, g)^{152}\text{Eu}$ reaction, has short-lived isomer, the half-life of which is 9.274 hours, this spectrum was measured on a day 2-weeks after irradiation. In the present study, separated measurement of 121.7825-MeV gamma ray in ^{152}Sm from that of 123.07-keV gamma ray in ^{154}Gd , corresponding ~ 600 eV-resolution for gamma ray detection, is needed as mentioned previously. The reason for such high-resolution measurement is as following. As illustrated in Fig. 2, activation of ^{152}Eu is estimated by the 123.07-keV transition strength in ^{154}Eu . The capture rate of the $^{153}\text{Eu}(n, g)^{154}\text{Eu}$ is, however, almost two order of magnitudes as small as that of $^{151}\text{Eu}(n, g)^{152}\text{Eu}$ capture rate. Therefore, separated measurement of the capture rate for the $^{153}\text{Eu}(n, g)^{154}\text{Eu}$ reaction is inaccessible by poor resolution measurement even with the enriched ^{153}Eu target

in a several % enrichment. In the present study, high resolution measurements have been carried out with the low-background condition. A sample of the gamma ray spectrum is illustrated in Fig. 7, showing, in deed, the resolved two peaks at $E_g = 121.7825$ and 123.08 keV. The yield ratio of these two components is:

$$\gamma(121.7825\text{keV})/\gamma(123.08\text{keV})=0.837/0.163.$$

The total counts of these composite peaks is 115,963 counts, yielding e.g. for the 123.08-keV g-ray, $115,963 \times 0.163 = 18,902$ counts.

Summary

By peak analysis, for the prominent peaks as listed in Table2, thermal-neutron capture cross-section ratio has been determined to be $\sigma(^{154}\text{Eu})/\sigma(^{152}\text{Eu}) = 55,923/721,567 = 0.075$. Further analyses of activated data for other nuclide listed in table 1 may yield more precise neutron flux, by which we are able to deduce the absolute Cross-sections $\sigma(^{154}\text{Eu})$ and $\sigma(^{152}\text{Eu})$, separately.

References

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Table 1. Irradiated samples in the present experiment.

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Element	Nuclide	Half-life	Amount
Sc	^{46}Sc	83.79d	1.0g
Co	^{60}Co	5.271y	1.0g
Au	^{198}Au	2.696d	0.21g
Eu	^{152}Eu	13.542y	1.0g
	^{154}Eu	8.593y	
^{151}Eu	^{152}Eu	13.542y	0.33g
^{153}Eu	^{154}Eu	8.593y	0.33g

Table 2. Results of peak analysis, for the prominent peaks.

$E_\gamma(\text{keV})$		$^{151}\text{Eu}(n,\gamma)^{152}\text{Eu}$		$^{153}\text{Eu}(n,\gamma)^{154}\text{Eu}$	
		counts	$1/\varepsilon^\#$	counts	$1/\varepsilon$
~122	121.782	97,061	287,162		
	123.08			18,902	55,923
344.3		53,097	331,856		
1085.8		7,240	102,549		
total		721,567		55,923	

[#]energy dependent detection efficien

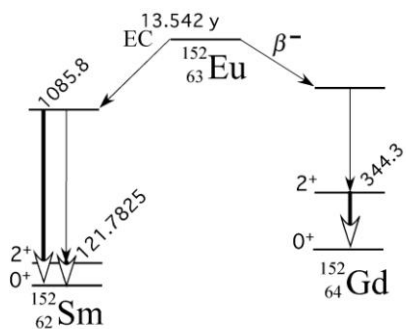


Figure 1. Decay scheme of A=152 nuclides

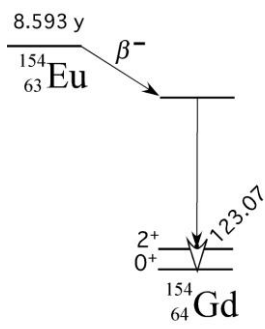


Figure 2. Decay scheme of ^{154}Eu .



Figure 3. Irradiation by thermal neutrons from K=12 MeV -AVF cyclotron. Samples are mounted between two bottles filled with water located at the right under the RI-production target.



Figure 4. Gamma detector is mounted inside the pure iron shield-box.

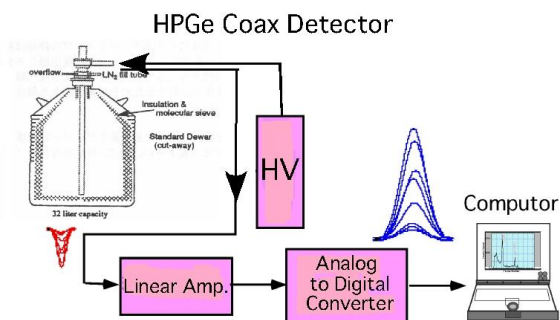


Figure 5. Electric diagram for the gamma ray analyzing system.

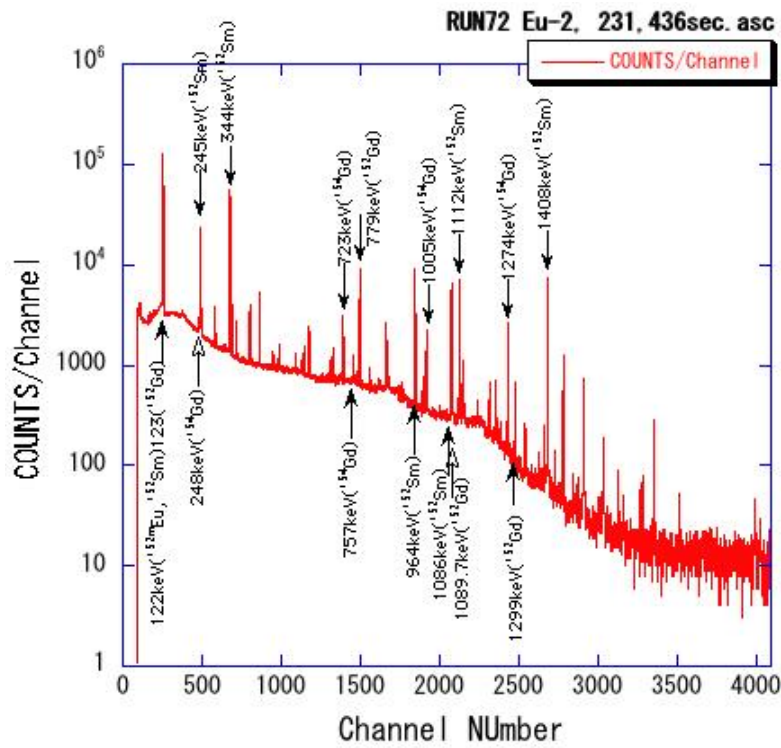


Figure 6. Typical gamma ray spectrum from the Eu sample after two weeks irradiation

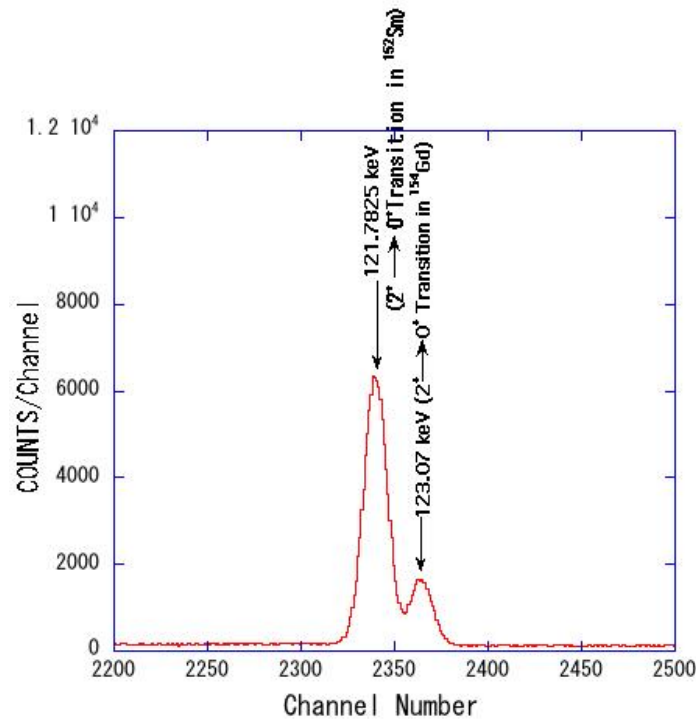


Figure 7. Typical gamma ray spectrum by high resolution measurement for the Eu sample of natural abundance.