Thermal-neutron Capture Cross-section by 151Eu Leading to the 9.27-hours Isomer

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I. 1. Thermal-neutron Capture Cross-section by ^{151}Eu Leading to the 9.27-hours Isomer

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In the course to accumulate the data estimating activation of concrete in the nuclear power plant due to thermal neutron capture by ^{151}Eu, the capture cross-section for ^{151}Eu Leading to the 9.27-hours isomer 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. The law of "clearance level" was enacted in 2007 as one of the law to regulate radiation safety of nuclear plants. The law excludes wastes from the regulation when their radiation level is smaller than the "clearance level". The radiation level of concrete that composes a big part of the building structure of the nuclear installation is examined by measurements and calculations, and the results are compared with "clearance level". For the effective and safety enforcement of the law, accumulation of the database of thermal-neutron capture-rate 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[1)]. We have reported[2)] high-Resolution measurements of gamma-rays from thermal-neutron capture by ^{151}Eu and ^{153}Eu. Europium oxide powder in natural abundance were bombarded by thermal neutrons. We concluded that by peak analysis, for the prominent peaks leading to the 121 keV state, thermal-neutron capture cross-section ratio has been determined to be $\sigma(^{154}\mathrm{Eu})/\sigma(^{152}\mathrm{Eu})$= 55,923/721567=0.075. Further analyses of activated data for other nuclide ^{45}Sc and ^{59}Co could yield more precise neutron flux, by which we were able to deduce the absolute Cross-sections $\sigma(^{154}\mathrm{Eu})$ and

σ(^{152}Eu), separately.

In this report, we discuss thermal neutron capture cross-section of ^{151}Eu leading to the 9.27-hr isomer in ^{152}Eu. Decay scheme of the he 9.27-hr isomer is illustrated in Fig. 1. There are seven gamma-ray decays[3,4] in which four decays are prominent, and three decays may be week. Note that the lowest transition between $2^+ \rightarrow 0^+$ states is singlet since transition in ^{154}Gd the $2^+ \rightarrow 0^+$ transition is not observed in the short-lived transition .

Thermal-neutron activation 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}Eu(n,γ). The neutron flux thus obtained by Au-experiments is estimated to be in the order of 10^4 (n/s.cm^2).

Gamma rays from activated samples have been analyzes 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. Figure 2 shows the simple electric diagram for the gamma ray analyzing system.

A sample of gamma ray spectrum, taken from europium sample at the time of one hour after two-hours bombardment, is illustrated in Fig. 3. The seven transition pointed out in Fig. 1 are observed as the results of peak identification. Figure 4 shows time dependence of decay of the 9.27-hr isomeric state obtained by counting 121.78-, 344.3-, 841.6-, 9643.4-keV gamma rays. The decay curve of seven decays is consistent with the life of ^{152m}Eu as shown in Fig. 4 by fitting.

In the general theory of RI-decay, the number of radioactive nucleus at the time t is:

$$N(t) = N_0 e^{-\lambda t} = N_0 e^{-\frac{0.693}{t_{1/2}}t}, \frac{dN(t)}{dt}[Bq] = -N_0\left(\frac{0.693}{t_{1/2}}\right)e^{-\frac{0.693}{t_{1/2}}t} \quad (1)$$

where $t_{1/2}$ is the half life of the radioisotope. After bombardment of thermal neutron, the initial number of radioisotope is:

$$N_0 = I(number\ of\ terget\ atom) \times n[(number\ of\ neutron)/cm^2] \times S^{AA}[barn\,10^{-24}\,cm^2] \quad (2)$$

where S^{AA} is capture cross section for nucleus-AA measured by barn (10^{-24} cm^2), and N_0 is obtained with the unit of $n \cdot S^{AA}$. For example, N_0 of $^{151}Eu_2O_3$ is:

$$N_0 = \frac{1.03 \times 0.48}{352} \times 2 \times 6.0 \times 10^{23} \times 10^{-24} n S^{Eu} \quad (3)$$

On the other hand, N_0 is related to the activity: $Act.$ (Bq) as following:

$$\left.\begin{array}{l} {}^{46}Sc \quad 83.79d \quad (1/1.0444\times10^{7})N_0 \\ {}^{60}Co \quad 5.271y \quad (1/2.3988\times10^{8})N_0 \\ {}^{152}Eu \quad 13.542y \quad (1/6.1625\times10^{8})N_0 \\ {}^{152m}Eu \quad 9.274h \quad (1/4.8176\times10^{4})N_0 \\ {}^{154}Eu \quad 8.593y \quad (1/3.9104\times10^{8})N_0 \\ {}^{198}Au \quad 2.696d \quad (1/3.3612\times10^{5})N_0 \end{array}\right\} = Act.(Bq) = \sum[counts/\sec]\times\frac{1}{\varepsilon(E_\gamma)} \qquad (4)$$

where ε denotes energy dependent detector efficiency, and summation should be taken over transitions concerning the amount of N_0. Measurement of gamma-ray counts gives us the corresponding ^{152m}Eu-activity in Bq. Then, by inserting N_0 in eq. (3) into eq. (4), we obtain $n\cdot S^{^{152m}Eu} = 7.187\times10^{10}$, where summation in eq.(4) is taken over 841.6-(13.1counts/sec, ε = 0.0671) and 963.4-keV(10.8 counts/sec, ε = 0.0609) gamma transitions. On the other hand, by counting gamma ray for ^{197}Au target, which have been bombarded in the same experimental condition, we obtain $n\cdot S^{Au} = 1.016\times10^{10}$. Note that the amount of neutron number is common for these two cases. Thus, by using S^{Au} =200 (barn) we obtain $S^{^{152m}Eu}$=1.41×10^{3} (barn).

We have observed gamma-ray from the decay of 9.27-hr isomer in ^{152}Eu. Observation of activity by this transition gives prompt information about radiation level by neutron capture by Europium. Together with data for activation of ^{197}Au, we have concluded that the thermal neutron capture cross-section leading to the 9.27-hr isomer is 1.41×10^{3} barn. This method to deduce thermal neutron capture cross-section may be applied to obtain capture cross-section e.g. to the 13.542-y ground state in ^{152}Eu.

References

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Table 1. Irradiated samples in the present experiment.

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	

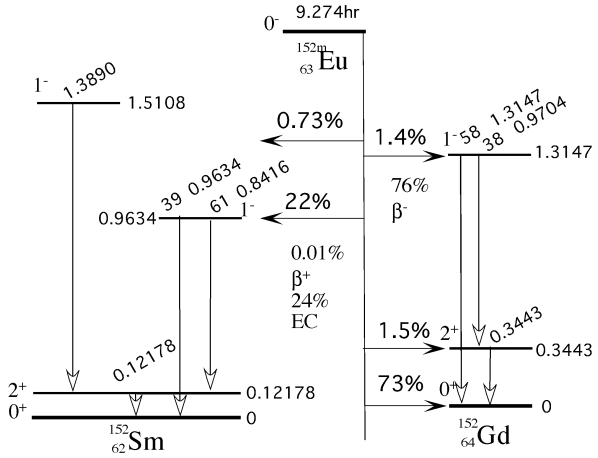

Figure 1. Decay scheme of the 9.27-hr isomer in ^{152}Eu.

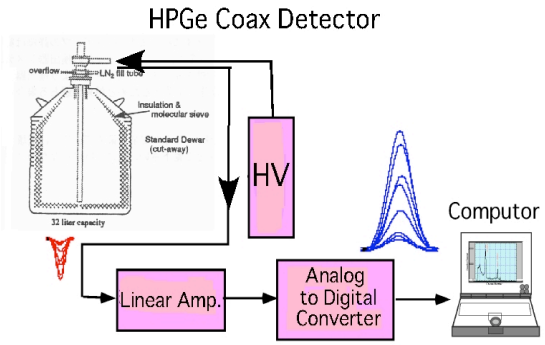

Figure 2. Electric diagram for the gamma ray measurement.

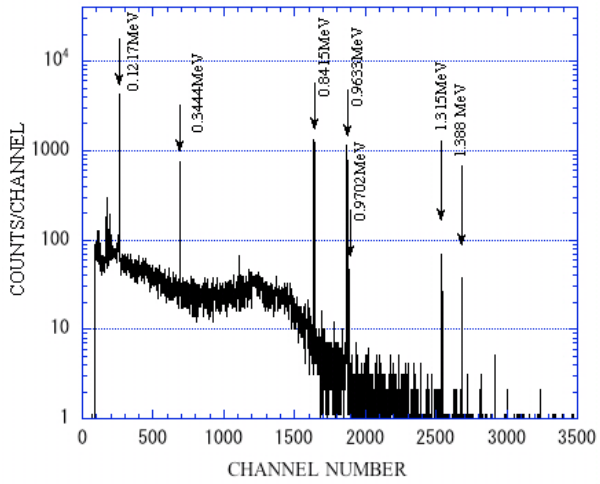

Figure 3. Gamma-ray spectrum for decay of the 9.27-hr isomer in ^{152}Eu. Seven gamma ray peaks indicated in Fig. 1 are seen.

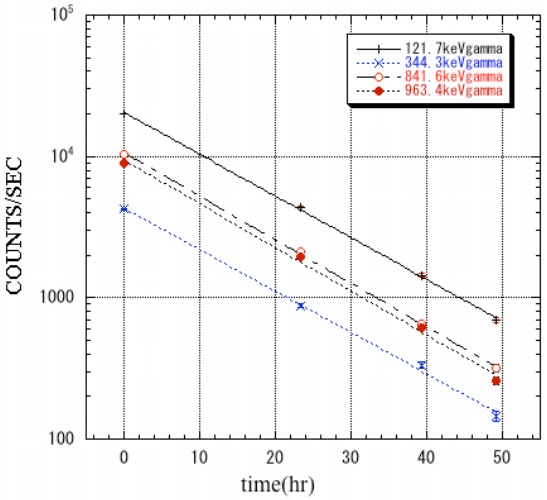

Figure 4. Decay curves of the 9.27-hr isomer measured with the 121.7-, 344.3-, 841.6-, and 963.4-keV gamma decays.