Journal of NUCLEAR SCIENCE and TECHNOLOGY, Supplement 2, p. 441–443 (August 2002)

Thermal Cross Section And Resonance Integral Measurements Of $^{57}Co(n,\gamma)$ ^{58}Co Reaction

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The thermal cross section and resonance integral of the reaction $^{57}Co(n,\gamma)$ ^{58}Co have been determined experimentally. The irradiations were performed at the IEA-R1 research reactor operating at 2 MW. Aliquots of ^{57}Co evaporated solution sealed inside quartz tubes were placed near the reactor core. All targets were irradiated together with a pair of Au-Al alloy foils, with and without Cd cover, in order to monitor the thermal and epithermal neutron fluxes by means of $^{197}Au(n,\gamma)^{198}Au$ reaction. Neutron fluence was determined using the Westcott formalism. The gamma-ray measurements were performed in a HPGe detector (35 %), previously calibrated with standard sources. The detector efficiency curve was fitted by the least-squares method applying covariance analysis to all uncertainties involved. Since no other experimental result has been reported so far, the present result has been compared with estimates from the literature.

KEYWORDS: Cobalt 57, Thermal Neutrons, Cross Section, Resonance Integral, Epithermal Neutrons, Activation Analysis, Gamma-Ray Spectrometry

I. Introduction

The accurate knowledge of neutron capture cross sections induced in radioactive nuclei became important in recent years due to research and development of nuclear transmutations associated with waste disposal management.[1–4] In previous works the cross section for $^{137}Cs(n,\gamma)^{138}Cs$ and $^{241}Am(n,\gamma)^{242}Am$ reactions had been measured.[5,6] The thermal neutron cross section and resonance integral for $^{57}Co(n,\gamma)^{58}Co$ reaction have been investigated. Since there is no experimental value for that reaction in the literature, the obtained value will be compared to that obtained from the study by Kopecky[7] and to the well known $^{59}Co(n,\gamma)^{60}Co$ reaction.

In the present work the cross section of ^{57}Co has been experimentally determined by means of the reaction $^{57}Co(n,\gamma)^{58}Co$ induced by thermal and epithermal neutrons. The radionuclide ^{57}Co decays by electron capture and gamma emission with a half-life of 271.70(9) d, as shown in Figure 1.[8] The principal gamma-ray transitions, with energies 122.0614(3) keV and 136.4743(5) keV have 85.60(17) % and 10.68(8) % emission probabilities per decay respectively.

After a neutron capture, the residual radionuclide can be found either in the metastable state ^{58m}Co or the ground state ^{58g}Co. The first one, with a half-life of 9.15(10) h, decays to the ground state mainly through internal conversion. The second one decays by electron capture and β^+ with a half-life of 70.82(3) d, producing a gamma-ray of 810.775(9) keV with 99.448(8) % emission probability per decay.

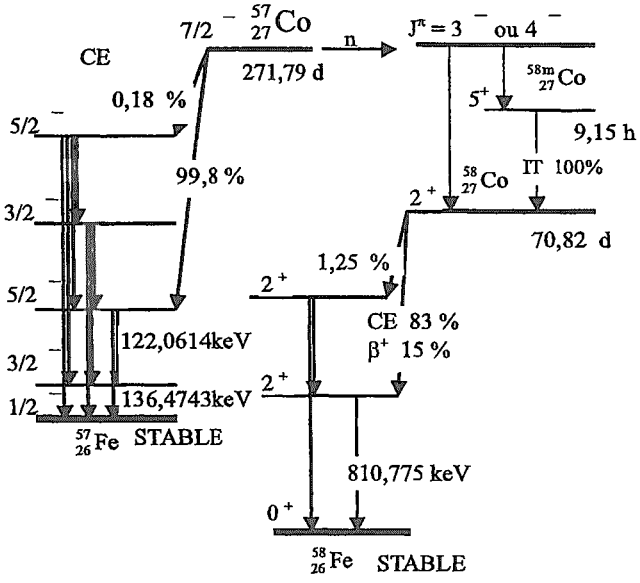

Fig. 1 Scheme of the $^{57}Co(n,\gamma)^{58}Co$ reaction.[8] The production and decay of isomer ^{58m}Co are shown.

II. Experimental

1. Irradiation

The irradiations were performed at the IPEN 2 MW pool-type research reactor. Targets consisting of ~ 0.8 MBq ^{57}Co carrier free source sealed inside quartz tubes were irradiated near the reactor core with and without Cd cover. In all the irradiations, a pair of Au-Al alloy foils (0.10 % of Au), one of them covered with Cd, was used to monitor the thermal and epithermal neutron fluxes in the irradiation position through the $^{197}Au(n,\gamma)^{198}Au$ reaction as described in Maidana et al.[6] The Au activities were used to determine the neutron fluence by the Westcott formalism.[9,10] The irradiation time was 15 h and the interval between the irradiation and counting was greater than 15 d, in order to wait for the decay of some contaminants found in the quartz tubes.

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2. Activity Determination

The gamma-ray measurements were performed in a HPGe detector (35 % Ortec), previously calibrated by means of ^{152}Eu, ^{137}Cs, ^{57}Co and ^{54}Mn standard sources. An additional calibrated source of ^{57}Co sealed inside a quartz tube was used. The detector efficiency curve was fitted by least-squares method applying covariance analysis to all uncertainties involved.[11,12]

The ^{58}Co activity was counted in a reproducible geometry (10 mm from the detector surface) with an absorber of Pb 2 mm thick. The obtained spectrum is shown in Figure 2. The area of the 810 keV gamma-ray peak followed the ^{58g}Co half-life. The small peak at the right of the 810 keV ^{58g}Co gamma-ray is the pile-up of the 122 and 692 keV ^{57}Co gamma-rays. The induced activity in the quartz tube from the (n,γ) reactions is observed in most of the spectrum peaks. In the measurement of the ^{57}Co activity, the source was placed at 250 mm from the detector end cap. All the measurements were performed in live time counting methodology with pile-up rejection. The decay scheme parameters used in the activity measurements are shown in Table 1.[8,13]

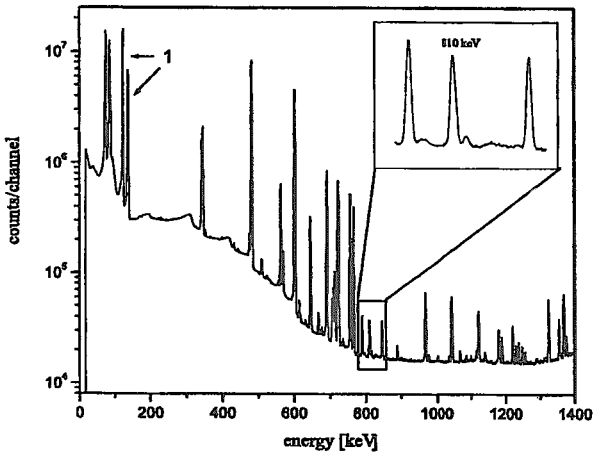

Fig. 2 Spectrum obtained with 20 h measurement of the irradiated ^{57}Co source. The dispersion is 0.2 keV/channel. The 122 and 136 keV ^{57}Co γ-ray are marked 1. The inset shows the 810 keV ^{58}Co peak γ-ray.

3. Cross Section and Resonance Integral Determination

The expressions used for the thermal cross section, σ_0, and Resonance Integral, I, are:

$$\sigma_0 = \frac{A_2\lambda_1}{A_1\phi_0\sqrt{\frac{4T}{\pi T_0}}} \quad (1)$$

$$I = \frac{A_{2c/Cd}\lambda_1}{A_{1c/Cd}\phi_{epi}} ln\frac{E_2}{E_1} \quad (2)$$

$A_1, A_{1c/Cd}$ ^{57}Co activities without and with the cadmium cover, respectively;
$A_2, A_{2c/Cd}$ ^{58}Co reaction product activities at the end of irradiation without and with the cadmium cover, respectively;
ϕ_0, ϕ_{epi} thermal and epithermal neutron fluxes determined with the Au-Al monitors;
T, T_0 moderator and reference temperatures;
E_1, E_2 neutron spectrum integration limits, corresponding to 0.5 eV and 1 MeV, respectively;
λ_1 ^{57}Co decay constant.

Table 1 Decay parameters used in the cross section measurement.[8,13] The numbers in the parentheses are the standard deviations applied to the last digits. The numbers in the brackets are the references where the data can be found.

Radionuclide	Half-life (d)	Gamma-ray Energy (keV)	Gamma-ray Intensity per Decay (%)
^{54}Mn	312.3(4)	834.843(6)	99.9758(24)
^{57}Co	271.70(9)	122.0614(3)	85.60(17)
		136.4743(5)	10.68(8)
^{58g}Co	70.82(3)	810.775(9)	95.57(47)
^{137}Cs	1.102(6)×10^4	661.660(3)	85.1(2)
^{152}Eu	4933(11)	121.7824(4)	28.37(13)
		244.6989(10)	7.53(4)
		344.2811(19)	26.57(11)
		778.903(6)	12.97(6)
		964.055(4)	14.63(6)
		1408.022(4)	20.85(9)
^{198}Au	2.6943(8)	411.8044(11)	99.448(8)

III. Results and Discussion

Two irradiations were performed in order to obtain the final results. The thermal neutron cross section for the ^{57}Co(n,γ)^{58}Co reaction obtained in the present work was (50.5±4.6) b. This value disagrees with the value ~ 6 b for ~ 0.025 eV neutrons obtained in the study by Kopecky,[7] based on the systematics of experimental values and the reaction theory. The resonance integral obtained was (20.0±1.9) b. The uncertainty in this result was due to a ^{58}Co contamination in the original solution. The value σ_{m+g} for the ^{59}Co(n,γ)^{60}Co reaction is 37.23(25) b[14] and the resonance integral is 73.41(57) b.[14] The greater excitation energy of the ^{60}Co compared with that of the ^{58}Co explains the higher resonance integral of the ^{59}Co(n,γ) reaction.

Acknowledgment

The authors would like to thank to the IEA-R1 reactor staff for helping in the irradiations. We are also grateful to the CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico, Brazil) and FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo, Brazil) for partial support to this research.

References

1) H. Harada, H. Watanabe, T. Sekine, Y. Hatsukawa, K. Kobayashi, T. Katoh, "Measurement of thermal neutron cross section of $^{137}Cs(n,\gamma)^{138}Cs$ reaction," *J. Nucl. Sci. Tech.*, **27**[6], 577 (1990).
2) C.D. Bowman, E.D. Arthur, P.W. Lichowsky, G.P. Lawrence, R.J. Jensen, J.L. Anderson, B. Blind, M. Cappiello, J.W. Davidson, T.R. England, L.N. Engel, R.C. Haight, H.G. Huges III, R.J. Ireland, R.A. Krakowsky, R.J. LaBeuve, R.T. Letellier, R.T. Perry, G.J. Russell, K.P. Staudhammer, G. Versamis, W.B. Wilson, "Nuclear energy generation and waste transmutation using an accelerator-driven intense thermal neutron source," *Nucl. Instrum. and Methods in Phys. Res.*, **A320**, 336 (1992).
3) T. Sekine, Y. Hatsukawa, K. Kobayashi, H. Harada, H. Watanabe, T. Katoh, "Measurement of thermal neutron cross section and resonance integral of the reaction $^{137}Cs(n,\gamma)^{138}Cs$," *J. Nucl. Sci. Tech.*, **30**[11], 1099 (1993).
4) T. Katoh, S. Nakamura, H. Harada, Y. Hatsukawa, N. Shinohara, K. Hata, K. Kobayashi, S. Motoishi, M. Tanase, "Measurement of Thermal Neutron Cross Section and Resonance Integral of the Reaction Cs-135(n,γ)Cs-136," *J. Nucl. Sci. Tech.*, 34[5], 431 (1997).
5) N. Maidana, M.S. Dias, M. F. Koskinas, "Measurement of the Thermal Neutron Capture Cross Section of Cs-137," *Radiochimica Acta*, **83**, 117 (1998).
6) N. Maidana, M.S. Dias, M. F. Koskinas, "Measurement of the Thermal Neutron Capture Cross Section and Resonance Integral of Am-241," *Radiochimica Acta*, **89**, 419 (2001).
7) J. Kopecky, *Atlas of neutron Capture Cross Section*, INDC(NDS)-362, International Atomic Energy Agency, Vienna, 52 (1997).
8) R.B. Firestone, *Table of Isotopes*, 8th. Edition, New York, (1996).
9) C.H. Westcott, *Effective Cross Section Values for Well-Moderated Thermal Reactor Spectra*, 3rd Edition, CRRP-960, Chalk River, Ont., Atomic Energy of Canada, (1960).
10) E.J. Axton, "Absolute measurement of the neutron flux density in the A.E.R.E. Reactor GLE'," *J. Nucl. Energy*, **A/B 17**, 125 (1963).
11) V.R. Vanin, R.M. Castro, O.A. Helene, P.R. Pascholati, M.F. Koskinas, M.S. Dias, "Determining Decay Data Correlations and Calibrating the Detector Efficiency with Multigamma-ray Sources," INDC(NDS)-403, International Atomic Energy Agency, Vienna, 75 (1999).
12) R. Tramontano, V.R. Vanin, "Mixing Activity-calibrated and Uncalibrated Gamma-ray Sources in Efficiency Calibration," *Appl. Radiat. Isot.*, **51**, 323 (1999).
13) International Atomic Energy Agency, *X-ray and Gamma-ray standards for detector calibration*, IAEA-TECDOC-619, International Atomic Energy Agency, Vienna, (1991).
14) J.H. Baard, W.L. Zijp, H.J. Nolthenius, *Nuclear Data Guide for Reactor Neutron Metrology*, Kluwer Academic Publisher, Dordrecht (The Netherlands), 92 (1989).