CROSS SECTION MEASUREMENT FOR ^{58}Ni(n,p)^{58m,g}Co IN THE 2-3 MeV NEUTRON ENERGY REGION

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Abstract

The excitation functions of ^{58}Ni(n,p)^{58m,g}Co reactions has been measured for neutrons in the energy range of 2-3 MeV produced via the D(d,n)^{3}He reaction. By fitting the measured total activity of the ^{58g}Co with an analytically derived function that takes into account the contribution from the decay of metastable to ground state, the respective cross sections σ_m and σ_g have been calculated.

Corrections for self absorption in metal samples, dead time and coincidence losses were carried out. Assumptions of constant flux during the long Neutron Generator irradiation time and a constant value for the ratio of metastable to ground state cross sections (σ_m/σ_g) were made. The results obtained show that both cross sections increase with neutron energy, σ_m from 11.5 to 48.5 mb and σ_g from 24.4 to 102.3 mb in the neutron energy range of 2.15 to 2.94 MeV.

Keywords : cross section, metastable and ground states, Neutron generator

1. Introduction

The measurement of the reaction cross section for the production of ^{58g}Co via (n,p) reaction of ^{58}Ni is complicated by the presence of an isomeric state ^{58m}Co that decays into the ground state with a half life of 9.15 hours, γ-ray energy (E_γ) of 0.0249 MeV and intensity (I_γ) =0.032. The decay scheme of ^{58}Co is as shown in figure 1[1]. The derivation of the metastable state contribution to measure ground state activity must therefore take into consideration direct ^{58m}Co production and metastable state decay to ^{58g}Co during irradiation, and the continuous decay of metastable state to ground state after sample irradiation.

The buildup of ^{58g}Co nuclides during irradiation can be expressed as[2];

$$\frac{dN_g(t)}{dt} = n\sigma_g\phi - \lambda_g N_g(t) + \lambda_m N_m(t) \tag{1}$$

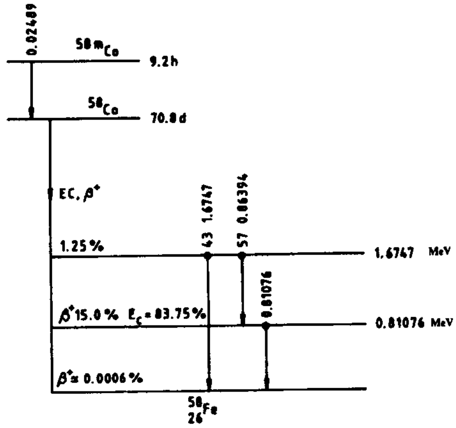

Figure 1. Decay scheme of ^{58}Co

where the number of metastable state nuclides produced during irradiation is

$$N_m^{0'} = \frac{n\sigma_m\phi}{\lambda_m}(1 - e^{-\lambda_m\Delta t}) \quad (2)$$

Therefore, at the end of a short irradiation Δt, the number of ground state nuclides is

$$N_g^0 = \frac{n\sigma_m\phi}{\lambda_g - \lambda_m}(e^{-\lambda_g\Delta t} - e^{-\lambda_m\Delta t}) + \frac{n(\sigma_g + \sigma_m)}{\lambda_g}\phi(1 - e^{-\lambda_g\Delta t}) \quad (3)$$

The buildup of ^{58g}Co nuclides after irradiation is expressed as;

$$\frac{dN_g(t)}{dt} = \lambda_m N_m(t) - \lambda_g N_g(t) \quad (4)$$

By substitution for $N_m(t)$ from equation at the end of irradiation, equation (4) is solved to obtain;

$$N_g(t_c) = \frac{\lambda_m}{\lambda_g - \lambda_m}N_m^0(e^{-\lambda_m t_c} - e^{-\lambda_g t_c}) + N_g^0 e^{-\lambda_g t_c} \quad (5)$$

Therefore, the total ^{58g}Co nuclides at time t_c after irradiation is

$$N_g(t_c) = \frac{n\phi}{\lambda_g}(\sigma_g - \frac{\lambda_m\sigma_m}{\lambda_g - \lambda_m})(1 - e^{-\lambda_g\Delta t})e^{-\lambda_g t_c} + \frac{n\sigma_m\phi}{\lambda_g - \lambda_m}(1 - e^{-\lambda_m\Delta t})e^{-\lambda_m t_c} \quad (6)$$

From equation (6), the number of decayed ^{58g}Co, (i.e. counts under the 810.8 keV peak) in the interval t_1 and t_2 is

$$N_d = \frac{n\phi}{\lambda_g}(\sigma_g - \frac{\lambda_m\sigma_m}{\lambda_g - \lambda_m})(1 - e^{-\lambda_g\Delta t})e^{-\lambda_g t_c}(1 - e^{-\lambda_g t_m}) + \frac{n\sigma_m\phi}{\lambda_g - \lambda_m}\frac{\lambda_g}{\lambda_m}(1 - e^{-\lambda_m\Delta t})e^{-\lambda_m t_c}(1 - e^{-\lambda_m t_m}) \quad (7)$$

where; n = number of the nickel atoms ,
σ = cross sections of reactions
ϕ = neutron flux,
λ = decay constant,
t_c = cooling time
Δt = irradiation time, and
t_m = measurement time.

In the short interval of irradiation Δt, the flux is considered a constant and equation (7) holds. However, during long irradiation with the neutron generator, flux fluctuation is normally the case and this affects measured activity when half lives of the metastable and ground states are very different. In such a case, the irradiation time T is divided into K intervals during which constant flux (M_i) is assumed. Equation (7) is thus modified to:

$$N_d = \sum_{i=1}^{k}\{\frac{n}{\lambda_g}\frac{M_i}{\Delta t}(\sigma_g - \frac{\lambda_m}{\lambda_g - \lambda_m}\sigma_m)(1 - e^{-\lambda_g\Delta t})e^{-\lambda_g t_i}e^{-\lambda_g t_c}(1 - e^{-\lambda_g t_m}) + \frac{n\sigma_m}{\lambda_g - \lambda_m}\frac{\lambda_g}{\lambda_m}\frac{M_i}{\Delta t}(1 - e^{-\lambda_m\Delta t})e^{-\lambda_m t_i}e^{-\lambda_m t_c}(1 - e^{-\lambda_m t_m})\} \quad (8)$$

Equation (8) can be reduced to $N_d = k_1 . e^{-\lambda_g t_c} + k_2 . e^{-\lambda_m t_c}$, for the purpose of a least square fitting process, where the values of k_1 and k_2 are obtained by the substitution of the appropriate values for variables of decay constants, irradiation time, counting time, cooling time, neutron flux and atomic number density. Thus, measured activity at various cooling times can be fitted to obtain the values of σ_g and σ_m.

2. Experimentation

Neutrons of energy in the 2-3 MeV range were produced via the D(d,n)^{3}He reaction in the home made neutron generator at the Institute of Experimental Physics, Kossuth University, Debrecen Hungary. Nickel samples (15x10x1 mm) and above 99% purity were irradiated for 75 hours at 0, 15, 30, 45, 60, 75, 90, 105, 120, 135, and 150 degrees to the direction of deuteron beam which was set at an accelerating voltage of 170 kV and current beam about 200 μA. Figure 2 shows the experimental setup. The neutron energy as a function of deuteron beam direction was adopted from results from a previous report [3]. The flux was monitored by the ^{115}In(n,n')^{115m}In reaction in high purity indium placed at 15 and 45 degrees, and changed at 8 -12 hours intervals. A BF_3 long counter was appropriately placed for use as a continous flux monitor. Table 1 is the nuclear data for the reactions involved.

Table 1. Nuclear Data.

Reaction Products	Half-life	E_γ (keV)	I_γ(%)
^{58m}Co	9.15h	24.9	3.2
^{58}Co	70.8d	810.8	99.45
^{115m}In	4.486h	336.2	45.8

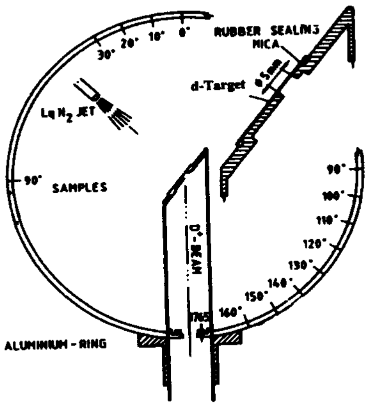

Figure 2. Experimental setup

Activity for ^{115m}In was measured with the Ge(Li) detector and reference cross section values taken from a previous report [4], while the activity of ^{58g}Co was measured with a well type NaI(Tl) detector. The ^{58g}Co activity for the different sample positions was measured for various cooling times up to 500 hours. Count rates were corrected for self-absorption, dead time and coincidenct losses [5].

3. Results and Discussion

Equation 7 which represented the measured activity of 810.8 keV gamma of ^{58g}Co was fitted with a least square routine to determine the metastable and ground state cross sections for ^{58}Co (shown in figure 3). The results for the cross sections measured are reported in Table 2 while figure 4 shows the behaviour of σ_g + $\sigma_m$with increase in neutron energy.

A good level of agreement is recorded between the results obtained from this work and those of other authors [6,7,8]. The results for both cross sections measured were found to increase within the energy range of 2.15 to 2.94 MeV. σ_m vary from 11.5 to 48.5 mb while σ_g vary from 24.4 to 102.3 mb.

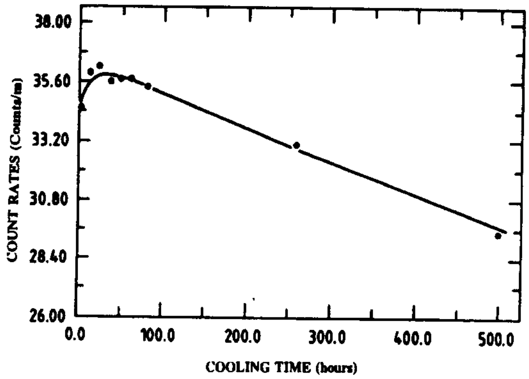

Figure 3. The decay curve of the ^{58g}Co isotope.

Table 2. Cross section of ^{58}Ni(n,p)^{58m}Co and ^{58}Ni(n,p)^{58g}Co

No.	Neutron Energy (MeV)	^{58}Ni(n,p)^{58m}Co (mb)	^{58}Ni(n,p)^{58g}Co (mb)
1	2.15	11.3	24.4
2	2.21	10.7	22.5
3	2.28	12.0	25.4
4	2.38	13.4	28.4
5	2.48	13.8	29.0
6	2.58	15.0	31.6
7	2.69	21.5	45.5
8	2.80	29.5	62.3
9	2.86	38.5	81.3
10	2.92	46.4	97.8
11	2.94	48.5	102.3

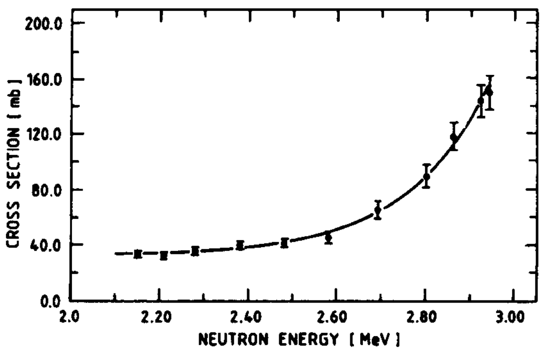

Figure 4. Cross section curve of ^{58}Ni(n,p^{m,g}Co reaction between 2-3 MeV

4. Acknowledgments

The authors are grateful to Professor CS. M. Buczko for the valuable discussion. Thanks are due to Mr. J. Szegedi for the technical assistance during the irradiations.

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