PERGAMON

Radiation Physics and Chemistry 61 (2001) 461–462

Radiation Physics and Chemistry

www.elsevier.com/locate/radphyschem

Monte Carlo calculation of resonance self-shielding factors for epithermal neutron spectra

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Abstract

In this work, the resonance self-shielding factor is calculated by means of the Monte Carlo technique for different materials (Au, Co, Mn), geometries (circular foils and wires) and incidence of neutrons (isotropic field and collimated beam). The results are compared with the values obtained by other authors.

Keywords: Resonance self-shielding; Epithermal neutrons; MCNP

1. Introduction

It is known that activation detectors cause neutron flux perturbation due to the resonance self-shielding effect, which depends mainly on the characteristics of the materials under irradiation. Calculated and experimental values of the resonance self-shielding factor, G_{res}, for various materials and geometries can be found in the literature (see, for example, Selander, 1960; Eastwood and Werner, 1962; Brose, 1964; Yamamoto and Yamamoto, 1965; Jefferies et al., 1983; Kumpf, 1986; Mo and Ott, 1987; Lopes, 1991). Most of these results are calculated using cross-sections that are no longer in use.

The aim of this work is to establish a calculation method for G_{res}, useful for multiple purposes, using the MCNP code (Briesmeister, 1997) and updated cross-sections (ENDF-B6). In particular we intend to use the method for calculating G_{res} to optimise the production of certain radionuclides useful for medical purposes.

In this study the adopted variables are the sample materials (Au, Co, Mn), geometry (foils and wires) and dimensions (thickness and radius for foils and radius for wires) of the target, and the incidence of the neutrons (isotropic field and collimated beam). To validate the methodology the results are compared with the values obtained by other authors.

2. Methodology of calculation

The epithermal neutron spectrum is assumed to vary as $E^{-(1+\alpha)}$, where E is the neutron energy and α a parameter accounting for the deviation from the $1/E$ law. In general the value of α lies in the range $-0.1 \leqslant \alpha \leqslant +0.2$ (Martinho, 1997) which covers practically all the experimental conditions of interest. The resonance self-shielding factor, G_{res}, is defined as the ratio between the reaction rates per atom in the real sample and in a similar and infinitely diluted sample. Thus:

$$G_{res} = \int_{E_1}^{E_2} \Phi(E)\sigma_{n,\gamma}(E)\mathrm{d}E \Big/ \int_{E_1}^{E_2} \Phi_0(E)\sigma_{n,\gamma}(E)\mathrm{d}E,$$

where $\Phi_0(E) \propto E^{-(1+\alpha)}$ is the original, non-perturbed, epithermal neutron flux per unit energy interval inside the infinitely diluted sample, $\Phi(E)$ represents the perturbed epithermal neutron flux inside the real sample, $\sigma_{n,\gamma}(E)$ symbolises the (n,γ) cross-section, and E_1 and E_2 are the respective lower and upper limits around the resonance energy E_{res}. The total neutron cross-section has been used in the calculation of the perturbed neutron flux $\Phi(E)$, thereby taking into account the neutron scattering in the sample. A fictitious density of

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0969-806X/01/$ - see front matter
PII: S0969-806X(01)00300-0

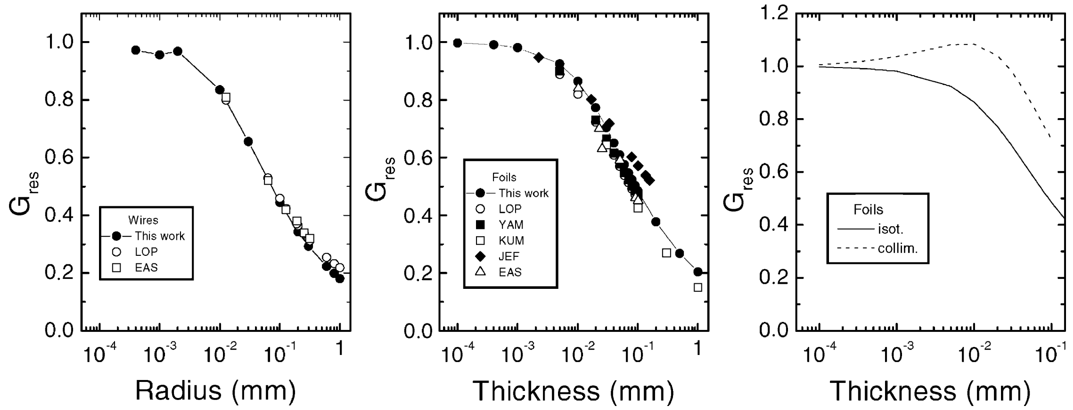

Fig. 1. Variation of the cobalt resonance self-shielding factor with wire radius and foil thickness. LOP—Lopes, 91; EAS—Eastwood, 62; YAM—Yamamoto, 65; KUM—Kumpf, 86; JEF—Jefferies, 83.

$10^{-6}\rho$ has been adopted in the simulation of the infinite dilution for calculating the non-perturbed reaction rate, ρ being the density of the material of the real sample.

3. Results and discussion

The study reveals that G_{res} does not depend significantly on α, being in accord with previous results from other authors (Jefferies et al., 1983). In addition, for disk shape foils the value of G_{res} remains practically constant for $R \geqslant 5$ mm (for $R < 5$ mm there is a small increase of G_{res} due to the so-called edge effect) (Hanna, 1963). For these reasons, present values have been obtained for $\alpha = 0$ and $R = 10$ mm for disk shape foils.

Fig. 1 shows a comparison of values of G_{res} for cobalt calculated in the present work and experimental and calculated values published previously. In general there is good agreement, particularly with experimental values. For a material immersed in an isotropic neutron flux, the values of G_{res} for a foil of a given thickness have been found to be practically equal to those for a wire of the same radius. The behaviour of G_{res} for a collimated parallel beam shows a broad maximum (>1) around $t = 0.01$ mm, indicating that there is an initial increase of the reaction rate as the thickness increases. One explanation for this effect, perhaps due to multiple scattering, is a scattering resonance cross-section which is larger than the neutron capture resonance cross-section ($\Gamma_n/\Gamma = 0.916$ for Co, Γ_n and Γ representing the neutron width and the total width of resonance at E_{res}, respetively). The effect is more pronounced for manganese ($\Gamma_n/\Gamma = 0.98$), and it is practically absent in samples of gold ($\Gamma_n/\Gamma = 0.11$).Similar results of G_{res} were obtained for Au and Mn. In both cases there is a good agreement between our results and published values.

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