EPITHERMAL NEUTRON FLUX CHARACTERIZATION OF THE IEA-R1 RESEARCH REACTOR, SAO PAULO, BRAZIL, FOR USE IN INAA.

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ABSTRACT

The nonideality of the epithermal neutron flux distribution at a reactor site parameter (α) and the thermal-to-epithermal neutron ratio (f) were determined in three typical irradiation positions of the IEA-R1 reactor of IPEN-CNEN/SP, Sao Paulo, Brazil, using the "Cd-ratio for multimonitor" and "bare bi-isotopic monitor" -methods respectively. This characterization is to be used in the K_0-method of NAA, recently introduced at the IPEN.

INTRODUCTION

When applying the K_0-method of instrumental (n,γ) activation analysis with reactor neutrons (INAA), it is found that the general accepted $1/E_n$-epithermal neutron flux distribution is not often acceptable from the standpoint of the analysis accuracy [1]. The use of the semiempirical representation [2,3] is better;

$$\varphi'_e(E_n) \sim 1/E^{1+\alpha}$$

which was proved to be satisfactory for INAA needs [4] and where α is a measure of the epithermal flux deviation from the ideal, and is a characteristic of the reactor irradiation position. Both positive and negative α-values are reported in the literature [5], corresponding to "softened" and a "hardened" epithermal spectrum, as compared to the ideal one. This is illustrated in Fig. 1. The $1/E^{1+\alpha}$ representation enables easy correction of the resonance integral (and hence of the analytical result) for the deviating epithermal spectrum [4]. Thus, when calculating the concentration of an element in a sample, α should be known to preserve the accuracy of the analysis.

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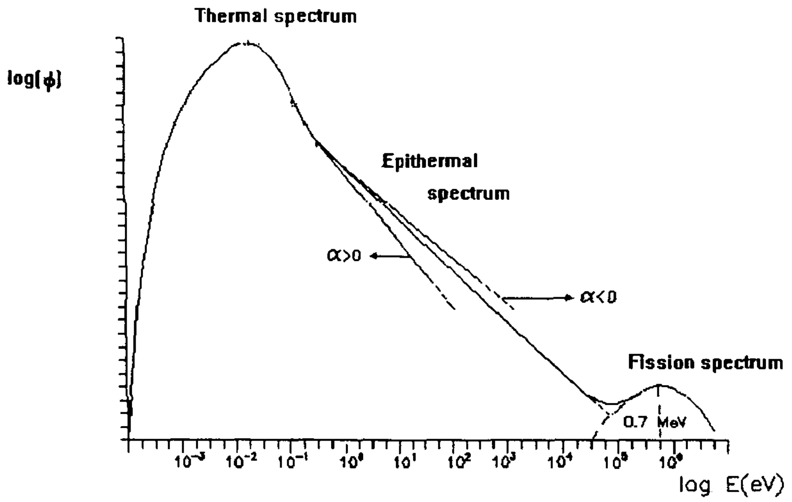

Figure 1.-Epithermal spectrum nonideality.

With the same aim, the thermal (subcadmium)-to-epithermal ratio - $f = \Phi_{th}/\Phi_e$ must be well known [6]. The designation "subcadmium" refers to the definition of Φ_{th}, the conventional thermal fluence rate, as $\Phi_{th}= n_s v_0$ where v_0 is the 2200 $m.s^{-1}$ neutron velocity and n_s is the "subcadmium" neutron density up to 0.55 eV neutron energy. On the other hand, Φ_e - the conventional epithermal neutron fluence rate, is defined as the true epithermal neutron fluence rate per unit lnE interval. The use of f is strictly associated with Q_0 (the resonance integral to 2200 ms^{-1} cross section ratio), both parameters being linked to the Høgdahl convention [7], on which the application of the K_0-method is based.

EXPERIMENTAL AND RESULTS

All through this work we investigate α and f in the three characteristic irradiation channels of the IEA-R1 reactor, i.e., in the "pneumatic transfer tube channel" (Station 4) and in the positions EIRA-24B and EIRA-36B (fixed systems for large irradiation).

We use thin high pure foils as α-monitors considering the self-shielding effects (0.125 mm Zr, 0.125 mm Au, 0.05 mm Co,). Relevant nuclear data for the nuclides chosen as monitors are given in Table 1. So as to obtain good statistics on A_{sp} values, the irradiation was repeated 3 times. In all studied positions, the monitors were irradiated during 30 minutes. After appropriate cooling times (24 – 48 h), γ-activities were measured on a HPGe (CANBERRA GMX20190, 1.9 keV for 1332 keV line of ^{60}Co). All monitor spectra were processed using the VISPECT system, developed at IPEN.

Table 1.- Nuclear data for the nuclides chosen as monitors [8,9]

Monitor	**E_r, eV**	**Q_0**	**G_{th}***	**G_{epi}***	**F_{Cd}**	**γ-line, keV**	**$T_{½}$**
^{197}Au(n,γ)^{198a}u	5.65 ± 0.40	15.7 ± 0.28	0.989	0.755	0.991	411.8	2.695 d
^{59}Co(n,γ)^{60}Co	136 ± 7	1.990 ± 0.054	0.986	0.950	1	1173.0	5.271 y
^{96}Zr(n,γ)^{97}Zr	338 ± 7	248.0 ± 0.4	1	0.966	1	743.6	16.74 h
^{94}Zr(n,γ)^{95}Zr	6260 ± 250	5.05 ± 0.10	1	0.987	1	(724.2 + 756.7)	64.033 d

* - Calculated by program CCOMP [10], using the De Corte methodology [11] and considering the Doppler effect.

The epithermal spectrum shape factor α was obtained [8] as the slope (-α) of the straight line when plotting log(T_i) versus log($E_{r,i}$/1 eV), which comes to the same as solving the implicit equation (1 eV omitted):

$$\alpha + \frac{\sum_{i}^{N}\left\{\left[\log(E_{r,i}) - \frac{\sum_{i}^{N}\log(E_{r,i})}{N}\right]\left[\log(T_i) - \frac{\sum_{1}^{N}\log(T_i)}{N}\right]\right\}}{\sum_{1}^{N}\left[\log(E_{r,i}) - \frac{\sum_{1}^{N}\log(E_{r,i})}{N}\right]^2} = 0$$

where N is the number of coirradiated α-monitors, $E_{r,i}$ - the average resonance energy of the monitor i and T_i was given by the "Cd-covered multi-monitor method" [12] as

$$T_i = \frac{(E_{r,i})^{-\alpha}(A_{sp,i})_{Cd}}{k_{0,Au}(i)\varepsilon_{p,i}F_{Cd,i}Q_{0,i}(\alpha)G_{e,i}}$$

with $A_{sp} = (N_p/t_m)/SDCw$, where N_p - measured net peak area, t_m - counting time, S - saturation factor, D - decay factor, C - counting factor and w - sample mass (in grams). $k_{0,Au}$ - tabulated k_0-factors, $\varepsilon_{p,i}$ - detector efficiency for used γ-line, $F_{Cd,i}$ - Cd-transmition factor and G_e is the correction factors for epithermal neutron self-shielding.

The thermal-to-epithermal neutron flux ratio (*f*) was determined by the "bare bi-isotopic monitor" method using Zr [13] as

$$f = \frac{G_{e,1}\frac{k_{0,Au}(1)\varepsilon_{p,1}}{k_{0,Au}(2)\varepsilon_{p,1}}Q_{0,1}(\alpha) - G_{e,2}\frac{A_{sp,1}}{A_{sp,2}}Q_{0,2}(\alpha)}{G_{th,2}\frac{A_{sp,1}}{A_{sp,2}} - G_{th,1}\frac{k_{0,Au}(1)\varepsilon_{p,1}}{k_{0,Au}(2)\varepsilon_{p,1}}}$$

were 1 = ^{97}Zr/^{97m}Nb (743 keV), 2 = ^{95}Zr (724.2 + 756.7 keV), G_{th} - the correction factors for thermal neutron self-shielding and $\varepsilon_{p,1} = \varepsilon_{p,2}$. Due to the single-decayed gamma lines, it is allowed to position the Zr monitor as close as possible to the detector cap.

Table 2 shows the obtained results for α and f. Average values and all statistic processing was performed using the BABXEL system. The quoted uncertainties were calculated according to the error propagation study given in [12]. Though relatively high (~10-30%), such inherent α-uncertainties are satisfactory for NAA needs, due to the large error reduction factor when calculating the concentration in the absolute or a single comparator method [4]. In this regard, large relative uncertainties are acceptable for lower absolute α's.

Table 2.- α and f-values determined in the irradiation positions of the IEA-R1M reactor.

Channel	α (Cd-ratio)	f (bare)
PT	0.16 ± 0.01	11.1 ± 0.6
EIRA-24B	0.14 ± 0.01	26.5 ± 0.2
EIRA-36B	0.15 ± 0.01	31.2 ± 0.3

Positive α-values correspond to a "softaned" (strongly thermalized) epithermal spectrum, which is indeed to be expected due to the reactor configuration and to ^{235}U enrichment (<20%) in the fuel elements [14]. The practically non-variation of α values in all studied position is relevant. The relative low f-value in the pneumatic channel is evidence of the presence of a great portion of fast neutron in that position.

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REFERENCES

1. F. DE CORTE, L. MOENS, A. SIMONITS, K. SORDO-EL HAMMAMI, A. DE WISPELAERE, J. HOSTE, J. Radioanal. Chem., 72 (1982) 275.

2. P.SCHUMANN, D. ALBERT, Kernenergie, 2 (1965) 88.

3. T.B.RYVES, Metrologia, 5 (1969) 119.

4. F. DE CORTE, L. MOENS, S. JOVANOVIC, A. SIMONITS, A. DE WISPELAERE, J. Radioanal. Nucl. Chem., 102 (1986) 37.

5. F. DE CORTE, S. JOVANOVIC, A. SIMONITS, L. MOENS, J. HOSTE, Kernernergie-Kerntechnik, Suppl. to Vol. 44 (1984) 385.

6. F. DE CORTE, A. SIMONITS. Vade Mecum for k_0-users, DSM Research, Gelen (NL) R29/11492, December, 1994.

7. O.T. HØGDAHL. Neutron absorption in pile neutron activation analysis: determination of cooper and gold in silver. Proceed. Symp. Radiochem. Methods of Anal., Salzburg, Oct. 19-23 (1965), IAEA, Vienna, 23-40.

8. F. DE CORTE, A. SIMONITS, J. Radioanal. Nucl. Chem. Articles 133/1 (1989) 43.

9. F. DE CORTE, A. SIMONITS, F. BELLEMANS M.C. FREITAS, S. JOVANOVIC, B. SMODIS, G. ERDTMANN, H. PETRI, A. DE WISPELAERE. J. Radioanal. Nucl. Chem. Articles 169 (1993) 125.

10. O. DIAZ RIZO. Ph.D. Thesis. Univ. Havana, 1997.

11. F. DE CORTE. Ph. D. Thesis, Univ. of Gent, 1987.

12. F. DE CORTE, K. SORDO-EL HAMMAMI, L. MOENS, A. SIMONITS, A. DE WISPELAERE, J. HOSTE, J. Radioanal. Chem. 62 (1981) 209.

13. A. SIMONITS, F. DE CORTE, J. HOSTE., J. Radioanal. Chem. 31 (1976) 467.

14. A.J. SOARES, A.M. NETO, Applications of IEA-R1 research reactor and services offered by the Center. In: RESEARCH REACTOR CENTER - CRPq, PROGRESS REPORT 1999-2000, Instituto de Pesquisas Energéticas e Nucleares, p. 101-102, 2001.