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The nonideality of the epithermal neutron flux distribution at a reactor site parameter (α) the thermal-to-epithermal neutron ratio (f) were determinated in the 3 typical irradiation positions of the TRIGA MARK III reactor of the National Nuclear Research Institute, Salazar, Mexico, using the "Cd-ratio for multimonitor" and "bare bi-isotopic monitor" -methods respectively. This characterization is of use in the K_0-method of NAA, recently introduced at the Institute.

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 often not satisfactory from the standpoint of the analysis accuracy [1]. Better is the use of the semiempirical representation [2,3]

$$\varphi_e(E_n) \sim 1/E^{1+\alpha}$$

whose 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 illustarted in Fig. 1

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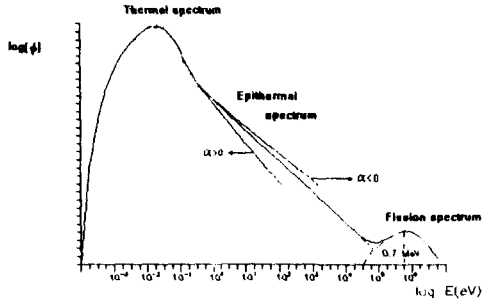

Fig. 1.-Epithermal spectrum nonideality.

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 know to preserve the accurary of the analysis.

With the same aim, the thermal (subcadmium)-to-epithermal ratio - $f = \Phi_{th}/\Phi_e$ most be well knowed [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 is the conventional epithermal neutron fluence rate, defined as the thrue 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] upon which the application of the K_0-method is based.

DETERMINATION OF α AND f VALUES.

The parameter α can be obtained [8] as the slope ($-\alpha$) of the straight line when plotting $\log(T_i)$ versus $\log(E_r/1\ eV)$, which comes to the same as solving the implicit equation (1 eV omitted):

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

where N is the number of coirradiated α-monitors, $E_{r,i}$ - the average resonance energy of the monitor i and T_i is given by the following expresions:

- In the "Cd-ratio for multi-monitor" method (A):

$$T_i = \frac{E_{r,i}^{\alpha}}{\left(F_{Cd,i}R_{Cd,i} - 1\right)Q_{0,i}(\alpha)\,G_{e,i}\;\;G_{th,i}}$$

where F_{Cd} - is the cadmium transmition factor for epithermal neutrons, R_{Cd} - the cadmium ratio and G_e and G_{th} - the correction factors for epithermal and thermal neutron self-shielding, respectively.

- In the "Cd-covered multi-monitor"-method (B):

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

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 [9,10].

- In the "bare multi-monitor"-method (C):

$$T_i = \left(E_{r,i}\right)^{\alpha}\frac{A_{sp,i}\;k_{0,Au}(i)\varepsilon_{p,i} - A_{sp,N+1}\;k_{0,Au}(N+1)\varepsilon_{p,N+1}}{Q_{0,i}(\alpha)G_{e,i}\;\;G_{th,i} - Q_{0,N+1}(\alpha)G_{e,N+1}\;\;G_{th,N+1}}$$

where "N+1" is an additionally coirradiated monitor and ε_p - is the experimental detector energy efficiency for the monitor γ-line..

After the knowledge of the epithermal spectrum shape factor α, the thermal-to-epithermal neutron flux ratio can be determinated by Cd-ratio method [11] as:

$$f = (F_{Cd}R_{Cd} - 1).\,G_e.\,Q_0(\alpha)\,/G_{th}$$

A proven technique for in-situ f-determination is the "bare bi-isotopic monitor"-method using Zr [12], according to:

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

were 1 = $^{97}Zr/^{97m}Nb$ (743 keV), 2 = ^{95}Zr (724.2 + 756.7 keV), 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.

EXPERIMENTAL AND RESULTS.

In this work we investigate α and f in the three characteristic irradiation channels of the Triga Mark III reactor (Fig.2), i.e., in the "central channel" (CC), in the "pneumatic transfer tube channel" (PT) and in the position No.8 of the "SIFCA" (fixed system for the large irradiation).

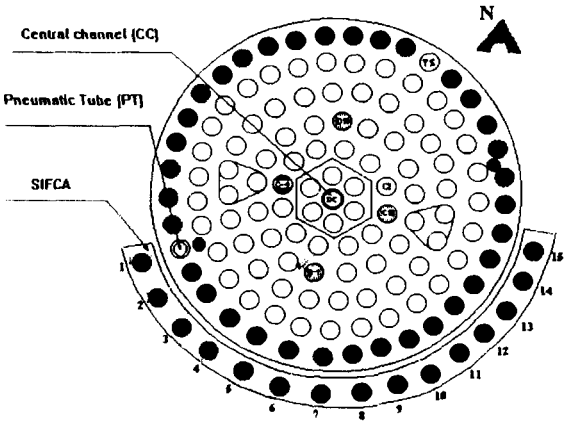

Figure 2.- Ground plan of the 1 MW Triga Mark III reactor.

Thin high pure for analysis foils we use as α-monitors to minimize self-shielding effects(0.125 mm Zr, 0.125 mm Au, 0.05 mm Co, 0.125 mm Zn, 10 μm Sn). 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 were repeated 5 times. Five minutes irradiation were performed in CC and PT and 20 minutes in SIFCA. After appropiate cooling times, γ-activities were measured on a HPGe (ORTEC, 1 8 keV for 1332 keV line of ^{60}Co). Efficiency and monitor spectra were proccesed using the Spectrum Analyzer system [13].

Table 1

Nuclear data for the nuclides chosen as monitors [9,10]

Monitor	E_r, eV	Q_0	F_{Cd}	γ-line, keV	$T_{½}$
$^{197}Au(n,\gamma)^{198}Au$	5.65 ± 0.40	15.7 ± 0.28	0.991	411.8	2.695 d
$^{59}Co(n,\gamma)^{60}Co$	136 ± 7	1.990 ± 0.054	1	1173.0	5.271 y
$^{112}Sn(n,\gamma)^{113m}Sn$	107.3 ± 0.7	48.4 ± 0.4	1	391.7	115.1 d
$^{96}Zr(n,\gamma)^{97}Zr$	338 ± 7	248.0 ± 0.4	1	743.6	16.74 h
$^{68}Zn(n,\gamma)^{69m}Zn$	529 ± 10	3.19 ± 0.18	1	438.6	13.76 h
$^{64}Zn(n,\gamma)^{65}Zn$	2560 ± 260	1.908 ± 0.094	1	1115.5	244.0 d
$^{94}Zr(n,\gamma)^{95}Zr$	6260 ± 250	5.05 ± 0.10	1	(724.2 + 756.7)	64.033 d

Table 2 shows the obtained results for Cd-ratio method. Average values and all statistic proccesing was performed using the BABXEL system. The quoted uncertains are calculated according to the error propagation study given in [8]. Trough 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 respect , large relative uncertainties are acceptable for lower absolute α's.

Table 2

α and f-values determinated in the irradiation positions of the TRIGA MARK III reactor.

Channel	α (meth.A)	α [15]	f (bare)	f [15]
CC	- 0.13 ± 0.01	- 0.12 ± 0.02	29 ± 2	35 ± 2
PT	- 0.14 ± 0.01	- 0.11 ± 0.02	40 ± 2	40 ± 3
SIFCA	- 0.08 ± 0.02	- 0.07 ± 0.02	64 ± 3	58 ± 4

Negative α-values correspond to a "hardened" (poorly thermalized) epithermal spectrum, which is indeed to be expected due to the reactor configuration and to a relatively high (70%) ^{235}U enrichment in the fuel elements [14].

The comparison with a preliminar determination of α and f in 1994 [15] shows good coincidence. The practically non-variation of α and f-values in that long reactor explotation period (without reactor recharge) is relevant. A more detailed study of the neutron flux characteristics of the Triga Mark III reactor, Salazar, for use in INAA is in preparation.

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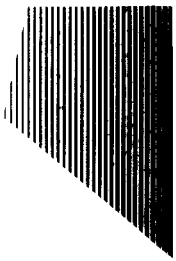

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