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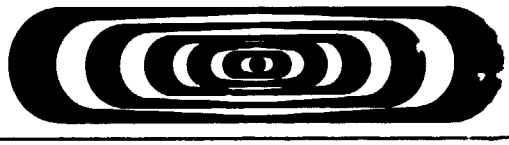

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THERMAL NEUTRON CAPTURE CROSS SECTION OF CHROMIUM, VANADIUM, TITANIUM AND NICKEL ISOTOPES

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ABSTRACT

The thermal neutron cross section of chromium,vanadium, titanium and nickel can be determined by measuring the pair spectrum of prompt gamma-rays emitted when targets of these elements are irradiated by a thermal neutron beam.Such measurements were carried out by irradiating the natural element mixed with a nitrogen standard (melamine) in the tangential beam hole of the IEA-R1 research reactor.
The pair spectrometer efficiency calibration curve in the 1.5 to 11 MeV energy range was performed with a melamine plus ammonium chloride mixed target. The cross section was calculated for the most prominent gamma transitions of each isotope, using nitrogen as standard and averaged over the obtained values. The resulting mean cross sections are as follows: (13.4 ± 0.7)b for ^{50}Cr,(0.79 ± 0,02)b for ^{52}Cr,(18.1 ± 0,7)b for ^{53}Cr, (4.9 ± 0.2)b for ^{51}V,(8.4 ± 0.1)b for ^{48}Ti, (4.41 ± 0.08)b ^{58}Ni, (2.54 ± 0.07)b for ^{60}Ni,(15.2 ± 0.5)b for ^{62}Ni and (1.6 ± 0.1) for ^{64}Ni.

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* The present work was performed at the Nuclear Physics Division of the IPEN-CNEN/SP.

SECÇÃO DE CHOQUE DE CAPTURA DE NEUTRONS TÉRMICOS DOS ISÓTOPOS DO CRÔMIO, VANÁDIO, TITÂNIO E NIQUEL.

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RESUMO

A secção de choque de captura de neutrons térmicos dos isótopos do crômio, vanádio, titânio e niquel pode ser determinada pela medida do espectro de raios gama prontos quando alvos destes elementos são irradiados num feixe de nêutrons térmicos. Estas medidas fora, realizadas irradiando uma mistura do elemento natural com um padrão de nitrogênio (melamina) no canal tangencial de irradiação do reator de pesquisa IEA-R1. A curva de calibração em eficiência do espectrometro de pares na região de energias de 1,5 all MeV foi obtida com um alvo misto de melamina e cloreto de amônia.

A secção de choque foi calculada como um valor médio a partir dos valores individuais das transições gama mais intensas de cada um dos isótopos, usando o nitrogênio como padrão. Os valores médios obtidos são, como segue: (13,4 ± 0,7)b para ^{50}Cr,(0,79 ± 0,02)b para ^{52}Cr, (18,1 ± 0,7)b para ^{53}Cr, (4,9 ± 0,2)b para ^{51}V, (8,4 ± 0,1)para ^{48}Ti, (4,4 ± 0,08b) para ^{58}Ni, (2,54 ± 0,07)b para ^{60}Ni, (15,2 ± 0,5)b para ^{62}Ni e (1,6 ± 0,1)b para ^{64}Ni.

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* O presente trabalho foi realizado na Divisão de Física Nuclear do IPEN-CNEN/SP.

INTRODUCTION

The determination of the total thermal neutron capture cross section for the (n,γ) reaction can be arrived in two ways. First, if all the primary transitions are identified, one can calculate their partial cross sections and, by summing all of them, one can determine the total neutron capture cross section. However, for most nuclei, the identification of all primary transitions is extremely difficult.

The second procedure to determine the total thermal neutron capture cross section is to normalize to the known total cross section of another element mixed with the sample before irradiation. Assuming thermal neutron capture alone, the thermal radioactive cross section can be readily obtained from a (n,γ) spectrum by the relation :

$$\sigma = \frac{A}{A_s}\,\frac{N_s}{N}\,\frac{\epsilon_s}{\epsilon}\,\frac{I_s}{I}\,\sigma_s \qquad (1)$$

where σ, A, N and I are the thermal neutron capture cross section, peak area, number of atoms, detection efficiency and the intensity of the transition respectively, and s refers to the standard.

Since both the isotope and the standard present many gamma transitions, one can calculate the cross section for each prominent transition of the isotope using all prominent transitions of the standard and average over all the obtained values.

Using the equation (1), for j standard transitions and n isotope transitions, the mean thermal neutron capture cross section σ for the isotope is given by:

$$\sigma = \frac{\sigma_s}{(j+n)}\,\frac{N_s}{N} \cdot \sum_{l=1}^{l=j}\sum_{k=1}^{k=n} \frac{A(E_k)\;\epsilon(E_l)\;I(E_l)}{A(E_l)\;\epsilon(E_k)\;I(E_k)} \qquad (2)$$

where E denotes the energy of the gamma transition being considered.

The radioative capture cross sections for ^{50}Cr, ^{52}Cr, ^{53}Cr, ^{51}V, ^{48}Ti, ^{60}Ni, ^{62}Ni and ^{64}Ni were determined by irradiating, in a thermal neutron beam, composite targets of the natural elements well mixed with melamine ($C_3H_6N_6$) and by measuring the pair spectrum of the prompt gamma rays. Nitrogen was used as standard because its well known and precise cross section, energies and intensities.

EXPERIMENTAL METHOD

The measurements were carried out through the use of the tangencial irradiation facility [1] of the IEA-R1 research reactor. At the sample irradiation position the thermal neutron flux is of the order of 5×10^{11} n/cm^2.s. Characteristics of the targets are detailed in Table I.

The prompt gamma rays following thermal neutron capture were detected by an improved pair spectrometer NaI(Tl)-Ge(Li)-NaI(Tl) described elsewhere [2].

Spectra were accumulated in a Hewlett-Packard 8192 channels multichannel analyzer and digital stabilization was used to guard against gain and baseline shifts.

Spectral analysis was achieved by means of the FORTRAN IV computer code Analysis [3] which provided the peak areas used in equation (2).

The prompt gamma rays intensities I(E) for the ^{59}Ni, ^{61}Ni, ^{63}Ni, ^{65}Ni, ^{52}V, ^{51}Cr, ^{53}Cr, ^{54}Cr and ^{49}Ti isotopes were taken from reference [4] to [9].

In equantion (2) the number of atoms is calculated as:

$$\frac{m \quad N_0 \quad f}{M} \qquad (3)$$

where m = mass of the natural element,

N_0 = Avogadro's number,

M = atomic mass of the isotope,

f = isotopic abundance of the isotope.

EFFICIENCY CALIBRATION CURVE

For a given gamma transition of energy E, we can define detector efficiency as:

$$\varepsilon = \frac{A(E)}{I(I)}$$

Where A(E) and I(E) are the corresponding peak area and intensity, respectively. So, we can determine the efficiency calibration curve by measuring the prompt gamma-ray spectrum of a target with a set of well-known energies and intensities.

The pair spectrometer efficiency calibration curve was determined by measuring a mixed sample of 14.2487g of melamine ($C_3H_6N_6$) and 0.4167g of ammonium chloride (NH_4Cl) in the energy region of 1.5 to 11 MeV. For this range of energy, the nitrogen and chlorine isotope have a large number of transitions with well known values of energy and intensity.

The gamma transition energies and intensities considered in our calculation were taken from Kenneth [10] for the nitrogen and from Krusche [11] for the chlorine and the respective cross sections taken from references [12] and [13].

The peak area is proportional to the cross section and to the number of atoms being irradiated.

So, it is possible to normalize the results for the chlorine to those

of nitrogen. This was done by using a normalization factor equal to 0.20 ± 0.01.

The efficiency calibration curve from 1.5 to 11.2 MeV was performed through three prompt gamma spectra measured in the energy range of 1.5 to 6.1 MeV, 3.4 to 8.0 MeV and 5.0 to 11 MeV.

The curves were normalized to the intermediate energy range and the experimental points were fitted to the polynomial function $\ln(\epsilon) = a_0 + a_1 \ln(E) + a_2 [\ln(E)]^2$.

RESULTS AND DISCUSSION

The thermal neutron capture cross section of ^{50}Cr, ^{52}Cr, ^{53}Cr, ^{51}V, ^{48}Ti, ^{58}Ni, ^{60}Ni, ^{62}Ni and ^{64}Ni were determined by measuring the pair spectrum of the (n, γ) reactions on natural element targets (Table I), using nitrogen as standard. The calculations were performed through equation (2). As an example, Table II shows the values obtained for ^{53}Cr and the resulting average cross section. The final results for the considered isotopes are presented in Table III, together with the cross section values reported in the literature.

As it can be seen from Table III, our results are in good agreement with those reported in the literature, except for ^{50}Cr, ^{48}Ti and ^{60}Ni. We can consider these values as new contributions to the determination of the real values. In the case of ^{52}Cr, ^{53}Cr, ^{58}Ni and ^{48}Ti, the precision of the results has been increased and we believe that it means an advance in the reseache of the nuclear properties.

TABLE I : CHARACTERISTICS OF THE TARGETS.

Target	Isotope	Mass of the natural element (g)	Isotopic Abundance (%)	Mass of Melamine (g)
Titanium	48	1.0332	73.94	11.0994
Vanadium	51	4.0196	99.75	10.2166
Chromium	50	4.0566	4.35	11.5445
	52		83.79	
	53		9.50	
Nickel	58	4.1726	67.88	11.0994
	60		26.23	
	62		3.66	
	64		1.08	

TABLE II : CALCULATED VALUES (IN BARNS) FOR THE THERMAL NEUTRON CROSS SECTION OF ^{53}Cr.

Standard* / Isotope*	5297.81	5533.38	5562.06	7298.91
6645.34	17.9 ± 2.2	18.2 ± 2.3	18.5 ± 2.3	18.0 ± 2.3
7099.71	17.7 ± 2.1	18.0 ± 2.2	18.3 ± 2.3	17.8 ± 2.2
8884.71	17.3 ± 3.2	17.6 ± 3.3	17.9 ± 3.4	17.4 ± 3.3
9718.82	18.5 ± 3.5	18.8 ± 3.6	19.1 ± 3.7	18.6 ± 3.6

Average thermal neutron cross section = 18. 1 ± 0.7 barns

* Transition energy in keV.

TABLE III : THERMAL NEUTRON CROSS SECTION IN BARNS.

Isotope	This Work	From Ref. [14]
^{50}Cr	13.4 ± 0.7	15.9 ± 0.2
^{52}Cr	[illegible] ± 0.02	0.79 ± 0.06
^{53}Cr	18.1 ± 0.7	18.2 ± 1.5
^{51}V	4.9 ± 0.2	4.9 ± 0.1
^{48}Ti	8.4 ± 0.1	7.84 ± 0.25
^{58}Ni	4.41 ± 0.08	4.6 ± 0.3
^{60}Ni	2.54 ± 0.07	2.9 ± 0.2
^{62}Ni	15.2 ± 0.5	14.5 ± 0.3
^{64}Ni	1.6 ± 0.1	1.52 ± 0.03

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