DETERMINATION OF CROSS-SECTIONS AND ISOMERIC RELATIONS IN THRESHOLD REACTIONS WITH FAST NEUTRONS FROM RADIOISOTOPIC SOURCE

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ABSTRACT

Cross-sections of $^{113}In(n,n')^{113}In^{m}$, $^{115}In(n,n')^{115}In^{m}$, $^{27}Al(n,p)^{27}Mg$ and $^{27}Al(n,\alpha)^{24}Na$ have been determined in absolute way. The experiment was carry out using a radio-isotopic neutron source of Pu-Be, with a intensity of 2.1 x 10^{7} n.s^{-1}, producing a neutron flux density of 1.7 x 10^{5} n.cm^{-2}.s^{-1}. There is agreement between obtained results and the averages reported in the literature. Spatial distribution of the neutron flux density was calculated in two way. Finally a new experimental method is exposed to the determination of the isomeric relations.

I. INTRODUCTION

The accurate knowledge of the excitation functions of fast neutron reactions are of interest from the point of view of nuclear reaction theory (spin distribution parameters, decay branching ratio), design of thermonuclear devices and for applications of data in dosimetry, neutron flux standardization analysis, etc.

Actually, the determination of cross-sections as nuclear data is carry out with appropriated facilities attend to the possibility to produce the reactions with very high energetic resolution in the neutron beam. However, its can be possible to find interest papers using radio-isotopic sources [1]. In this case, the neutron cross-section values are obtained as averages in the energetic range imposed by the energetic spectra of the employed sources. In a Pu-Be source, the studied range is find between 0 any 12 MeV, with maximum in 3, 7 and 10 Mev approximately

Is impossible to conform a excitation function using the radio-isotopic neutron sources, but its permit be located the mean values of the cross-sections in the excitation functions reported [2]. This values can be compared with the mean cross-sections determined experimentally. In his work the reactions studied were: $^{113}In(n,n')^{113}In^{m}$, $^{115}In(n,n')^{115}In^{m}$, $^{27}Al(n,\alpha)^{24}Na$ y $^{27}Al(n,p)^{27}Mg$.

By other hand, the investigation of the energy dependence of the isomeric relations gives information on the role of spin values in the formation of the isomeric states. For this reason, in this work, a method for the determination of the isomeric relations with the existent conditions in the Neutron Physics laboratory of the Institute of Nuclear Sciences and Technology of Havana, Cuba (INST), is proposed follow a similar methodology present in [3], but adapted to those reactions which produce metastable states and basics with half past times very short and the same order. This is the case of the $^{113}In(n,2n)^{112m,g}In$, which is also exposed in this work.

II EXPERIMENTAL PROCEDURE

High purity (Goodfellows) natural foils of 10 mm of diameter and 0.5 mm of thickness were used for the experimental determination of the threshold cross-section, using the neutron flux density from a Pu-Be source with 2.1 x 10^7 n.$s^{'1}$. The irradiation time was of hours or days, depending of the neutron flux density obtained: 1.7 x10^5 n.cm^{-2}.s^{-1} (on the source) and the half past times of those analyzed states. Table 2 shows the resume of the energy range among threshold and maximum energy which were reported in [2], the kind of reaction studied, the half pass times, the energy of the gamma line measured and the branching ratio as are reported in [4].

Table I Reactions and nuclear data used in the measurements

Energy Range (MeV)	Studied Reaction	$T_{1/2}$	E_γ (keV)	I_γ (%)
0.99 - 13.97	$^{113}In(n,n')^{113}In^m$	1.66 h	391.7	64.2
0.44 - 14.8	$^{115}In(n,n')^{115}In^m$	4.49 h	336.2	45.8
1.2-14.4	$^{27}Al(n,\alpha)^{24}Na$	15.02 h	1368.5	100.0
5.4 - 15.5	$^{27}Al(n,p)^{27}Mg$	9.45 m	843.8	72.0

Measurements of gamma ray lines associated to each one reaction were carried out in a HP Ge INTERTECHNIC of 4.0 keV of resolution in the 1332.4 keV gamma line of ^{60}Co. The peak areas analysis was based on the program SPECTRUM ANALIZER [5] developed for IBM compatible personal computers. The total absorption peak was calculated by mean of program EFIC v. 1.0, developed in the project EUROMET 482 by investigators of INST.

Irradiation Geometry:

All foils were irradiated on the surface of source to make use of the maximal neutron flux density. This fact obliged to realize geometrical corrections, to keep in mind the no punctual geometry of the source . Figure 1 shows the irradiation device whit it three irradiation positions: 2.36, 3.83 and 5.83 cm from the surface source. Whit its three irradiation positions, furthermore the surface, were obtained four values of neutron flux density be able to est-
ablish the comparison among results.

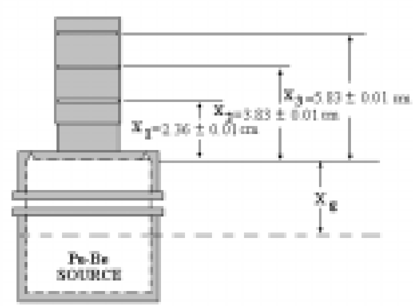

Fig 1 Irradiation Geometry

For a punctual geometry, the neutron flux density can be calculated by:

$\Phi_1(x_i) = \dfrac{Q}{4\pi(x_g + x_i)^2}$, where Q is the intensity of the source, x_i is the monitor position on the source and x_g is the distance from the upper surface of the source to it geometrical center (1.88 cm).

However, if we take into account the source dimensions, the expression used most be: $\Phi_2(x_i) = \dfrac{Q}{2\pi a^2 + 2\pi al}.\Omega(x_i)$, where **a** and **l** are respectively the radius and the height of the source and $\Omega(x_i)$ is the geometric factor subtended from the disc foil to the surface of the source, which is determined by the Monte Carlo method. Figure 2 shows the comparison among values of experimental neutron flux density determined by the reaction $^{115}In(n,n')^{115}In^m$

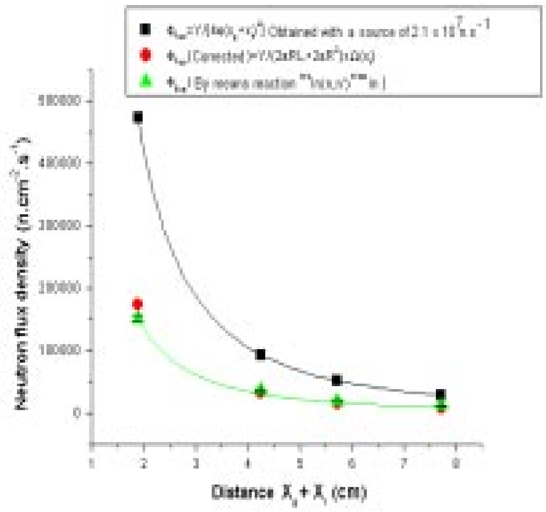

Fig 2 Neutron flux density comparison

III ABSOLUTE DETERMINATION OF $\overline{\sigma}$

The absolute determination of $\overline{\sigma}$ is based by the use of the expression to calculate the response function of the HP Ge detector, for gamma rays which come from the activated product nucleus, presented above in Table I:

$$\overline{\sigma} = \frac{A_{nc}\lambda W.e^{\lambda t_d}\, t_r/t_v}{0.6\Phi_2 I_\gamma \theta \varepsilon_p m(1 - e^{\lambda t_i})(1 - e^{-\lambda t_r})} \qquad (1)$$

where:

A_{nc} is the net peak area or number of counts in the full-energy peak, corrected for pulse losses (dead time, random and true coincidences), λ is the constant decay, W is atomic weight, 0.6 is the Avogadro's number, Φ_2 is the neutron flux density to x_i = 0 cm and integrated for all the energy spectrum of the Pu-Be source from 1.4 to 12.0 Mev, I_γ is the branching ratio, θ is the isotopic abundance, ε_p is the absolute efficiency of the full-energy peak for zero distance between the monitor and the detector , m is the monitor mass and t_d, t_i,

t_v y t_r are respectively the decay time of product isotope, irradiation time of the monitor, life time of the detector counting and the real time of the detector counting.

Comparison among $\bar{\sigma}$ values experimentally obtained in four reaction of Table I, with the reported by other authors [2] by means of excitation functions, should be realized averaging the values of the reported cross-sections between the reaction threshold energy and the maximum energy reported in the excitation function and the energy sector corresponding to Pu-Be source, i.e.:

$$\bar{\sigma} = \frac{\int_{E_{umbral}}^{E_{max}} \sigma(E)\Phi(E)dE}{\int_{E_{umbral}}^{E_{max}} \Phi(E)dE} \qquad (2)$$

Figures 3a and 3b show a example of the comparison procedure in the $^{113}In(n,n')^{113}In^m$ reaction. Figure 3a shows a sample of the neutron flux fractions vs. the neutron energy in the Pu-Be source, while we can observe in figure 3b the excitation function of the cited reaction conformed with the results of different authors. Data where don't appear experimental information reported, are evaluated for be able to realize the $\bar{\sigma}$ calculation by means of expression (2).

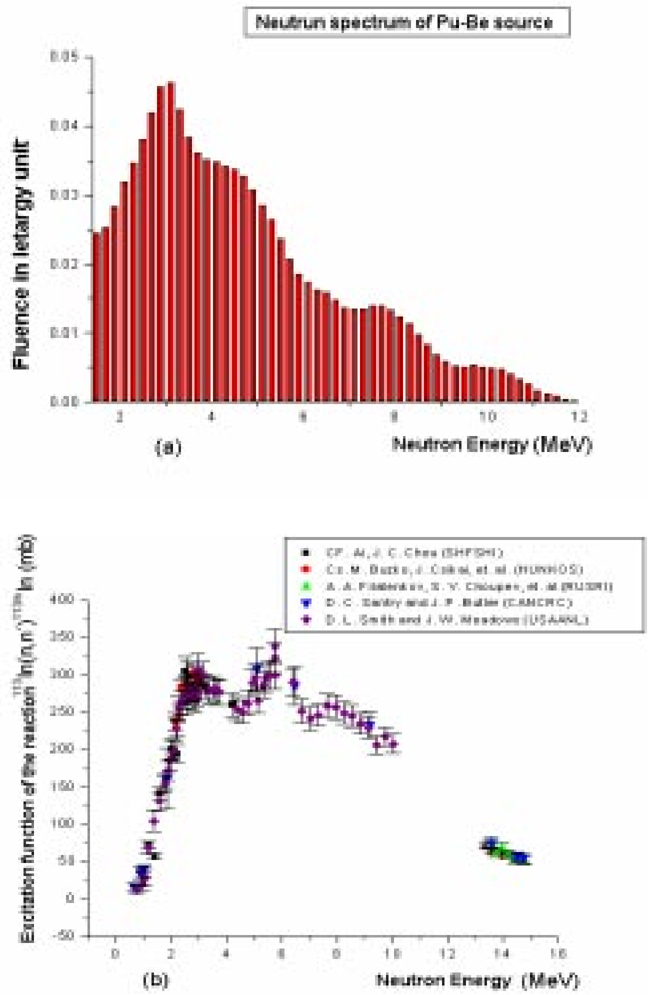

Fig 3 Neutron distribution in a Pu-Be source the excitation function of the reaction $^{113}In(n,n')^{113}In^m$.

IV DETERMINATION OF THE ISOMERIC RELATIONS

The activation formula of the ground state, with activation cross-section σ_g, which include the de-excitation of the isomeric states with activation cross-section σ_m, it vary due to the post-irradiation contribution of the nucleus which find in its excited state. Therefore, the number of atoms in ground state which decay in cooling time **t**, its can be express as:

$$\Delta N_g(t) = \left[N_g(\sigma_g,\sigma_m,t_i,\Phi_2,n) - \frac{\alpha\lambda_m N_m(\sigma_m,t_i,\Phi_2,n)}{\lambda_g - \lambda_m} \right] \left(1 - e^{-\lambda_g t}\right) + \frac{\alpha\lambda_m N_m(\sigma_m,t_i,\Phi_2,n)}{\lambda_g - \lambda_m} \left(1 - e^{-\lambda_m t}\right) \qquad (3)$$

where $N_g(\sigma_g,\sigma_m,t_i,\Phi_2,n)$ is the number of atoms in ground state, after irradiation of the monitor and depend of the formation cross-section of the ground state σ_g, of the metastable state σ_m,, the neutron flux density of the source Φ_2 and number of atoms in the target or monitor **n**, $N_m(\sigma_m,t_i,\Phi_2,n)$ is the number of atoms in metastable state, after the irradiation of the monitor, λ_g, λ_m, y σ_g, σ_m are the decay constants and the cross-sections of formation of ground and metastable states, respectively and α is the branching ratio in the decay of the metastable state.

If we now write:

$$A = \left[N_g(\sigma_g,\sigma_m,t_i,\Phi_2,n) - \frac{\alpha\lambda_m N_m(\sigma_m,t_i,\Phi_2,n)}{\lambda_g - \lambda_m} \right] \text{ y } B = \frac{\alpha\lambda_m N_m(\sigma_m,t_i,\Phi_2,n)}{\lambda_g - \lambda_m}$$

Then, the response function of the HP Ge detector corrected for pulse losses as function of cooling time it can write as:

$$A_{nc}(t) = A.\left(1 - e^{-\lambda_g t}\right) + B.\left(1 - e^{-\lambda_m t}\right)$$

where A and B are now the fitting parameters of the response function of the detector as function of the cooling time and in this way its can be determined the formation cross-sections of the ground state σ_g, of the metastable state σ_m, the activation cross-section $\sigma_{act}=\sigma_g+\sigma_m$ and the isomeric relations σ_m/σ_g y σ_m/σ_{act}.

V RESULTS AND CONCLUSIONS

Knowing the neutron flux density $\Phi_2(x_i=0)$, substituting it in (1) is very easy determined the average activation cross-sections of the studied reactions. Table 2 reports the results of the determined cross-sections by the expression (1) and the determined by the averages reported by means of excitation functions, take in to account that the irradiation was realized with a source of Pu-Be (expression 2).

Table 2 Comparison of the average cross-sections.

Reaction	**$\bar{\sigma}$ Experimental (1) (mb)**	**$\bar{\sigma}$ Reported (2) (mb)**	**Concord (%)**
$^{113}In(n,n')^{113}In^m$	272 ± 21	305 ± 30	89
$^{115}In(n,n')^{115}In^m$	221 ± 13	258 ± 26	86
$^{27}Al(n,\alpha)^{24}Na$	8.3 ± 0.7	9.8 ± 1.5	82
$^{27}Al(n,p)^{27}Mg$	30.0 ± 2.0	28.4 ± 8.5	93

The errors on the experimental determinations of the cross-sections by the expression (1), were due fundamentally to the error in the determination of neutron flux density, and depend at the same time of the intensity reported on the passport $Q = (2.1 \pm 0.1) \times 10^7$ n.s^{-1} and the determination of net peak area error, which was fixed for the measurement times so that producing errors in the gaussian fitting below 5 %. In the case of cross-sections reported, determined by expression (2), the errors were due fundamentally to the individual errors reported by the authors in [2] and the fitting realized for the evaluated data.

Table 2 also shows the concordances in per cent amount the values experimentally determined in this work and the reported in the literature. All results are above of 80 %, therefore its are in the same order of concordances amount the cross-section data which appear reported in the excitation functions by different authors.

For the determination of the isomeric relations in the reaction $^{113}In(n,2n')^{112}In^{m,g}$ was used data reported en la Table 3:

Table 3 Data used for the determination of the isomeric relation

Studied Reactions	$T_{1/2}$	E_γ (keV)	I_γ (%)
$^{113}In(n,2n')^{112}In^{m}$	20.9 m	155.5	12.8
$^{115}In(n,2n')^{112}In^{g}$	14.4 m	511.0	43.6

Gamma line of 511.0 keV was used for to find the number of decay nucleus in ground state without the positronic background in the laboratory. Figure 4 shows the fitting realized in the determination of A and B, which were determined the cross-section of metastable state and the isomeric relations:

$$\sigma_m = (65 \pm 9) \text{ mb}$$

$$\frac{\sigma_m}{\sigma_g} = 2.065 \pm 0.268$$

$$\frac{\sigma_m}{\sigma_m + \sigma_g} = 0.320 \pm 0.006$$

Unfortunately, its results can’t be compared with accuracy and only tendencies may be achieved, because in the literature appear only the result obtained with neutron generator, i.e. with energies around 14 MeV.

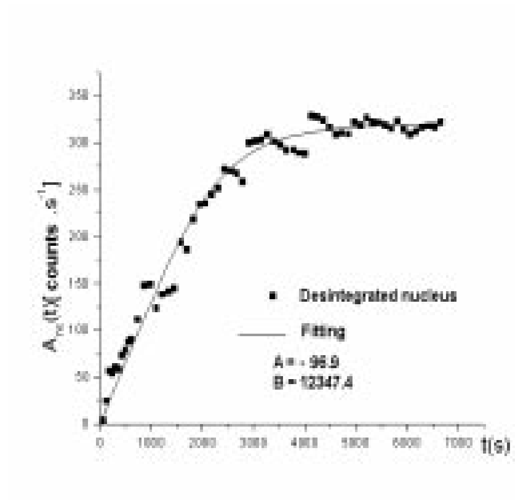

Fig 4 Results from the fitting of $A_{nc}(t)$ for the reaction $^{113}In(n,2n')^{112}In^{m,g}$.

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