International Atomic Energy Agency

INDC(CCP)-389
Distr. L

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INTERNATIONAL NUCLEAR DATA COMMITTEE

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Translated from Jadernye Konstanty 1993/1 p. 13-16

December 1994

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

Printed by the IAEA in Austria
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94-11796 (20)
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UDC 539.172.4

NEUTRON RADIATIVE CAPTURE CROSS-SECTIONS FOR THE ^{232}Th AND ^{197}Au NUCLEI IN THE 0.37-1 MeV REGION

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ABSTRACT

The activation method was used to measure the neutron radiative capture cross-sections for thorium-232 in the energy range from 0.37 to 1 MeV relative to $\sigma_{n,\gamma}$ for ^{157}Au and $\sigma_{n,f}$ for ^{235}U. The neutron source was the reaction T(p,n)^{3}He. The induced activity was recorded with a Ge(Li) detector on the basis of the ^{233}U gamma-line with E = 312 keV. At the same time, the radiative capture cross-section for ^{197}Au relative to $\sigma_{n,f}$ for ^{235}U was determined.

INTRODUCTION

The ecological consequences of large-scale use of nuclear power are a subject of constant and extensive discussion. These include the problem of disposal of heavy transactinides. In this connection, ever-increasing interest is being shown in the ^{232}Th-^{233}U cycle, in which transactinide accumulation is lower.

The present work was carried out as part of studies on the above cycle in order to refine the capture cross-sections for ^{232}Th. It is in continuation of our earlier work, especially that reported in Ref. [1], and extends the latter to the region of lower neutron energies.

EXPERIMENT

The experimental procedure and the procedure of treatment of experimental results were described in our earlier studies [1, 2, 3, 4], where we presented all the relations needed to determine the cross-sections to be measured on the basis of experimentally determined and calculated parameters. Here we mention only some aspects of the procedure.

The activation method was used to measure the radiative capture cross-section for ^{232}Th relative to cross-sections $\sigma_{n,\gamma}$ for ^{197}Au and $\sigma_{n,f}$ for ^{235}U. At the same time, the radiative capture cross-section for ^{197}Au relative to $\sigma_{n,f}$ for ^{235}U was measured in the experiment.

The neutron source was the reaction T(p,n)^{3}He, which was conducted in the KG-2.5 accelerator of the Institute of Physics and Power Engineering. We used ScT_2 targets with a thickness of 0.64-0.90 mg/cm^2 (96-135 keV at the reaction threshold). The target was cooled by air.

The thorium samples (ThO_2) were packed in stainless steel containers. The thorium and gold samples were 2 cm in diameter and about 1 g in weight. The samples were fixed close to each other in the target assembly at a distance of $\sim$4 cm from the neutron source centre.

The distance of the ^{235}U layer in the flow-type fission chamber from the neutron source was $\sim$5 cm. The induced activities were recorded with a Ge(Li) detector - with respect to the ^{198}Hg line with E_γ = 411.8 keV for gold and the ^{233}U line with E_γ = 311.9 keV for thorium.

An SM-3 computer was used to control the electronics of the experimental assembly.

MEASUREMENT OF THE DECAY AND FISSION EVENT RECORDING EFFICIENCY

The efficiency of decay event recording by the Ge(Li) detector was determined in the following manner. First of all, we determined the dependence of photon recording efficiency ϵ_γ on photon energy at such a distance d from the detector surface that the samples of the isotopes under study could be regarded as points. At this distance the dependence of ϵ_γ on photon energy was measured with the help of standard gamma sources. This dependence was described functionally. It was used to calculate the values of ϵ_γ for the ^{198}Hg and ^{233}U γ-lines. These ϵ_γ values were then used to determine the absolute values of activities of the thorium and gold samples irradiated with neutrons from the BR-1 fast reactor. The measurements were performed at the same distance d from the detector surfaces. Thereafter the activity of the same samples was measured in the geometry in which the samples irradiated in the accelerator had been measured.

On the basis of these measurement results, using the values of quantum yield of the gamma rays recorded in the decay scheme of the nuclides under study, we calculated the efficiencies of recording decay events for ^{198}Au and ^{235}Th.

The efficiency of recording fission events for ^{235}U was determined from the results of processing the pulse amplitude spectrum of the fission chamber irradiated by a known thermal neutron flux. The flux magnitude was determined from the induced activity of a thin gold sample irradiated at the same time in the same flux. The absolute value of the activity of this sample was found by the 4π β-γ coincidence method. The obtained value of efficiency refers to some chosen recording threshold, and this was taken into account in treating the results of measurements in the accelerator.

CORRECTIONS FOR SCATTERED NEUTRONS

Scattered neutrons make an appreciable contribution to the effect recorded for all the detectors used in the study (^{232}Th, ^{197}Au and fission chamber with a ^{235}U layer). Their influence is taken into account for each detector separately. A unified neutron recording model was used for all the detectors:

$$N_{tot} = N_{\exp} + \sum_{i=1}^{n} N_{\Phi_i} \tag{1}$$

Here N_{tot} is the number of interactions of source neutrons in the absence of components of the experimental assembly and N_{Φ_i} the number of interactions occurring because of the presence of the experimental assembly ("background interactions"). The number of "background interaction" sources is n = 5-6.

Transforming expression (1), we obtain

$$N_{\exp} = N_{tot}\,(1 - \sum_{i=1}^{n} \Delta N_{\Phi_i}) = N_{tot} \cdot B. \tag{2}$$

Expression $B = (1 - \sum_{i=1}^{n} \Delta N_{\Phi_i})$ is the correction for scattered neutrons.

In several of our previous studies, for example Ref. [4], B was measured experimentally. In processing the present experiment's data we used results obtained by calculation.

The calculations were performed by the Monte Carlo method and the BRAND program package [5]. The geometrical configuration of the experimental assembly and the distances between the components were reproduced accurately. The mass of the assembly was 25.7 g (0.40 · 10^{24} nuclei), and the chemical composition comprised 14 elements. The statistical uncertainty of the calculated values was within 0.3-0.5%.

The calculated value of the correction in the notation used above was $(1 - \sum_{i=1}^{n} \Delta N_{\Phi_i})$.

These calculations do not enable us to determine the background of the room - the influence of neutrons scattered in the room where the irradiation is performed. Therefore, for all the detectors the values of ΔN_{Φ_i} were determined experimentally. In the neutron energy region considered the room background varied in the following ranges: fission chamber 1.6-2.4%, Au sample 0.5-0.9%, thorium sample 0%. Correction B was calculated from the calculation and experimental data by the above formula. The results of calculation of correction for all the detectors are given in Fig. 1. The uncertainties given in the figure represent the total uncertainties of calculation and experiment.

For one of the detectors, namely the fission chamber, correction B was calculated and experimentally determined. Comparison yielded the following results. The B_{exp}/B_{cal} ratio has a scatter of 0.980-1.002 and an uncertainty of 1.2-1.8%. From these results it can be concluded that the agreement between calculation and experiment is good. Specifically, in the case of the fission chamber it can be stated that the use of the calculated instead of the measured values of B changes the obtained radiative capture cross-section values by not more than 2%.

During treatment of the experimental data preference was given to the calculated corrections B for the fission chamber. This choice was based on the following considerations. The radiative capture cross-section calculations use the ratios B_{Th}/B_{fc} and

B_{Au}/B_{fc}, where B_{Th}, B_{Au} and B_{fc} are the corrections for scattered neutrons in the case of thorium, gold and fission chamber, respectively. The sources of possible systematic errors during the calculations are identical for all the detectors and their influence is quantitatively similar. Therefore, the use of the ratio of these calculated corrections should partially compensate for the systematic uncertainty in the calculation results.

MEASUREMENT RESULTS

The evaluated data for $\sigma_{n,\gamma}$ of ^{197}Au and $\sigma_{n,f}$ of ^{235}U from the standards library were used as the standard cross-sections in the present study.

Table 1 gives the results of our measurements of $\sigma_{n,\gamma}$ for ^{197}Au relative to $\sigma_{n,f}$ for ^{235}U in comparison with the evaluated data from the ENDF/B-VI library. The good agreement between our data and the evaluation is noticeable.

Table 2 gives the measurement results of the radiative capture cross-sections for ^{232}Th relative to $\sigma_{n,\gamma}$ for ^{197}Au and $\sigma_{n,f}$ for ^{235}U in comparison with the evaluated data from BROND-2 [6], ENDF/B-VI [7] and JENDL-3 [8].

In the case of 800 and 1000 keV neutron energies, the data of the present study show satisfactory agreement with those of our earlier work [1]. Our data are in good agreement with the JENDL-3 evaluation for 370, 439 and 552 keV but are 8-12% lower in the case of 800 and 1000 keV.

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Table 1. Results of measurements of $\sigma_{n,\gamma}$ for ^{197}Au relative to $\sigma_{n,f}$ for ^{235}U

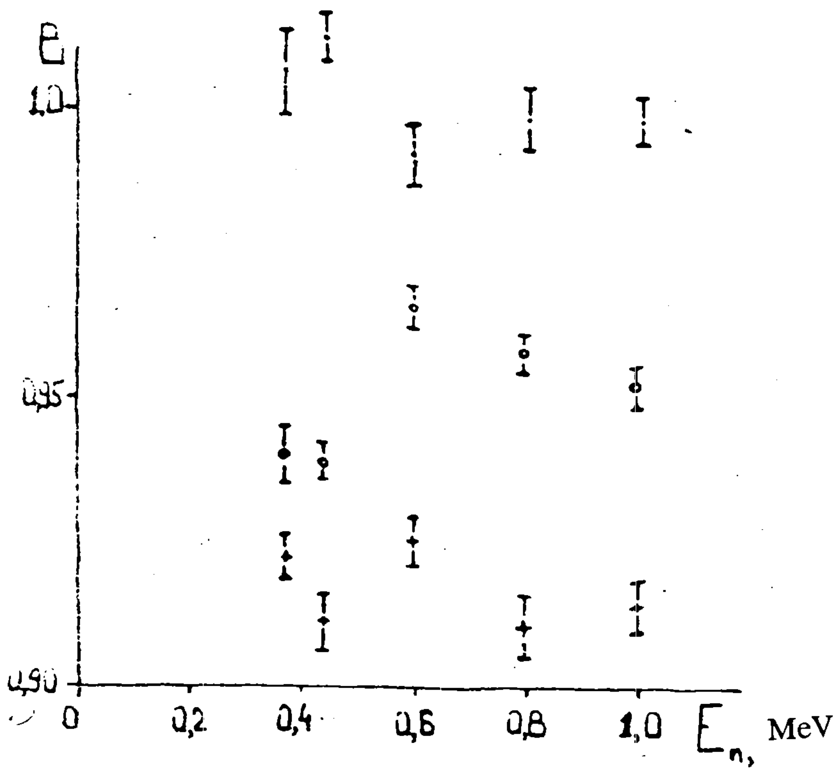
N	$<E_n> \pm\sqrt{D}$, keV	Present work, mb	ENDF/B-VI data, mb
1.	370±32	170±3	170,5±1,3
2.	439±38	151±3	149,5±1,2
3.	592±31	113±3	111±1,4
4.	800±32	87,5±1,6	83,8±1,6
5.	1000±31	80,5±3	80,3±2,5

Table 2. Results of measurements of $\sigma_{n,\gamma}$ for ^{232}Th

N	$<E_n>$ $\pm\sqrt{D}$ keV	Relative to		BROND, mb	ENDF/B-VI mb	JENDL-3, mb
		$\sigma_{n,\gamma}$ ^{197}A, mb	$\sigma_{n,f}$ ^{235}U, mb			
1.	370±32	137±5	135±5	150	143	128,5
2.	439±38	129±2,5	130±3,5	150	145	131
3.	592±31	134±3,5	136±4,5	165	165	139
4.	800±32	140±3,5	137±4,5	163	160	151
5.	1000±31	113±4,5	112±3	135	135	130

Remarks: The uncertainties are give as %. D denotes dispersion of the spectrum of neutrons irradiating the detectors [1, 2, 3].

<u>Fig. 1</u>. Corrections for scattered neutrons: o - fission chamber with [235]U + gold sample, ● - ThO_2 sample.



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