INDC(POL)-003/L

No 1197/I/PL

INSTYTUT BADAN JADROWYCH
ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ
INSTITUTE OF NUCLEAR RESEARCH

INR--1197

REPORT No 1197 /I/PL

PROGRESS REPORT
ON NUCLEAR DATA RESEARCH IN POLAND
/May 1969 - April 1970/

Gathered by
Andrzej Marcinkowski

WARSZAWA
1970

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Drukuje i rozprowadza:
OŚRODEK INFORMACJI O ENERGII JĄDROWEJ
przy Pełnomocniku Rządu dla Spraw Wykorzystania Energii Jądrowej
Warszawa, Pałac Kultury i Nauki

Wydaje
Instytut Badań Jądrowych

Nakład 540 egz., Objętość ark. wyd. 1,66
Ark. druk 2,75, Data złożenia maszynopisu
przez autora 9. V. 1970, Oddano do druku
19. V. 1970 Druk ukończono VI 1970.
SP-09/250/66 Zam. nr 245/70

Editor's Note

This progress Report on nuclear data research in Poland /May 1969 - April 1970/ contains only information on research, which is closely related to the activities of the International Data Committee of the International Atomic Energy Agency in the field of neutron physics. It does not include any information about other nuclear research as for example in the field of charged particles nuclear physics or the use of neutrons for solid state physics studies.

The individual reports are not intended to be complete or formal, and must not be quoted in publications without the permission of the authors.

Uwagi od wydawcy

Raport ten zawiera wyłącznie informacje o badaniach w zakresie fizyki neutronowej przeprowadzonych w Polsce /maj 1969 - kwiecień 1970/ i związanych z działalnością Komitetu Danych Jądrowych Międzynarodowej Agencji Energii Atomowej.

Pominięto wyniki badań w innych dziedzinach fizyki jądrowej, w tym również badań prowadzonych przy użyciu cząstek naładowanych oraz w zakresie fizyki ciała stałego przy użyciu neutronów.

Poszczególne prace zawierają wstępne omówienie wyników badań nie wyczerpujące poruszanych tematów i nie powinny być cytowane bez uzyskania zgody autorów.

Замечания от редакции

Сборник этот содержит лишь сообщения о проведенных в Польше в период от мая 1969 до апреля 1970 исследованиях в области нейтронной физики, связанных с деятельностью Комитета по Ядерным Данным Международного Агенства Атомной Энергии. В данный сборник не включены результаты работ из других областей ядерной физики а именно результаты исследований с помощью заряженных частиц а также результаты исследований в области твердого тела с применением нейтронов.

Доклады эти не являются полными и поэтому не рекомендируется ссылаться на них без особого согласия авторов.

CONTENTS

Investigation of the Nuclear Surface by Means of (n,α) Reactions.

N.Jaskóła, W.Osakiewicz, J.Turkiewicz.

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and

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The cluster structure of the nuclear surface has been investigated using the (n,α) reactions, induced by the 14 MeV neutrons. The use of such reactions as a tool for investigating the nuclear surface has been proposed in our earlier works (1), (2). This method has been successfully used in several works (3), (4), (5), (6), to obtain the information about alpha clustering at the surface of heavy nuclei. In our model the (n,α) reaction is assumed to take place only in a thin nuclear surface layer because of small mean free path of alpha particles in nuclear matter. The dominance knock-out mechanism in this reaction is also supposed. If the cross section and the energy spectrum of emitted alpha particles are known it is possible to extract the alpha clustering probability at the nuclear surface.

Following the notation used in (2) the cross section for the (n,α) reaction can be writen as:

$$\sigma(n,\alpha) = \int_V \int_{\vartheta_2}^{\vartheta_2} \int_{\varphi_1(\vartheta)}^{\varphi_2(\vartheta)} \tilde{v} p N_\alpha \, \sigma(\vartheta) \sin\vartheta \, d\varphi \, d\vartheta \, dV$$

where ρ is the fraction of the time the surface nucleon spends as a part of an alpha substructure.

Recently we performed the calculations of the factor ρ for the following nuclei : ^{122}Te, ^{159}Tb, ^{162}Dy, ^{168}Er and ^{169}Tm. The results are presented in Fig.1 in which are also presented our earlier results /^{139}La, ^{181}Ta, ^{197}Au / together with values obtained by other authors.

Calculations taking into account, the deformations of nuclei are in progress.

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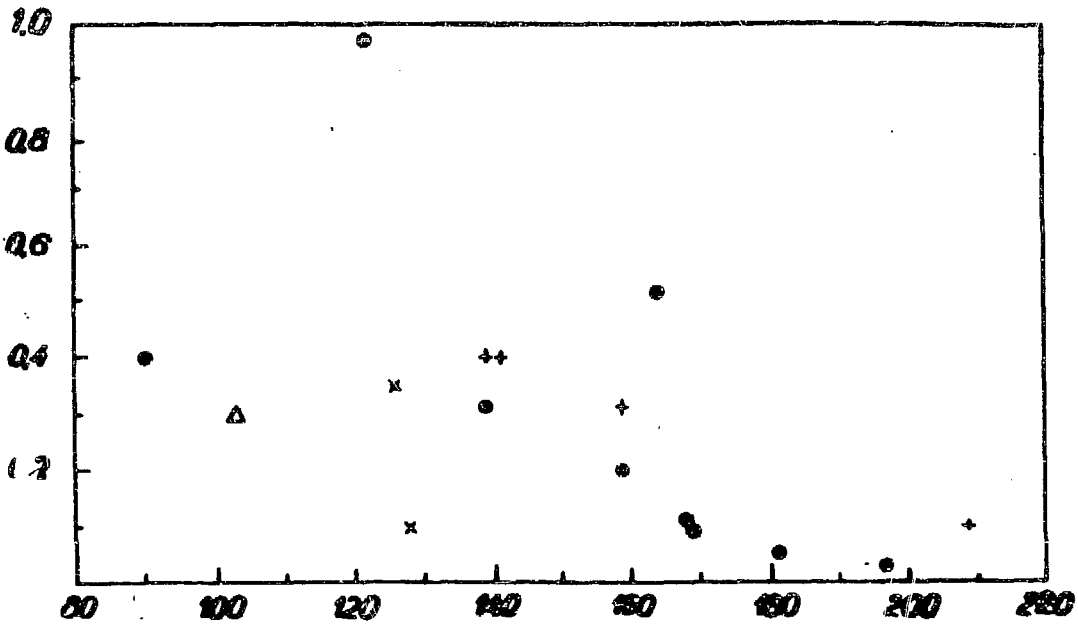

Fig.1. The tendency to alpha clustering at the nuclear surface in its dependence on the mass number; ● this work; + ref./3/; △ ref./5/; × ref./6/; ● ref./7/.

Energy Spectra of Alpha Particles from the (n,α) Reactions Induced by 14.2 MeV Neutrons in Dysprosium Isotopes.

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J.Turkiewicz, L.Zemło.

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and
Institute of Experimental Physics, University of Warsaw.

The studies of the (n,α) reactions induced by fast neutrons in heavy nuclei, results of which were earlier described /1/, /2/, /3/, have been continued. The energy distributions of alpha particles from the $^{161}Dy(n,\alpha)^{158}Gd$, $^{163}Dy(n,\alpha)^{160}Gd$ and $^{164}Dy(n,\alpha)^{161}Gd$ reactions at 14.2 MeV have been measured using semiconductor detectors as alpha particle spectrometers. The dysprosium targets were made of oxides and deposited on the thick aluminium backings by means of sedimentation from the suspension in isopropyl alcohol.

The results of the measurements are shown in Figs.1 - 2. All the spectra were measured for the forward angles. The error bars in the figures refer to statistical errors only.

Fig.1 shows also the theoretical predictions obtained by applying the Weisskopf-Ewing formula. The values used for inverse cross sections were taken from the calculations of Huizenga and Igo /4/. The energy dependence of the level density was assumed in the form: $\rho(U) \sim U^{-2}\exp(2\sqrt{aU})$, with the density parameter a taken from Erba et al./5/. The calculated curves are not normalized and are given to indicate the shape and the position of the evaporation spectra only.

The theoretical analysis is not yet finished and further calculations are in progress.

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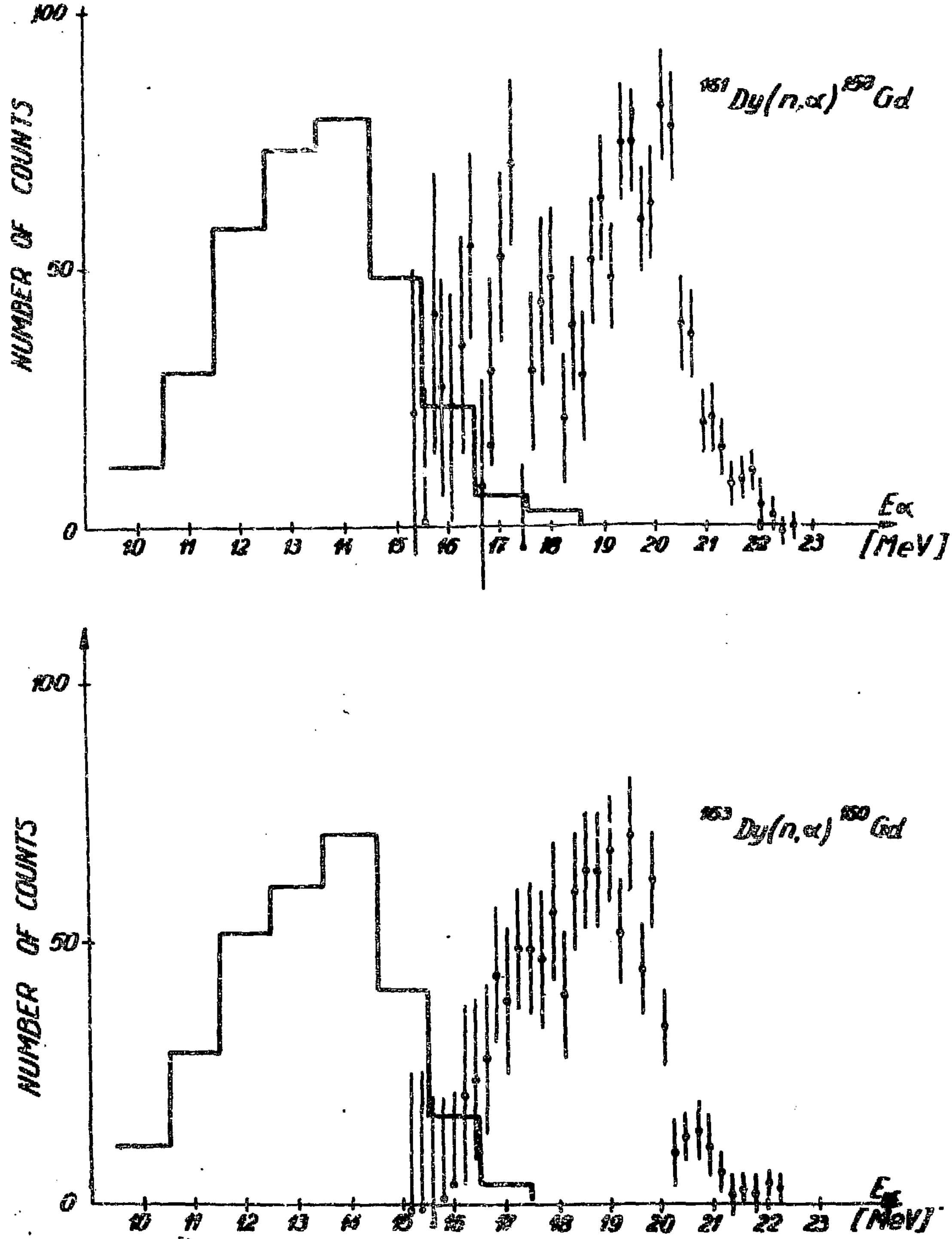

Fig. 1 The experimental α- particle spectra from the $^{161}Dy/n,\alpha/^{158}Gd$ and $^{163}Dy/n,\alpha/^{160}Gd$ reactions,and the predistions of the statistical theory.

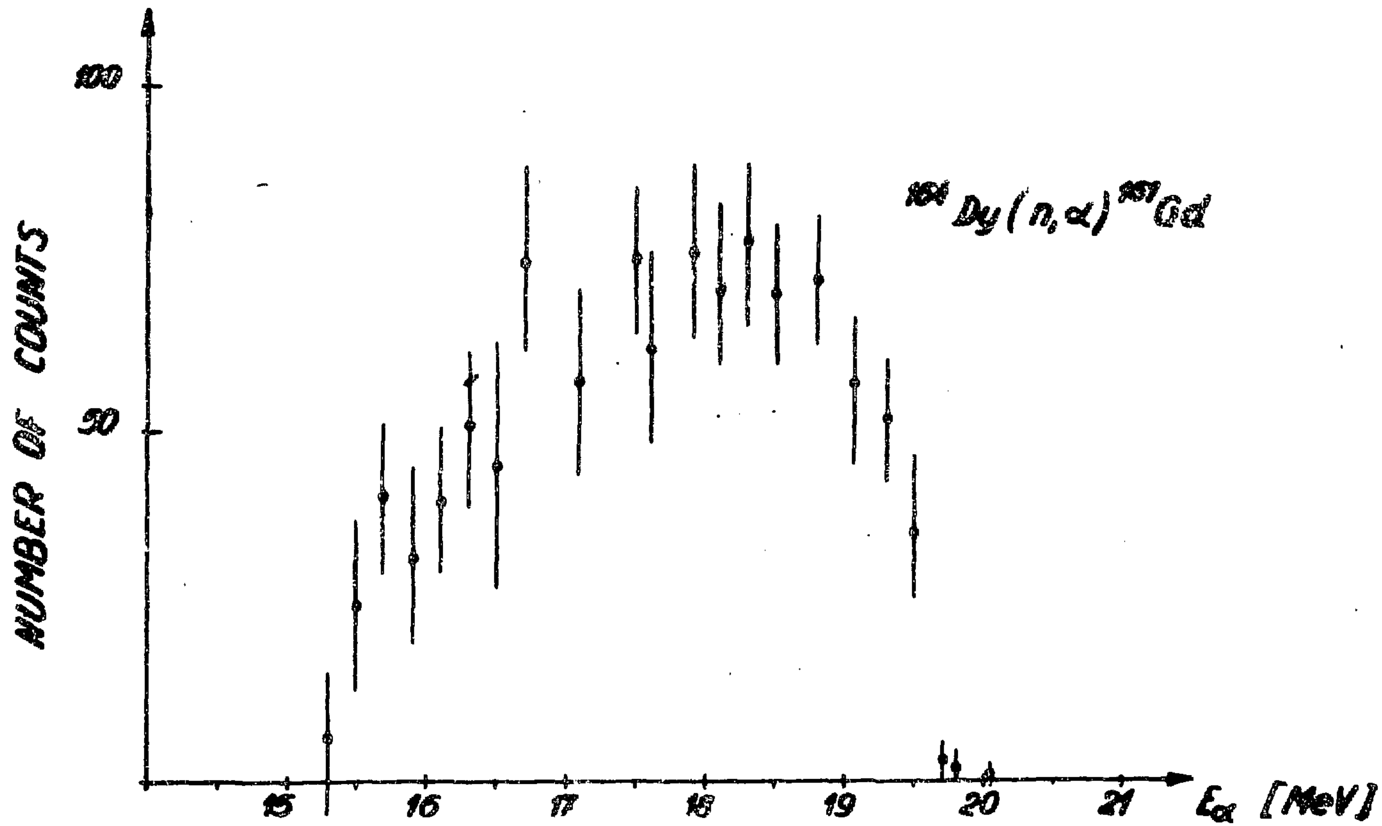

Fig. 2 The experimental α- particle spectrum from the $^{164}Dy/n,\alpha/^{161}Gd$ reaction.

Isomeric Cross Section Ratios and Total Cross Sections for the $^{113}In(n,2n)^{112g,m}In$ and $^{115}In(n,2n)^{114g,m}In$ Reactions

W.Grochulski, J.Karolyi[x)], A.Marcinkowski, J.Piotrowski, E.Saad[xx)], K.Siwek and Z.Wilhelmi

1. INTRODUCTION

The application of the nuclear level density based on the superconductivity model [1)] for calculating the cross section ratios and total cross sections was presented in ref./2/,/3/. To collect more experimental material for confirming the correctness of the description of isomeric ratios by the superconductivity model the cross sections for the $^{113}In(n,2n)^{112g,m}In$ and $^{115}In(n,2n)^{114g,m}$ reactions were measured in the neutron energy range from 13.1 MeV to 18.2MeV. The results obtained were compared with the statistical model predictions calculated as in ref. /2/.

2. EXPERIMENTAL PROCEDURE

Samples of spectrally pure indium were irradiated with neutrons obtained in the $^3H(d,n)^4He$ reaction. The deuterons were accelerated in a 3 MeV Van de Graaff accelerator. The changes of the neutron flux during irradiation were determi-

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x) on leave from the Institute of Nuclear Research, Debrecen, Hungary,

xx) on leave from the Atomic Energy Establishment of UAR

ned by counting in a CsI scintillator the protons recoiled from a polyethylene foil.

The gamma activity of the irradiated samples was measured using the spectrometer with a single 3 x 3 inch. NaI(Tl) crystal. The photo-peak efficiencies of the spectrometer were taken from tables of Crouthamel /4/. The β^- were measured using a GM counter. In the case of the $^{113}In(n,2n)^{112g,m}In$ reaction the 14.3 m and 20.7 m β^+ activities allowed to determine the isomeric ratio by measuring the annihilation quanta. The cross section σ_m for the population of the metastable state was measured relative to the known cross section of the $^{64}Zn(n,2n)^{63}Zn$ reaction. Having σ_m and the isomeric ratio the total cross section was determined.

In the case of the $^{115}In(n,2n)^{114g,m}In$ reaction σ_m was determined by measuring the 51 d activity of the 191 keV γ- rays relative to the cross section of the $^{204}Pb(n,2n)^{203}Pb$ /5/ reaction. The attenuation of the gamma rays in the samples was taken into account. The σ_g cross section for the population of the ground state was determined by measuring the 72s - β^- activity refering to the 51d- β^- activity resulting from the decay of the ^{114m}In state.

3. RESULTS

The results of measurements of the isomeric ratios and total cross section are shown in Table 1 and in Figs. from 1 to 4. The experimental errors are statistical errors only. The neutron energy spread was determined according to the method described in ref. /2/.

The results of the isomeric ratios for the $^{113}In(n,2n)$ $^{112g,m}In$ reaction confirm the single measurement at E_n = 14.7 MeV done by Rötzer /7/ who obtained the value σ_g/σ_m = 0.2. The result obtained in ref. /6/ is much higher.

The total cross section values presented in ref. /6/ and ref. /7/ agree within the experimental errors with our measurements.

Results for the $^{115}In(n,2n)^{114g,m}In$ reaction agree well with the isomeric ratio for 14.7 MeV neutrons given in ref. /6/ and ref. /7/ and the cross sections measured by Prestwood and Bayhurst /8/ but differs considerably from those obtained by Menlove et.al. /9/.

4. COMPARISON OF THE EXPERIMENTAL RESULTS WITH THE STATISTICAL THEORY

The theoretical calculations were performed according to the statistical method described in detailes in ref./2/. The optical model transmission coefficients were taken from the tables of Mani, Melkanoff and Iori /10/.

Because of the high excitation energies involved in both reactions the level density was used for describing the excited states. The nuclear level density was calculated using the superconductivity model. This model refers to doubly even nuclei. For an odd-odd or odd-mass nucleus the excitation energy was shifted in the way presented in chapter 5 of ref. /3/.

Table 1

E_n (MeV)	$^{113}In(n,2n)^{112g,m}In$		$^{115}In(n,2n)^{114g,m}In$	
	σ_g/σ_m	σ_{tot} (mb)	σ_g/σ_m	σ_{tot} (mb)
12.98 ± 0.15	0.23±0.06	1369±137	0.191±0.011	1394±166
13.33 ± 0.10	0.13±0.01	1356± 68	0.155±0.003	1623± 68
13.86 ± 0.09	0.15±0.01	1503± 74	0.173±0.003	1748± 82
14.52 ± 0.12	0.06±0.01	1527± 56	0.191±0.003	1805±218
15.15 ± 0.14			0.225±0.004	1727± 78
15.17 ± 0.14	0.06±0.01	1557± 37		
15.44 ± 0.16		1725± 49	0.173±0.003	1670± 73
15.95 ± 0.19				1745±178
15.98 ± 0.19	0.10±0.02	1489± 99		
16.28 ± 0.16	0.13±0.02	1377±101		
16.59 ± 0.09			0.188±0.015	1785±273
16.86 ± 0.25			0.188±0.009	1794±186
16.87 ± 0.25	0.17±0.04	1462±219		
17.35 ± 0.24			0.185±0.017	1929±298
17.37 ± 0.24	0.16±0.03	1408±158		
17.82 ± 0.17			0.147±0.009	2014±326
17.83 ± 0.13	0.14±0.02	1445±139		

Figs.1 and 2 present the measured and the calculated isomeric ratios for the $^{113}In(n,2n)^{113g,m}In$ and $^{115}In(n,2n)^{115g,m}In$ reactions, respectively. The theoretical results (solid lines) describe correctly the measured values. The systematical enhancement of the theoretical total cross sections over the experimental ones (Figs.3 and 4) is less pronounced here as in the cases of (n,2n) reactions on lighter target nuclei /2/, /3/.

This behaviour could indicate that the competition between the emission of the second neutron and gamma deexcitation in the excitation energy region near to the threshold for the emission of the third neutron (about 17,5 MeV for the reactions considered) is less important.

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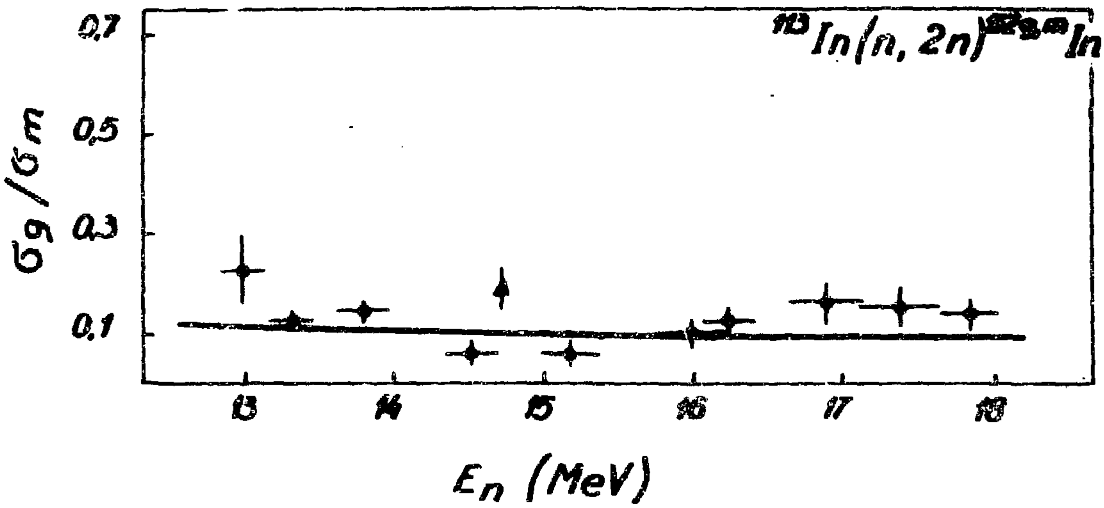

Fig.1 The isomeric ratios for the $^{113}In(n,2n)^{112g,m}In$ reaction. ● – our results; ▲ – result of ref. /7/. The solid line presents the statistical calculations based on the superconductivity model of the level density.

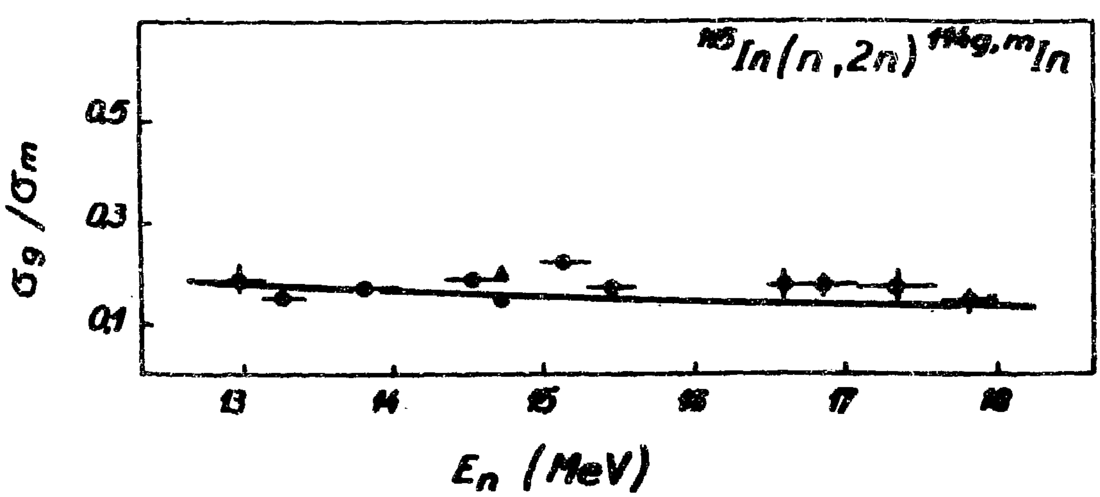

Fig.2 The isomeric ratios for the $^{115}In(n,2n)^{114g,m}In$ reaction. ● –our results; ▲ –result of ref./7/; o – result of ref. /6/. The solid line presents the statistical calculations.

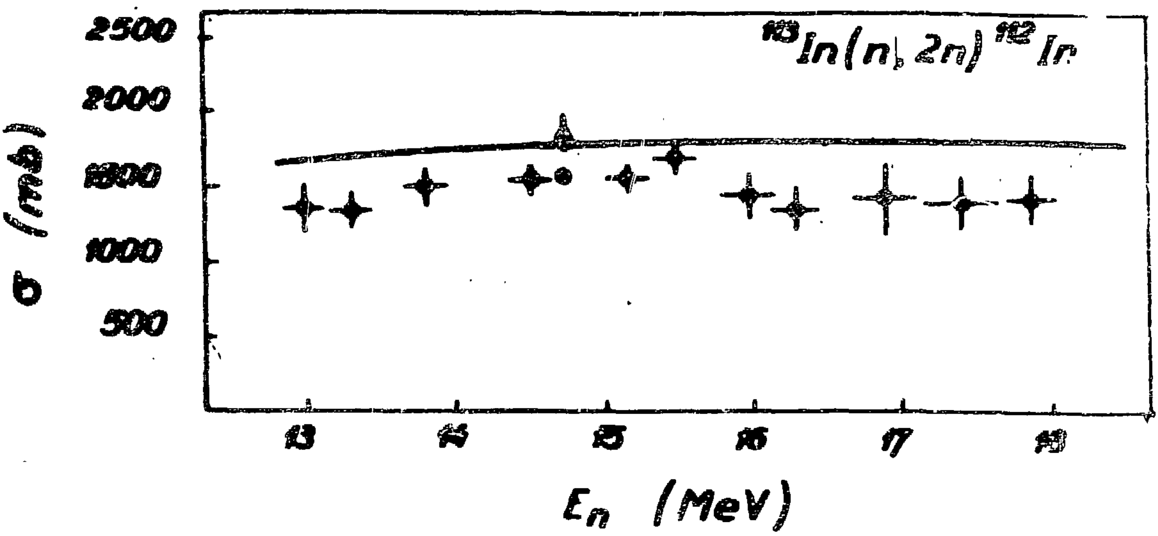

Fig.3 The cross sections for the $^{113}In(n,2n)^{112}In$ reaction. ● - our results; ▲ - the result of ref. /6/; ▲ - the result of ref. /7/. The solid line presents the statistical calculations.

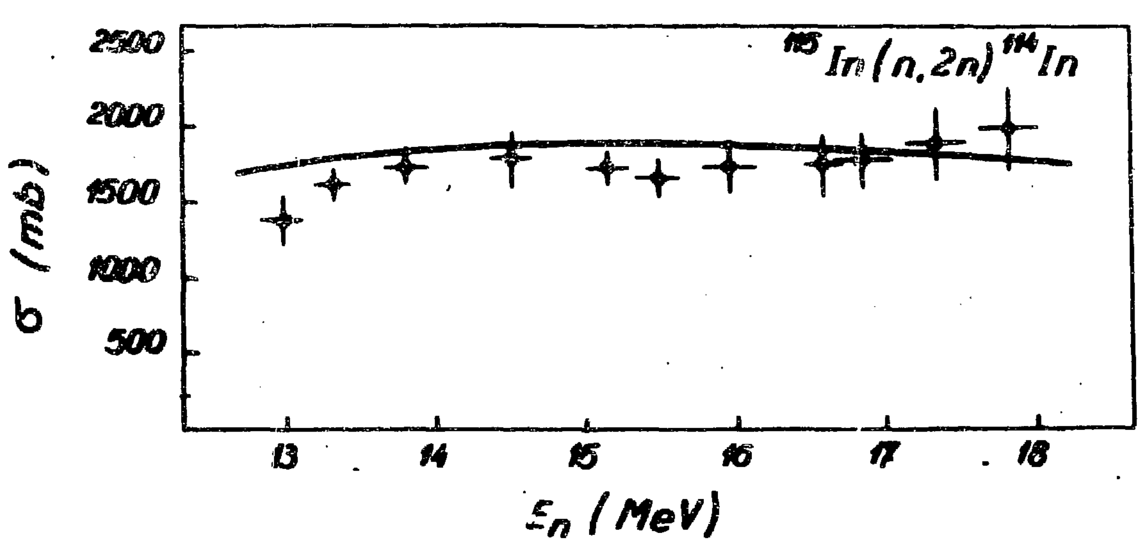

Fig.4 The cross sections for the $^{115}In(n,2n)^{114}In$ reaction. ● - our results. The solid line presents statistical calculations.

Cross Sections for the $^{113}In(n,n')^{113m}In$, $^{115}In(n,n')^{115m}In$, $^{204}Pb(n,n')^{204m}Pb$ and $^{204}Pb(n,2n)^{203}Pb$ Reactions in the Neutron Energy Range 13 - 18 MeV.

P. Decowski, W. Grochulski, A. Marcinkowski, J. Karolyi, J. Piotrowski, E. Saad, K. Siwek-Wilczyńska, I.M. Turkiewicz, Z. Wilhelmi.

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The absolute cross sections for the $^{113}In(n,n')^{113m}In$ $^{115}In(n,n')^{115m}In$, $^{204}Pb(n,n')^{204m}Pb$ and $^{204}Pb(n,2n)^{203}Pb$ reactions were evaluated from the γ-activity measurements with the use of the scintillation spectrometer. The reaction final products were identified by their characteristic γ-ray transitions and the least square analysis of the decay curves. The neutrons were obtained in the Van de Graaff accelerator from the $^{3}T(d,n)^{4}He$ reaction. The proper choice of the irradiation angle and the deuteron energy allowed to get neutrons in the energy range 13 - 18 MeV. The measurements were refered to the well known cross reactions of the $^{56}Fe(n,p)^{56}Mn$ reaction[1] except the $^{115}In(n,n')^{115m}In$ case in which the cross sections were related to the cross sections of the $^{64}Zn(n,2n)^{63}Zn$ reaction[2].

Special care was taken about the influence of low energy neutrons from the $^{2}D(d,n)^{3}He$ reaction on deuterons gathered in the tritium target during the deuteron bombardment. To take into account this effect a target made from the same material as the tritium target but not containing tritium was bombarded with deuterons and the activity induced in the irradiated samples was investigated. Correction connected with this effect were significant for the highest deuteron energies and small angles of neutron emission.

The results are shown in Tables 1 - 4 and in Figs. 1 - 4.

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Table 1

Cross Sections for the $^{113}In(n,n')^{113m}In$ Reaction

En MeV	mb
12.98 ± 0.15	104 ± 21
13.33 ± 0.10	62 ± 9
13.88 ± 0.09	37 ± 7
14.52 ± 0.12	42 ± 6
15.05 ± 0.20	30 ± 6
15.14 ± 0.14	27 ± 4
15.44 ± 0.17	19 ± 3
15.98 ± 0.17	38 ± 6
16.59 ± 0.09	45 ± 9
17.85 ± 0.14	34 ± 29

Table 2

Cross Sections for the $^{115}In(n,n')^{115m}In$ Reaction

En MeV	mb
12.98 ± 0.15	172.0 ± 14.3
13.33 ± 0.10	104.1 ± 1.9
13.84 ± 0.09	83.5 ± 1.5
14.52 ± 0.12	83.8 ± 1.2
15.14 ± 0.14	65.0 ± 0.5
15.98 ± 0.19	64.5 ± 2.3
16.28 ± 0.16	55.8 ± 2.9
16.87 ± 0.25	51.6 ± 11.4
17.37 ± 0.24	62.6 ± 12.9
17.83 ± 0.13	60.8 ± 12.4

Table 3

Cross Sections for the $^{204}Pb(n,n')^{204m}Pb$

En MeV	mb
12.85 ± 0.17	80.9 ± 1.9
12.98 ± 0.15	71.8 ± 1.7
13.56 ± 0.13	80.1 ± 1.0
14.18 ± 0.15	63.3 ± 0.5
15.05 ± 0.26	56.8 ± 0.4
15.41 ± 0.27	48.8 ± 0.3
15.48 ± 0.19	40.1 ± 0.4
16.59 ± 0.09	41.9 ± 0.4
17.83 ± 0.13	33.2 ± 7.7

Table 4

Cross Sections for the $^{204}Pb(n,2n)^{203}Pb$ Reaction

En MeV	mb
12.98 ± 0.15	1966 ± 60
13.56 ± 0.13	1963 ± 19
14.18 ± 0.15	1856 ± 18
15.03 ± 0.20	1830 ± 17
15.41 ± 0.27	1759 ± 17
15.98 ± 0.19	1874 ± 90
16.59 ± 0.09	1998 ± 57
17.37 ± 0.24	2010 ± 73
17.83 ± 0.13	1896 ± 67

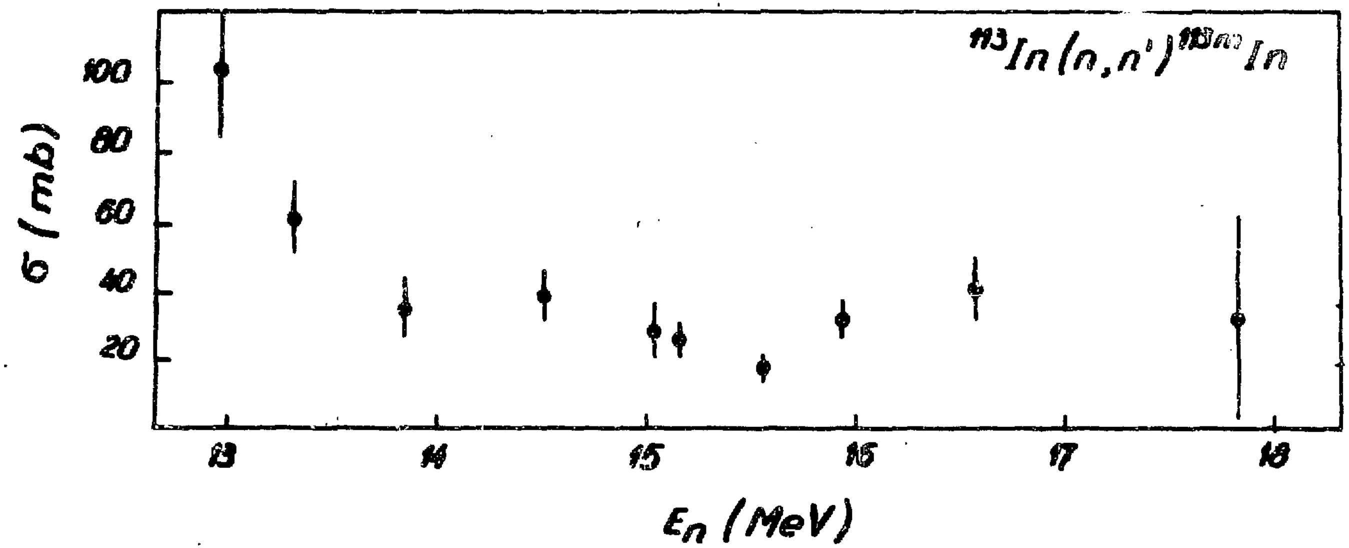

Fig. 1. Cross sections for the $^{113}In(n,n')^{113m}In$ reaction.

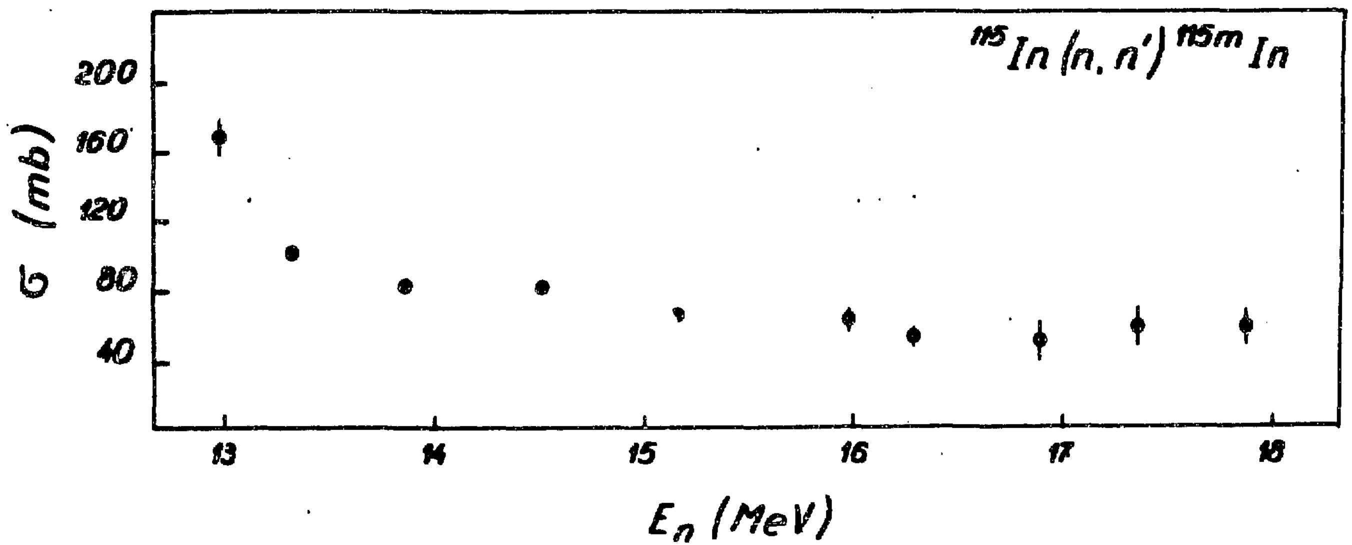

Fig.2. Cross sections for the $^{115}In/n,n'/^{115m}In$ reaction.

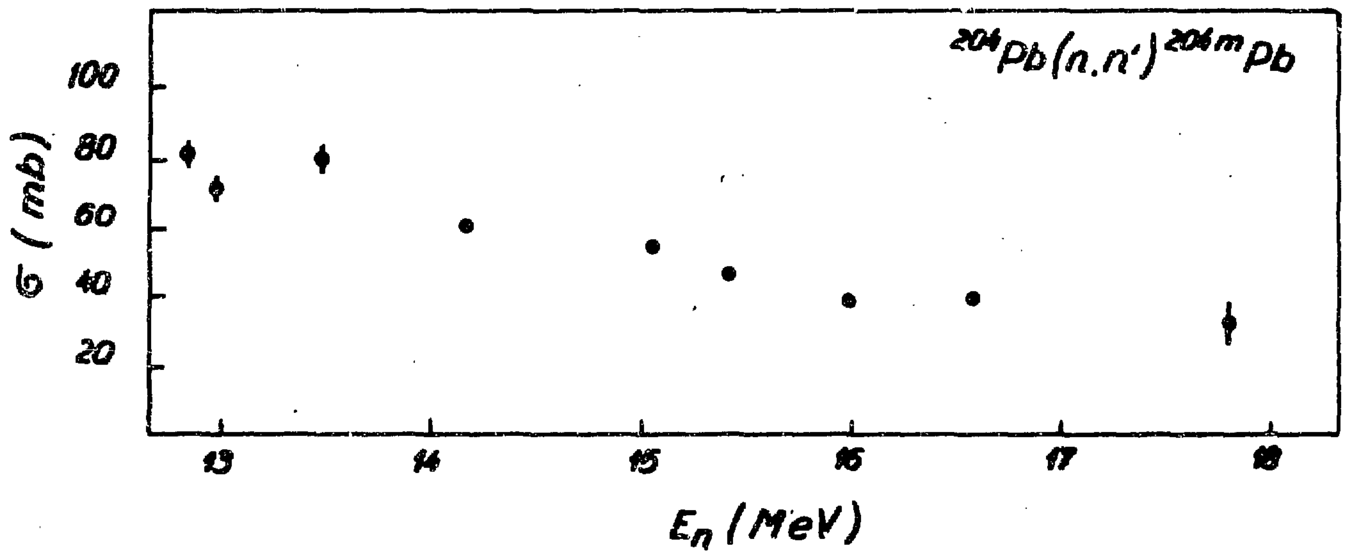

Fig.3. Cross sections for the ^{204}Pb/n,n'/^{204m}Pb reaction.

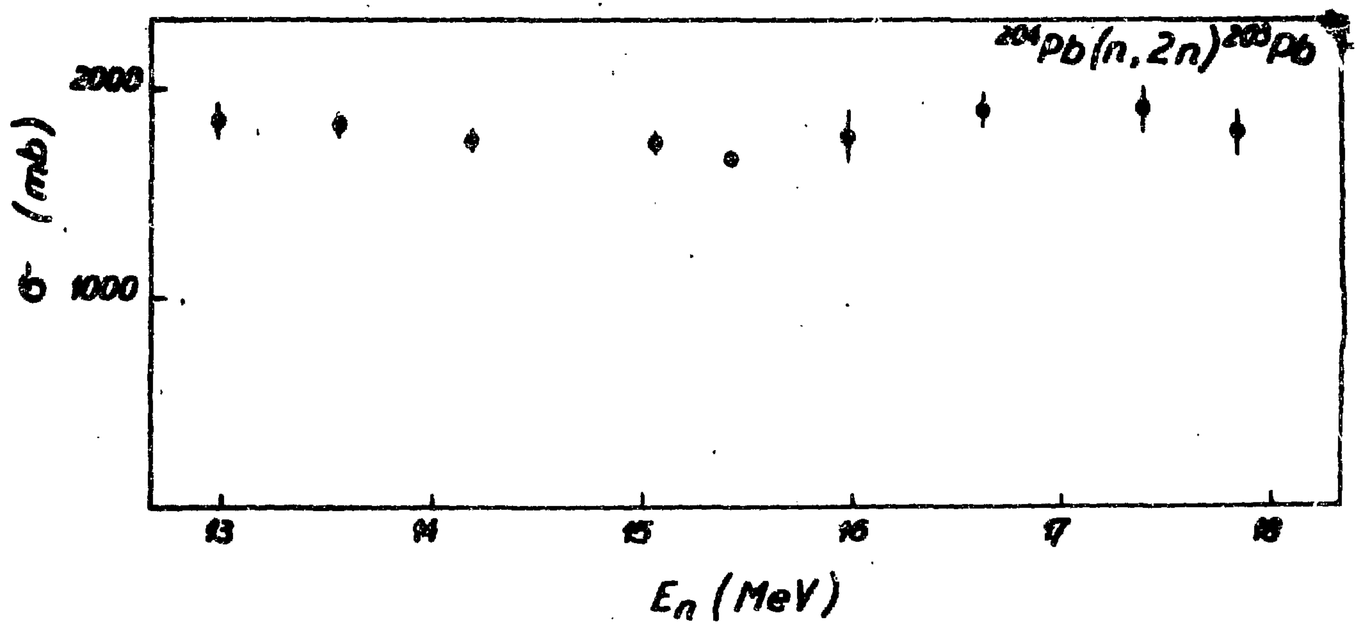

Fig.4. Cross sections for the ^{204}Pb/n,2n/^{203}Pb reaction.

Measurement of High-energy γ-ray Spectra in Strong Neutron Flux

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Figure 1 shows the geometrical arrangement of the system measuring high energy γ-ray emitted in fast neutron capture. The NaI(Tl) (4"x4") crystal was placed in a lead cylinder with walls 10 cm thick, enclosed in a 20 cm paraffin layer containing boron carbide; the target side, where the NaI crystal was not shielded with lead, paraffin with lithium hydride was used.

A significant reduction of the background was achieved owing to the use of a pulsed proton beam. After a series of test it was found that the following conditions of beam pulsation are optimal: length of the current pulse 30 μs, repetition time 1.2 ms, and pulse height analyser opening time 0–30 μs. In our experiments $^3H(pn)^3He$ reaction served as source of neutrons.

The tritium targets consisted of a copper backing on which 15 μm silver and subsequently 0.45 mg/cm^2 of titanium with 0.8 Ci tritium absorbed were deposited. Such a construction of the target allowed to limit the number of γ-quanta from the (n,gamma) and (p,gamma) in the target backing itself.

In Fig 2 γ-spectra for the reactions In(n,γ), ^{181}Ta(n,γ) and ^{197}Au(n,γ) measured by this method are given as an example.

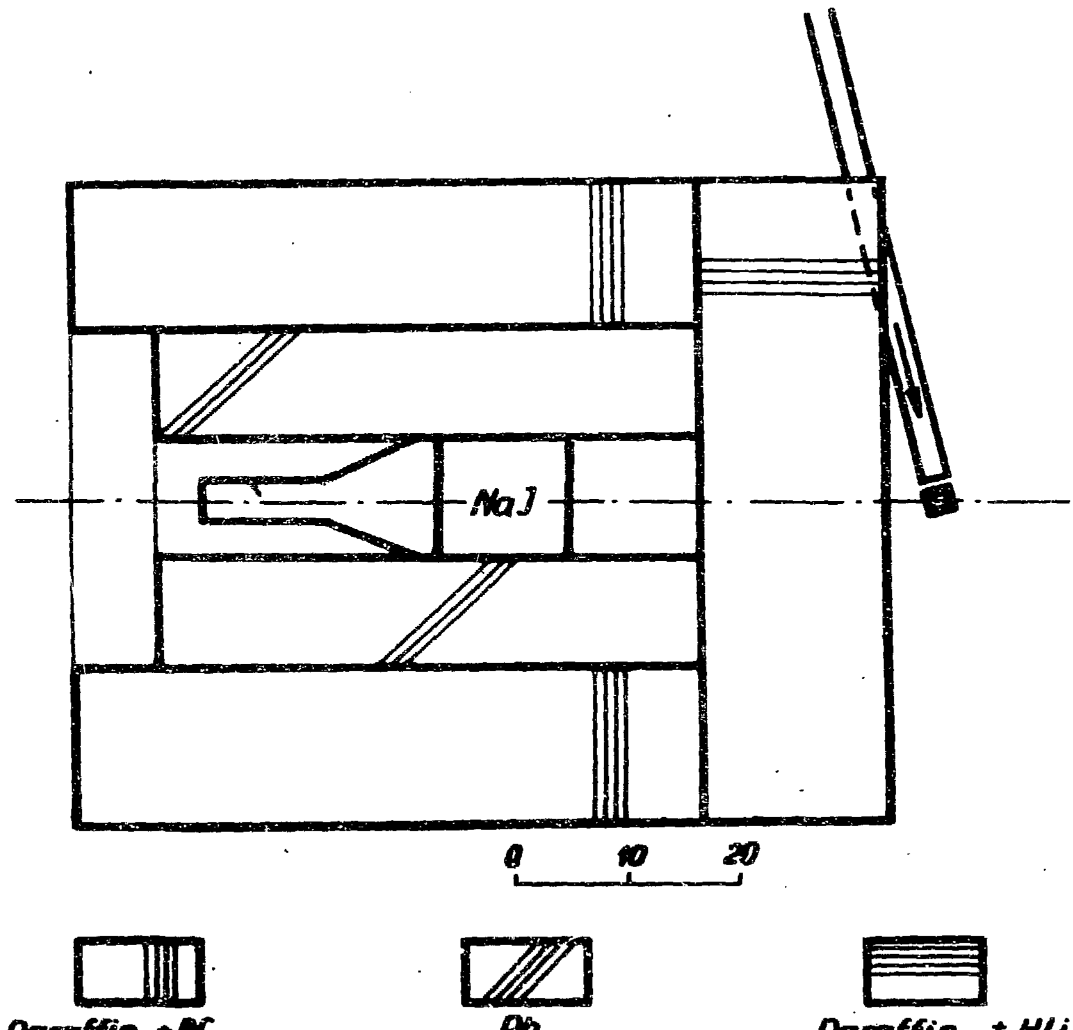

Fig. 1

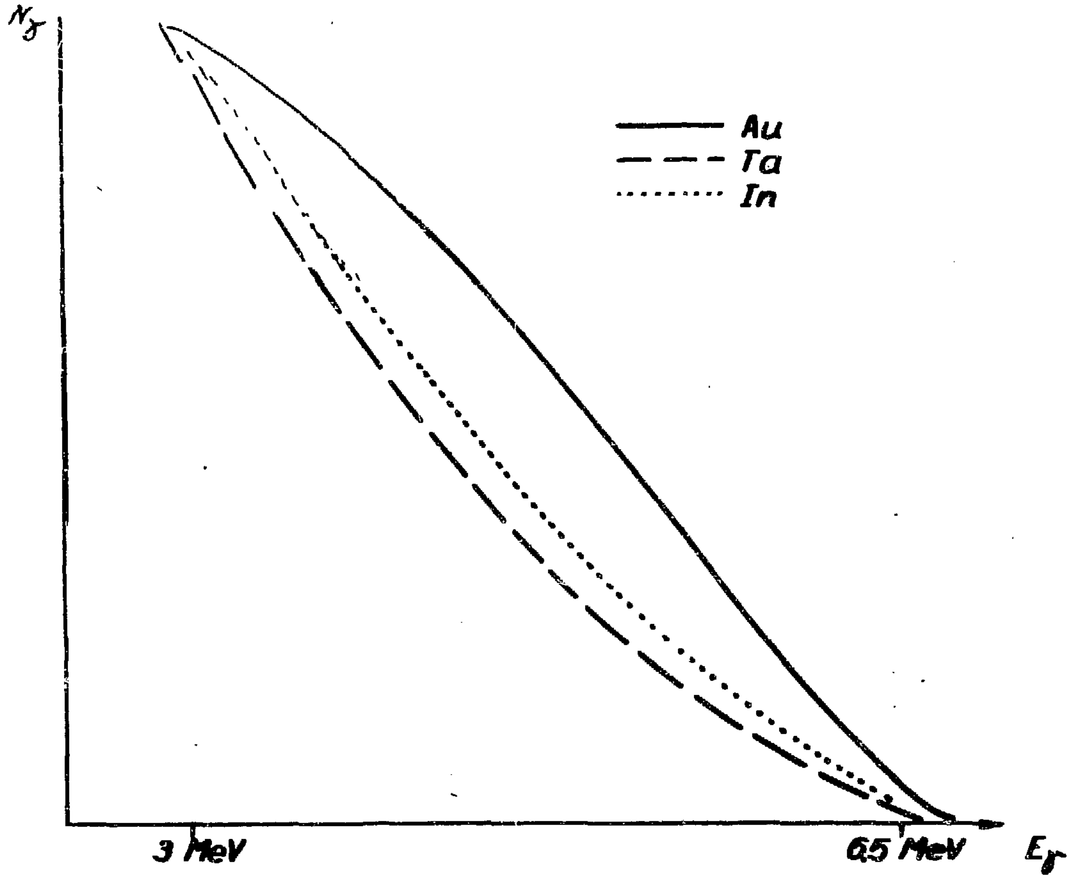

Fig. 2

Excitation of Short-living Isomeric Activities in ^{77}Se, ^{122}Sb, ^{137}Ba, ^{167}Er and ^{179}Hf using 14.5 MeV Neutrons.

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Abstract

The cross-sections for the production of short-living isomeric states in ^{77}Se, ^{122}Sb, ^{137}Ba, ^{167}Er and ^{179}Hf through the /n,2n/ and /n,n'/ reactions using 14.5 MeV neutrons have been measured. The contribution due to the second reaction may be studied using natural and enriched samples.

In our work isotopically enriched samples were used /^{78}Se, ^{123}Sb, ^{137}Ba, ^{168}Er, ^{180}Hf/.

For Se, Ba and Er the contribution of the /n,n' γ / reaction for 14.5 MeV neutron energy was estimated.

The measured cross-sections and the spectroscopic data used in the evaluation of the cross-sections are summarized in Table I.

For the reactions considered in this work and in our earlier work [4] only the metastable cross-section σ_m was measured. The ground state cross-section σ_g cannot be measured with the activation method because of it is stable or very long living . Where σ_m was measured σ_g was evaluated by subtracting the experimental σ_m value from the theoretical total cross-section /$\sigma_T = \sigma_m + \sigma_g$/.

Table I

Target, reactions and isomeric nucleus	Half life of product /sec/	ref.	Energy of gamma transition /keV/	ref.	Conversion coefficient	ref.	Cross-sections measured in our work E_n=14.5 MeV
$^{78}Se/n,2n/^{77m}Se$	17.5	[1]	161	[1]	0.79±0.06	[2]	703±70
$^{77}Se/n,n'/^{77m}Se$							593±30
$^{123}Sb/n,2n/^{122m}Sb$	249	[1]	60	[1]	0.65	[2]	731±73
$^{138}Ba/n,2n/^{137m}Ba$	153.5	[3]	661	[1]	0.098	[2]	1048±100
$^{137}Ba/n,n'/^{137m}Ba$							365±36
$^{168}Er/n,2n/^{167m}Er$	2.3	[1]	208	[1]	0.46	[2]	403±40
$^{167}Er/n,n'/^{167m}Er$							343±34
$^{180}Hf/n,2n/^{179m}Hf$	18.7	[1]	217	[1]	0.055/tot/	[2]	590±70

If we assume a compound-nucleus mechanism for the /n,2n/ reaction and the spins of the isomers considered, the isomeric ratio should yield information about the spin cut-off parameter /which characterizes the spin dependence of the assumed nuclear level-density /.

The method of Huizenga and Vandenbosch [5] was applied in computations for the nuclei investigated. The values of penetrability factors for neutrons were taken by us from Mani and Melkanoff [6] . The composite model for nuclear level densities proposed by Gilbert and Cameron [7] was used.

In table II a comparison is made between the calculated and experimental isomeric cross-section ratios. The accordance is satisfactory for Se, Sb, Ba, Ce and Nd. We point out however that in calculations for these nuclei the spin cut-off parameter obtained simply from Gilbert and Cameron model was used. It seems that the method of Huizenga and Vandenbosch and Cameron level density model is quite useful for some nuclei. Experimental results for Sm, Er and Hf seem to suggest a different values of spin cut-off parameter than predicted by Gilbert and Cameron model. Theisomericratio for Sm /for which exist experimental values of σ_m and σ_g [8] / Er and Hf were calculated for different spin cut-off parameters and different ν of the γ-rays emitted in the de-excitation processes. The spin cut-off parameter was considered energy independent. Results are given in Fig.1. The experimental isomeric cross-section ratio was defined as the ratio of the cross-section σ_l for the population of the lower spin state to the cross-section σ_h for the population of the higher spin state. The mean values of the spin cut-off parameter can be evaluated:

/3,8±0,3/ for ^{143}Sm, /2,5 ± 0,3/ for ^{167}Er and /2,4±0,3/ for ^{179}Hf. These values are lower than the calculated ones obtained from the formula given in [7] . Further study of rare-earth region /for which scare information can be found/ might lead to more examples of this type.

Table II

Reaction	I_m	I_g	σ_m exp [mb]	σ_{tot} estim from [9] [mb]	$\left(\frac{\sigma_m}{\sigma_{tot}}\right)_{exp}$	$\left(\frac{\sigma_m}{\sigma_{tot}}\right)_{calc}$	Spin cut-off parameter estimated from Cameron [7]	Spin cut-off parameter estimated from our exp.
$^{78}Se(n,2n)^{77}Se$	7/2	1/2	703	1030	0.70	0.82	3.6	-
$^{123}Sb(n,2n)^{122}Sb$	8	2	731	1750	0.42	0.44	4.35	-
$^{138}Ba(n,2n)^{137}Ba$	11/2	3/2	1105	1900	0.60	0.63	4.6	-
$^{140}Ce(n,2n)^{139}Ce$	11/2	3/2	1280	1850	0.69	0.57	3.74	-
$^{142}Nd(n,2n)^{141}Nd$	11/2	3/2	1069	1720	0.62	0.66	4.83	-
$^{144}Sm(n,2n)^{143}Sm$	11/2	3/2	564	1530	0.37	0.65	5	3.8 ± 0.3
$^{168}Er(n,2n)^{167}Er$	1/2	7/2	403	2150	0.19	0.10	4.6	2.5 ± 0.3
$^{180}Hf(n,2n)^{179}Hf$	1/2	9/2	680	1900	0.36	0.17	4.75	2.4 ± 0.3

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Figure captions

1. Comparison of the measured isomeric cross-section ratios with the theoretical curves plotted in terms of the spin cut-off parameter σ and the multiplicity ν of gamma rays in the cascade.

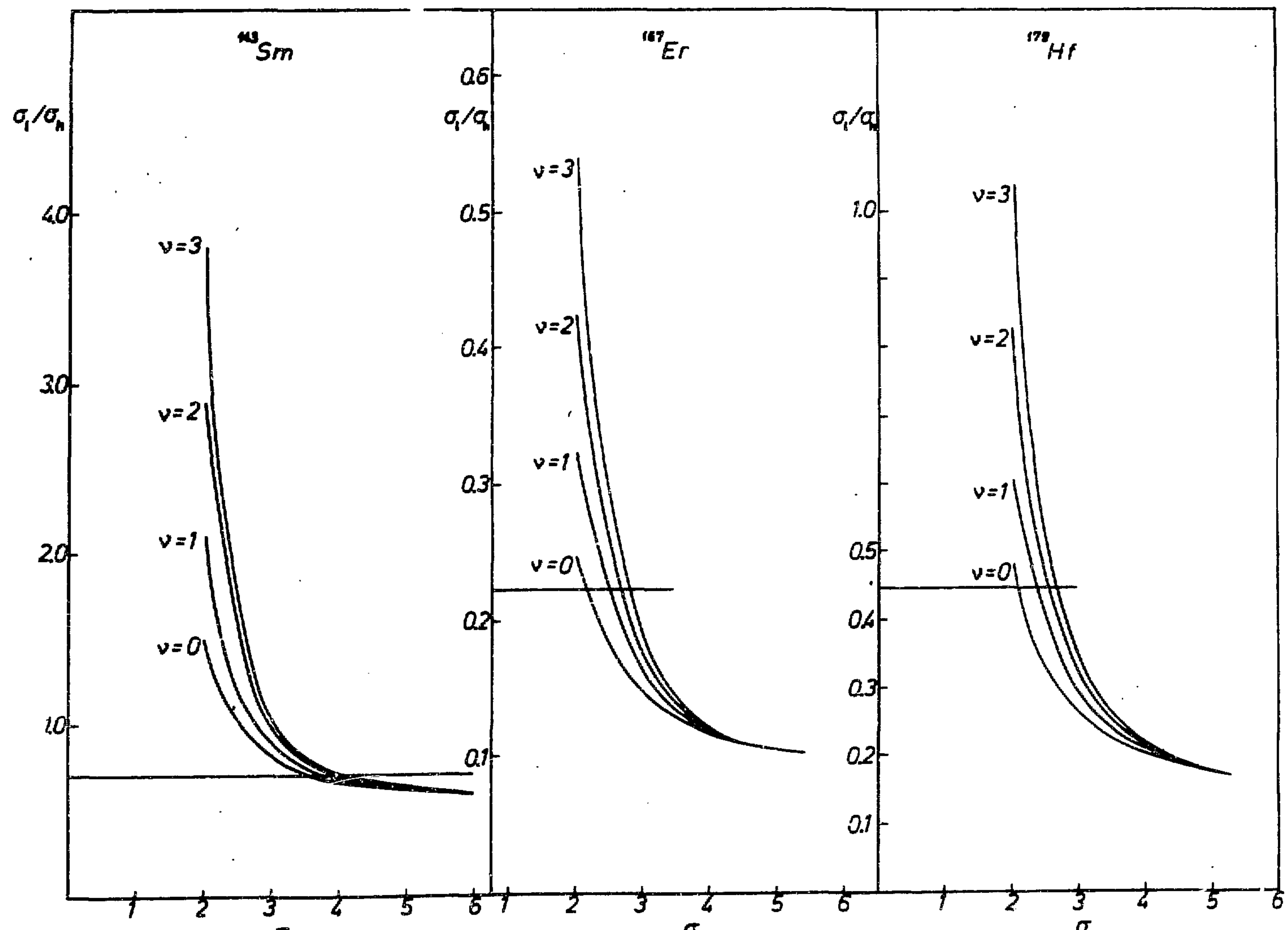

Figure 1

THE CODE "MINIGASKET"

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The MINIGASKET code reported previously, has became operational .The code which is based on the Gulf General Atomic code GASKET computes the thermal scattering law $S_s/\alpha,\beta/$ in incoherent approximation for polycrystals. Reliable data for isotopic graphite with Koppel-Young phonon distribution has been obtained. The code is to be supplemented with a FLANGE code, which calculates single and double differential cross sections and its moments, involving the elastic coherent component.

IBJ/1184/XXI/PR.Report.

Estimation of Quality Factor /QF/ in Tisuue-like Phantom Irradiated with 14.8 , 5, 3.3 MeV Neutrons.

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The dependence of the light output of the NE102A plastic scintillator upon the LET of the charged particle has been applicated to quality factor estimation at different depth of a tissue like phantom. [1] .

A cylindrical TE phantom /30 cm. dia. x 60 cm./ was exposed to 14.8 , 5, 3.3 MeV neutrons from D/dn/^{3}He reaction. The set of the detectors consists of a TE ionization chamber and NE102A scintillator optically connected with EMI 9524S photomultiplier. The set of the detectors were moved accross the phantom and the currents from ionization chamber and scintillation counter were simultaneously measured.

The quality factor was estimated from the approximated formula [1] :

$$\bar{Q} = 11/1 - 0.91 \frac{J_f}{K \; J_k}$$

where J_f - current of the scintillation counter

J_k - current of the ionization chamber

K - factor, which normalizes $\frac{J_f}{K \; J_k} = 1$ for gamma rays of ^{60}Co.

The results of the measurements were illustrated on Fig.1 and compared with Snyder's calculations.

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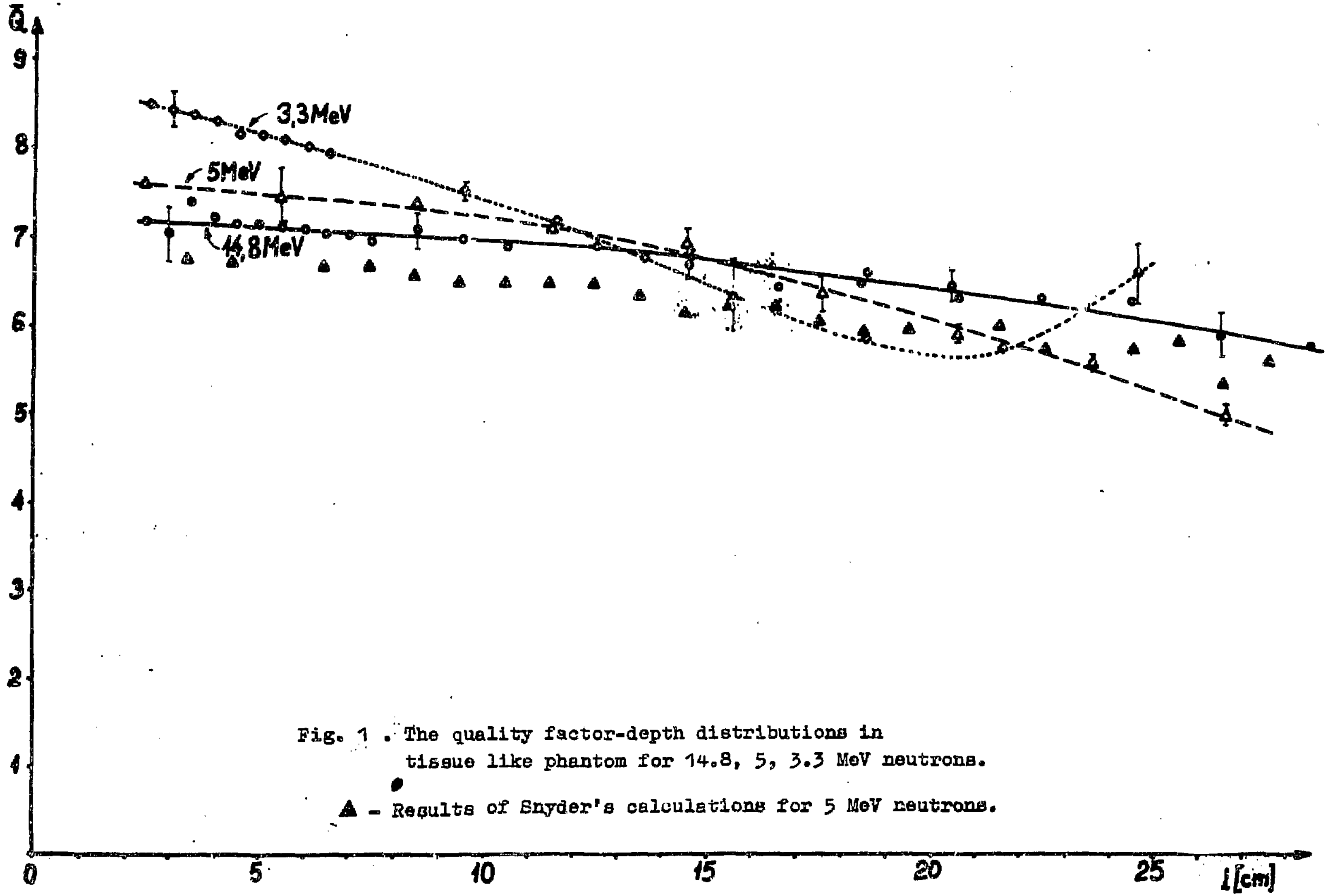

Fig. 1 . The quality factor-depth distributions in
tissue like phantom for 14.8, 5, 3.3 MeV neutrons.

▲ – Results of Snyder's calculations for 5 MeV neutrons.

Penenetration of a Two-dimensional Fission Barrier

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Summary

The understanding of the nuclear fission phenomenon requires a knowledge of the potential and kinetic energy of the nucleus in a fairly extensive region of nuclear deformation [1,2]. The description of the process in terms of the quadrupole ($\lambda = 2$) deformation parameter only, proves to be insufficient. The role of the other deformation modes such as hexadecapole ($\lambda = 4$) and octupole ($\lambda = 3$) have been proved to be very important as well. In this paper we focus our attention on the dynamical aspects of fission treated as a two dimensional process with two degrees of freedom: quadrupole and hexadecapole. In this case the collective nuclear Hamiltonian can be written as

$$H=V(\varepsilon_2,\varepsilon_4)+\frac{1}{2}B_{\varepsilon_2\varepsilon_2}\dot{\varepsilon}_2^2+B_{\varepsilon_2\varepsilon_4}\dot{\varepsilon}_2^2\varepsilon_4^2+\frac{1}{2}B_{\varepsilon_4\varepsilon_4}\dot{\varepsilon}_4^2 \quad (1)$$

where the potential energy V and the inertial parameters $B_{\varepsilon_i \varepsilon_j}$ are treated as functions of the quadrupole and hexadecapole deformation parameters ε_2 and ε_4. The potential energy surface $V(\varepsilon_2, \varepsilon_4)$ that exhibits a saddle point (or two saddle points) has been calculated earlier [1]. In the present paper the three inertial parameters $B_{\varepsilon_2\varepsilon_2}, B_{\varepsilon_2\varepsilon_4}$ and $B_{\varepsilon_4\varepsilon_4}$ are calculated by means of the microscopic methods of the nuclear structure theory [3]. Then the effect of the existence of the two degrees of freedom ε_2 and ε_4 on fission dynamics are discussed. The considerations involve essentially the penetration problem of a two - dimensional potential barrier. One of the possibilities discussed consists in performing the penetration calculation along the "steepest descent" path in the potential energy surface. The problem can then be reduced to the one - dimensional penetration of the barrier in the appropriate direction in the $\varepsilon_2, \varepsilon_4$ plane.

Another possibility that is believed to be more fundamental is then discussed. It consists in diagonalising first the kinetic energy term in eq. (1) and then facing a two dimensional penetration problem. A rigorous solution of the last problem (ie. without the WKB approximation) may be obtained in a simple case when the potential energy V(x,y) (where x,y are deformation parameters after diagonalisation) is separable:

$$V(x,y) = f(y) + g(x) \qquad (2)$$

and the inertial parameters are independent of the deformation. In the particular case of the second-order polynomial form of the potential

$$V(x,y)=\frac{1}{2}(B_{yy}\omega_{tr}^{2}y^{2}-B_{xx}\omega_{long}^{2}x^{2}) \qquad (3)$$

the solution of the penetration problem is a straightforward generalisation into a two-dimentional case of the well-known Hill-Wheeler solution for the parabolic barrier 4 .

In the present state it is difficult to estimate the final effect of the inclusion of the second degree of freedom. Very preliminary calculations show that diagonalisation of the kinetic energy tends to lower the logarithm of the spontaneous fission life time by a factor of 20 to 30 %, roughly.

In the case of the separable potential the hight of the potential barrier is not affected by the second dimention. The zero-point energies for the equilibrium and saddle points are the same in this case and they do not need to be taken into account in the penetration problem.

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