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Editor s Note

This progress Report on nuclear data research in Poland "May 1976 - April 1977 contains only information on research, which is closely related to the activities of the International Nuclear Data Commitee of the International Atomic Energy Agency in the field of charged particles and neutron physics. It does not include any information about other nuclear research as for example 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 informacje o badaniach w zakresie fizyki jądrowej średnich energii przeprowadzonych w Polsce /maj 1976 - kwiecień 1977/ i związanych z zdziałalnością Komitetu Danych Jądrowych Międzynarodowej Agencji Energii Atomowej.

Pominięto wyniki badań w innych dziedzinach fizyki jądrowej, w tym również badań 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 zgody autorów.

Замечания от редакции

Этот сборник содержит сообщения о проведенных в Польше в период от мая 1976 до апреля 1977 исследованиях в области физики средних энергий, связанных с деятельностью Комитета по Ядерным Данным Международного Агенства Атомной Энергии.

Не включены результаты исследований с области применения нейтронов в физике твердого тела. Доклады не являются полными и не рекомендуется ссылаться на них без согласия авторов.

CONTENT

ANGULAR DISTRIBUTION OF 14 MeV NEUTRONS SCATTERED ON SILICON TO ISOLATED STATES IN A VERY WIDE ANGULAR RANGE

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The problem of obtaining reliable experimental data for the analysis of nuclear scattering is of great importance. Usually the data are restricted to an easily accessible angular range. Few attempts have been made to extend the known range to the small angle scattering and to the backward scattering region [1, 2, 3].

Differential cross sections for 14 MeV neutrons scattered on silicon have been measured by several authors. However, their measurements were restricted to certain parts of the angular range see, e.g. [4, 5, 6]. The experiment of Bonazzola et al. [3] extended those data to the extreme backward angles. In our laboratory differential cross sections for transitions to the ground and to the first excited states have been neasured using the same nethod, in an angular range from 6.2° to 176.6°. Plate geometry was used throughout the experiment and two small /1.5" x 1.5"/ liquid scintillators detected the scattered neutrons at the same angle at a distance of 135 cm or 160 cm from the scatterer. The scatterer /40 cm x 20 cm x 2 cm/ was high purity natural silicon.

The time-of-flight spectrometer worked with associated particle method. The time spectra of neutrons and gamma rays were detected for both detectors. In order to diminish the background very efficient neutron gamma discrimination was used and the experimental conditions have been carefully chosen. A single run took approximately 72 hours. The stability of the resolution obtained was high. This allowed a complete separation of the measured tran-

sitions. The resolution was checked during the experiment by an auxiliary electronic pulse and by the shape of the fast gamma peak. For any long time run the gamma peak half width was better than 1 nsec. The intensity of those peaks was a check for the quality of monitoring, and of the stability of the detector efficiency. Fig. 1 schematically shows the experimental arrangement and Fig. 2 gives two examples of the neutron and gamma ray time spectra for two angles. The neutron differential cross sections measurements were corrected for the shape of the incident neutron flux distribution, for finite angular resolution of the system as well as for attenuation and multiple scattering of neutrons in the sample. There is a good agreement with most of the known data except the extreme backward angles. Our analysis led us to the conclusion that this discrepancy is due to unsatisfactory resolution of the quoted data [3].

The very large angular range allows an interesting analysis, because the backward scattered neutrons come much closer to the scattering centre. Thus some valuable results on the LS coupling potential have been obtained. The obtained deformation parameter β_2 is in good agreement with the other known data. The results of the analysis by the DWBA and coupled--channels theories will be published elsewhere [8]. Additional informations on experimental details are given in [7, 8, 9].

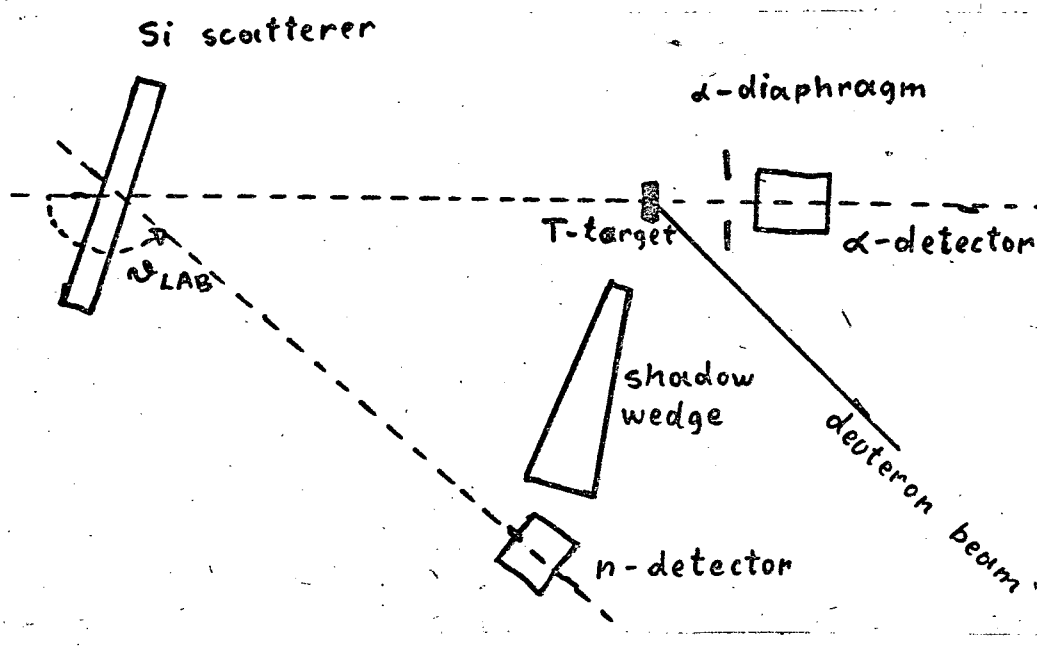

Fig. 1. Experimental arrangement - top view.

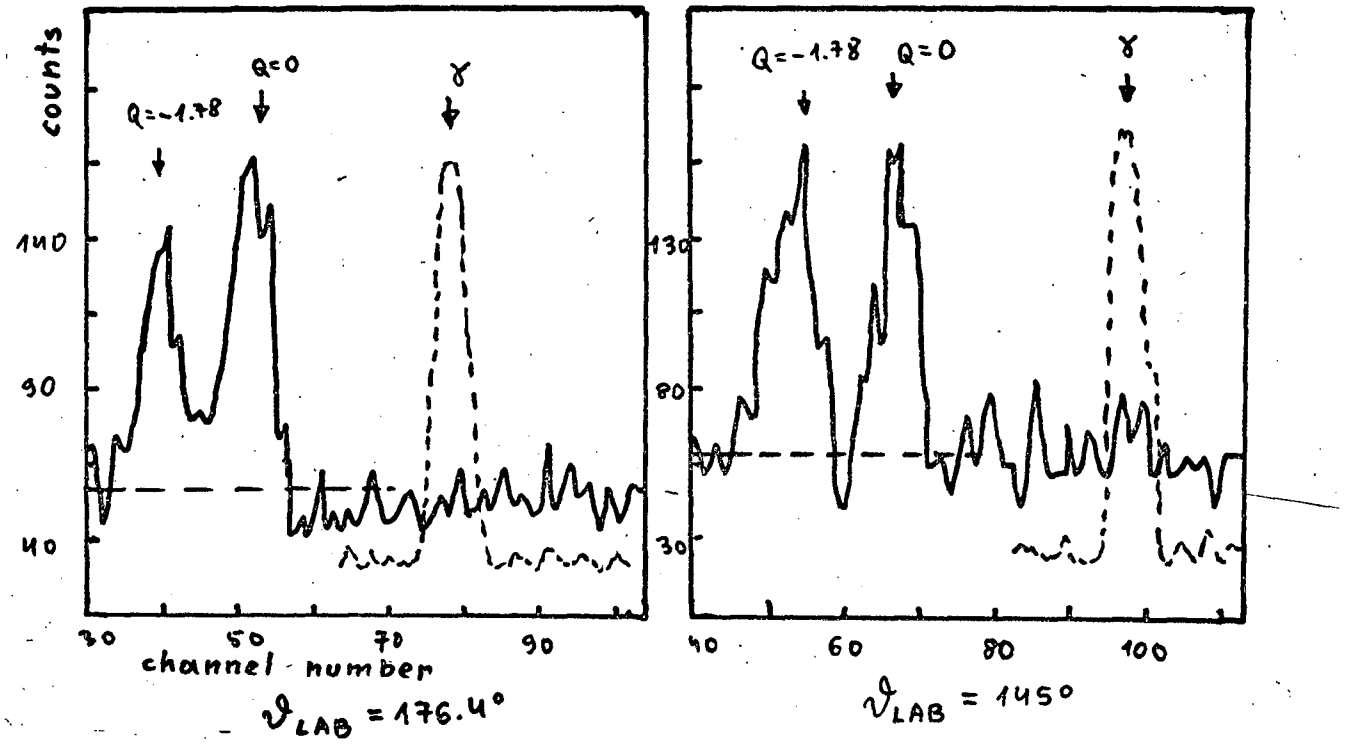

Fig. 2. Examples of the neutron and gamma ray time spectra

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ANGULAR DISTRIBUTION OF ALPHA PARTICLES FROM $^{14}N(n,\alpha)^{11}B$ REACTION AT 18.0 MeV

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The telescopic system described in our earlier work [1] has been used for the study of the $^{14}N(n,\alpha)^{11}B$ reaction induced by 18.0 ± 0.26 MeV neutrons. Neutrons were obtained from the $^{3}He(d,n)^{4}He$ reaction using the 2 MeV deuteron beam from the Van de Graaff accelerator. The flux of neutrons was measured by proton - recoil counter. The nitrogen target was preparated by evaporation of melamine $(C_3H_6N_6)$ onto a tantalum foil. The thickness of the target amounted to 1.5 mg/cm^2. The three - - dimentional analyses of each event enregistered in the telescope was performed with Nuclear Data 4420 multiparameter system. All events were stored on a CDC compatible magnetic tape and then fed for further processing off line to obtain alpha - particle energy spectra. Fig. 1 presents an alpha - particle spectrum taken with the telescope set at zero degree. Two groups of alphas coresponding to the transitions to the ground (α_0) and the first excited (α_1) states of the ^{11}B nucleus can be distinguished. The angular distributions of alpha particles are presented in Tables I and II, and also in Fig. 2. The data are given in c.m. system. The angular spreads were calculated with a Monte Carlo method [2]. The indicated errors are statictical only.

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TABLE I

$E_n = 18$ MeV $\qquad$ $^{14}N(n, \alpha_0)\,^{11}B$

Θ [deg]	$\Delta\Theta$ [deg]	$d\sigma/d\Omega$ [mb/sr]	$\Delta\, d\sigma/d\Omega$ [mb/sr]
11.0	6.0	0.62	0.07
15.0	6.0	0.72	0.11
25.0	5.0	0.60	0.11
36.0	5.0	0.66	0.11
47.0	5.0	0.61	0.08
58.0	5.0	0.33	0.19
68.5	4.5	0.43	0.09
79.0	4.0	0.31	0.07
94.5	4.0	0.21	0.09
109.4	3.0	0.37	0.10
125.0	2.8	0.03	0.16
146.0	2.5	0.63	0.12

TABLE II

E_n = 18 MeV $^{14}N(n, \alpha_1)\,^{11}B$

Θ [deg]	$\Delta\Theta$ [deg]	$d\sigma/d\Omega$ [mb/sr]	$\Delta\, d\sigma/d\Omega$ [mb/sr]
11.0	6.0	0.84	0.08
15.3	5.5	0.45	0.11
25.3	6.0	0.53	0.11
36.3	5.5	0.65	0.09
47.3	5.5	0.90	0.09
58.3	5.0	1.01	0.19
69.0	4.5	0.51	0.09
79.7	4.5	0.25	0.08
95.0	4.0	0.38	0.10
110.0	3.5	0.36	0.10
125.0	2.8	0.0	0.05
146.4	2.7	0.48	0.20

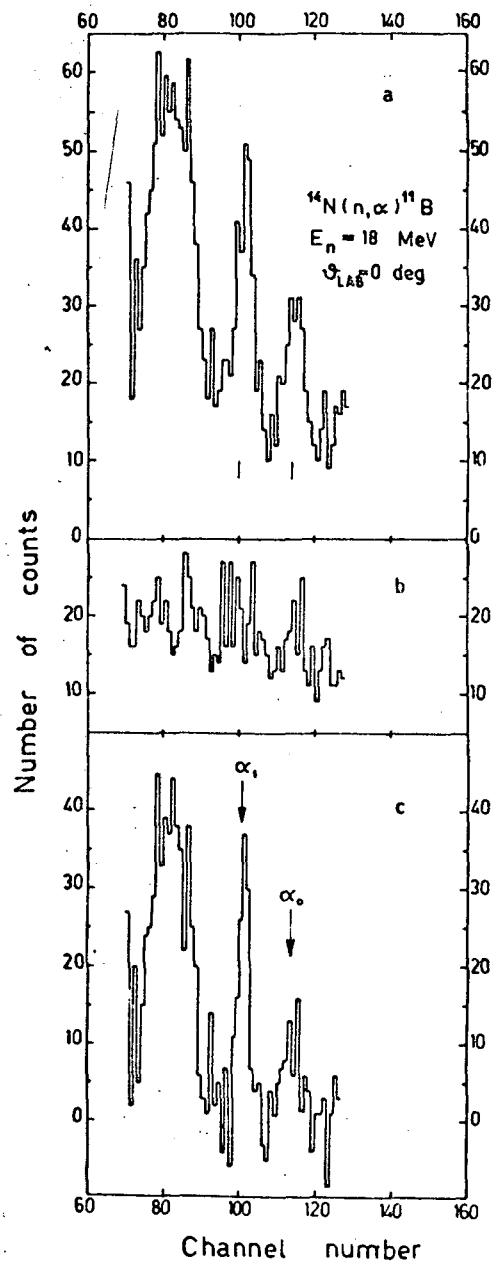

Fig. 1. The alpha-particle spectra at zero degree.

a/ The alpha spectrum measured with melamine target.

b/ The background spectrum.

c/ The background - corrected spectrum of alpha particles from the $^{14}N(n,\alpha)^{11}B$ reaction.

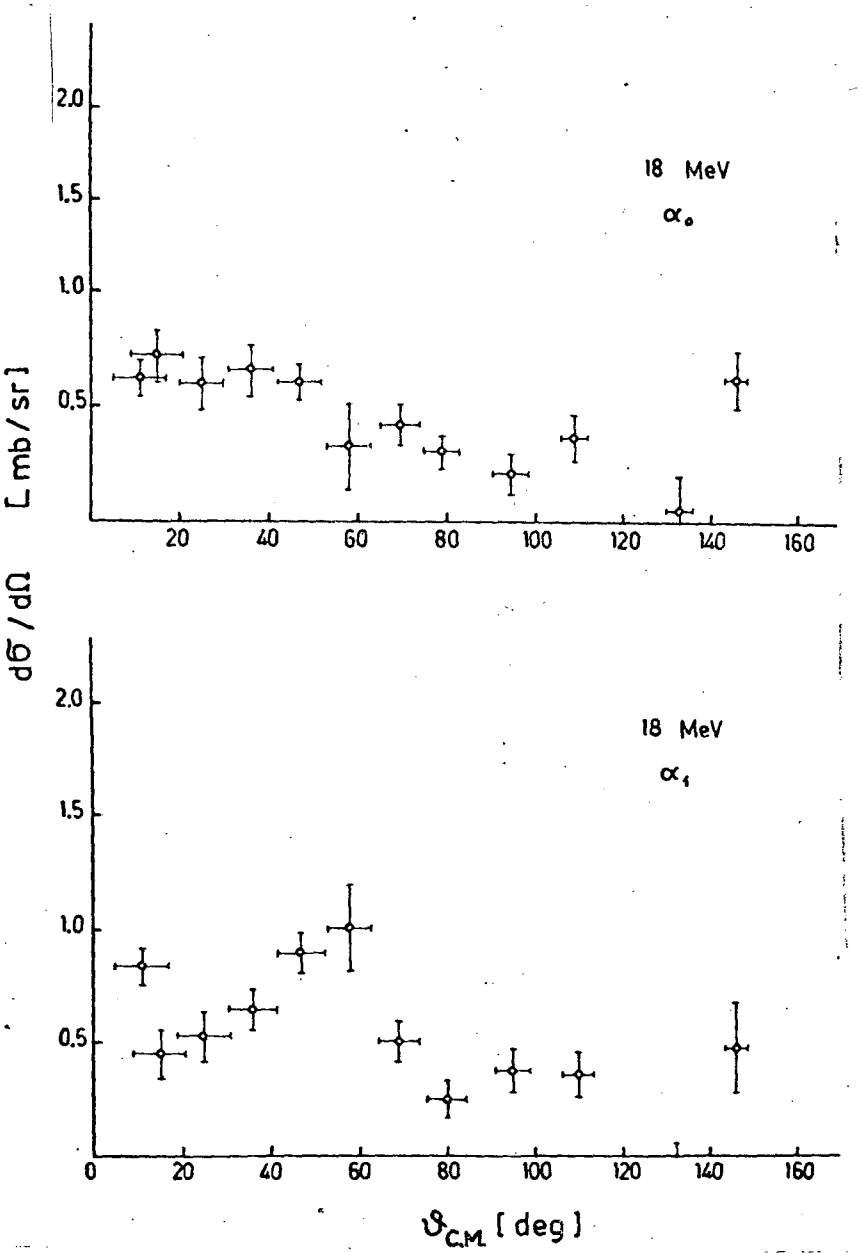

Fig. 2. The angular distributions of alpha particles leading to the ground (α_0) and the first (α_1) excited states of ^{11}B.

DIFFERENTIAL CROSS SECTIONS FOR THE $^{143}Nd(n,\alpha)^{140}Ce$ REACTION INDUCED BY 18.2 MeV NEUTRONS

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Using semiconductor α -particle spectrometer [1] the energy distribution of α -particles from $^{143}Nd(n, \alpha)^{140}Ce$ reaction at $E_n = 18.20 \pm 0.16$ MeV have been measured. The neutrons were obtained in the Van de Graaff accelerator LECH from the $^{3}H(d,n)^{4}He$ reaction. The neutron flux was monitored by counting the recoil protons from thin polyethylene foil. The absolute calibration of neutron monitor was performed by using the activation method. The measurements were refered to $^{56}Fe(n,p)^{56}Mn$ reaction, the cross section for which was accepted as 57 mb for neutron energy 18.2 MeV [2]. Uncertainty of the monitor calibration amounts to about 15%. The samples of neodymium were made of oxide Nd_2O_3 isotopically enriched in ^{143}Nd (88.4%). The target thickness was equal to 3 mg/cm^2.

The results of the absolute differential cross sections are listed in Table 1 and also presented in Fig. 1. Only statistical errors are included. As can be seen from the Fig. 1 the characteristic feature of the α -particle spectrum is the presence of two peaks corresponding to the ground state and excited states of the residual nucleus ^{140}Ce.

In Fig. 2 the energy distribution of neutrons the angular spread and the energy spread of measurements are shown. These spreads were calculated by Monte Carlo method [3].

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TABLE I

Differential cross sections for $^{143}Nd(n, \alpha)^{140}Ce$ reaction at $E_n = 18.2$ MeV

E_α^{lab} [MeV]	$d^2\sigma/d\Omega dE$ [μb/sr·MeV]	E_α^{lab} [MeV]	$d^2\sigma/d\Omega dE$ [μb/sr·MeV]	E_α^{lab} [MeV]	$d^2\sigma/d\Omega dE$ [μb/sr·MeV]
20.00	218.7± 66.2	22.90	373.9± 46.0	25.80	57.0± 19.0
20.10	225.1± 62.0	23.00	323.8± 45.5	25.90	38.1± 14.7
20.20	353.9± 60.6	23.10	341.1± 43.0	26.00	29.5± 11.8
20.30	259.6± 59.3	23.20	302.8± 39.7	26.10	35.2± 13.0
20.40	181.5± 58.0	23.30	318.0± 39.2	26.20	53.9± 13.8
20.50	242.7± 57.8	23.40	391.7± 39.8	26.30	14.1± 13.2
20.60	153.0± 56.0	23.50	395.8± 40.8	26.40	11.6± 12.3
20.70	219.7± 55.1	23.60	377.4± 41.2	26.50	-10.2± 10.2
20.80	268.2± 55.1	23.70	537.7± 45.1	26.60	14.4± 10.4
20.90	135.9± 53.9	23.80	452.2± 41.9	26.70	19.0± 10.2
21.00	178.5± 54.7	23.90	423.4± 40.9	26.80	16.9± 9.6
21.10	219.7± 53.7	24.00	380.9± 41.5	26.90	13.5± 11.0
21.20	247.1± 50.8	24.10	314.7± 40.3	27.00	.8± 10.5
21.30	192.4± 48.2	24.20	225.5± 35.0	27.10	29.9± 9.3
21.40	194.1± 49.9	24.30	270.9± 32.5	27.20	53.5± 14.9
21.50	252.3± 48.7	24.40	211.4± 32.3	27.30	36.2± 12.7
21.60	200.5± 49.7	24.50	140.0± 26.4	27.40	82.0± 17.5
21.70	209.8± 45.7	24.60	86.0± 24.4	27.50	130.4± 18.7
21.80	141.9± 44.0	24.70	51.2± 18.7	27.60	118.8± 20.3
21.90	209.5± 46.9	24.80	27.9± 19.9	27.70	77.2± 16.8
22.00	285.3± 47.7	24.90	21.9± 19.9	27.80	48.8± 15.2
22.10	195.9± 44.0	25.00	33.9± 19.7	27.90	27.1± 11.8
22.20	248.0± 46.2	25.10	26.7± 19.1	28.00	27.3± 10.8
22.30	308.9± 46.2	25.20	68.3± 19.3	28.10	-2.2± 5.3
22.40	293.1± 46.3	25.30	89.6± 18.2	28.20	-6.1± 4.2
22.50	315.7± 45.4	25.40	89.7± 19.3	28.30	-5.6± 5.2
22.60	324.6± 44.0	25.50	62.3± 15.5	28.40	10.2± 8.8
22.70	393.6± 44.5	25.60	82.6± 18.4		
22.80	349.6± 45.4	25.70	87.7± 19.7		

Cross section integrated in the 20.00 - 28.40 MeV range is equal 1.45 ± 0.03 mb/sr.

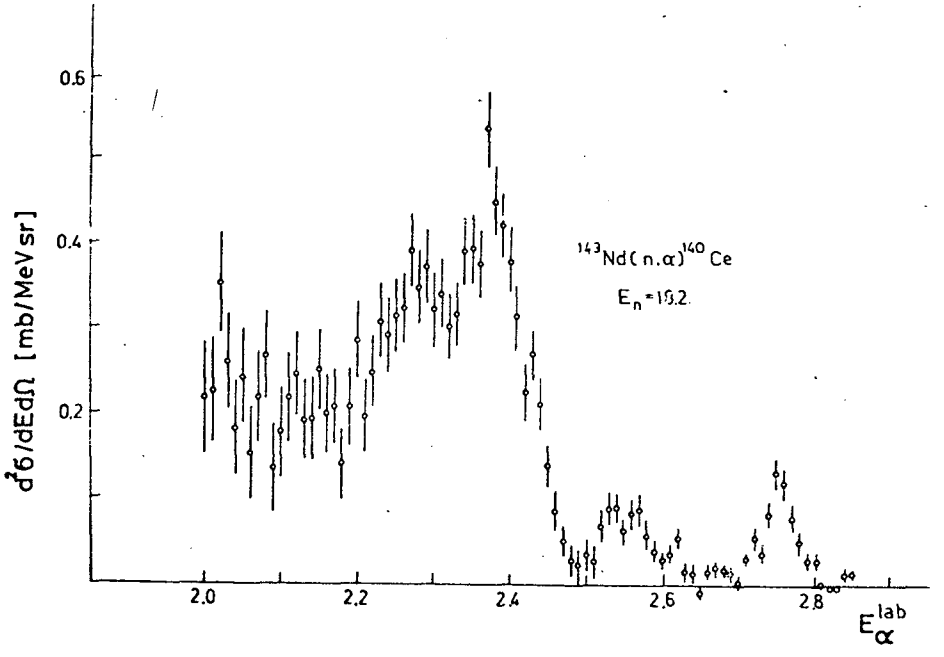

Fig. 1. Energy spectrum of α -particles from the $^{143}Nd(n, \alpha)^{140}Ce$ reaction at 18.2 MeV.

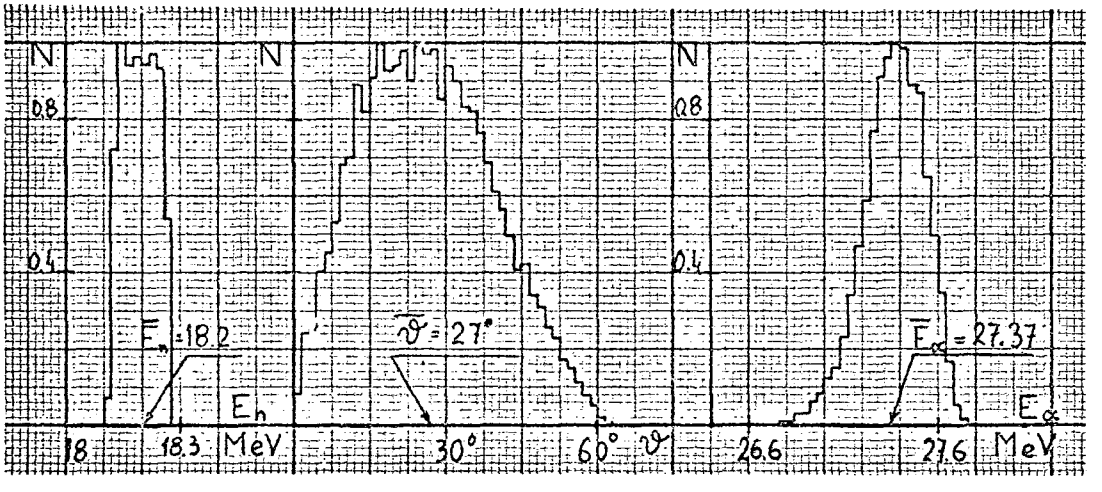

Fig. 2. The experimental energy distribution of neutrons as well as energy and angular spreads of α -particles.

ANGULAR DISTRIBUTIONS OF ALPHA PARTICLES FROM THE $^{147}Sm(n,\alpha)^{144}Nd$ REACTION INDUCES BY 12.1 AND 14.1 MeV NEUTRONS

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Angular distributions of α -particles emitted in the $^{147}Sm(n,\alpha)^{144}Nd$ reaction at En = 12.1 and 14.1 MeV were measured by direct registration of α -particles. The experimental arrangement used in the measurements was described in our earlier work [1]. The neutrons were obtained from the $^{3}H(d,n)^{4}He$ reaction with deuterons accelerated up to 2 MeV in the Van de Graaff accelerator "LECH". The neutron energy was selected by a suitable choice of the emission angle. The neutron energy spreads due to the deuteron energy loss in the ^{3}H-Ti target and geometrical conditions were 200 and 300 keV for 12.1 and 14.1 MeV neutrons respectively. The neutron flux was measured by counting the recoil protons from a thin polyethylene foil. The recoil protons were registered by a thin CsI(Tl) scintillator followed by photomultiplier and standard electronics. The absolute calibrations of the neutron monitor was performed by measuring of the 847 keV γ - transition in ^{56}Fe produced in $^{56}Fe(n,p)^{56}Mn$ reaction with successive β -decay of ^{56}Mn. The cross sections for the $^{56}Fe(n,p)^{56}Mn$ reaction were taken as 110 mb for both neutron energies [2]. Uncertainty of the monitor calibration amounts to about 15%.

The investigated targets were made of samarium oxide enriched with ^{147}Sm to about 96.4%. The Sm_2O_3 layers thicknesses of about

2.3 and 3.0 mg/cm^2 were deposited onto thick carbon backings by means of sedimentation from suspensions in isopropyl alcohol.

The energy calibration of the alpha spectrometer was performed with employment of alphas from ThC and ThC′ and from the reaction $^{28}Si(n,\alpha)^{25}Mg$ produced in the silicon detector by the incident neutrons.

The angular distributions of α-particles emitted in the $^{147}Sm(n,\alpha)^{144}Nd$ reaction at 12.1 and 14.1 MeV neutrons are presented in Tables 1 and 2. These distributions contain all α-particles with energies corresponding to excitations of the final nucleus up to 5.5 MeV. In the bottom of the tables the angular spreads of the measurements are also shown. These spreads were calculated by Monte-Carlo method [3]. The errors indicated in the tables are only statistical.

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2. D.C.Santry, J.Butler, Can. J. Phys., 42 1964 1030,

3. L.Zemło, INR Report, 1464/I/PL/B 1973.

TABLE I

Angular distribution of α -particles for $^{147}Sm(n,\alpha)^{144}Nd$ reaction at $E_n = 12.1$ MeV

ϑ [deg]	$d\sigma/d\Omega$ [mb/sr]
27	0.72 ± 0.06
46	0.42 ± 0.05
63	0.21 ± 0.04
90	0.12 ± 0.04
117	0.06 ± 0.04
134	0.01 ± 0.04
155	0.02 ± 0.04

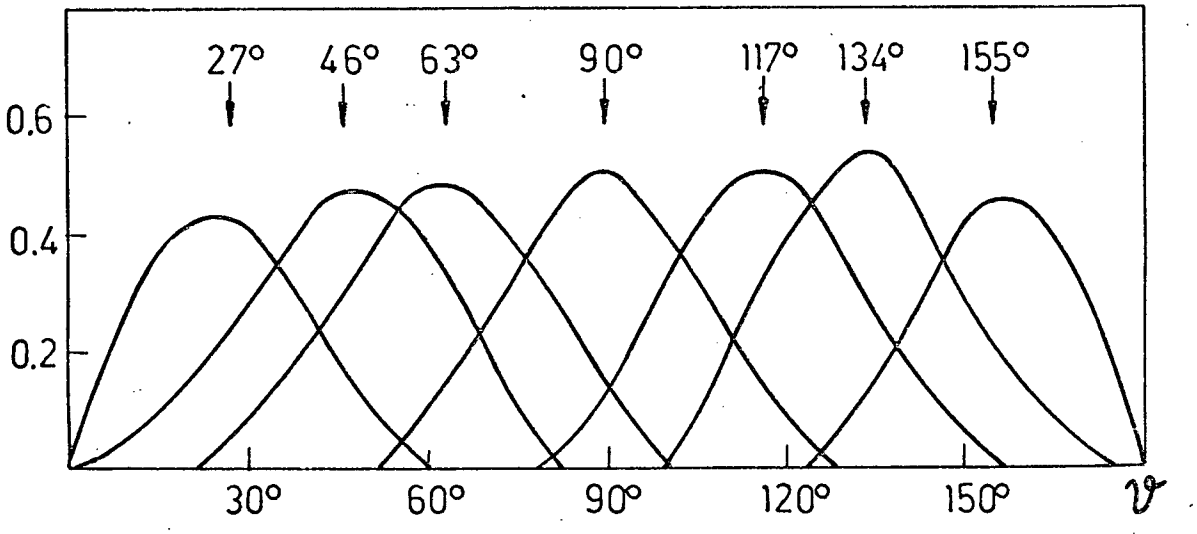
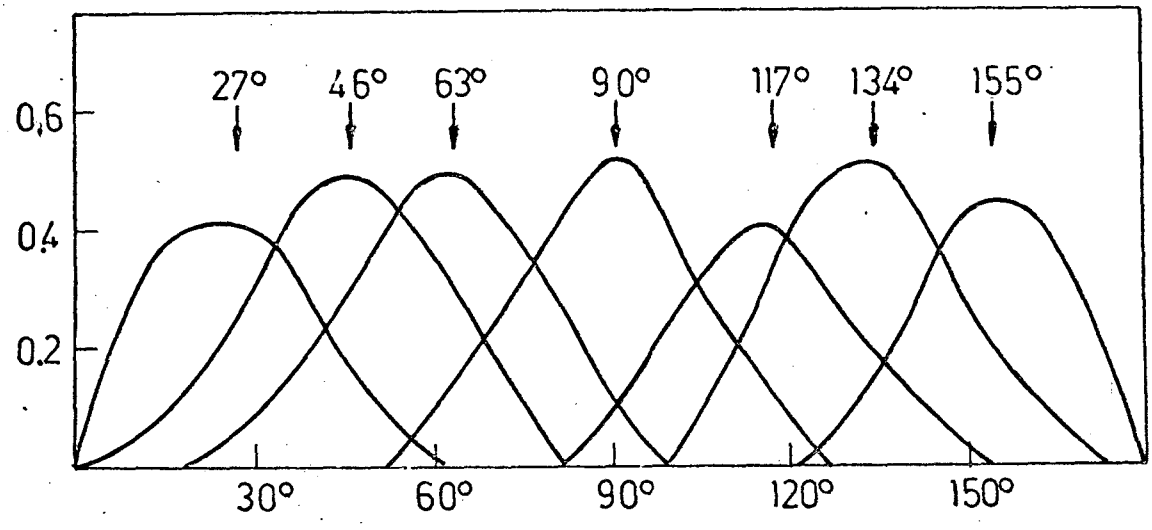


TABLE II

Angular distribution of α -particles for $^{147}Sm[n,\alpha]^{144}Nd$ reaction at E_n = 14.1 MeV

ϑ [deg]	$d\sigma/d\Omega$ [mb/sr]
27	0.83 ± 0.06
46	0.43 ± 0.05
63	0.28 ± 0.04
90	0.14 ± 0.04
117	0.02 ± 0.03
134	0.01 ± 0.03
155	-0.01 ± 0.04



CROSS SECTIONS FOR THE $^{139}La(n,alpha)^{136}Cs$ REACTION INDUCED BY FAST NEUTRONS

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Excitation function of the $^{139}La(n,alpha)^{136}Cs$ reaction was measured in the neutron energy range 13-17 MeV by the activation method. Neutrons were produced in a titanium-tritium target with 440 keV and 990 keV deuterons from the Van de Graaff accelerator. The angular dependence of the neutron energy from the $T(d,n)^4He$ reaction was used to obtain monoenergetic neutrons of a desired energy. Samples of pure (99.56% purity) metallic lantanium were used. The activities induced in the lantanium samples were determined by means of a 30 cm^3 Ge(Li) detector. The photopeak of the 1050 keV gamma line od the ^{136}Cs decay was used for the activity determination.

The cross sections of the investigated reaction were measured in reference to the $^{56}Fe(n,p)^{56}Mn$ reaction cross section. For the $^{56}Fe(n,p)^{56}Mn$ cross sections the values reported by Liskien and Paulsen were used [1]. The level schemes and transition probabilities were taken from the tables of Lederer et al. [2].

The experimental results are given in Table I.

The cross section error consists of the statistical error, the uncertainity of the neutron flux, the error of the Ge(Li) detector efficiency,

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x/ Warsaw Technical University, Institute of Physics.

the error of the sample weight and the reference cross sections error. The neutron energy spreads were calculated with a Monte Carlo method using the computer code LOS [3]. The gamma ray attenuation was calculated using the computer programme Selfa [4] with the gamma-ray attenuation coefficients taken from Lejpunski et al. [5].

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TABLE I

Cross sections for the $^{139}La(n,\alpha)^{136}Cs$ reaction

Neutron Energy MeV	Measured cross sections mb
13.0 ± 0.1	1.4 ± 0.2
13.3 ± 0.1	1.4 ± 0.1
13.9 ± 0.2	1.6 ± 0.1
14.5 ± 0.2	1.6 ± 0.1
15.1 ± 0.1	1.7 ± 0.1
15.5 ± 0.2	2.0 ± 0.2
15.9 ± 0.1	2.2 ± 0.4
16.6 ± 0.2	2.4 ± 0.5

CROSS SECTIONS FOR THE $^{191}Ir(n,2n)^{190}Ir$ AND $^{193}Ir(n,2n)^{192}Ir$ REACTIONS

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The (n,2n) reaction on Ir isotopes is of importance in reactor dosimetry applications using the activation technique. The present work fulfils the request listed in the WRENDA 76/77 edited by the NDS of IAEA [1]. The excitation curves for the $^{191}Ir(n,2n)^{190g+m1}Ir$, $^{191}Ir(n,2n)^{190m2}Ir$ and the $^{193}Ir(n,2n)^{192g+m1}Ir$ reactions were measured in the neutron energy range from 13.04 MeV to 17.86 MeV.

The samples of natural high purity irydium were irradiated with neutrons from the $^{3}H(d,n)^{4}He$ reaction at deuteron energies 0.4 MeV, 0.9 MeV and 1.8 MeV. The activated samples were counted for their γ-activities by a 30 ccm Ge(Li) spectrometer. In case of $^{190g+m1}Ir$ the decay with a half-life 12 d of the 361 keV, 371 keV, 407 keV and 518 keV γ-rays was followed. The $^{190m2}Ir$, 3.2 h, activity was identified by measuring the 361 keV and the 502 keV γ-rays, and for $^{192g+m1}Ir$ decaying with the half-life 74.2 d the sum of the 308 keV and 316 keV as well as the 468 keV γ-rays were measured. The observed γ-activities were refered to the activities induced in the monitoring reaction $^{56}Fe(n,p)^{56}Mn$ with known cross section [2].

The results of measurements together with the reference reaction cross sections are presented in Table 1. The errors attached contain the statistical uncertainties as well as the systematic errors with inclu-

TABLE II

Decay data adopted for cross section determination [3]

Residual nucleus	E_γ	Intensity	Conversion coeficient
^{190}Ir	371	0.217	0.05
	361	0.123	0.0518
	518	0.315	0.0728
	407	0.27	0.0364
$^{190m2}Ir \rightarrow {}^{190g}Ir$	-	0.05	-
$^{190m2}Ir \rightarrow {}^{190m}Os$	-	0.95	-
^{190m}Os	502	1.0	0.024
^{192g}Ir	308	0.342	0.092
	316	0.945	0.078
	468	0.514	0.027

TABLE 1. Cross sections for (n,2n) reaction on Ir isotopes and the reference reaction cross sections

E_n MeV	$^{191}Ir(n,2n)^{190g+m1}Ir$ mb	$^{191}Ir(n,2n)^{190m2}Ir$ mb	$^{193}Ir(n,2n)^{192g+m1}Ir$ mb	$^{56}Fe(n,p)^{56}Mn$ mb
13.04 ± 0.38	1763 ± 121	87.0 ± 6.1	1824 ± 131	113.0
13.35 ± 0.24	1790 ± 99	85.7 ± 5.4	-	114.0
13.87 ± 0.34	1752 ± 97	92.8 ± 5.4	1750 ± 130	112.0
14.49 ± 0.34	1875 ± 97	105.6 ± 6.5	-	107.0
15.04 ± 0.28	1882 ± 105	109.4 ± 6.1	1775 ± 132	99.2
15.40 ± 0.24	1711 ± 127	104.0 ± 6.7	1513 ± 111	92.5
15.94 ± 0.46	1781 ± 113	142.0 ± 9.9	1721 ± 127	86.5
16.59 ± 0.11	1512 ± 93	138.2 ± 10.1	1459 ± 111	74.5
17.42 ± 0.44	1192 ± 78	141.1 ± 10.4	1193 ± 91	64.5
17.86 ± 0.08	1005 ± 64	128.5 ± 9.3	1008 ± 76	60.0

sion of the errors of the monitoring reaction. The decay data adapted in the calculations of the cross sections are gathered in Table 2.

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EVALUATION OF THE EXCITATION CURVE FOR THE $^{58}Ni(n,2n)^{57}Ni$ REACTION

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The aim of this work was to evaluate the excitation curve for the $^{58}Ni(n,2n)^{57}Ni$ reaction in the neutron energy range from the threshold energy up to 28 MeV. The cross sections for this reaction have been requested in WRENDA 76/:: by A.Michaudon /ref. no 250/ for fission reactor development and by D.Breton /ref. no 1409/, Y.Seki /ref. no 1410/ and G.D.McCracken /ref. no 1411/ for fusion reactor purposes.

The evaluation was based on 15 accepted experimental data sets or single-energy cross sections. The recommended cross sections have been tabelarized in 0.1 MeV energy steps. The estimated accuracy is 11.4% for energies lower than 14 MeV, 8.7% between 14 MeV and 16 MeV, and worse at higher energies. The detailed description of the evaluation procedure will be published in our forthcoming paper. Some of the results are presented in Figs 1 and 2.

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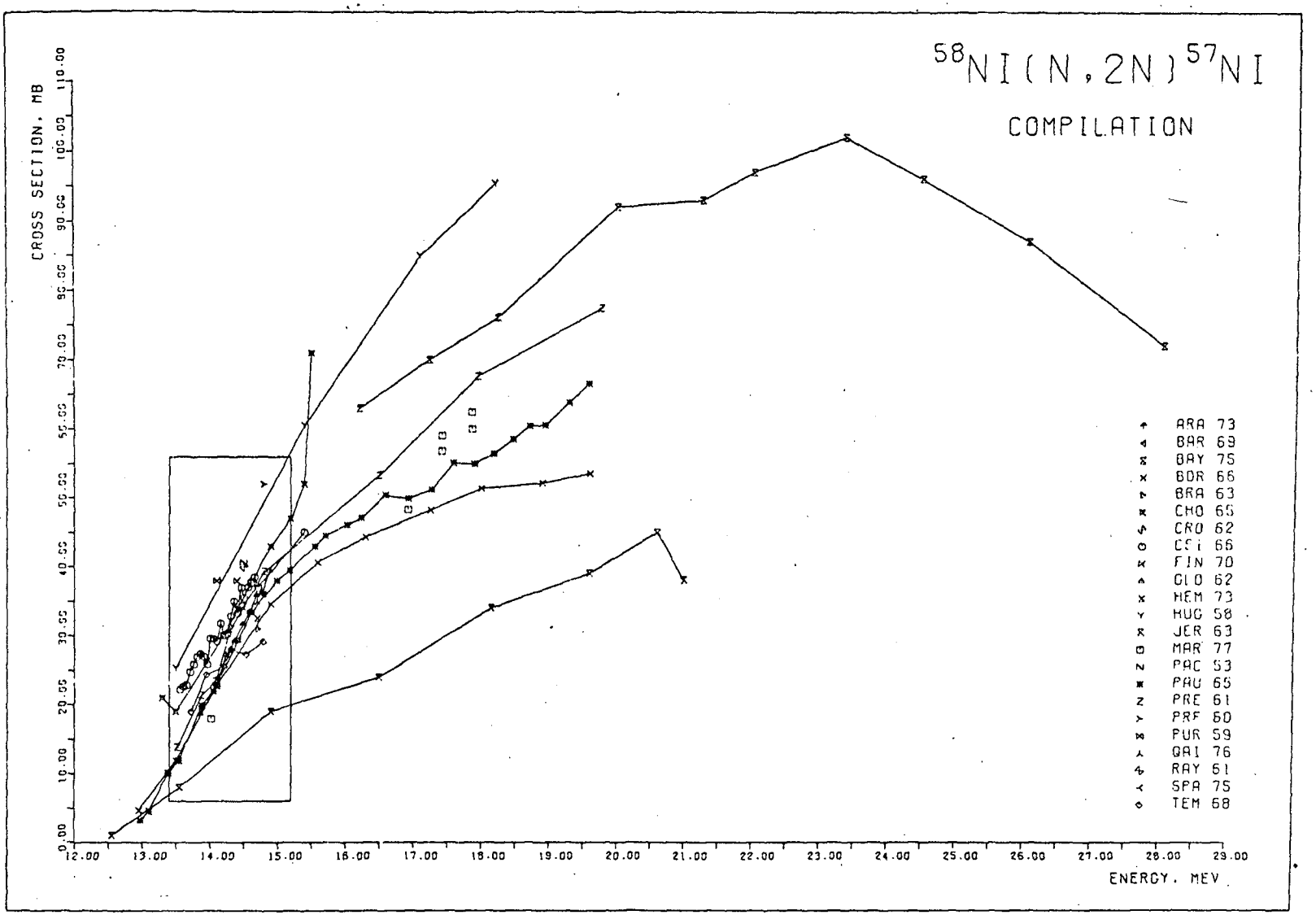
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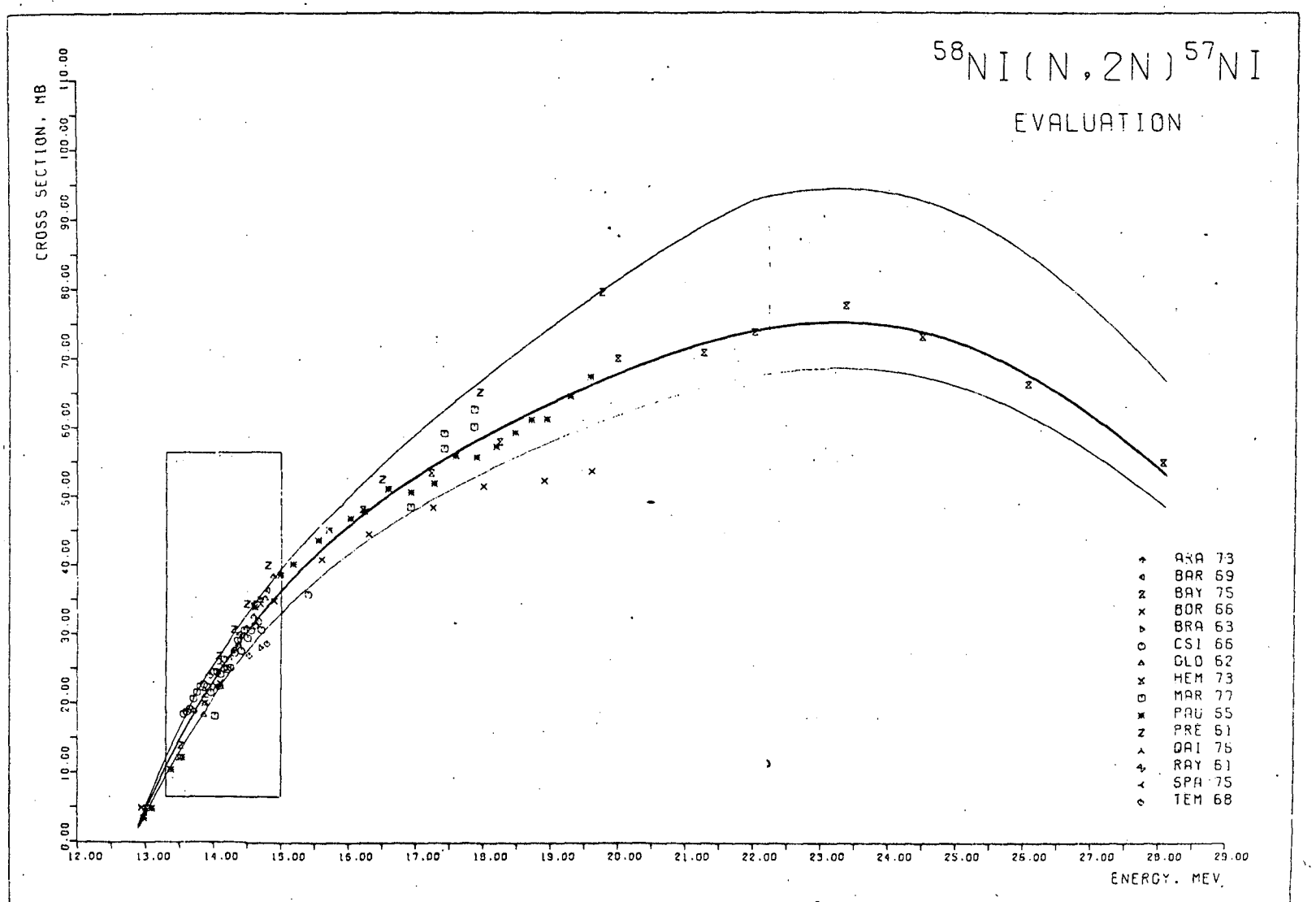
ENERGY, MEV
ARA 73
BAR 69
BAY 75
BDR 66
BRA 63
CHO 65
CRO 62
CSI 66
FIN 70
GLO 62
HEM 73
HUG 58
JER 63
MAR 77
PAC 53
PAU 65
PRE 61
PRF 60
PUR 59
QAI 76
RAY 61
SPA 75
TEM 68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HEM 73
MAR 77
PAU 55
PRE 61
QAI 76
RAY 61
SPA 75
TEM 68

A "FORTRAN" PROGRAM FOR CALCULATION OF THE SUPER-CONDUCTIVITY FUNCTIONS AND THE NUCLEAR LEVEL DENSITY

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The theory of sperconductivity has been applied to the description of the pairing effects in the nuclear level density [1 - 4]. The calculation scheme of the nuclear level density proposed in the present work was used repeatedly in calculations of the excitation curves for nuclear reactions in the frame of the statistical model. The aim of this work lies in describing the physical concept underlying the method prior to describing the FORTRAN code itself.

An approximate general expression for the density of nuclear states can be obtained on the basis of thermodynamics

$$\omega = \frac{\exp S}{(2\pi)^{1/2 n} \sqrt{\det\left(\frac{\partial^2 S}{\partial \mu_i \partial \mu_j}\right)_{\mu_0}}} \qquad (1)$$

where S is the entropy of the nucleus, μ_i are the Lagrange multipliers corresponding to the integrals of motion considered, n of this integrals is taken into account. Here μ_0 defines the point in space, where the Lagrange multipliers are taking physical meaning. The entropy of a nucleus is the sum of the neutron and proton entropies, the same beeing true for the energy of the system.

The pairing Hamiltonian [1] provides the following expressions for the entropy

$$S = 2\sum_k \ln\left[1+\exp(-\beta E_k)\right] + 2\beta \sum_k \frac{E_k}{1+\exp(\beta E_k)}, \qquad (2)$$

and energy

$$E = \sum_k \varepsilon_k \left[1 - \frac{\varepsilon_k - \lambda}{E_k} \operatorname{tgh}\left(\tfrac{1}{2}\beta E_k\right)\right] - \frac{\Delta^2}{G}, \qquad (3)$$

where $E_k = \sqrt{(\varepsilon_k - \lambda)^2 + \Delta^2}$, k is the index of the singleparticle levels with energies ε_k taken from the Nillson model, λ is the Fermi level, β the inverse of the thermo-dynamic temperature t, Δ the energy gap in the level spectrum and G is a constant defining the strenght of the pairing interaction taken from ref. [5].

For practical calculations it is necessary to know the values of λ and Δ for both neutrons and protons, as functions of the temperature t. These can be obtained from the state equation

$$\frac{2}{G} = \sum_k \frac{\operatorname{tgh}\left(\frac{1}{2}\beta E_k\right)}{E_k} \qquad (4)$$

and the equation defining the number of nucleons N of a given kind

$$N = \sum_k \left[1 - \frac{\varepsilon_k - \lambda}{E_k} \operatorname{tgh}\left(\tfrac{1}{2}\beta E_k\right)\right] \qquad (5)$$

Nuclear state density for a given excitation energy U and angular momentum projection M is calculated from the following expressions

$$\omega(U,M) = A(U)\,\omega\left(U - \frac{M^2 t}{2\sigma^2}\right),$$

$$A(U) = \frac{\omega(U)}{\sum_M \omega\left(U - \frac{M^2 t}{2\sigma^2}\right)} ,$$

$$U = \frac{M^2 t}{2\sigma^2} + U_t \quad , \tag{6}$$

where σ^2 is the spin cut-off function as given in ref. [3] and $\frac{M^2 t}{2\sigma^2}$ stands instead of the rotational energy. The quantities S_n, S_p, $\det\left(\frac{\partial^2 S}{\partial\mu_i \partial\mu_j}\right)_{\mu_0}$, $A_n, \Delta_p, \lambda_n, \lambda_p, E_n, E_p$ / n - neutrons, p - protons/, which define $\omega(U)$ as well as the $\sigma^2 = \sigma_n^2 + \sigma_p^2$ are calcultaed as functions of t and ascribed to the excitation energy

$$U_t = \left[E_n(t) - E_n(0)\right] + \left[E_p(t) - E_p(0)\right] . \tag{7}$$

The gap $\Delta = 0$ defines the critical temperature t_c above which the superconductivity disappears.

Introducing of the σ^2 functions to the description of the spin dependence of the level density encompasses the approximations described in detail in ref. [6]. The σ^2 taken from ref. [3] fails in describing the moment of inertia of the nucleus at low energies. In order to improve the behaviour of $\frac{M^2 t}{2\sigma^2}$ at low energies the true rotational yrast energies have been calculated within the approach proposed originally by Kammuri [2], who considered the additional inte-

grall of motion namely the projection of the angular momentum M, and the corresponding Lagrange multiplier ω.

In this formalism we obtaine in the zero-temperature limit the following modified expressions insted of eqs. (4) and (5)

$$\frac{2}{G}=\sum_{E_k>\omega m_k}\frac{1}{E_k}\,, \tag{8}$$

$$N=\sum_{E_k<\omega m_k}1+\sum_{E_k>\omega m_k}\left[1+\frac{\varepsilon_k-\lambda}{E_k}\right]. \tag{9}$$

In these equations m_k are the projections of the singleparticle level angular momenta. From eqs. (8) and (9) with $\Delta=0$ the critical values ω_{cr} and λ_{cr} may be evaluated. For $\omega>\omega_{cr}$ the following equation is valid

$$N=\sum_{|\varepsilon_k-\lambda|<\omega m_k}1+\sum_{|\varepsilon_k-\lambda|>\omega m_k}\left[1-\frac{\varepsilon_k-\lambda}{|\varepsilon_k-\lambda|}\right]. \tag{9a}$$

When solving eqs. (8) and (9) the effective rotational energy E_{rot} can be calculated from equations similar to (3) and (7) taken in the zero-temperature limit [2]. The corresponding yrast spin projection /beeing a sum of the projections for protons and neutrons [4]/ is given by the formula

$$M_y=\sum_{|\varepsilon_k-\lambda|<\omega m_k}m_k\,. \tag{10}$$

Such calculations, when omitting some spurious solutions, provide yrast lines, which were approximated by the following expression

$$E_{rot} = a M_y^2 + b M_y \quad , \tag{11}$$

where $a = 0.072 \exp[-0.02039A]$, $b = 0.26$ amd A is the mass number of the nucleus. It has been found that the approximation $\frac{M^2 t}{2\sigma^2} = E_{rot}$ for $\frac{M^2 t}{2\sigma^2} > E_{rot}$ describes fairly well the exact dependence of the effective rotational energy on t predicated by the Kammuri model.

The superconductivity model describes the even-even nuclei. The level density for an odd-mass nuclei can be obtained by appropriate energy shifts, ΔU, consisting of two components, one ΔU_1, taking account of the energy difference between the ground states of the odd-mass or odd nucleus and the neighbouring even nuclei, the second one, ΔU_2, accounting for the fact that in the vicinity of closed shells addition of an odd nucleon affects also the properties of the highly excited nucleus. These shifts are calculated according to the method described in refs. [7].

The computer code WAXWA founds the superconductivity parameters with use of the minimizing procedure MINCON [8]. The program provides 3 x 60 values of $\omega(U)$, $\frac{t}{2\sigma^2}$ and M_y with energy step ΔU = 0.5 MeV from 0.5 MeV to 30 MeV. Additionally the output contains the angular momentum distribution of the level density, calculated from the formula

$$\rho(U,J) = \omega(U,M=J) - \omega(U,M=J+1) . \tag{12}$$

These are tablerized with an energy step ΔU = 3 MeV from 0.5 MeV to 30 MeV for 30 spin values starting with 0 or 1/2.

The only input data required are the mass-number A and the atomic number Z of the nucleus in question.

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ANALYSIS OF THE TOTAL RADIATION WITH FOR NEUTRON RESONANCES

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In this work we have analysed the dependence of the total readiation width Γ_γ on the resonance energy E_{res}. The measured radiative widths of 1500 resonances for 102 isotopes from ^{45}Sc to ^{238}Cm have been considered. The dependence of the total radiative width on the resonance energy was described by means of Czebyszew's polynomials [2]. The fit to the experimental data has been performed [1] using the least squares method. It was found that the majority of the experimental widths are fitted best by the zero-order polynominal. In cases where the total radiation width is determined with accuracy better than 5% a weak dependence of Γ_γ on E_{res} can be noticed. Basing on these results we have assumed that the radiation width does not depend on the resonance energy. Taking this into account the average radiation width were calculated and their dependence on the effective excitation energy U as well as on the level density parameter a /determining the density of single-particle states close to the Fermi energy/ and the mass number A has been investigated. The following expression for the total radiation width was obtained

$$\Gamma_\gamma = 11.7\, A^{-1.6}\, U^{0.8}\, a^{-0.2}.$$

Here Γ_γ is expressed in eV, U in MeV and a in MeV^{-1}. The parameters U and a describing best the experimental radiative width as well as Γ_γ obtained from formula (1) are presented in Table 1. It is worthwhile to note that the average radiation width obtained in the present work differ from those reproted in refs [3, 4].

TABLE 1

Izotope	A	U MeV	a MeV^{-1}	Γ_γ meV
1	2	3	4	5
Sc	46	8.77	7.4	
Cr	54	6.52	8.4	
Fe	57	6.39	7.9	
Co	60	7.49	8.4	
Ni	59	7.60	9.3	
Ni	61	6.44	10.5	
Ni	62	7.35	9.7	
Cu	64	7.92	9.4	496
Cu	66	7.07	9.8	367
Ga	70	7.65	11.1	360
Ga	72	6.52	12.3	388
Ge	71	6.41	12.3	177
Ge	73	5.76	13.3	187
Ge	74	6.88	13.5	239
Ge	75	5.57	12.2	217
As	76	7.33	13.3	325
Se	75	6.74	13.8	247
Se	77	6.28	13.7	230
Se	78	7.09	14.0	332
Se	79	5.64	14.5	203
Se	81	5.46	14.6	190
Rb	86	8.65	10.9	198

1	2	3	4	5
Rb	88	6.03	10.9	132
Sr	89	5.08	11.1	197
Zr	91	5.88	12.3	320
Zr	92	6.50	12.6	152
Zr	93	5.72	13.9	342
Zr	95	5.34	14.5	260
Rh	104	7.00	18.5	136
In	116	6.78	17.1	111
Sb	122	6.81	17.7	117
Sb	124	6.47	17.0	84
Te	123	5.74	18.9	173
Te	124	6.74	18.0	158
Te	125	5.44	19.6	115
Te	126	6.30	18.5	150
Te	127	5.19	19.7	145
Te	129	4.98	20.0	172
Xe	130	6.70	17.8	110
Xe	132	6.29	16.7	126
Ba	131	6.32	19.1	124
Ba	135	5.80	17.6	94
Ba	136	7.04	15.5	127
La	140	5.16	15.9	64
Pr	142	5.84	16.7	94
Nd	144	5.54	18.9	86
Nd	145	4.57	19.5	90
Nd	146	5.24	21.0	48

1	2	3	4	5
Nd	147	4.26	23.9	50
Nd	149	4.09	27.8	72
Pm	148	5.90	20.9	85
Sm	148	5.91	20.7	55
Sm	150	5.37	25.3	51
Sm	151	4.37	26.4	85
Sm	152	5.55	25.9	73
Sm	153	4.79	25.0	74
Sm	155	4.84	22.9	112
Eu	152	6.31	24.8	128
Eu	154	6.44	23.1	106
Gd	153	5.27	25.9	68
Gd	155	5.57	24.6	83
Gd	156	6.44	23.2	101
Gd	157	5.40	22.8	111
Gd	158	5.98	22.4	97
Gd	159	6.90	17.2	122
Tb	160	6.38	21.7	117
Dy	162	5.95	23.2	140
Dy	163	5.75	20.7	159
Dy	165	4.60	22.7	69
Ho	166	6.24	21.9	78
Er	167	5.52	22.9	112
Er	168	6.27	21.1	102
Tm	170	6.59	21.1	94
Yb	172	6.30	22.8	111

1	2	3	4	5
Yb	173	5.52	21.6	104
Yb	174	6.12	20.7	99
Yb	175	4.96	21.9	86
Hf	178	5.93	23.4	57
Ta	182	6.06	21.7	52
W	183	5.53	21.9	94
W	184	5.87	22.9	95
W	185	5.15	22.5	60
W	187	4.89	22.9	74
Re	186	6.18	22.4	55
Re	188	5.87	23.2	72
Ir	192	6.20	23.2	73
Ir	194	6.07	21.8	79
Pt	196	6.19	21.1	86
Au	198	6.51	19.1	141
Pa	232	5.56	25.3	49
Pa	235	4.68	34.9	58
U	234	5.32	30.1	52
U	235	4.54	31.4	19
U	236	4.87	32.2	41
Np	238	5.49	29.2	58
Pu	239	4.97	29.7	46
Pu	240	5.22	30.3	51
Pu	241	4.57	31.0	30
Pu	242	4.91	31.5	48

1	2	3	4	5
Am	242	5.53	28.9	41
Am	244	5.36	30.1	50
Cm	245	4.81	29.6	42

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NEUTRON ORBIT RADII IN THE INVESTIGATIONS OF SUB-COULOMB (d,p) STRIPPING

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Quite the contrary to the information about proton distribution in atomic nuclei, experimental data on neutron distribution are scarce and not reliable e.g. [1] . A promissing way of obtaining the information about rms radii of neutron orbits $\langle r^2_{nlj} \rangle^{1/2}$, is based on comparison of the measured differential cross sections of sub-Coulomb single-neutron transfer with the cross sections calculated by means of DWBA method [2, 3] . Due to the low energy in both reaction channels the results of calculations slightly depend on the choice of optical model parameters for protons and deuterons, but they are sensitive to the choice of parameters of the bound state potential of transfered neutron, particularly to r_o and a . However, all pairs of values of these parameters (r_o, a) which correspond to the theoretical cross section equal to the experimental one /using spectroscopic factor from another independent experiment/, lead to almost identical values of $\langle r^2_{nlj} \rangle^{1/2}$.

Excitation functions and absolute differential cross sections of the reactions $^{62}Ni(d,p)^{63}Ni$, $^{64}Ni(d,p)^{65}Ni$ and $^{74}Ge(d,p)^{75}Ge$, leading to different states of final nucleus up to excitation energy 4 MeV,

discussed in this paper, were measured by means of scattering chamber with cooled surface barrier silicon detectors. Experiments were carried out in energy range 2,7 - 3,3 MeV and angular range 70° - 160°. Deutron beam was delivered by Warsaw van de Graaff accelerator "LECH". Experimental energy resolution was 24 - 35 keV. The targets used were made of enriched isotopes and were 100 - 200 $\mu g/cm^2$ thick.

The results for $^{62}Ni(d,p)^{63}Ni$ were analysed on the basis of DWBA calculations using DWUCK 2 code. Up to now with help of spectroscopic factors from paper [4], we have obtained values of rms radii of neutron orbits for three selected levels of ^{63}Ni. These preliminary results with error cautiously estimated for about $\pm 0,30$ fm are presented in Table 1.

TABLE 1

Excitation energy MeV	Separation energy MeV	nlj	S	$r^2_{nlj}{}^{1/2}$ fm
0	6,841	$2p_{1/2}$	0,37	4,38
1,002	5,839	$2p_{1/2}$	0,33	4,63
2,953	3,880	$3s_{1/2}$	0,19	5,52

Our result for $2p_{1/2}$ orbit in ^{63}Ni is in agreement with $4,38 \pm 0,15$ fm value obtained by Chapman et al [5] for $2p_{1/2}$ orbit in ^{61}Ni. Further experimental and theoretical work is in progress.

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THE LEVEL STRUCTURE OF THE ^{127}Cs NUCLEUS

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The structure of low lying levels in the ^{127}Cs nucleus is known from ref. 1 where the isomeric state with $I^{\pi} = 11/2^-$ was populated in the ^{127}I $(\alpha, 4n)^{127}$Cs reaction and its γ - decay was studied. Some information is also available from the β^+ - decay of the ^{127}Ba nucleus /see refs. 2, 3/. In the present work the band structure in ^{127}Cs above the $11/2^-$ isomeric state was studied. The existence of a decoupled band based on the $11/2^-$ state /proton in the $h_{11/2}$ subshell/ was expected. Such decoupled bands were observed in the neighbouring nuclei with Z = 57 /refs. 4, 5/ and Z = 59 /ref. 6/ giving information on the shape of nuclei /sign of the deformation, departure from the axial symetry - ref. 7/.

In the present experiment the excited states of the ^{127}Cs nucleus were populated in the ^{127}I$(\alpha, 4n)^{127}$Cs reaction at an alpha particle energy of 51 MeV. The measurements of the single gamma spectra /prompt and delayed/, the gamma - gamma two dimensional coincidences and the γ- ray angular distributions were performed using Ge(Li) detectors. Besides, the excitation function was measured at four alpha

energies ranging from 43 MeV up to 51 MeV. The preliminary analysis of results gives evidence on the existence of a band structure. The main two bands are built on the isomeric $11/2^-$ and the $7/2^+$ states at the excitation energy of 453 keV and 273 keV, respectively. The tentative level scheme of ^{127}Cs is given in figure 1.

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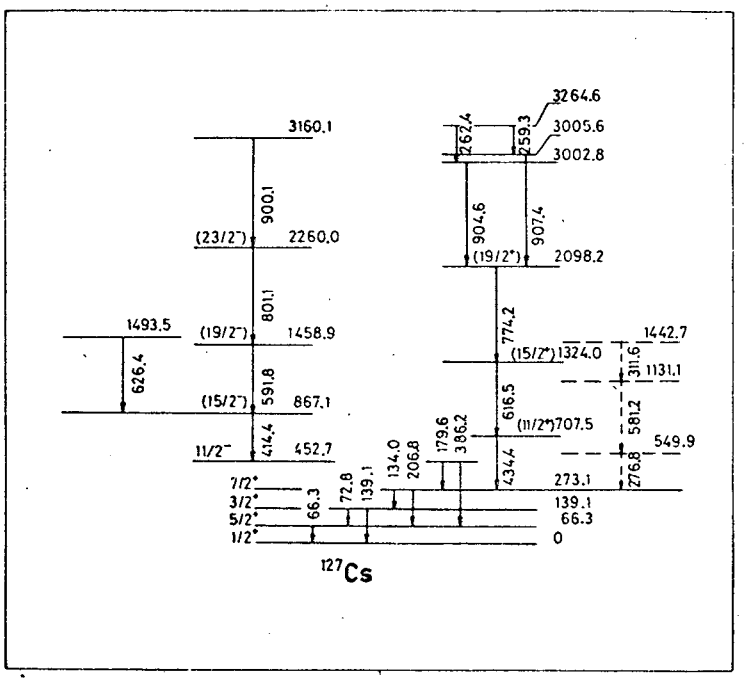

Fig. 1. Tentative level scheme for ^{127}Cs. The isomeric state $(11/2^-)$ and the states below it are known from refs. 1, 3.

STUDY OF ^{124}Xe AND ^{126}Xe STRUCTURE

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The β^+ decay of ^{124}Cs and ^{126}Cs was investigated. These nuclei were obtained in (p,n) reactions with 10 MeV protons from Proton Linear Accelerator at Swierk. The gaseous Xe targets, enriched with 124 and 126 isotopes, were used. Single γ - ray and $\gamma-\gamma$ coincidence spectra were measured. Proposed level schemes of ^{124}Xe and ^{126}Xe are shown on the figure.

Even - even Xe isotopes are typical examples of transitional nuclei. Potential energy surface calculated by macroscopic - - microscopic method exhibits very weak dependence on γ - deformation. It indicates a tendency to the strong coupling between γ - vibrations and rotation and very important role of the γ - dependence of the kinetic energy part of the collective Hamiltonian. Therefore, the collective model taking into account the γ - dependence of the inertial functions [1] was used to interpret the energies of levels and transition probabilities B (E2) for $^{124,\ 126}$Xe. It was shown that the model can quantitatively reproduce the experimental data, but the renomalization of the microscopic inertial functions was needed.

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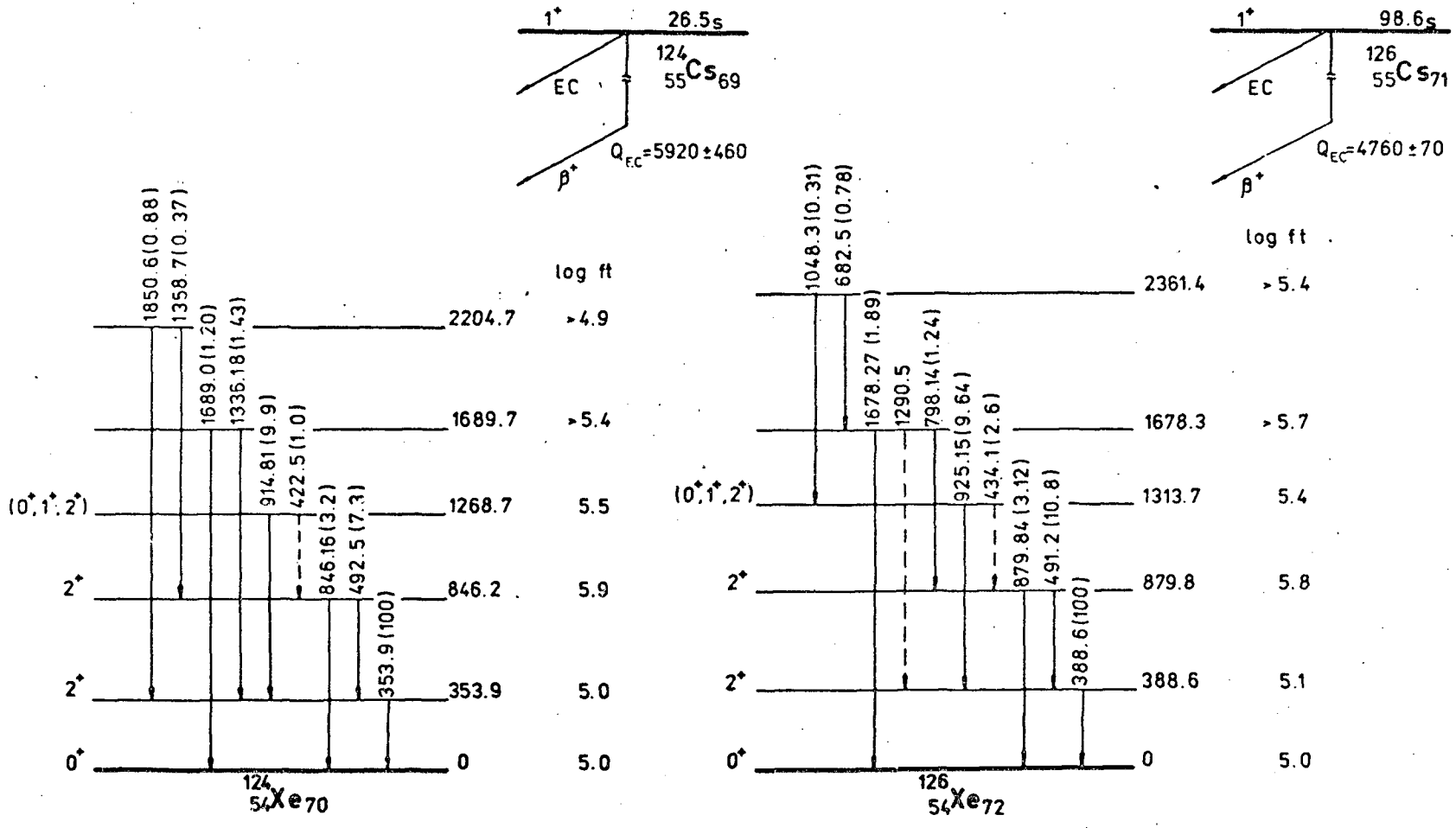
1+
26.5s
124 55Cs69
EC
β+
QEC=5920±460
1+
98.6s
126 55Cs71
EC
β+
QEC=4760±70
log ft
2204.7 >4.9
1689.7 >5.4
(0+,1+,2+) 1268.7 5.5
2+ 846.2 5.9
2+ 353.9 5.0
0+ 0 5.0
1850.6(0.88)
1358.7(0.37)
1689.0(1.20)
1336.18(1.43)
914.81(9.9)
422.5(1.0)
846.16(3.2)
492.5(7.3)
353.9(100)
124 54Xe70
log ft
2361.4 >5.4
1678.3 >5.7
(0+,1+,2+) 1313.7 5.4
2+ 879.8 5.8
2+ 388.6 5.1
0+ 0 5.0
1048.3(0.31)
682.5(0.78)
1678.27(1.89)
1290.5
798.14(1.24)
925.15(9.64)
434.1(2.6)
879.84(3.12)
491.2(10.8)
388.6(100)
126 54Xe72