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PROGRESS REPORT ON NUCLEAR DATA RESEARCH IN POLAND /May 1970–April 1971/

Gathered by

A. MARCINKOWSKI

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ИНФОРМАЦИОННЫЙ ЦЕНТР ПО ЯДЕРНОЙ ЭНЕРГИИ
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Editor's Note

This progress Report on nuclear data research in Poland /May 1970 - April 1971/ contains only informations 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 1970 - kwiecień 1971/ 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 1970 до апреля 1971 исследованиях в области нейтронной физики, связанных с деятельностью Комитета по Ядерным Данным Международного Агенства Атомной Энергии.В данных не включены результаты работ из других областей ядерной физики а именно результаты исследований с помощью заряженных частиц а также с области применения нейтронов в физике твердого тела.Доклады эти не являются полными и не рекомендируется ссылаться на них без согласия авторов.

CONTENTS

1. Polarization of neutrons from the $^{3}H(d,n)^{4}He$ reaction at low deuteron energies. 4

2. Cross Sections for the $^{71}Ga(n,p)^{71m}Zn$, $^{71}Ga(n,2n)^{70}Ga$, $^{75}As(n,p)^{75m}Ge$, $^{75}As(n,p)^{75}Ge$, $^{75}As(n,2n)^{74}Ac$, $^{80}Se(n,2n)^{79m}Se$, $^{80}Se(n,np)^{79}As$, $^{82}Se(n,2n)^{81m}Se$, $^{117}Sn(n,p)^{117}In$, $^{117}Sn(n,n')^{117m}Sn$, and $^{118}Sn(n,2n)^{117m}Sn$ reactions in the neutron energy range from 13 to 18 MeV. 8

3. Calculations of the compound reaction cross sections with accounting for the effect of gamma - particle competition. 14

4. Energy spectra of alpha particles from the $^{153}Eu(n,\alpha)^{150}Pm$, $^{160}Dy(n,\alpha)^{157}Dd$, $^{162}Dy(n,\alpha)^{159}Gd$ and $^{164}Dy(n,\alpha)^{161}Gd$ reactions with 14.2 MeV neutrons. 16

5. On the knock-on mechanism in the (n,α) reaction. 22

6. Energy-angular distribution of alpha particles emitted during the thermal neutron fission of ^{235}U . 27

7. Investigation of the neutron capture high energy gamma-rays. 29

8. Neutron energy spectra from negative muon absorption on complex nuclei. 34

9. Excitation of isomeric activities in Rb, Y, Pd, Cd, W, Os and Pb using 14.8 MeV neutrons. 42

10. Excitation of 3 min activity in ^{190}Re in the $^{190}Os(n,p)^{190}Re$ reaction using 14.8 MeV neutrons. 43

11. The decay scheme of ^{232} Pa. 48

12. Levels of ^{230}Th and ^{230}U fed in the decay of ^{230}Pa. 50

13. The code FLANGE - AL 4 52

14. The code HEXSCAT - S 52

15. The routine of thin tritium-titanium, tritium-zirconium and deuterium-titanium, deuterium-zirconium targets. 53

Polarization of neutrons from the $^{3}H(d,n)^{4}He$ reaction at low deuteron energies.

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Polarization of neutrons from the $^{3}H(d,n)^{4}He$ reaction appears to be negligible for deuteron energies up to 300 keV confirming the description of the reaction as an S-wave formation of a 3/2 + state in ^{5}He. For deuteron energy of 1.8 MeV in the region of 90^{o} c.m. the polarization amounts to as much as 16% /1/.

We have performed polarization measurements just in the region of transition from a non - polarizing resonance to a region of rapidly increasing polarization. Using the method and aparatus described in ref /2/ we have measured the angular distribution of polarization at deuteron energy 1.4 MeV and the energy distribution of polarization for angles 60^{o} and 90^{o} for deuteron energies from 0.5 MeV up to 1.6 MeV. The results are shown in Figs 1 and 2.

The results of polarization measurements have been analysed together with the date on total and differential cross section. The compound nucleus formation has been assumed to be mainly responsible for the reaction. Results of the analysis point to the existence in ^{5}He of a 5/2 + state at an excitation energy of about 20 MeV and of a 1/2 + state situated near the well known 3/2 + state at excitation energy 16.70 MeV.

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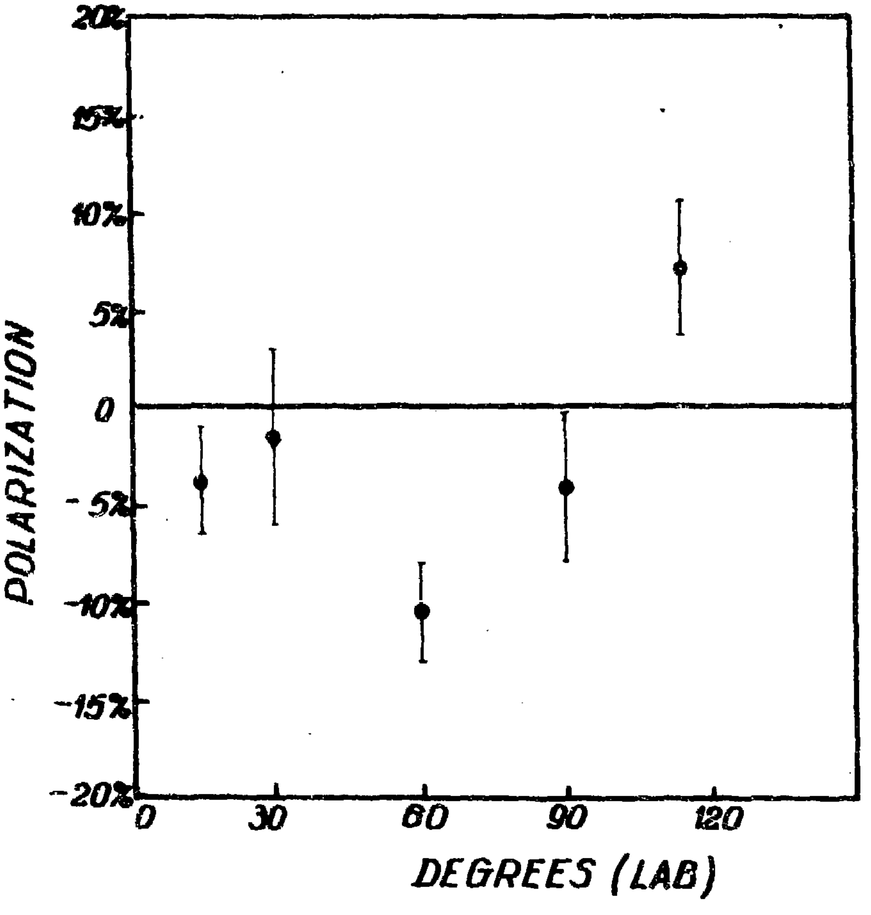

Fig. 1 . The angular dependence of neutron polarization at deuteron energy 1.4 MeV .

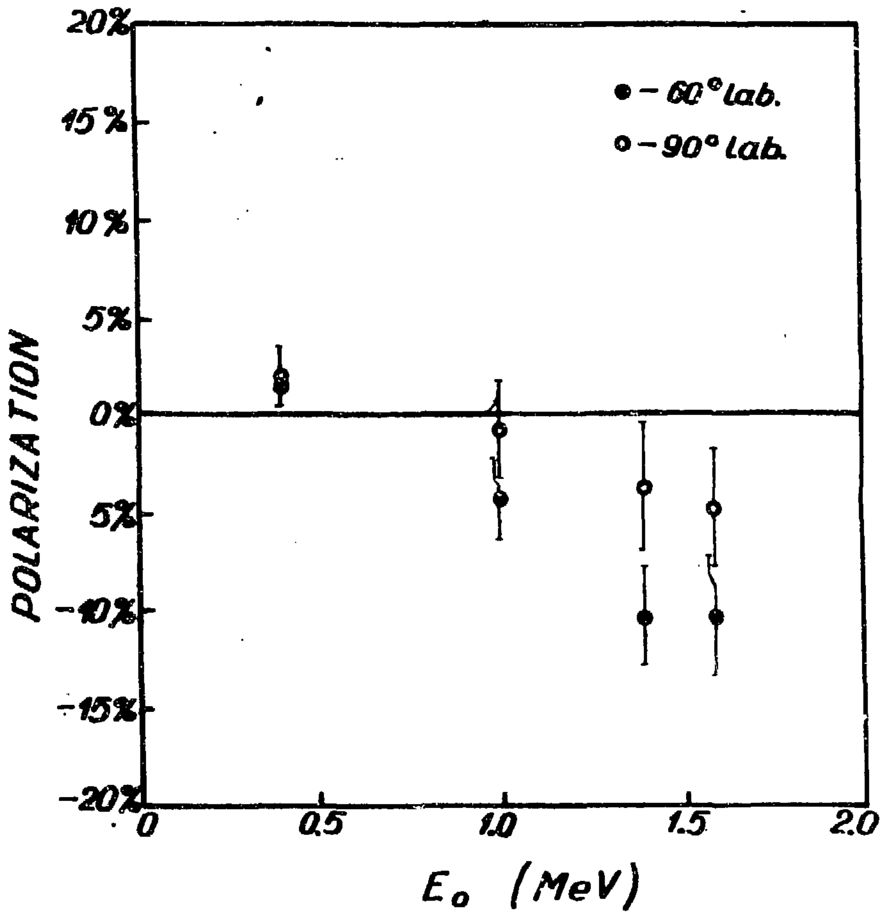

Fig. 2 . The energy dependence of polarization of neutrons emitted at 60^0 and 90^0 in the lab. system.

Cross Sections for the ^{71}Ga(n,p)^{71m}Zn, ^{71}Ga(n,2n)^{70}Ga, ^{75}As(n,p)^{75m}Ge, ^{75}As(n,p)^{75}Ge, ^{75}As(n,2n)^{74}As, ^{80}Se(n,2n)^{79m}Se, ^{80}Se(n,np)^{79}As, ^{82}Se(n,2n)^{81m}Se, ^{117}Sn(n,p)^{117}In, ^{117}Sn(n,n')^{117m}Sn and ^{118}Sn(n,2n)^{117m}Sn Reactions in the Neutron Energy Range from 13 to 18 MeV.

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The absolute cross sections for the ^{71}Ga(n,p)^{71m}Zn, ^{71}Ga(n,2n)^{70}Ga, ^{75}As(n,p)^{75m}Ge, ^{75}As(n,p)^{75}Ge, ^{75}As(n,2n)^{74}As, ^{80}Se(n,2n)^{79m}Se, ^{80}Se(n,np)^{79}As, ^{82}Se(n,2n)^{81m}Se, ^{117}Sn(n,p)^{117}In, ^{117}Sn(n,n')^{117m}Sn and ^{118}Sn(n,2n)^{117m}Sn reactions were evaluated from the gamma activity measurements with the use of the scintillation spectrometer. The reaction final products were identified by their characteristic gamma-ray transition energies and the least square analysis of the decay curves. The neutrons were obtained in the Van de Graaff accelerator from a ^{3}H(d,n)^{4}He reaction. The proper choice of the irradiation angle and the deuteron energy allowed to get neutrons in the energy range from 13 to 18 MeV. The measurements were refered to the well known cross section of the ^{56}Fe(n,p)^{56}Mn reaction. The results are shown in Tables 1 - 11 .

Table 1

Cross Section for the $^{71}Ga(n,p)^{71m}Zn$ Reaction

E_n MeV	mb
13.36 ± 0.14	10.4 ± 0.1
13.90 ± 0.09	9.5 ± 0.1
14.47 ± 0.11	10.4 ± 0.3
15.06 ± 0.17	11.5 ± 0.1
15.36 ± 0.20	9.6 ± 0.2
15.88 ± 0.19	7.1 ± 2.0
16.51 ± 0.11	9.5 ± 2.1

Table 2

Cross Section for the $^{71}Ga(n,2n)^{70}Ga$ Reaction

E_n MeV	mb
13.36 ± 0.14	1098 ± 26
13.90 ± 0.09	1153 ± 25
14.47 ± 0.11	1135 ± 25
15.06 ± 0.17	1130 ± 32
15.36 ± 0.20	1148 ± 23
16.51 ± 0.11	1046 ±127

Table 3

Cross Section for the $^{75}As(n,p)^{75m}Ge$ Reaction

E_n MeV	mb
13.02 ± 0.14	12.4 ± 1.6
13.36 ± 0.14	23.3 ± 0.5
13.90 ± 0.09	20.7 ± 0.7
14.47 ± 0.11	21.1 ± 0.7
15.06 ± 0.17	18.2 ± 0.8
15.36 ± 0.20	17.9 ± 0.7
15.88 ± 0.19	10.7 ± 1.2
16.51 ± 0.11	8.9 ± 1.1

Table 4

Cross Section for the $^{75}As(n,p)^{75}Ge$ Reaction

E_n MeV	mb
13.02 ± 0.14	28.5 ± 0.9
13.36 ± 0.14	28.8 ± 0.7
13.90 ± 0.09	38.1 ± 0.8
14.47 ± 0.11	31.2 ± 1.0
15.06 ± 0.17	26.5 ± 0.8
15.36 ± 0.20	30.4 ± 0.8
15.88 ± 0.19	27.6 ± 0.9
16.51 ± 0.11	19.9 ± 0.6
17.32 ± 0.20	12.5 ± 1.0
17.78 ± 0.15	12.4 ± 0.8

Table 5

Cross Section for the $^{75}As(n,2n)^{74}As$ Reaction

E_n MeV	mb
13.02 ± 0.14	955 ± 15
13.36 ± 0.14	890 ± 6
13.90 ± 0.09	955 ± 21
14.47 ± 0.11	1027 ± 10
15.06 ± 0.17	1109 ± 14
15.88 ± 0.19	1299 ± 19
16.51 ± 0.11	1312 ± 20
17.32 ± 0.20	1245 ± 186
17.78 ± 0.15	1321 ± 122

Table 6

Cross Section for the $^{80}Se(n,2n)^{79m}Se$ Reaction

E_n MeV	mb
13.02 ± 0.14	193 ± 37
13.36 ± 0.14	196 ± 4
13.90 ± 0.09	165 ± 6
14.47 ± 0.11	189 ± 5
15.06 ± 0.17	203 ± 14
15.36 ± 0.20	186 ± 5
15.88 ± 0.19	192 ± 36
16.51 ± 0.11	178 ± 32
17.32 ± 0.20	190 ± 36
17.78 ± 0.15	180 ± 21

Table 7

Cross Section for the $^{80}Se(n,np)^{79}As$ Reaction

13.36 ± 0.14	3.8 ± 3.0
14.47 ± 0.11	1.0 ± 3.2
15.06 ± 0.17	8.4 ± 4.4
15.36 ± 0.20	7.3 ± 2.4
15.88 ± 0.19	4.1 ± 9.2
16.51 ± 0.11	13.2 ± 4.2
17.32 ± 0.20	35.3 ± 10.6
17.78 ± 0.15	71.2 ± 13.5

Table 8

Cross Section for the $^{82}Se(n,2n)^{81m}Se$ Reaction

E_n MeV	mb
13.02 ± 0.14	1506 ± 285
13.36 ± 0.14	1702 ± 20
13.90 ± 0.09	1692 ± 37
14.47 ± 0.11	1587 ± 37
15.06 ± 0.17	1628 ± 18
15.36 ± 0.20	1616 ± 18
15.88 ± 0.19	1796 ± 190
16.51 ± 0.11	1715 ± 161
17.32 ± 0.20	1520 ± 231
17.78 ± 0.15	1425 ± 142

Table 9

Cross Section for the $^{117}Sn(n,p)^{117}In$ Reaction

E_n MeV	mb
13.02 ± 0.14	10.7 ± 2.1
13.36 ± 0.14	10.6 ± 0.3
13.90 ± 0.09	10.0 ± 0.3
14.47 ± 0.11	10.1 ± 0.4
15.06 ± 0.17	12.7 ± 1.4
15.36 ± 0.20	11.6 ± 0.3
16.51 ± 0.11	16.9 ± 2.6

Table 10

Cross Section for the $^{117}Sn(n,n')^{117m}Sn$ Reaction

E_n MeV	mb
13.36 ± 0.14	287 ± 31
13.90 ± 0.09	272 ± 14
14.47 ± 0.11	284 ± 14
15.06 ± 0.17	255 ± 25
15.36 ± 0.20	286 ± 8

Table 11

Cross Section for the $^{118}Sn(n,2n)^{117m}Sn$ Reaction

E_n MeV	mb
13.02 ± 0.14	624 ± 80
13.36 ± 0.14	761 ± 41
13.90 ± 0.09	808 ± 28
14.47 ± 0.11	745 ± 59
15.06 ± 0.17	805 ± 21
15.36 ± 0.20	890 ± 34
15.88 ± 0.19	1055 ±164

Calculations of the Compound Reaction Cross Sections with Accounting for the Effect of the Gamma - Particle Competition.

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An algol program for the statistical model calculations was elaborated. In the calculations the competition of the gamma radiation was taken into account with respect to the neutron and proton emissions on each step of the reaction. When the experimental strenghts of the E1,E2 and M1 transitions were used a satisfactory agreement between the measured and calculated cross sections was obtained.

The superconductivity level density formulae [1] were modified in order to introduce the rotational spin cut - off ("yrast levels"). At low excitation energies the real level sequences were used as far as their exact energies, spins and parities were known.

The results show that for neutron induced reactions at 14 MeV the influence of the "yrast levels" on the cross sections is much lower than of the gamma-ray emission.

It was found that the calculated cross section of the (n,n') reaction is distinctly influenced by the $(n,\gamma n')$ process.

An extensive program of calculation of the (n,n') $(n,2n)$ and (p,γ) cross sections for a wide range of nuclei is in progress.

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Energy Spectra of Alpha Particles from the $^{153}Eu(n,\alpha)^{150}Pm$, $^{160}Dy(n,\alpha)^{157}Gd$, $^{162}Dy(n,\alpha)^{159}Gd$ and $^{164}Dy(n,\alpha)^{161}Gd$ Reactions with 14.2 MeV Neutrons.

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The studies of the energy distributions of alpha particles emmited in the (n,α) reactions induced by 14.2 MeV neutrons on rare earth isotopes, have been continued. In addition to the energy spectra of alphas from the 14.2 MeV reactions induced on ^{139}La, ^{159}Tb, ^{162}Dy, ^{163}Dy, ^{166}Er, ^{168}Er and ^{169}Tm, which were earlier described /1/, /2/, /3/, /4/ the present work gives results with ^{157}Eu, ^{160}Dy, ^{162}Dy and ^{164}Dy targets.

The 14.2 MeV neutrons used in the experiment were obtained from $^{3}H(d,n)^{4}He$ reaction with deuterons accelerated up to 500 keV in a Van de Graaff accelerator. A neutron energy spread due to the deuteron energy loss in the neutron target and geometrical conditions was about $\pm$ 150 keV. The neutron flux incident on the target was monitored by counting the recoil protons from a thin polyethelene foil. The accuracy of neutron monitoring was better than 2%.

The targets were made of oxides and deposited on thick carbon backings by means of sedimentation from the suspensions in isopropyl alcohol.

A description of the investigated targets is given in Table 1.

Table 1

target	isotopic abundance %	chemical compound	Thickness mg/cm^2
^{153}Eu	90	Eu_2O_3	3.0
^{160}Dy	77.6	Dy_2O_3	3.9
^{162}Dy	94.0	Dy_2O_3	5.4
^{164}Dy	97.8	Dy_2O_3	4.9

The alpha particle energy was measured using n-type surface barrier silicon detectors of 15 mm diameter. The experimental arrangement was described in our earlier work /3/.

The results of alpha aprticle spectra measurements are shown in Figs 1-2. All the spectra were measured for the forward angles ($0^o \pm 60^o$). The error bars in the figures refer to statistical errors only.

In Figs 1 and 2 the theoretical predictions obtained by applying the Weisskopf-Ewing formula are also shown. The energy dependence of the level density was taken in the high excitation energy limit of the free fermion gas model with the density parameter "a" given by Erba et al. /5/.

The values used for inverse cross sections were taken from the calculations of Huizenga and Igo /6/. The calculated curves are not normalized and are given to indicate the shape and the position of the evaporation spectra only.

All experimental spectra are significantly shiffted towards higher energies in comparison with the predictions of the statistical theory. In addition from plots of the reduced spectra the values of the level density parameters much smaller than those reported by Erba et al./5/ were found. The comparison of these a-values is shown in table 2.

Table 2

Nucleus	Level density parameter a (MeV^{-1}) present work	Erba et al./5/
^{150}Pm	7.7	-
^{157}Gd	4.9	20.2
^{159}Gd	7.2	21.6
^{162}Gd	5.0	22.8

This disagreement and the existence of high energy alpha particles in experimental spectra suggest the strong contribution of direct processes in the investigated reactions.

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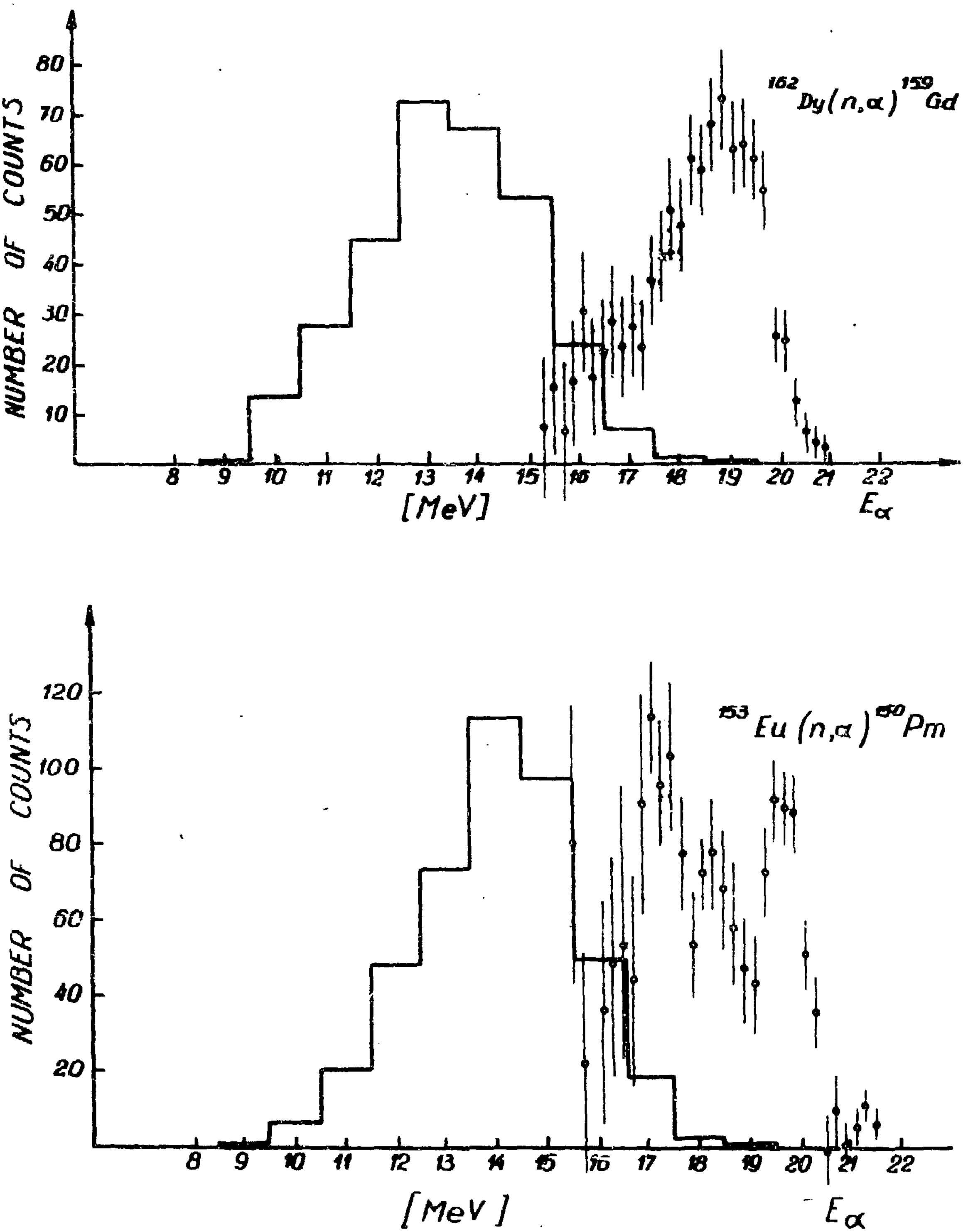
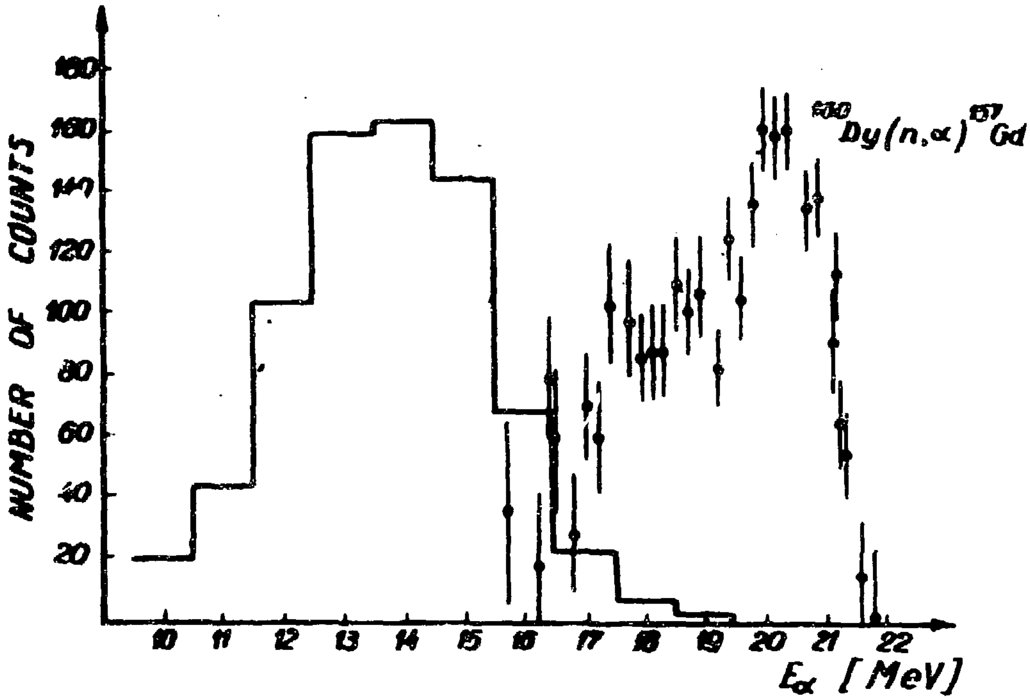


Fig.1. The experimental α - particle spectra from the $^{162}Dy(n,\alpha)^{159}Dg$ and $^{153}Eu(n,\alpha)^{150}Pm$ reactions, and the predictions of the statistical theory.



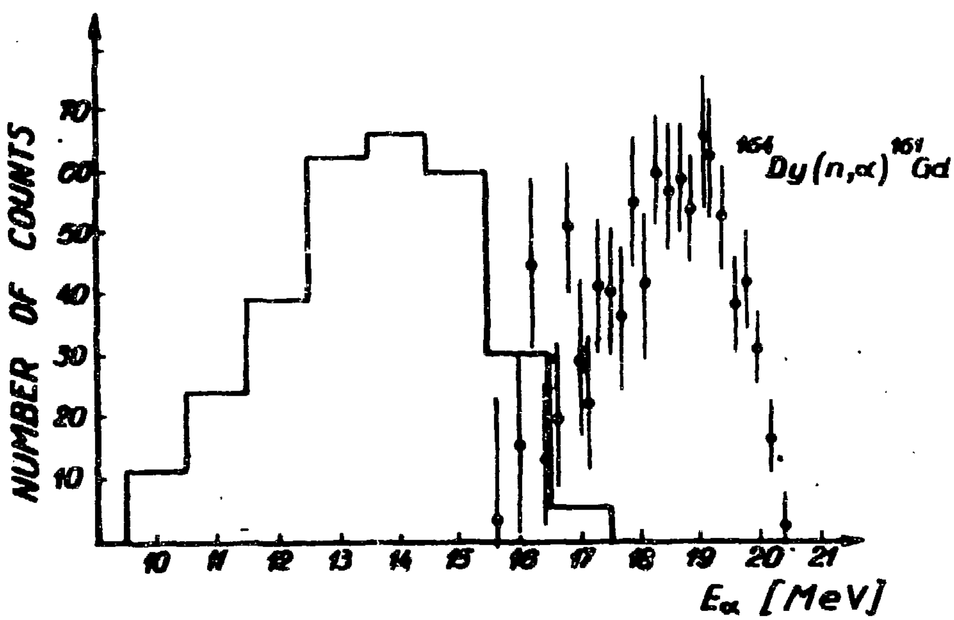


Fig.2. The experimental α - particle spectra from the $^{160}Dy(n,\alpha)^{157}Gd$ and $^{164}Dy(n,\alpha)^{161}Gd$ reactions, and the predictions of the statistical theory.

On the Knock-On Mechanism in the (n,α) Reactions

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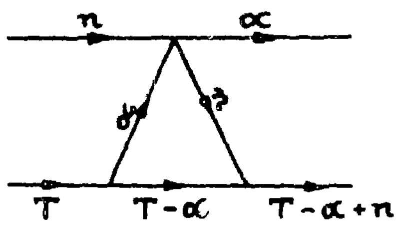
During the past few years the (n,α) reactions on the rare-earth nuclei were investigated in our laboratory /1-4/. It was shown that the compound nucleus mechanism for these reactions must be excluded due to unphysical (too small) values of the density level parameters which would have been used.

The existence of high energy α-particles in experimental spectra and the small values of the separation energy of α-like structure in rare-earth nuclei suggests the assuming of the direct mechanism of the investigated reactions. The incident neutron remove the α-particle from nuclei and occupies the one-particle state in nuclear well. These types of reactions correspond to the triangular graphs of the dispersion theory of nuclear direct reactions developed by I.S. Shapiro /5/.



The cross section for the reaction (n,α) which is dominated by the knock-on mechanism may be written as follows:

$$\frac{d\sigma}{d\omega} = \frac{xy}{z + w\cos\theta}\left[\arctan\left(\frac{z + w\cos\theta}{y}\right)^{1/2}\right]^2$$

$$\begin{aligned} x &= x(E_n, \gamma_\alpha, \gamma_n, Z, Q) \\ y &= y(E_\alpha^B, E_n^B) \\ z &= z(E_n, Q) \\ w &= w(E_n, Q) \end{aligned} \qquad (1)$$

In the formula (1) E_n is the kinetic energy of neutrons in Lab. system, Z is the charge of the final nucleus. The γ_α, γ_n are the reduced widths of the α-particle and neutron respectively. The Q is the mass difference of the entrance and exit channels. The E_α^B and E_n^B are the binding energies of the α-particle and neutron. The formula (1) can be applied only for those nuclei for which $E_\alpha^B > 0$, $Q > 0$.

In this report we present the analysis of the reaction $^{162}Dy(n,\alpha)^{159}Gd$. The experimental arrangement was the same as described in our previous papers /1-4/. Fig.1 shows the relative cross-sections measured for the forward angles as the functions of the excitations energy of the final nucleus. The solid line represents the calculated relative cross sections. The neutron reduced width were computed numerically. The Saxon-Woods well was assumed /6/. The excitation energies of neutrons were taken from Nilsson model. The final state interactions of α-particle with final nucleus were also taken into account /7/. Taking into account uncertainty in the assignement of the energy scale the overall agreement of the theoretical predictions with experimental data is quite good. The investigation of this model in the case of other nuclei are in progress.

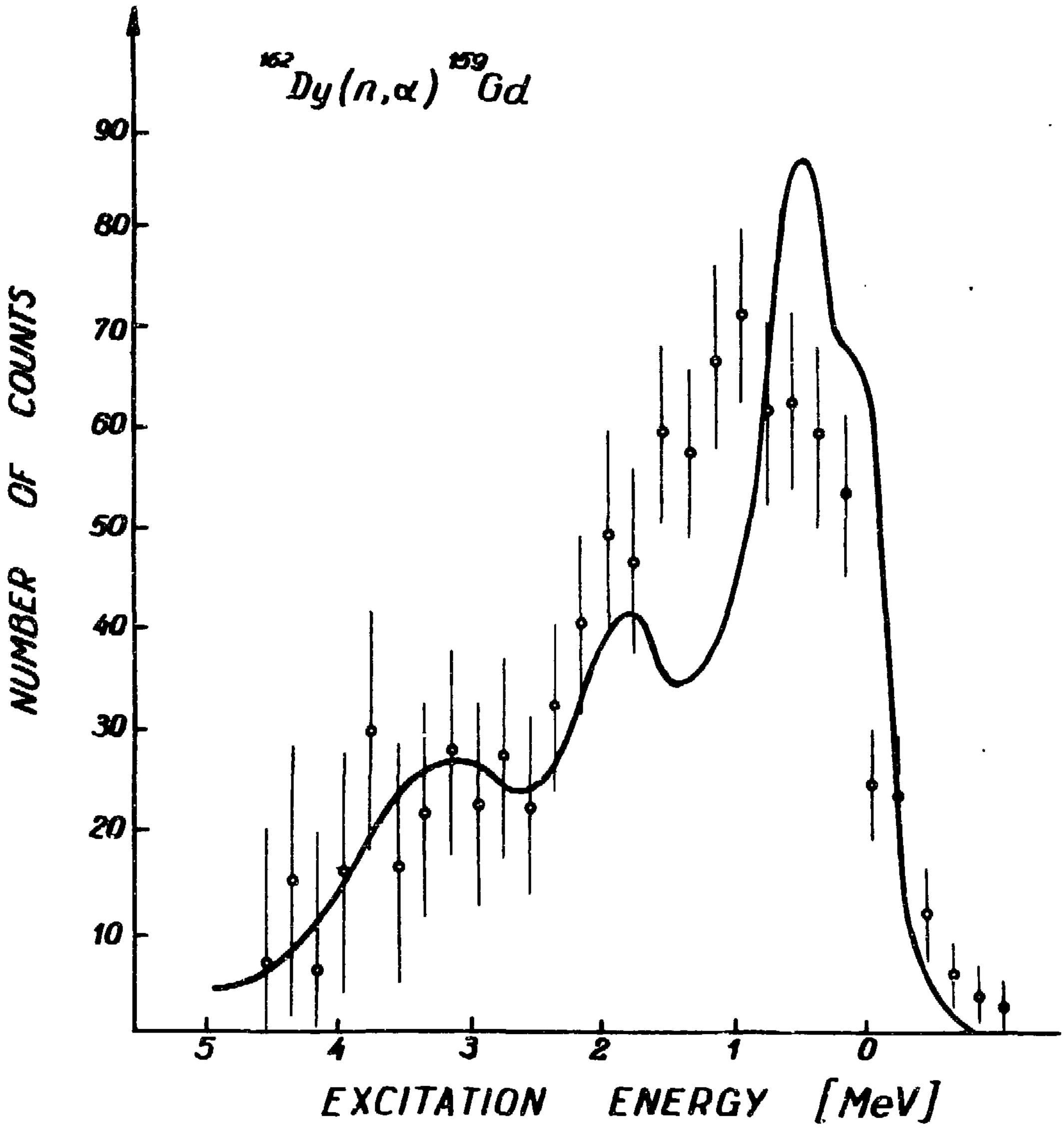


Fig. 1. The experimental and theoretical energy spectra of α - particles from the $^{162}Dy(n,\alpha)^{159}Gd$ reaction.

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Energy - angular distribution of alpha particles emitted during the thermal neutron fission of ^{235}U

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The energy - angular distribution of alpha particles emitted during a thermal neutron fission of ^{235}U has been measured. The FWHM of the angular distribution is equal 20 ± 3 degrees, which is about 50 per cent less then in the case of ternary fission of ^{252}Cf, as measured by Fraenkel [1/]. It suggests that the kinetic energy of fragments at the scission moment can be much less then 40 MeV, as calculated in ref. 2.
Unexpectedly high rate of the alpha particles was registered at angles close to 0° and 180° /about 5 per cent of the total tripartition yield/. The energy spectra of these particles evidences that there are evaporated in flight from the fully accelerated fragments. The anisotropy of emission in the center of mass system can be caused by the angular momentum of fragments.

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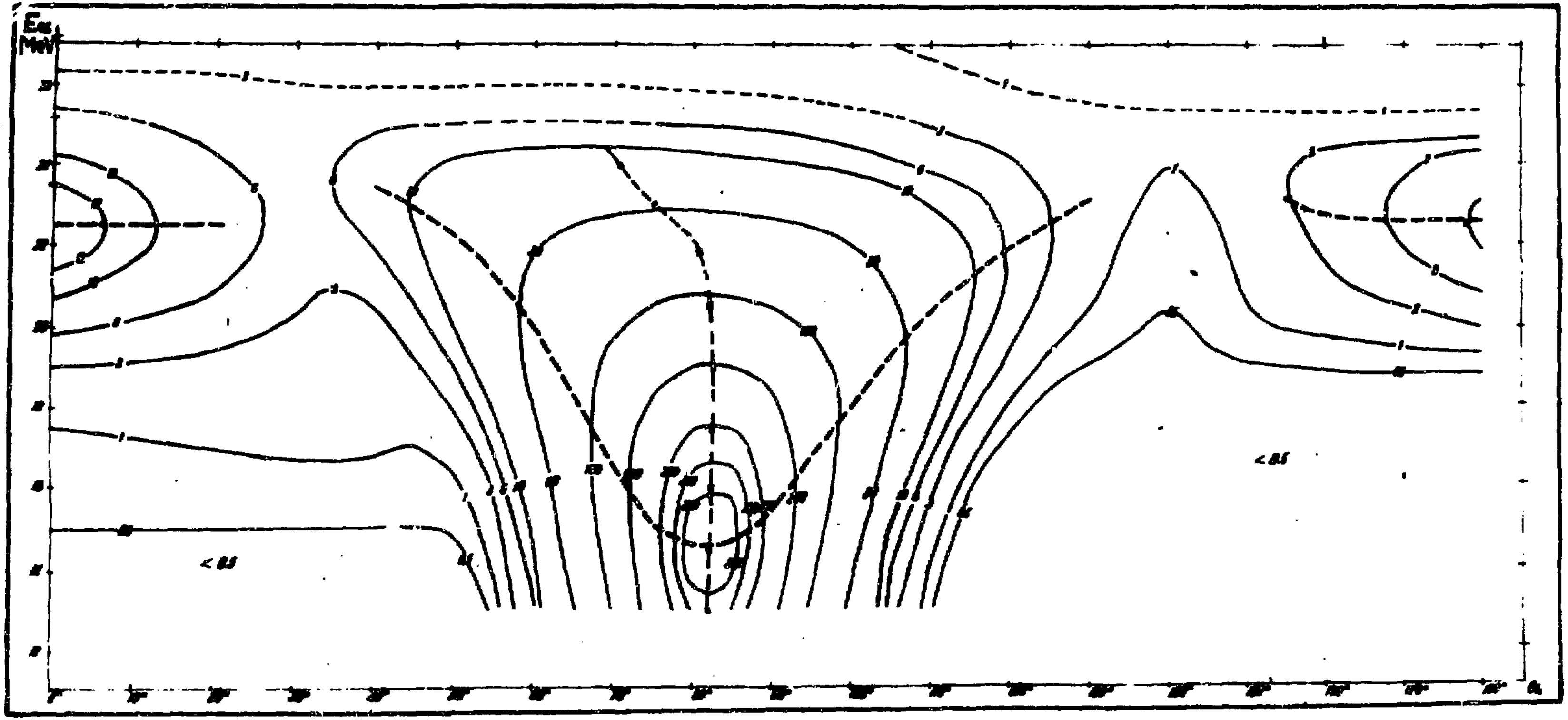

Fig. 1. Contour diagram of the $Y(E_\alpha, \theta)$ distribution. The intensity is given in arbitrary units. The dashed contour lines display results extrapolated using the energy spectra of alpha particles. The cross dashed line - energy dependence of the maximum of the angular distribution, the thick dashed curves - the angular dependence of the mean value of α particle energy distribution.

Investigation of the neutron capture high energy gamma rays

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The measurement of γ-ray spectra from (n,γ) reaction for heavy nuclei; In, Sb, I, Cs, Zb, Ho, Ta, Au and U have been performed in the neutron energy range 0.03 - 1.5 MeV. The experimental set-up is described in ref /1/. Some spectra for the neutron energy E_n = 400 keV are shown in figs 1,2 and 3. A distinct reinforcement of the γ-ray intensity in the high energy part of the γ-ray spectrum is observed.

The ratios $\sigma_\gamma(E_\gamma > 3.75\ \mathrm{MeV})/\sigma_{tot}$ versus neutron energy for In, Ta and Au nuclei are shown in fig.4.

The cross-sections $\sigma_\gamma(E_\gamma > 3.75\ \mathrm{MeV})$ and ratios $\sigma_\gamma/\sigma_{tot}$ at 400 keV neutron energy for In, Sb, I, Cs, Tb, Ho, Ta, Au and U nuclei are summarised in table I.

The theoretical predictions of cross-sections and cross-section ratios obtained with the assumption of compound nucleus mechanism /2/ are shown in figs 1,2,3 as solid lines and in table I. Comparison of the experimental values with theoretical ones points to the correctness of the description. The quantitative and qualitative agreement is obtained when in the probability of the γ-ray emission an existance of a "pigmy" resonance /2/ is taken into account.

The theoretical expectation based on direct interactions are three orders of magnitude lower then the measured ones (table I).

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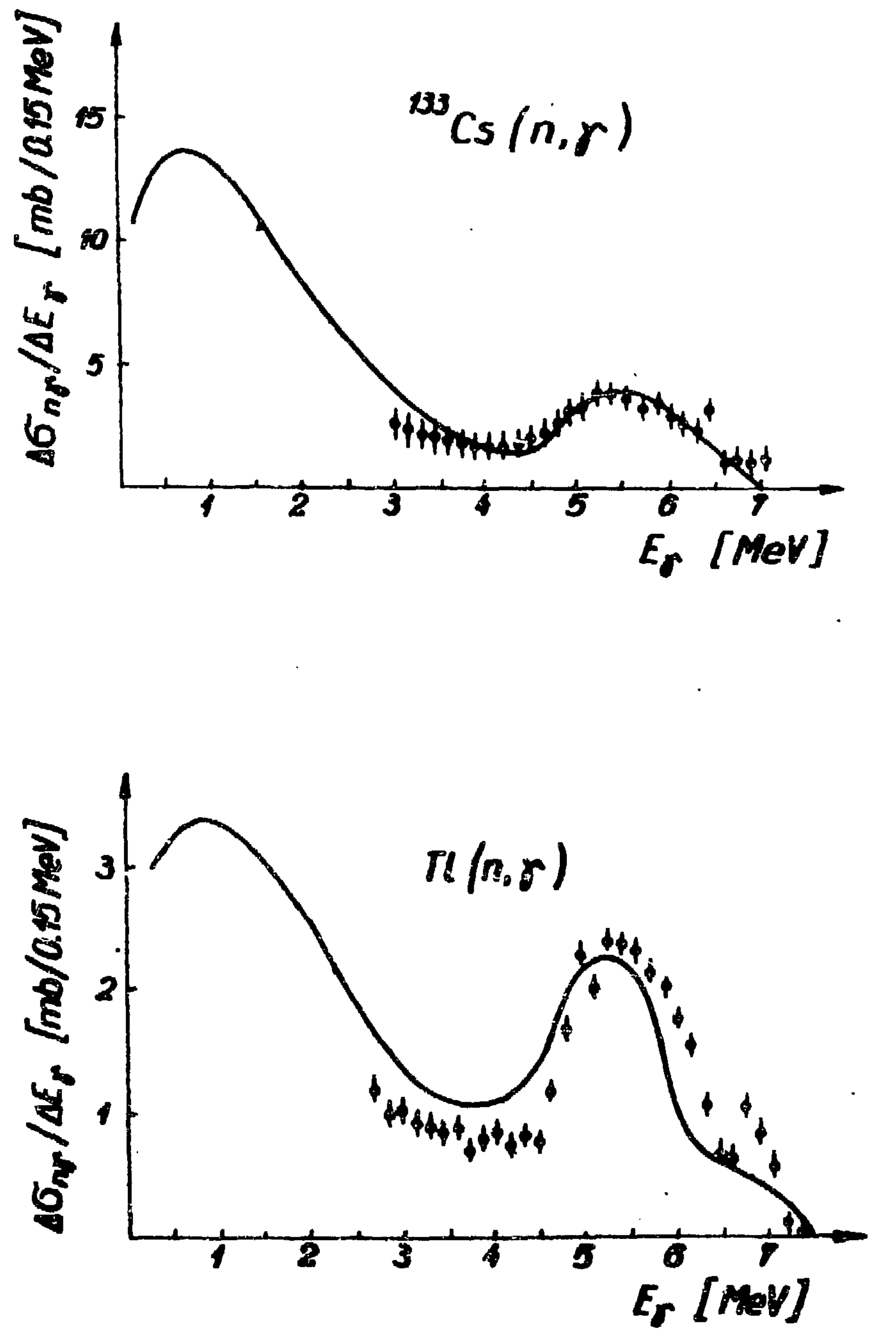

Fig. 1 - 3 . The gamma-ray spectra at neutron energy 400 keV.

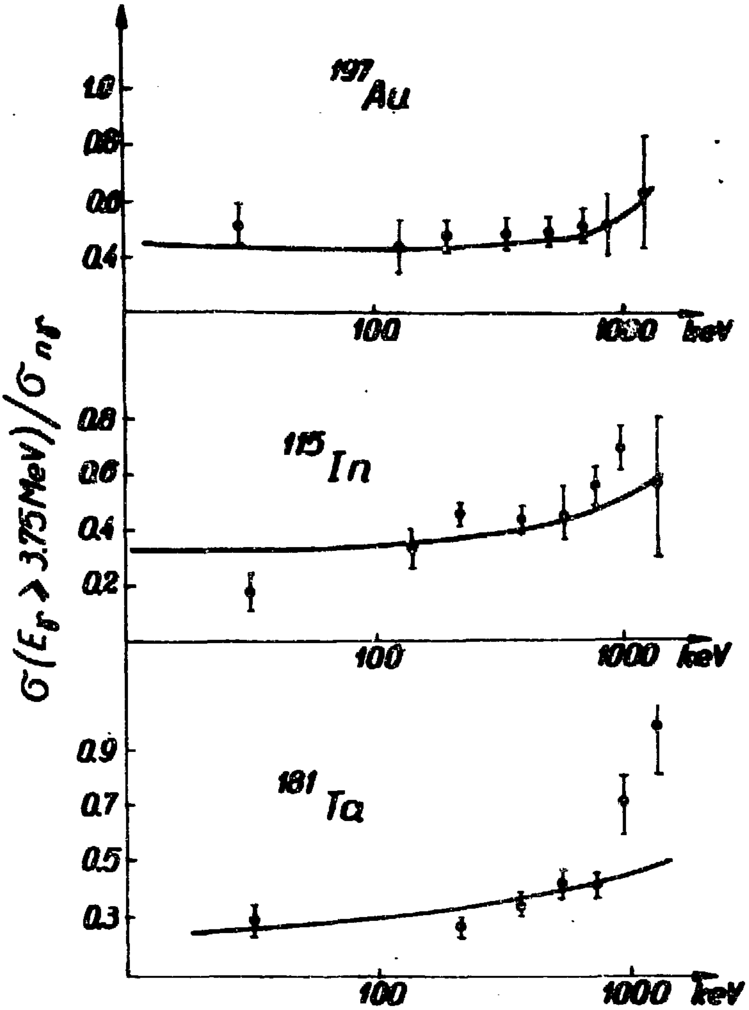

Fig. 4 . $\sigma_\gamma(E_\gamma > 3.75$ MeV) - the cross section of the (n,γ) reaction with emission of high energy γ- rays ($E_\gamma > 3.75$ MeV ; σ_{tot} - cross section of the (n,γ) reaction.

Table I

Target	Measured values $E_n = 0.4$ MeV			Theoretical calcul $\sigma_{n\gamma}(E_\gamma > 3.75$ MeV$)$	
	$\sigma_{n\gamma}(E_\gamma > 3.75$ MeV$)$ (mb)	$\sigma_{n\gamma}$ (mb)	$\sigma_{n\gamma}(E_\gamma > 3.75$ MeV$)/\sigma_{n\gamma}$	CN (mb)	DI (μb)
^{115}In	108 ± 7	250	0.43 ± 0.05	127	0.026
Sb	65 ± 5	130	0.50 ± 0.05	74	0.1
^{127}I	67 ± 5	150	0.44 ± 0.03	67	0.17
^{133}Cs	60 ± 15	150	0.40 ± 0.08	65	230
^{159}Tb	129 ± 9	350	0.37 ± 0.05	145	—
^{165}Ho	102 ± 7	300	0.37 ± 0.05	107	0.055
^{181}Ta	68 ± 5	205	0.34 ± 0.05	55	0.08
^{197}Au	104 ± 8	190	0.53 ± 0.03	108	0.021
Tl	28 ± 3	40	0.70 ± 0.07	32	0.1
^{238}U	6.3 ± 0.5	127	0.050 ± 0.005	7.1	—

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NEUTRON ENERGY SPECTRA FROM NEGATIVE MUON ABSORPTION ON COMPLEX NUCLEI

It has been proposed in some theoretical works [1-4], that in nuclear muon capture the excitation of collective states of the intermediate nucleus is dominant. These states should be the isotope analogues of the giant dipole resonance states excited by photon absorption or inelastic electron scattering. An indirect confirmation of this mechanism was the agreement of the experimental total muon capture rates with the theoretical ones obtained under this assumption. It was shown by theoretical calculations that more direct evidence should be the measurements of the energy spectra of neutrons emitted from these particle unstable giant resonance states. In these spectra some structure similar to those observed in the particle spectra from photo absorption, should be seen. In this work the results of neutron energy spectra measurements from muon capture on ^{16}O, ^{32}S, ^{40}Ca and Pb /previously reported [5]/, are presented. This work was performed using pure muon

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beam with momentum 150 MeV/c, from the muon channel of the Dubna 680 MeV synchrocyclotron. Detector and target configuration is shown in Fig. 1. Muon stop events were detected by $123\bar{4}$ coincidences. The target thickness in neutron counter direction was 2 g/cm^2, 4 g/cm^2, 4 g/cm^2, 6 g/cm^2 for water, melted sulfur, metallic calcium and lead, respectively. As neutron detector the stilbene crystal 30 mm in diameter and 20 mm thick with 56 AVP photomultiplier was used. Neutron events were separated from gamma events by pulse shape discrimination system [6]. Pulses from neutron detector passed 0.05 μsec after muon stopping were registered during 2 μsec, 1 μsec, 1 μsec and 0.3 μsec time interval for water, sulfur, calcium and lead, respectively. In muon stopping and neutron spectrometer channel the anti-pile-up circuits with 6 μsec dead time were used. The background was measured with LiH as a target. The energy calibration of neutron spectrometer was performed using γ-ray, Po-Be sources, and 14 MeV neutrons from a neutron generator. The pulse height spectra were transformed into recoil proton energy spectra. These spectra were then differentiated and corrected for the efficiency of neutron detector. The energy resolution /FWHM/ for neutrons was: 0.6 MeV for E_n = 3 MeV and 1 MeV for E_n = 10 MeV.

No corrections for multiple scattering in the stilbene crystal and the target were applied.

In Fig. 2-5 neutron energy spectra from muon capture on ^{16}O, ^{32}S, ^{10}Ca and Pb are presented. As can be seen in these spectra there are some narrow peaks and continuous background. The latter for sulfur, calcium and lead can be interpreted as due to the evaporation mechanism. Dotted curves in Figs. 3 and 4 present the evaporation neutron spectra assuming constant nuclear temperature [7]. In the case of lead, Fig. 5, the part of the spectrum below 5 MeV can be described by Le Couteur's many neutrons evaporation formula. The oxgen data, Fig. 2, show the large peak centered at about 4.5 MeV which was theoretically predicted [4], as result of the transition from 2^- giant resonant state in ^{16}N to ground state of ^{15}N.

In general all these spectra are similar to photoabsorption particle spectra. The resonance mechanism of nuclear muon capture is supported by this experiment. It is concluded that nuclear muon capture can be applied to the investigations of high excited nuclear states which cannot be reached in another way.

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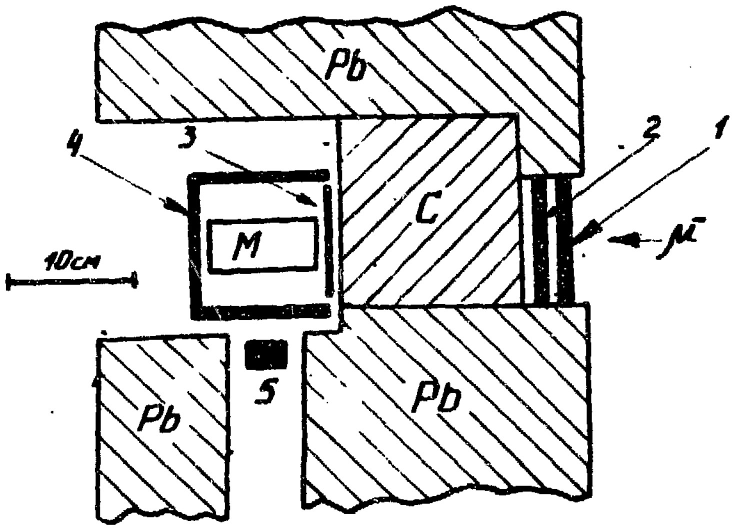

Fig. 1 .

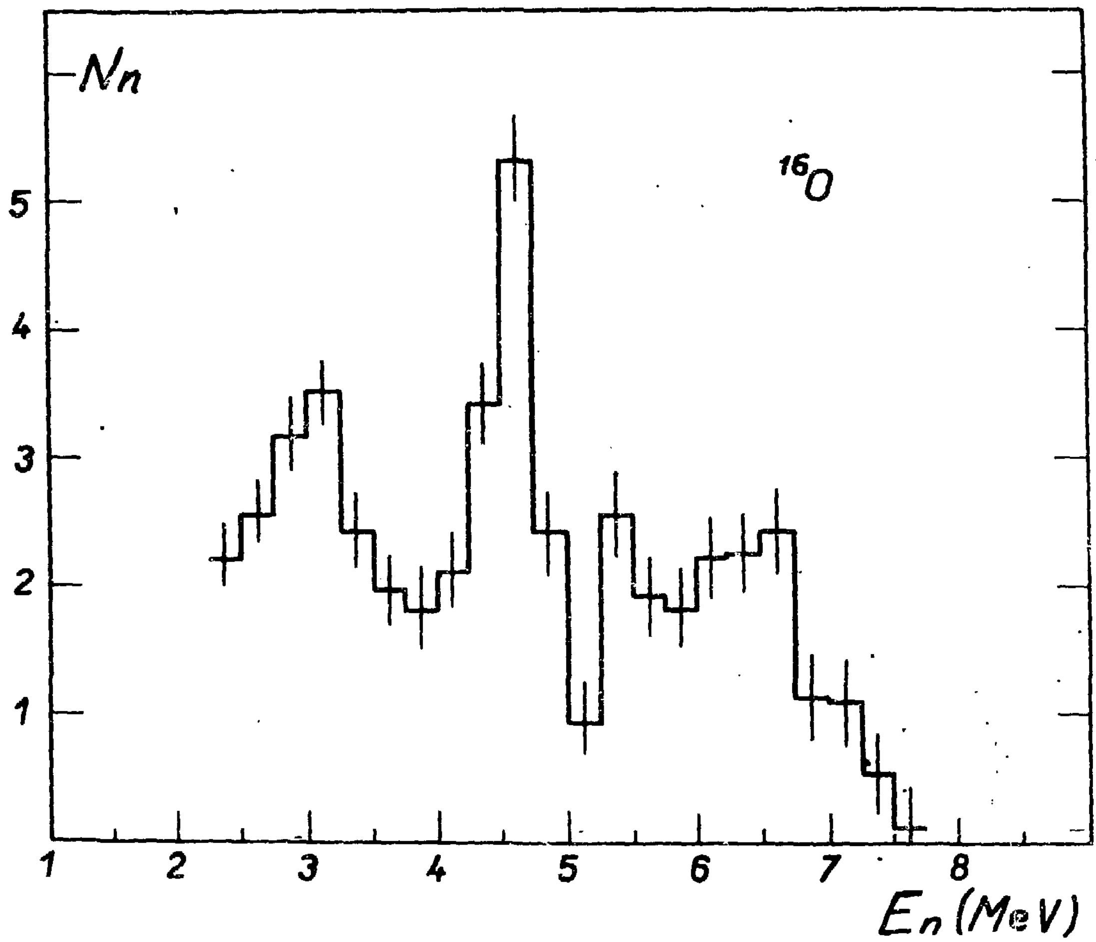

Fig. 2 .

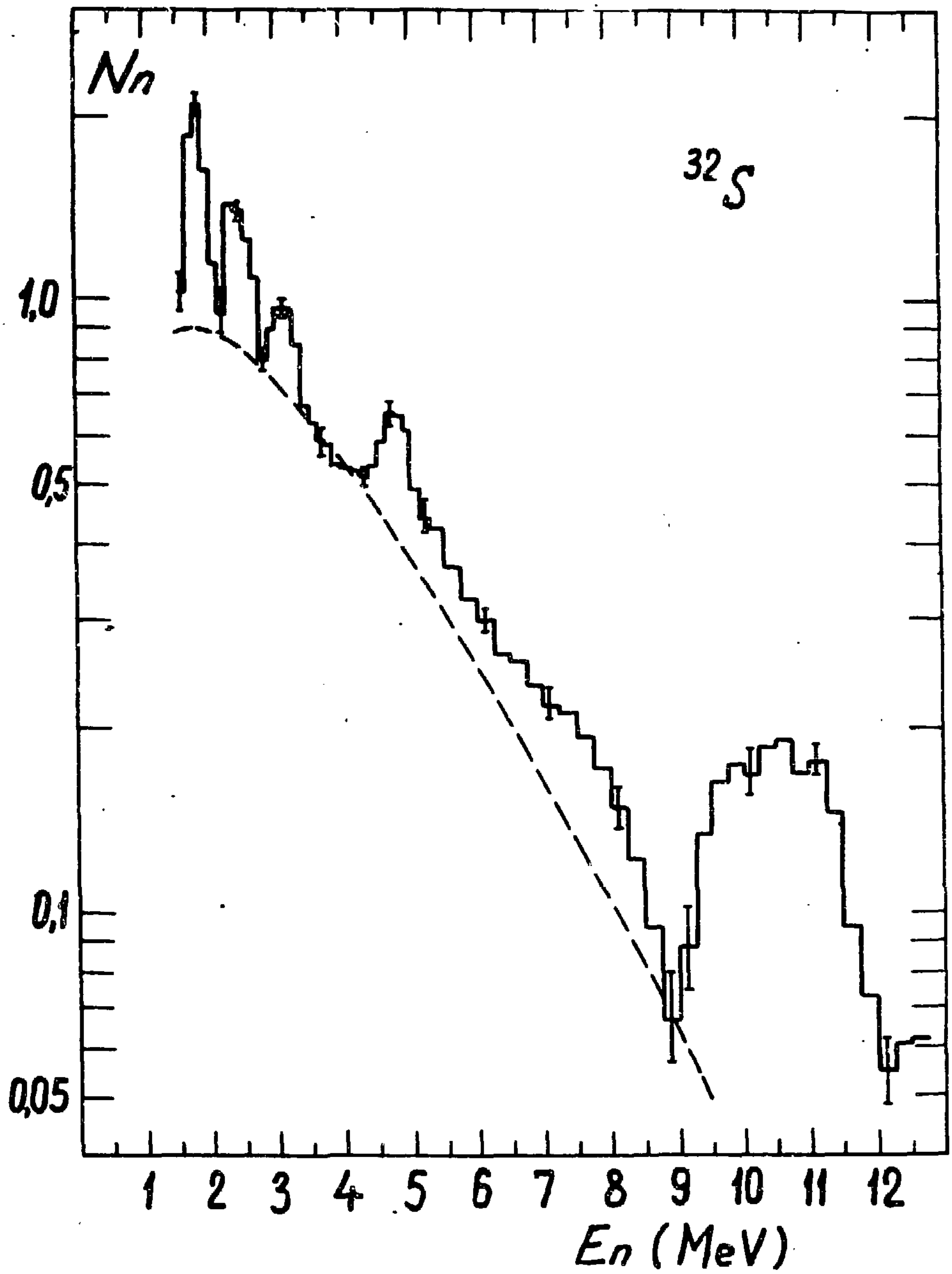

Fig. 3 .

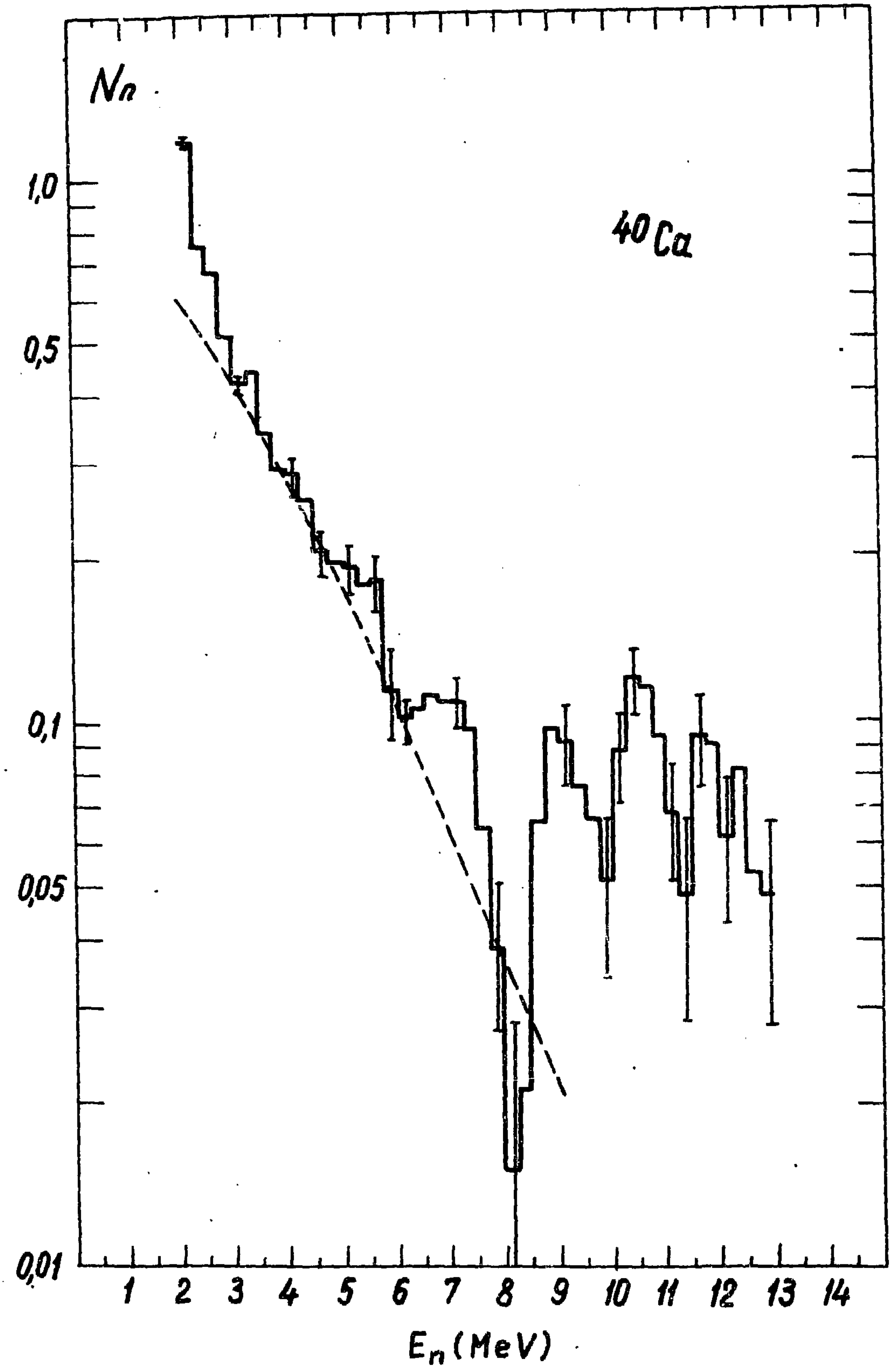

Fig. 4 .

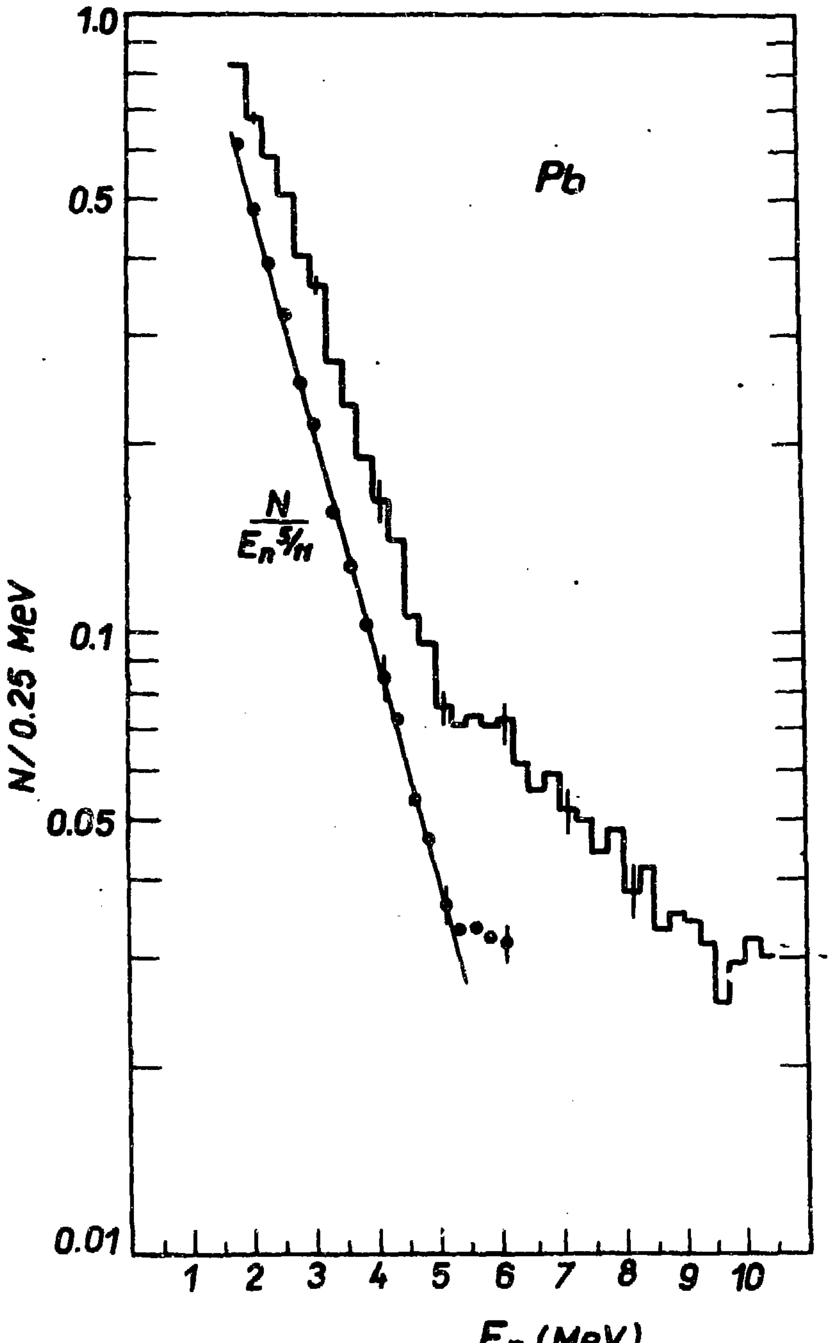

Fig. 5 .

Excitation of isomeric activities in Rb, Y, Pd, Cd, W, Os and Pb using 14.8 MeV neutrons

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Activation cross-sections of ^{84m}Rb, ^{86m}Rb, ^{89m}Y, ^{107m}Pd, ^{109m}Pd, ^{111m}Cd, ^{185m}W, ^{190m}Os and ^{203m}Pb for 14.8 MeV neutrons were measured using Ge(Li) and NaI(Tl) detectors. The following values in millibarns were obtained: $^{85}Rb(n,2n)^{84m}Rb$ (20.5 min.) 412 $\pm$ 40; $^{87}Rb(n,2n)^{86m}Rb$ (1 min.) 432 $\pm$ 45; $^{89}Y(n,n')^{89m}Y$ (16.5 s) 438 $\pm$ 44; $^{108}Pd(n,2n)^{107m}Pd$ (21 s) 590 $\pm$ 60; $^{110}Pd(n,2n)^{109m}Pd$ (4.8 min.) 554 $\pm$ 55; $^{112}Cd(n,2n)^{111m}Cd$ (48 min.) 812 $\pm$ 80; $^{111}Cd(n,n')^{111m}Cd$ (48 min.) 167 $\pm$ 17; $^{186}W(n,2n)^{185m}W$ (1.7 min.) 1152 $\pm$ 110; $^{190}Os(n,n')^{190m}Os$ (10 min.) 15 $\pm$ 1.5; $^{204}Pb(n,2n)^{203m}Pb$ (6.1 s) 1020 $\pm$ 100.

Excitation of 3 min activity in ^{190}Re in $^{190}Os(n,p)^{190}Re$ reaction using 14.8 MeV neutrons.

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Introduction

After irradiation of natural osmium with 14 MeV neutrons gamma lines with the 3 min. half-life have been observed. They have been assigned to the decay of the ^{190}Re ground state to excited states of ^{190}Os [1] . The nucleus considered was a subject of considerable number of studies by neutron capture gamma-ray spectroscopy [2,3], charged particle excitation [4], decay of the ground and isomeric states of ^{190}Ir [5] and decay of the ^{190}Re ground

ground state created in $^{192}Os(\gamma,pn)$ reaction [1]. The aim of the present work was to study the production of ^{190}Re in the $^{190}Os(n,p)^{190}Re$ reaction.

Experimental procedure

Radioactive sources of Re were produced through the (n,p) reaction on natural osmium metal powder (5g) of spectroscopic purity, using 14.8 MeV neutrons. The neutron flux varied at the sample position between $5 \cdot 10^8$ - $1 \cdot 10^9$ neutrons/sec·cm^2. The gamma spectrum was measured using a 5 cm^3 Ge(Li) spectrometer. In view of small intensities of gamma lines from the decay of Re, the Ge Li detector was shielded with 15 cm Pb (Cd+Cu lined). In this experiment a cycle of 10 min. irradiation and one minute pause to avoid the 6 sec ^{192}Re activity from the $^{192}Os(n,p)^{192}Re$ reaction, and 10 min. counting period was applied.

Results and discussion

The measured gamma spectrum of ^{190g}Re and ^{190m}Os is shown in fig. 1. The energy values and intensities of gamma lines from the decay of ^{190g}Re are in good agreement with the results of Haustein and Voigt [1]. These authors show that one particular level 3^- in ^{190}Os at 1387 keV is populated in ~ 100% beta decay branch. Besides the gamma lines from the decay of ^{190g}Re there are prominent lines belonging to the 10 min. isomer in ^{190}Os. This fact allows us to determine the $^{190}Os(n,p)^{190g}Re$ reaction cross section relative to the $^{190}Os(n,n'\gamma)^{190m}Os$ reaction by comparing the intensities of the neighbouring lines in the spectrum belonging to Re and Os respectively. The conversion coefficients and branching ratios were taken from refs. [1,5]. Using the $^{190}Os(n,n'\gamma)^{190m}Os$ reaction cross-section as the internal monitor with $\sigma = 15 \pm 1.5$ mb [6], the cross section of the $^{190}Os(n,p)^{190g}Re$ reaction was found to be $\sigma = 1.95 \pm 0.20$ mb.

Attempts were made to produce the 2.8 h activity reported by Baro et al. [7] and Aten and de Feyfer [8] and ascribed to the isomer of ^{190m}Re. Our results confirm the existence of few lines with similar half-life. The half -life of the strongest line with energy 187 keV was found to be $T_{1/2} = 3 \pm 0.5$ h.

Acknowledgment : The authors are indebted to A. Sulik for operation of the 200 kV accelerator.

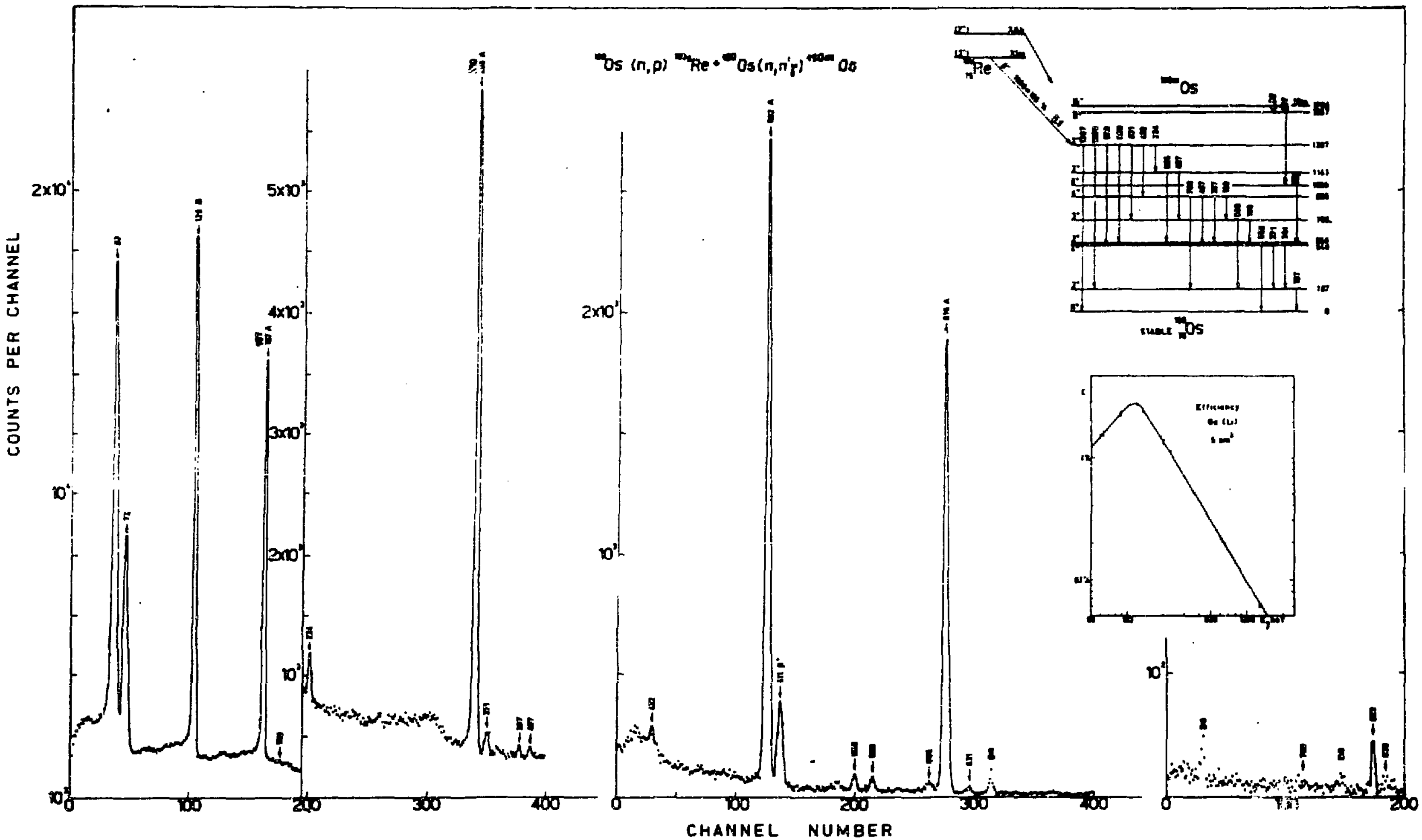

Fig. 1 . Gamma-ray spectrum of the ^{190g}Re and ^{190m}Os source after 10 min. irradiation, 1 min. delay and 10 min. counting periods repeated 7 times for each energy range. Energies in keV.Unlabelled: ^{190}Re transitions, A: ^{190m}Os transitions, B: ^{191}Os transisions.

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The decay scheme of ^{232}Pa ж/

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Abstract: Magnetic and semiconductor /Ge and Si/ spectrometers were used to study the $^{232}Pa \rightarrow {}^{232}U$ decay scheme. The following γ lines, new with respect to the earlier data reported by Bjørnholm et al.[1/], were observed: 922.7, 1003.3, 1016.4, 1051.4, 1055.4, 1085.4, 1125.1, 1132.7 and 1164.5 keV. Conversion coefficients and multipolarity assignments were determined for several of these transitions. Due to the e-γ coincidence studies it was possible to show that the 1125.1 and 1055.4 keV E1 transitions feed respectively the 2^+ and 4^+ levels of the ^{232}U ground state band. This indicates the existence of the new ^{232}U levels at 1172.8 and 1212.1 keV which are interpreted as 2^- and 3^- members of the $K^{\pi} = 1^-$ octupole band. Another new level is proposed at 1132.9 keV. As deduced from β-γ coincidence experiments, the

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ж/ Institute of Nuclear Research Report 1232/IA/PL /1970/
Acta Physica Polonica /in print/

1/ S. Bjørnholm, F. Boehm, A.B. Knutsen and O.B. Nielsen, Nucl. Physics 42 /1963/ 469 decay energy of ^{232}Pa is equal to 1337 ± 10 keV. The discussion of experimental data in terms of nuclear models is concentrated on the octupole bands and their Coriolis interaction.

Levels of ^{230}Th and ^{230}U fed in the decay of ^{230}Pa ${}^{*}/$

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Abstract: The ^{230}Pa decay to levels of ^{230}Th and ^{230}U is investigated using Si(Li) and Ge(Li) spectrometers for singles-spectra measurements, and a Ge(Li) spectrometer combined with a six-gap β spectrometer or with a NaI(Tl) detector coincidence measurements. The decay scheme is proposed with accounts for all but one of the 50 transitions observed in the present investigation. The following bands of the ^{230}Th excited states are established or proposed (in parantheses: level energies in keV, spin values and parities of the levels): the ground-state band (53.19, 2^+ and 174.12 4^+), the quadrupole bands (β: 634.7, 0^+ and 677.8, 2^+; γ: 781.4, 2^+ and 825.4, 3^+; $\beta + \gamma$ (?): 1009.61, 2^+ and

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${}^{*}/$ Institute of Nuclear Research, Report 1251/IA/PL(1970). Acta Physica Polonica /in print/

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1052.6, 3^+) and the octupole bands ($K^\pi = 0^-$: 508.20, 1^- and 571.71, 3^- : $K^\pi = 1^-$: 951.91, 1^- ; 971.70, 2^- and 1012.2, 3^- : $K^\pi = 2^-$: 1079.20, 2^- and 1127.85, 3^-). The $^{230}Pa \rightarrow {}^{230}Th$ decay energy, Q, is deduced from the measured relative probabilities of the K capture transitions to several excited states in ^{230}Th: $Q = 1315^{+15}_{-10}$ keV. For ^{230}U, the first excited 2^+ state is observed at 51.72 keV and the bandhead state of the $K^\pi = 0^-$ octupole band is proposed at 366.5 keV. The experimental data are discussed in terms of nuclear models, with emphasis on the band-mixing effects.

The Code FLANGE - AL 4

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The code based on the algorithm of the General Atomic FLANGE code computes the double differential scattering cross section $\sigma(E',\mu)$, the zeroth and first Legendre moments of the scattering kernel $\sigma_0(E'\rightarrow E)$, $\sigma_1(E'\rightarrow E)$, the zeroth and first Legendre moments of the single differential scattering cross section $\sigma_0(E')$, $\sigma_1(E')$. All these quantities are calculated from the scattering law incoherent inelastic thermal scattering of neutrons from polycrystalline materials.
IBJ/1260/XXI/PR Report.

The Code HEXSCAT - S

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The code based on the General Atomic HEXSCAT code calculates the zeroth and first Legendre moments of the coherent elastic neutron scattering cross section for polycrystalline moderators with hexagonal lattice.
IBJ/1300/XXI/PR Report.

The Routine Production of Thin Tritium-Titanium, Tritium-Zirconium and Deuterium-Titanium, Deuterium-Zirconium Targets.

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A method of production of thin D and T targets has been devised. The targets posess the following desireable features:

1. Negligible loss of hydrogen in vacuum.
2. Negligible loss of tritium and deuterium in temperaturas up to 300°C.
3. Strong binding between the absorbing metal and the backing.

The targets produced have been used in a range of experiments conducted in the Institute of Nuclear Research IBJ.

Also, targets of special construction have been produced such as targets with a copper backing on which 15 μ silver and subsequently 0.45 mg/cm^2 of titanium with 0.8 Ci tritium absorbed were deposited. Typical targets have following characteristics:

Tritium targets

Targets are made of a thick metod backing covered by a thin layer of titanium or zirconium deposited in vacuum.

The tritium is absorbed in the titanium or zirconium. The tritium/titanium, tritium/zirconium atomic ratio varies from 1.2 - 1.9 .

tritiated titanium zirconium Ø mm	titanium zirconium µg/cm²	backing Ø mm	backing thickness mm	Average act.Ci (± 10%)
	200-350			1,1
25.4	350-600	28,5	0.5	2.2
	600-900			3.5
	200-350			1.1
25.4	350-600	38.0	0.5 or 1	2.2
	600-900			3.5

Backing metal-cooper or silver.

<u>Deuterium Targets</u>

Deuterium targets are manufactured exactly in the same way as tritium targets. (see above)

The same dimensions are available.

The deuterium titanium - deuterium zirconium atomic ratio varies from 1.4 - 1.9 .

The amount of deuterium varies from 0.5 - 2 ml according to thicknes of titanium or zirconium layer.

Tritium targets emit bremsstrahlung radiation with a continuous spectrum of maximum energy 18 keV. This provides means of differentiating between tritium and deuterium targets, as well as providing a rough check on the tritium content of a target.