ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

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AN INVESTIGATION OF PROPERTIES OF TRANSURANIC ELEMENTS

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An application of mathematical methods developed in constructing the theory of superconductivity [1] in order to investigate properties of atomic nucleus is found to be rather fruitful. The investigations of the pairing correlations of nucleons of the superconductive type which have been published in [2-5] allowed one to account for some properties of nuclei which do not appear in the model of independent particles. In a further development of this approach a "superfluid" model of a nucleus [6] has been formulated by one of us, and the strongly - deformed elements have been investigated[7-9] on the foundation of this model.

The properties of transuranic elements have been investigated in [7] on the foundation of the superfluid model of a nucleus. The spectra of the single-quasi-particle levels of odd-mass nuclei were calculated there and it was shown that the density of the calculated levels is in a good agreement with experiment and it is about twice as large as that given in the Nilsson's scheme. The energies of the two-quasi-particle excited states of a number of even-even nuclei were calculated. Corrections to β and γ - transitions were found which are connected with the superfluidity of the ground- and excited states. It is shown that the corrections play an important role in the nucleus.

Later on an improved scheme of calculations has been suggested [2] based on the use of experimental data on the single-particle levels of odd nuclei and on the pairing energies. On the foundation of this scheme appropriate calculations for nuclei in the region $154 \leq A \leq 188$ were performed and a satisfactory agreement with experiment was obtained.

In the present paper we continue the investigation of the properties of nuclei in the range $225 \leq A \leq 255$ on the foundation of the improved scheme, namely: we choose the main parameters of the model basing on experimental data on the single-quasi-particle levels of odd nuclei and on the pairing energies, we analyse the probabilities of β - transitions and calculate the two -quasi-particle energy levels of a number of even--even nuclei.

1. Choice of single-particle levels and pairing interaction constants

The basic foundations and the properties of the "superfluid" model of a nucleus as well as all necessary equations are given in [7-9] . For the ground state of the even system, for example, the equations for obtaining the correlation function C and the chemical potential λ are of the form:

$$\frac{2}{G} = \sum_{s} \frac{1}{\sqrt{C^2 + \{E(s) - \lambda\}^2}} \tag{1}$$

$$n = \sum_{s} \left\{ 1 - \frac{E(s) - \lambda}{\sqrt{C^2 + \{E(s) - \lambda\}^2}} \right\} \tag{2}$$

where G is the constant of pairing interaction, n is the number of nucleons in the system under consideration. The summation is performed over the single particle levels of the energy $E(s)$ of the average field. The energy of the system is written in the ground state, as

$$\mathcal{E} = \sum_{s} E(s) \left\{ 1 - \frac{E(s) - \lambda}{\sqrt{C^2 + \{E(s) - \lambda\}^2}} \right\} - \frac{C^2}{G} \tag{3}$$

Our calculations are based on somewhat changed levels of energy of the average field given in the Nilsson's scheme. To determine the states we have used notations founded on asymptotic quantum numbers: N is the total number of oscillatory quanta, n_z is the number of oscillatory quanta along the axis, perpendicular to the symmetry axis, Λ is the component of the particles orbital angular momentum along the symmetry axis. Σ is the projection of the particles spin on this axis, $K = \Lambda \pm \Sigma$, Π is the parity. The state is written as $K \Pi [N n_z \Lambda]$ or more briefly $N n_z \Lambda \uparrow$ provided $K = \Lambda + \Sigma$ or $N n_z \Lambda \downarrow$ provided $K = \Lambda - \Sigma$; $\hbar\omega_0^{\circ} = 41 A^{-1/3}$ Mev . Further, K denotes the final filled single particle level of the average field for $G = 0$, $K-1$, $K-2$ and so on denote the hole states and $K+1$, $K+2$ and so on the particle states.

The summation in Eqs. (1) and (2) is performed over energy levels of the average field though it was performed over twenty- four levels around the level K in the first papers [7] , further [9] in order to improve upon the reliability of calculations, the number of levels was increased up to thirty- six ones. We investigate how strongly the results of calculations depend upon the cut off in Eqs. (1) and (2). For this we calculate the correlation functions C and $C(K)$ [$C(K)$ is the correlation function of the ground state of the system with an odd number of nucleons) for $Z = 94$ and $Z = 93$ and the pairing energy P_Z for $Z = 94$, when below the state K the summation is carried out over seventeen levels of the average field, and above the K -state various cutoffs are performed, namely: for $K+3$, $K+6$, $K+9$, $K+12$, $K+15$ and $K+18$. For the calculation results see Table 1. For the same value of $G_Z = 0,0185\ \hbar\omega_0^0$ (corresponding to real nuclear forces in summation over thirty-six levels) the correlation function C strongly depends on the cutoff increasing with an expansion of the summation region. However, in this case the magnitude of the pairing energy P_Z changes strongly, too. The ratio $C(K)/C$ weakly depends upon the cutoff if the later is performed sufficiently high. According to the superfluid model of a nucleus the quantity G_Z is found by comparing the calculated values of P_Z with experimental values of pairing energies, the values of G_Z being dependent on the cutoff. Therefore, to clear up the role of the cutoff it is necessary to make calculations for such different values of G_Z so as to obtain for each cutoff the same value of the pairing energy. The results of such calculations are given in the lower part of Table 1, we failed to choose such G_Z's so as to obtain strictly the same value of pairing energies for all cutoffs. However, alterations of P_Z for $K+6$ and larger are small. From Table 1 it is seen that if below K more than six levels are summed then the correlation function C and the ratio $C(K)/C$ and so all superfluid properties are practically independent of the cutoff in obtaining the same value of the pairing energy.

Thus, the main characteristics of superfluid states are practically independent of the cutoff if it is made at energies both major to K and minor to K and higher than 3 MeV. In restricting the summation in equations such as (1) and (2) there is no need to introduce a cutoff constant since the pairing interaction constant G seems as though it would renormalized with account of this cutoff.

We shall compute the characteristics of superfluid states, the relative probabilities of β - transitions and the energy levels of even-even nuclei basing on experimental data on the single-quasi-particle levels of odd nuclei and on the pairing energies. To carry out this program we change the position of a number of levels in the Nilsson's proton and neutron schemes so as to obtain spectra of single-quasi-particle levels of odd nuclei which agree with experiment. In doing so, we choose such G_N's and G_Z's so as to get experimental values of pairing energies. We solve the equations of the type (1) and (2) on the electronic computer and compute the energies $\mathcal{E}$, $\mathcal{E}(K_i)$, $\mathcal{E}(K_i, K_\ell)$ of the ground and excited states. Table 2 gives the relative position of a number of levels of the average field in the proton and neutron schemes and there are also those changes $E(\lambda) - E_N(\lambda)$ which we have made oompared with the Nilsson's schemes for $\delta = 0{,}24$, whose parameters are represented in Table 1, case C [5]. ($E_N(\lambda)$ are the energy levels in the Nilsson 's scheme). It is seen from Table 2 that we may restrict ourselves to one set of energy values for the proton system and to one set for the neutron system for all nuclei in the range $225 \leq A \leq 255$ although the equilibrium deformation ohanges somewhat in the transition from one nucleus to another.

The behaviour of the caloulated single-quasi-particle levels of nuolei with an odd number of neutrons is given in Fig.1, and with an odd number of protons in Fig.2. We assume the ground state energy to be equal to zero below $\mathcal{E}(K) = 0$ we plot the energies of the hole excited states, above $\mathcal{E}(K) = 0$ we plot the energies of the particle excited states. On the left we indicate the oharaoteristics of states and conneot the identical characteristics by dashed lines. From the comparison of the energy levels (Fig.1 and 2) with experimental data it follows that the obtained values of spins and of particles for the ground states of all nuclei are correct in this region, for the exception of those of Th^{229} and Bk^{243}. The calculated excited-state energies agree with experimental data in most cases. However, as it is seen from Table 2 we do not take into account the ohange of the average field in the transition from one nucleus to another. Therefore, we can not account for such changes in the behaviour of single particle levels, for example, the approach of the level 631↓ to the level 743↑ in $^{143}_{32}U^{235}$ in comparison with $^{143}_{34}Pu^{237}$.

In finding oonstants of pairing interaction G_N for the neutron system and G_Z for the proton one the oalculated values of the pairing energies were carefully compared with experimental data [11]. The results of the analysis are given in Fig.3 and 4 where experimental values of pairing energies P_N or P_Z are connected by the dashed lines and the computed ones by the full lines. The pairing energies were computed from the formula:

$$P_N(Z,N) = \frac{1}{4}\left\{3\mathcal{E}(Z,N-1) - 3\mathcal{E}(Z,N) + \mathcal{E}(Z,N+1) - \mathcal{E}(Z,N-2)\right\} \qquad (4)$$

From Fig.3 and 4 it is seen that a satisfactory agreement was obtained between the calculated and the experimental values of the pairing energies. Their discrepancy does not exceed 100 KeV.

From the comparison of the calculated values of the pairing energies with experimental data we get the following values for the pairing interaction constants

$$G_N = \frac{26}{A}\ \text{Mev} = 0{,}0165\ \hbar\omega_0^{\circ}$$

$$G_Z = \frac{29}{A}\ \text{Mev} = 0{,}0185\ \hbar\omega_0^{\circ} \qquad (5)$$

in summation over thirty-six levels of the average field. In [9] for the region $154 \leq A \leq 188$ they have been found $G_N = \frac{26}{A}$ MeV, $G_Z = \frac{22}{A}$ MeV and it has been noted that G_Z was a somewhat understated value. Thus, in both regions of deformed nuclei $154 \leq A \leq 188$ and $225 \leq A \leq 255$ the constants of pairing interaction change according to the law $\frac{1}{A}$ and take the values: $G_N.A = 26$ MeV, $G_Z.A = (28-29)$MeV. The obtaining of the same value of $G_N.A$ for all neutron systems and of the same value of $G_Z.A$ for all proton systems in both groups of strongly-deformed nuclei means that the region of effective interaction which is limited to the aforementioned cut-off has been chosen correctly. The values (5) for G_Z and G_N are smaller than the correspondling values in [7] by $0{,}0035\ \hbar\omega_0^{\circ}$ because of the increase of the number of summed levels from twenty-four up to thirty-six. The values (5) are somewhat larger than those found in [5], where $G_N.A =$ (16-19) MeV and $G_Z.A = (22-25)$ MeV. This is due to the fact that the summation in [5] was carried out over a very large number of levels.

We consider the obtained correlation functions. The values of the correlation functions C for even system and the ratios of the correlation functions of the excited states to those of the ground states are given in Table 3. From th Table it can be seen that the blocking effect is also important in the transuranic region as in the rare-earth region [9]. The values of C for the neutron systems decr sed somewhat compared to the rare-earth region [9]. In spite of the decrease of G_N's and G_Z's in comparison with [7], C's slightly changed for the neutron systems (see Table 6 for $G_N = 0{,}022\ \hbar\omega_0^{\circ}$). For the proton system in [7] understated values of C and $C(K_1, K_2)$ have been obtained because of the fact that the summation region was selected non-symmetrical, so below K the summation was carried out only over four-seven levels. The values of correlation functions C for the proton systems very slightly decreased in the region $225 \leq A \leq 255$ in comparisor with the region $154 \leq A \leq 188$ [9]. It should be noted that the values of C for $Z = 92 - 100$ are approximately the same as those for $N = 92 - 100$ in the rare-earth region [9]. Table 4 gives the ratios of the correlation functions of the ground states of odd systems $C(K)$ to C. In the considered region the ratios for the neutron system are the same as in $154 \leq A \leq 188$ [9], and for the proton system in the transuranic region $C(K)/C$'s are somewhat larger than in the rare-earth one.

Thus, the efficiency of the pair correlations of nucleons of a superconductive type decreases very slightly in the transition from the region $154 \leq A \leq 188$ to the region $225 \leq A \leq 255$.

2. Analysis of the probabilities of β - transitions

General rules of constructing corrections to β -transitions connected with the superfluidity of the ground and excited states are given in [12]. In [9] these corrections are calculated and the probabilities of β - transitions of even and odd nuclei are analysed in the region $154 \leq A \leq 188$. We shall make a similar analysis of the probabilities of β transitions in the region under consideration $225 \leq A \leq 255$.

We compute corrections for the superfluidity $R = R_N \cdot R_Z$ for β transitions between single-quasi-particle states in odd nuclei. Calculations are carried out on the computer by the formulae given in [12] making use of the schemes of the single-particle levels of the average field and of the constants G_N and G_Z which have been found in the previous Section. The results obtained are plotted in Fig.5-8. The neutron corrections R_N are given in Fig.5 which correspond to β -transitions without any changes in the number of nucleon pairs in the neutron system. The neutron corrections R_N which correspond to transitions in which the number of nucleon pairs changes by unity are given in Fig.6. A position of the ground state of an odd nucleus is denoted by ⊗ the number of neutrons has been writing on the curves for the odd system. The single-particle states (labeled with respect to the number of neutrons) are plotted on the abscess axis, whose quantum numbers are given in Table 2. Similar curves for the proton systems are plotted in Fig.7 and 8.

We investigate the probabilities of β transitions in odd nuclei. With this aim we systematize the experimental data and the results of calculations on Tables 5 and 6. Initial and final nuclei are written in the first column of these Tables, an additional classification is given in the second column. I are transitions belonging to the first group, II are transitions belonging to the second one [12] they are first to be written for the proton system and then for the neutron one. The third column contains $R\eta$, where $\eta = \langle I_i \; K_i \; \lambda \; K_f - K_i \mid I_f \; K_f \rangle^2$
The experimental values of $\log ft$, with an appropriate reference are given in the

fourth column. We calculate $\log(ft)_\tau$'s normalizing them with respect to the first from the given set of transitions between identical single-particle states in various nuclei. The values of $\log ft_\tau$ are given in the fifth column of Tables 5 and 6. The values of $\log[ft, R\eta]$ are written down in the last column. From Tables it is seen that the corrections for the superfluidity are essential for β - transitions belonging to the second group where they allow us to explain changes in the values of $\log ft_э$ for β - transitions between identical states in various nuclei.

Making use of the corrections R (Fig.5-8) and of the data from Tables 5 and 6 we can compute the values of $\log(ft)_\tau$ for β - transitions between the aforementioned states in any odd nuclei.

It is interesting to compute absolute values of $\log ft$ using the wave functions obtained by Nilsson. The results of calculation are given in Table 7a, the fifth column of which contains the values of $\log ft$ calculated without including pairing correlations with the aid of the formula

$$ft = \frac{B}{(1-x)F^2 + xG^2} \tag{6}$$

where B and x are the constants F and G are the Fermi and Gamow-Teller's matrix elements. If pairing correlations of the superconductive type are taken into account and the statistical multiplier is singled out, then the expression $(ft)_{abs}$ takes the form

$$(ft)_{abs} = \frac{B}{(1-x)F^2 + xG^2}(R\eta)^{-1} \tag{7}$$

The values of $\log(ft)_{abs}$ are written in the seventh column. From Table 7a it is seen that the corrections related to the superfluidity of the ground- and excited states improves the agreement between theory and experiment. However, as in [13] the calculated absolute values of $(ft)_{abs}$ are smaller than the experimental values of $(ft)_э$ by a factor of 5-10.

We consider β - transitions in even nuclei. The relative probabilities of β - transitions in even nuclei can be calculated, making use of data on β - decay in odd nuclei between the same single-particle states, only in these cases when the selection rules are the same and there is no K or Λ - forbiddenness in even nuclei. We sum up experimental data (Table 7b and 7c) over β - decays of even nuclei and compare them with our calculations. We write the data obtained so that all transitions between the same single-particle states may be in the same place. We write also β - transitions in odd nuclei which have been used by us for determining single-particle matrix elements. From Tables 7b and 7c it is seen that the calculated values of $\log(ft)_{\tau}$ are in a satisfactory agreement with experimental data. This agreement proves the correctness of the two-quasi-particle aspect of the states of odd-odd nuclei and of the excited states of even-even nuclei as well.

As it has been noted in [9] it is advisable to go over from the systematization of the observable values of $\log ft$, to the systematization of $\log[ft, R\eta]$'s excluding the influence of pairing correlations and statistical arguments. In [9] the classification of β - transitions is given in the following form:

$$4{,}0 < \log ft, R\eta < 4{,}7 \qquad au$$

$$5{,}5 < \log ft, R\eta < 6{,}5 \qquad ah$$

$$5{,}5 < \log ft, R\eta < 6{,}5 \qquad 1u$$

From Tables 5,6, 7b and 7c it is seen that most values of $\log ft, R\eta$ go into these regions of values, however, there appears to be a tendency for a removing the lower boundary of the values of $\log ft, R\eta$ from 5,5 up to 5,0 for transitions $1u$.

3. Two-quasi-particle levels of Pu^{240} and Cm^{244}

We calculate the energies of the two-quasi-particle levels of Pu^{240} and Cm^{244} and the values of $\log(ft)_{\tau}$ for appropriate β - transitions. Here there are no new parameters, since all parameters are determined in studying odd nuclei.

Making use of the values of G_N and G_Z and the single-particle scheme given in the first Section we calculate, as it has been done in [9] the energies of the ground-and the two-quasi-particle excited states with the aid of the computer. The results of calculations are given in Tables 8-9. The neutron levels are written in the upper part of Tables 8 and 9 and the proton levels in the lower part of Tables 8-9. The configurations of the excited states are given in the first column, the quantum characteristics of the states K-2, K-1 and other being written at the bottom of both neutron levels and proton levels. In the second column we give $K\pi$, the state with Σ =0 being first written, and below the state with Σ =1. In the third column we give the calculated energies of these levels. The measured energies of levels with configuration setted up as single-particle one are given in the fourth column. β - transitions from odd-odd nuclei whose configurations are at the top of the corresponding columns are given on the righthand side of Table. In the left column we write the β -transition classification, provided $\Delta I \leq 2$ and in the right column we write the observable values of $\log ft_э$ and in brackets the calculated values of $\log ft_т$. The notations are the same as in [9], F are the β - transitions belonging to the third group, and Λ - transitions are Λ - forbidden.

Thus, the energies of the two-quasi-particle levels of even-even nuclei are predicted in Tables 8-9 and it is shown at what rates these levels will be settled for corresponding β - transitions. In the case of Pu^{240} there is not a single state with an uniquely determined configuration, and the levels with the energies 1,42, 1,53 and 1,6 MeV will go evidently into the scheme of the calculated states. The calculated energies of the neutron levels of Pu^{240} differ little from the calculations in [7].

In the case of Cm^{244} the level 6+ with the energy 1,042 MeV and $\log ft_э = 5,9$ has been discovered experimentally in [14] which agrees well with our calculations giving energy equal to 0,92 MeV and $\log(ft)_т = 6,0$.

Thus, in the transuranic region an agreement has also been obtained between experiment and calculations carried out on the basis of the superfluid model. of a nucleus. For a further study of the physical nature of the excited states of transuranic elements it is necessary to increase the amount of the experimental material.

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Table 1

Investigation of the role of the cutoff

	K + 3	K + 6	K + 9	K +12	K +15	K +18
$\mathcal{G}_z\,(\hbar\omega_0^\circ)$	0,0185	0,0185	0,0185	0,0185	0,0185	0,0185
$\rho_z\,(\hbar\omega_0^\circ)$	0,037	0,055	0,070	0,081	0,091	0,102
$C\,(\hbar\omega_0^\circ)$	0,059	0,077	0,091	0,103	0,114	0,125
$C(K)/C$	0,64	0,75	0,79	0,81	0,83	0,83
$\mathcal{G}_z\,(\hbar\omega_0^\circ)$	0,024	0,023	0,021	0,020	0,019	0,0185
$\rho_z\,(\hbar\omega_0^\circ)$	0,074	0,1025	0,101	0,103	0,094	0,102
$C\,(\hbar\omega_0^\circ)$	0,106	0,130	0,128	0,127	0,123	0,125
$C(K)/C$	0,84	0,85	0,84	0,84	0,83	0,83

Table 2

Single-particle levels of the average field

Neutron system				Proton system			
N	Charac. of the levels	Energy $E(s)$ in $\hbar\omega_0^\circ$	$E(s)-E_N(s)$ in $\hbar\omega_0^\circ$	Z	Charac. of the levels	Energy $E(s)$ in $\hbar\omega_0^\circ$	$E(s)-E_N(s)$ in $\hbar\omega_0^\circ$
I37	3/2 + [63I]	-0,0I	-0,0I	89	3/2 + [65I]	0	0
I39	5/2 - [752]	0	0	9I	I/2 - [530]	0,04	+0,0I
I4I	5/2 + [633]	0,05	0	93	5/2 + [642]	0,I2	0
I43	7/2 - [743]	0,I3	0	95	5/2 - [523]	0,I4	-0,0I
I45	I/2 + [63I]	0,I7	-0,03	97	3/2 - [52I]	0,27	-0,05
I47	5/2 + [622]	0,25	-0,04	99	7/2 + [633]	0,28	-0,0I
I49	7/2 + [624]	0,3I	-0,07				
I5I	9/2 - [734]	0,37	-0,09				
I53	I/2 + [620]	0,45	0				

Table 3

The values of the correlation functions

	Proton system $G_Z = \frac{29}{A}$						Neutron system $G_N = \frac{26}{A}$								
Z or N	90	92	94	96	98	I00	I38	I40	I42	I44	I46	I48	I50	I52	I54
C(K,K+I)/C	0,67	0,59	0,I0	0,28	0	0	0,53	0,4I	0,0I	0	0	0	0	0,5I	0,66
C(K-I,K+I)/C	0,08	0,63	0,47	0,40	0,54	0	0,6I	0,44	0,4I	0,35	0,25	0,4I	0,55	0,8I	0,69
C(K,K+2)/C	0,72	0,64	0,68	0,33	0,47	0,53	0,65	0,62	0,50	0,43	0,33	0,3I	0,43	0,54	0,67
C(K,K)/C	0,69	0,63	0,4I	0,66	0,I9	0,59	0,54	0,57	0,57	0,49	0,58	0,58	0,64	0,59	0,64
C(K-I,K)/C	0,70	0,66	0,53	0,67	0,60	0,59	0,62	0,59	0,62	0,59	0,63	0,69	0,73	0,73	0,69
C(K+I,K+2)/C	0,73	0,7I	0,72	0,75	0,49	0,68	0,65	0,69	0,70	0,64	0,65	0,62	0,62	0,64	0,68
C(K-2,K-I)/C	0,72	0,69	0,65	0,72	0,72	0,68	0,70	0,59	0,69	0,72	0,75	0,8I	0,85	0,85	0,8I
C(K+I,K+4)/C	0,82	0,80	0,76	0,84	0,59	0,7I	0,75	0,76	0,78	0,72	0,72	0,65	0,63	0,66	0,69
C(K+2,K+3)/C	0,8I	0,82	0,85	0,80	0,73	0,78	0,79	0,8I	0,8I	0,79	0,76	0,73	0,69	0,66	0,69
C in unit $\hbar\omega_0^0$	0,I46	0,I37	0,I25	0,II3	0,I09	0,I04	0,II9	0,II2	0,I04	0,099	0,097	0,099	0,I07	0,II7	0,I26

Table 4

The ratios $C(K)/C$

Proton system

Z odd/Z even	87/88	89/90	91/92	93/94	95/96	97/98	99/I00
C(K)/C	0,89	0,88	0,86	0,83	0,74	0,7I	0,7I

Neutron system

N odd/N even	I37/I38	I39/I40	I4I/I42	I43/I44	I45/I46	I47/I48	I49/I50	I5I/I52	I53/I54
C(K)/C	0,84	0,8I	0,75	0,69	0,63	0,60	0,63	0,72	0,80

Table 2

ah β - transitions in the odd nuclei

β-transiti	addition. classif.	R.η	$log(ft)_3$	$log(ft)_2$	$log[ft, R\eta]$
$s_z = \{5/2 + [642]\} \rightleftarrows s_N = \{5/2 + [622]\}$					
$Np^{239} \to Pu^{239}$	I II	0,I6	6,9/I0/	-	6,I
$s_z = \{5/2 + [642]\} \rightleftarrows s_N = \{7/2 + [624]\}$					
$Am^{243} \leftarrow Pu^{243}$	II I	0,I3	6,I/I0/	6,I	5,2
$Np^{239} \to Pu^{239}$	I II	0,07	6,8/I7/	6,4	5,6
$s_z = \{5/2 - [523]\} \rightleftarrows s_N = \{7/2 - [743]\}$					
$Np^{237} \leftarrow Pu^{237}$	II I	0,22	6,8/I0/	-	6,I
$s_z = \{7/2 + [633]\} \rightleftarrows s_N = \{7/2 + [624]\}$					
$Am^{243} \leftarrow Pu^{243}$	I I	0,48	~6/I0/	-	~5,7

Table 6

1u β- transitions in the odd nuclei

β - transition	addition. classif.	R.η	$log(ft)_3$	$log(ft)_2$	$log[ft, R\eta]$
$s_z = \{1/2 - [530]\} \rightleftarrows s_N = \{3/2 + [631]\}$					
$Pa^{233} \to U^{233}$	I II	0,06	7,2/I5/	7,2	6,0
$Pa^{237} \to U^{237}$	I II	0,29	≃7,0/I6/	~6,5	≃6,5
$s_z = \{3/2 - [521]\} \rightleftarrows s_N = \{1/2 + [631]\}$					
$Bk^{245} \to Cm^{245}$	I II	0,04	~7,0/I7/	7,0	~5,6
$Am^{241} \leftarrow Cm^{241}$	II I	0,I4	≃7,3/I7/	6,5	≃6,4
$Np^{237} \leftarrow U^{237}$	I I	0,43	6,0/I0/	6,0	5,6
$s_z = \{3/2 - [521]\} \rightleftarrows s_N = \{5/2 + [622]\}$					
$Bk^{245} \to Cm^{245}$	I II	0,22	7,0/I6/	-	6,3
$s_z = \{5/2 - [523]\} \rightleftarrows s_N = \{5/2 + [622]\}$					
$Am^{239} \to Pu^{239}$	I I	0,29	6,0/I0/	6,0	5,5
$Am^{241} \leftarrow Pu^{241}$	I I	0,20	5,7/I7/	6,2	5,0
$Am^{245} \to Cm^{245}$	I I	0,53	~6,2/I0/	5,8	~5,9
$s_z = \{5/2 - [523]\} \rightleftarrows s_N = \{7/2 + [624]\}$					
$Am^{245} \to Cm^{245}$	I I	0,34	~6, 2/I0/	6,2	~5,7
$Am^{243} \leftarrow Pu^{243}$	I I	0,I6	6,I/I7/	6,5	5,3
$Am^{239} \to Pu^{239}$	I I	0,33	~6,3/I7/	6,2	~5,8
$s_z = \{5/2 + [642]\} \rightleftarrows s_N = \{7/2 - [743]\}$					
$Np^{239} \to Pu^{239}$	I I	0,49	6,5/I7/	6,5	6,2
$Np^{237} \leftarrow Pu^{237}$	I I	0,26	~6,8/I7/	6,8	~6,2
$Np^{235} \to U^{235}$	I I	0,25	6,6/I7/	6,8	6,0
$s_z = \{7/2 + [633]\} \rightleftarrows s_N = \{9/2 - [734]\}$					
$Bk^{249} \to Cf^{249}$	I I	0,I8	6,9/I0/	-	6,2

Table 7a

Calculated absolute values of $\log ft_{abs}$ of the ah transitions in the odd nuclei.

Parent nucleus	State I	State K π [Nn$_z$Λ]	Daughter nucleus	State I'	State K' π'[N'n'$_z$Λ']	log ft without calculation of the pairing correlation	R.η	$\log ft_{abs}$	$\log ft_э$
$^{I43}_{94}Pu^{237}$	7/2	7/2 − [743]	$^{I44}_{93}Np^{237}$	5/2	5/2 − [523]	5,4	0,22	6,I	6,8/I0/
$^{I46}_{93}Np^{239}$	5/2	5/2 + [642]	$^{I45}_{94}Pu^{239}$	7/2	7/2 + [624]	5,3	0,07	6,5	6,8/I7/
$^{I49}_{94}Pu^{243}$	7/2	7/2 + [624]	$^{I48}_{95}Am^{243}$	7/2	7/2 + [633]	4,2	0,48	4,6	~6/I0/
$^{I46}_{93}Np^{239}$	5/2	5/2 + [642]	$^{I45}_{94}Pu^{239}$	5/2	5/2 + [622]	4,9	0,I6	5,7	6,9/I0/

Table 7b

ah β-transitions in the even nuclei

State	β-transition	State	R.η	$\log(ft)_э$	$\log(ft)_t$	$\log[ft, R\eta]$
5/2 + [642]	$Np^{239} \rightarrow Pu^{239}$	7/2 + [624]	0,07	6,8/I7/	<u>6,8</u>	5,6
1+ 642↑ − 624↓	$Np^{240} \rightarrow Pu^{240}$	0+ ground	0,I7	6,7/I6/	6,4	5,9
1+ 642↑ − 624↓	$Np^{240} \leftarrow U^{240}$	0+ ground	0,I3	5,7/I8/	6,5	4,8

Table 7c

1u β-transitions in the even nuclei

State e	β-transition	State	R.η	$\log(ft)_э$	$\log(ft)_t$	$\log[ft, R\eta]$
5/2 − [523]	$Am^{239} \rightarrow Pu^{239}$	5/2 + [622]	0,29	6,0/I0/	<u>6,0</u>	5,5
0− 523↓ − 622↑	$Am^{242} \rightarrow Cm^{242}$	0+ ground	0,I3	7,I/20/	6,4	6,2
0− 523↓ − 622↑	$Am^{242} \rightarrow Pu^{242}$	0+ ground	0,06	~7,6/20/	6,7	~6,4
6− 523↓ + 624↓	$Am^{244} \rightarrow Cm^{244}$	6 + n 622↑ + 624↓	0,32	5,9/I4/	6,0	5,4
5/2 + [642]	$Np^{239} \rightarrow Pu^{239}$	7/2 − [743]	0,49	6,5/I7/	<u>6,5</u>	6,2
I− 642↑ − 743↑	$Np^{236} \rightarrow Pu^{236}$	0+ ground	0,I0	6,6/2I/	7,2	5,6
I− 642↑ − 743↑	$Np^{236} \rightarrow U^{236}$	0+ ground	0,09	7,0/2I/	7,2	5,9

Table 8

A = 240 ${}^{146}_{94}\mathrm{Pu}^{240}$

State	Kπ	Energy (MeV) Calculated	Energy (MeV) Measured	${}^{147}_{93}\mathrm{Np}^{240}$ $1+$ $pK,\ nK+2$ Classif.	log ft
		Neutron levels			
K,K+1	3+	0,9		2F	
	2+			aF	
K,K K+1,K+1	0+	~1,2			
K-1,K+1	1-	1,3		1F	
	6-				
K,K+2	3+	1,3		2	
	4+				
K-1,K	4-	1,5		I* F	
	3-				
K-1,K+2	7-	1,6		Iu	(7,0)
	0-				
K+1,K+2	6+	1,6			
	1+			ah	(6,9)
K-2,K+1	5+	1,7			
	0+			aF	
K,K+3	5-	1,8			
	4-				
K+2,K	2+	2,0		aF	
	3+			2F	
K+1,K+3	2-	2,0		1F	
	7-				

K-2 = 633↓ K-1 = 743↑ K== 631↓ K+1 = 622↑ K+2 = 624↓ K+3 = 734↑ K+4 = 620↑

State	Kπ	Energy (MeV) Calculated	Energy (MeV) Measured	Classif.	log ft
		Proton levels			
K,K+1	5-	1,3		Iu	(6,8)
	0-				
K,K K+1,K+1	0+	~1,4			
K-1,K+1	3+	1,7		2F	
	2+			aF	
K-1,K	2-	1,8		1(2)	
	3-			1*Λ(2)	
K,K+2	1-	1,8		1 (1* h)	
	4-				
K+1,K+2	4+	1,8		aF	
	1+				
K,K+3	1+	1,8		ah	(5,8)
	6+				
K+1,K+3	6-	1,8		1F	
	1-				
K-2,K+1	4-	1,9			
	1-				
K-1,K+2	1+	2,0		aF	
	2+			aF	
K-2,K	1+	2,0		a (2)	
	4+				

K-2 = 651↑ K-1 = 530↑ K= 642↑ K+1 = 523↓ K+2 = 521↑ K+3 = 633↑ K+4 = 514↓

Table 9

A = 244 $^{148}_{96}Cm^{244}$

State	Kπ	Energy (MeV) Calculated	Energy (MeV) Measured	$^{149}_{95}Am^{244}$ нет 6− pK, nK+1 Classific.	log ft
Neutron levels					
K,K+1	6+ 1+	0,92	1,042[14]	Iu	5,9 (6,0)
K,K K+1,K+1	0+	~1,2			
K-1,K+1	3+ 4+	1,3		I*h	
K,K+2	2– 7–	1,4		aF	
k-1,K	3+ 2+	1,5			
K+1,K+2	8– 1–	1,6		2F	
K-1,K+2	5– 4–	1,7		aF	
K-2,K+1	7– 0–	1,7		ah	(6,4)
K,K+3	2+ 3+	1,8			
K-2,K	1– 6–	1,9		aF	
K+1,K+3	4+ 3+	2,1		I*h	

K-2=743↑ k-1 = 631↓ K = 622↑ K+1 = 624↓ K+2 = 734↑ K+3 = 620↑ K+4 = 613↑

State	Kπ	Energy (MeV) Calculated	Energy (MeV) Measured	Classific.	log ft
Proton levels					
K,K+1	4+ 1+	1,36		I*h	
K,K+2	6– 1–	1,40		ah	(5.9)
K-1,K+1	1– 4–	1,52		2F	
K-1,K+2	1+ 6+	1,54		1F	
K,K K+1,K+1	0+	~1,7			
K+1,K+2	2– 5–	1,7		aF	
K-1,K	5– 0–	1,87		ah	(6,4)
K,K+3	1+ 6+	1,88		Iu	
K-2,K+1	1+ 2+	1,94			
K+1,K+3	5+ 2+	2,16		1F	
K+2,K+3	0– 7–	2,18		aF	

K-2 = 530↑ K-1 = 642↑ K = 523↓ K+1 = 521↓ K+2 = 633↓ K+3 = 514↓ K+4 = 521↓

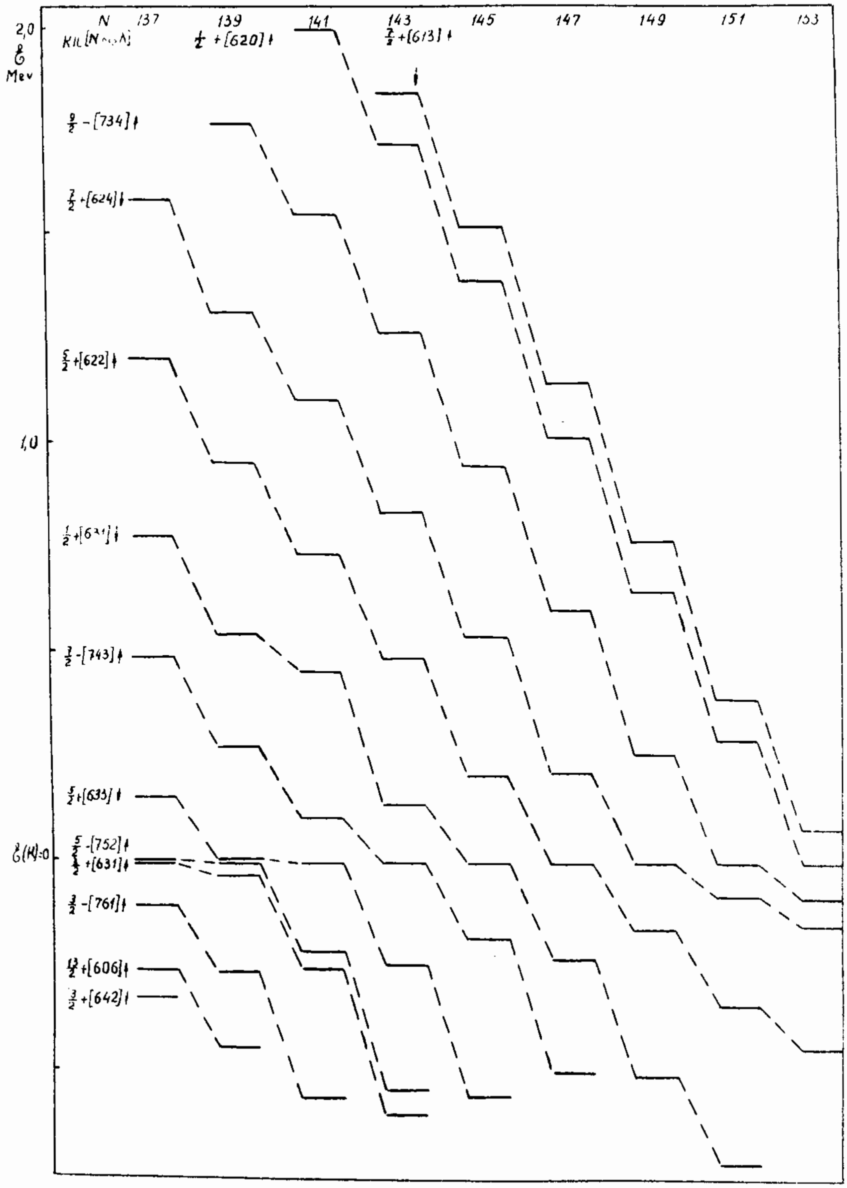

N
137
139
141
143
145
147
149
151
153
2,0
1,0
Mev
$\frac{1}{2}$ +[620]↑
$\frac{7}{2}$ +[613]↑
$\frac{9}{2}$ -[734]↑
$\frac{7}{2}$ +[624]↓
$\frac{5}{2}$ +[622]↑
$\frac{3}{2}$ -[743]↑
$\frac{5}{2}$ +[633]↑
$\frac{5}{2}$ -[752]↑
$\frac{1}{2}$ +[631]↓
$\frac{3}{2}$ -[761]↑
$\frac{13}{2}$ +[606]↑
$\frac{3}{2}$ +[642]↑

Fig.1.

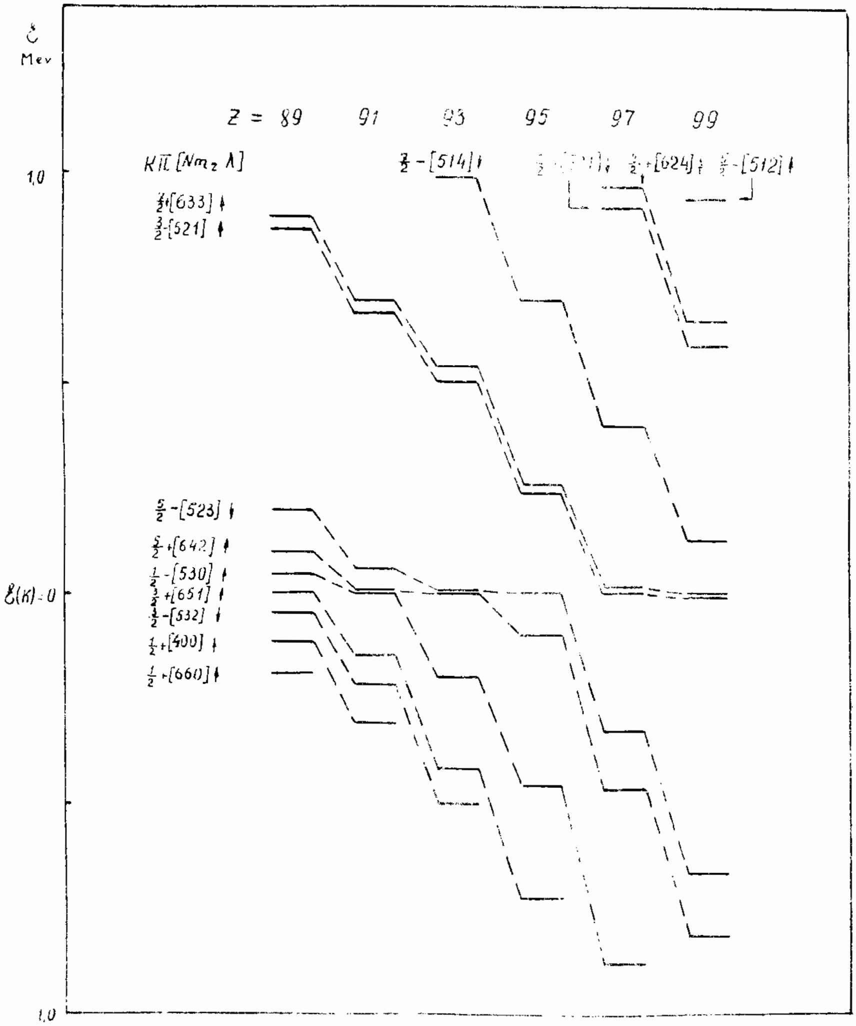
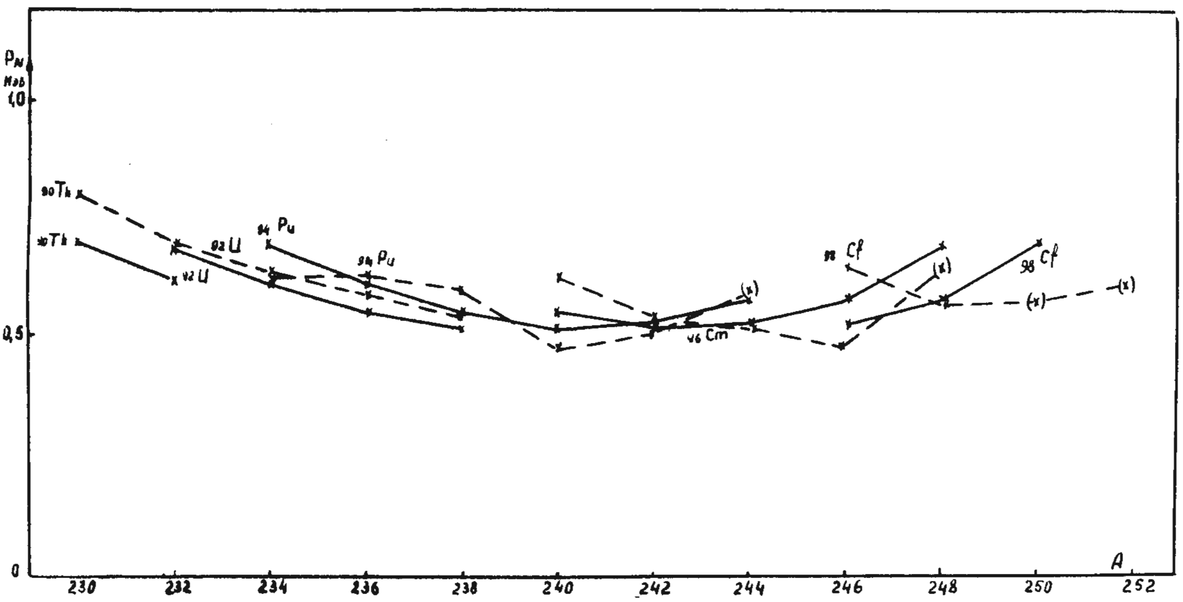
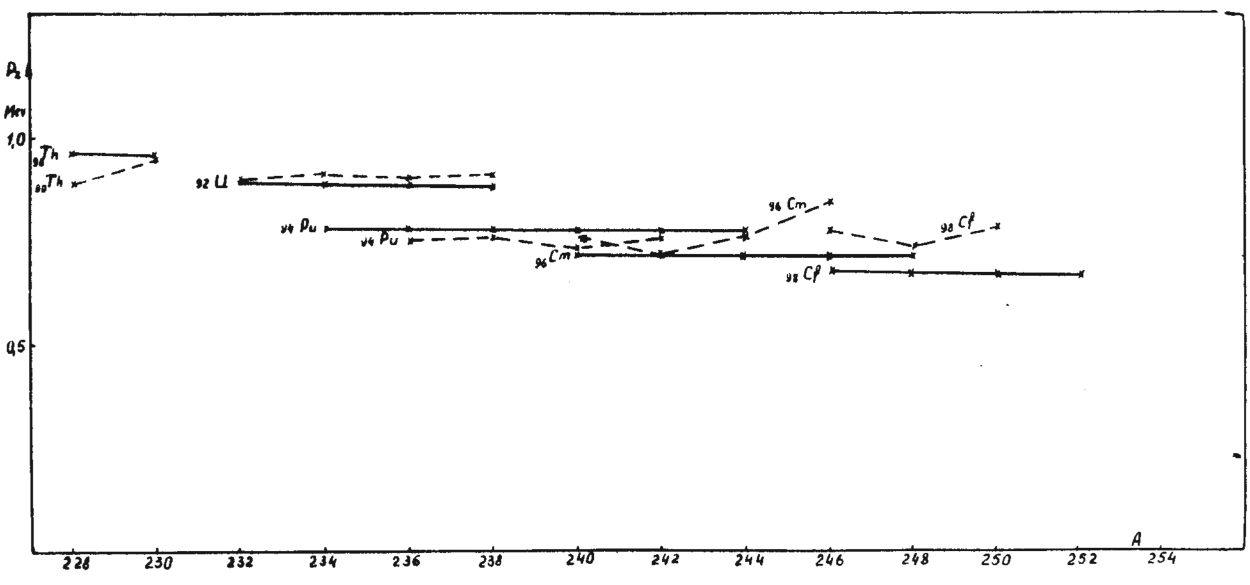

ℰ
Mev
Z = 89
91
93
95
97
99
KΠ [Nn_z Λ]
1,0
7/2 - [514]
5/2 + [624]
5/2 - [512]
7/2 + [633]
3/2 - [521]
5/2 - [523]
5/2 + [642]
1/2 - [530]
3/2 + [651]
3/2 - [532]
1/2 + [400]
1/2 + [660]
ℰ(K) = 0
1,0

Fig.2.



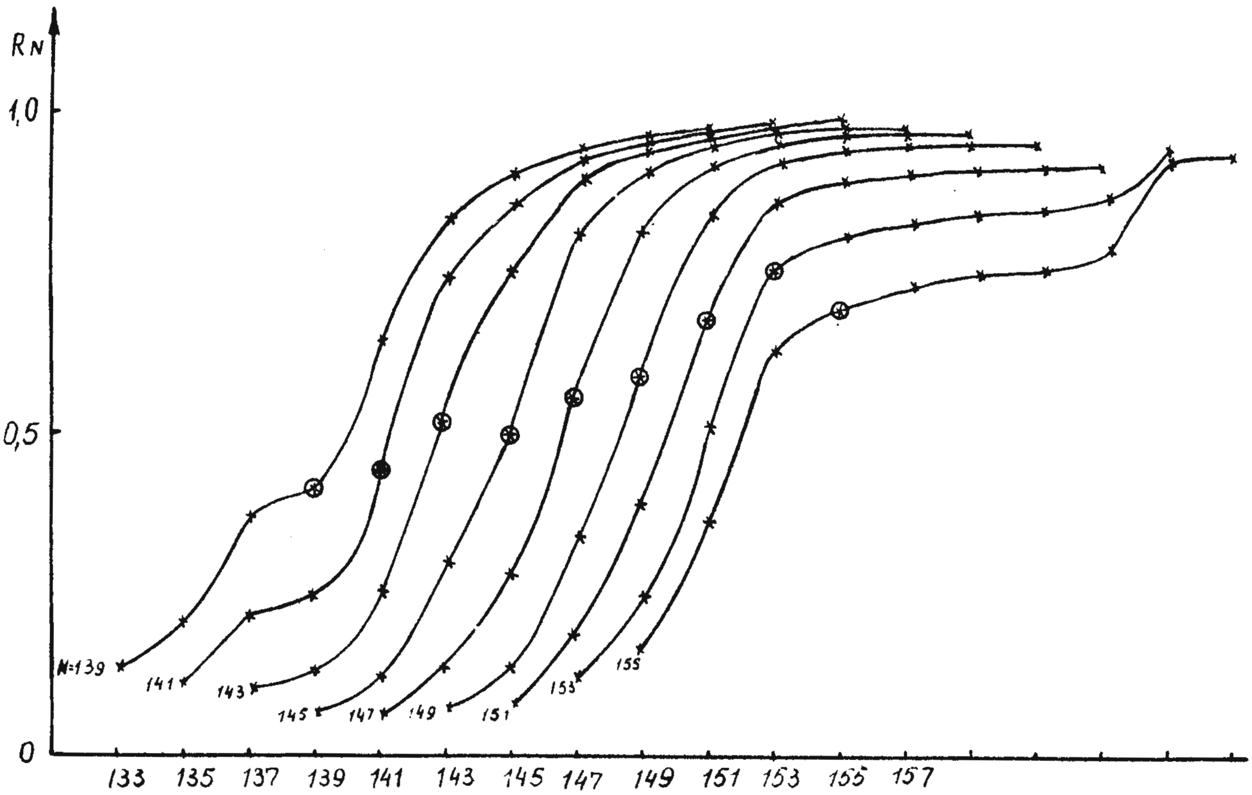
P_N
Mev
1,0
0,5
0
90Th
90Th
92U
92U
94Pu
94Pu
96Cm
98Cf
98Cf
(x)
(x)
(x)
(x)
A
230
232
234
236
238
240
242
244
246
248
250
252

Fig.3.



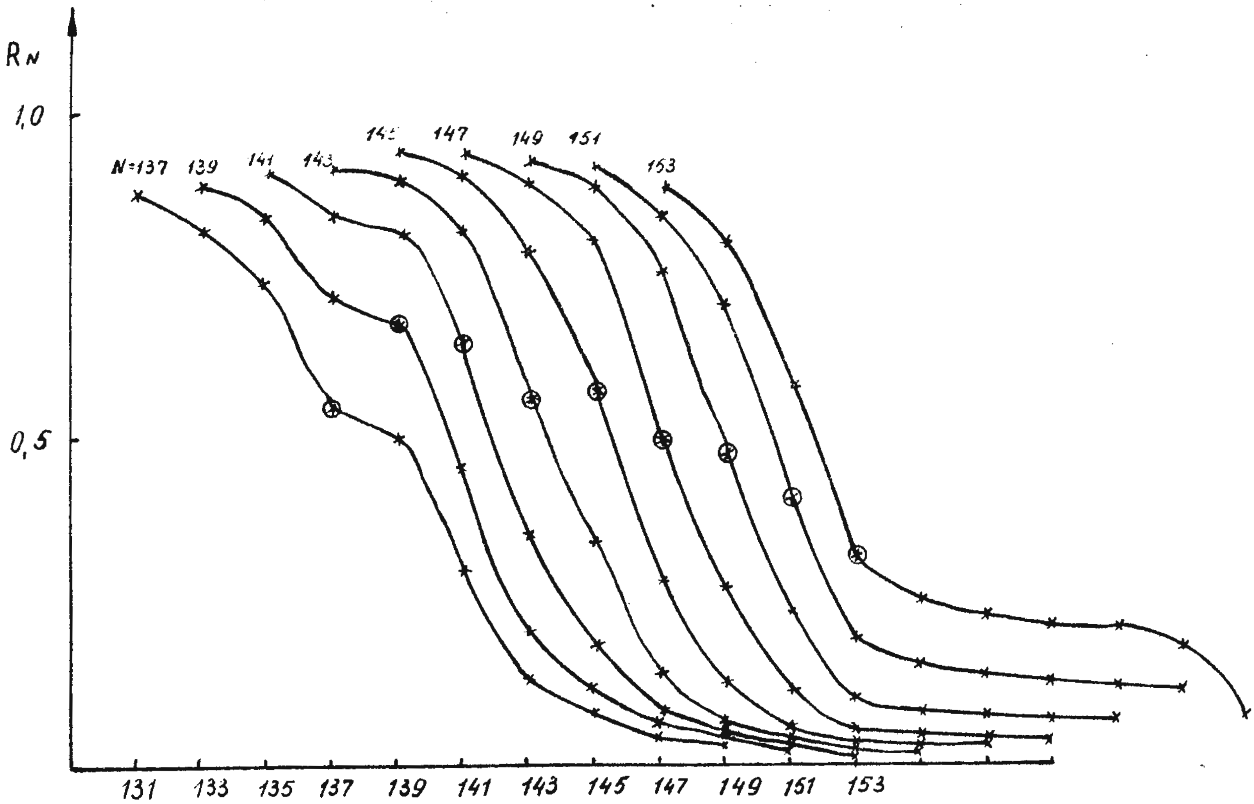
P_z
Mev
1,0
0,5
90Th
90Th
92U
94Pu
94Pu
96Cm
96Cm
98Cf
98Cf
A
228
230
232
234
236
238
240
242
244
246
248
250
252
254

Fig.4.



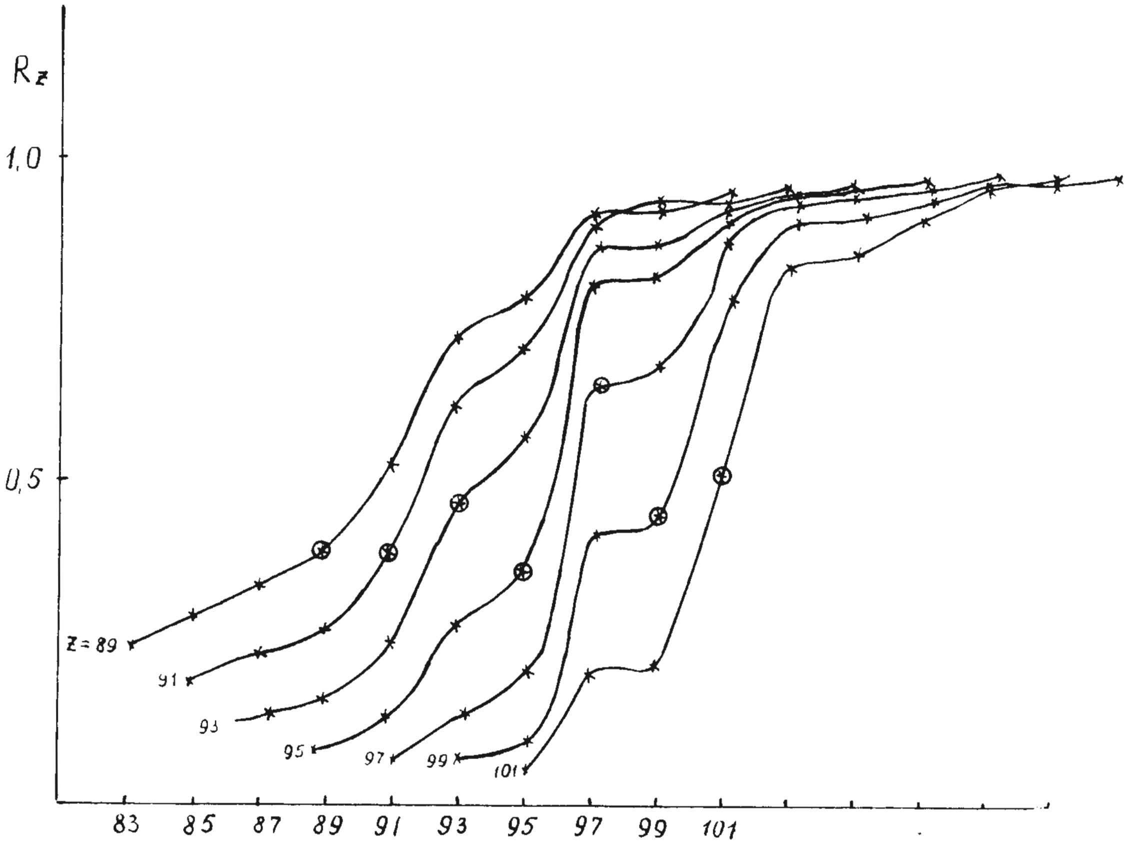
RN
1,0
0,5
0
N=139
141
143
145
147
149
151
153
155
133
135
137
139
141
143
145
147
149
151
153
155
157

Fig.5.



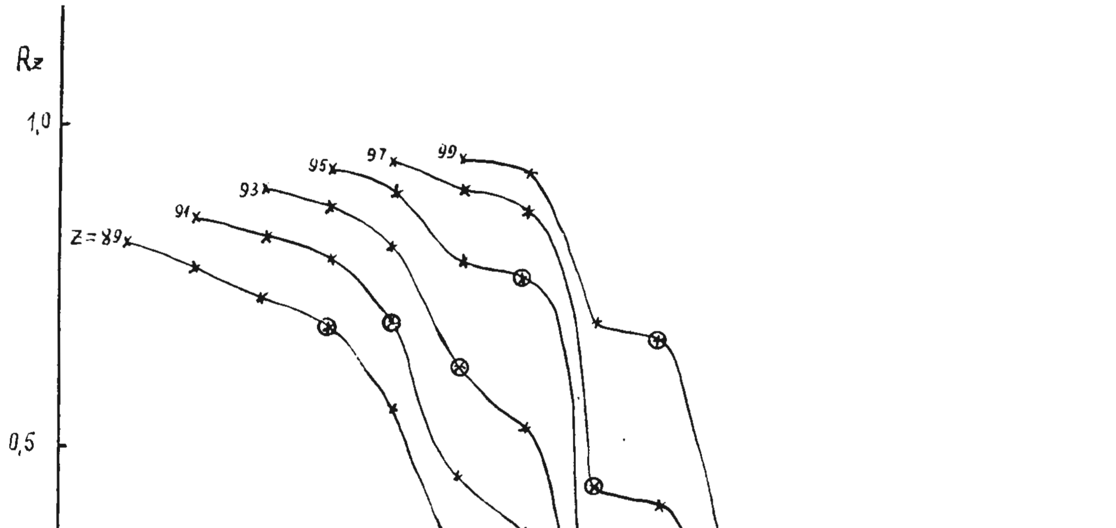
RN
1,0
0,5
N=137
139
141
143
147
149
151
153
131
133
135
137
139
141
143
145
147
149
151
153

Fig.6.



R_z
1,0
0,5
Z = 89
91
93
95
97
99
101
83
85
87
89
91
93
95
97
99
101

Fig.7.



R_z
1,0
0,5
Z = 89
91
93
95
97
99
83
85
87
89
91
93
95
97
99
101

Fig.8.

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