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MODIFIED MODEL OF NEUTRON RESONANCES WIDTH DISTRIBUTION. RESULTS OF REDUCED NEUTRON WIDTHS APPROXIMATION FOR MASS REGION $35 \leqslant A \leqslant 249$

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Модифицированная модель распределений ширин
нейтронных резонансов. Результаты аппроксимации приведенных нейтронных
ширин для области масс $35 \leqslant A \leqslant 249$

Распределения приведенных нейтронных ширин s-, p- и d-резонансов ядер для любых типов в области масс $35 \leqslant A \leqslant 249$ с максимальной точностью аппроксимированы моделью, представляющей экспериментальный набор данных как суперпозицию не более чем четырех независимых нейтронных амплитуд. В предположении, что каждая из этих амплитуд является распределением Гаусса с единственным максимумом, определены наиболее вероятные значения вклада каждой из амплитуд в суммарное распределение ширин, наиболее вероятные их средние значения и дисперсии. Сопоставление полученных значений χ^2 для такого варианта с величиной χ^2, полученной при описании экспериментальных данных единственным распределением нейтронных амплитуд с подгоняемыми параметрами кривой Гаусса, показывает, что практически все ширины из представленных 157 наборов данных могут иметь различающиеся типы волновых функций.

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Modified Model of Neutron Resonances Width Distribution. Results of Reduced
Neutron Widths Approximation for Mass Region $35 \leqslant A \leqslant 249$

The distributions of the reduced neutron widths of s-, p- and d-resonances of nuclei of any type from nuclear mass region $35 \leqslant A \leqslant 249$ were approximated with maximal precision by the model which presents experimental data set as a superposition of a maximum of four independent neutron amplitudes. Under the assumption that each of these amplitudes has the Gauss distribution with the unique maximum there were determined the most probable values of contribution of each amplitude in summary width distribution, their most probable mean values and dispersions. Comparison of the obtained χ^2 values with value χ^2 at description of the experimental data by one distribution of neutron amplitudes with best fitted parameters shows that all widths from more than 157 analyzed data sets can have different types of wave functions.

Communication of the Joint Institute for Nuclear Research. Dubna, 2011

1. INTRODUCTION

Experimental investigation of superfluidity of heated nuclei can give unique information on such fundamental physics process as interaction and intertransition between Fermi and Bose systems. As compared with the other objects of investigation the new principle data can be obtained in this case owing to radical difference of parameters of macrosystems and nucleus.

The main parameter that characterizes the degree of superfluidity of heated nucleus is entropy which is determined by its density ρ of excited levels [1]. The special interest for its study is the region of nuclear excitation energy from doubled energy of nucleon paring Δ up to their binding energy B_n. Just here the process of break up of Cooper pairs of nucleons onto the pairs of independent quasi-particles is developed. Unfortunately, just in this region of excitations the ρ value is determined in the experiment with inevitable and, often, rather significant systematical errors. This conclusion follows from the comparison of nuclear properties, obtained from interpretation of data of the one-step reactions (which determine ρ from the total gamma spectra [2] or spectra of evaporation nucleons [3]) and two-step reaction $(n, 2\gamma)$.

Respectively, a nucleus can be presented as

a) the system of noninteracting Fermi particles,

b) the Bose condensate (practically — only below nucleon binding energy B_n) or

c) the mixture of increasing number of quasi-particles and some number of phonons, where break-up of Cooper pair number n occurs with interval of about $2\Delta_n$, which decreases with increase of nuclear excitation energy [4].

These principally incompatible conclusions [2–4] of a nuclear properties point to the presence of serious systematical errors in different experiments. The most probable and largest systematical error is caused by the use of the model ideas of unknown [5] probability of the reaction product emission, corresponding to transition of nucleus between its excited levels and low sensitivity to variations of the desired parameters [6].

The noticeable problem can be also an error in determination of the experimental density of neutron resonances $\rho_\lambda = D_\lambda^{-1}$ from the results of analysis of the experimental data with the use of the neutron time-of-flight method. This

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value is a basic for any experiments where nuclear level density in the excitation region above some MeV is derived from the spectra of gamma rays or evaporation nucleons. But, potentially high precision in determination of D_λ^{-1} can be realized, at least, by careful accounting and correction of all systematical errors of the experiment. This statement concerns, first of all, the model intended for description of distribution form of the obtained values of reduced neutron widths of resonances Γ_n^0 (or $\Gamma_n^1\ldots$) for its following extrapolation below sensitivity threshold of the experiment. Of course, precision of this procedure is determined by degree of correspondence of theoretical ideas on distribution of Γ_n^0 to the experiment.

The not removable uncertainty D_λ^{-1} is caused by the fact that the independent variable of the analyzed distribution of the widths $X = \Gamma_n^0/\langle\Gamma_n^0\rangle$ always contains unknown systematical error. This error is caused by impossibility of unambiguous determination of the mean value $\langle\Gamma_n^0\rangle$ only from the set of the experimental values of widths. According to the theoretical analysis, the Γ_n^0 value for neutron resonances is determined by few-particle components of wave function, whose square contribution in normalizing is estimated [7] in nuclei of middle and large mass by the value of about 10^{-6}–10^{-9}. It is generally accepted that the experimentalists use the Porter–Thomas hypothesis [8] for description of fluctuations of Γ_n^0 and parameters of its distribution. The smallness and chaotic character of items of neutron amplitudes of resonances are determined by strong fragmentation [9] of low-lying one- and two-quasi-particle states of a nucleus, i.e, it is confirmed by modern nuclear theory. Another obligatory condition of applicability of [8] — mathematical expectation of mean value of amplitude $A = \sqrt{\Gamma_n^0}$ must be equal to zero and its dispersion — to mean $\langle\Gamma_n^0\rangle$. Both conditions:

$$M(A) = 0,$$
$$D(A) = \langle\Gamma_n^0\rangle \tag{1}$$

are not tested in modern analysis of experimental values Γ_n^0, i.e., *applicability of the Porter–Thomas distribution is postulated, but ground conditions of its truth are not proved.*

Experimental distribution of widths is not also tested for possibility of existence of superposition of several gamma functions with different values $M(A)$ and $D(A)$. The latter situation can appear at presence of groups of neutron resonances with noticeably (or strongly) differing structure of wave functions and is trivial at presence of two and more spins of resonances. Approximation [4, 10, 11] of level density below B_n, derived from intensities of two-step gamma cascades, shows that the structure of any nucleus at increase of excitation energy undergoes cyclic change because of discrete character of break-up process of Cooper pairs of nucleons. Corresponding conclusion was obtained for different tested functional dependences of correlation function of two nucleons Δ_n on excitation energy

of a nucleus for the set of ≈ 40 nuclei from the mass region $40 \leqslant A \leqslant 200$. High reliability of establishment of this fact is conditioned by its obtaining in the framework of the only model-free method for determination of ρ [12] realized by now practically.

Cyclic change of structure of neutron resonances at increase of excitation energy of a nucleus must occur owing to appearance of nuclear states with increasing number of quasi-particles and with possible variation of number and type of phonons. Fragmentation of these complicating nuclear states inevitably changes the coefficients of wave functions of neutron resonances (as is follows from the main notions of quasi-particle–phonon model of a nucleus). As a result, there is possible violation of the Porter–Thomas distribution in its existing today interpretation (1).

2. MODERN STATUS OF PROBLEM OF THE EXPERIMENTAL DATA ANALYSIS

Distributions of the experimental Γ_n^0 values are usually approximated at analysis in different form of functional dependence [8]. But experimental data contain fixed (and limited) quantity of information. Therefore, the accessible for its extraction maximally possible volume must not depend on analysis type. And choice of the form of data presentation and algorithms of analysis are determined only by problems of obtaining of maximally precise values of the determined parameters at presence of random and systematical errors and, it is desirable, the best visualization of the obtained results.

The main problem of analysis of distribution of the measured neutron widths at presence of their registration threshold — *absolute absence of the experimental data on value of its portion which is really observed in experiment.* In the other words, modern experiment cannot give the $\Gamma_n^0/\langle\Gamma_n^0\rangle$ values. As a consequence, here arises the problem of the random value unit — it must not depend on presentation form for distribution. The most suitable form of the data presentation for the task under solution is cumulative sum of the experimental values $X = \Gamma_n^0/\langle\Gamma_n^0\rangle$, which increases at increasing X. The main preference of such a presentation is clearness of the presence of change in form of distribution and the lowest degree of its dependence on the error $\langle\Gamma_n^0\rangle$ and revealing of the most strong misprints. The example of expected random cumulative sums for distribution [8] is shown in Fig. 1.

Corresponding analysis was performed for the values of widths of neutron resonances obtained experimentally and included in known compilations (for example, in [13, 14] or library ENDF/B-VII [15]).
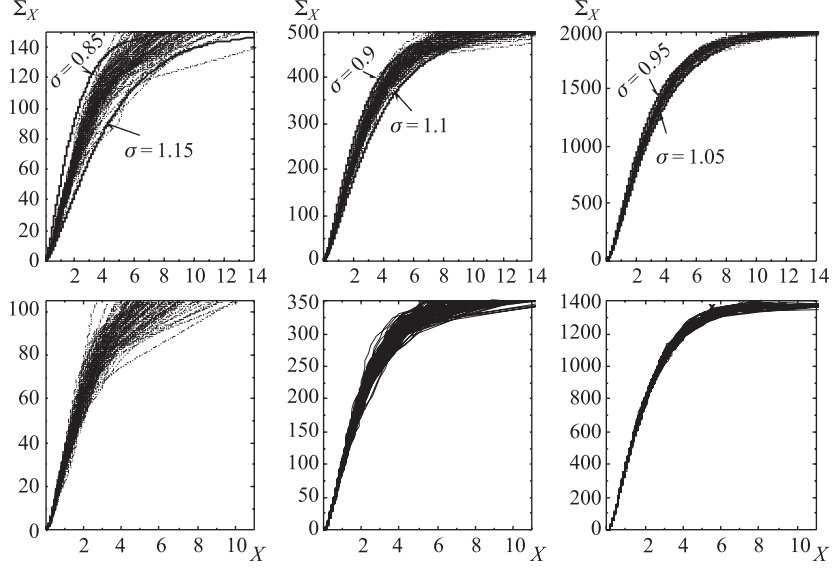
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Fig. 1. Top row — the example of cumulative sums for some tens of sets from 150, 500 and 2000 random X values. Bottom row — cumulative sums for the same sets after exclusion of 30% of the lowest X values

3. THE MODEL AND METHOD FOR THE SUGGESTED ANALYSIS

The sample average $\langle \Gamma_n^0 \rangle$ for the experimental cumulative sum was determined from this set without accounting for omitted resonances and their unresolved multiplets. This uncertainty does not tell on influence of ratio of values χ^2 for different approximating functions — the shapes of experimental and approximating distributions and their relative difference for cumulative sum X do not depend on the units in which the Γ_n^0 width is determined.

The fitted object is the sum of k distributions of gamma functions $\Gamma(X)$ for square of normally distributed random amplitudes with independent variables X_k each. The desired parameters in compared variants are the most probable value b_k of amplitude A_k, its dispersion σ_k and the total contribution C_k of gamma-function number k for the variable

$$X_k = ((A_k - b_k)^2)/\sigma_k^2 \tag{2}$$

in the full experimental cumulative sum of widths $S_{\exp}(X)$. The maximum possible value of k is determined by variation of its tested values at the beginning from $k = 1$.

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The number of distribution k and sign of amplitude A_k for given resonance are unknown. That is why, further was used only its positive value because (2) is invariant with respect to simultaneous change of sign of both A_k and b_k. But everywhere it is supposed that in considered distribution number k can exist the only singular desired value b_k, i.e., any distribution number k of widths has the only one most probable value of amplitude. There is the main (and absolutely necessary) hypothesis of the analysis of distributions of the reduced neutron widths of resonances performed below. It should be noted in addition that the modules of values b_k and σ_k are strongly correlating variables, at least, for large enough values b_k.

Concrete value of function $P(X)$ for variable (2) in the described analysis was obtained by compression and shifting of the generally known Euler gamma function. The obtained in this way value corresponds to the magnitude of the above-mentioned function for the variable $X = (A\sigma + b)^2$. At present, the basis for this algorithm for setting of parameters of approximating function is excellent degree of description of all known experimental distributions of the widths.

It is obvious that the case: $k = 1$, $b_k = 0$ and $\sigma = 1$ corresponds to distribution [8]. The case of arbitrary value $b_k = \mathrm{const}$ and $\sigma = 0$ corresponds to the degenerate (caused) distribution of widths for corresponding value of amplitude. Any other values of approximation parameters correspond to any point of the spectrum of possible values of amplitudes for wave functions of concrete neutron resonances. According to the main axiom of mathematical statistics, their most probable values correspond to minimum of χ^2. Naturally, the best values of k, b, σ and contribution of each from k partial distributions in the total sum are distorted by random fluctuations of widths in maximally possible extent. However, unlike usual approximations of distributions of neutron widths, the *obtained values of the parameters contain maximally possible information on their real structure*.

Analysis of the different spins of resonance data sets was approximated a distribution $g\Gamma_n^0$ (s-resonances of even-odd and A-odd target nuclei) or only Γ_n^0 for fixed (on basis of some information) spins of resonances. More correct, methodically and physically, is to separate approximation of the data of the one and the same spin. But, it is true only for the case if they were determined for the all resonances with high enough precision. In principle, real analysis must take into account the distortions of the experimental data so that the most probable parameters of the width distribution would be maximally reliable at presence of arbitrary systematical errors. By this reason, it was performed in the given work only for $g\Gamma_n^0$.

The region of approximation for distribution [8] must be great enough. In all the calculations adduced below it was corresponded to the interval from zero to the maximal experimental values of $1.5\,X_{\max}$. Cumulative sum in point $X_{\max}$ was normalized to the number of the experimentally determined widths. By this,

the region (0–$1.5\,X_{\max}$) in all cases contained more than $M = 1000$ points, where there was minimized the difference of the experimental cumulative sum $S_{\exp}$ and approximating function S_{fit}. This is necessary because the approximating function is determined by numerical integration of width distribution.

In the region of neutron resonances, the experimental level density of nuclei from mass region $40 \leqslant A \leqslant 200$ obtained in Dubna (by model-free method of analysis of intensities of two-step cascades), according to [4, 10, 11], is described by the sum of four (sometimes three) partial level densities with a different number of quasi-particles and phonons. Just from this it follows that neutron resonances can, in principle, have several different types of wave functions. In practice, it is accepted by calculating problems that the experimentally observed resonances can in limiting case belong, maximum, to four different distributions of Γ_n^0 for even–even target nuclei. It is true for A-odd nuclei (and all p-resonances) at equality $\langle g\Gamma_n^0 \rangle$ for resonances with different spins J. In the other case, the results of approximation can be determined also by the possible spin dependence of the neutron strength functions.

Physically, from parameters of different variants of approximation of the total set of level density, obtained for 40 nuclei in Dubna, it is followed also to limit the maximal value k by magnitude $k = 4$. In this case the system of corresponding nonlinear equations will be badly stipulated and sometimes degenerated. Last remark concerns only «partial» cumulative sums with number k, sum S_{fit} of which is the approximation of experimental value $S_{\exp}$. And instead of determination of their unique function parameters value, in this case it is necessary and possibly to determine only limited region of A_k, b_k and σ_k variations, which corresponds to one and the same χ^2 minimum.

4. PRACTICAL APPROXIMATION OF THE DATA

Relative smallness of set of the experimental values of widths and exponential functional dependence of probability of their observation at different $g\Gamma_n^0$ very strongly complicate the process of search of approximating function S_{fit}, which provides the lowest value $\chi^2 = ((S_{\exp} - S_{\mathrm{fit}})/\sigma_{\mathrm{cum}})^2/M$. Therefore, it is worthwhile to realize this operation so that the algorithm for search of the minimum would admit stable approximation of $S_{\exp}$ at presence of two and more distributions weakly differing by parameters b and σ, sum of which is equal to S_{fit}. Practical degeneration of the realized process makes difficult (but does not exclude) the use of the Gauss method for solution of systems of nonlinear equations in form of existing library programs. But the cases of appearance (as the most probable value) of near-to-zero values σ and corresponding to them «steps» in cumulative sums exclude possibility to use this method, i.e., some part of neutron width sets contains, as the most probable, some quantity of nonrandom values.

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In this situation the most simple way for fit the parameters of the width distribution is to use the Monte Carlo method of solution of the systems of degenerated equations. Namely, combination of randomly choice of elements of correction vector of parameters for fitted function with maximum possible variation of their initial values. By the use of two and more sets of unknown parameters (2) for approximating curve, it is very worthwhile to account strong anticorrelation of the total value of cumulative sums for different k for acceleration of convergence of the length of correction vector to zero. The used (and decreasing with different speed) in this work their values for the beginning of random process were varied usually by 1 to 5 percents of initial values of b, σ and C. This provided achievement of local minimum of χ^2 after some tens of thousands of iterations. Obvious criterion of achievement of absolute minimum of χ^2 for such well-regulated function as cumulative sums — equality of value of approximating function to the value $0.5(S_i + S_{i+1})$ for its element number $i + 1$. It is effective at estimation of approximation precision for the main part of the experimental data, but may be noneffective for the maximal values X_i.

In practice, the unsolvable problem is setting of dispersion σ_{cum} of each point of cumulative sum for arbitrary X value for calculation of unshifted value χ^2. The regularity of the data set in cumulative sum sharply decreases fluctuations of form of the data analyzed here. By normalization of cumulative sum on the experimental number of resonances, σ_{cum} changes from zero to the some maximal value in region of magnitudes $X \approx 2$–10 (see. Fig. 1) and then — up to zero. Dispersion of each element of cumulative sum consists from the experimental error of neutron width and unknown value of its fluctuations. Naturally, it must be one and the same in all variants of approximation for $1 \leqslant k \leqslant 4$.

Methodically, the problem has the simple solution: there are generated the large (minimum 10^6 random numbers) sets of cumulative sums of squares of normally distributed random values with given b and σ for each partial function. Then, by means of usual relations of mathematical statistics, from these sums the dispersion of cumulative sum $\sigma_{\text{cum}} = f(X)$ in any point X for each value of variable is determined. But, really this procedure requires unacceptable computer time. Therefore, possible change in value χ^2 for different expected densities of neutron resonances for realistic magnitudes of dispersions of cumulative sums was performed only for ^{232}Th, ^{233,235}U and ^{239}Pu and only in variants $b = 0$ and $\sigma = 1$. The main results of analysis given here keep also in the realized case $\sigma_{\text{cum}} = 1$.

Besides, it must be taken into account that the practical search of parameters b and σ, which provide minimum of χ^2 in the used algorithm of analysis, cannot guarantee the best approximation of the experimental data in arbitrary variant of calculation. Only variation of initial values and ways of random processes many times repeated provides the sufficient for practical applications reliability and precision of determination of the lowest possible value χ^2. The results of
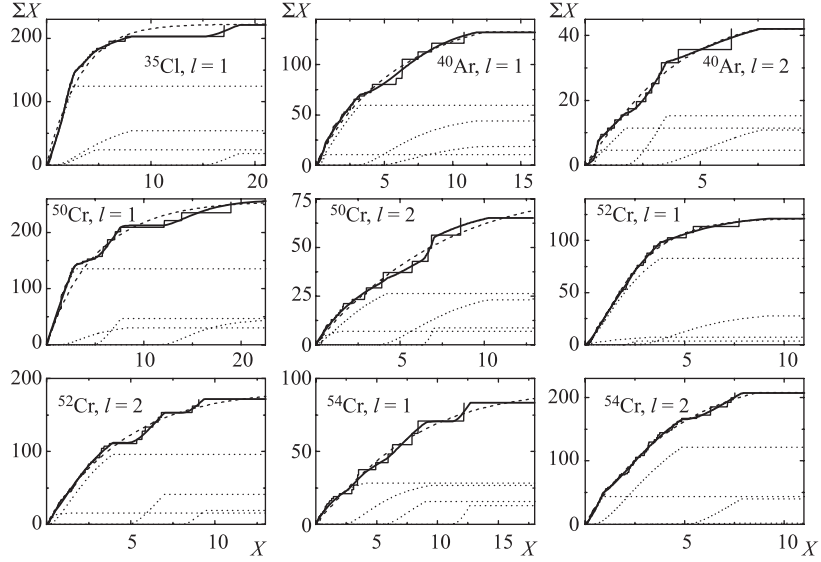
Fig. 2. The results of approximation of neutron distribution widths for ^{35}Cl, ^{40}Ar and ^{50,52,54}Cr. Histogram — the experiment, dashed line — approximation for $k = 1$, thick line — $k = 4$, dotted lines — the variant of decomposition of experimental distribution over partial functions
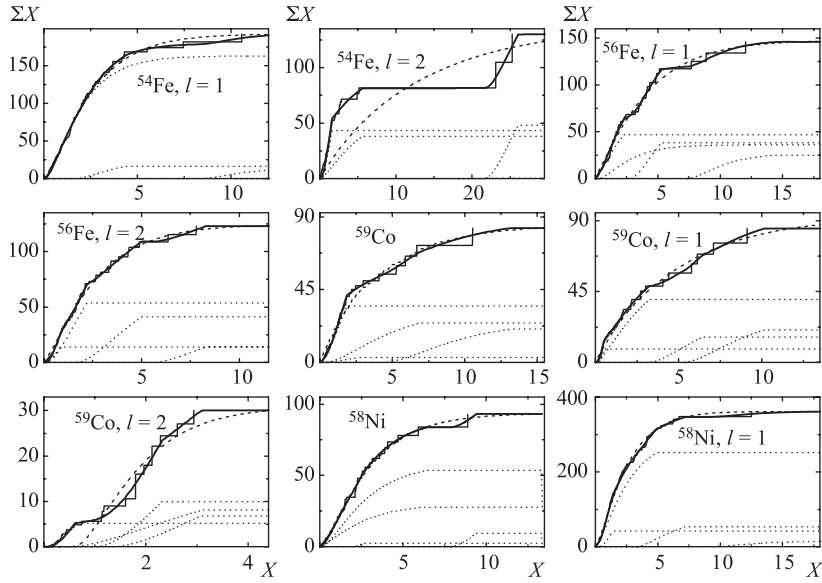

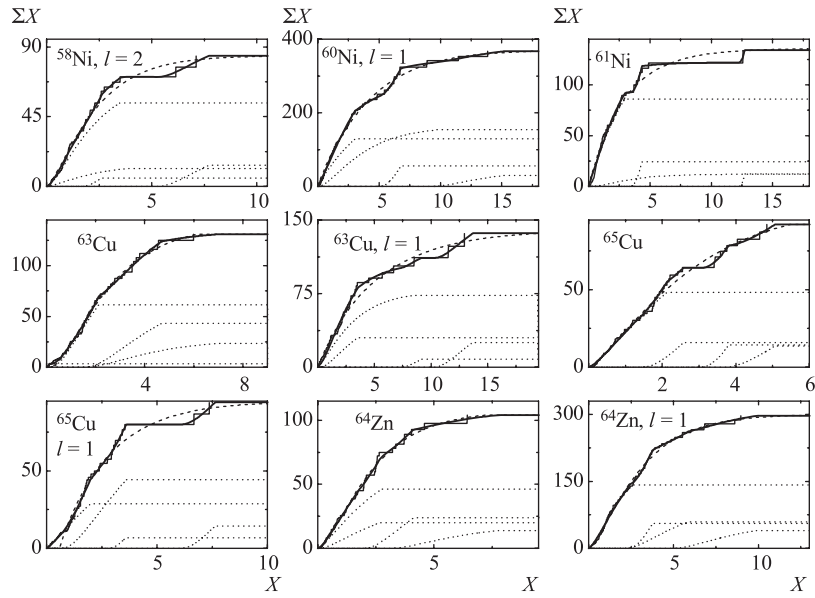Fig. 3. The same as in Fig. 2, for ^{54,56}Fe, ^{59}Co and ^{58}Ni

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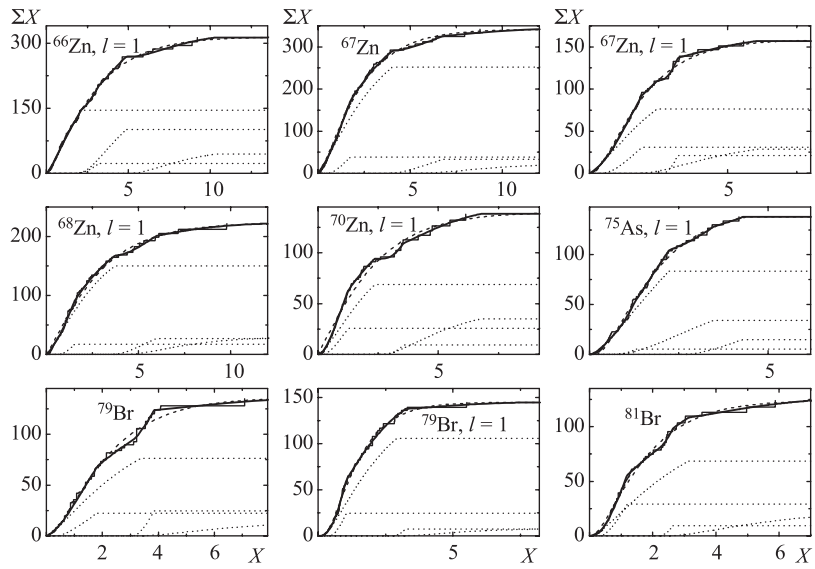Fig. 4. The same as in Fig. 2, for ^{58,60,61}Ni, ^{63,65}Cu and ^{64}Zn

Fig. 5. The same as in Fig. 2, for ^{66,67,68,70}Zn, ^{75}As and ^{79,81}Br

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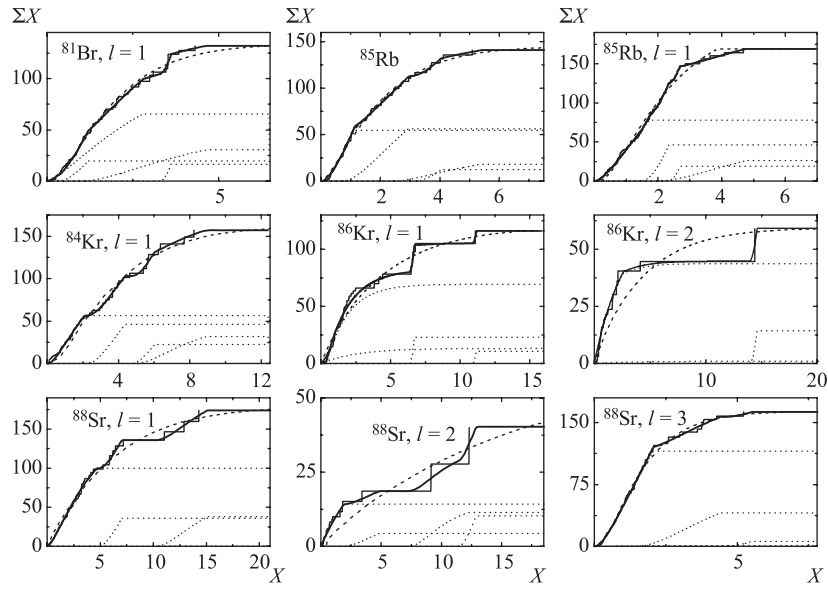
Fig. 6. The same as in Fig. 2, for ^{81}Br, ^{85}Rb, ^{84,86}Kr and ^{88}Sr
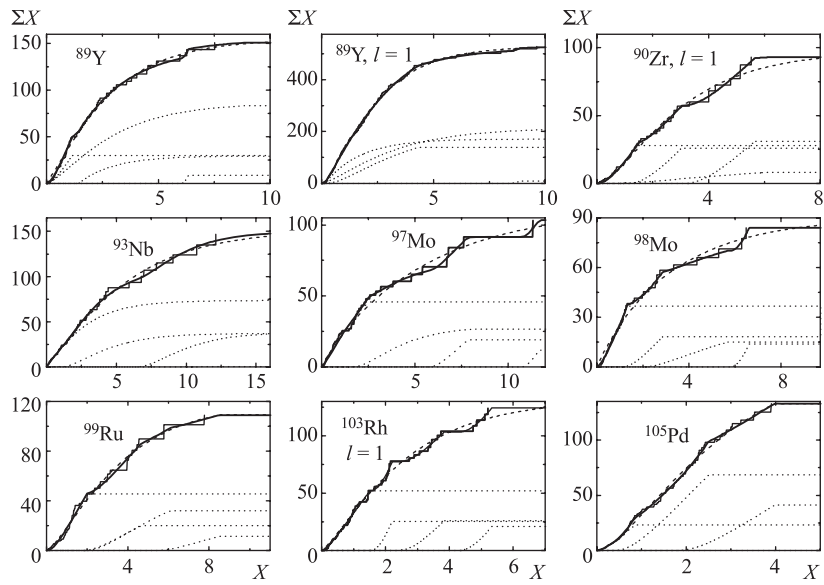
Fig. 7. The same as in Fig. 2, for ^{89}Y, ^{90}Zr, ^{93}Nb, ^{97,98}Mo, ^{99}Ru, ^{103}Rh and ^{105}Pd
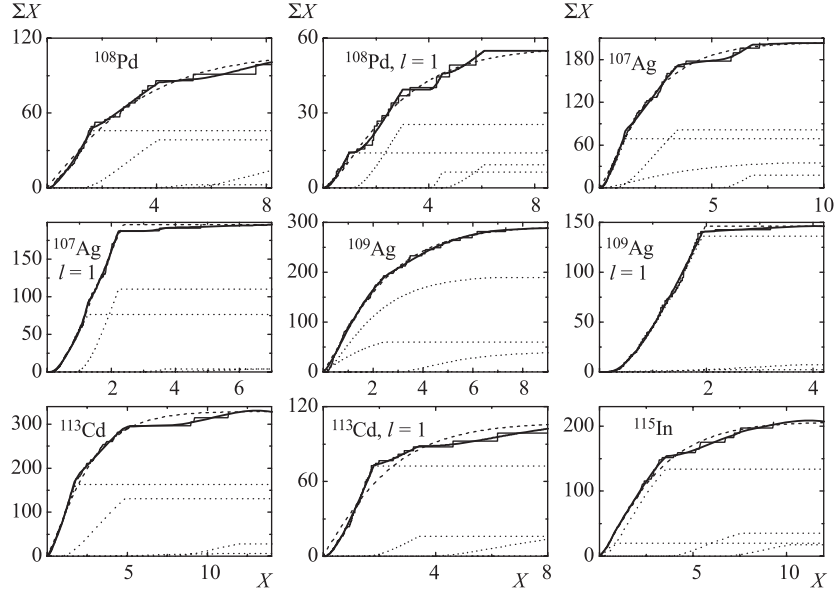
Fig. 8. The same as in Fig. 2, for ^{108}Pd, ^{107,109}Ag, ^{113}Cd and ^{115}In
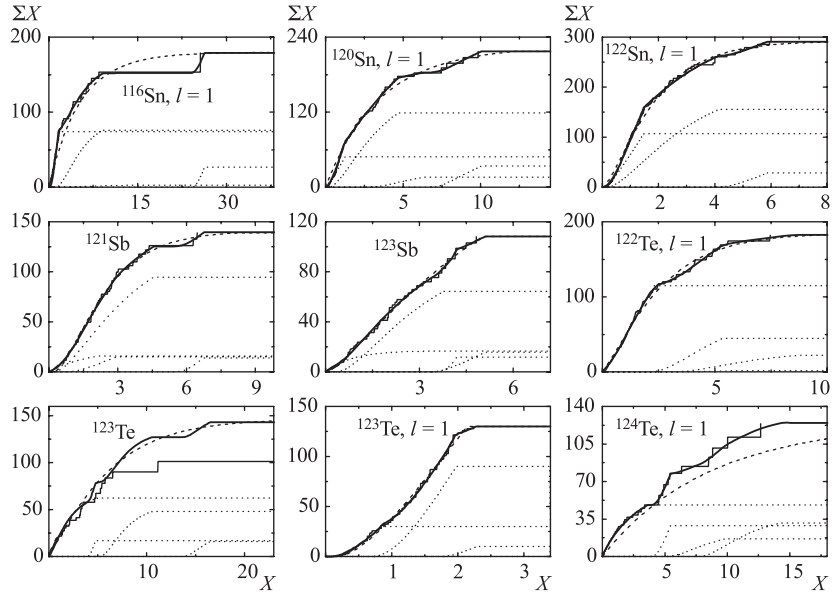
Fig. 9. The same as in Fig. 2, for ^{116,120,122}Sn, ^{121,123}Sb and ^{122,123,124}Te

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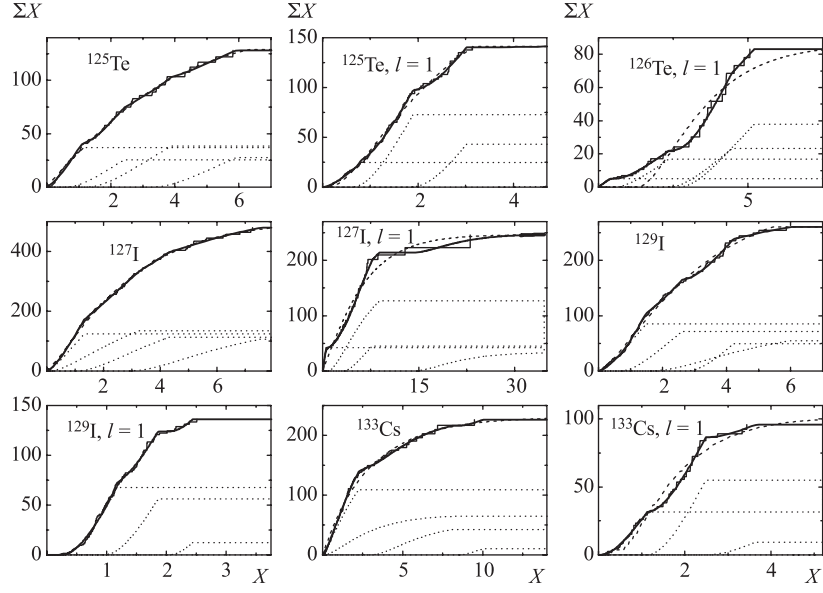
Fig. 10. The same as in Fig. 2, for ^{125,126}Te, ^{127,129}I and ^{133}Cs
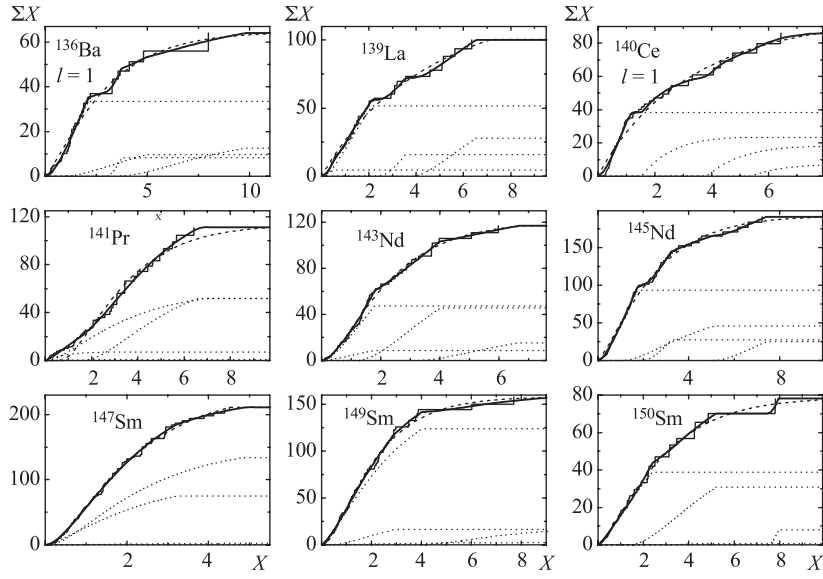
Fig. 11. The same as in Fig. 2, for ^{136}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{143,145}Nd and ^{147,149,150}Sm
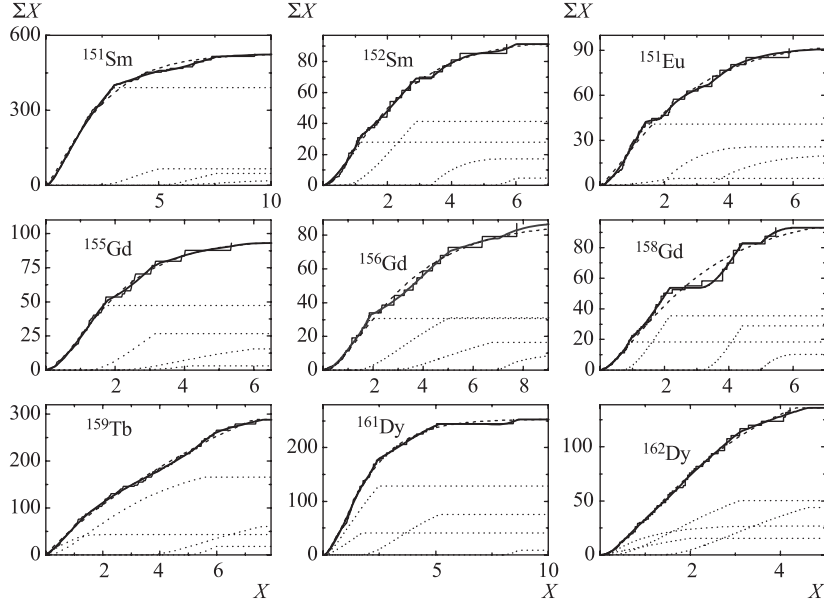
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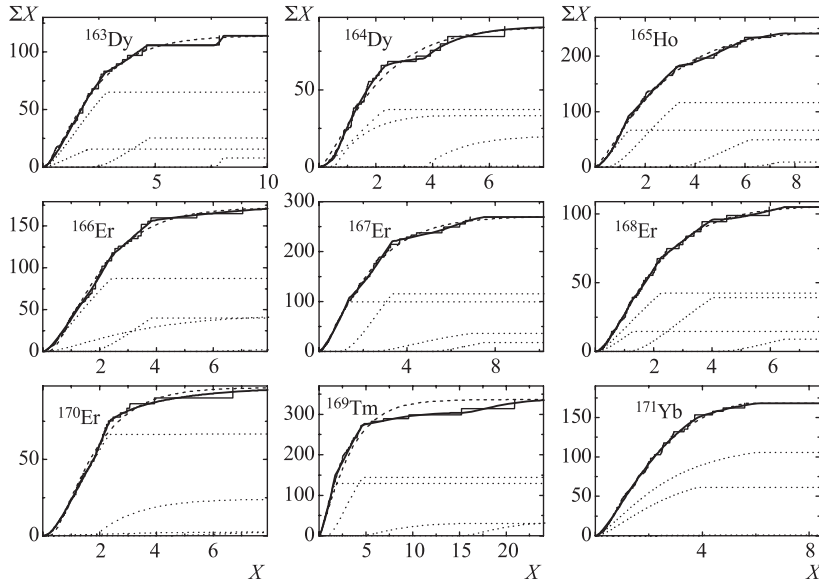Fig. 12. The same as in Fig. 2, for ^{151,152}Sm, ^{151}Eu, ^{155,156,158}Gd, ^{159}Tb and ^{161,162}Dy

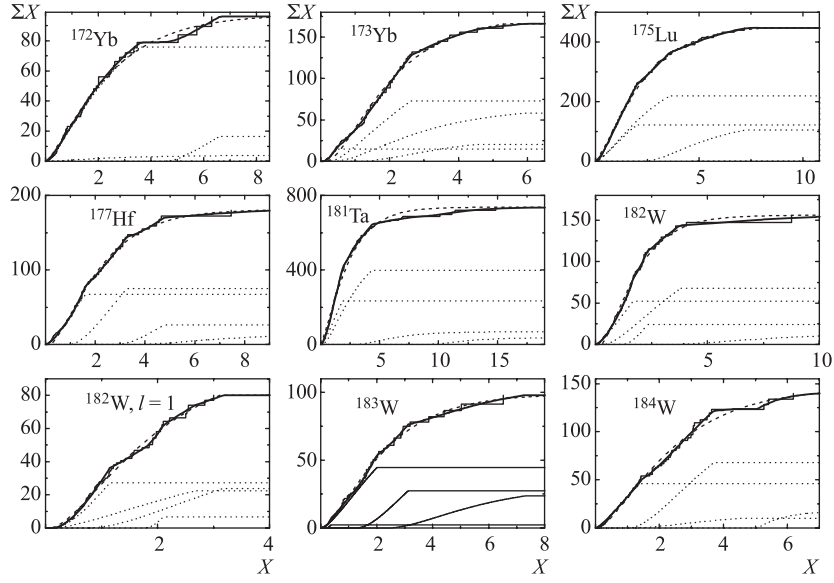Fig. 13. The same as in Fig. 2, for ^{163,164}Dy, ^{165}Ho, ^{166,167,168,170}Er, ^{169}Tm and ^{171}Yb

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Fig. 14. The same as in Fig. 2, for ^{172,173}Yb, ^{175}Lu, ^{177}Hf, ^{181}Ta and ^{182,183,184}W
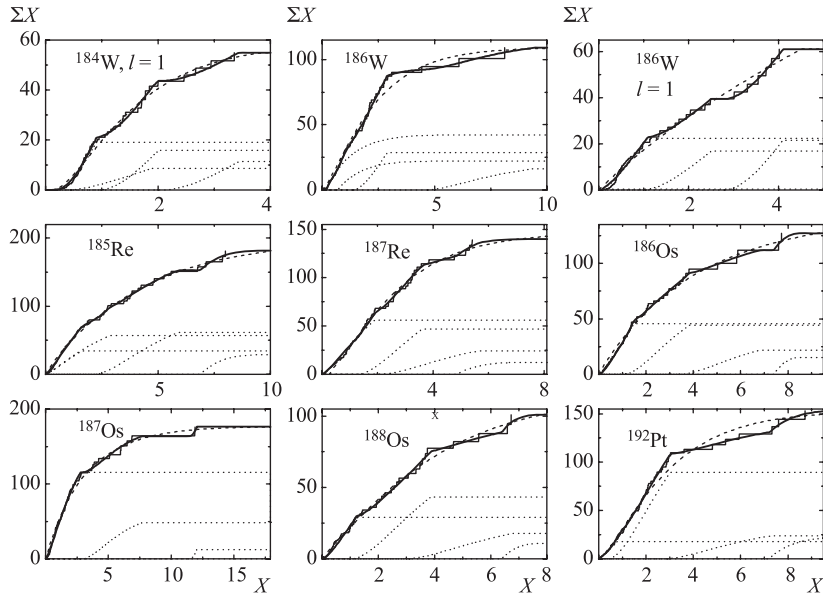

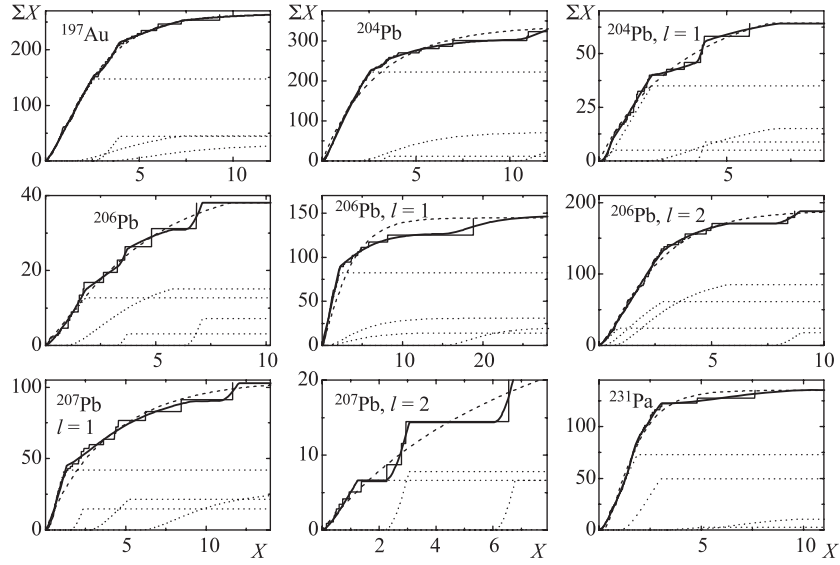Fig. 15. The same as in Fig. 12, for ^{184,186}W, ^{185,187}Re, ^{186,187,188}Os and ^{192}Pt

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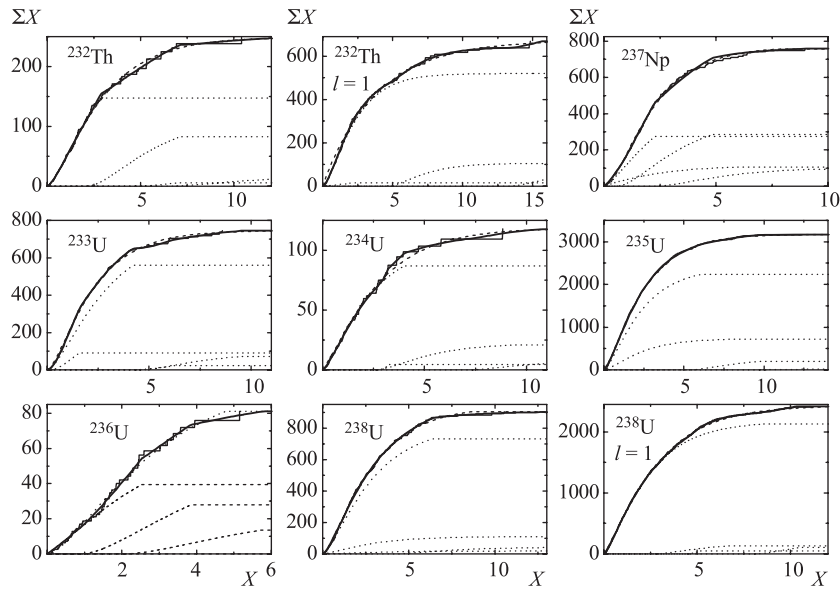Fig. 16. The same as in Fig. 2, for ^{197}Au, ^{204,206,207}Pb and ^{231}Pa

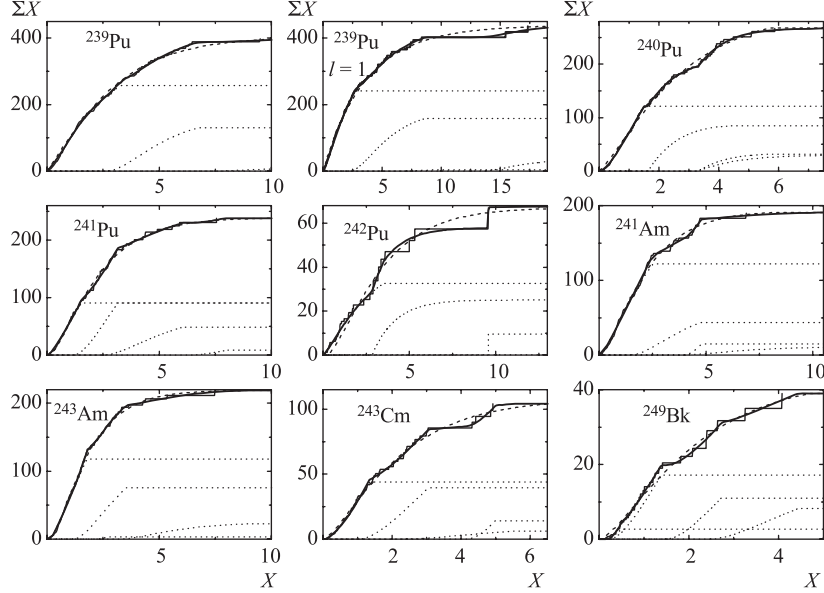Fig. 17. The same as in Fig. 2, for ^{232}Th, ^{237}Np and ^{233,234,235,236,238}U

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Fig. 18. The same as in Fig. 2, for ^{239,240,241,242}Pu, ^{241,243}Am, ^{243}Cm and ^{249}Bk

approximation of the experimental cumulative sums, as is seen from the comparison of the data presented in Figs. 2–18 for each nucleus, depend on model notions and, first of all, on concrete value k. The analysis was limited by nuclei in which the set of s-resonances had, with some exceptions, the value $N_r \approx 90$ and more.

5. ON INFLUENCE OF EXPERIMENTAL SYSTEMATICAL ERRORS ON THE APPROXIMATION PARAMETERS

An attempt of objective estimation of the portion of resonances not observed in experiment with accounting of possible discrepancy of their real distribution to the Porter–Thomas distribution was realized in [16]. There was obtained, proceeding from independence of χ^2 on varied portion of omitted resonances, that this criterion of the maximum likelihood method can have the lowest and equal value in the interval corresponding to the portion of omitted resonances from zero to $\approx 90\%$. This result is truthful, at least, for actinides, i.e., the value of the most serious systematical error for density of neutron resonances (and, correspondingly, mean value of widths) cannot be objectively determined at present from the model approximations of the observed data and following extrapolation of the approximated distributions to their zero value.

Some notion on the value of the next by significance uncertainty of analysis can be obtained from the data [14] for ^{99}Tc. According to this compilation, at
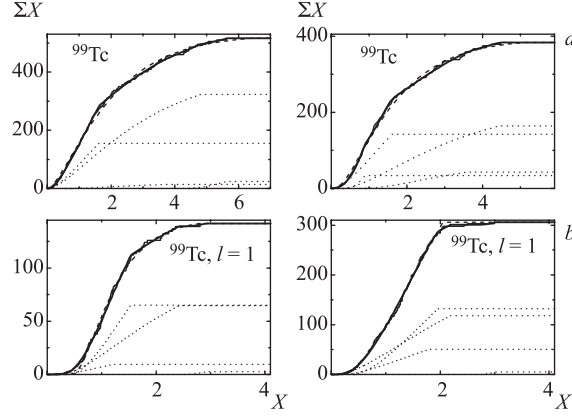
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Fig. 19. Approximation of two sets of neutron widths of s- (a) and p-resonances (b) ^{99}Tc

present there are two Γ_n^0 value sets [17, 18], which contain: a) 658 and b) 689 s- and p-resonances. Accordingly, the number of s-resonances for them is equal to 516 and 383. The results of approximation of these four sets are compared in Fig. 19. It is seen that the errors of determination of orbital momentum of resonance and/or their omission do not change principally the conclusion on possible difference of structure of neutron resonances and rather weakly change the form of cumulative sum for the case $l = 0$. Twofold change of number of p-resonances noticeably distorts the form of cumulative sum in the region of the largest values of X. The sum of the χ^2 values for $l = 0$ and $l = 1$ in variant $k = 1$ for the set (a) is 1.3 times more than for (b); for $k = 4$ they practically coincide, i.e., examined systematical errors in determination of l and Γ_n^0 values bring distortions in the picture of the nuclear properties studied here, which are acceptable for reliability of conclusions obtained below.

6. PROBLEMS OF INTERPRETATION OF THE RESULTS OF ANALYSIS

The key problems of analysis of the form of neutron width distributions for the experimental data, as can be seen from the data presented in Figs. 2–18, are the determination of the number of possible types of their wave functions with maximally possible reliability and determination of $\langle g\Gamma_n^0 \rangle$ with the highest precision. The seriously problem here is the really unknown and not removable fluctuations of cumulative sums in function of parameter X. It is necessary to extract new information on properties of neutron resonances at presence of different nature significant deviations of the experimental data from their real value and not removable ambiguity of the used algorithm of analysis.

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Parameters of approximation (Figs. 2–18) contain superposition of useful and wrong information and depend on:

a) portion of resonances with the widths which are less than the registration threshold,

b) structure of resonances under consideration,

c) systematical error of determination of mean value $\langle g\Gamma_n^0 \rangle$,

d) systematical errors of determination of parameters of the each existed resonance and

e) magnitude of dispersion of their pure «nuclear» fluctuations.

This mixture can be decomposed onto components only with using of the additional experimental data. *The existing and potentially possible nuclear models like [8] cannot provide acceptable for the present solution of such a problem.* The ground here can be only a hypothesis of the Gauss form of distribution of neutron amplitudes. But the performed analysis also is not more or less strong proof of the last assumption — the lack of any facts which contradict any hypothesis cannot be its proof.

The attempt [16] of maximally correct approximation of the distribution parameters of the experimentally observed resonances for the following extrapolation of the distribution to $\Gamma_n^0 = 0$ demonstrated that the accepted in [8] assumption about small portion of omitted resonances is not grounded. There is possible situation with nonzero probability that the number of resonances below the threshold of experiment can many times exceed the number of the observed resonances: analysis [16] showed that the maximally probable density of resonances can be 5–10 times larger than the accepted values. This conclusion was obtained in the framework of the only hypothesis of the Gaussian form of the distribution of neutron widths and does not require fixation of values k, b and σ.

Besides, this analysis allows us to estimate of the lowest number of resonances which permits one to determine realistically the presence/absence of noticeable variations of structure of the wave functions of resonances. Any distribution from assumed superposition must contain much more resonances than the number of parameters (which equals three for every k). Both the proof of truth or mistakenness of possible very considerable error of determination of D_λ^{-1}, and the fact of existence of groups of resonances with different structure of their wave functions require corresponding decrease of the observation threshold of weak resonances and precise enough determination of their parameters as compared with the level of the experiment informativeness achieved by now.

In spite of this, the performed analysis of 157 sets of resonances allows one to make conclusion on high probability that in experiment there is really observed superposition of levels whose wave functions concern two or more of their types. Such a result was obtained owing to revealed in [16] zero or very weak dependence of parameter χ^2 (i.e., form of general approximating curve) for different number of omitted resonances in wide enough interval of their values.

In Fig. 20 is shown the histogram of values of ratio R of approximation parameters $\chi^2(k = 4)$ to $\chi^2(k = 1)$. From this distribution follows that the analyzed set of the data has value $\langle R \rangle = 0.33$ (19). This permits one to make the conclusion on high probability of existence of resonances with different structures for nuclei of different mass and orbital momentums $0 \leqslant l \leqslant 3$. Realistic estimation of reliability of this conclusion requires, most probably, analysis of the factors of distortions of the experimental data (b)–(d).
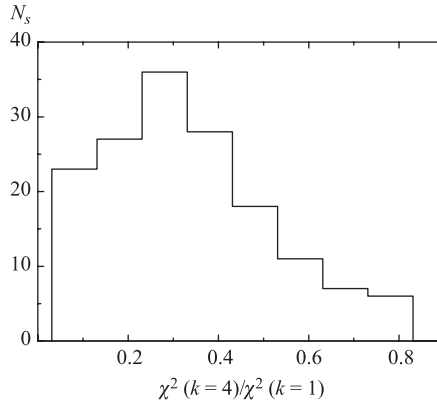

Fig. 20. Frequency distribution of the sets of resonances for different values $\chi^2(k = 4)/\chi^2(k = 1)$ ratio

7. CONCLUSION

1. The results of the performed analysis do not contradict the notion of normal distribution of neutron amplitudes with the changing from nucleus to nucleus parameters b and σ, at least, for the main part of studied resonances. In this case, the mean value of amplitudes and their dispersion can depend on structure of wave function of levels excited by resonance neutrons and, in principle, on excitation energy of a nucleus.

2. A totality of the data on parameters σ and b and dynamics of their change with change of mass of a nucleus fully permits possibility of values $\sigma = 1$ and $b = 0$ in some energy intervals of neutron resonances. The width of corresponding interval and its location in scale of excitation energy of given nucleus cannot be, most probably, one and the same for different nuclei.

3. Precision of the approximated by model [8] neutron resonance widths distribution (in the generally accepted notions or with the varied values of parameters b and σ) is enough for any practical applications.

4. It is possible that for determination of the reliable properties of a nucleus it is *necessary* to make the estimate of required precision of parameters of the width distribution for concrete situation (experiment) and to use the best data for parameters of the available sets of widths.

5. The presence of several neutron amplitudes with different mean values and dispersions is alternative to [8] notion on distribution $g\Gamma_n^0$ practically for all nuclei studied here. It is worthwhile to take into account this possibility in

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analysis of distributions of widths by using of the new experimental data for maximal reliability of the obtained conclusions.

6. The increase of precision of determination of any nuclear physics parameters requires, most probably, to take into account the degree of influence of structure of the excited nuclear levels on their density and emission probability of the nuclear reaction products in wide excitation energy diapason. In particular, in the region of neutron resonances.

7. The unique conclusion on this statement requires one to perform the experiment, in which the observables depend on structure of the wave function of resonances. For example, there can be the experiment, where the ratio of intensities of the primary gamma transitions is measured to the groups of levels with different number of the broken Cooper pairs. This conclusion was made in [19] on the basis of approximation of the radiative strength functions of the primary gamma transitions below and close to the neutron binding energy diapason.

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