MODIFIED MODEL OF NEUTRON RESONANCES WIDTH DISTRIBUTION. RESULTS OF TOTAL GAMMA-WIDTHS APPROXIMATION

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Abstract

Functional dependences of probability to observe given Γ_n^0 value and algorithms for determination of the most probable magnitudes of the modified model resonance parameters distribution were used for analysis of the experimental data on the total radiative widths of neutron resonances. As in the case of neutron widths, for precise description of the Γ_γ distributions requires a superposition of 3 and more probabilities distributions for squares of the random normally distributed values with the non-zero average and non-unit dispersion .

This result confirms the preliminary conclusion obtained earlier at analysis of Γ_n^0 on presence in all 56 tested sets of resonances several groups noticeably differing by the structure of their wave functions from each other.

1. Introduction

In 1936 N. Bohr suggested the hypothesis [1] on extremely complicated structure of high-lying levels of compound-nucleus. After this, respectively, the properties of neutron resonances are described in frameworks of statistical approach. But, the experience of the science shows that the real picture of the phenomenon under study is usually much more complicated than any hypotheses and notions on it. Most probably, the hypothesis [1] is not a exception , as well.

Estimation of its precision can be performed on the basis of the modern experimental data and theoretical developments of existing nuclear models. So, the realized in FLNP JINR idea of obtaining the direct and reliable experimental information on such nuclear parameters as the level density and radiative strength functions [2], and interpretation of the obtained data [3,4] shows that structure of a nucleus below the neutron binding energy B_n undergoes cyclic change with a step of about $2\Delta_n$. By this, the correlation function of the Cooper pair of nucleons in heated nucleus below B_n insignificantly differs from the analogous value Δ_0 for cold nucleus (although, most probably, decreases at increase of excitation energy). A degree of fragmentation of nuclear structures like n-quasi-particles $\otimes$ m-phonons for these states in region B_n according to theoretical analysis by L.A. Malov and V.G. Soloviev [5], cannot be the same. Id est., one can expect that in the wave functions of neutron resonances at change of their energy can appear available for observation changes.

It is absolutely necessary for their revealing to execute two conditions:

(a) to use the algorithm of analysis for any experimental data with the lowest possible quantity of model notions and
(b) to perform quantitative comparison of few variants of approximation of the tested resonance parameter distributions, for example. The more essential is the second condition – just it determines the vector of required changes in the existing notions of nuclear properties in the studied region of excitation. Unfortunately, the variants of analysis of neutron

resonances parameters performed by now did not take into account these circumstances. But, both conditions were to a full degree realized in [6].

2. Conditions of Γ_γ analysis

The intensity of the primary gamma-transitions following decay of neutron resonance depends on the same components of their wave functions. Therefore, in the distributions of partial radiative widths must appear the peculiarities which are analogous to those appearing in distributions of reduced neutron widths. First of all, there is the discrepancy [7] with the Porter-Thomas distribution [8] in any form. The indirect answer on this question can be obtained from the analysis of the distributions of cumulative sums of the relative Γ_γ values in maximally wide interval of nuclear mass.

For analysis of form of distribution of the random Γ_γ values was used the same algorithm and programs which were prepared for analysis of the reduced neutron widths distribution. The independent variable of analysis $X_\gamma = \Gamma_\gamma / <\Gamma_\gamma>$ corresponds to the ratio of total radiative width of given resonance to the mean experimental value of the tested set. Naturally, all events with X=1 (used by determination of Γ_n^0 for some resonances) were excluded from analysis. This selection is really nonessential because corresponding portion of cumulative sum can be with good precision approximated by value σ<0.01. The analysis was performed by analogy with the analysis of reduced neutron widths for two hypotheses. The first – the distribution of the total radiative widths of resonances corresponds to distribution of squares of the normally distributed random values with one and the same dispersion and mean value (k=1). The second one's used the same distributions with several set ($k\leq 4$) of different parameters. Practical basis for this variant is obvious asymmetry of cumulative sums of distributions of the experimental X_γ values for many nuclei. Unfortunately, the use of relative values of radiative widths inevitably shifts obtained values parameters b and σ.

3. **Results of analysis and their interpretation**

In Fig. 1 are presented model distributions of squares of the random $X=((\xi+b)/\sigma)^2$ values for parameters b=0.5, 1, 2; σ =0.01, 0.03, 0.10 for ξ – standard normally distributed random variable. Cumulative sums were normalized, naturally, to the average $<X>$. In Fig. 2 – approximation of the experimental distributions of Γ_γ for ^{151}Eu and ^{235}U. These target-nuclei essentially differ only by parity of proton number. But difference of he mean spacing D_0 between resonances, neutron binding energy B_n and spin of target I is not changed of principle. In table are presented quantitative results of the relative Γ_γ values cumulative sums distributions approximation for some differing by their parameters nuclei with maximal number of their existing experimental values. Also, there is any nonprinciple difference for part of table data, but the part of cumulative sum of two most essential functions of superposition conserves with high precision. There is the sufficient argument in favour of conclusion that the experimental data on neutron resonances parameters correspond to several sets of noticeably differing by their wave functions structure.

In figures 3-8 are presented the results of approximation of the radiative width distributions for 54 sets of the data, although analysis was performed for some larger number of the sets. Practical selection was done by condition that the sets of s-resonances in figures in most cases correspond to not less than 45-50 Γ_γ values. Id est., number of points of the approximating curve for superposition from k=4 approximated "partial" functions exceeds maximal number of parameters of approximation by a factor ≈4 and more. The ratios $\chi^2(k=4)/\chi^2(k=1)$ for all 56 data sets are shown in Fig. 9.

The ratio of the criteria χ^2 of the best fit for Γ_γ has random nature as for analogous distribution of neutron widths. However, considerable decrease of its value for the case of Γ_γ does not allow one to connect the observed picture only with effect of random fluctuations.

Table. The approximated main parameters of nuclei with the largest values of number N_γ of experimentally determined values Γ_γ. $R=\chi^2(k=4)/\chi^2(k=1)$ – the ratio of the best fit parameters of both variants of analysis; S – the portion of two functions with maximal contribution in cumulative sum; σ and b – dispersion and their most probable mean value.

Nucleus	N_γ	R	$\chi^2(k=4)/N_\gamma$	S_1	σ_1	b_1	S_2	σ_2	b_2
^{60}Ni, l=1	173	0.027	0.015	0.45	0.08	0.85	0.34	0.07	0.49
^{151}Eu	185	0.073	0.044	0.49	0.008	1.	0.36	0.02	0.95
^{151}Sm	525	0.033	0.012	0.44	0.06	0.68	0.38	0.06	0.87
^{235}U	2297	0.068	0.042	0.43	0.006	0.97	0.31	0.05	0.76

It follows from both the data of this figure and form of dependence of cumulative sums of the X_γ values for different nuclei that the Γ_γ values with high probability depend on structure of the wave function of a neutron resonance, and the set of the experimental values of widths can be divided onto several groups of resonances noticeably differing by structure of wave function of corresponding high-excited nuclear level.

Unfortunately, this conclusion can be mistaken if systematical errors of Γ_γ are caused by the strong enough unknown and determinate by experiment condition dependence on resonance energy, its neutron widths and so on, For example, by the larger, as compared with the mean, probability of resonances omission not only with small Γ_n^0, but and with small Γ_γ. Or – in the case if in the experiment was revealed only very small part (for instance, from several to 10-20%) of really existing levels of compound nucleus with fixes spin above B_n. Such possibility follows directly from the attempt [9] approximation of actinides reduced neutron widths experimental distributions and following its extrapolation to the $\Gamma_n^0=0$ value in frameworks of the modified model of neutron widths distribution. (The Porter-Thomas distribution [8] is its particular case).

4. **Conclusion**

Practically model-free analysis of the neutron resonances total radiative widths distributions confirms the determined specific of the existing experimental data:
(a) the absence of uniformity of the Γ_γ distributions for different nuclei,
(b) significantly better correspondence of the experimental data to the hypothesis of superposition in those data the of combination of resonances with noticeably differing structure, than to the assumption on practical (in the frameworks of modern status of science) constancy of their structure.

Probable presence of groups of resonances with the different mean values $<\Gamma_\gamma>$ quite corresponds to the conclusion [10] on difference of the radiative strength functions of the primary transitions which exceed the limits of the expected random fluctuations. This conclusion well explains and difference of the strength functions, measured in the thermal point, with the data for ^{60}Ni obtained [11] from re-analysis of the intensities of gamma-cascades following proton capture in several tens of ^{59}Co proton resonances [12].

Final conclusion concerning this matter can be obtained after observation corresponding differences in the spectra of the primary transitions in a number of neutron resonances of the same nucleus. Modern state of nucleus quasi-particle-phonon model development does not exclude [13] possibility of qualitative observation of such dependence.

References

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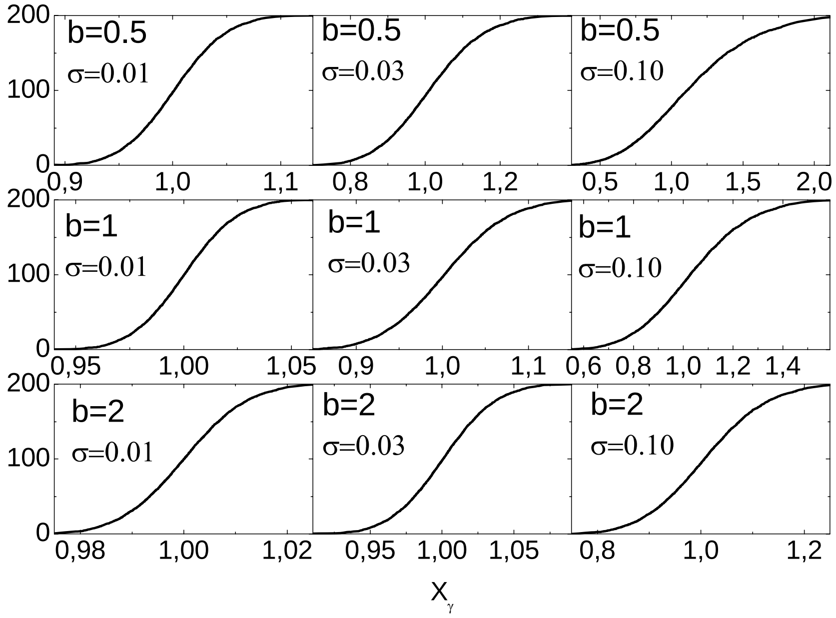

Fig 1. The expected distribution of cumulative sums of relative values Γ_γ of the total radiative widths of resonances. The dispersion σ and mean value b are also given in figure.

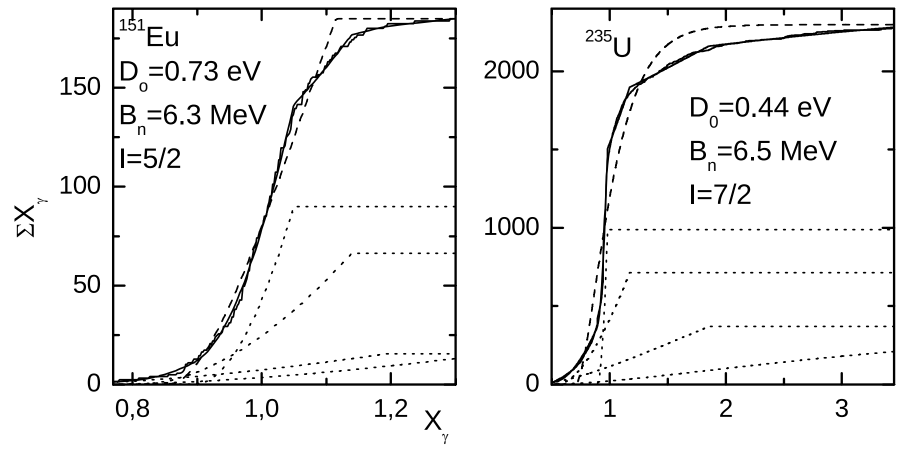

Fig. 2. The result of Γ_γ distribution approximation for ^{151}Eu and ^{235}U. Histogram – experiment, dashed line - k =1, solid - k =4, dotted lines – variant of decomposition of the last into four "partial" functions.

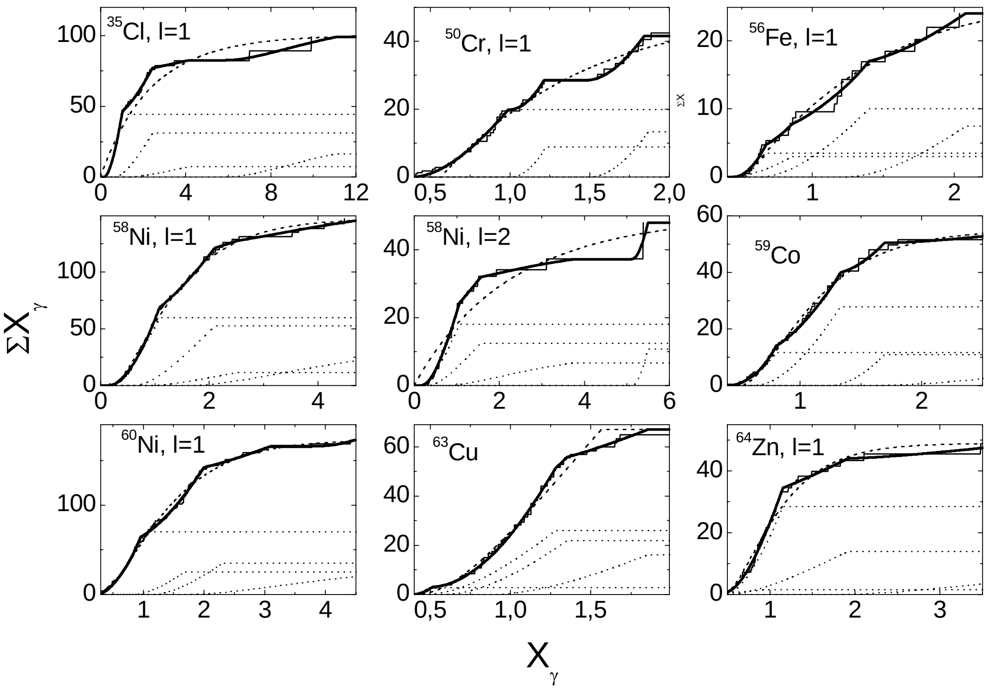

Fig. 3.The same, as in Fig. 2, for ^{35}Cl, ^{50}Cr, ^{56}Fe, ^{58,60}Ni, ^{59}Co, ^{63}Cu and ^{64}Zn.

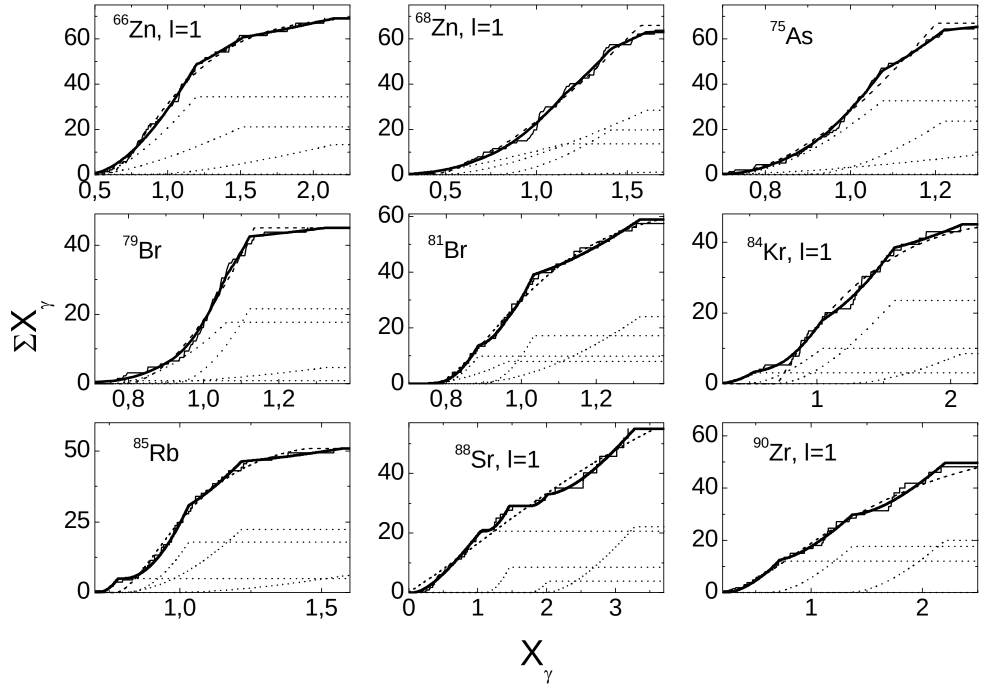

Fig. 4. The same, as in Fig. 2, for ^{66,68}Zn, ^{75}As, ^{79,81}Br, ^{84}Kr, ^{85}Rb, ^{88}Sr and ^{90}Zr.

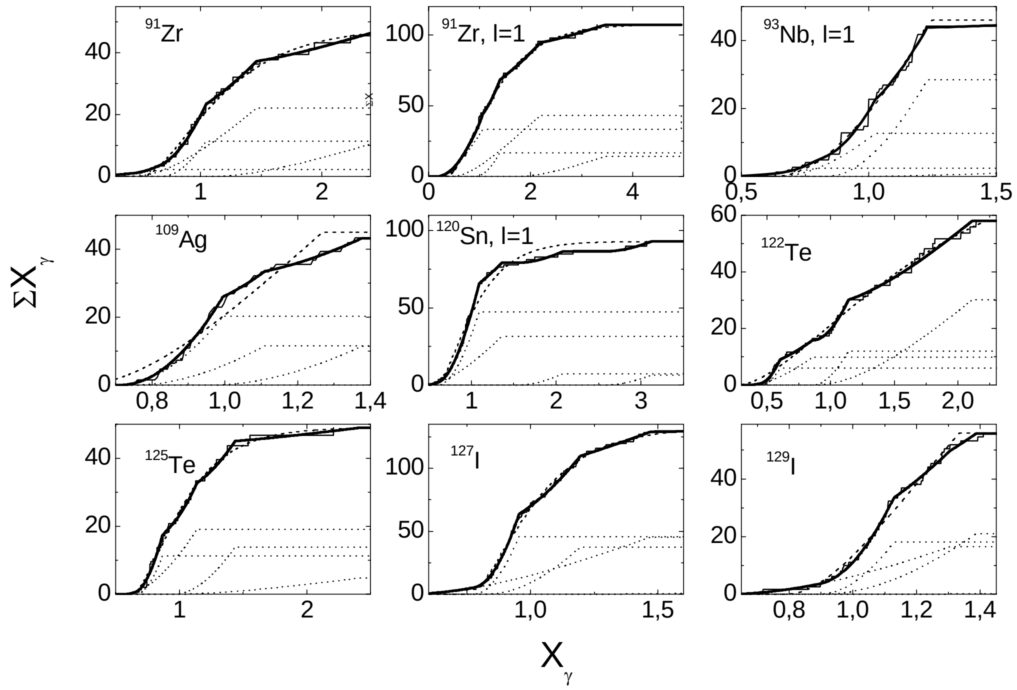

Fig. 5. The same, as in Fig, 2, for ^{91}Zr, ^{93}Nb, ^{109}Ag, ^{120}Sn, ^{122,125}Te and ^{127,129}I.

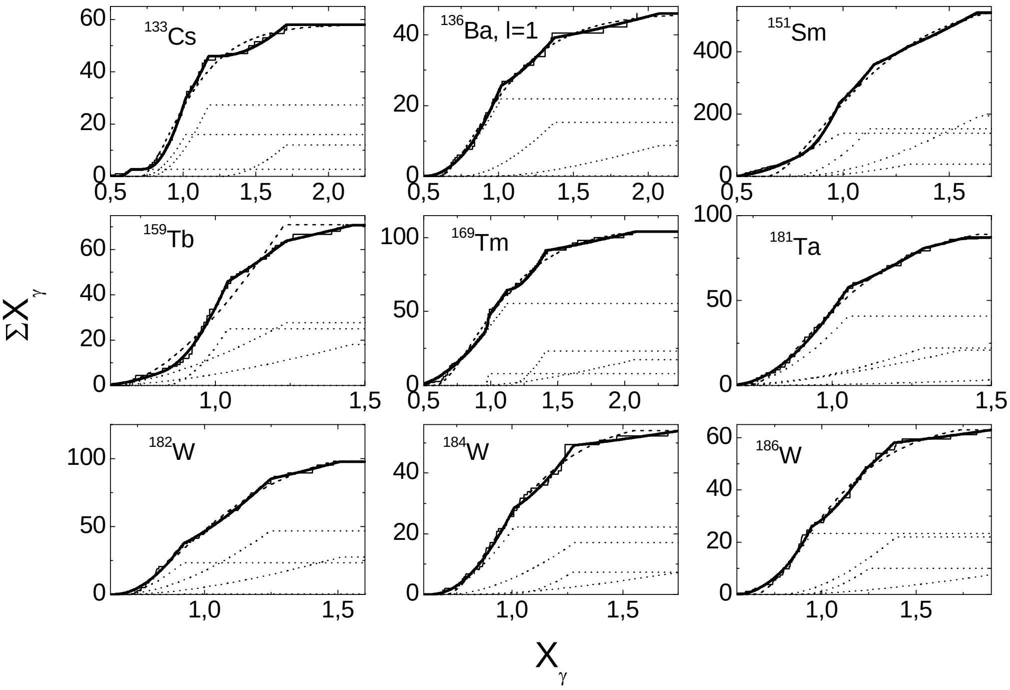

Fig. 6. The same, as in Fig. 2, for ^{133}Cs, ^{136}Ba, ^{151}Sm, ^{159}Tb, ^{169}Tm, ^{181}Ta and ^{182,184,186}W.

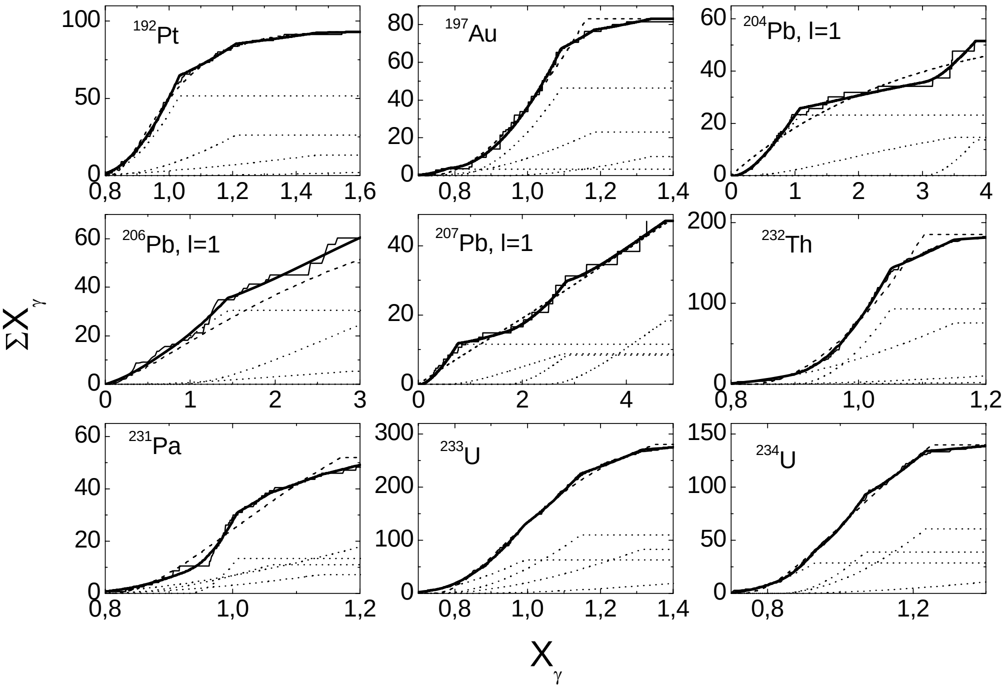

Fig. 7. The same, as in Fig. 2, for ^{192}Pt, ^{197}Au, ^{204,206,207}Pb, ^{232}Th, ^{231}Pa and ^{233,234}U.

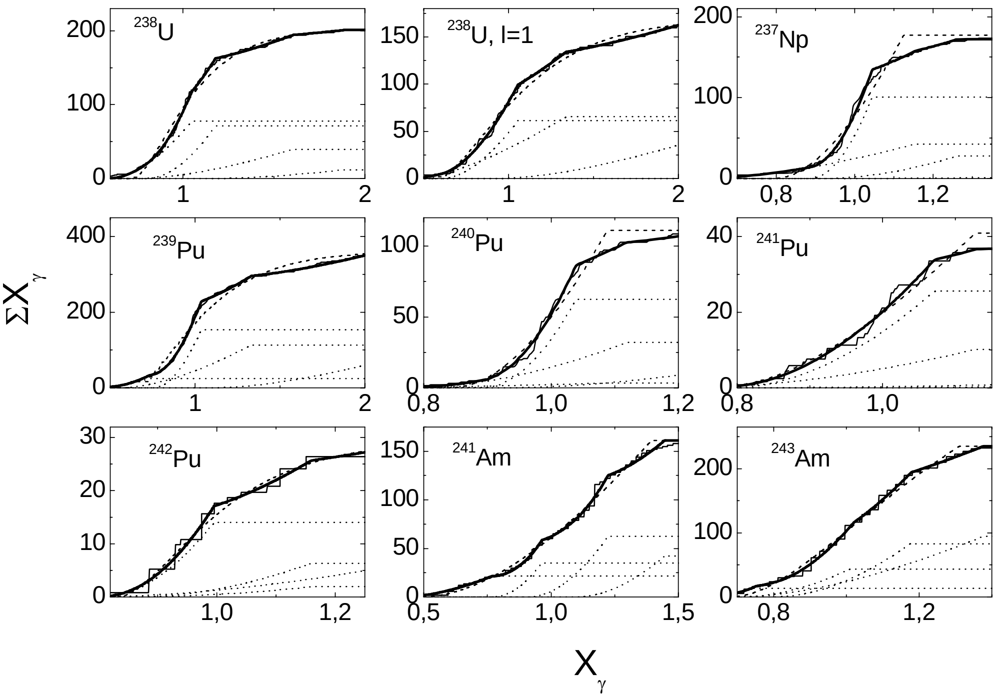

Fig. 8. The same, as in Fig. 2, for ^{238}U, ^{237}Np, ^{239,240,241,242}Pu and ^{241,243}Am.

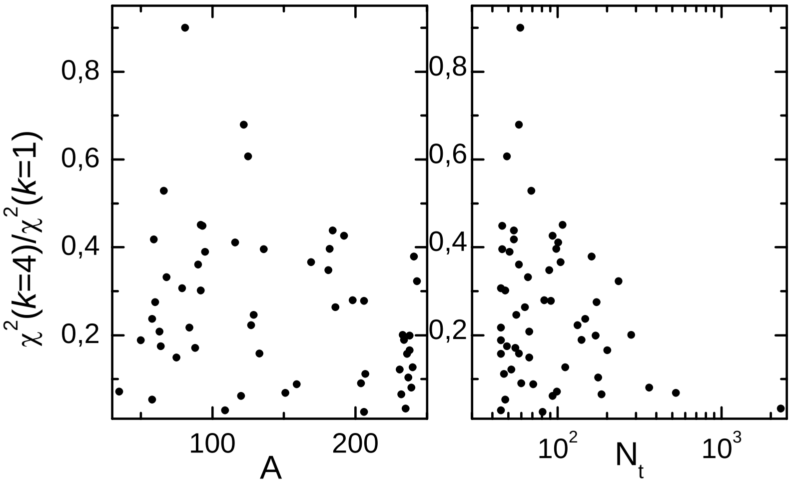

Fig. 9. The ratios of criteria of quality of best fit for two variants of analysis in function of mass A of a nucleus or on number N_t of resonances in the set. The mean value over 56 sets equals 0.26(17).