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EVALUATION OF AVERAGE NEUTRON RESONANCE PARAMETERS OF ACTINIDES WITH THE ACCOUNT OF EXPERIMENTAL RESOLUTION AND DISCRIMINATION THRESHOLD

Final Report of Research Contract 9503/RB

Yu.V. Porodzinskij, E.Sh. Sukhovitskij, V.M. Maslov

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Abstract

Average neutron resonance parameters are used for adjusting of input data for optical and statistical model calculations. Unfortunately, the current state of existing average resonance parameter libraries does not satisfy the accuracy requested for evaluation of nuclear reaction data. Due to the drawbacks of the methods used, discrepancies greater than quoted errors occur between average resonance parameter values in Beijing, Bologna, Brookhaven and Obninsk libraries. In the present work, we developed a sophisticated and physically transparent method for determination of average neutron resonance parameters from experimental data sets. The main idea of it is that experimentally missed distances do not disappear, but are added to the neighbours. New evaluation of average resonance parameters (^{229}Th - ^{252}Cf) was performed, accounting for the missing levels caused by poor experimental energy resolution and discrimination threshold. Obtained values of average level spacings produce a smooth systematic of the main level density parameter.

June 1998

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1. Introduction

Evaluated values of average reduced neutron widths and level spacings in resolved resonance region used for fixing of optical and statistical model parameters are of major concern. Virtually trivial averaging of experimental resonance parameters never gives reliable results even for thoroughly investigated nuclei, as experimental resonance missing effects the results. Existing methods [1-3], taking resonance missing into account, give rather discrepant results [4-5]. The drawbacks of available methods are due to consideration of the level missing caused by poor experimental energy resolution and discrimination threshold separately. However both these factors are correlated. In other words two strong resonances are usually resolved even being close to each other, while weak resonance can be shadowed by the strong one on the sufficient distance and remains unresolved.

2. Method

Let us introduce the method, that was developed for the determination of $<\Gamma^0_n>$ and $<D>$. We assume that reduced neutron widths and level spacings distributions are $f(x)$ and $\varphi(y)$ with $x=g\Gamma_n^0/<g\Gamma_n^0>$ and $y=D/<D>$ accordingly. We suppose reduced neutron widths and level spacings no correlating, hence $f(x)\varphi(y)$ is the distribution for resonances with the reduced neutron width x to have neighbouring one at the distance y (this is the distance from one side of the resonance, for the sake of definition let it be from the left).

We also introduce an experimental probability $\Psi(x,y,E)$ to resolve the resonance with the reduced width x and the distance y to the neighbouring one in the vicinity of energy E. Now we can get the $f_1(x)$ distribution of the reduced neutron widths that were not missed during the experiment,

$$f_1(x)=\frac{f(x)}{E_2-E_1}\int_{E_1}^{E_2} dE \int_0^{\infty}\varphi(y)\psi(x,y,E)dy,$$

where E_1, E_2 are the lower and upper boundaries of experimentally covered energy region. A - the portion of resonances resolved in the experiment can be found easily as $A=\int_0^{\infty} f_1(x)dx$. Of course $1-A$ is the portion of the experimentally missed resonances. In analogous way we determine $\varphi_1(y)$:

$$\varphi_1(y)=\frac{\varphi(y)}{E_2-E_1}\int_{E_1}^{E_2} dE \int_0^{\infty} f(x)\psi(x,y,E)dx.$$

One can see that $\int_0^{\infty}\varphi_1(y)dy=A$, hence distributions $f_1(x)$ and $\varphi_1(y)$ normalised in the uniform correlated manner.

Let us now consider that missing of resonances results in resolving groups instead of isolated resonances. In our case we are taking into account grouping in doublets only, hence $A>0.5$. If energy resolution of the experiment is less than $<D>$ unresolved groups with three and more resonances have much lower probability. Missed level spacings distribution appears to be $\varphi(y)-\varphi_1(y)$. These level spacings are the distances between resonances in the unresolved doublets. In our assumptions these level spacings do not disappear, as they have common scale with the resolved, but are added to the neighbouring ones. As the result additional distribution $\varphi_2(y)$ is measured in experiment:

$$\varphi_2(y)=\frac{1}{A}\int_0^y[\varphi(z)-\varphi_1(z)]\varphi_1(y-z)dz \ .$$

Of course $\int_0^\infty \varphi_2(y)dy=1-A$. And at last we must take into account that distribution $\varphi_3(y)$ of the distances to which missed were added must be subtracted from experimentally measured distribution $\varphi_1(y)$. It is:

$$\varphi_3(y)=\varphi_1(y)\frac{1-A}{A} \ .$$

Now we can give the expected distribution of experimentally observed level spacings:

$$\varphi_{obs}(y)=[\varphi_1(y)(2-\frac{1}{A})+\varphi_2(y)]/A \ .$$

Neutron reduced widths distribution transforms in the same correlated manner, since we consider that the area under the unresolved doublet is the sum of the areas under single resonances of the doublet. The areas are proportional to the reduced neutron widths, so:

$$f_2(x)=\frac{1}{A}\int_0^x[f(z)-f_1(z)]f_1(x-z)dz \ ,$$

$$f_3(x)=f_1(x)\frac{1-A}{A} \ ,$$

$$f_{obs}(x)=[f_1(x)(2-\frac{1}{A})+f_2(x)]/A \ .$$

Now we have to define $f(x)$, $\varphi(y)$ and $\psi(x,y,E)$.

For $f(x)$ we use:

$$f(x)=\frac{(1+\alpha)^{3/2}}{\sqrt{2x\pi}}\left\{\frac{1}{\sqrt{g_1}}exp\left[-\frac{x}{2g_1(1+\alpha)}\right]+\frac{\alpha^{3/2}}{\sqrt{g_2}}exp\left[-\frac{x\alpha}{2g_2(1+\alpha)}\right]\right\}.$$

And for $\varphi(y)$ we use[6]:

$$\varphi(y)=\frac{\pi}{2}\left\{y\left[\frac{\alpha^3}{(1+\alpha)^3}exp\left[-\frac{\pi}{4}y^2\frac{\alpha^2}{(1+\alpha)^2}\right]erfc\left(\frac{\sqrt{\pi}}{2}y\frac{1}{1+\alpha}\right)+\right.\right.$$

$$\left.\frac{1}{(1+\alpha)^3}exp\left[-\frac{\pi}{4}y^2\frac{1}{(1+\alpha)^2}\right]erfc\left(\frac{\sqrt{\pi}}{2}y\frac{\alpha}{1+\alpha}\right)\right]+$$

$$\left.\frac{4\alpha}{\pi(1+\alpha)^2}exp\left[-\frac{\pi}{4}y^2\frac{1+\alpha^2}{(1+\alpha)^2}\right]-\right\},$$

where $\alpha=\langle D_{J1}\rangle/\langle D_{J2}\rangle$, $g_1=(2J_1+1)/2/(2I+1)$ and $g_2=(2J_2+1)/2/(2I+1)$.

Both neutron reduced widths distribution and level spacings one take into account possible existence of two systems of resonances with different spins J_1 and J_2 and $\langle D_{J1}\rangle$, $\langle D_{J2}\rangle$ accordingly in the resolved resonance region. In case of even nuclei, with resonances of equal spin, they become the well known Porter-Thomas [7] and Wigner [8] distributions. Resonance spacings distributions involved in our approach for even and odd nuclei differ considerably (see Fig.1). Resonances of the same spin are repulsed, hence small resonance spacing for such resonances are improbable. In case of odd nuclei the spins of s-wave resonances may be different and the influence of level repulsion is diminished. This may result in much greater experimental resonance missing for odd nuclei. One, applying Wigner distribution for analysis of odd nuclei $\langle D\rangle$, does not take into account considerable probability for existence of small distances, that are more probably missed in experiment and overestimates $\langle D\rangle$.

We consider that the probability to resolve resonances in the experiment $\psi(x,y,E)$ can be modelled by:

$$\psi(x,y,E)=\frac{1+\alpha}{\alpha+exp\left[\frac{c\Delta(E)}{x^s y\langle D\rangle}\right]}\frac{1}{\left(\frac{x_0}{x}\right)^p+1},$$

where $\Delta(E)$- is experimental energy resolution; x_0 - is diffusive threshold of widths discrimination; p - determines the curvature of the discrimination threshold; s - defines correlation between weak resonance and poor resolution level missing; c - a parameter, which determines rate of the level missing when the energy resolution deteriorates; a - is normalisation constant.

Model resolution function $\psi(x,y,E)$ describes typical experimental situation. It decreases to zero when x, y, $x^s y$, $1/x_0$ or $\langle D\rangle/\Delta(E)$ urge towards zero, and becomes unity when x, y, $x^s y$, $1/x_0$ or $\langle D\rangle/\Delta(E)$ are growing.

3. Results and discussion

Average resonance and resolution function parameters are found by fitting theoretically expected neutron widths and level spacings distributions to experimental ones within framework of the best likelihood method with the computer code created on the base of the suggested approach. Figures 2-33 show comparison of experimental and adjusted expected reduced neutron widths and level spacings distributions for all actinides experimental resolved resonance parameter sets for which are measured.

Tables 1 and 2 give evaluated values of s-wave strength functions and average level spacings for these nuclei and comparison with other evaluations. Resonance parameters used in this evaluation were taken from BNL-325, except marked by *, which had been taken from our evaluations [9-14].

Although our evaluated values are rather different from those in Bologna, Obninsk, Beijing and BNL libraries, they usually coincide, at least with one of these evaluations within quoted errors, which are usually very large, except some cases. In case of ^{246}Cm our $\langle D\rangle$=17.58 eV is much lower as we took into consideration experimental shadowing of ^{246}Cm resonances by contaminating isotopes in the sample. The reason for our ^{247}Cm low $\langle D\rangle$=1.181 eV is the same. Our ^{242m}Am $\langle D\rangle$=0.271 eV is much lower, as based on our new resonance parameters evaluation including additional resonances, appeared as a result of thorough shape resonance analyse.

We claim our results seem to be more reliable, since we rely simultaneously on both reduced neutron widths and level spacings distributions. With the proposed method we may treat experimental data sets with up to 50% resonance missed, enlarge involved data base and thus reduce statistical errors .

The main level density parameter a was obtained by fitting the neutron resonance spacing $\langle D\rangle$. The total level density is calculated with a phenomenological model by Ignatyuk et al. [15], which takes into account shell, pairing and collective effects. The equilibrium deformation is assumed axially symmetric. The shell corrections were calculated with liquid-drop Myers-Swiatecki parameters and experimental nuclear masses. The A-dependence of a/A is shown on Fig.34. It is evident that global systematic of a over actinide region is hardly possible. On the contrary, the isotopic dependencies of a/A seem to be rather smooth for Th, Pu, Am and Cm nuclei. The local systematic of $a/A=\alpha+\beta A$ could be readily obtained.

4. Conclusions

New evaluation of average neutron resonance parameters for all actinides, experimental resolved resonance parameters for which are available, was performed on the base of a newly suggested approach. The main advantage of the suggested method is the possibility of simultaneous self-consistent analysis of experimental reduced neutron widths and level spacings distributions, changes of which due to missing are considered correlated. That allows to enlarge the involved data base, to improve statistics and makes our evaluated results more stable.

5. Acknowledgements

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7. Figure captions

Fig. 1 Comparison of level spasing distributions with the taking into account existence of one and two spin resonance systems.
Fig. 2 Comparison of ^{229}Th data: a-cumulative sum of levels; b-cumulative sum of reduced neutron widths; c-reduced neutron width distribution; d-level spacing distribution.
Fig. 3 Comparison of ^{230}Th data: a-cumulative sum of levels; b-cumulative sum of reduced neutron widths; c-reduced neutron width distribution; d-level spacing distribution.
Fig. 4 Comparison of ^{232}Th data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig. 5 Comparison of ^{231}Pa data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig. 6 Comparison of ^{233}Pa data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig. 7 Comparison of ^{232}U data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig. 8 Comparison of ^{233}U data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig. 9 Comparison of ^{234}U data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.10 Comparison of ^{235}U data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.11 Comparison of ^{236}U data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.12 Comparison of ^{237}U data: figs a-,d- are the same as for ^{229}Th.
Fig.13 Comparison of ^{238}U data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.14 Comparison of ^{237}Np data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.15 Comparison of ^{238}Pu data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.16 Comparison of ^{239}Pu data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.17 Comparison of ^{240}Pu data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.18 Comparison of ^{241}Pu data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.19 Comparison of ^{242}Pu data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.20 Comparison of ^{244}Pu data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.21 Comparison of ^{241}Am data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.22 Comparison of ^{242m}Am data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.23 Comparison of ^{243}Am data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.24 Comparison of ^{242}Cm data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.25 Comparison of ^{243}Cm data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.26 Comparison of ^{244}Cm data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.27 Comparison of ^{245}Cm data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.28 Comparison of ^{246}Cm data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.29 Comparison of ^{247}Cm data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.30 Comparison of ^{248}Cm data: figs a-, b-, c-, d- are the same as for ^{230}Th.
Fig.31 Comparison of ^{249}Bk data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.32 Comparison of ^{249}Cf data: figs a-, b-, c-, d- are the same as for ^{229}Th.
Fig.33 Comparison of ^{252}Cf data: figs a-, d- are the same as for ^{230}Th.
Fig.34 The a/A dependence for actinides deduced from our evaluated $\langle D \rangle$ values.

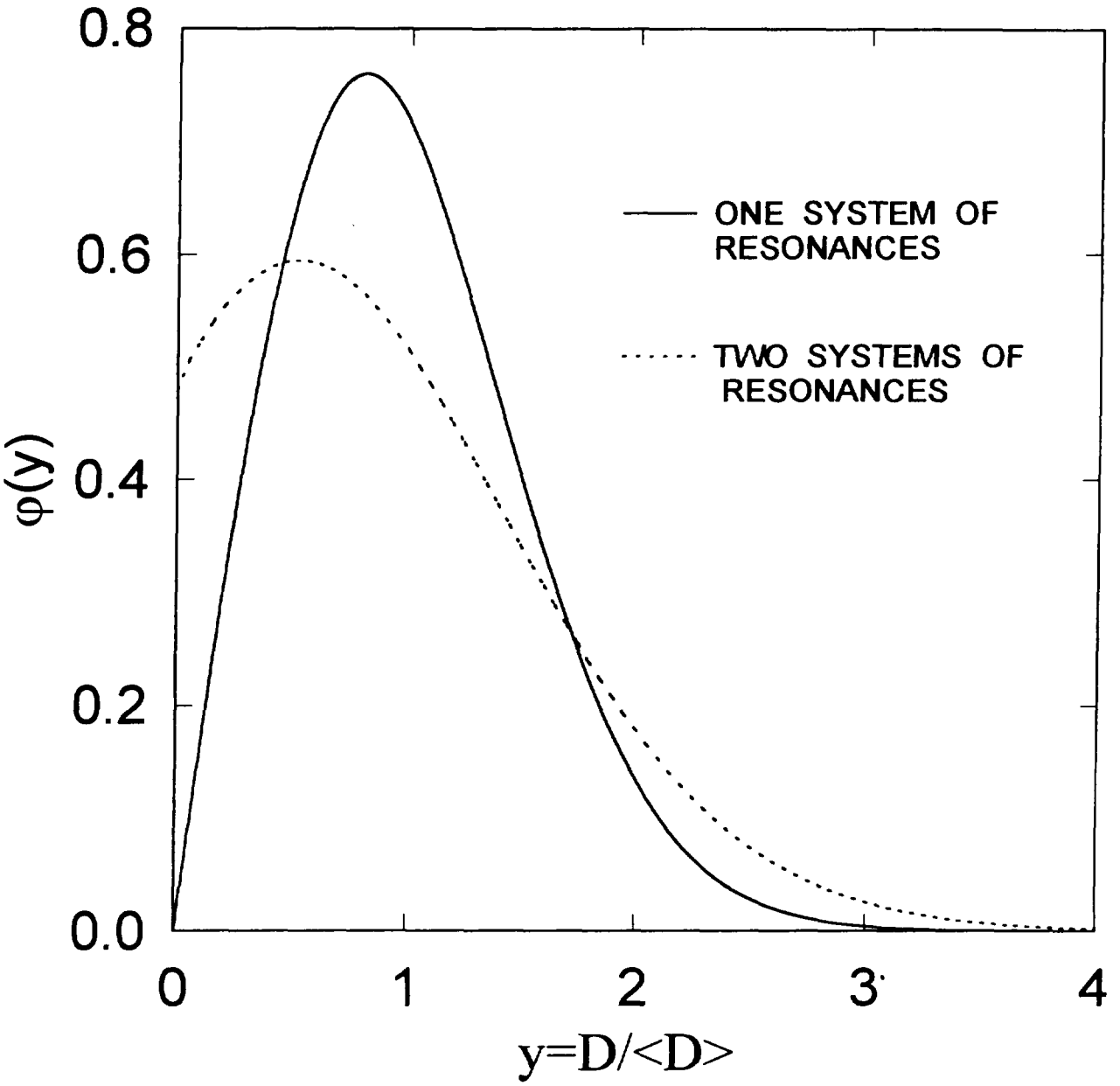

Fig.1 Comparison of level spacing distributions with one and two systems of resonances

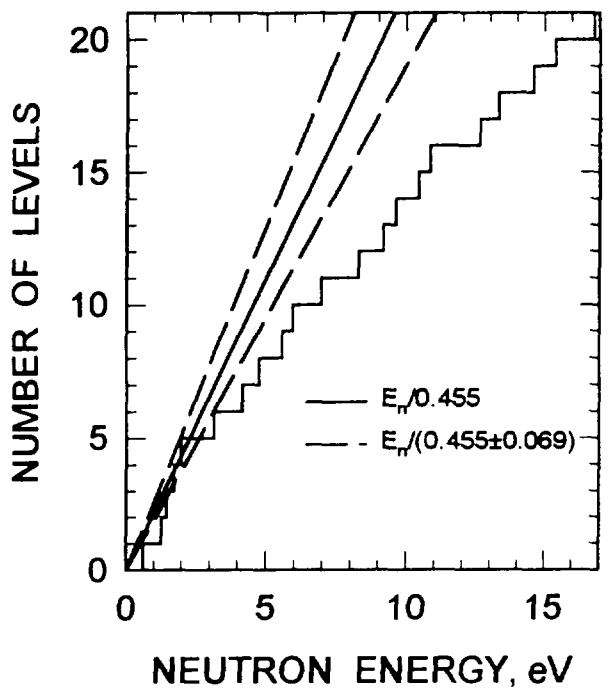

Fig.2a ^{229}Th: Cumulative sum of levels

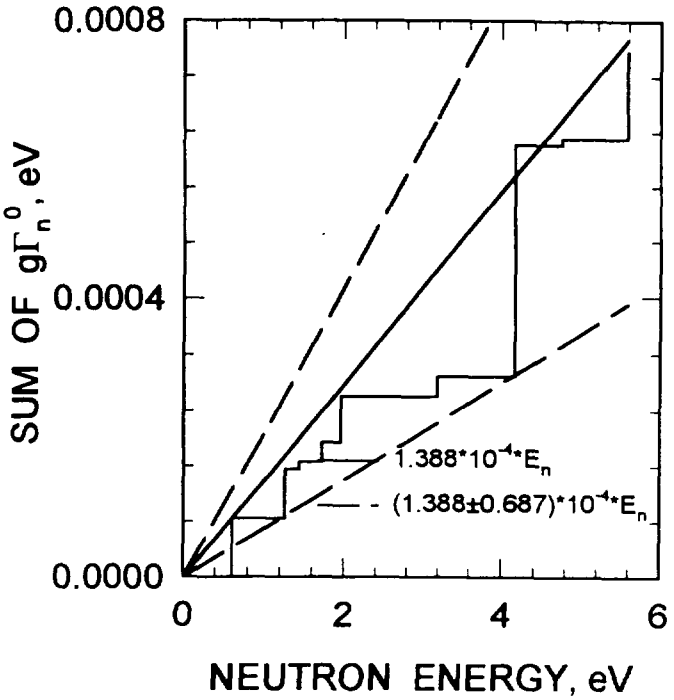

Fig.2b ^{229}Th: Cumulative sum of reduced neutron widths

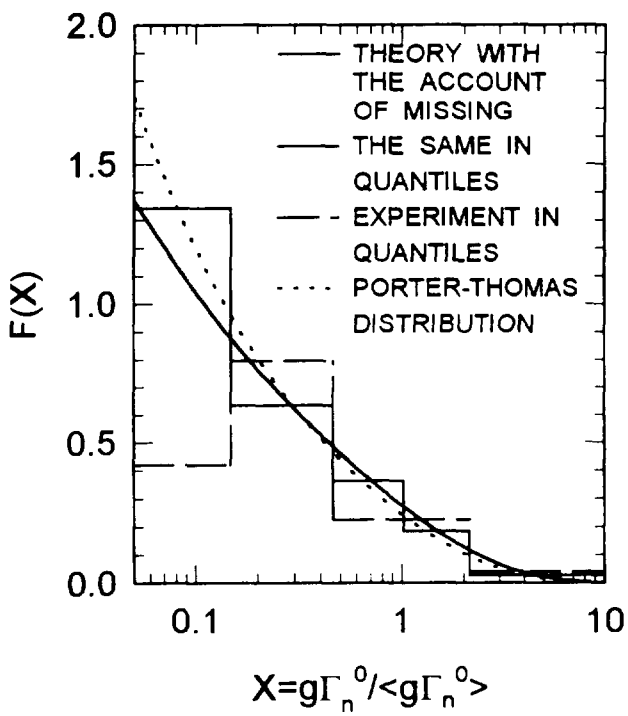

Fig.2c ^{229}Th: Reduced neutron width distribution

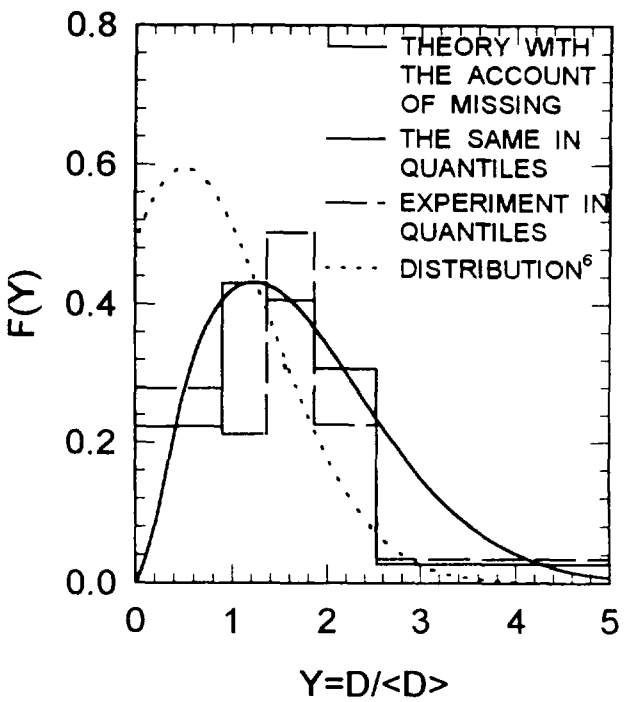

Fig.2d ^{229}Th: Level spacing distribution

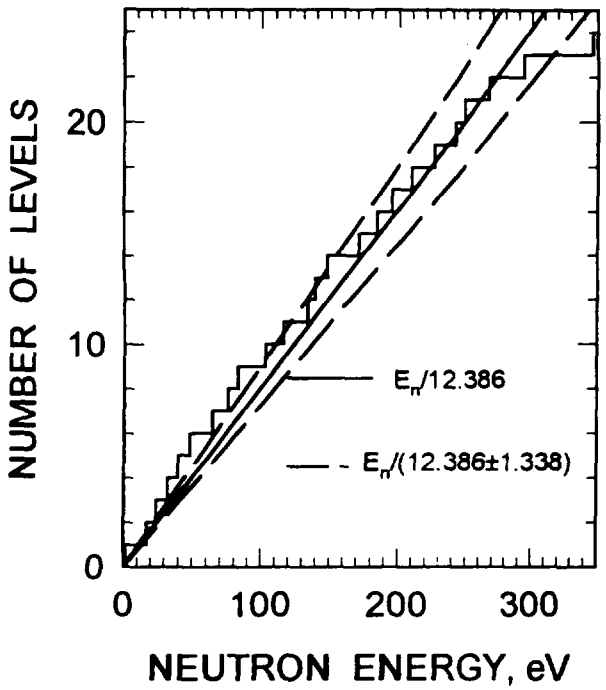

Fig.3a ^{230}Th: Cumulative sum of levels

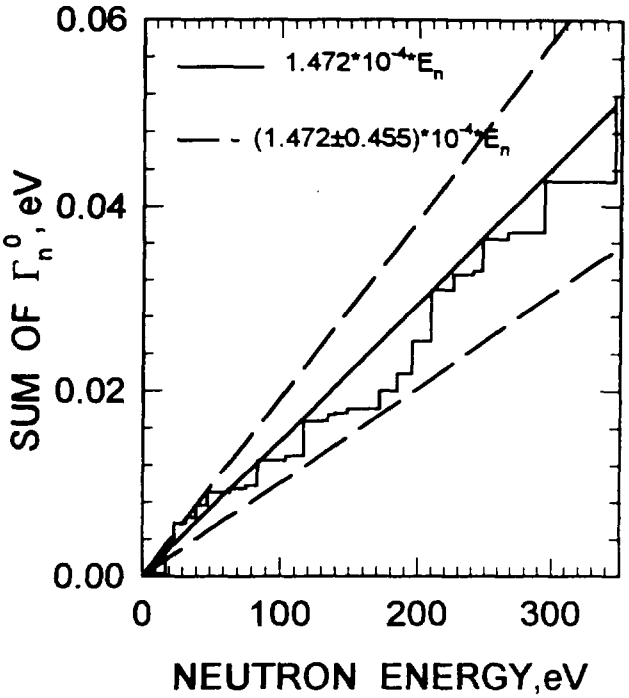

Fig.3b ^{230}Th: Cumulative sum of reduced neutron widths

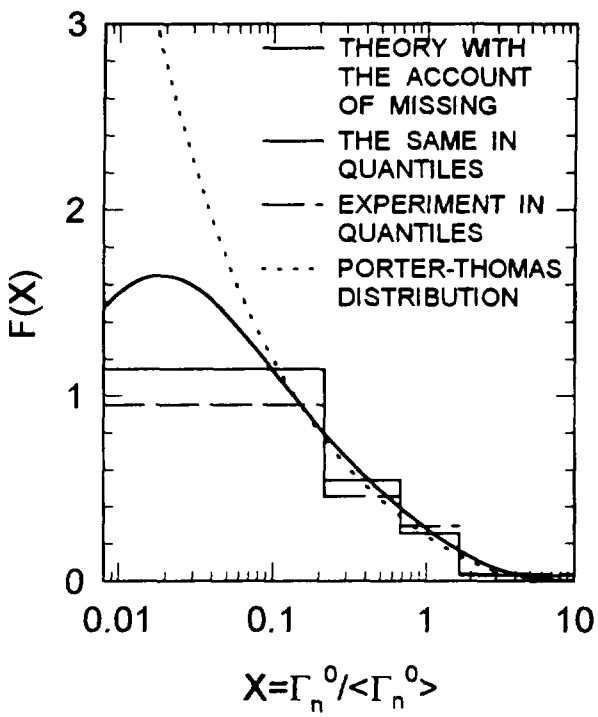

Fig.3c ^{230}Th: Reduced neutron width distribution

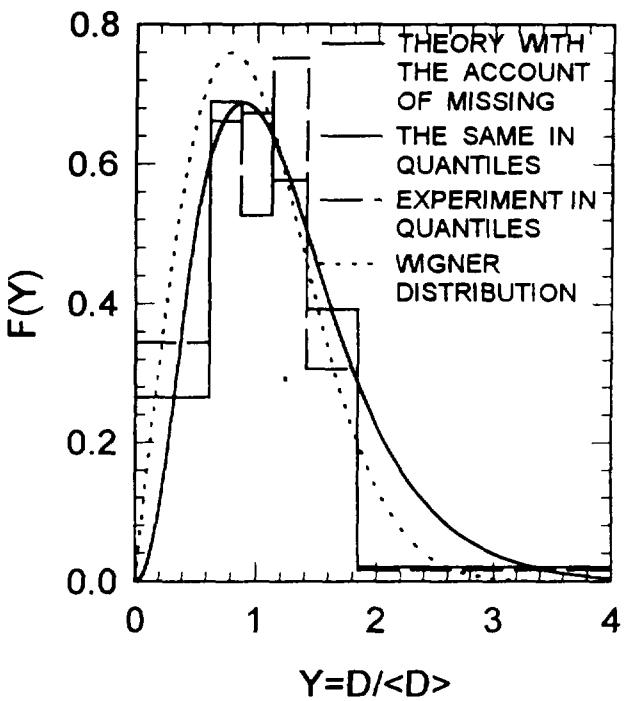

Fig.3d ^{230}Th: Level spacing distribution

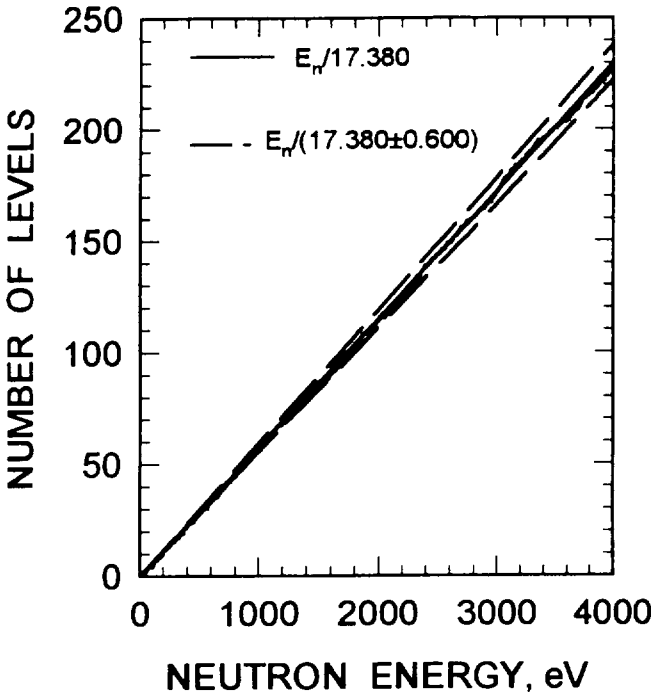

Fig.4a ^{232}Th: Cumulative sum of levels

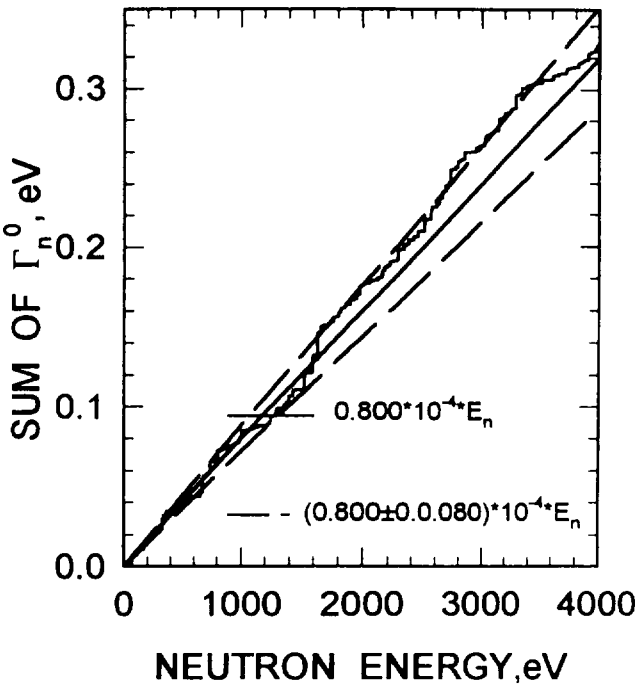

Fig.4b ^{232}Th: Cumulative sum of reduced neutron widths

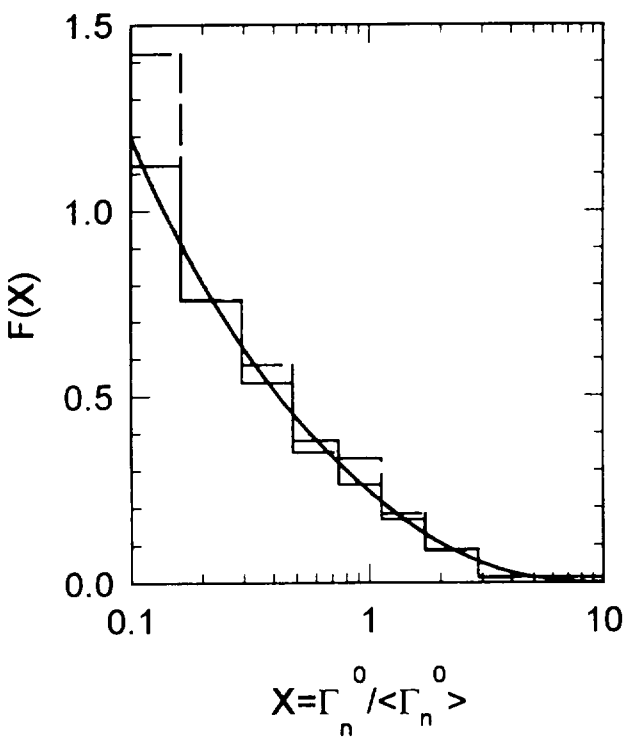

Fig.4c ^{232}Th: Reduced neutron width distribution

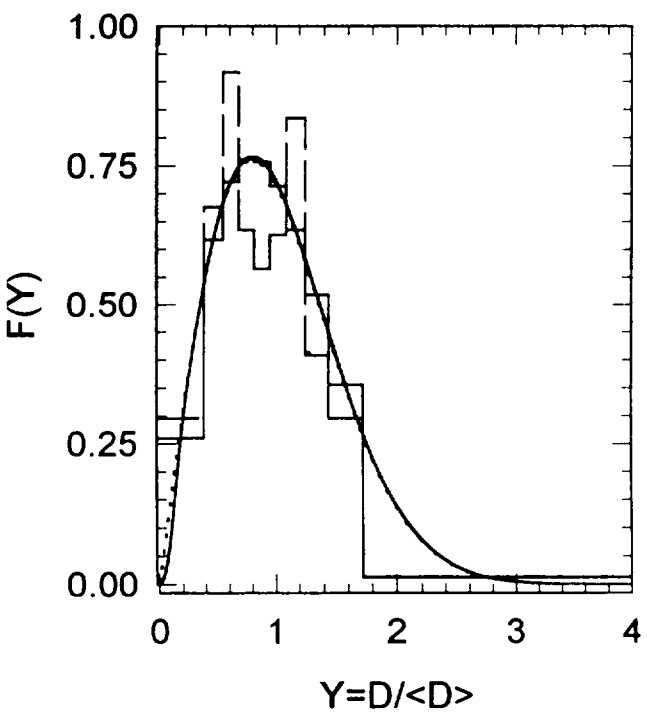

Fig.4d ^{232}Th: Level spacing distribution

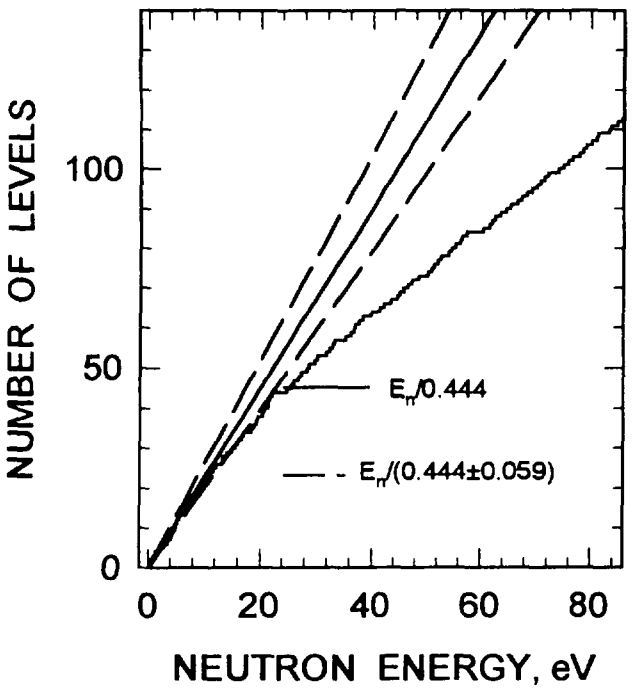

Fig.5a ^{231}Pa: Cumulative sum of levels

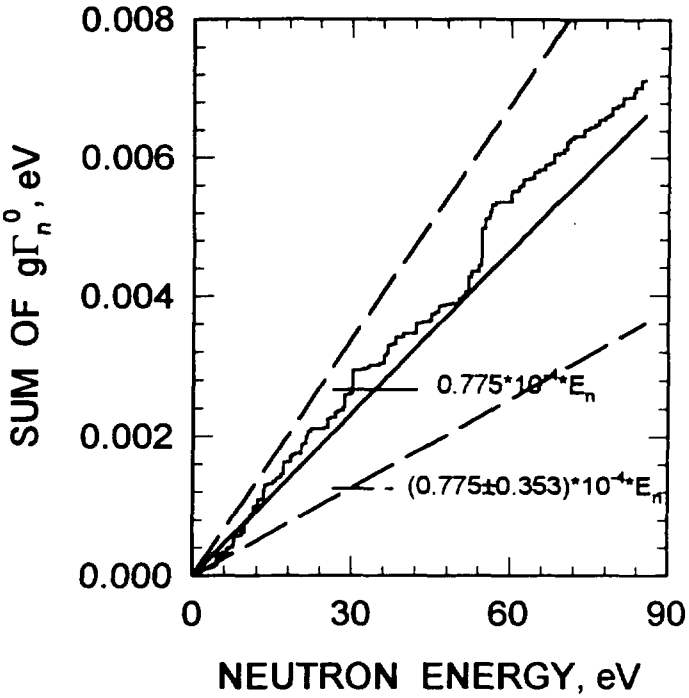

Fig.5b ^{231}Pa: Cumulative sum of reduced neutron widths

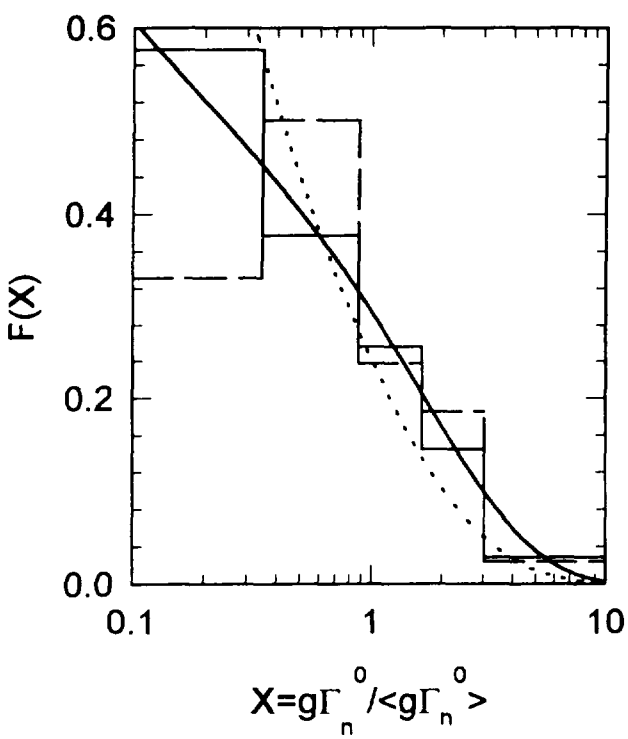

Fig.5c ^{231}Pa: Reduced neutron width distribution

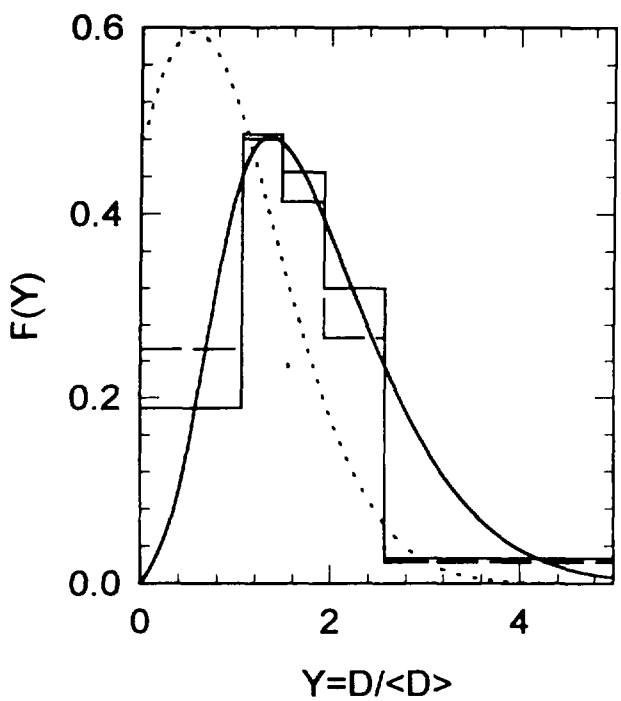

Fig.5d ^{231}Pa: Level spacing distribution

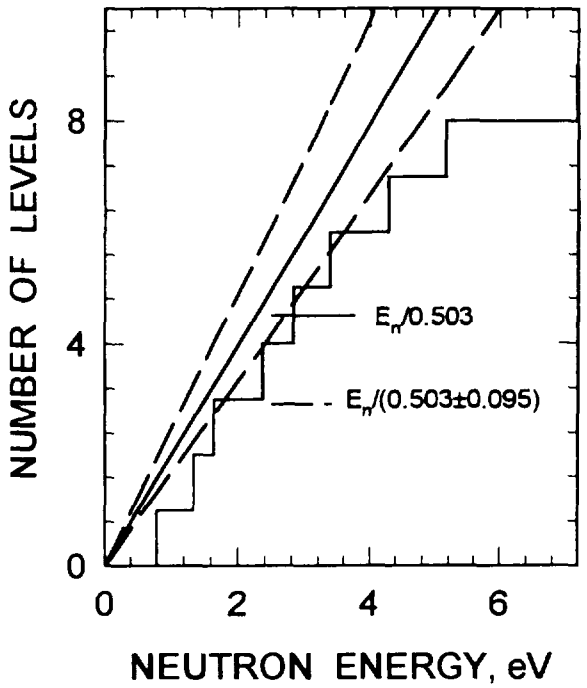

Fig.6a ^{233}Pa: Cumulative sum of levels

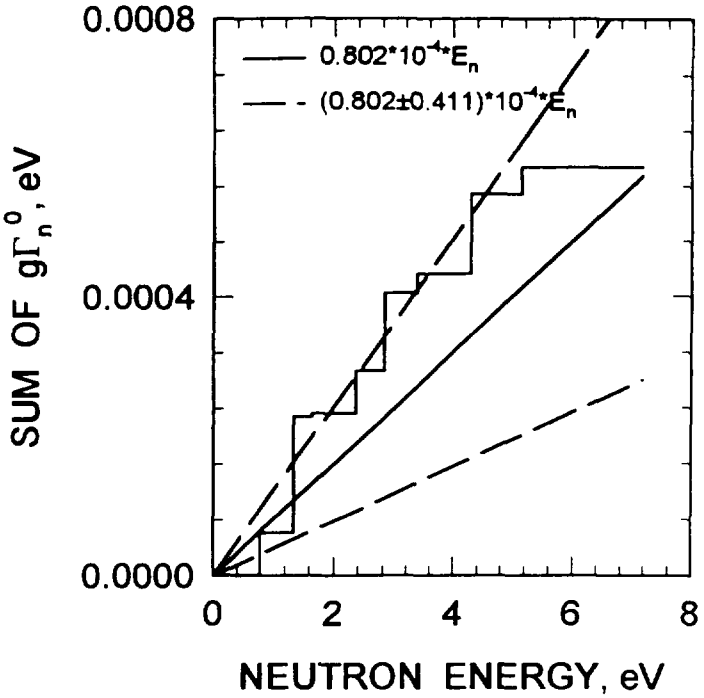

Fig.6b ^{233}Pa: Cumulative sum of reduced neutron widths

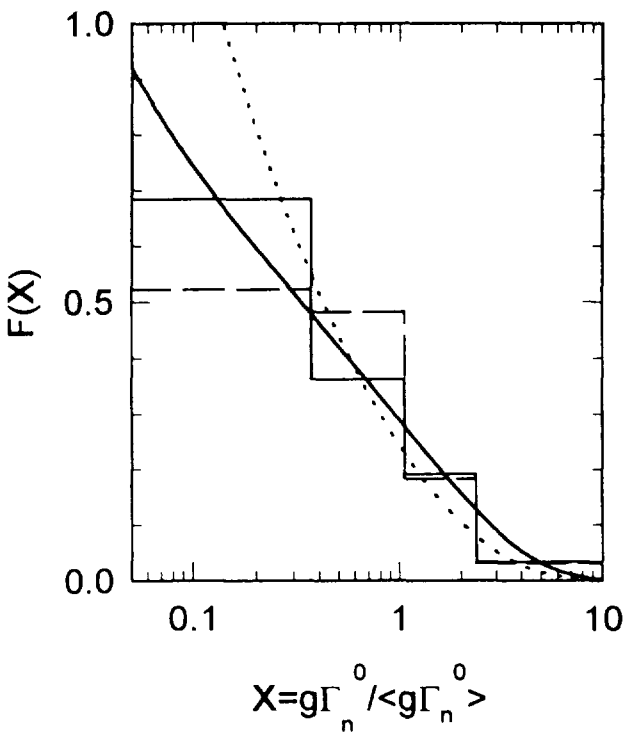

Fig.6c ^{233}Pa: Reduced neutron width distribution

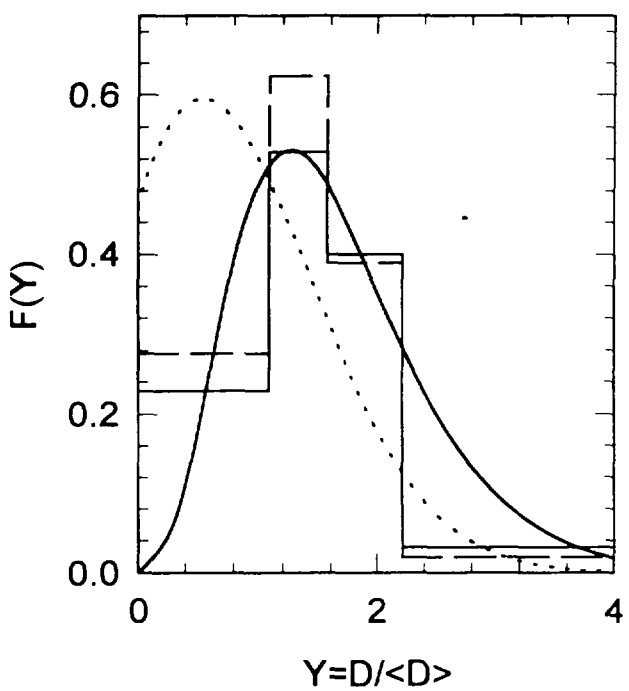

Fig.6d ^{233}Pa: Level spacing distribution

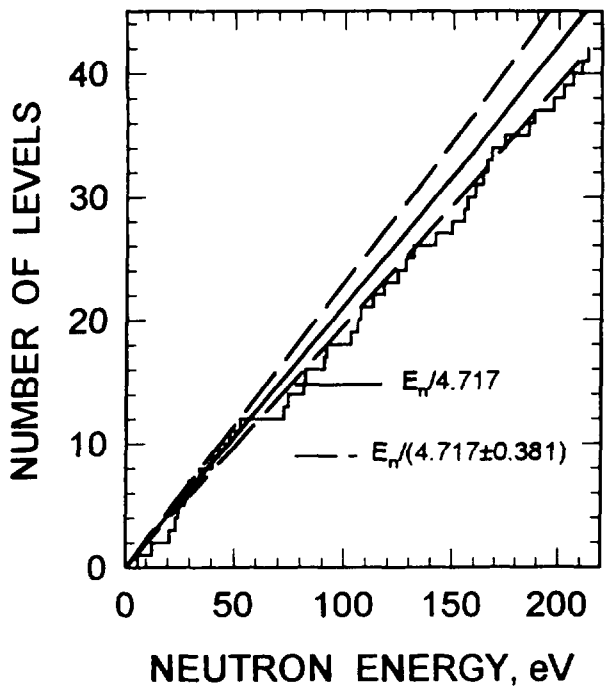

Fig.7a ^{232}U: Cumulative sum of levels

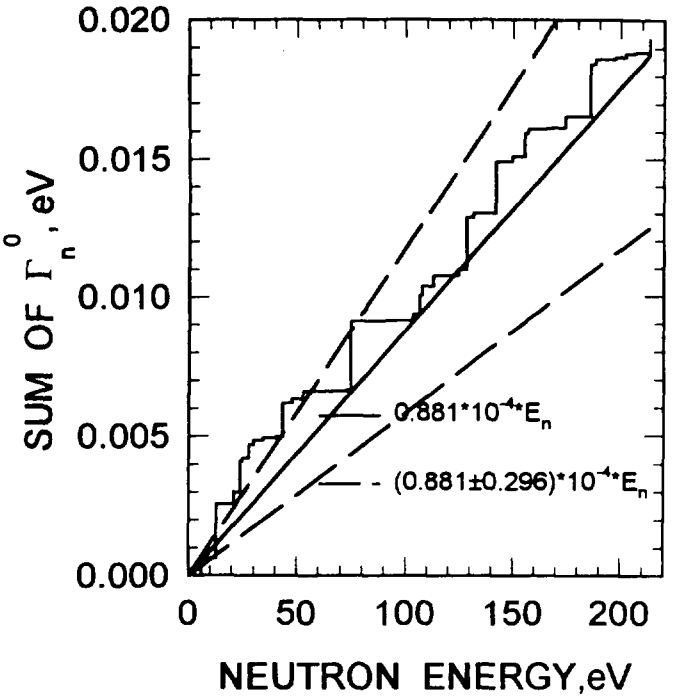

Fig.7b ^{232}U: Cumulative sum of reduced neutron widths

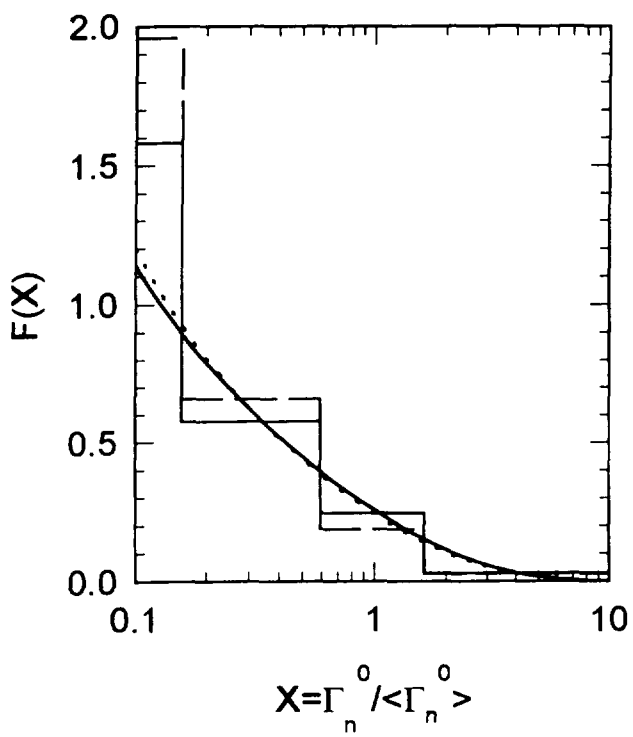

Fig.7c ^{232}U: Reduced neutron width distribution

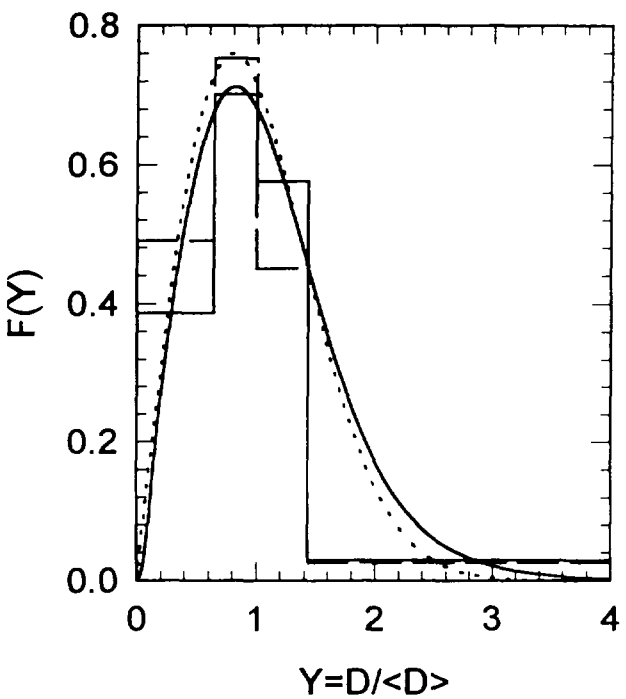

Fig.7d ^{232}U: Level spacing distribution

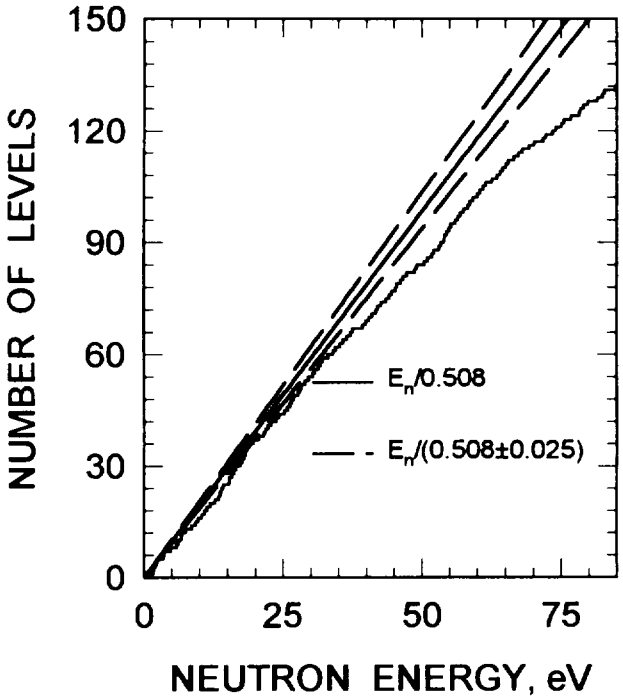

Fig.8a ^{233}U: Cumulative sum of levels

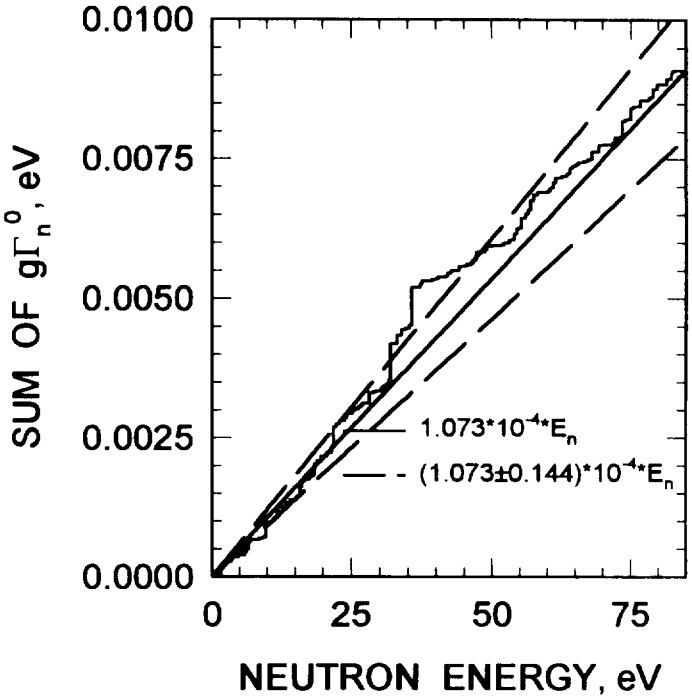

Fig.8b ^{233}U: Cumulative sum of reduced neutron widths

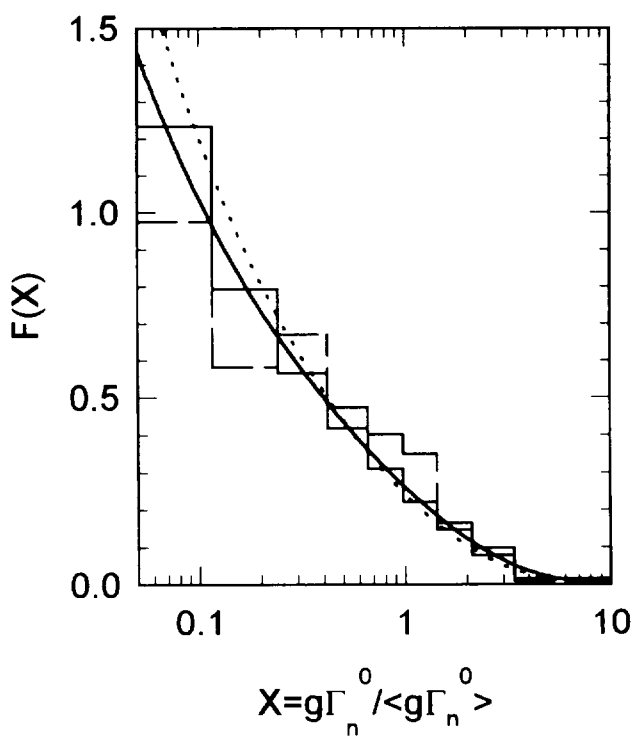

Fig.8c ^{233}U: Reduced neutron width distribution

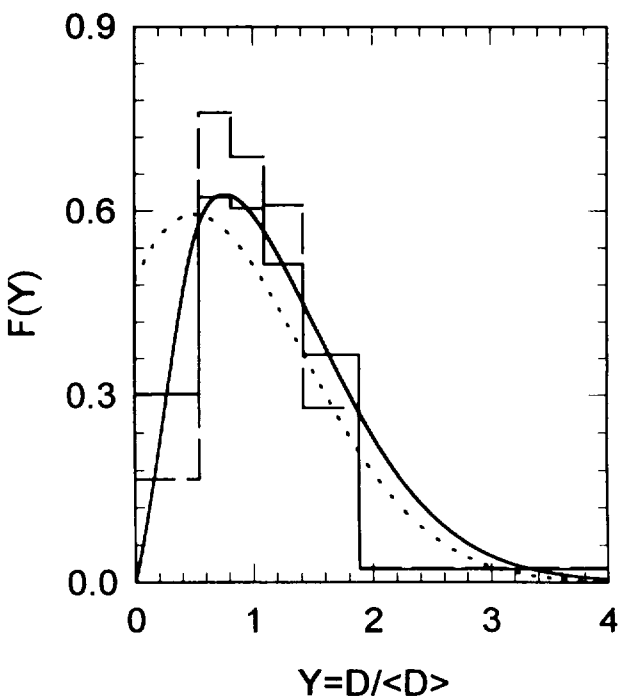

Fig.8d ^{233}U LEVEL SPACING DISTRIBUTION

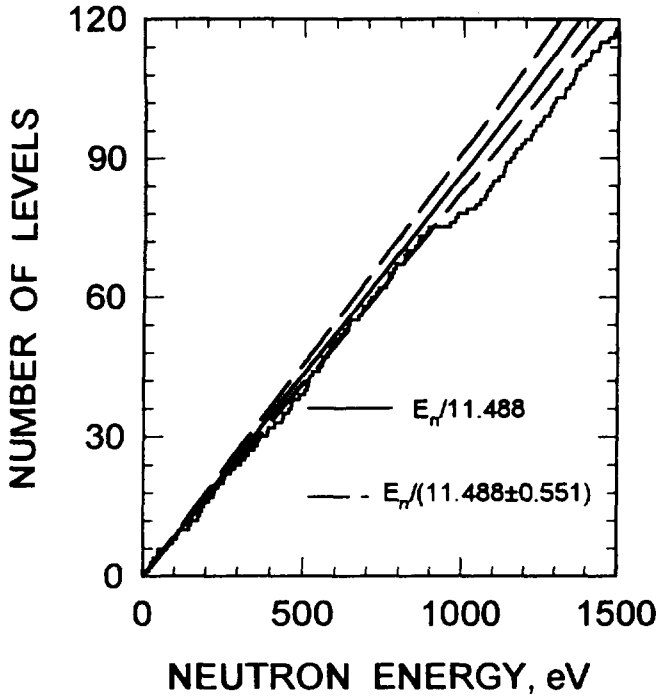

Fig.9a ^{234}U: Cumulative sum of levels

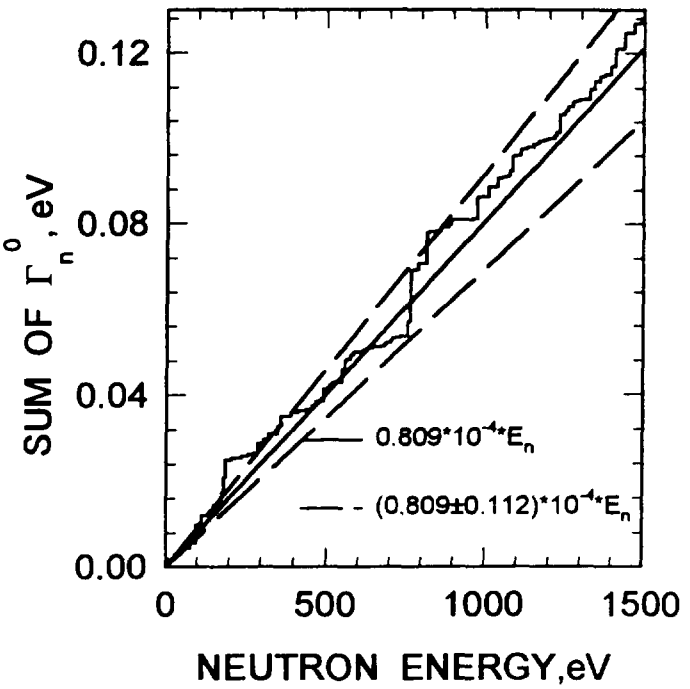

Fig.9b ^{234}U: Cumulative sum of reduced neutron widths

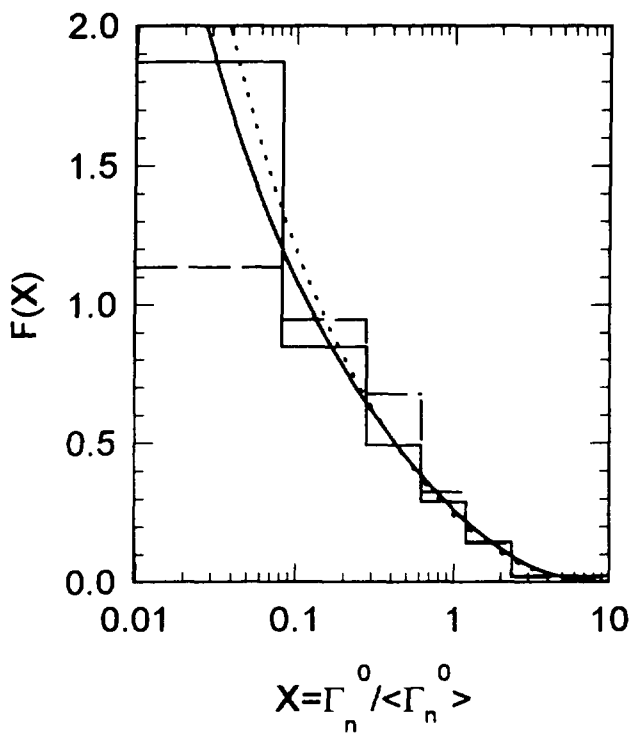

Fig.9c ^{234}U: Reduced neutron width distribution

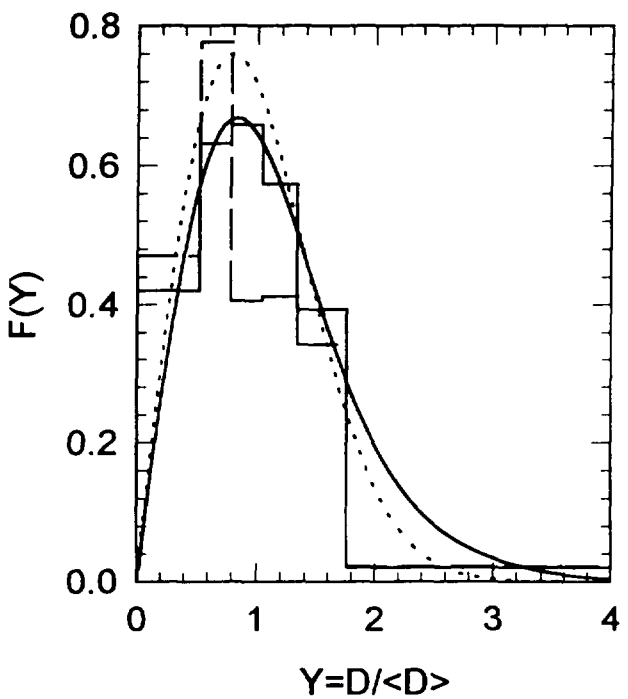

Fig.9d ^{234}U: Level spacing distribution

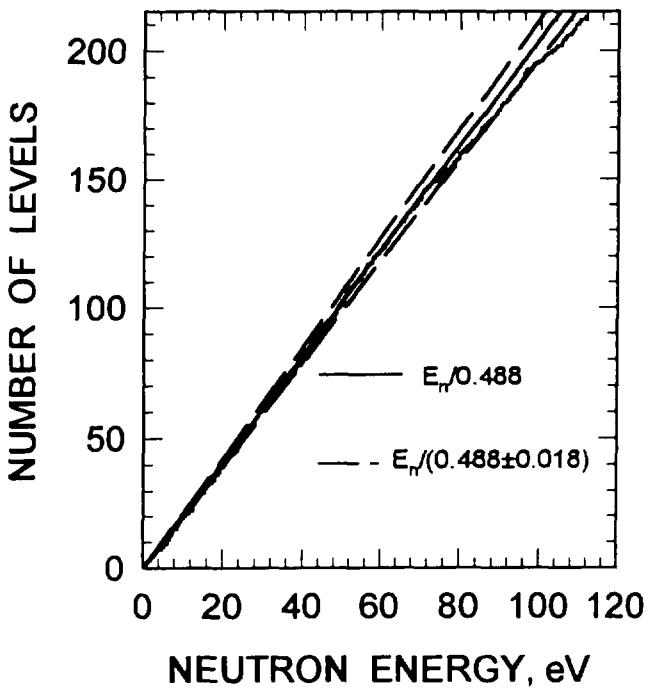

Fig.10a ^{235}U: Cumulative sum of levels

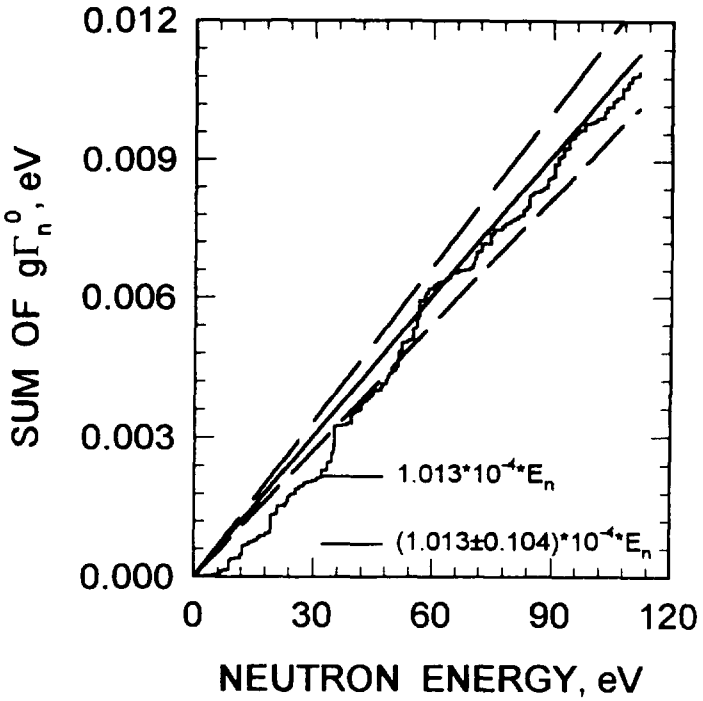

Fig.10b ^{235}U Cumulative sum of reduced neutron widths

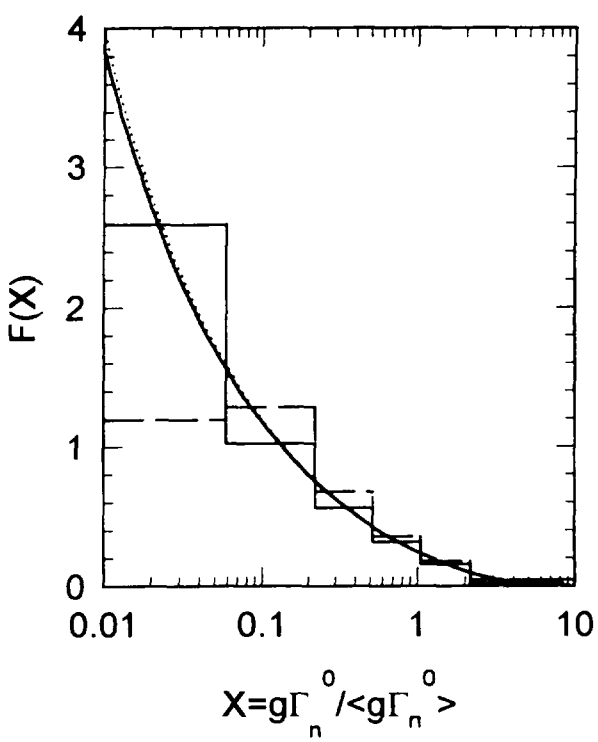

Fig.10c ^{235}U: Reduced neutron width distribution

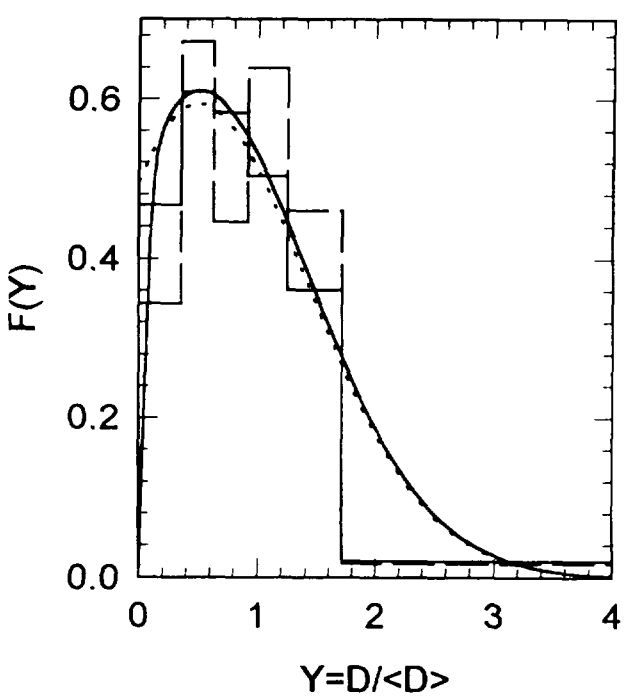

Fig.10d ^{235}U: Level spacing distribution

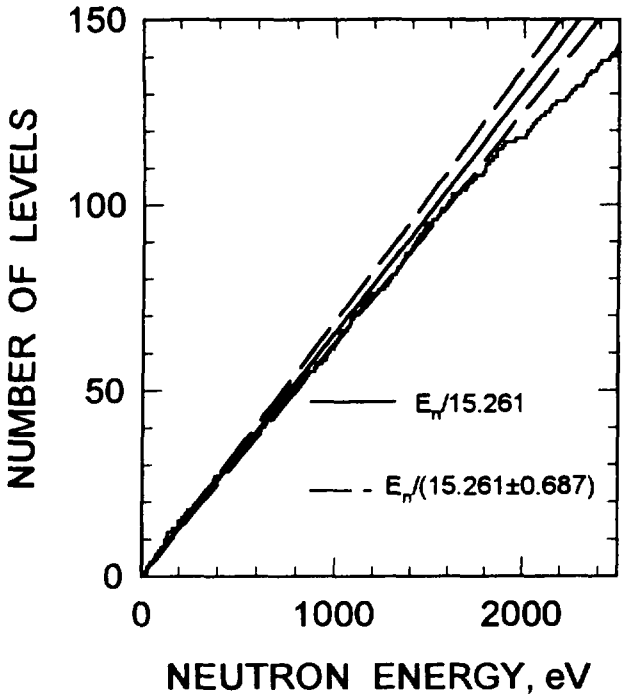

Fig.11a ^{236}U: Cumulative sum of levels

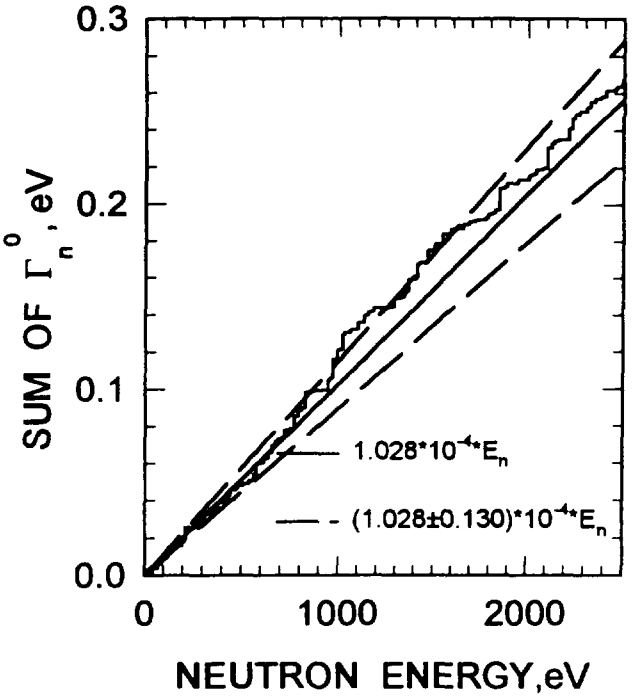

Fig.11b ^{236}U: Cumulative sum of reduced neutron widths

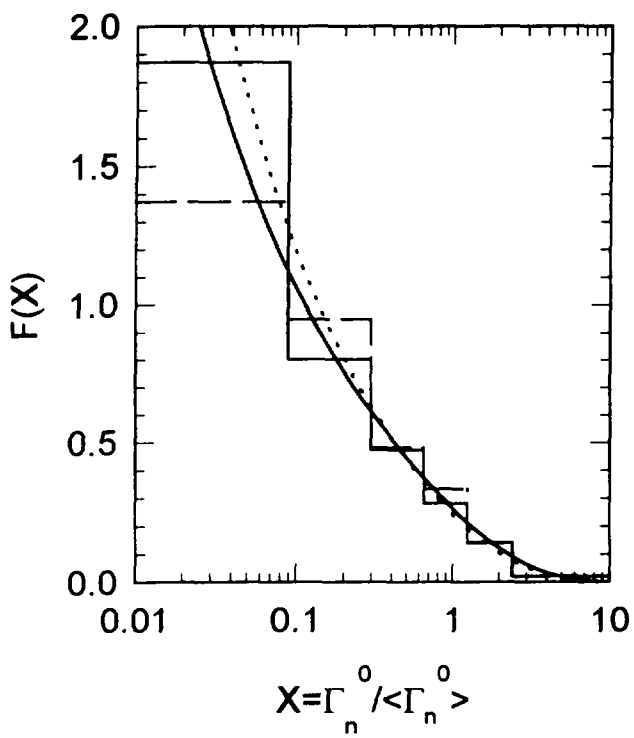

Fig.11c ^{236}U: Reduced neutron width distribution

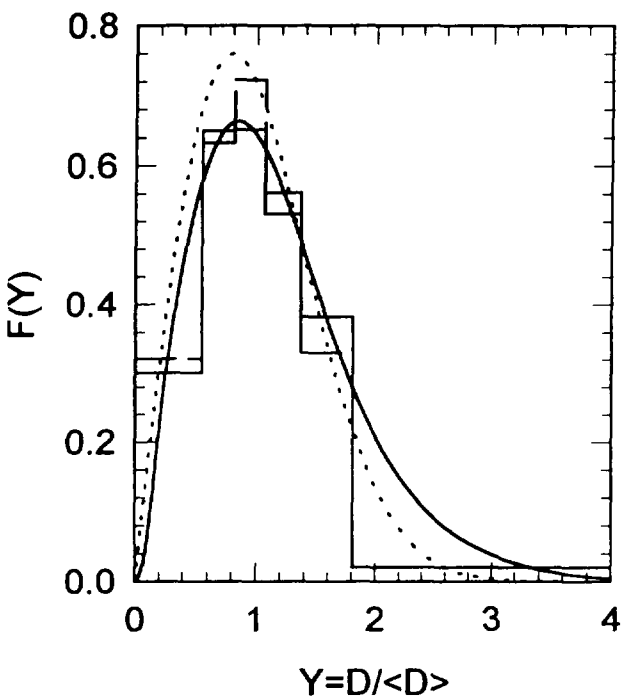

Fig.11d ^{236}U: Level spacing distribution

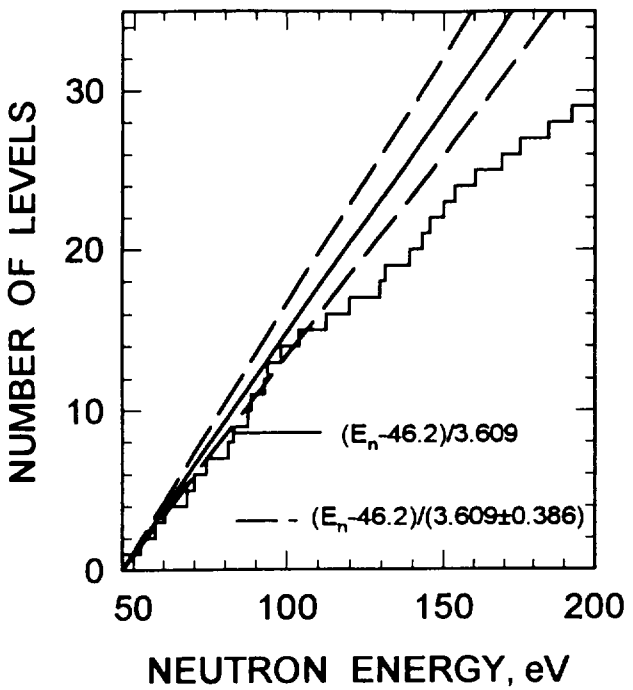

Fig.12a ^{237}U: Cumulative sum of levels

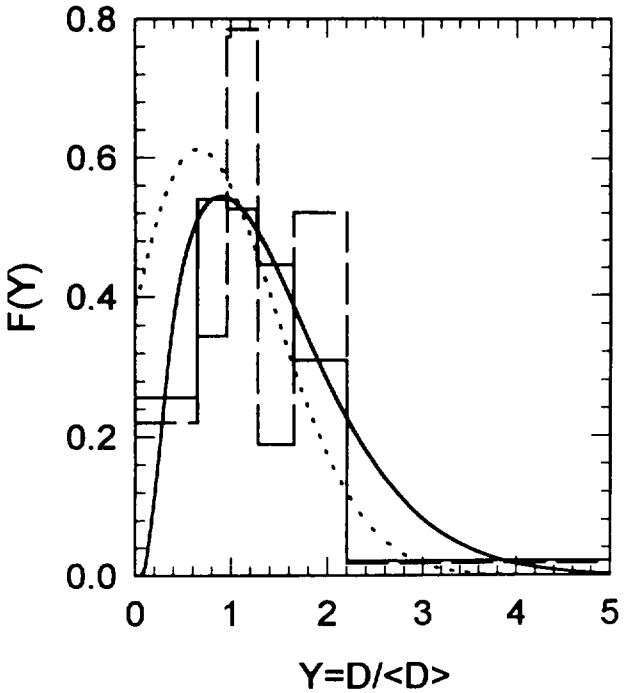

Fig.12d ^{237}U: Level spacing distribution

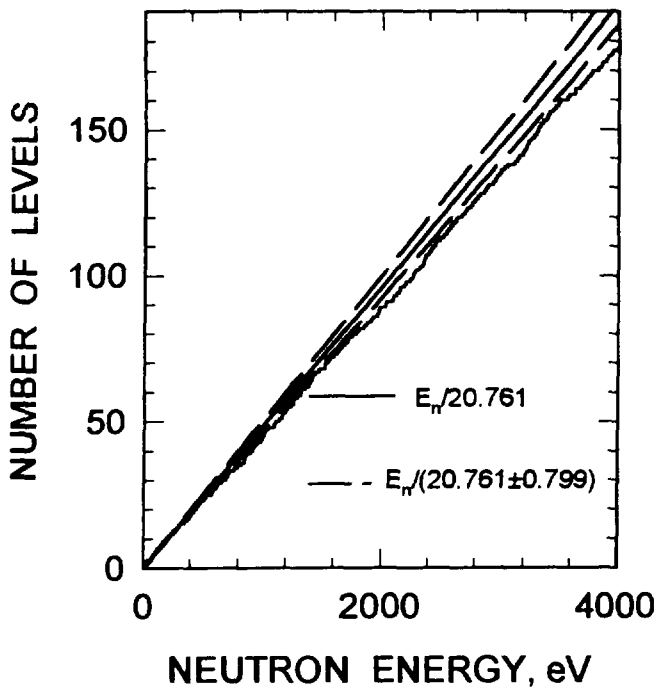

Fig.13a ^{238}U: Cumulative sum of levels

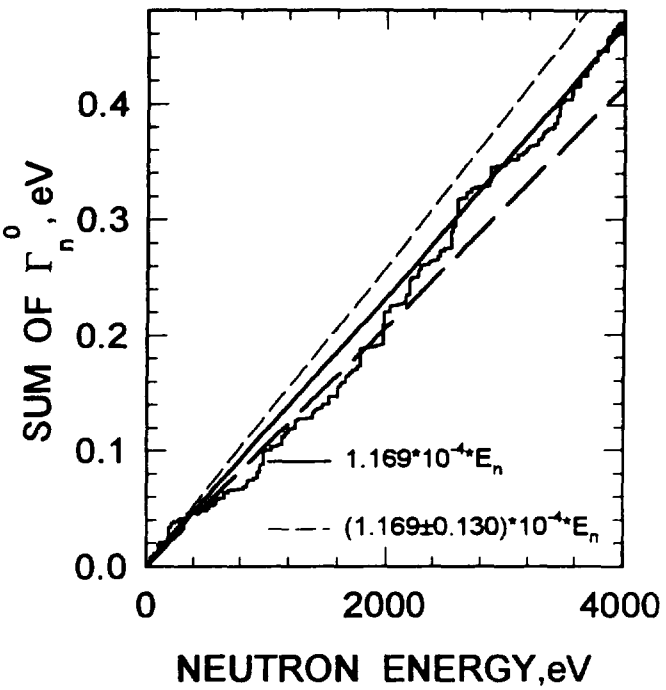

Fig.13b ^{238}U: Cumulative sum of reduced neutron widths

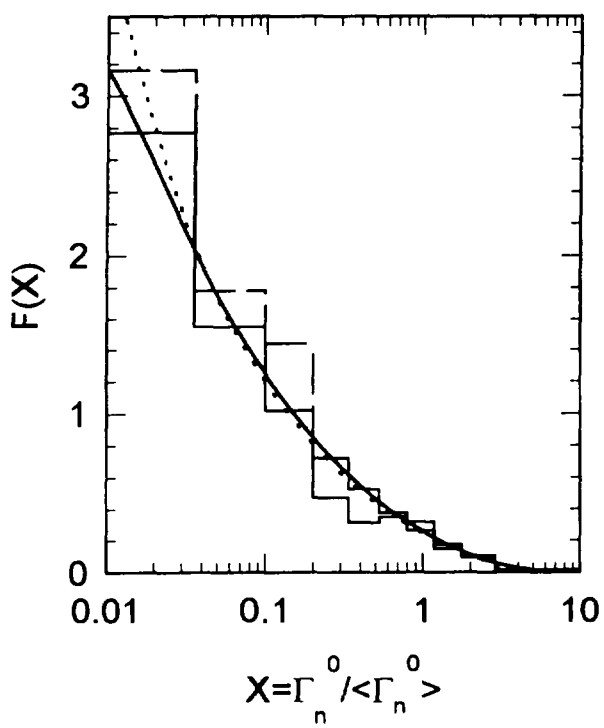

Fig.13c ^{238}U: Reduced neutron width distribution

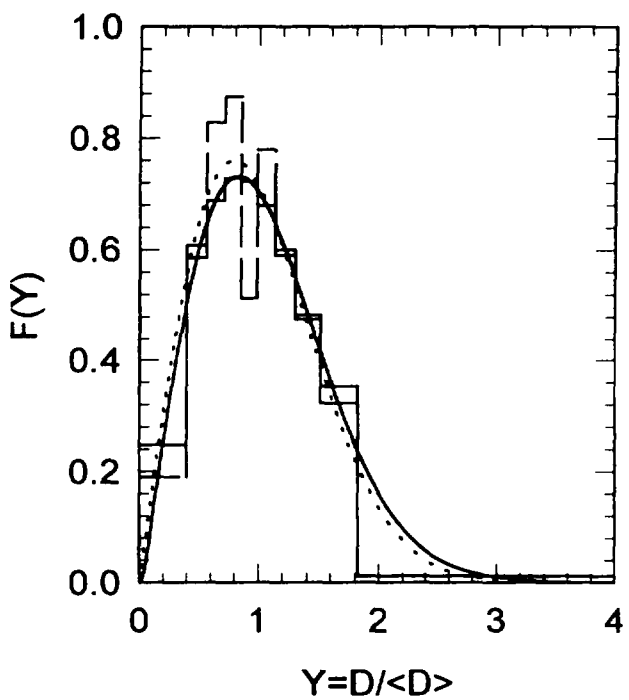

Fig.13d ^{238}U: Level spacing distribution

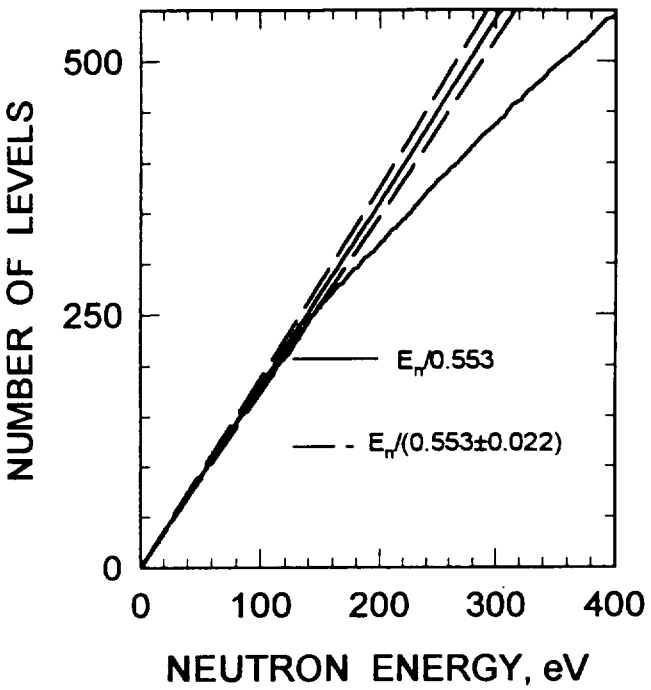

Fig.14a ^{237}Np: Cumulative sum of levels

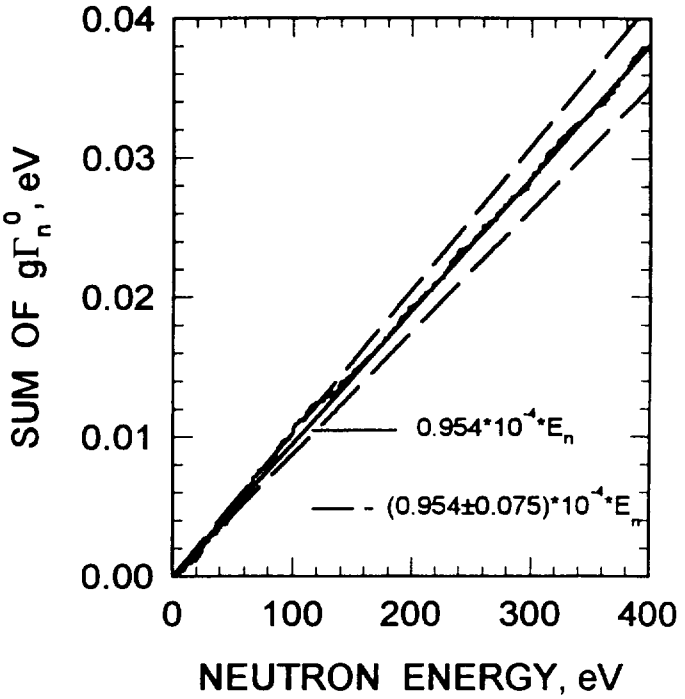

Fig.14b ^{237}Np: Cumulative sum of reduced neutron widths

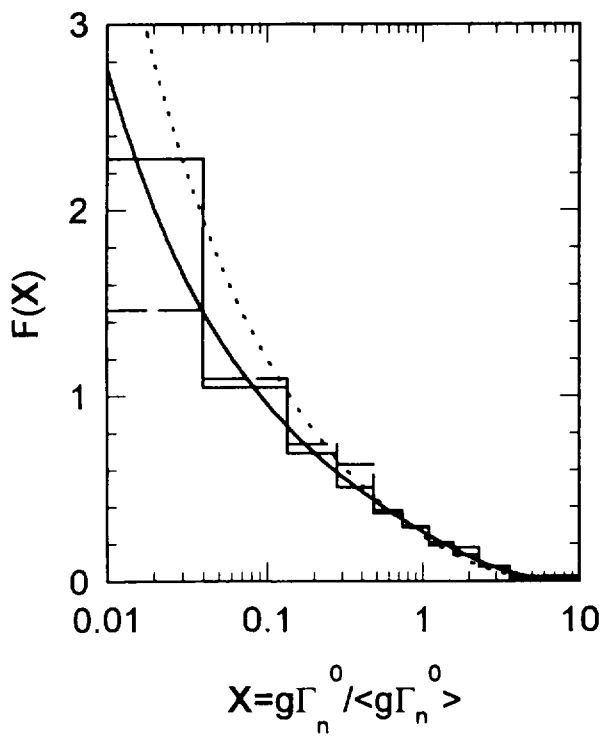

Fig.14c ^{237}Np: Reduced neutron width distribution

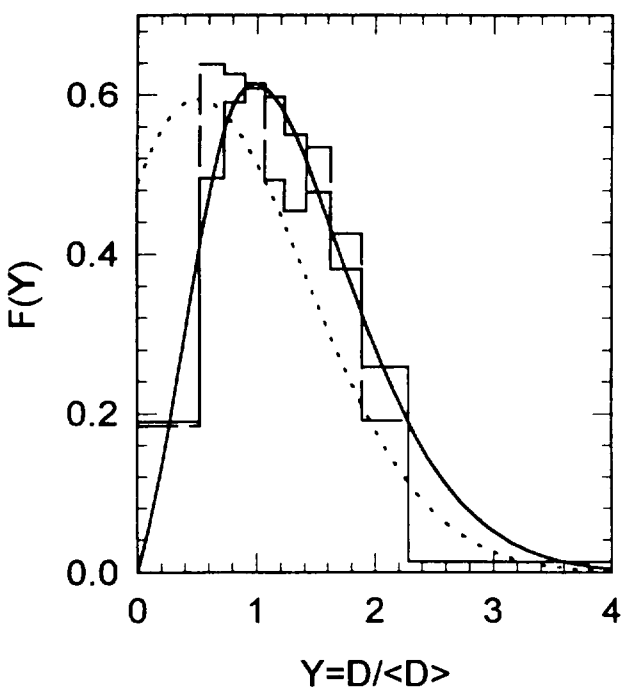

Fig.14d ^{237}Np: Level spacing distribution

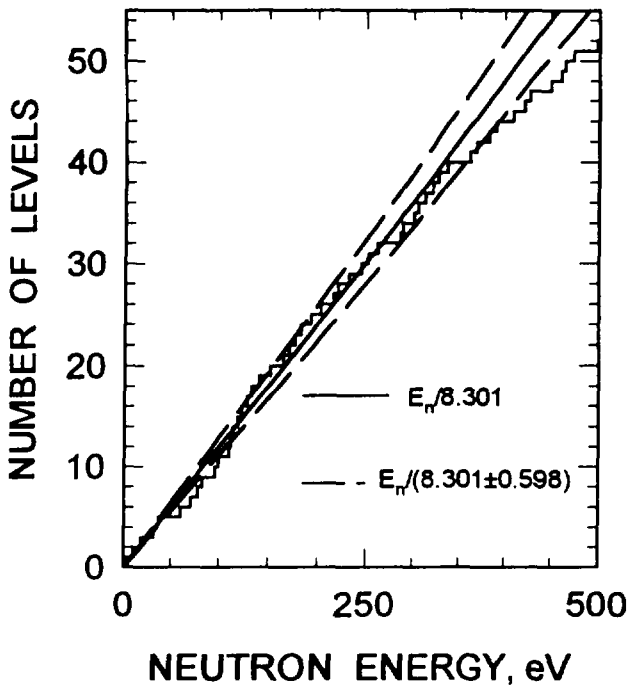

Fig.15a ^{238}Pu: Cumulative sum of levels

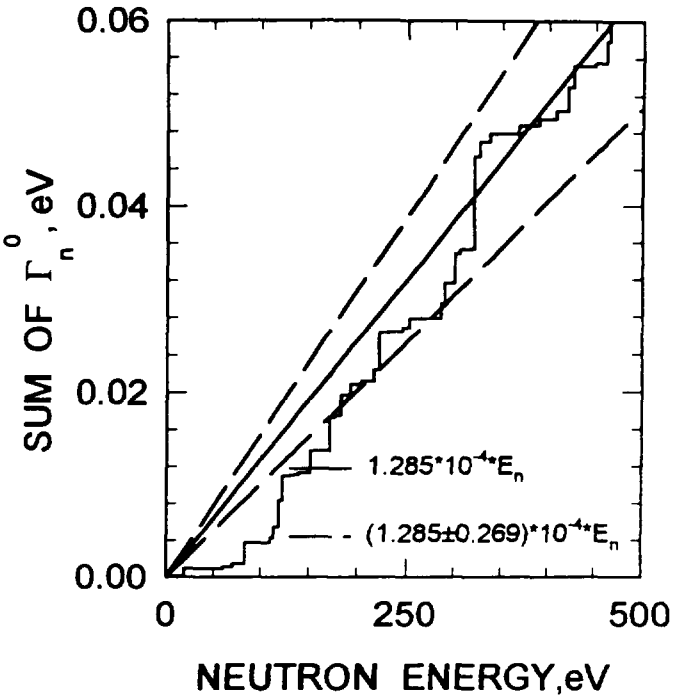

Fig.15b ^{238}Pu: Cumulative sum of reduced neutron widths

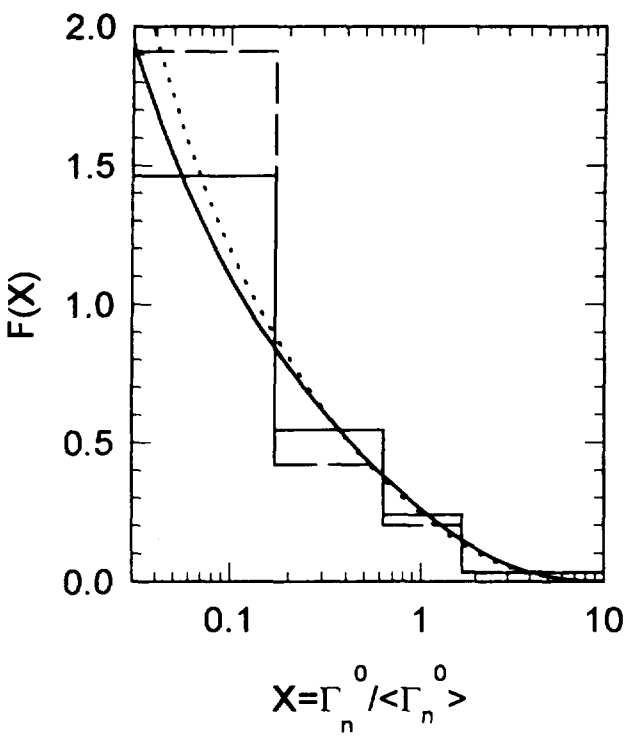

Fig.15c ^{238}Pu: Reduced neutron width distribution

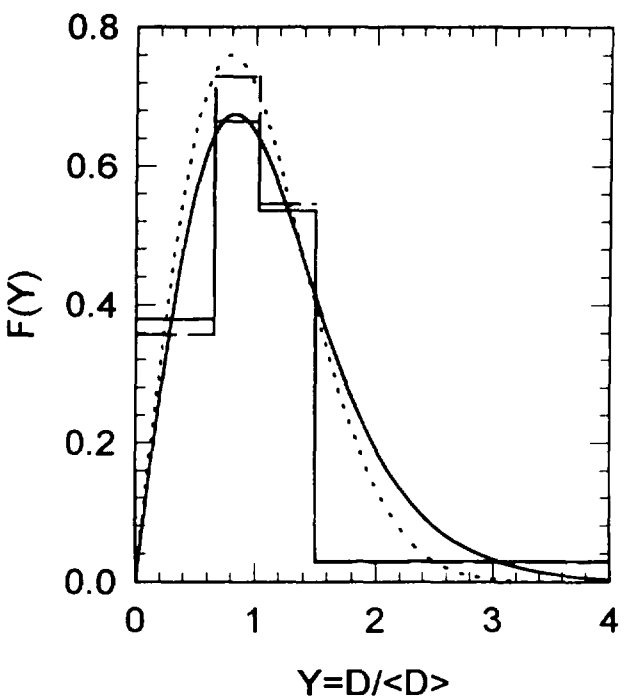

Fig.15d ^{238}Pu: Level spacing distribution

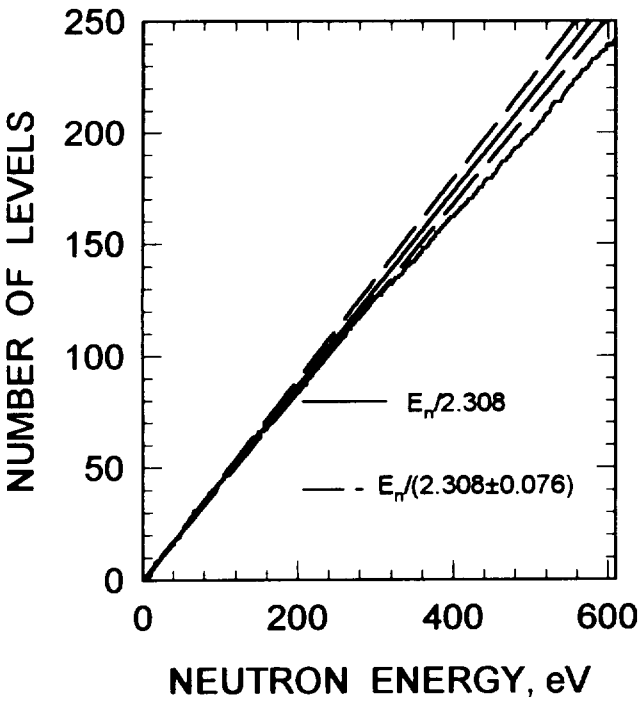

Fig.16a ^{239}Pu: Cumulative sum of levels

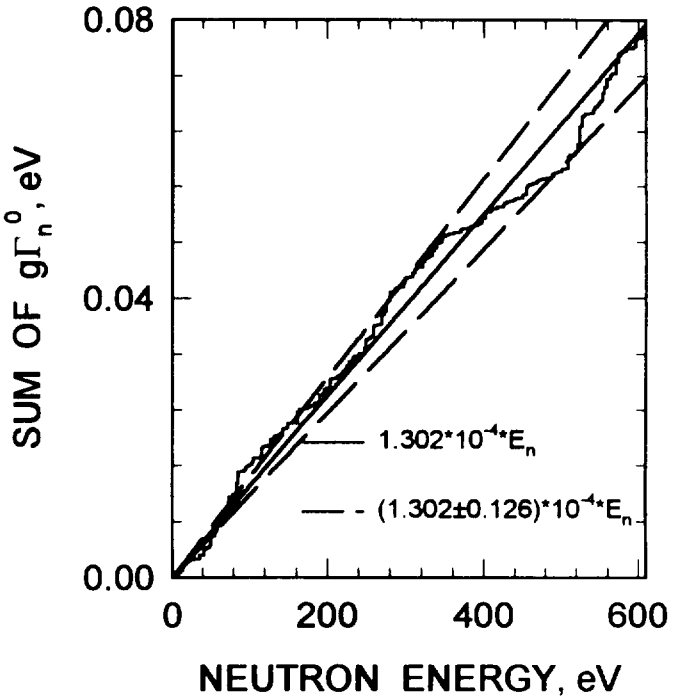

Fig.16b ^{239}Pu: Cumulative sum of reduced neutron widths

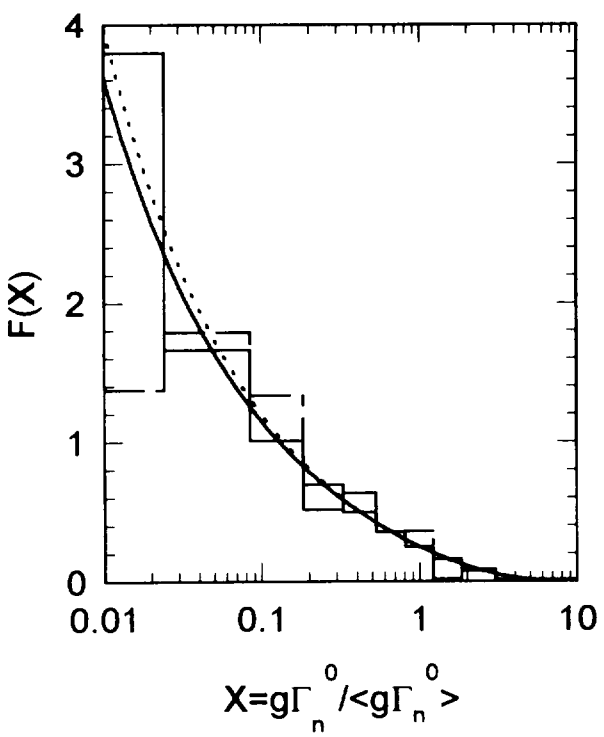

Fig.16c ^{239}Pu: Reduced neutron width distribution

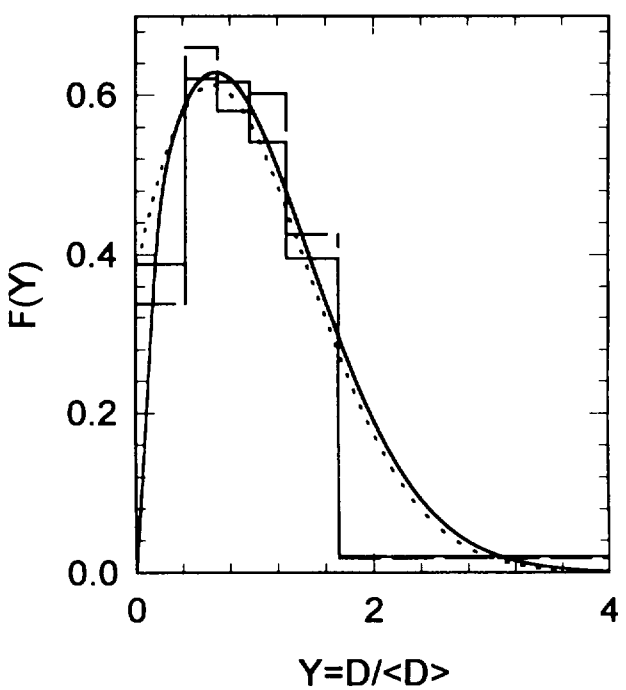

Fig.16d ^{239}Pu: Level spacing distribution

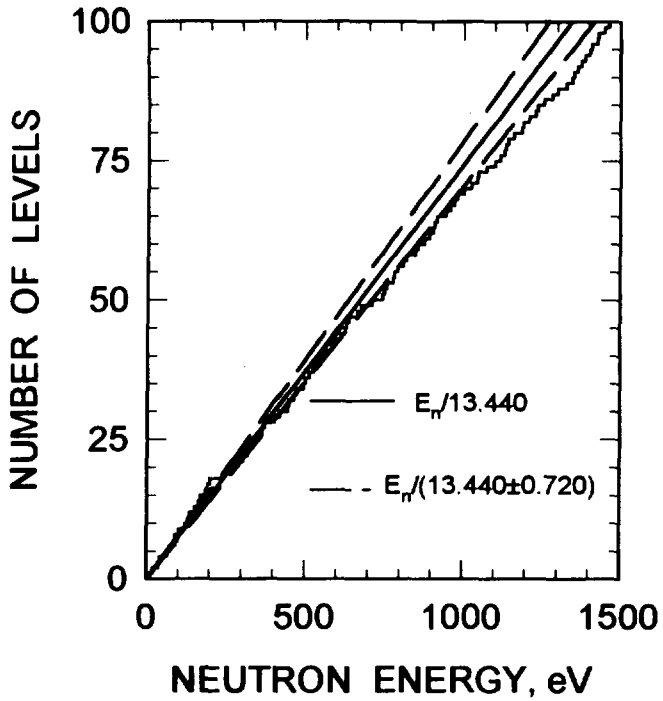

Fig.17a ^{240}Pu: Cumulative sum of levels

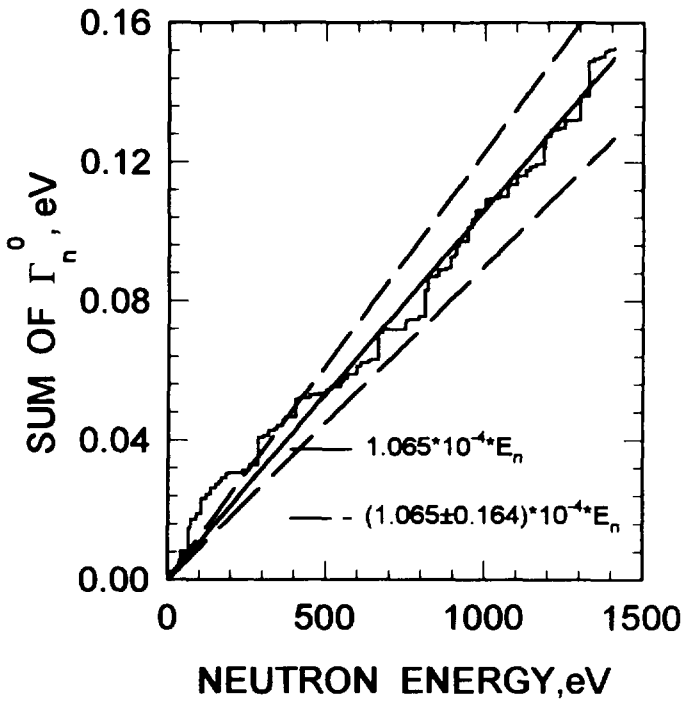

Fig.17b ^{240}Pu: Cumulative sum of reduced neutron widths

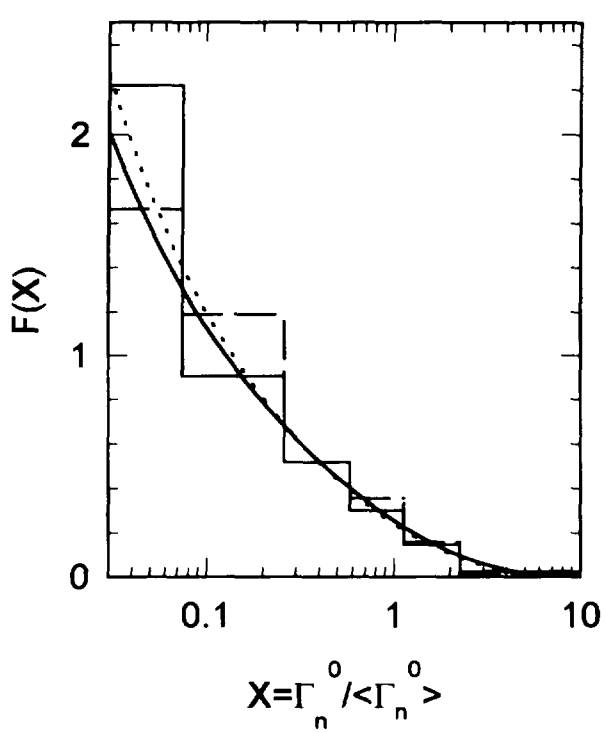

Fig.17c ^{240}Pu: Reduced neutron width distribution

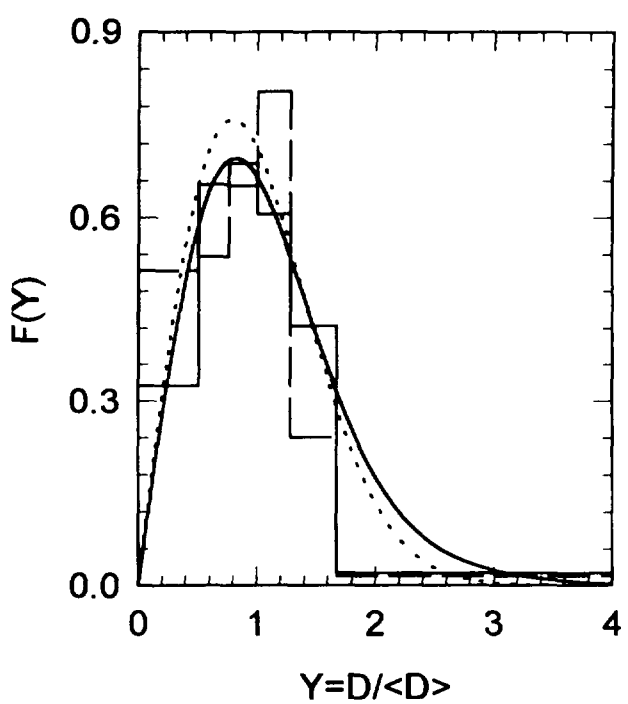

Fig.17d ^{240}Pu: Level spacing distribution

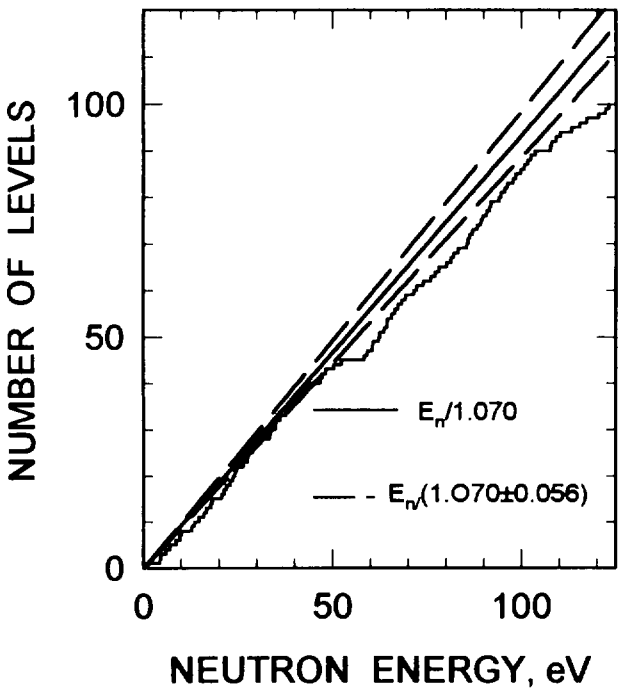

Fig.18a ^{241}Pu Cumulative sum of levels

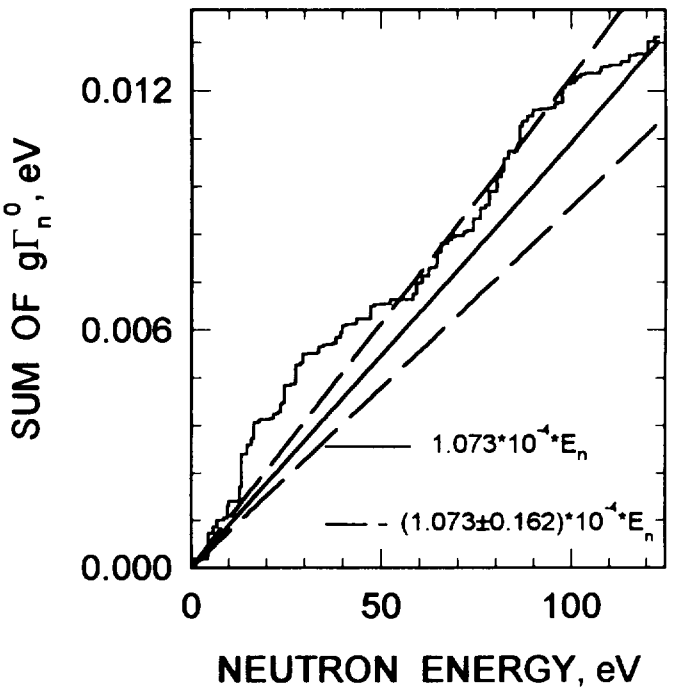

Fig.18b ^{241}Pu: Cumulative sum of reduced neutron widths

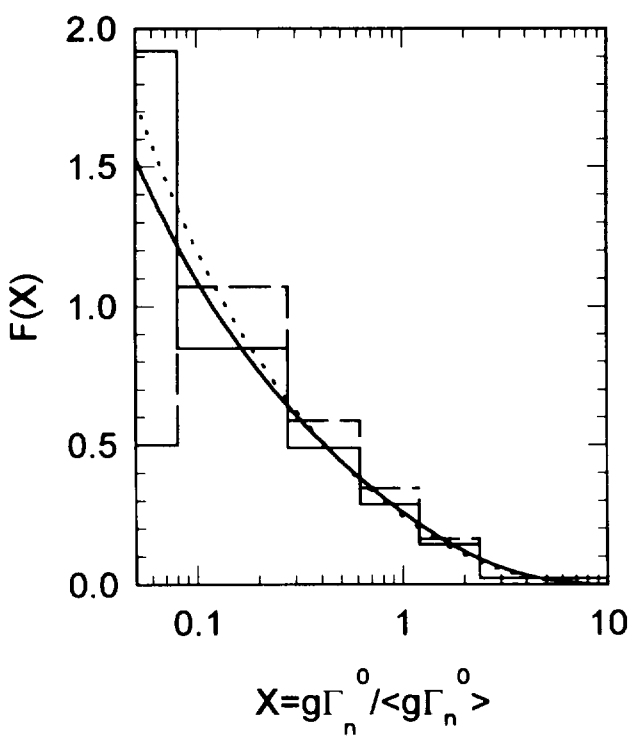

Fig.18c ^{241}Pu: Reduced neutron width distribution

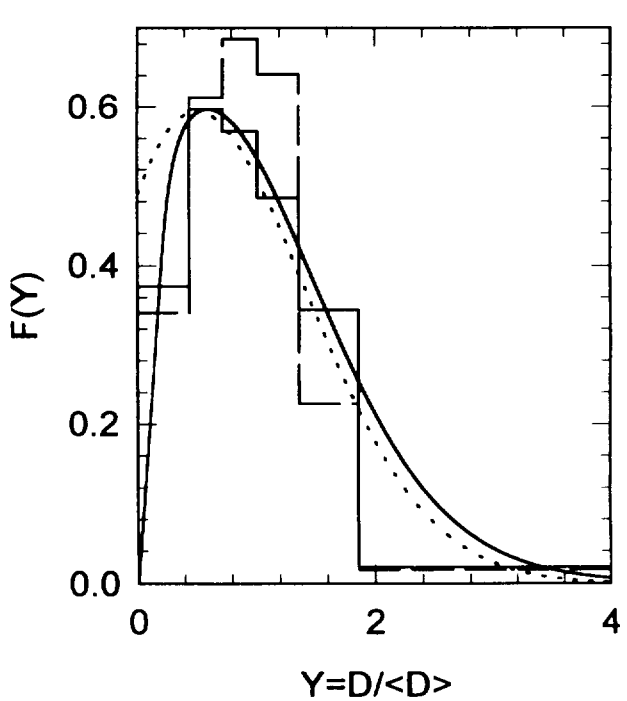

Fig.18d ^{241}Pu: Level spacing distribution

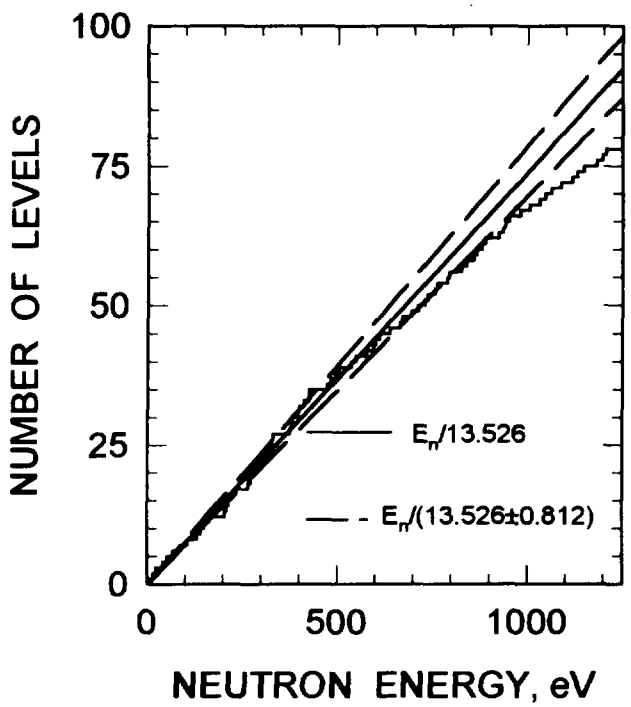

Fig.19a ^{242}Pu: Cumulative sum of levels

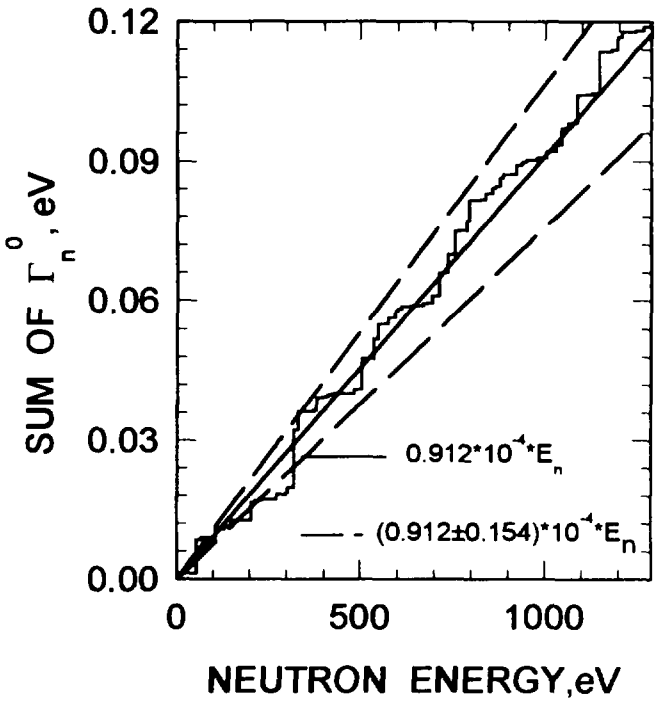

Fig.19b ^{242}Pu: Cumulative sum of reduced neutron widths

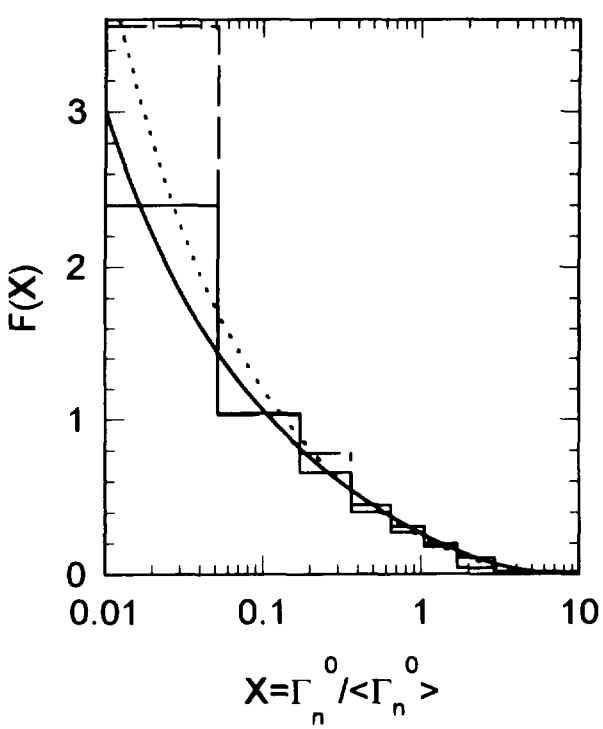

Fig.19c ^{242}Pu: Reduced neutron width distribution

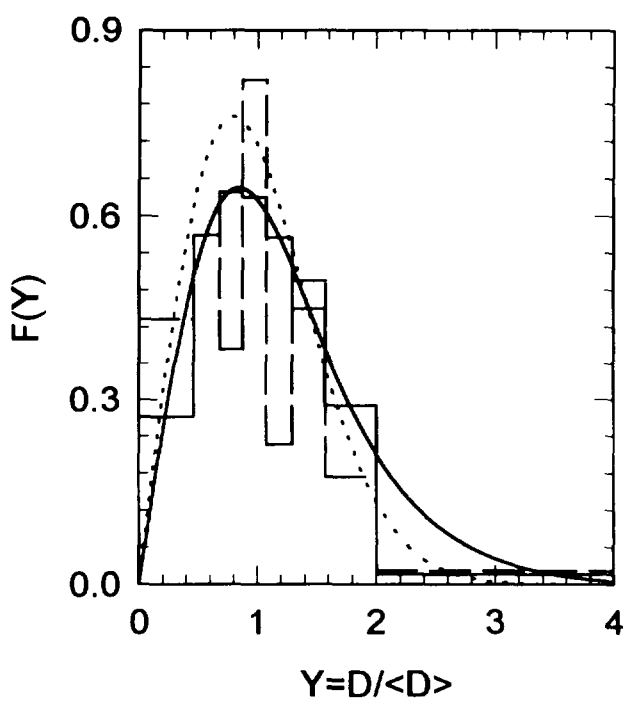

Fig.19d ^{242}Pu: Level spacing distribution

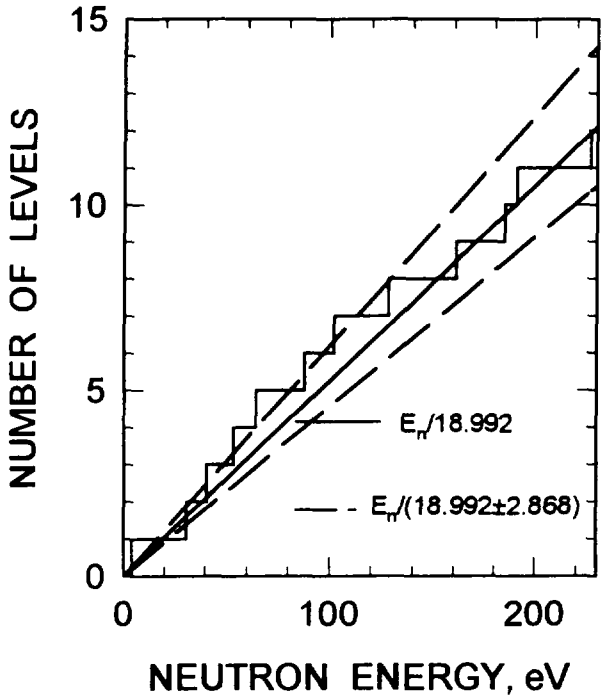

Fig.20a ^{244}Pu: Cumulative sum of levels

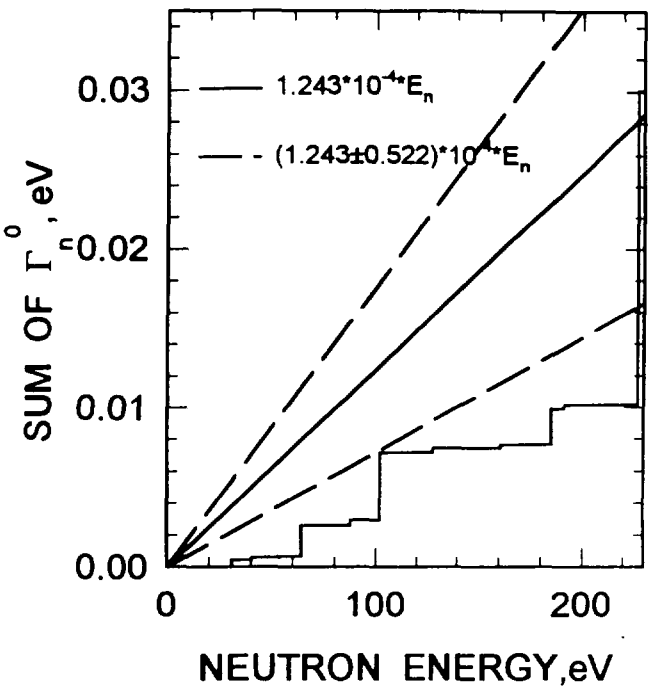

Fig.20b ^{244}Pu: Cumulative sum of reduced neutron widths

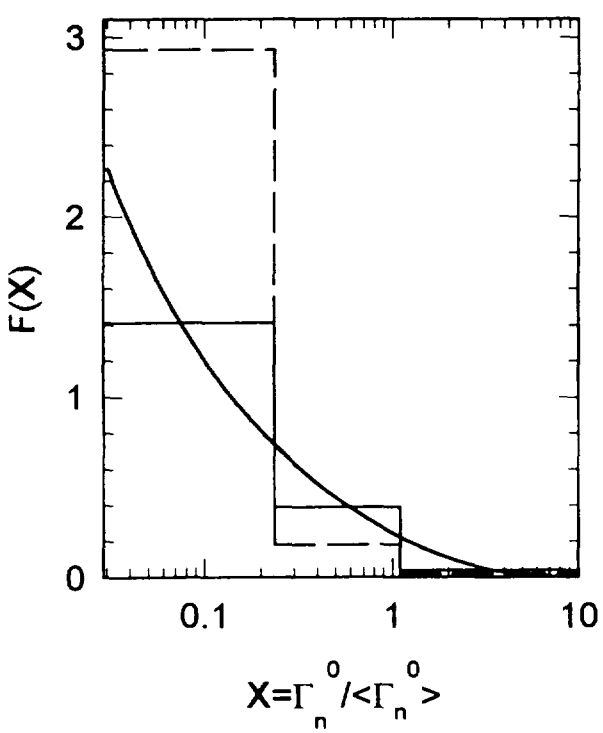

Fig.20c ^{244}Pu: Reduced neutron width distribution

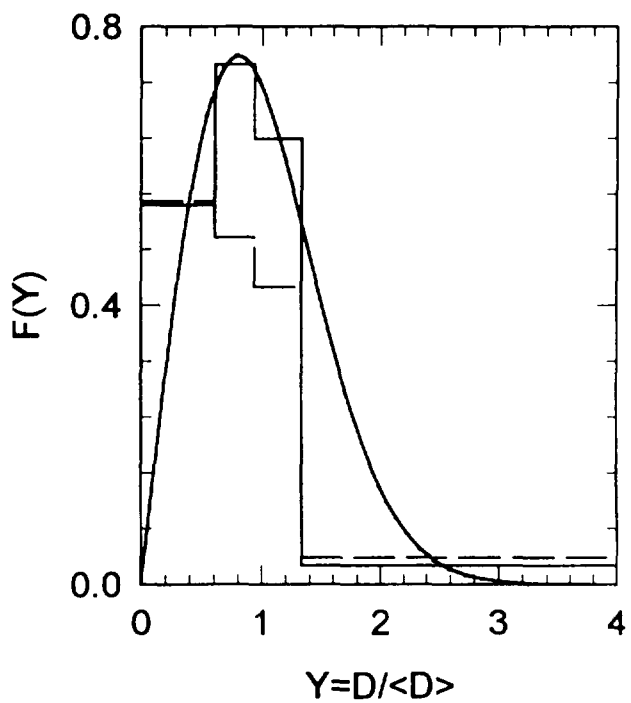

Fig.20d ^{244}Pu: Level spacing distribution

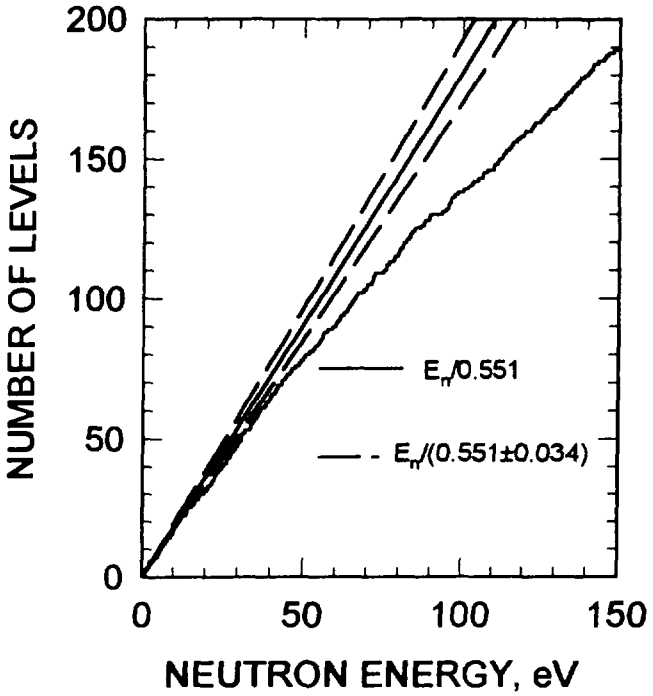

Fig.21a ^{241}Am: Cumulative sum of levels

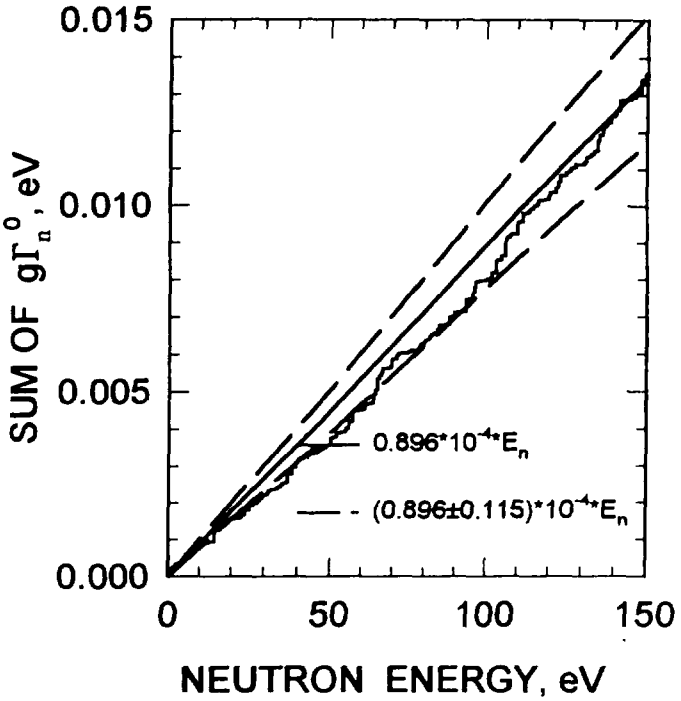

Fig.21b ^{241}Am: Cumulative sum of reduced neutron widths

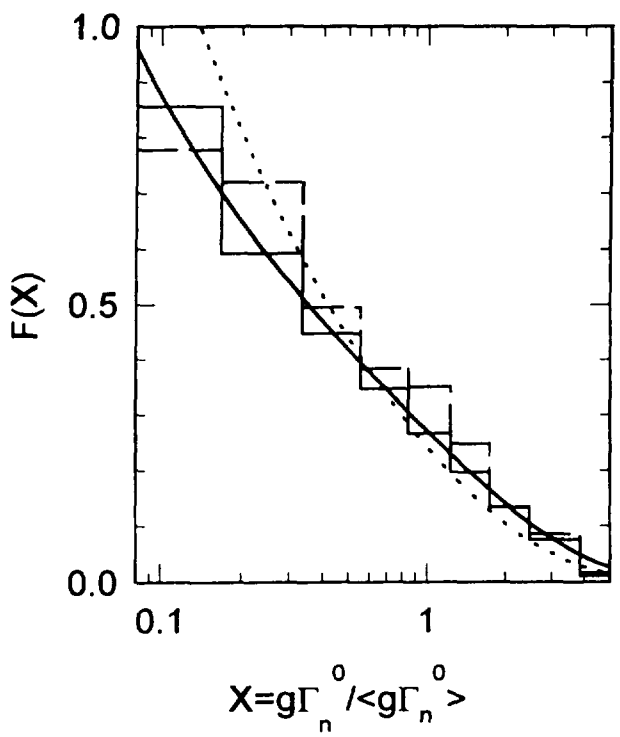

Fig.21c ^{241}Am: Reduced neutron width distribution

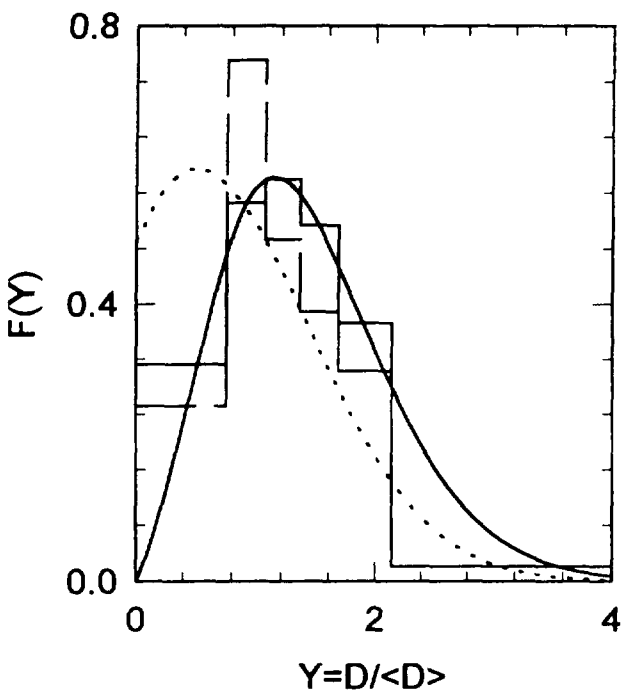

Fig.21d ^{241}Am: Level spacing distribution

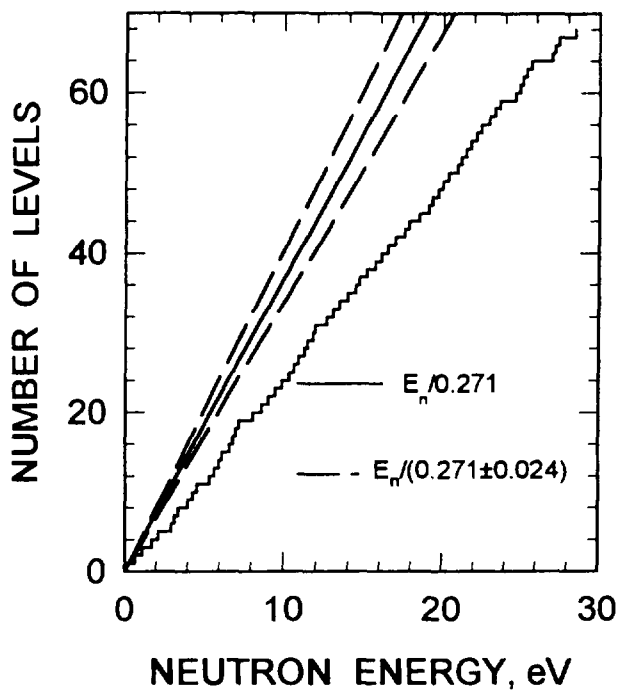

Fig.22a ^{242m}Am: Cumulative sum of levels

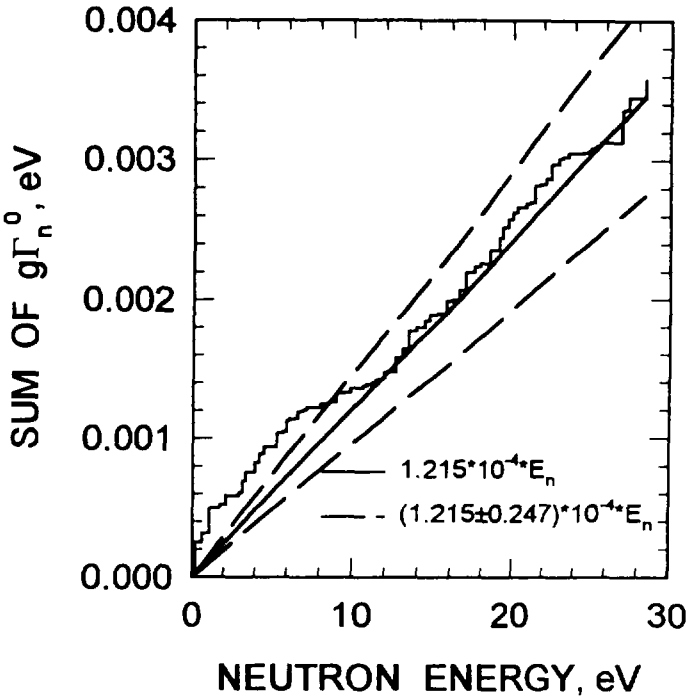

Fig.22b ^{242m}Am: Cumulative sum of reduced neutron widts

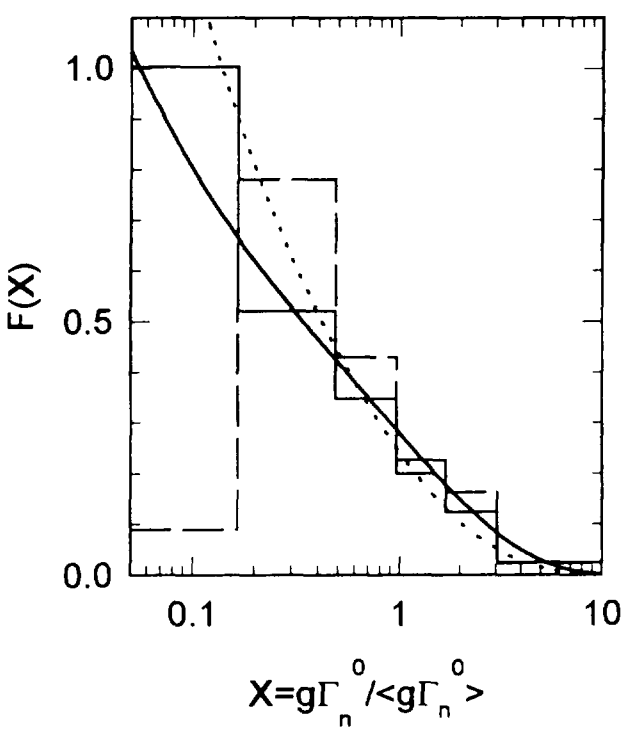

Fig.22c ^{242m}Am: Reduced neutron width distribution

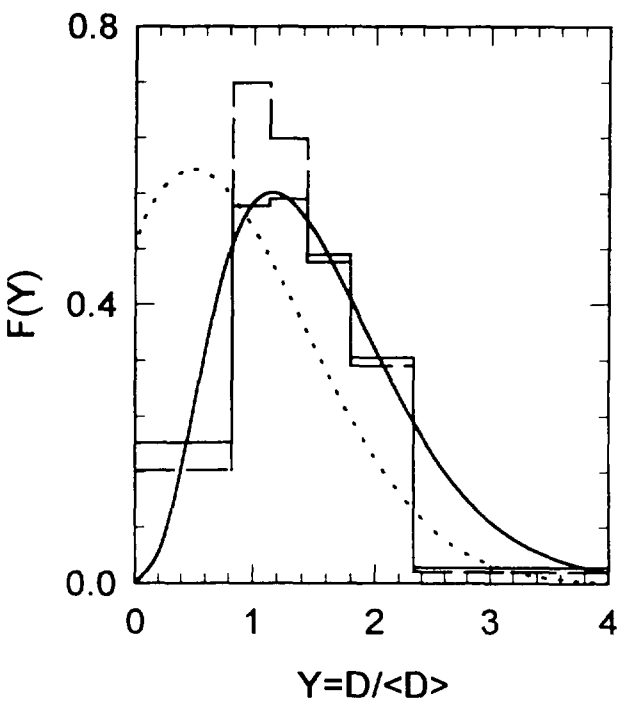

Fig.22d ^{242m}Am: Level spacing distribution

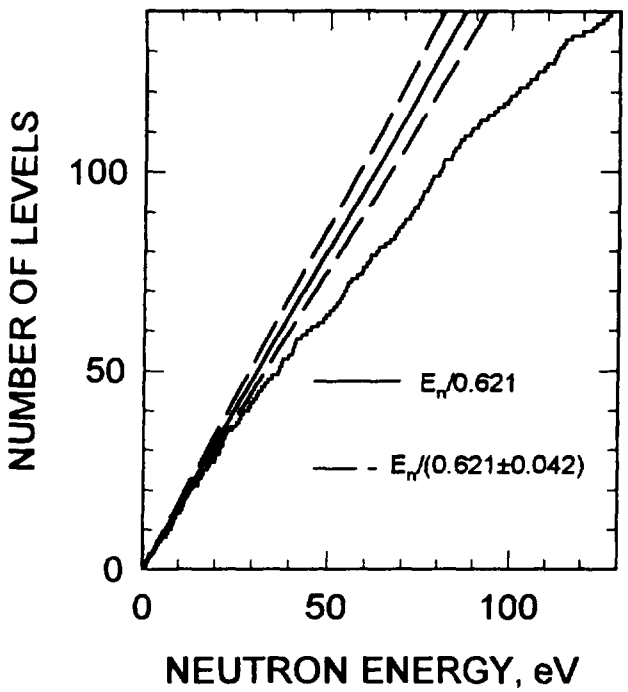

Fig.23a ^{243}Am: Cumulative sum of levels

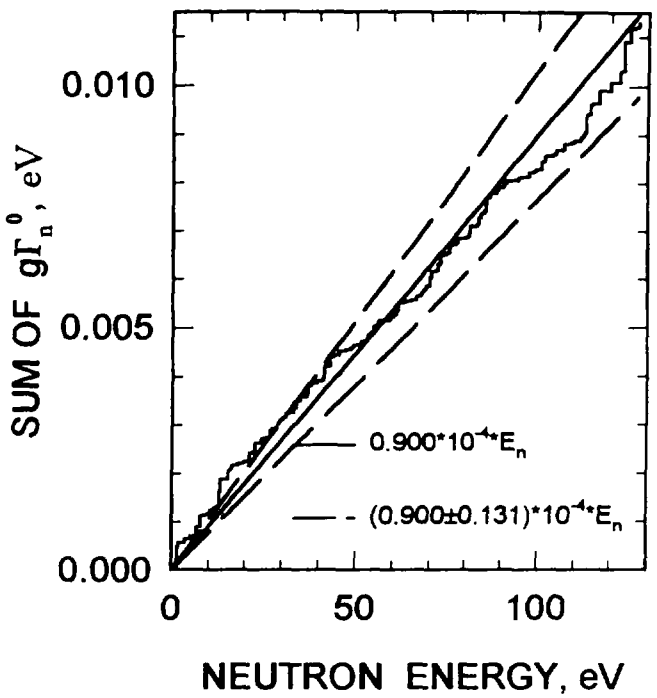

Fig.23b ^{243}Am: Cumulative sum of reduced neutron widths

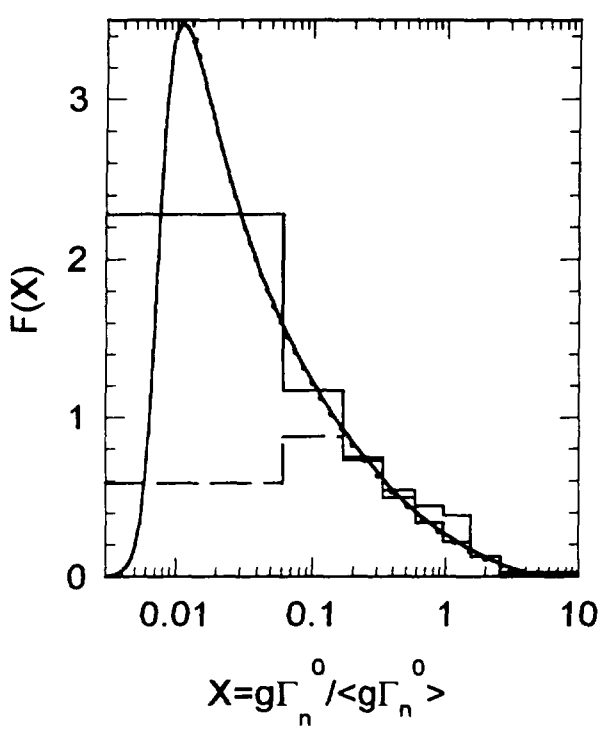

Fig.23c ^{243}Am: Reduced neutron width distribution

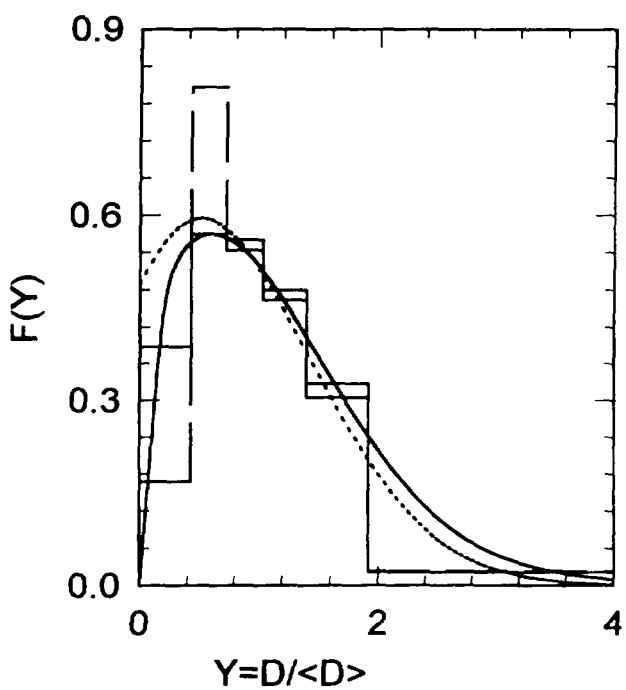

Fig.23d ^{243}Am: Level spacing distribution

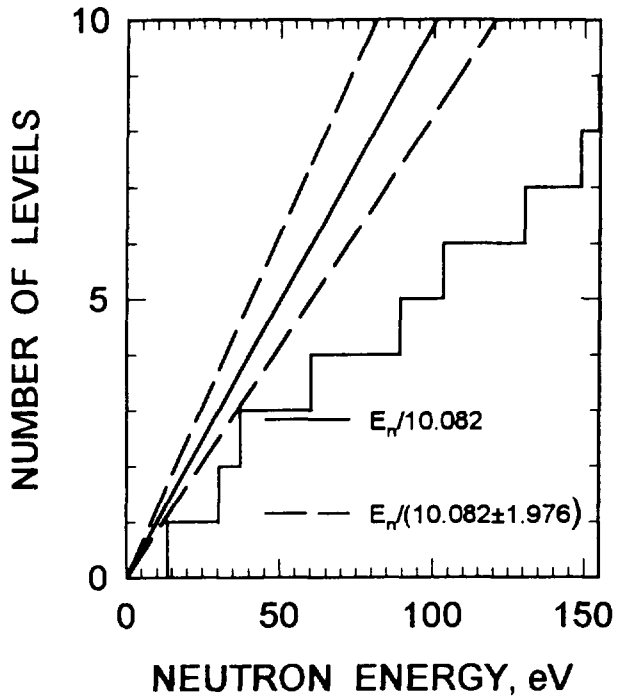

Fig.24a ^{242}Cm: Cumulative sum of levels

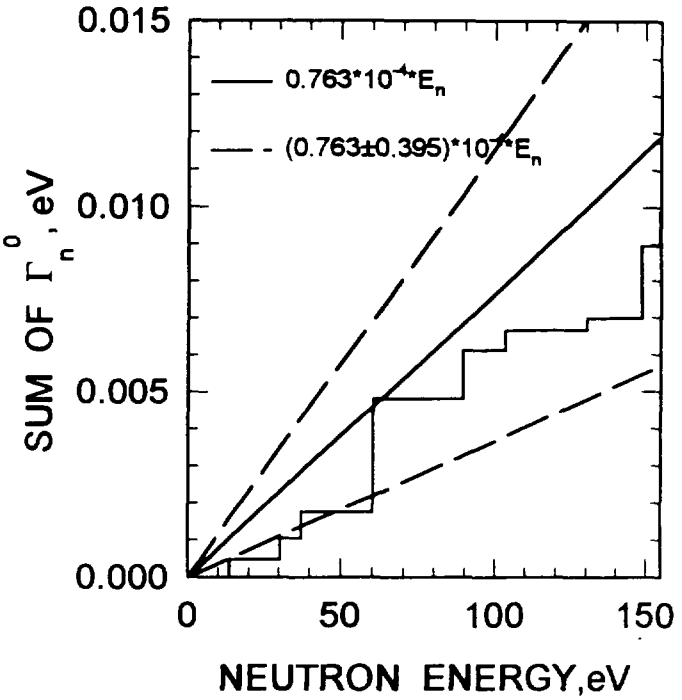

Fig.24b ^{242}Cm: Cumulative sum of reduced neutron widths

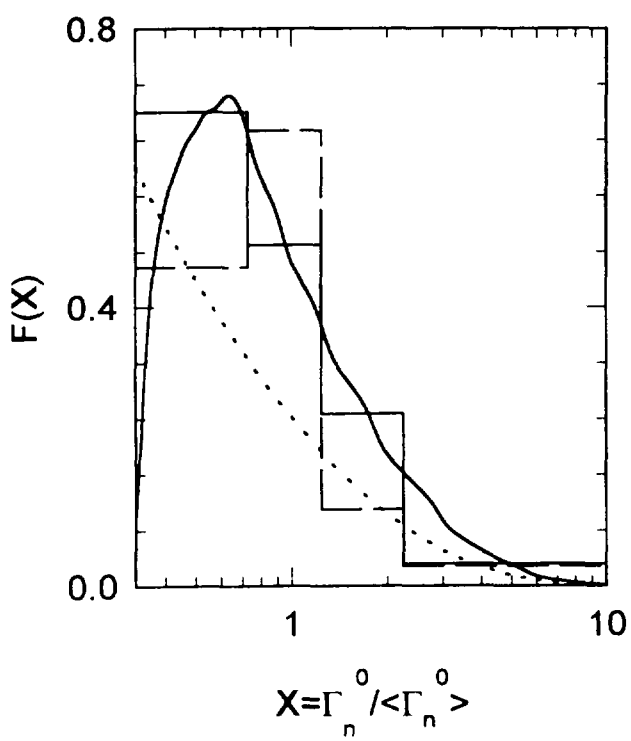

Fig.24c ^{242}Cm: Reduced neutron width distribution

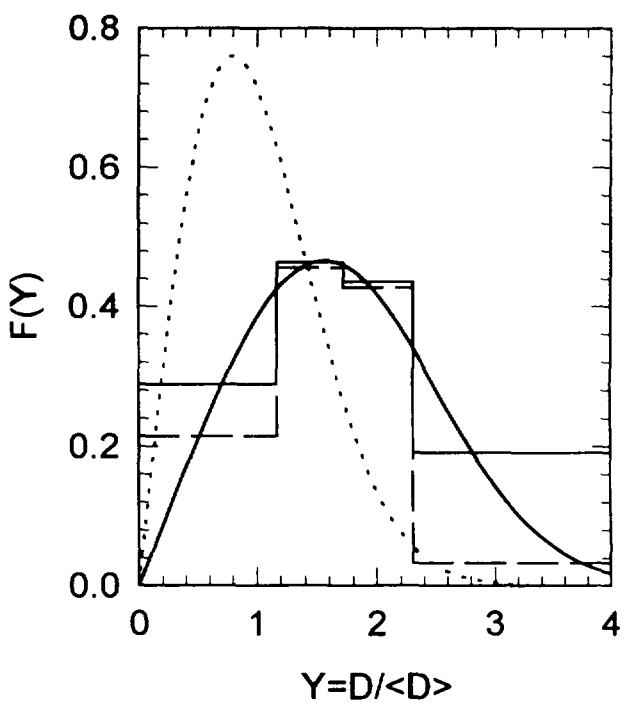

Fig.24d ^{242}Cm: Level spacing distribution

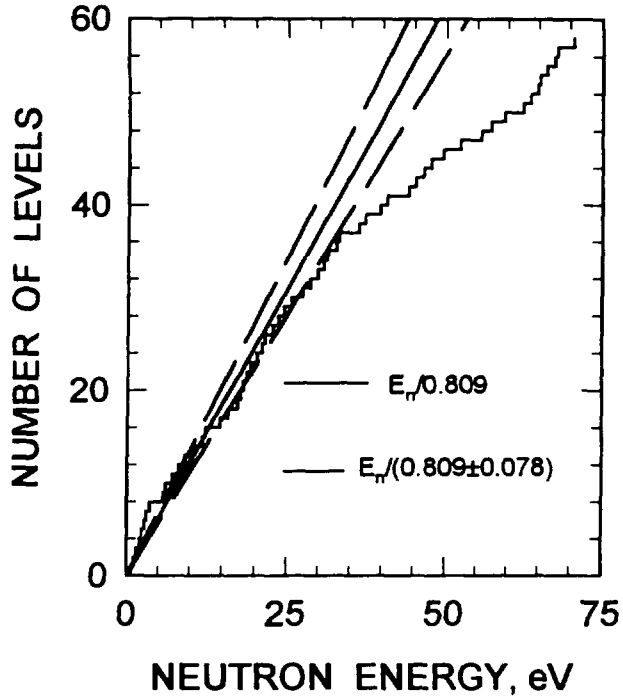

Fig.25a ^{243}Cm: Cumulative sum of levels

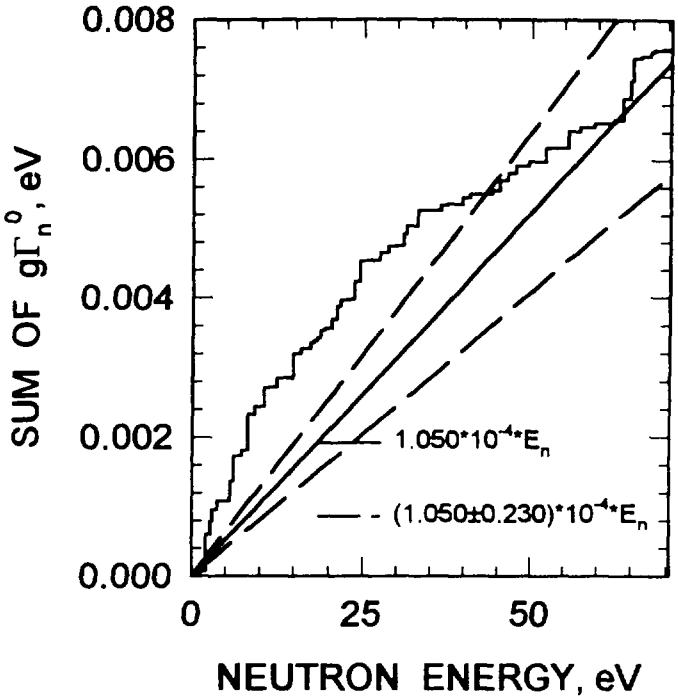

Fig.25b ^{243}Cm: Cumulative sum of reduced neutron widths

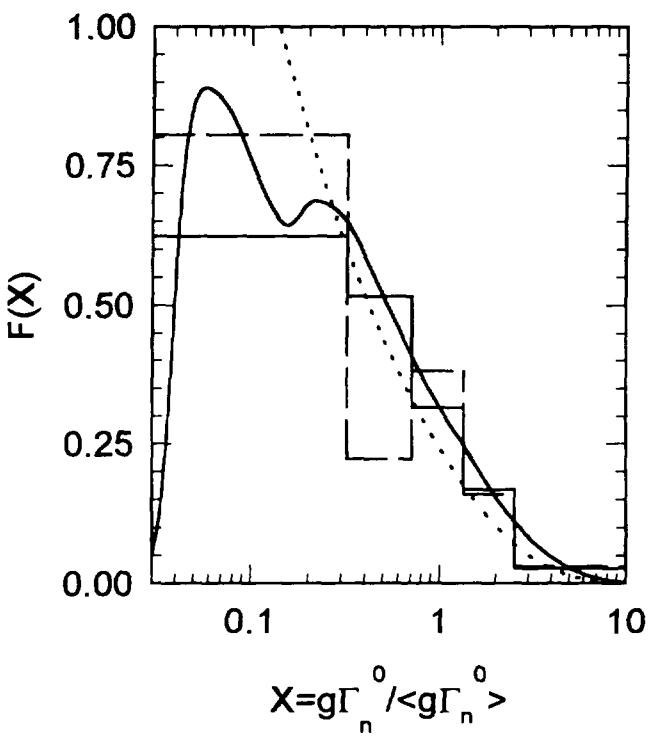

Fig.25c ^{243}Cm: Reduced neutron width distribution

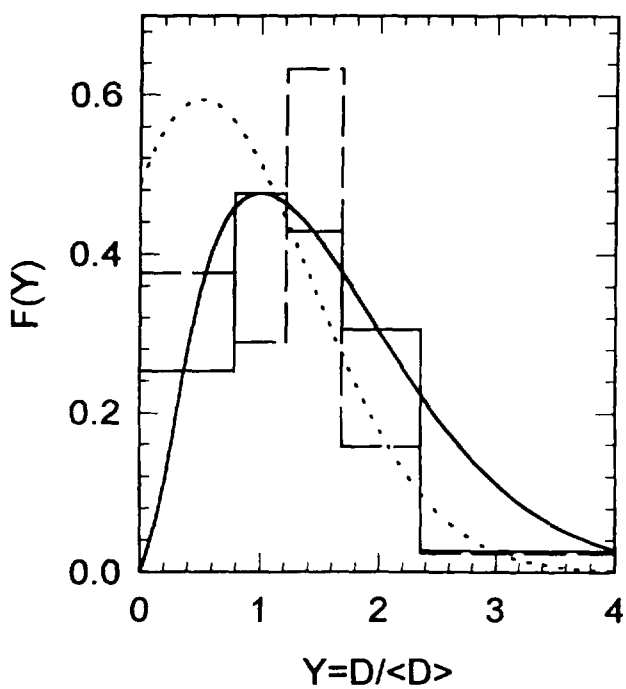

Fig.25d ^{243}Cm: Level spacing distribution

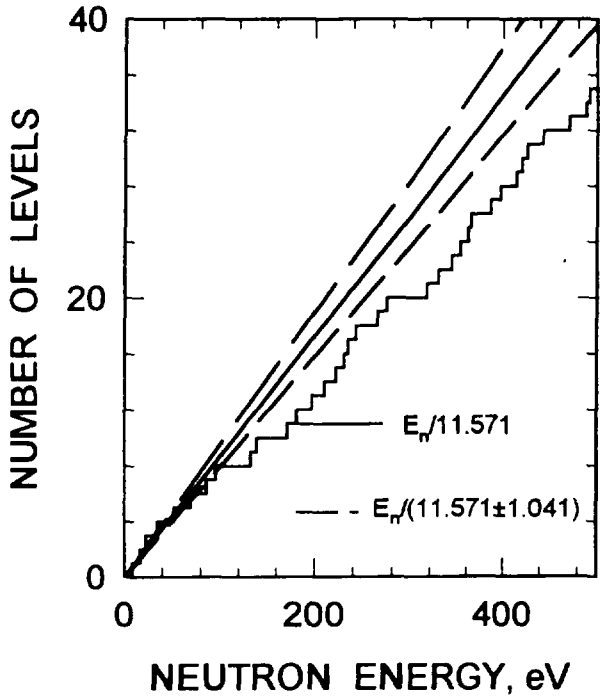

Fig.26a ^{244}Cm: Cumulative sum of levels

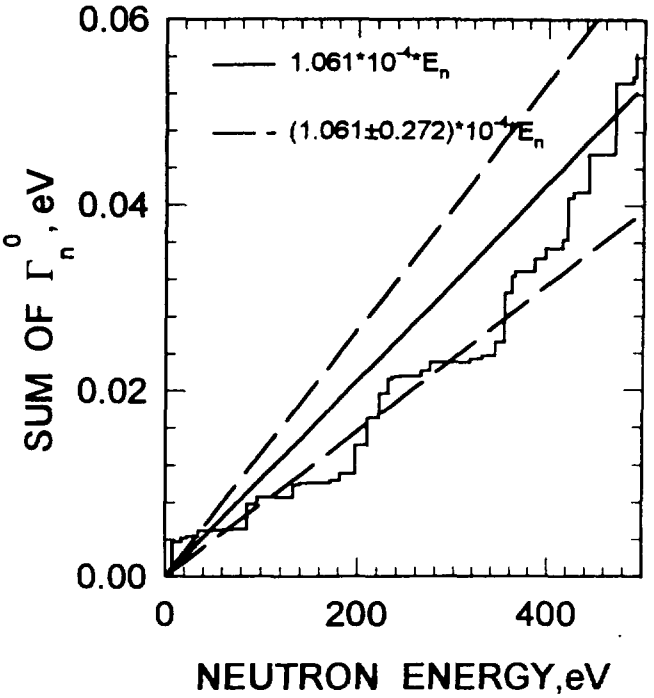

Fig.26b ^{244}Cm: Cumulative sum of reduced neutron widths

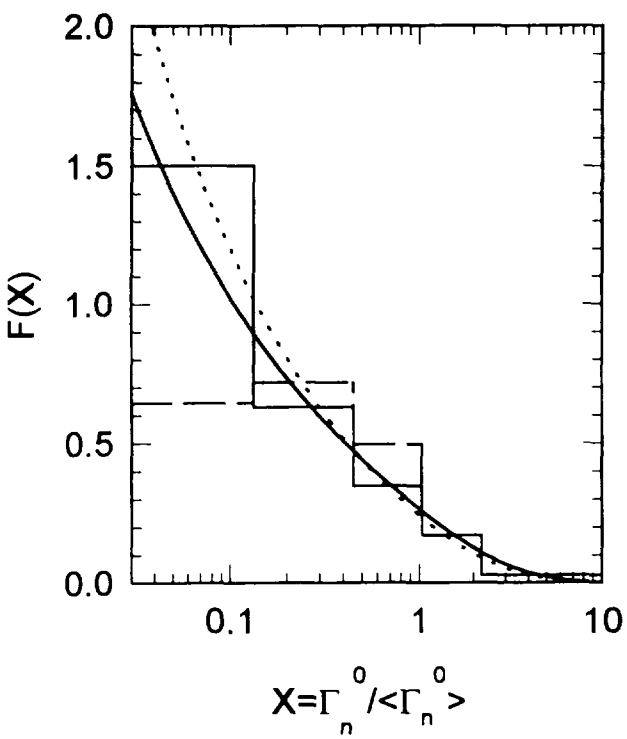

Fig.26c ^{244}Cm: Reduced neutron width distribution

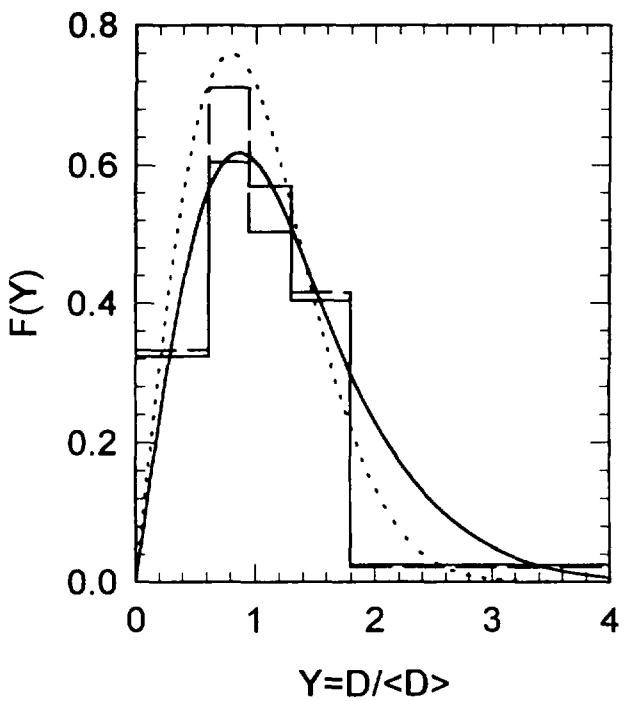

Fig.26d ^{244}Cm: Level spacing distribution

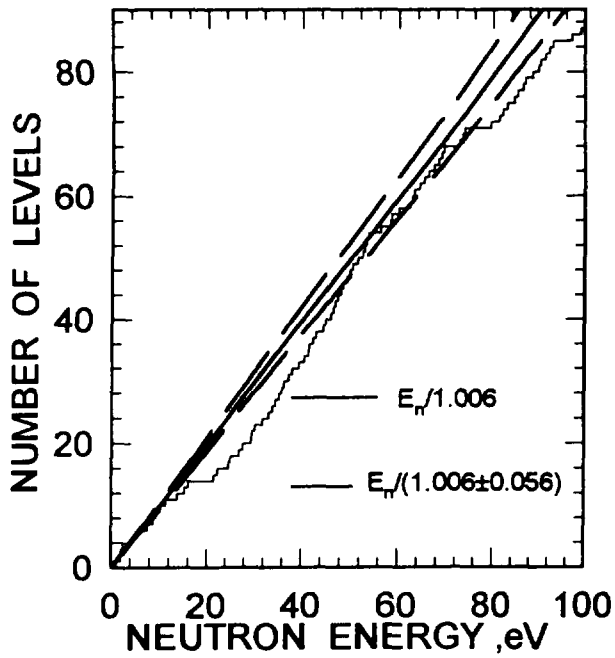

Fig.27a ^{245}Cm: Cumulative sum of levels

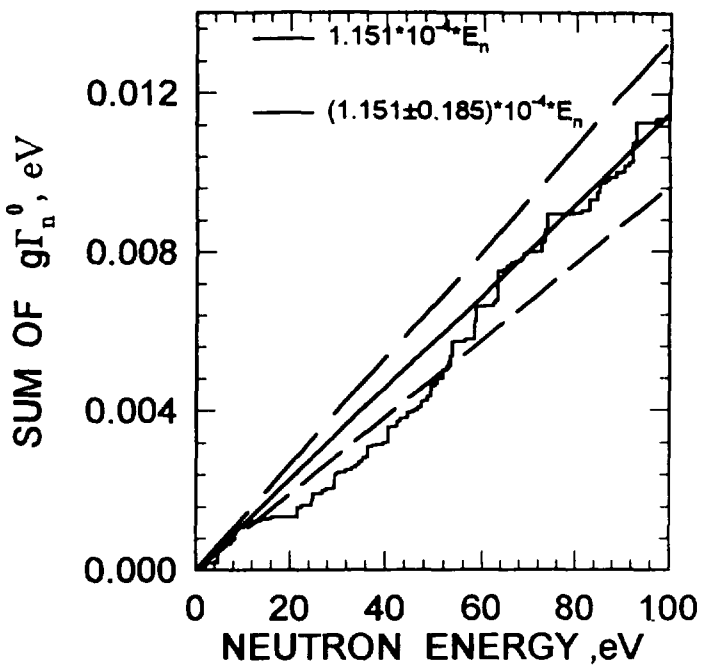

Fig.27b ^{245}Cm: Cumulative sum of reduced neutron widths

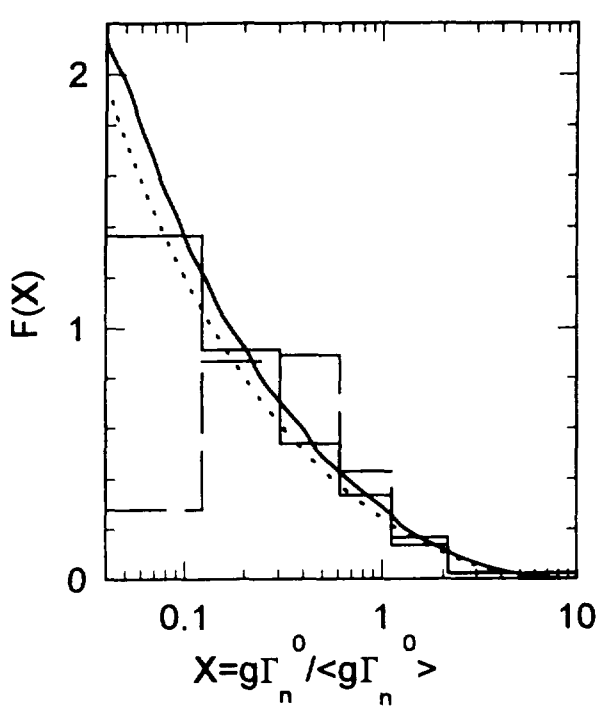

Fig.27c ^{245}Cm: Reduced neutron width distribution

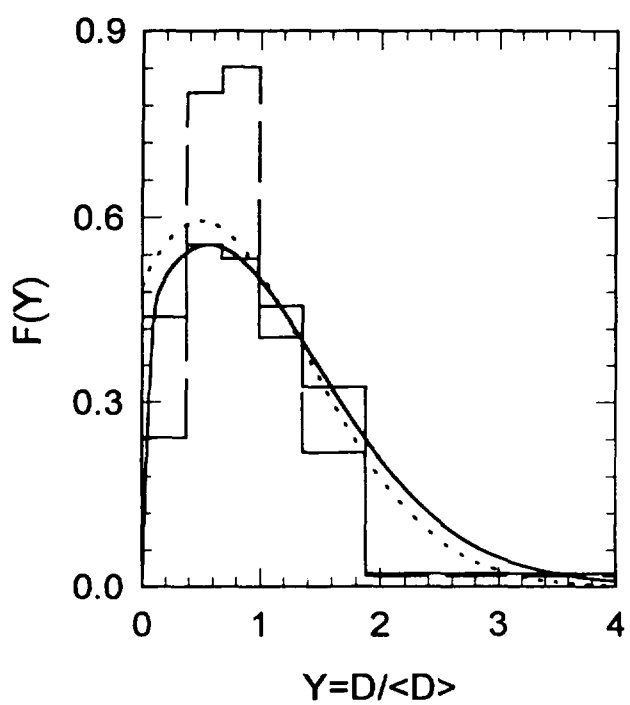

Fig.27d ^{245}Cm: Level spacing distribution

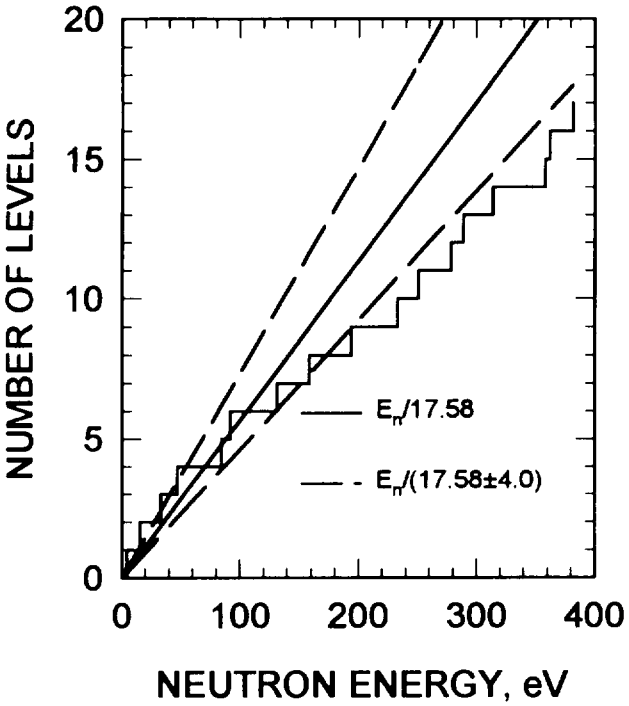

Fig.28a ^{246}Cm: Cumulative sum of levels

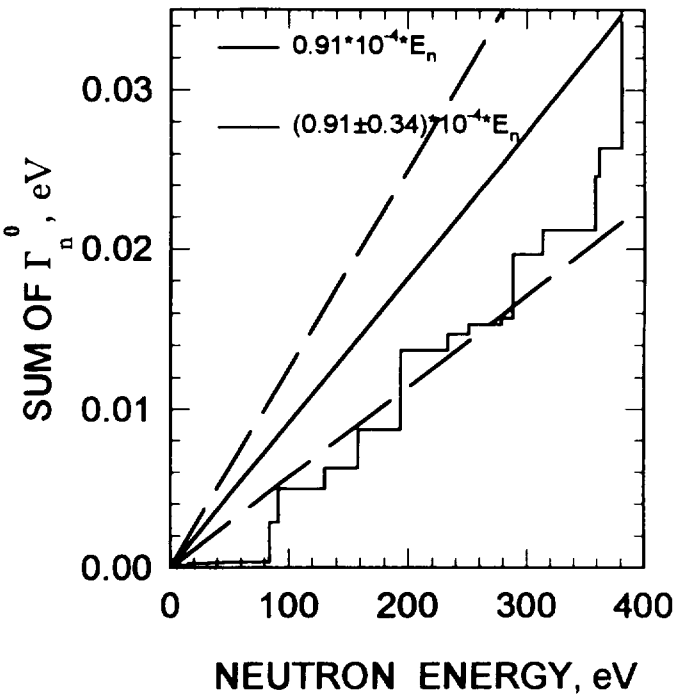

Fig.28b ^{246}Cm: Cumulative sum of reduced neutron widths

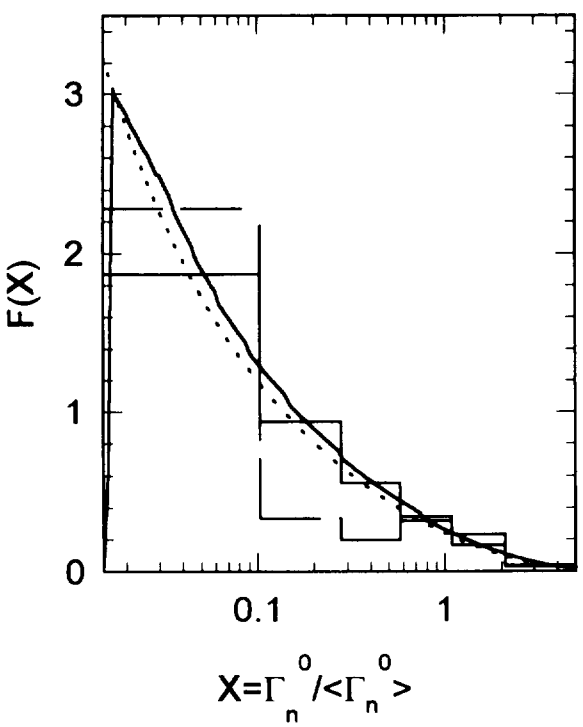

Fig.28c ^{246}Cm: Reduced neutron width distribution

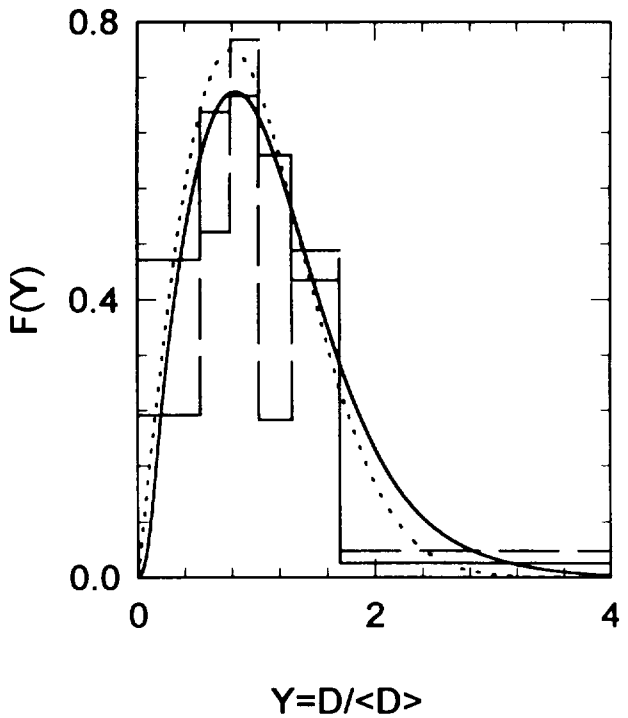

Fig.28d ^{246}Cm: Level spacing distribution

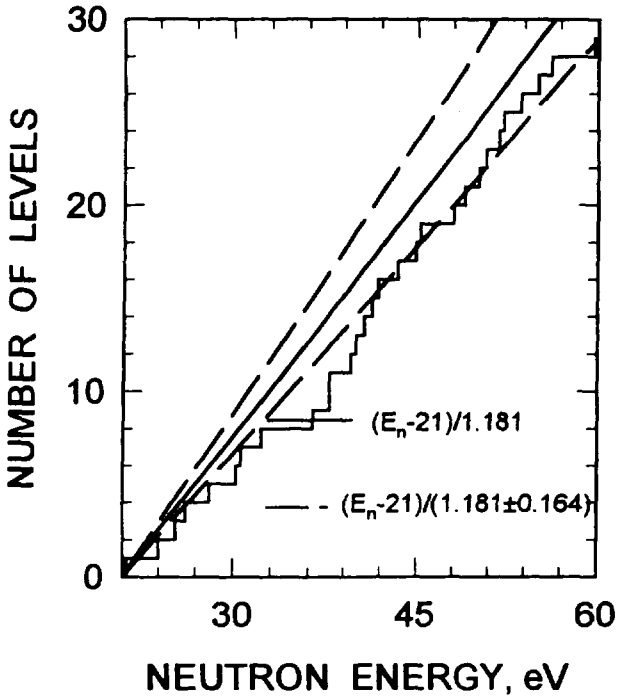

Fig.29a ^{247}Cm: Cumulative sum of levels

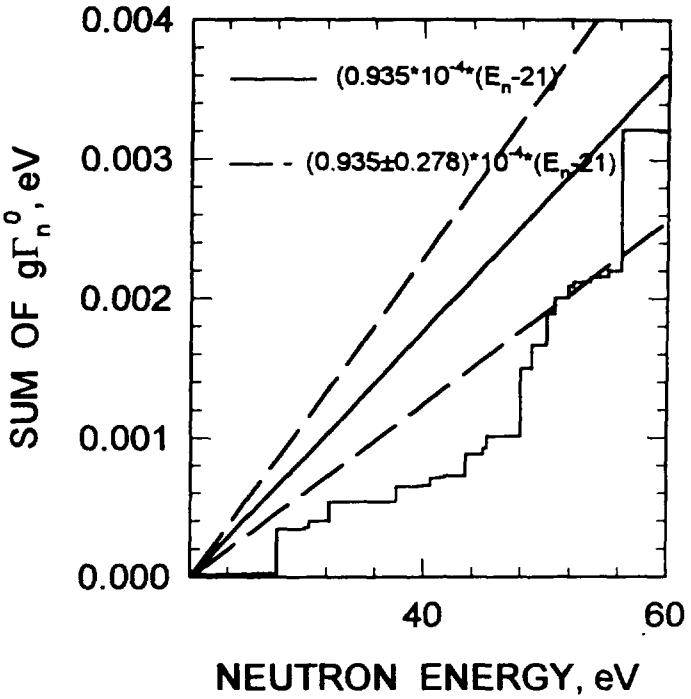

Fig.29b ^{247}Cm: Cumulative sum of reduced neutron widths

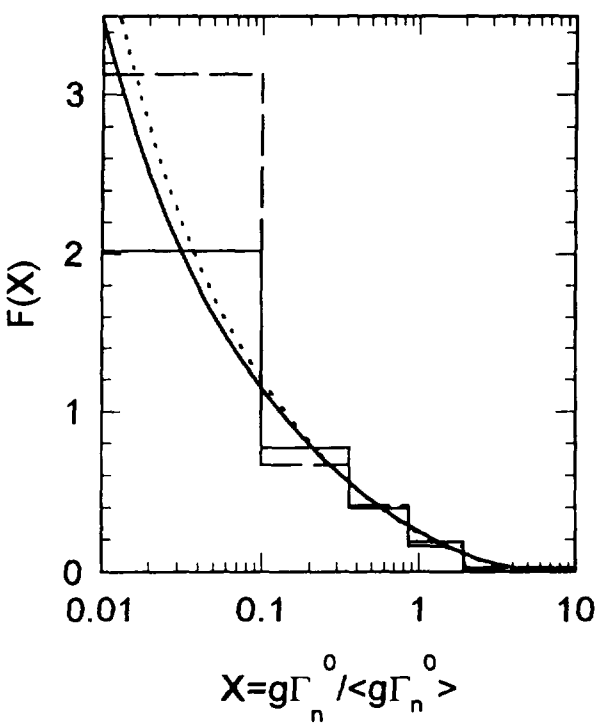

Fig.29c ^{247}Cm: Reduced neutron width distribution

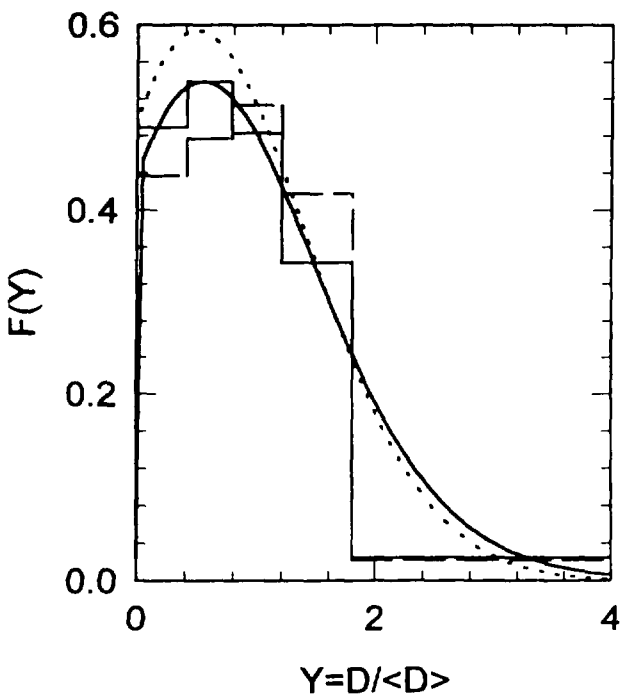

Fig.29d ^{247}Cm: Level spacing distribution

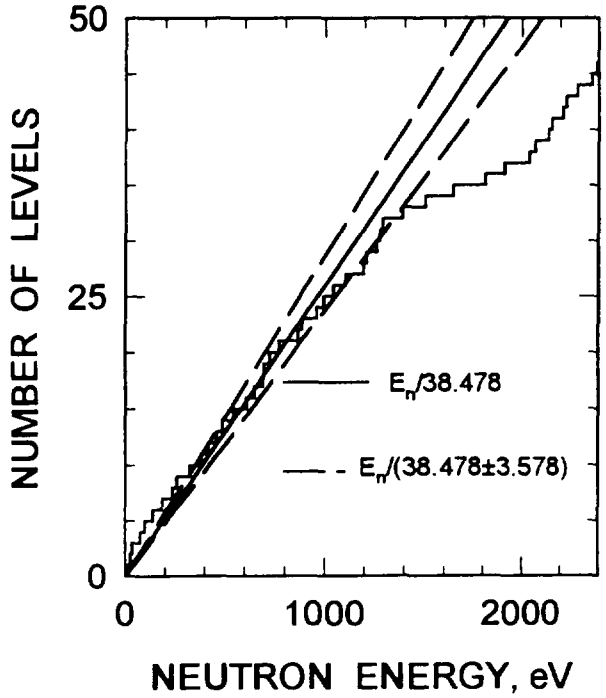

Fig.30a ^{248}Cm: Cumulative sum of levels

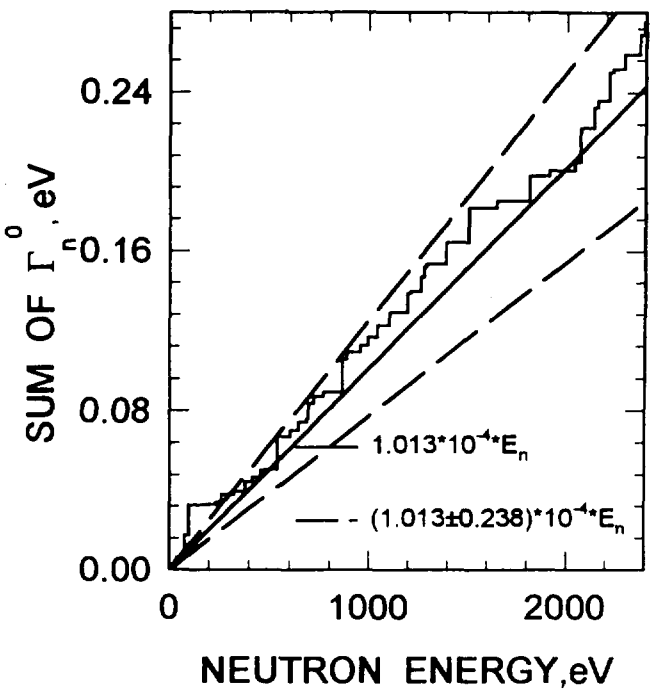

Fig.30b ^{248}Cm: Cumulative sum of reduced neutron widths

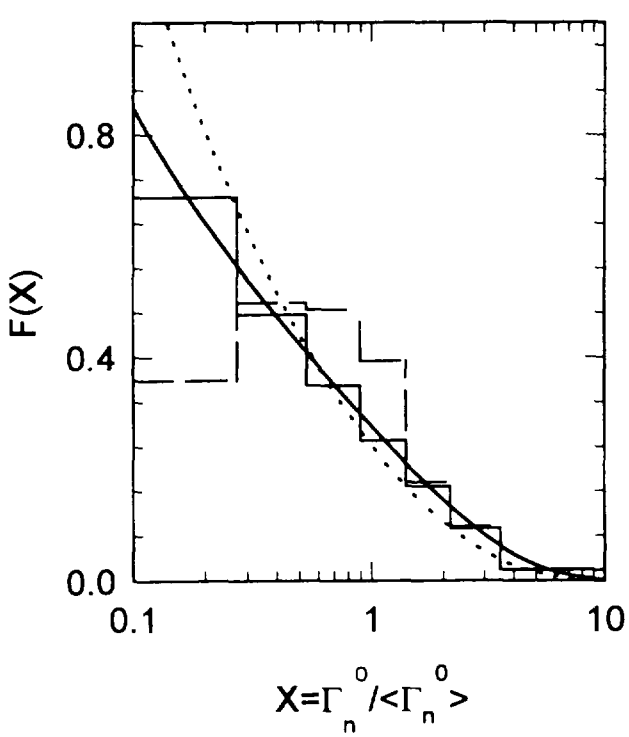

Fig.30c ^{248}Cm: Reduced neutron width distribution

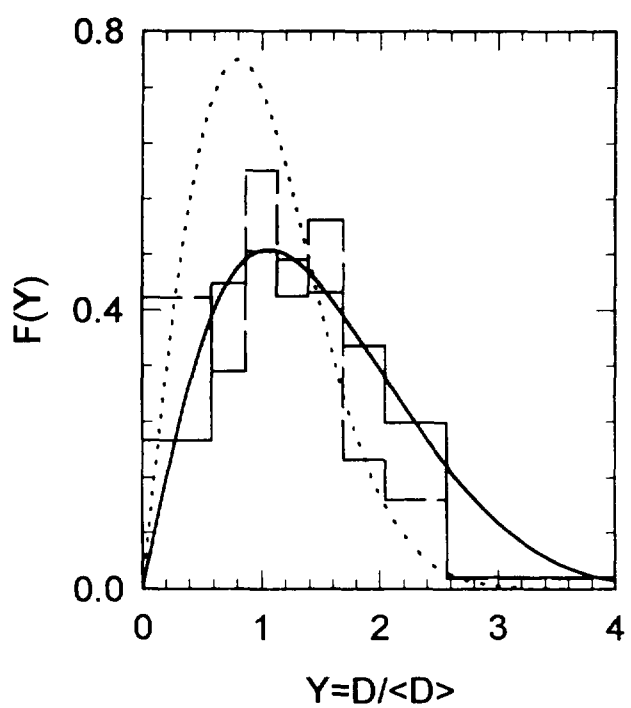

Fig.30d ^{248}Cm: Level spacing distribution

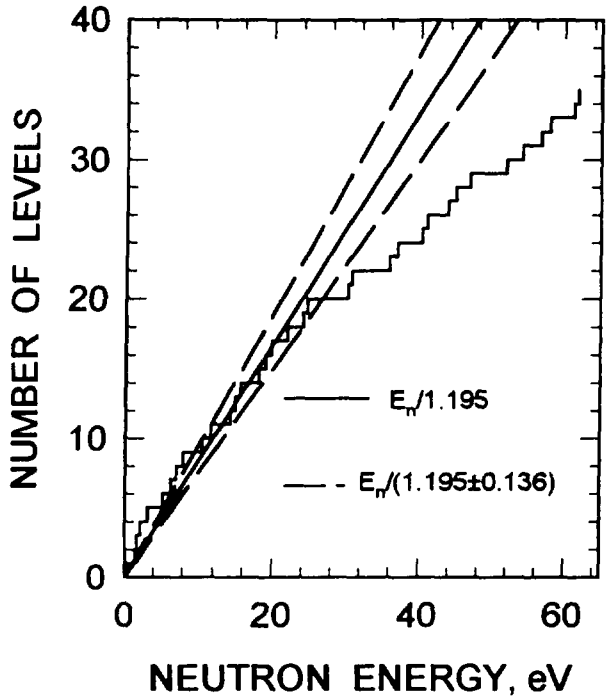

Fig.31a ^{249}Bk: Cumulative sum of levels

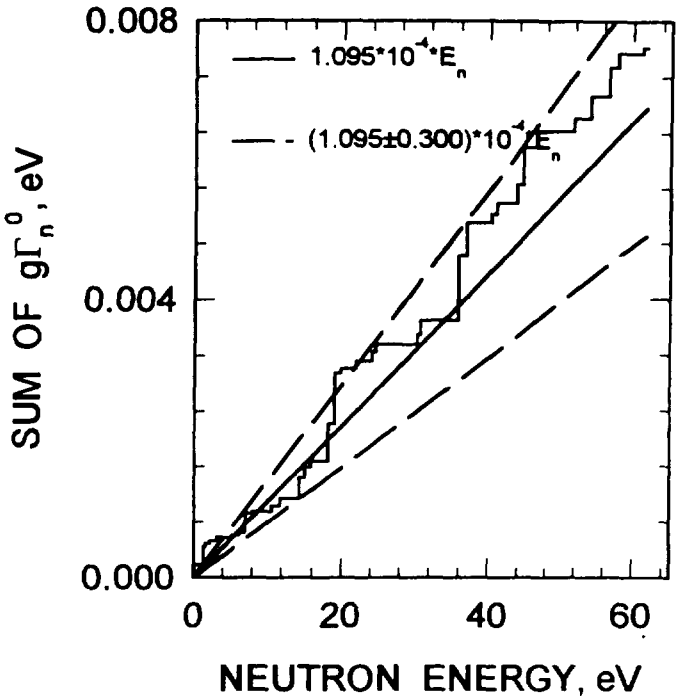

Fig.31b ^{249}Bk: Cumulative sum of reduced neutron widths

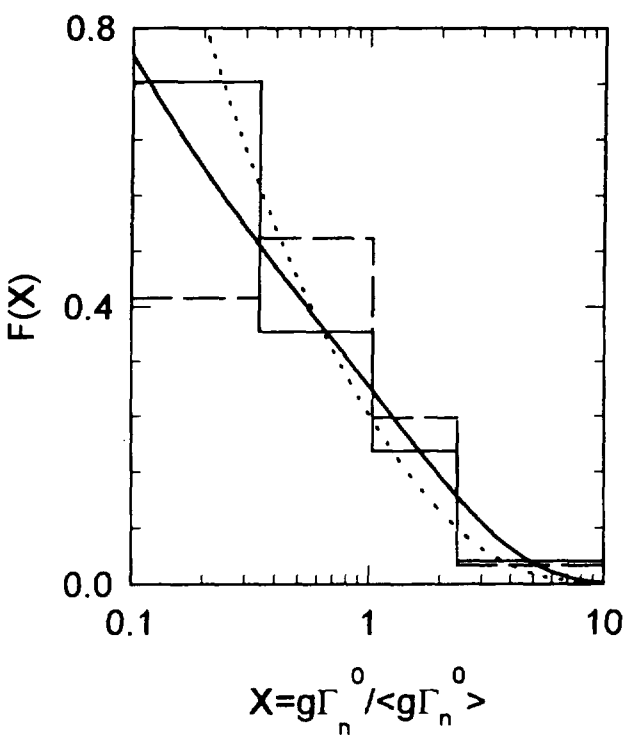

Fig.31c ^{249}Bk: Reduced neutron width distribution

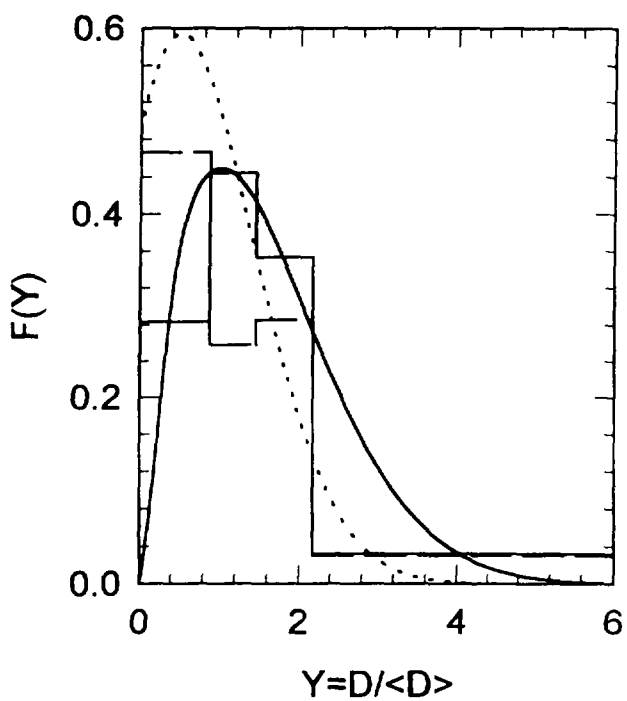

Fig.31d ^{249}Bk: Level spacing distribution

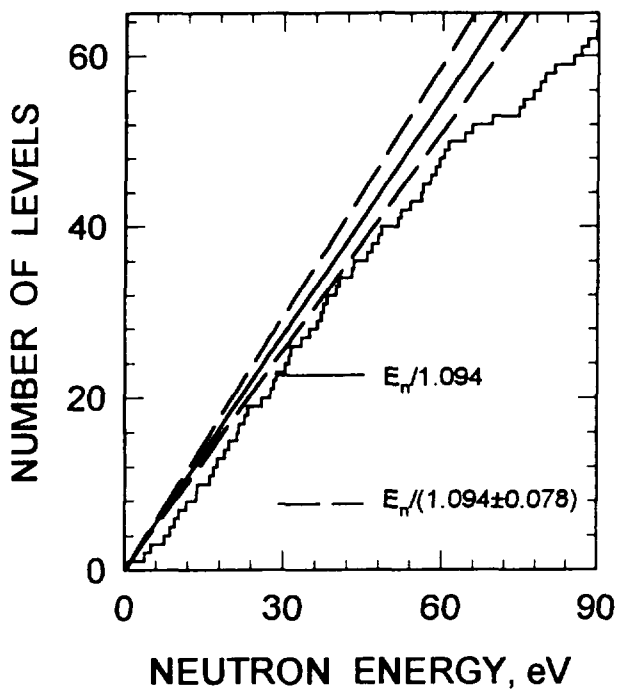

Fig.32a ^{249}Cf: Cumulative sum of levels

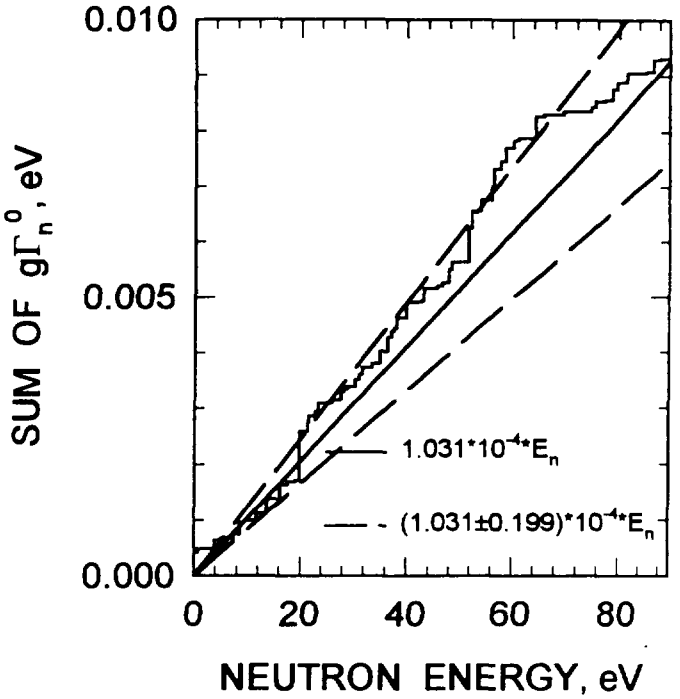

Fig.32b ^{249}Cf: Cumulative sum of reduced neutron widths

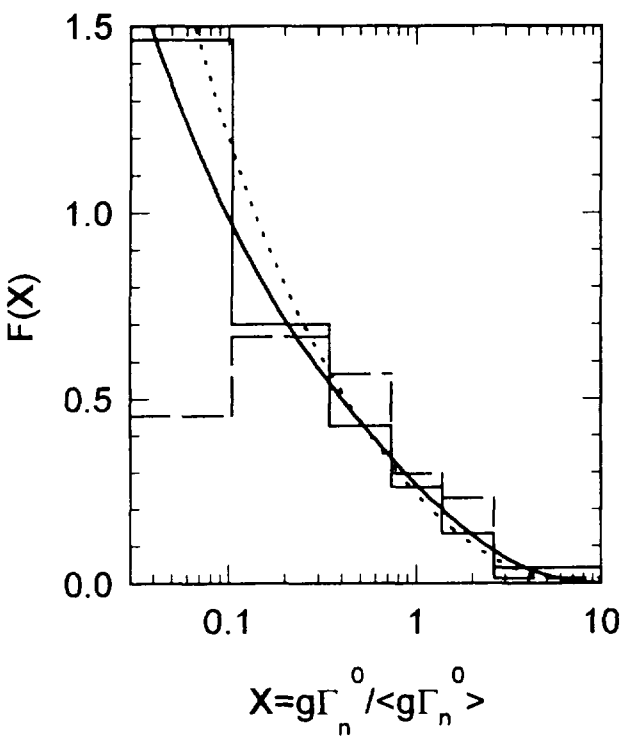

Fig.32c ^{249}Cf: Reduced neutron width distribution

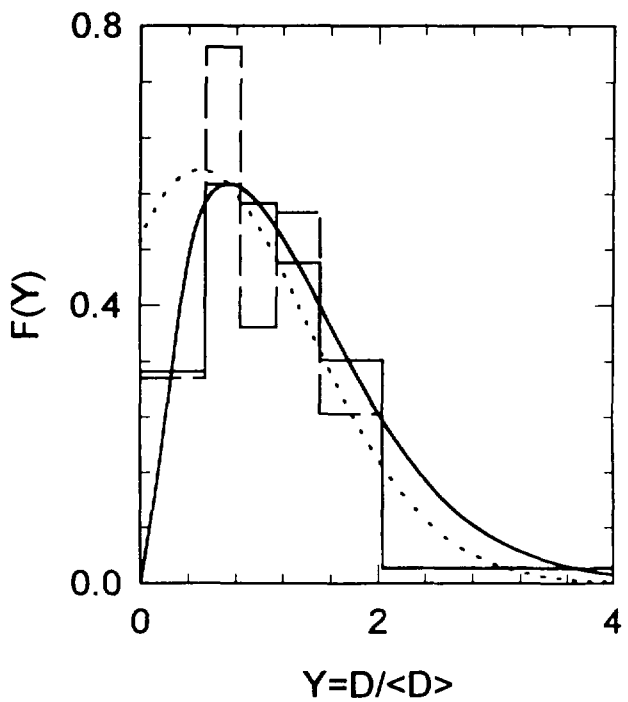

Fig.32d ^{249}Cf: Level spacing distribution

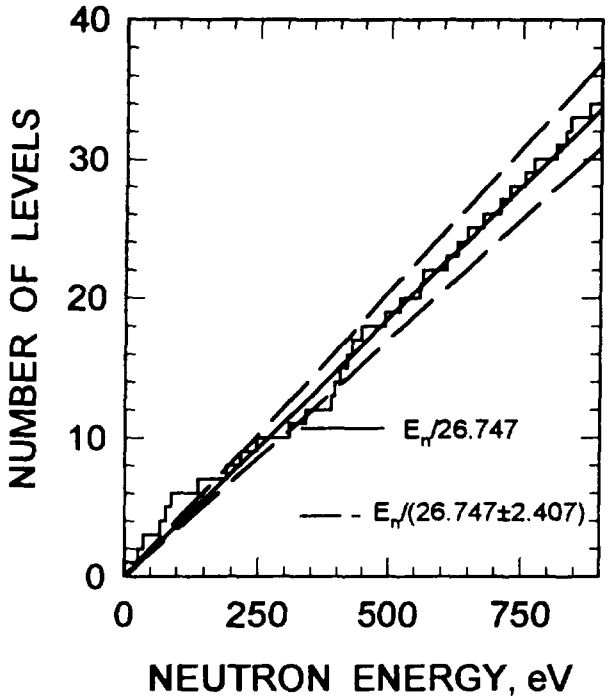

Fig.33a ^{252}Cf: Cumulative sum of levels

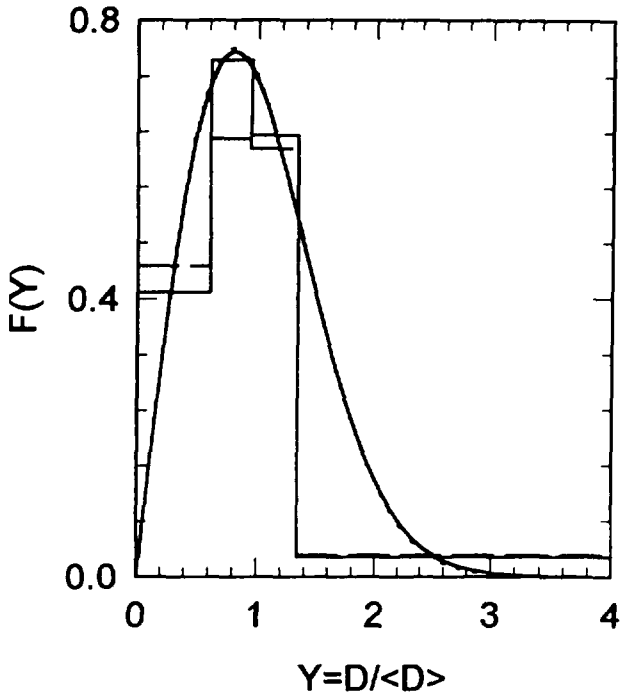

Fig.33d ^{252}Cf: Level spacing distribution

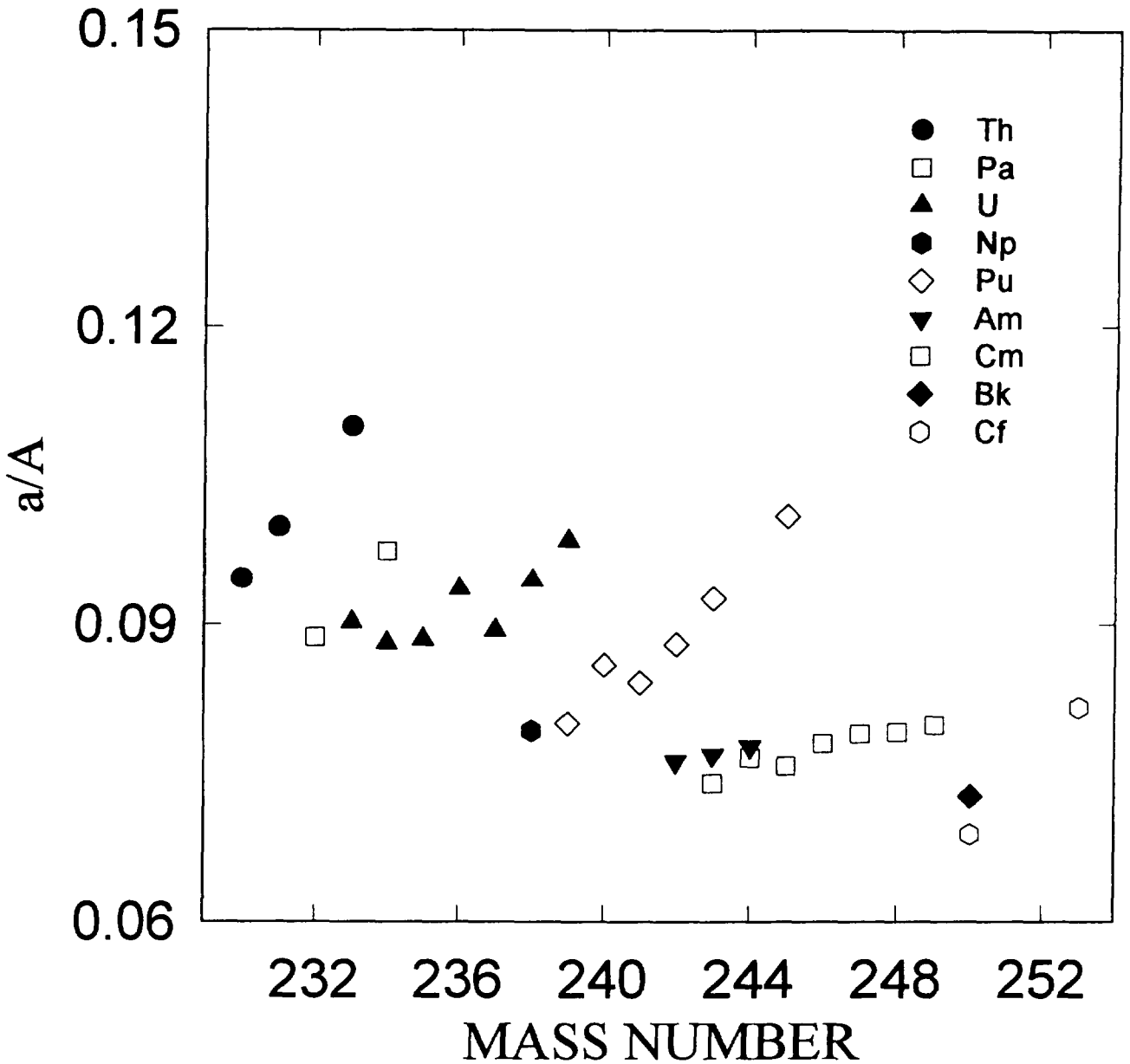

Fig.34 The main parameter of level density dependence for actinides

Table 1. Average level spacings of neutron s-resonances for actinides recommended by different laboratories

Isotope	<D>,eV BNL	<D>,eV Obninsk	<D>,eV Beijing	<D>,eV Bologna	PRESENT		
					ΔE,eV;	Estimated missing	<D>,eV
^{229}Th	0.53±0.15	0.62±0.12	0.55±0.07	2.12±0.31	0-16.8	0.431	0.455±0.069
^{230}Th	9.6±1.3	9.6±1.5	11.0±0.8	13.8±5.5	0-350	0.197	12.386±1.338
^{232}Th	16.8±1.0	16.6±0.6	16.4±0.6	16.55±1.25	0-4000	0.009	17.380±0.600
^{231}Pa	0.45±0.05	0.45±0.05	0.73±0.04	0.55±0.10	0-85.63	0.449	0.444±0.059
^{233}Pa	0.59±0.09	0.70±0.10	1.18±0.11	0.695±0.195	0-7.18	0.376	0.503±0.095
^{232}U	4.6±0.7	4.6±0.7	4.40±0.35	5.7±1.1	0-213.2	0.081	4.717±0.381
^{233}U	0.55±0.05	0.55±0.05	0.50±0.02	0.55±0.05	0-85	0.193	0.508±0.025
^{234}U	10.6±0.5	12.0±0.8	12.5±0.6	12.15±1.65	0-1500	0.134	11.488±0.551
^{235}U	0.44±0.06	0.43±0.01	0.55±0.02		0.117	0.035	0.488±0.018
^{236}U	14.7±0.8	15±1	15.8±0.5	16.45±2.55	0-2640	0.161	15.261±0.687
^{237}U	3.5±0.8	3.5±0.8	3.02±0.29		46.2-195	0.301	3.609±0.386
^{238}U	20.9±1.1	20.8±0.3	21.0±0.5	22.3±1.3	0-4000	0.056	20.761±0.799
^{237}Np	0.52±0.04	0.57±0.03	0.75±0.03	1.8±0.4	0-400	0.252	0.553±0.022
^{238}Pu	9.0±0.7	8±1	9.4±0.8		0-500	0.126	8.301±0.598
^{239}Pu	2.3±0.1	2.20±0.05	2.51±0.07	2.38±0.18	0-610	0.066	2.308±0.076
^{240}Pu	13.6±0.7	12.4±0.7	15.4±0.5	15.0±1.15	0-1408.6	0.097	13.440±0.720
^{241}Pu	0.9±0.1	0.73±0.08	1.26±0.04	0.96±0.16	0-123.5	0.137	1.070±0.056
^{242}Pu	15.5±1.7	13.5±1.5	22.8±1.0	37.7±2.6	0-1286	0.163	13.526±0.812
^{244}Pu	17±3		26.4±4.2		0-235	0.004	18.992±2.868
^{241}Am*	0.55±0.05	0.58±0.04	0.61±0.02	0.66±0.16	0-150	0.311	0.551±0.034
^{242m}Am*	0.40±0.08	0.40±0.08	0.35±0.02	0.33±0.08	0-28.45	0.355	0.271±0.024
^{243}Am *	0.60±0.06	0.73±0.06	0.98±0.03	0.77±0.17	0-127.38	0.319	0.621±0.042
^{242}Cm	25±8	14±3	10.4±1.1	22.9±10.1	0-155	0.420	10.082±1.976
^{243}Cm*	1.1±0.2	0.75±0.15	0.90±0.06	1.3±0.2	0-70.5	0.315	0.809±0.078
^{244}Cm	12±1	11.8±1.2	10.8±0.6		0-491.9	0.195	11.571±1.041
^{245}Cm*	1.4±0.1	1.3±0.2	1.55±0.14	1.47±0.13	0-100	0.126	1.006±0.056
^{246}Cm*	34±7	30±5	22.7±3.0	36±6	0-385	0.120	17.58±4.0
^{247}Cm	1.4±0.1	1.8±0.3	1.60±0.14	2.0±0.1	21-60	0.019	1.181±0.164
^{248}Cm	33±5	28±5	44.0±2.5	40±8	0-2391	0.325	38.478±3.578
^{249}Bk	1.0±0.1	1.0±0.1	1.06±0.06	1.6±0.2	0-62	0.380	1.195±0.136
^{249}Cf	0.7±0.1	0.7±0.1	0.64±0.03	1.0±0.1	0-90	0.230	1.094±0.078
^{252}Cf	27±3	27±4	17.4±2.1		0-900	0.010	26.747±2.407

Table 2. Neutron strength functions for actinides recommended by different laboratories

Isotope	$s_0 x10^4$ BNL	$s_0 x10^4$ Obninsk	$s_0 x10^4$ Bologna	$s_0 x10^4$ PRESENT
^{229}Th	0.62±0.16	1.15±0.15	0.51±0.17	1.388±0.687
^{230}Th	1.5±0.4	1.28±0.15	1.465±0.435	1.472±0.455
^{232}Th	0.84±0.07	0.87±0.07	0.84±0.07	0.800±0.080
^{231}Pa	0.81±0.10	0.78±0.08	0.45±0.05	0.775±0.353
^{233}Pa	0.75±0.06	0.75±0.08	0.355±0.045	0.802±0.411
^{232}U	0.91±0.20	1.4±0.3	0.97±0.07	0.881±0.296
^{233}U	1.04±0.07	1.04±0.07	0.545±0.035	1.073±0.144
^{234}U	0.86±0.11	0.85±0.10	0.755±0.105	0.809±0.112
^{235}U	1.0±0.1	0.88±0.08		1.013±0.104
^{236}U	1.0±0.1	1.08±0.10	0.97±0.13	1.028±0.130
^{238}U	1.2±0.1	1.03±0.08	0.94±0.04	1.169±0.130
^{237}Np	1.02±0.06	0.97±0.07	0.315±0.095	0.954±0.075
^{238}Pu	1.3±0.3	1.3±0.3		1.285±0.269
^{239}Pu	1.3±0.1	1.25±0.10	0.795±0.015	1.302±0.126
^{240}Pu	0.93±0.08	1.05±0.10	0.935±0.085	1.065±0.164
^{241}Pu	1.06±0.14	1.23±0.13	0.56±0.50	1.073±0.162
^{242}Pu	0.9±0.1	0.98±0.08	0.52±0.03	0.912±0.154
^{244}Pu	0.9±0.3			1.243±0.522
^{241}Am*	0.90±0.09	0.88±0.06	0.475±0.025	0.896±0.115
^{242m}Am*	1.4±0.3	1.3±0.2	1.0±0.4	1.215±0.247
^{243}Am *	0.98±0.09	0.98±0.06	0.51±0.04	0.900±0.131
^{242}Cm	0.9±0.3	0.65±0.15	0.98±0.38	0.763±0.395
^{243}Cm*	1.30±0.26	1.5±0.2	0.60±0.04	1.050±0.230
^{244}Cm	0.92±0.17	1.0±0.2		1.061±0.272
^{245}Cm*	1.18±0.27	1.05±0.15	1.225±0.075	1.151±0.185
^{246}Cm*	0.50±0.16	0.45±0.15	0.5±0.1	0.91±0.34
^{247}Cm	0.75±0.18	0.55±0.15	0.35±0.01	0.935±0.278
^{248}Cm	1.0±0.2	1.10±0.12	1.0±0.2	1.013±0.238
^{249}Bk	0.90±0.20	0.90±0.20	0.48±0.06	1.095±0.300
^{249}Cf	1.00±0.17	1.00±0.17	0.6±0.1	1.031±0.199

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