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A STUDY OF THE ACCURACY OF $\bar{\sigma}$-FACTORS FOR ROOM-TEMPERATURE MAXWELLIAN SPECTRA FOR U AND Pu ISOTOPES

BY

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A B S T R A C T

At this time, when the 2200 m/sec values of the neutron cross sections and other constants of fissile nuclei are again under review, it is important to have up-to-date values of the g-factors for these nuclei and particularly to have reliable estimates of their accuracy. This is because the g-factors which arise in interpreting measurements of data made in Maxwellian neutron spectra, or reactor spectra approximating thereto, affect many of the values which form the basis of a regression analysis, and the relative weights given to different values depend directly on accuracy estimates. The present report describes a detailed study of the possible changes in the shapes of curves of variation of the cross sections with neutron energy, based on the measured values used to fix these curves, and complements a study on a more theoretical basis by E. Vogt et al (unpublished). It is concluded that the best estimates of the accuracy of the room-temperature g-factors (quoted as standard deviations) are as follows:

	U-233	U-235	Pu-239
g (abs)	± 0.12%	± 0.09%	± 0.285%
g (fiss)	± 0.20%	± 0.155%	± 0.285%
g (eta)	± 0.16%	± 0.174%	± 0.325%

A less complete study of this problem for Pu-241 is also described.

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Etude de la précision des facteurs-g pour les spectres maxwelliens à la température ambiante des isotopes U et Pu

par C.H. Westcott

Résumé

A l'heure où les valeurs de 2 200 m/sec des sections efficaces de neutrons et autres constantes des noyaux fissiles sont de nouveau passées en revue, il est important d'avoir des valeurs à jour pour les facteurs-g de ces noyaux et de pouvoir fiablement évaluer leur précision. La raison en est que les facteurs-g (dont il est question lorsqu'on interprète les mesures effectuées dans les spectres neutroniques maxwelliens ou dans les spectres de réacteurs qui s'en rapprochent) influencent un grand nombre de valeurs qui forment la base d'une analyse de régression et les poids relatifs donnés aux différentes valeurs dépendent directement de la précision des estimations. Ce rapport décrit une étude détaillée sur les changements pouvant se produire dans les formes des courbes de variation des sections efficaces avec l'énergie neutronique. Cette étude repose sur les valeurs mesurées employées pour fixer ces courbes et elle complète un travail plus théorique effectué par E. Vogt et ses collaborateurs (non publié). La conclusion est que les meilleures estimations de la précision des facteurs-g à la température de la pièce (cités comme déviations types) sont les suivantes:

	U-233	U-235	Pu-239
g (abs)	± 0.12%	± 0.09%	± 0.285%
g (fiss)	± 0.20%	± 0.155%	± 0.285%
g (eta)	± 0.16%	± 0.174%	± 0.325%

Il est également question d'une étude moins complète de ce problème pour l'isotope Pu-241.

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ERRATA (In Text)

p. 13, second line of section 5, for "adjust read "adjust".

p. A.III.1, bottom line for contribution read contributions.

p. A.V.2, top line for ("normal" read ("normal").

p. A.V.12, line 24, for If was read It was.

(OVER)

ERRATA (Cont'd)

(In Figures, Unclear "Case" Codes)

p. 61 Fig. 16A is case BV, Fig. 16B is case BC.

p. 64-66 Fig. 19A, 20A, 21A are case B, (19B, 20B and 21B are R).

p. 67 Fig. 22A and 22B are case B, (22C is R).

p. 70 Fig. 25A, B and C are case A, 25D and E are A+.

p. 71 Fig. 26A and 26F are HD, 26C is HD+; Fig. 26B and G are NJ, 26D is NJ+ and Fig. 26E is N.

1. INTRODUCTION

Earlier compilations (from this laboratory) (AECL-407, 607 and 1101) of the g-factors which express (in terms of the 2200 m/sec values) the effective cross sections for Maxwellian neutron spectra, or (together with an s-factor) for spectra of well-moderated thermal reactors, gave values for many isotopes and for temperatures up to 600°C or 1500°C. The present study concentrates on establishing the accuracy of the g-factors for U-233, U-235, Pu-239 and (less exhaustively) Pu-241, primarily for a 20°C neutron spectrum, and with less precision for somewhat higher temperatures. This question of the accuracy of "g" has never been adequately studied, and especially since the rate of improvement of the experimental data on which the g-factors were based has slowed down of recent years, it appeared preferable to study accuracies than to recalculate g-factors for a wider set of reactions or a wider range of temperature. This study has been done concurrently with a study under IAEA auspices for a revision of the 1965* survey of 2200 m/sec constants (cross sections and, e.g. $\bar{\upsilon}, \eta, \alpha$) for the same isotopes. For the regression-type analysis used in this work, knowledge of the accuracy of g-values is essential. The lower accuracy of Pu-241 data generally, and the recent g-factor reevaluation for Pu-241 by Lemmel and Westcott, (Journal of Nuclear Energy, Vol. 21 p. 417, 1967), together relieve us of the necessity of studying this isotope in the same depth as the others. In all the isotopes studied it is found that the largest uncertainty in the low-temperature g-factors derives from

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* Westcott, Ekberg, Hanna, Pattenden, Sanatani and Attree Atomic Energy Rev., Vol. 3, No. 2, p. 2, (1955)

the fact that the experimental data is scarce or inaccurate for low neutron energies, i.e., in general below about 10 to 20 milli-eV.

The g-factor is defined exactly as in AECL-1101, so that g-1 measures the departure of the variation of the cross-section with energy from the 1/v-law; consequently it is convenient for both σ_a and σ_f to work in terms of the variation of $\sigma\sqrt{E}$ with energy. Notation otherwise follows normal practice; note that $\sigma_\gamma = \sigma_a - \sigma_f$, while α is defined as σ_γ/σ_f so that $1 + \alpha = \sigma_a/\sigma_f$. Therefore, writing $x = \sigma\sqrt{E}$ and M(E) for the Maxwellian density (not flux) distribution function* for temperature T, we have since $\int_o^\infty M(E)dE = 1$, $g = (1/x_o)\int_o^\infty x.M(E)\ dE$, which for a given reaction is only a function of T. We should note that since g depends on x/x_o, a renormalization of σ does not in itself change the g-factor. Also, if the 1/v-law applies, so that $\sigma \propto E^{-\frac{1}{2}}$, $g \equiv 1$; further T_o is the absolute (Kelvin) temperature equivalent to $20.4_4°C$. The quantity g_η is defined, as usual** as equal to g_f/g_a, and $g_{1+\alpha} = 1/g_\eta$. The quantity obtained by

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* This requires that $M(E) = 2\sqrt{E/\pi}(kT)^{-3/2} \cdot e^{-E/kT}$; we also write $x_o = \sigma_{2200}\sqrt{kT_o}$ where kT_o is the energy of a 2200 m/sec neutron (0.025298 eV).

** Although $\eta = \nu/(1 + \alpha)$ and ν is constant in the thermal region, so that we can define a $g_{(1 + \alpha)}$ equal to the reciprocal of g_η, this is not in fact equivalent to $g_{(1 + \alpha)} = 1/(1 + \alpha_o) \int_o^\infty [1 + \alpha(E)]M(E)\ dE$ where $\int_o^\infty M(E)dE = 1$. Instead, in defining g_η we in fact average over the rate of absorption of neutrons and not just over the Maxwellian spectrum, so that $g_\eta = (1 + \alpha_o) \times \int_o^\infty \frac{\sigma_a\sqrt{E}}{1 + \alpha} M(E)dE \Big/ \left[\int_o^\infty \sigma_a\sqrt{E}\ M(E)dE\right]$ which is readily seen to be equal to g_f/g_a since $\sigma_f = \sigma_a/(1 + \alpha)$.

writing $x = \alpha$ in the above definition of "g" is not a normally used quantity, although it may be applicable in special cases.

2. SOURCE OF EXPERIMENTAL DATA AND OUTLINE OF METHODS

Most of the experimental data is now available in SCISRS* and a magnetic tape version of this for the isotopes concerned was obtained from the National Neutron Cross-Section Centre at Brookhaven; this was supplemented by some additional data which was added to the tape in a similar format. This procedure differs from that used in the 1960 and earlier compilations (AECL-407, -670, and -1101) where the shapes of the curves were taken from the BNL-325 compilation, and only amended where new data had become available or inconsistencies were found (e.g. between σ_f, σ_a and α). Since our interest was confined to "thermal" values, only data below 0.4 eV were retrieved from the SCISRS tape. The abbreviations in use in SCISRS for identifying data sets are those used here in tables and curves wherever abbreviations are necessary.

Unfortunately we do not have available a uniform and reliable indicator of the true accuracy of each datum stored in SCISRS - even when errors are quoted (which is for a small fraction only of the data) it is usually unclear whether systematic (e.g., normalization), statistical, or a combination of both errors is entered. For our purpose we only wish to establish curve shapes, so that we would be interested in systematic errors, if they were known to exist, only if their origin could be identified in such a

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* Denotes "Sigma Center Information Storage and Retrieval System", See Report BNL-883 (1964)

way that corrections for them could be made. We have therefore been led to attach "weights" (i.e. accuracy criteria) to the various sets of data from the internal evidence, i.e., from the "spread" of the points themselves, and generally we have done this for each data set from averages taken over several discrete ranges of energy.

In view of this limitation of the data it has not been possible to avoid the arbitrariness of making judgments based on familiarity with the technology used in measuring this type of data; a logical self-consistency was not always possible. Thus "best" curves through a collection of several sets of data for a given quantity were chosen "by eye", and then described mathematically - "spreads" or mean square residuals from these lines were used as a basis for weights. Sometimes the "eye-ball" curves were modified as a result of a previous "adjust" operation, giving the work a partly iterative character--there could also be other changes (e.g. data renormalization) as the work proceeded. Subsequently an "adjust" operation yielded curves for σ_f, σ_a and α which were "consistent" (i.e. $\sigma_a = \sigma_f (1 + \alpha)$ for each energy) - to do this required a knowledge of the relative 'accuracy' of the previously-chosen σ_a, σ_f and α curves stated as a weight per unit energy interval derived from the number and weight of the data points on which each curve was based. This was necessary since each of the original curves had been drawn using data for one quantity considered separately. At a later stage, weights were attached to the individual data sets (generally for a number of energy ranges) and a least-squares method used to fit an analytic function of E to the points. By varying such things as the order of the polynomial in this function and the range over which the fit

is made a number of different fitted curves is produced. By examining these curves, it is hoped to learn how far the curve shapes would be expected to be able to vary while still giving a fit which is not unreasonable in view of what is known about the physics of neutron-nuclei interactions.

It then appears, although some elements of arbitrariness have to be admitted, that a reasonably representative set of fits has been obtained; applying some "factor of safety" (discussed below) we can use the range of variation of the g-factors corresponding to these sets to estimate standard deviations for these g-factors, i.e. how much variation in g-factors is likely in view of all the available experimental data. This was also confirmed in some cases by using different (alternative) "best" curves estimated by eye, applying the "adjust" procedure described above and noting how far the g-factors for alternative adjusted curves differ from one another (without any polynomial fitting). For U-235 and Pu-239, where alternative "best" curves were suggested by the data, this additional method tends to give changes in g of the order of the standard deviation derived from fitting but if it gives smaller changes, it can do little to confirm the errors estimated from the fitting procedure. With this introduction, a detailed account of the work follows.

3. PRESENTATION AND ASSESSMENT OF EXPERIMENTAL DATA

As a first step, all data are plotted using the G-20 computer. Since the points are numerous and small differences are to be studied, an open scale (displaced zero) plot has been adopted--thus for U-235 (σ_a and σ_f) the whole (10-inch) range of ordinates represents only about a 10% range of $\sigma\sqrt{E}$. The "zero displacement" (quantity subtracted from $\sigma\sqrt{E}$ for

plotting) may be a function of energy and those used are given in Appendix I. This is purely a matter of convenience since all data points and curve-fitting recipes are similarly treated, but the use of an open scale of this type greatly aids the assessment of the differences between different data sets. Note also, that the choice of $\sigma\sqrt{E}$ rather than σ as the quantity plotted in itself allows a smaller (and more nearly constant) zero displacement to be used.

Some sets of points were immediately seen to have a very large spread or "scatter"--these are usually from the older measurements, and in general these data were rejected. In a few cases the spreads were not unacceptably large but the shapes of curve indicated were so different from those of other data for the same quantity that their rejection for this reason alone seemed indicated. It is true that a very numerous set of points having too large a spread could be treated by averaging several successive data, so as to reduce the spread, but in most of the unacceptable cases the original spread was so large that this approach was of little value. A list, with comments, of data sets not used for these reasons is given in Appendix IV.

In a few cases where the SCISRS files indicated the statistical accuracy of each point, and in a few other important cases cited below where this information was obtained from the literature, these errors were used rather than values based on the internal evidence (spread of the points) which was the general basis for the "weights".

Curves are then drawn by eye so as to give a good representation of the trends indicated by the points, most weight being given to the sets of points exhibiting the smallest spreads. Clearly this is a somewhat arbitrary process, partly superseded by later stages of this study by

the polynomial "fits", but this "eye-balling" forms an unavoidable first step, and for producing "best" curves it seems surprisingly good in the light of the subsequent more sophisticated procedures. Analytical descriptions are given to these smooth "eye-balled" curves; this is done piecewise, using for each of a reasonable number of ranges of energy a polynomial in E, with or without a Breit-Wigner term added. The resulting analytical "recipes" (v. Appendix I), produced for σ_f, σ_a and α, are then plotted automatically with the SCISRS data to confirm the correctness of the steps so far. At this stage the computer also forms the sums of squares of the deviations of the points of each set from the "eye-ball" curves, the sums being taken over selected ranges of energy, corresponding to the energy regions for which the "weights" are calculated (v. Appendix II).

The weights given are the reciprocals of the mean square deviation of the points from the "eye-ball" or "consensus" curve expressed* in (per cent)^2, i.e., $10^{-4}\ \bar{x}^2/\overline{\Delta x^2}$. For the "adjust" procedure, what is required is the weight per unit energy interval (not per point) summed for all the data sets contributing to a given "consensus" curve. For this we arbitrarily take the sum of the products of weight per point times the number of points per 12½ milli-eV ($\approx \frac{1}{2}kT_0$) energy interval; since only relative weights are needed this convention is acceptable. The results are given in Table A.II.2; from the Appendix it will also be seen that the adjust weights have been made continuous, whereas the weights of data sets for "fitting" may jump suddenly from one value to another at the ends of the energy range. For "adjust" to give smooth curves, this continuity feature is necessary.

* It is important that for the α data the percentages are taken in terms of $1 + \alpha$, not α, since we later use "adjust" based on $\sigma_f(1 + \alpha)/\sigma_a = 1$.

4. PROBLEMS IN ASSIGNING "WEIGHTS"

There are several problems in defining weights from these sums of squared residuals for the points in a given set of data; these are of two types, viz., problems of philosophy and the difficulties due to small-sample statistics or special problems. We consider the latter first. In Appendix I are explained the cases where alternative "eye-ball" lines seemed desirable, respectively fitting different groups of sets of measurements of the same quantity, i.e., when the consensus indicated by several sets of measurements differed from that which would fit other sets. These differences are unexplained but could be due to systematic errors affecting some classes of experiment--they are an unsatisfactory feature of the data especially for σ_f(U-235) and σ_a(Pu-239), and give rise to a considerable difficulty in pursuing the present study.

Another systematic effect may arise from the arbitrariness of the eye-ball curves--the weights of sets of points lying near the curve concerned would be much greater than of a set of points following a parallel line (especially if the spread of the points is less than the displacement of the line); renormalization is clearly the answer in such a case, and this has been done whenever it seemed needed. Also, to help meet objections of this type, some of the eye-ball curves were readjusted and the changes in the resulting weights or fitted curves observed as a measure of what changes were possible; see also Appendix IIC for the procedure in the difficult cases of σ_f(U-235) and σ_a(Pu-239). The problems of small sample statistics also arose, but mostly these affected the weights significantly only when a few points fell in the energy range concerned; for more numerous sets of points

the weight seemed to depend relatively weakly on the choice of "eye-ball" curves for any changes likely to be made in practice, except for the cases, already mentioned, discussed in Appendix IIC. But there seemed to be no need, judging from the effects found in fits for different weights, to know weights generally to better than ±25% (or up to ±40% for less important curves), so that the accuracies achieved seem satisfactory.

There is another possible logical problem involved in the procedure described above for obtaining "weights", viz., that the "eye-ball" curves for σ_a, σ_f and α are determined separately and are not in fact mutually consistent. It should be noted that the "weights" attached to data sets are used in two processes. For the second procedure ("fits") the results depend on the relative weights of individual sets of data, while in the first procedure ("adjust"), all that is required is the total relative weight (per unit length of curve) attached to the sum total of σ_a (and σ_T) measurements, of σ_f and of α measurement. At least for "adjust", it seems clear that a weighting depending on the measured data for each quantity separately is the correct quantity to use, so that "spreads" from the separate unadjusted curves are appropriate.

Initially, the same basis was used in estimating weights to be used in the "fitting" procedure, but here the underlying philosophy is less clear. As a general proposition, and for completely arbitrary choices of "recipes" if the data points lay completely randomly on the graphs, it cannot be denied that there would be a definite risk of getting into tautological argument by first choosing weights for sets of data from their mean square deviations from an arbitrarily-

chosen "recipe" and then using a least squares procedure to determine the "best" curve through the points; obviously for simply random data the result would be likely to be that the original recipe would be more or less well reproduced as the "best" fitted curve. The onus is therefore on us to show that this is not the case for our study.

There seems to be no simple fundamental answer to this point; but as practical answers, several points can be made. First, a few fits have been made on the simplest assumption (e.g., giving all data points equal weights), and the results so obtained lay quite as close as could be expected to the curves obtained by our much more sophisticated procedure. And renormalization was always used to remove the worst effects of one set of data lying systematically "off" the recipe or consensus curves.

The point is rather that the data certainly cannot be described as filling the whole area of the graphs uniformly. Giving a uniform and equal weight to all data points--certainly an extreme assumption--was found not to displace the fitted curves, to any serious extent. Indeed, the whole process may be regarded as in a general way iterative, starting from this point (see discussion in Appendix II). Using a first (rather approximate) set of weights in "adjust", the shape changes called for by the consistency requirement may be seen, and if they represent definite trends, might cause us to make a revision in the "eye-ball" recipes used; weights for "fitting" are not needed until a later stage and therefore these may be deduced from the deviations from improved "recipes". Although the present report presents only final "recipes" and "weights", and the stages of the present study are not detailed, a process having a considerable similarity

to that just described formed part of the evolution of both the "old" to "new" sets of weights of which mention is made in Appendix IIC. It must be admitted, however, that limitations of time for this study rendered an evolutionary approach necessary--if the work were now repeated a more logical procedure, including allowing at least some normalization factors to be fitted also, could be adopted. However, it would appear that this would not appreciably change the results obtained, since the main limitations are all in the data available.

To summarize, there appears to be no practical alternative to the use of the "spread" of the data points as a measure of their accuracy, with all the small-sample statistical problems that this theoretically involves. However, and especially for U-233 where non-statistical divergent trends have not been identified, it has seemed desirable to apply "factors of safety" to our deduced errors to allow for this difficulty. This is in addition to using a χ^2 test as a measure of statistical goodness, and multiplying our computed error estimates by a mean χ. The place where the worst effects of the paucity of experimental data shows up is always for low energies, below about 0.02 eV, and this, while true for all isotopes, stands out most for U-233. In the descriptions which follow, therefore, U-235 and Pu-239, which have special problems, are discussed first, and U-233, where the problem is mainly a low-energy indeterminacy, is discussed later in the light of the low-energy problems of the other isotopes.

There then remains the question of whether weights should be determined from departures from "adjusted" curves, instead of setting weights before adjusting (in the sense that

$\sigma_f(1+\alpha)$ should = σ_a). This could relatively easily have been done using the preliminary version of the "adjust" results as the base curves for deducing the mean squares residuals from which final "weights" for each data set could have been estimated, i.e., by extending the iterative process already described (note: the procedure for "adjust" itself requires the weights to be already known).

This question was examined most closely for U-233, where the difficulties due to divergent recipes did not arise, although a trial derivation of weights from "consistent" curves was in fact made for each of the three isotopes. For this the mean square deviations of each set of points from one or more sets of curves which the polynomial fit gave was used; these curves were automatically consistent, and in fact curves were chosen from the fitted sets which were closely of the same shape as the final version of the "adjust" curves. The results showed that except for the "difficult" cases of σ_f(U-235) and σ_a(Pu-239), the "weights" would indeed vary within a range of the order of ±30% wide, though on the average the changes might be only some ±10%. Few systematic trends were evident, but it was only for the cases where alternative weights are given in Table AII.1 that the alternative recipes gave weights differing by factors of 1.5, 2 or 3 or more.

Taking therefore the U-233 case, we see from Figure 6 that the largest difference (in the important region below 0.1 eV) between the original recipes and the results from "adjust" occurs for fission. This corresponds to the statement in Appendix I(C.3), that for this isotope σ_f is the least well determined quantity. However, comparing the points of Figure 1 with the curve of Figure 6, we see that

if an "adjusted" curve were used for deriving the mean square deviation, the result would be a considerable further downweighting of all the fission data. While renormalization could largely correct this, a large renormalization would be involved; while this is an unwelcome situation, we feel that we should give the σ_f measurements in this case the "benefit of the doubt" and retain the weights obtained in the original process of using unadjusted recipes. Since this situation may apply elsewhere also, the same has been done for the other isotopes.

5. THE "ADJUST" PROCEDURE

So far the σ_f, σ_a and α data and the corresponding recipes have been dealt with separately. The "adjust procedure is used to generate consistent curves for absorption, fission and $1 + \alpha$. The adjustment is done on a point-for-point least squares basis, with as inputs to the computer the three ($\sigma_a\sqrt{E}$, $\sigma_f\sqrt{E}$ and $1 + \alpha$) recipes and relative weights for each quantity. These are weights-per-unit energy range as explained above, generated by summing for all the data contributing to each quantity. However, the weights are estimated for fairly broad energy ranges, but in order to avoid producing discontinuities in the adjusted curves, it is necessary to make the weights continuous functions of the energy variable. Thus, as the Table A.II.2 (cf Appendix II.B) shows, one may use a constant weight for $0>E>0.02$ eV, and from say 0.03 eV onwards, but for the transition region (in this case from 0.02 to 0.03 eV) a linear variation of the weight is assumed. This is in fact also physically reasonable, although it is impracticable to derive directly from the data a continuously varying weight.

Adjustments in the sense of reducing the weights are made whenever systematic discrepancies appear, or when the indicated weight approaches or exceeds that corresponding to a 0.1% accuracy, which is taken as the limit believed attainable with present measuring techniques.

The results of some typical "adjust" procedures are shown in Figures 5b and 6 to 9, where insets show how the low energy ends of the curves vary if alternative recipes (taken from Appendix I) are chosen for U-235 and Pu-239.

In the "adjust" procedure also the g-factors corresponding to the input recipes are calculated, as well as those given by the resulting adjusted curves; in general these are obtained for 20.44°C temperature, and for higher temperatures up to 140 or 180°C in intervals of 20°C or 40°C. Generally, the "adjust" procedure is truncated at E = 0.2 eV, and between this energy and 0.4 eV, where the recipes terminate, the integral is calculated from the unadjusted recipes. Up to 140°C the errors caused by this procedure are quite small; however, if the temperature is above 150°C this may cease to be a good approximation. For Pu-239 both the unadjusted and the adjusted recipes contain the dominant term due to the 0.3 eV resonance, only the small excess being adjusted, so that the error likely due to not doing the adjustment above 0.2 eV remains small. Since the main aim of the present work was to obtain g-factors and estimates of their accuracy for the purpose of interpreting measurements in terms of 2200 m/sec values, and also because the experimental data generally become less accurate for the energy range 0.2 to 1 eV, no attempt to calculate g-factors for higher temperature has been made.

The g-factors resulting from the "adjust" procedure for the most important of the alternative recipes of Appendix I are given in Table 1. The correspondence of some of these cases to the graphs of figs. 5b to 9 will be obvious. In the table for each isotope the first combination of recipes is that preferred; the temperature-increments are given only for these recipes. Other increments can be inferred from the Δ(R-SH), Δ(R-LO) and Δ(R-RS) entries. The temperature effects and the "spreads" of the g's will be further discussed in section 9 below; the cases involving MLA or HI are of minor importance but are included to show what the effects would be.

6. PROCEDURES FOR POLYNOMIAL FITTING TO THE DATA POINTS

The recipes so far used ("eye-ball" curves) are defined piecewise; it appears also worth while to attempt to produce single recipes to fit the data in one range (say for the whole range 0 to 0.2 eV). Each quantity would still be expressed as a power series in E_o using a least squares procedure to determine its coefficients; if a Breit-Wigner term is also needed it is chosen at the outset and its coefficients are not fitted. Discussion of an unpublished MS by E. Vogt et al. was helpful in this connection.

It is not a priori clear over what range of energies such a polynomial, or what order of polynomial, will give a good fit. For example, the large resonance for Pu-239 at 0.3 eV might have rendered a least squares polynomial fitting for this element difficult, or limited the energy range over which the fitting would be satisfactory; in fact it was found that the

TABLE 1

g-factors from "adjust" for 20.4_4 °C

Isotope Code	Absorption orig.	Absorption adjd.	Fission orig.	Fission adjd.	Eta(1/1+α) orig.	Eta(1/1+α) adjd.
U-233						
RST/R/R	0.9960	0.99615	0.99645	0.9963	1.0004	1.00015
Δ for T	-30	-28	-28	-355	+2	-65
U-235						
R/RSH/R	0.9790	0.97905	0.9763	0.9769	0.99725	0.9978
Δ for T	-237	-238	-2395	-256	-245	-20
R/R/R	0.9790	0.9793	0.9770	0.9771	0.99795	0.9977
R/SH/R	0.9790	0.9788	0.9756	0.9767	0.99655	0.9979
Δ(R-SH) at 20°	-	+5	+14	+4	-	-2
Δ(R-SH) at 140°	-	+25	-7	-8	-	-11
R/MLA/R	0.9790	0.9797	0.97815	0.9776	0.99915	0.99785
Pu-239						
LOR/R/RRS	1.0736	1.0757	1.05445	1.0523	0.9822	0.9783
Δ for T	+1511	+1533	+1131	+11165	-288	-311
LO/R/RRS	1.07325	1.07535	1.05445	1.05165	0.9825	0.9780
R/R/RRS	1.07455	1.07675	1.05445	1.0543	0.9813	0.97915
Δ(R-LO) at 20°	+13	+14	-	+265	-12	+115
Δ(R-LO) at 140°	-35	-25	-	+5	+275	+24
HI/R/RRS	1.0725	1.07555	1.05445	1.0565	0.9832	0.9823
Δ(R-RS) at 20°	-	+5	-	-16	-	-195

(A final "5" digit indicates next place = 4,5 or 6).

Δ for T is increment for a 120°C temperature rise (to 140.4_4 °C).

Note that (cf App. I) $\Delta(\text{LOR-LO}) = \frac{1}{4}\,\Delta(\text{R-LO})$; RSH is halfway between R and SH and RRS between R and RS.

inclusion of a suitable pre-set Breit-Wigner term avoided any such trouble. We therefore approached the problem with an open mind as to the upper limit of fitting and as to the polynomial order. As a code in the tables below we write E_m;N (case), to denote a particular fit, the "case" code being as in Appendix II, thus 0.1;5 (0) means case "0", fit for $0 < E < 0.1$ eV with 5 terms (a power series in E up to and including E^4) for both $\sigma_a\sqrt{E}$ and $\sigma_f\sqrt{E}$.

We therefore have the possibility of repeating the fitting process many times, say for E_{max} 0.10, 0.15 and 0.20 eV (0.12 eV was also used) and for series of 4, 5, 6, 7 or 8 terms; thus, instead of one "adjust" result, we might have, say 10-15 different fits. There were also the alternative choices of weights (cases), given in Appendix II, giving a total of up to 50-70 fits, as against only about 5 alternatives in "adjust". It was hoped that the variety so obtained would enable us to find limits on what variations of g-factors were possible or acceptable, and this indeed seems to have been achieved. From the considerations of the unpublished MS (E. Vogt et al) already mentioned, it would seem that the type of effect (e.g. due to a small resonance whose existence had not been suspected) which would make a low-order polynomial an unlikely representation of the data is indeed likely to occur only rarely on the basis of nuclear systematics.

A large series of polynomial fits have therefore been undertaken for U-233, U-235 and Pu-239. Some of these exhibited certain peculiar features to be discussed below, but in general it may be said that this approach appears to have yielded a representative set of reasonably "good" fits, from the spread of which the accuracy of g can be estimated; there were some

"unacceptable" fits which serve well to indicate the limitations inherent in the data. The lowest order fit which seemed reasonable was a cubic, and fits of up to 7th order (N=8) were undertaken; the upper limit of order which gives reasonable fits is discussed later. For now we note only that generally a lower order fit suffices for the narrower (0 to 0.10 or 0.12 eV) ranges of fitting, than is desirable for a wider range, e.g. 0 to 0.2 eV.

The question of low order fits merits separate consideration. For a fit to $\sigma\sqrt{E}$ vs E, a one-term fit ($\sigma\sqrt{E}$=Const) is a trivial case for which $g \equiv 1$ identically. A linear (2-term) fit permits g to take values other than 1, but is not physically very useful, especially if fitting over a range $6kT_o$ - $8kT_o$ wide, since points at the end of the range tend to determine the slope and hence the quantity g-1, whereas g should be mainly determined by points in the range from $\frac{1}{2}kT$ to 2kT, where the Maxwellian spectrum is relatively intense. For reasons of this type, quadratic fits (3 terms) have not been employed in this work; while cubic (4-term) fits over the range 0 - 0.2 eV have been included, these have mainly served to demonstrate the relative invariance of the g-factors so deduced in spite of changes of the weights or other assumptions. Examination of typical fitted curves, or of the position of data points for, e.g. U-235 (cf figs. 13-18) will demonstrate that if we restrict ourselves to a parabolic or cubic fit over the whole range, the (negative) slope of the curve near energy kT_o is almost entirely dictated by the rise of the consensus curve above 0.07 eV, for both fission and absorption, notwithstanding the spread of the data (especially for fission) at low energies*. Similarly, the statistical "standard" error for g which the fitting calculations indicate is found to be unduly small for

* For an actual fit restricted to cubic form see Fig. 12A for U-233.

0 - 0.2 eV cubic-type fits. Clearly this does not mean that the g-factor obtained is correspondingly accurate, since it is due to a limitation implicit in the choice of this type of fit; this is confirmed by noting that if either the range is reduced (to 0.12 or 0.10 eV) or the order of fit is increased (to say 6 or 7) the "error" figure rises to a value which varies little with the choice of order or range of fit.

One other quite striking general conclusion from an examination of the fitted curves is that the experimental data are all relatively scarce and inaccurate at energies below about 0.02 eV, and that therefore many of the fitted curves tend to exhibit quite considerable variation from one another and departures from the "eye-ball" curves as the E=0 axis is approached. The extreme case of this occurred for one set of weights for U-233 (for an 0.1;8 (0) fit) see fig.12c; for this case the σ_a and σ_f lines crossed, which would imply negative σ_γ or α (this is clearly physically impossible, but this condition was not implicit in the fit procedure). Lesser variations of curve shape at low energies are quite frequent, and it appears that the largest uncertainty in the 20°C g-factors is usually that due to the uncertainty in $\sigma\sqrt{E}$ (or α) in this range--in some cases the variations start only below 0.01 or 0.015 eV but often they persist up to 0.025 eV.

7. DISCUSSION OF RESULTS OF FITTING: U-235 and Pu-239

We discuss these two isotopes together since for each the main problems are connected with the alternative recipes (App. I) and the consequent options in choosing weights (App. II) for σ_f (U-235) and σ_a (Pu-239). The "adjust" operation did not for

either isotope show that either alternative was unreasonable (though it did indicate some slight trend favouring LO for Pu-239 over R); the data for both isotopes show a general scarcity and decrease of accuracy at low energies. For U-235 the σ_a data are better than the σ_f and α data in this region, but for Pu-239 it is in σ_a that the recipe options appear, so that no quantity is well determined near E=0 for this isotope. The general accuracy of all data is also lower for Pu-239 than for U-235. In contrast to U-233 (see below), the "old" sets of weights did not give rise to specific difficulties (cf App. II C), except that there were early problems (before "fliers" were excluded) for Pu-239, where also the nearness of the large 0.3 eV resonance might have been expected to give rise to problems for a wide (0 to 0.2 eV) range of fit, but difficulties for this case were in fact not clearly seen in the final fits.

When the spread of the g-factors from fitting (tables 3 and 4) are examined, trends are seen, as expected, depending on which option for weights is used, but for the most affected quantities (those for which the alternate recipes occurred, viz. σ_f for U-235 and σ_a for Pu-239) only about 50% of the total "spread" appears to be a systemative Δg correlated with option; the "spreads" found within the individual options (being the other 50%) are of about equal size. For the other quantities (σ_a or α of U-235; σ_f or α of Pu-239) the "spreads" found for individual options are greater than the option-correlated deviations. There is, of course, a similar trend in the fitted curves, that cases based on "SH" weights tend to reproduce "SH" recipes, and similarly.

The behaviour of the χ^2 (as depending on weight-option) are also interesting. We may expect that a weighting option using

a "whichever is best" basis may lead to a higher χ^2, since data near one of the alternative recipes may have a rather high weight--at the same time other data near the other recipe can also have high weights, but no fit can lie close to them both in the "discrepant" region. For all "0" sets of weights this basis was used, and for these, and case "B" of Pu-239 (also tending to a "whichever is best" basis) χ^2 will be seen (in Tables 2-4) to be noticeably higher than for other cases. Naturally the magnitude of the difference depends on the data in question--for U-235 both "BC" and "BV" are compromises with some best-weight tendency--in fact the use of authors' claimed weights for "BV" makes χ^2 higher for this than for "BC"--but there is also in "MR" a "whichever is best" element in respect of the alternative recipes R and MLA, all of which is reflected in the trends of χ^2. One cannot push this point too far, however, in view of the sometimes rather arbitrary treatment in estimating data-accuracies.

8. DISCUSSION OF RESULTS OF FITTING FOR U-233 AND GENERAL POINTS

Table 2 gives the numerical results from fitting for U-233. For this isotope both σ_f and α data were of poor accuracy, at low energies especially, but no alternative recipes (App. I) were needed. In the following discussion it is the problem of the shape of the curves at low-energy which predominates; this is really a general problem for all three isotopes, as will be seen from Figs. 10-24. The discussion of App.II.C.3 refers particularly to the use of a fictitious datum for α at E=0 to stabilize the curve-shapes at low energy; for the later sets of weights this "pseudo-point" appeared unnecessary. Comparing the computed errors of the g's in Table 2 for cases 2 and 3 (the latter has the

TABLE 2

U^{233}

FIT	χ^2	$\hat{\sigma}_a$	$\sigma_a(E_o)$	g_a	$\hat{\sigma}_f$	$\sigma_f(E_o)$	g_f	$g_{\bar{\nu}}$
0.1;4 (0+)	1.18	572.8 ± .4	574.6 ± .4	.99672 ± 55	523.9 ± .5	525.0 ± .6	.99775 ± 78	1.00103 ± 65
0.1;4 (0)	1.21			.99730 ± 54			.99841 ± 94	1.00121 ± 91
0.1;4 (1)	1.02	572.2 ± .3	574.2 ± .3	.99643 ± 44	523.1 ± .6	524.6 ± .5	.99734 ± 88	1.00091 ± 82
0.1;4 (2)	1.02	572.2 ± .3	574.2 ± .3	.99644 ± 44	522.9 ± .6	524.5 ± .5	.99715 ± 86	1.00071 ± 80
0.1;4 (3)	1.02	572.2 ± .3	574.2 ± .3	.99643 ± 54	523.0 ± .5	524.5 ± .5	.99720 ± 75	1.00077 ± 66
0.1;5 (0+)	1.18	573.0 ± .4	574.3 ± .5	.99778 ± 80	524.1 ± .5	524.6 ± .7	.99893 ± 105	1.00115 ± 76
0.1;5 (0)	1.20			.99845 ± 79			1.00094 ± 164	1.00265 ± 162
0.1;5 (1)	1.03	572.2 ± .3	574.2 ± .4	.99645 ± 61	523.1 ± .7	524.0 ± .6	.99741 ± 156	1.00097 ± 150
0.1;5 (2)	1.03	572.2 ± .3	574.2 ± .4	.99646 ± 61	522.9 ± .7	524.5 ± .6	.99681 ± 142	1.00085 ± 133
0.1;5 (3)	1.03	572.2 ± .3	574.2 ± .4	.99645 ± 61	523.0 ± .5	524.5 ± .6	.99714 ± 101	1.00068 ± 84
0.1;6 (0+)	1.18	573.0 ± .4	574.2 ± .5	.99785 ± 81	524.1 ± .6	524.6 ± .7	.99912 ± 109	1.00128 ± 81
0.1;6 (0)	1.20			.99860 ± 79			1.00238 ± 204	1.00401 ± 213
0.1;6 (1)	1.04	572.2 ± .3	574.2 ± .4	.99644 ± 61	523.0 ± .8	524.5 ± .6	.99718 ± 161	1.00075 ± 199
0.1;6 (2)	1.03	572.2 ± .3	574.2 ± .4	.99644 ± 61	522.7 ± .7	524.6 ± .6	.99631 ± 101	.99986 ± 152
0.1;6 (3)	1.03	572.2 ± .3	574.2 ± .4	.99644 ± 61	523.0 ± .5	524.5 ± .6	.99713 ± 211	1.00070 ± 85
0.1;7 (0+)	1.18	573.1 ± .4	574.1 ± .5	.99819 ± 88	524.1 ± .6	524.6 ± .7	.99916 ± 133	1.00097 ± 113
0.1;7 (0)	1.19			.99912 ± 90			1.00566 ± 250	1.00692 ± 252
0.1;7 (1)	1.03	572.3 ± .4	574.1 ± .4	.99682 ± 71	524.2 ±1.1	524.4 ± .7	.99964 ± 253	1.00284 ± 246
0.1;7 (2)	1.04	572.3 ± .4	574.1 ± .4	.99681 ± 71	522.9 ± .7	524.6 ± .6	.99669 ± 164	.99988 ± 154
0.1;7 (3)	1.04	572.3 ± .4	574.1 ± .4	.99681 ± 71	523.0 ± .5	524.6 ± .6	.99683 ± 122	1.00002 ± 107
0.1;8 (0+)	1.18	572.9 ± .7	574.2 ± .5	.99771 ± 159	525.2 ±1.0	524.0 ± .8	1.00212 ± 245	1.00441 ± 215
0.1;8 (0)	1.19			.99932 ± 110			1.00476 ± 300	1.00785 ± 301
0.1;8 (1)	1.04	572.6 ± .6	574.0 ± .4	.99746 ± 135	524.4 ±1.3	524.3 ± .7	1.00015 ± 273	1.00269 ± 251
0.1;8 (2)	1.04	572.6 ± .6	574.1 ± .4	.99746 ± 135	523.7 ± .9	524.3 ± .7	.99881 ± 227	1.00135 ± 199
0.1;8 (3)	1.04	572.6 ± .6	574.1 ± .4	.99747 ± 135	523.8 ± .9	524.3 ± .7	.99906 ± 225	1.00160 ± 197
0.15;4 (0+)	1.19	572.4 ± .4	574.8 ± .4	.99596 ± 29	523.2 ± .5	526.0 ± .6	.99461 ± 41	.99865 ± 35
0.15;4 (0)	1.21			.99656 ± 29			.99481 ± 42	.99829 ± 37
0.15;4 (1)	1.09	571.8 ± .3	574.4 ± .3	.99556 ± 24	521.8 ± .5	524.9 ± .5	.99419 ± 37	.99863 ± 32
0.15;4 (2)	1.09	571.8 ± .3	574.4 ± .3	.99556 ± 24	521.8 ± .5	524.9 ± .5	.99419 ± 37	.99862 ± 32
0.15;4 (3)	1.09	572.0 ± .3	574.4 ± .3	.99590 ± 24	522.1 ± .5	525.1 ± .5	.99431 ± 36	.99840 ± 31
0.15;5 (0+)	1.16	572.8 ± .4	574.6 ± .4	.99690 ± 58	523.6 ± .5	525.1 ± .6	.99707 ± 80	1.00019 ± 63
0.15;5 (0)	1.19			.99764 ± 56			.99767 ± 99	1.00010 ± 91
0.15;5 (1)	1.08	572.0 ± .3	574.2 ± .3	.99607 ± 46	522.7 ± .6	524.5 ± .5	.99646 ± 90	1.00038 ± 83
0.15;5 (2)	1.08	572.0 ± .3	574.2 ± .3	.99608 ± 47	522.6 ± .6	524.5 ± .5	.99627 ± 88	1.00018 ± 80
0.15;5 (3)	1.08	572.0 ± .3	574.2 ± .3	.99642 ± 47	522.6 ± .5	524.5 ± .5	.99640 ± 76	.99998 ± 65
0.15;6 (0+)	1.15	573.1 ± .4	574.2 ± .5	.99798 ± 77	523.8 ± .5	524.5 ± .7	.99867 ± 102	1.00009 ± 73
0.15;6 (0)	1.17			.99878 ± 78			1.00137 ± 157	1.00269 ± 149
0.15;6 (1)	1.08	572.2 ± .3	574.1 ± .4	.99668 ± 59	523.2 ± .7	524.2 ± .6	.99806 ± 146	1.00138 ± 140
0.15;6 (2)	1.08	572.2 ± .3	574.1 ± .4	.99671 ± 59	522.8 ± .6	524.2 ± .6	.99733 ± 134	1.00062 ± 126
0.15;6 (3)	1.08	572.2 ± .3	574.1 ± .4	.99671 ± 59	522.7 ± .5	524.3 ± .6	.99710 ± 97	1.00038 ± 81

(Cont'd)

U^{233}

(Cont'd)

FIT	χ^2	$\hat{\sigma}_a$	$\sigma_a(E_o)$	g_a	$\hat{\sigma}_f$	$\sigma_f(E_o)$	g_f	g_η
0.15;7 (0+)	1.16	573.1 ± .4	574.3 ± .5	.99788 ± 80	523.9 ± .6	524.6 ± .7	.99865 ± 104	1.00077 ± 74
0.15;7 (0)	1.175			.99879 ± 80			1.00187 ± 201	1.00318 ± 194
0.15;7 (1)	1.07	572.3 ± .3	574.3 ± .4	.99653 ± 60	522.8 ± .8	524.5 ± .6	.99679 ± 190	1.00026 ± 185
0.15;7 (2)	1.07	572.3 ± .3	574.3 ± .4	.99654 ± 60	522.5 ± .7	524.6 ± .6	.99601 ± 156	.99947 ± 148
0.15;7 (3)	1.07	572.3 ± .3	574.3 ± .4	.99653 ± 60	522.8 ± .5	524.5 ± .6	.99680 ± 98	1.00027 ± 81
0.15;8 (0+)	1.16	572.9 ± .4	574.3 ± .5	.99761 ± 84	523.9 ± .6	524.5 ± .7	.99870 ± 119	1.00109 ± 97
0.15;8 (0)	1.175			.99856 ± 83			1.00292 ± 234	1.00447 ± 227
0.15;8 (1)	1.08	572.2 ± .4	574.3 ± .4	.99642 ± 66	523.0 ±1.0	524.5 ± .7	.99729 ± 225	1.00087 ± 219
0.15;8 (2)	1.08	572.2 ± .4	574.3 ± .4	.99642 ± 66	522.5 ± .7	524.6 ± .6	.99592 ± 161	.99950 ± 152
0.15;8 (3)	1.08	572.2 ± .4	574.3 ± .4	.99642 ± 66	522.7 ± .5	524.5 ± .6	.99655 ± 109	1.00013 ± 94
0.2;4 (0+)	1.24	572.1 ± .4	574.8 ± .4	.99539 ± 19	522.7 ± .5	526.3 ± .6	.99325 ± 26	.99785 ± 22
0.2;4 (0)	1.21	505.5 ± .6	573.5 ± .4	.99586 ± 19	401.4 ±1.4	524.6 ± .6	.99370 ± 26	.99781 ± 22
0.2;4 (1)	1.10	571.8 ± .3	574.4 ± .3	.99541 ± 17	521.4 ± .5	524.9 ± .5	.99331 ± 23	.99788 ± 19
0.2;4 (2)	1.10	571.8 ± .3	574.4 ± .3	.99541 ± 16	521.4 ± .5	524.9 ± .5	.99331 ± 23	.99788 ± 19
0.2;4 (3)	1.11	571.8 ± .3	574.4 ± .3	.99541 ± 17	521.7 ± .5	525.2 ± .5	.99327 ± 23	.99784 ± 19
0.2;5 (0+)	1.22	572.5 ± .4	574.8 ± .4	.99596 ± 40	523.2 ± .5	525.8 ± .6	.99517 ± 56	.99921 ± 47
0.2;5 (0)	1.24			.99670 ± 40			.99528 ± 62	.99855 ± 55
0.2;5 (1)	1.09	572.0 ± .3	574.3 ± .3	.99602 ± 34	522.0 ± .5	524.8 ± .5	.99465 ± 56	.99862 ± 50
0.2;5 (2)	1.09	572.0 ± .3	574.3 ± .3	.99603 ± 34	521.0 ± .5	524.8 ± .5	.99461 ± 56	.99858 ± 49
0.2;5 (3)	1.09	572.0 ± .3	574.3 ± .3	.99601 ± 34	522.3 ± .5	524.0 ± .5	.99488 ± 52	.99887 ± 45
0.2;6 (0+)	1.17	573.1 ± .4	574.3 ± .4	.99795 ± 64	523.8 ± .5	524.6 ± .6	.99850 ± 87	1.00055 ± 67
0.2;6 (0)	1.19			.99872 ± 64			.99984 ± 115	1.00109 ± 107
0.2;6 (1)	1.07	572.3 ± .3	574.0 ± .4	.99700 ± 51	523.1 ± .6	524.2 ± .6	.99801 ± 107	1.00101 ± 99
0.2;6 (2)	1.07	572.3 ± .3	574.0 ± .4	.99702 ± 51	522.9 ± .6	524.1 ± .6	.99704 ± 102	1.00062 ± 94
0.2;6 (3)	1.07	572.3 ± .3	574.0 ± .4	.99703 ± 51	522.8 ± .5	524.1 ± .6	.99746 ± 84	1.00043 ± 71
0.2;7 (0+)	1.17	573.0 ± .4	574.4 ± .5	.99760 ± 77	523.7 ± .5	524.7 ± .7	.99811 ± 101	1.00052 ± 72
0.2;7 (0)	1.19			.99845 ± 77			1.00056 ± 165	1.00209 ± 156
0.2;7 (1)	1.06	572.2 ± .3	574.3 ± .4	.99642 ± 59	522.9 ± .7	524.4 ± .6	.99710 ± 154	1.00069 ± 148
0.2;7 (2)	1.06	572.2 ± .3	574.3 ± .4	.99644 ± 59	522.6 ± .7	524.5 ± .6	.99642 ± 138	.99998 ± 130
0.2;7 (3)	1.06	572.2 ± .3	574.3 ± .4	.99643 ± 59	522.7 ± .5	524.4 ± .6	.99657 ± 96	1.00014 ± 80
0.2;8 (0+)	1.18	573.0 ± .4	574.3 ± .5	.99783 ± 79	523.7 ± .6	524.6 ± .7	.99838 ± 104	1.00055 ± 74
0.2;8 (0)	1.18			.99873 ± 79			1.00267 ± 202	1.00392 ± 194
0.2;8 (1)	1.065	572.2 ± .3	574.2 ± .4	.99644 ± 59	523.1 ± .8	524.3 ± .6	.99771 ± 191	1.00128 ± 186
0.2;8 (2)	1.07	572.2 ± .3	574.2 ± .4	.99646 ± 59	522.6 ± .7	524.5 ± .6	.99645 ± 156	.99999 ± 148
0.2;8 (3)	1.07	572.2 ± .3	574.2 ± .4	.99645 ± 59	522.7 ± .5	524.5 ± .6	.99660 ± 97	1.00015 ± 80

(All errors in g's are x 10^{-5})

TABLE 3

U^{235}

FIT	χ^2	$\hat{\sigma}_a$	$\sigma_a(E_o)$	g_a	$\hat{\sigma}_f$	$\sigma_f(E_o)$	g_f	g_η
0.1;4 (O)	1.123	663.2 ± .3$_5$	677.5 ± .4	.97890 ± 45	567.2 ± .4	580.9 ± .6	.97632 ± 69	.99737 ± 81
0.1;4 (BC)	1.083	663.0 ± .2$_5$	677.2 ± .3	.97893 ± 30	567.3 ± .3$_5$	580.6 ± .5	.97701 ± 59	.99804 ± 63
0.1;4 (BV)	1.107	662.9 ± .2$_5$	677.2 ± .3	.97887 ± 30	567.0 ± .3$_5$	580.6 ± .5	.97662 ± 59	.99771 ± 63
0.1;4 (MR)	1.015	663.1 ± .2$_5$	677.3 ± .3	.97906 ± 30	568.1 ± .4	580.8 ± .5	.97827 ± 66	.99919 ± 69
0.1;4 (SH)	1.086	662.8 ± .2$_5$	677.1 ± .3	.97884 ± 30	566.4 ± .3$_5$	580.0 ± .5	.97667 ± 58	.99778 ± 63
0.1;5 (O)	1.091	663.2 ± .3$_5$	677.4 ± .5	.97904 ± 64	567.2 ± .4	582.1 ± .7	.97438 ± 86	.99523 ± 106
0.1;5 (BC)	1.075	663.0 ± .2$_5$	677.2 ± .3	.97904 ± 40	567.3 ± .3$_5$	581.3 ± .5$_5$	.97591 ± 72	.99680 ± 79
0.1;5 (BV)	1.095	662.9 ± .2$_5$	677.2 ± .3	.97895 ± 40	567.0 ± .3$_5$	581.4 ± .5$_5$	.97530 ± 72	.99626 ± 78
0.1;5 (MR)	1.016	663.1 ± .2$_5$	677.2 ± .3	.97925 ± 40	568.1 ± .4	580.9 ± .6	.97792 ± 87	.99864 ± 90
0.1;5 (SH)	1.074	662.8 ± .2$_5$	677.1 ± .3	.97892 ± 40	566.5 ± .3$_5$	580.8 ± .5$_5$	.97533 ± 73	.99634 ± 79
0.1;6 (O)	1.055	663.2 ± .3$_5$	677.2 ± .5	.97936 ± 67	567.4 ± .4	581.9 ± .7	.97502 ± 88	.99557 ± 109
0.1;6 (BC)	1.058	663.0 ± .2$_5$	677.2 ± .3	.97906 ± 40	567.4 ± .3$_5$	581.2 ± .5$_5$	.97631 ± 73	.99719 ± 79
0.1;6 (BV)	1.073	662.9 ± .2$_5$	677.2 ± .3	.97897 ± 40	567.2 ± .3$_5$	581.3 ± .5$_5$	.97571 ± 73	.99667 ± 79
0.1;6 (MR)	1.009	663.1 ± .2$_5$	677.2 ± .3	.97923 ± 40	568.1 ± .4	580.9 ± .6	.97786 ± 87	.99860 ± 90
0.1;6 (SH)	1.055	662.9 ± .2$_5$	677.1 ± .3	.97892 ± 40	566.6 ± .3$_5$	580.9 ± .6	.97550 ± 73	.99651 ± 80
0.15;4 (O)	1.130	663.0 ± .3	677.6 ± .4	.97848 ± 25	567.1 ± .4	580.3 ± .5	.97740 ± 28	.99890 ± 36
0.15;4 (BC)	1.073	662.8 ± .2$_5$	677.3 ± .2$_5$	.97859 ± 20	567.2 ± .3$_5$	580.3 ± .4	.97750 ± 27	.99889 ± 32
0.15;4 (BV)	1.095	662.8 ± .2$_5$	677.3 ± .3	.97857 ± 20	567.1 ± .3$_5$	580.1 ± .4	.97743 ± 27	.99884 ± 32
0.15;4 (MR)	1.111	663.0 ± .2$_5$	677.4 ± .3	.97865 ± 21	568.0 ± .3$_5$	580.9 ± .4	.97785 ± 27	.99918 ± 32
0.15;4 (SH)	1.077	662.7 ± .2$_5$	677.2 ± .2$_5$	.97856 ± 20	566.4 ± .3$_5$	579.5 ± .4	.97751 ± 26	.99892 ± 32
0.15;5 (O)	1.127	663.0 ± .3$_5$	677.6 ± .4	.97845 ± 47	567.1 ± .4	580.9 ± .6	.97628 ± 64	.99778 ± 77
0.15;5 (BC)	1.073	662.8 ± .2$_5$	677.3 ± .3	.97869 ± 32	567.2 ± .3$_5$	580.6 ± .5	.97684 ± 56	.99812 ± 62
0.15;5 (BV)	1.093	662.8 ± .2$_5$	677.3 ± .3	.97864 ± 32	567.0 ± .3$_5$	580.6 ± .5	.97649 ± 56	.99780 ± 62
0.15;5 (MR)	1.113	663.0 ± .2$_5$	677.3 ± .3	.97883 ± 32	568.1 ± .4	580.9 ± .5	.97794 ± 63	.99909 ± 67
0.15;5 (SH)	1.075	662.7 ± .2$_5$	677.2 ± .3	.97861 ± 32	566.4 ± .3$_5$	580.0 ± .5	.97653 ± 55	.99788 ± 61
0.15;6 (O)	1.106	663.1 ± .3$_5$	677.3 ± .5	.97903 ± 62	567.1 ± .4	581.9 ± .6$_5$	.97463 ± 81	.99551 ± 100
0.15;6 (BC)	1.069	662.9 ± .2$_5$	677.1 ± .3	.97891 ± 38	567.2 ± .3$_5$	581.1 ± .5	.97601 ± 69	.99704 ± 76
0.15;6 (BV)	1.086	662.8 ± .2$_5$	677.1 ± .3	.97884 ± 38	567.0 ± .3$_5$	581.2 ± .5	.97544 ± 69	.99652 ± 76
0.15;6 (MR)	1.113	663.0 ± .2$_5$	677.1 ± .3	.97913 ± 39	568.1 ± .4	580.9 ± .5$_5$	.97787 ± 83	.99871 ± 86
0.15;6 (SH)	1.068	662.7 ± .2$_5$	677.1 ± .3	.97881 ± 38	566.4 ± .3$_5$	580.6 ± .5$_5$	.97550 ± 70	.99662 ± 76
0.15;7 (O)	1.093	663.1 ± .3$_5$	677.2 ± .5	.97920 ± 66	567.2 ± .4	582.2 ± .7	.97433 ± 82	.99502 ± 104
0.15;7 (BC)	1.061	662.9 ± .2$_5$	677.2 ± .3	.97889 ± 39	567.3 ± .3$_5$	581.3 ± .5$_5$	.97578 ± 70	.99682 ± 76
0.15;7 (BV)	1.075	662.8 ± .2$_5$	677.2 ± .3	.97882 ± 39	567.1 ± .3$_5$	581.5 ± .5$_5$	.97520 ± 69	.99630 ± 76
0.15;7 (MR)	1.114	663.0 ± .2$_5$	677.2 ± .3	.97911 ± 39	568.0 ± .4	581.0 ± .6	.97762 ± 85	.99848 ± 88
0.15;7 (SH)	1.058	662.7 ± .2$_5$	677.1 ± .3	.97878 ± 39	566.5 ± .4	580.9 ± .5$_5$	.97513 ± 71	.99627 ± 77

(Cont'd)

(Cont'd) U^{235}

FIT	χ^2	$\hat{\sigma}_a$	$\sigma_a(E_o)$	g_a	$\hat{\sigma}_f$	$\sigma_f(E_o)$	g_f	g_η
0.15;8 (O)	1.062	663.1 ± .3$_6$	677.2 ± .5	.97926 ± 66	567.4 ± .4	581.4 ± .7	.97590 ± 91	.99657 ± 111
0.2;4 (O)	1.155	663.0 ± .3	677.6 ± .4	.97856 ± 16	567.1 ± .4	580.3 ± .5	.97723 ± 16	.99864 ± 21
0.2;4 (BC)	1.049	662.8 ± .2$_5$	677.3 ± .2$_5$	.97865 ± 16	567.2 ± .3$_5$	580.4 ± .4	.97729 ± 15	.99861 ± 20
0.2;4 (BV)	1.068	662.8 ± .2$_5$	677.3 ± .3	.97864 ± 16	567.0 ± .3$_5$	580.2 ± .4	.97731 ± 15	.99863 ± 20
0.2;4 (MR)	1.091	662.9 ± .2$_6$	677.4 ± .3	.97867 ± 16	567.9 ± .4	581.1 ± .4	.97727 ± 15	.99857 ± 20
0.2;4 (SH)	1.050	662.7 ± .2$_5$	677.2 ± .2$_5$	.97865 ± 16	566.4 ± .3$_6$	579.5 ± .4	.97743 ± 15	.99876 ± 20
0.2;5 (O)	1.158	663.0 ± .3$_5$	677.6 ± .4	.97847 ± 33	567.1 ± .4	580.2 ± .5	.97756 ± 40	.99907 ± 50
0.2;5 (BC)	1.051	662.8 ± .2$_6$	677.3 ± .3	.97867 ± 26	567.3 ± .3$_5$	580.2 ± .4	.97760 ± 37	.99891 ± 43
0.2;5 (BV)	1.071	662.8 ± .2$_5$	677.3 ± .3	.97864 ± 26	567.1 ± .3$_5$	580.1 ± .4	.97744 ± 37	.99877 ± 43
0.2;5 (MR)	1.084	663.0 ± .2$_5$	677.4 ± .3	.97878 ± 26	568.1 ± .4	580.4 ± .4$_5$	.97832 ± 39	.99952 ± 44
0.2;5 (SH)	1.053	662.7 ± .2$_5$	677.2 ± .3	.97862 ± 26	566.4 ± .4	579.5 ± .4	.97748 ± 36	.99883 ± 42
0.2;6 (O)	1.142	663.0 ± .3$_6$	677.6 ± .4	.97849 ± 51	567.1 ± .4	581.2 ± .6	.97570 ± 69	.99715 ± 83
0.2;6 (BC)	*1.048*	*662.8* ± .2$_5$	677.3 ± .3	.97859 ± 34	567.2 ± .3$_5$	580.8 ± .5	.97661 ± 60	.99797 ± 66
0.2;6 (BV)	1.065	662.8 ± .2$_5$	677.3 ± .3	.97854 ± 34	567.0 ± .3$_5$	580.8 ± .5	.97619 ± 60	.99760 ± 66
0.2;6 (MR)	1.086	663.0 ± .2$_5$	677.4 ± .3	.97877 ± 35	568.1 ± .4	580.9 ± .5	.97797 ± 68	.99918 ± 72
0.2;6 (SH)	1.047	662.7 ± .2$_5$	677.3 ± .3	.97851 ± 34	566.4 ± .3$_5$	580.1 ± .5	.97624 ± 60	.99768 ± 65
0.2;7 (O)	1.136	663.1 ± .3$_5$	677.4 ± .4$_5$	.97884 ± 62	567.1 ± .4	581.8 ± .6$_5$	.97474 ± 81	.99581 ± 100
0.2;7 (BC)	1.042	662.8 ± .2$_5$	677.1 ± .3	.97887 ± 38	567.2 ± .3$_5$	581.2 ± .5	.97594 ± 69	.99701 ± 75
0.2;7 (BV)	1.057	662.8 ± .2$_6$	677.1 ± .3	.97880 ± 38	567.0 ± .4	581.3 ± .5	.97537 ± 69	.99649 ± 75
0.2;7 (MR)	1.084	662.0 ± .2$_5$	677.2 ± .3'	.97909 ± 39	568.1 ± .4	581.0 ± .5$_5$	.97776 ± 82	.99865 ± 86
0.2;7 (SH)	1.040	662.7 ± .2$_5$	677.1 ± .3	.97877 ± 38	566.4 ± .4	580.6 ± .5$_5$	.97542 ± 70	.99658 ± 76
0.2;8 (O)	1.109	663.1 ± .3$_6$	677.2 ± .5	.97928 ± 66	567.3 ± .4	582.2 ± .6$_5$	.97439 ± 81	.99500 ± 103
0.2;8 (BV)	1.048	662.8 ± .2$_5$	677.2 ± .3	.97880 ± 38	567.1 ± .3$_5$	581.5 ± .5	.97520 ± 69	.99632 ± 75
0.2;8 (MR)	1.084	663.0 ± .2$_5$	677.2 ± .3	.97907 ± 39	568.0 ± .4	581.1 ± .5$_6$	.97756 ± 69	.99845 ± 87
0.2;8 (SH)	1.032	662.7 ± .2$_6$	677.10 ± .3	.97876 ± 38	566.5 ± .3$_5$	580.9 ± .5$_6$	.97513 ± 70	.99630 ± 76

(All errors in g's are x 10^{-5})

TABLE 4

Pu^{239}

FIT		χ^2	$\hat{\sigma}_a$	$\sigma_a(E_o)$	g_a	$\hat{\sigma}_f$	$\sigma_f(E_o)$	g_f	g_η
0.1;4	(O)	1.37	1088.2 ±	1012.7 ± 1.3	1.07454 ± 100	780.3 ±	739.7 ± 1.6	1.05487 ± 168	.98169 ± 166
0.1;4	(B)	1.22	1087.2 ± .9	1011.1 ± 1.4	1.07528 ± 103	778.8 ± 1.3	738.5 ± 1.3	1.05452 ± 142	.98069 ± 145
0.1;4	(R)	1.02	1096.5 ± 1.4	1015.1 ± 1.7	1.08019 ± 132	782.4 ± 1.3	740.8 ± 1.4	1.05619 ± 144	.97778 ± 152
0.1;4	(L)	1.07	1086.1 ± .8	1009.7 ± 1.4	1.07571 ± 100	778.3 ± 1.3	738.0 ± 1.3	1.05466 ± 142	.98042 ± 144
0.1;5	(O)	1.35	1088.7 ±	1014.6 ± 1.4	1.07303 ± 106	779.0 ±	741.8 ± 1.9	1.05146 ± 278	.97989 ± 260
0.1;5	(B)	1.19	1087.6 ± .9	1012.9 ± 1.4	1.07371 ± 109	777.7 ± 1.4	740.9 ± 1.5	1.04964 ± 239	.97758 ± 223
0.1;5	(R)	1.01	1096.4 ± 1.4	1017.5 ± 1.9	1.07754 ± 173	781.2 ± 1.5	743.2 ± 1.6	1.05103 ± 247	.9754 ± 230
0.1;5	(L)	1.05	1086.5 ± .8	1011.4 ± 1.4	1.07427 ± 107	777.3 ± 1.4	740.3 ± 1.5	1.04997 ± 239	.97738 ± 222
0.12;4	(O)	1.34	1088.5 ± .8	1012.3 ± 1.3	1.07532 ± 92	779.9 ± 1.4	739.6 ± 1.5	1.05445 ± 127	.98059 ± 130
0.12;4	(B)	1.21	1087.4 ± .9	1010.6 ± 1.3	1.07599 ± 94	778.7 ± 1.2	738.2 ± 1.3	1.05482 ± 106	.98032 ± 115
0.12;4	(R)	1.03	1096.6 ± 1.4	1015.7 ± 1.6	1.07966 ± 113	782.3 ± 1.3	740.8 ± 1.3	1.05591 ± 108	.97800 ± 121
0.12;4	(L)	1.07	1086.4 ± .84	1009.5 ± 1.3	1.07619 ± 91	778.3 ± 1.2	737.8 ± 1.3	1.05491 ± 106	.98023 ± 114
0.12;5	(O)	1.33	1088.7 ± .8	1014.2 ± 1.4	1.07348 ± 106	780.1 ± 1.5	740.5 ± 1.8	1.05340 ± 239	.98129 ± 227
0.12;5	(B)	1.20	1087.7 ± .9	1012.4 ± 1.4	1.07431 ± 109	778.2 ± 1.4	739.7 ± 1.4	1.05202 ± 205	.97926 ± 196
0.12;5	(R)	1.03	1096.6 ± 1.4	1015.8 ± 1.8	1.07949 ± 163	781.5 ± 1.4	741.5 ± 1.5	1.05402 ± 210	.97640 ± 206
0.12;5	(L)	1.06	1086.6 ± .8	1010.9 ± 1.4	1.07487 ± 107	777.7 ± 1.4	739.1 ± 1.4	1.05226 ± 205	.97897 ± 196
0.12;6	(O)	1.32	1088.9 ± .8	1014.2 ± 1.4	1.07366 ± 109	779.1 ± 1.6	742.4 ± 2.0	1.04945 ± 310	.97745 ± 288
0.12;6	(B)	1.18	1087.9 ± .9	1012.7 ± 1.4	1.07426 ± 111	776.7 ± 1.5	741.5 ± 1.6	1.04741 ± 272	.97500 ± 249
0.12;6	(R)	1.01	1096.9 ± 1.4	1018.0 ± 2.0	1.07754 ± 176	780.2 ± 1.6	744.2 ± 1.7	1.04832 ± 281	.97288 ± 255
0.12;6	(L)	1.05	1086.8 ± .9	1011.2 ± 1.4	1.07473 ± 108	776.2 ± 1.5	740.8 ± 1.6	1.04778 ± 272	.97492 ± 250
0.12;7	(O)	1.32	1089.0 ± 0.9	1015.1 ± 1.6	1.07280 ± 134	778.8 ± 1.7	742.8 ± 2.0	1.04852 ± 337	.97736 ± 311
0.15;4	(O)	1.30	1088.6 ± .8	1011.4 ± 1.2	1.07631 ± 81	779.0 ± 1.3	740.0 ± 1.5	1.05265 ± 92	.97802 ± 97
0.15;4	(B)	1.26	1087.6 ± .9	1009.9 ± 1.2	1.07684 ± 80	777.7 ± 1.1	738.3 ± 1.2	1.05345 ± 75	.97828 ± 83
0.15;4	(R)	1.09	1096.4 ± 1.4	1016.3 ± 1.5	1.07874 ± 89	781.4 ± 1.2	741.3 ± 1.3	1.05408 ± 76	.97714 ± 85
0.15;4	(L)	1.13	1086.5 ± .9	1008.9 ± 1.2	1.07695 ± 78	777.3 ± 1.2	737.8 ± 1.2	1.05352 ± 75	.97824 ± 82
0.15;5	(O)	1.29	1088.6 ± .9	1013.4 ± 1.4	1.07439 ± 103	780.0 ± 1.4	739.8 ± 1.6	1.05431 ± 185	.98130 ± 179
0.15;5	(B)	1.25	1087.7 ± .9	1011.4 ± 1.4	1.07539 ± 105	778.4 ± 1.3	738.6 ± 1.3	1.05375 ± 158	.97988 ± 156
0.15;5	(R)	1.09	1096.8 ± 1.4	1014.9 ± 1.7	1.08074 ± 143	781.9 ± 1.4	740.5 ± 1.4	1.05587 ± 162	.97698 ± 164
0.15;5	(L)	1.13	1086.6 ± .9	1010.1 ± 1.4	1.07579 ± 103	778.9 ± 1.3	738.1 ± 1.3	1.05397 ± 158	.97974 ± 156

(All errors in g's are x 10^{-6})

(Cont'd)

(Cont'd)

FIT	χ^2	$\hat{\sigma}_a$	$\sigma_a(E_o)$	g_a	$\hat{\sigma}_f$	$\sigma_f(E_o)$	g_f	g_ν
0.15;6 (O)	1.27	1089.0 ± .9	1014.2 ± 1.4	1.07376 ± 105	779.7 ± 1.5	741.1 ± 1.9	1.05221 ± 272	.97984 ± 225
0.15;6 (B)	1.24	1088.0 ± .9	1012.5 ± 1.4	1.07453 ± 107	777.5 ± 1.4	740.3 ± 1.5	1.05031 ± 234	.97746 ± 219
0.15;6 (R)	1.08	1096.8 ± 1.4	1017.0 ± 1.9	1.07844 ± 171	780.9 ± 1.5	742.5 ± 1.6	1.05175 ± 242	.97525 ± 267
0.15;6 (L)	1.12	1086.9 ± .9	1011.0 ± 1.4	1.07505 ± 105	777.0 ± 1.4	739.6 ± 1.5	1.05064 ± 234	.97730 ± 219
0.15;7 (O)	1.27	1089.1 ± .9	1014.2 ± 1.4	1.07377 ± 114	778.7 ± 1.6	742.3 ± 2.0	1.04898 ± 320	.97692 ± 297
0.15;7 (B)	1.24	1088.0 ± .9	1012.9 ± 1.5	1.07422 ± 115	776.2 ± 1.5	741.5 ± 1.6	1.04684 ± 284	.97451 ± 261
0.15;7 (R)	1.08	1097.1 ± 1.4	1018.0 ± 2.0	1.07775 ± 174	779.7 ± 1.6	744.2 ± 1.7	1.04767 ± 293	.97210 ± 264
0.15;7 (L)	1.11	1086.9 ± .9	1011 5 ± 1.5	1.07463 ± 123	775.8 ± 1.6	740.8 ± 1.6	1.04722 ± 284	.97449 ± 261
0.2;4 (O)	1.31	1089.0 ± .8	1011.5 ± 1.1	1.07659 ± 69	778.2 ± 1.4	740.2 ± 1.4	1.05138 ± 68	.97658 ± 73
0.2;4 (B)	1.25	1087.9 ± .9	1009.6 ± 1.1	1.07762 ± 67	776.7 ± 1.1	738.1 ± 1.2	1.05219 ± 58	.97650 ± 62
0.2;4 (R)	1.11	1096.0 ± 1.3	1016.9 ± 1.5	1.07783 ± 69	780.1 ± 1.2	741.4 ± 1.3	1.05219 ± 58	.97621 ± 63
0.2;4 (L)	1.135	1086.8 ± .8	1008.5 ± 1.1	1.07763 ± 66	776.2 ± 1.1	737.7 ± 1.2	1.05226 ± 58	.97646 ± 62
0.2;5 (O)	1.30	1089.0 ± .9	1012.0 ± 1.3	1.07604 ± 93	779.6 ± 1.4	739.6 ± 1.5	1.05405 ± 127	.97957 ± 128
0.2;5 (B)	1.24	1087.9 ± .9	1010.8 ± 1.3	1.07681 ± 95	778.3 ± 1.2	738.2 ± 1.3	1.05436 ± 109	.97961 ± 114
0.2;5 (R)	1.09	1097.0 ± 1.4	1015.5 ± 1.6	1.08027 ± 118	781.9 ± 1.3	740.6 ± 1.3	1.05584 ± 112	.97739 ± 121
0.2;5 (L)	1.125	1086.9 ± .9	1009.6 ± 1.3	1.07654 ± 93	777.9 ± 1.2	737.7 ± 1.3	1.05447 ± 109	.97951 ± 114
0.2;6 (O)	1.29	1089.2 ± .9	1013.8 ± 1.4	1.07441 ± 104	779.8 ± 1.4	740.3 ± 1.7	1.05341 ± 211	.98045 ± 202
0.2;6 (B)	1.24	1088.1 ± .9	1012.0 ± 1.4	1.07523 ± 107	778.2 ± 1.4	739.0 ± 1.4	1.05300 ± 186	.97933 ± 180
0.2;6 (R)	1.10	1097.0 ± 1.4	1015.2 ± 1.8	1.08066 ± 156	781.6 ± 1.4	740.7 ± 1.5	1.05521 ± 191	.97645 ± 188
0.2;6 (L)	1.12	1087.0 ± .9	1010.5 ± 1.5	1.07572 ± 105	777.7 ± 1.4	738.4 ± 1.4	1.05328 ± 186	.97914 ± 179
0.2;7 (O)	1.28	1089.3 ± .9	1014.0 ± 1.4	1.07431 ± 104	779.5 ± 1.5	741.1 ± 1.9	1.05086 ± 279	.97910 ± 260
0.2;7 (B)	1.22	1088.3 ± .9	1012.3 ± 1.4	1.07500 ± 107	776.9 ± 1.5	740.6 ± 1.5	1.04897 ± 243	.97579 ± 227
0.2;7 (R)	1.08	1097.16± 1.4	1017.1 ± 1.9	1.07874 ± 172	780.4 ± 1.5	743.0 ± 1.6	1.05026 ± 253	.97359 ± 234
0.2;7 (L)	1.115	1087.2 ± .9	1010.9 ± 1.5	1.07547 ± 108	776.5 ± 1.5	740.0 ± 1.5	1.04931 ± 244	.97567 ± 227
0.2;8 (O)	1.28	1089.4 ± .9	1013.9 ± 1.4	1.07451 ± 114	778.8 ± 1.6	742.0 ± 2.0	1.04959 ± 319	.97681 ± 296
0.2;8 (B)	1.23	1088.3 ± .9	1012.3 ± 1.5	1.07506 ± 117	776.5 ± 1.6	740.9 ± 1.6	1.04797 ± 285	.97479 ± 262
0.2;8 (R)	1.08	1097.5 ± 1.4	1017.78± 2.0	1.07834 ± 173	780.0 ± 1.6	743.9 ± 1.7	1.04858 ± 293	.97241 ± 265
0.2;8 (L)	1.12	1087.2 ± 0.9	1011.0 ± 1.5	1.07541 ± 114	776.1 ± 1.6	740.3 ± 1.6	1.04831 ± 286	.97480 ± 262

(All errors in g's are x 10^{-5})

α = 0.095 (at zero energy) pseudo-point, weight 3.0 units) we see that for the average fit the g_a accuracy is not improved, while the error of g_α is reduced by about 25% and g_f almost as much. This is a modest change for the effect of a point placed where there are no other data. The case 3 g's are therefore included in the estimate of "spreads", but (because cases 1, 2 and 3 all have a considerable similarity) the older 0 and 0+ cases are retained but treated separately, as giving definitely less reliable fits.

In fact, the main problem for U-233, and one also applying to both other isotopes, is deciding, for those curves behaving anamalously near E = 0, at what point we must draw the line and declare a fit "unacceptable", and so exclude the corresponding g-factors from account when compiling the total "spread" for each type of g. In this context, acceptability is judged from the reasonableness of the shapes in view of what is known of the theory of neutron-nuclear interactions. Although it is known that multi-level curves may vary in shape much more than single level Breit-Wigners, the smallest likely level-widths (set by Γ_γ as a lower limit, see BNL-325, 1965, Vol. III) for these heavy nuclei makes sudden departures below 10-15 milli-eV from the trends established above this energy rather unlikely, but it is still a matter of judgment based on familiarity with both theory and the available measured data. In Appendix V some aspects of this are discussed further.

Tables 2, 3 and 4 show the $\hat{\sigma}$, $\sigma_{22_{00}}$ and g-factors obtained from the fitting procedure for U-233, U-235 and Pu-239 respectively, together with the standard deviations calculated as explained in Appendix III, i.e., from the accuracy assigned to each input datum (multiplying by χ may give a rough estimate based on the

average spreads of the points, as mentioned in the middle of section 5 above). However, the "spreads" of the g-values themselves appear to be a better indication of the overall accuracy, though this should be no less than the mean χ times the computed "errors". This is because the computations assume that a given order of polynomial plus the chosen Breit-Wigner terms can be expected to give a good fit to the $\sigma\sqrt{E}$ concerned, and although mathematically convenient, this assumption has no physical basis. Inspection of the selection of fitted curves shown in figs. 10 - 24 may support the feeling that we have achieved an adequate number of fits representative of various possible fluctuations but it would be quite difficult to prove this. The use of a "factor of safety", applied to errors deduced from "spreads", has already been mentioned--this factor will be largest (in fact almost x2) for U-233, where the "cases" used (except 0 and 0+) are rather similar, and least for Pu-239 where the source of the divergent trends of the recipes seems clear and no awkward decisions between claimed accuracies and observed spreads within a single data set arose to complicate the assessment.

9. THE "SPREADS" OF g-FACTORS OBTAINED

We have already noted that for low-order wide-range fits the choice of fit in itself reduces the calculated errors and makes the fits for all "cases" similar; this is clear from Tables 2-4. The trends represented by the systematic differences between g's for the cases ("SH" and "MR") based mainly on SH (in contrast to R) recipes for U-235, and similarly for R, L and B cases

for Pu-239, are also seen in this table, and the curve-shape differences (see figures cited above) also show the characteristics indicated in App. II.C.

The fact that for g_f (U-235) and g_a (Pu-239) the systematic difference (due to the recipe differences (R-SH and R-LO) respectively) is of the same order as the "spread" of g's (for acceptable curve shapes) for either group taken separately was mentioned above (section 7) and is in fact derived from the values* in Tables 3 and 4; the only slightly smaller systematic differences for g_η (U-235) and the definitely smaller ones for g_f and g_η (Pu-239) are also seen from this table. These facts are relevant to the interpretation of the observed spread of the g-values in terms of a standard deviation (the former being generally 3 to $3\frac{1}{2}$ times the latter, see Appendix V(A)). Also in Appendix V is a summary of which curve shapes were felt to be unacceptable (some "borderline" cases also exist). The spreads shown in Table 5 are those given by the g's of tables 2-4 and it will be seen that the mean of the spreads with and without borderline cases is that adopted. Table 5 also shows the spread of the 20.44°C g's deduced from "adjust", from Table 1; the additional spread which would be given by the (subsidiary) option between R and RS has been included, but MLA is regarded as something between borderline and unacceptable (HI has already been regarded as rejected--it is in Table 1 only to show what effect it would produce).

Both these "adjust" spreads and the spreads from "fitting" are for 20.44°C Maxwellian spectra--in App. V(C) the question of widening the "spreads" (because of an accidental cancellation at

* See, for example, the differences between cases MR and SH of Table 3 and cases R and L of Table 4.

TABLE 5

Summary of Spreads of g-factors

	g_{abs}	g_{fiss}	g_{eta}
U-233			
A	0.99615	0.9963	1.00015
F	0.99703	0.99764	1.00138 - [0.99840
FB	0.99747] - 0.99549	0.99806] - 0.99419	0.99784
$\Delta(x10^5)$	176	365	326
U-235			
A	0.97905] - 0.9788	0.9771] - 0.9767	0.9979 - 0.9977
AB(?)	(0.9797)] -	(0.9776)] -	
F	0.97925 - 0.97851	0.97832 - [0.97530	0.99952 - [0.99626
FB		0.97438}*	0.99523}*
		0.97463]	0.99551]
$\Delta(x10^5)$	74	342(63)	371(92)
Pu-239			
A	1.0770 - 1.0751	1.0551] - 1.05085	0.98015] - 0.9770
A(HI)		(1.0565)] -	(0.9823)] -
F	1.08074 - [1.07371	1.05619 - [1.04741	0.98069] - [0.97288
FB	1.07303	1.04684	0.98169] - [0.97210
$\Delta(x10^5)$	737(189)	917	870(120)

Deduced Standard Deviations and Factors of Safety

	U-233	U-235	Pu-239
Safety Factor	1.65(abs, 2.3)	1.25(abs, 3.75)	1.1
Std. Dev. %, abs	0.12	0.09	0.285
Std. Dev. %, fiss	0.20	0.155	0.285
Std. Dev. %, eta	0.16	0.174	0.325

For detailed explanation and acceptability criteria (also of asterisk *) see App. V. B.4
A = from "adjust" procedure, F = from fitting procedure; (B) denotes borderline acceptability. Δ = "spread", followed (in brackets) by ΔT if applicable.

20°C of the effects of some of the differences between alternative recipes) is discussed, and the final "effective" spreads chosen, taking this into account, are also listed in Table 5, together with the factor of safety (see section 8 above) and the final standard deviation. The "independent" errors (v. App. V(D)), needed for the 2200 m/sec regression analysis, are listed, with the recommended g-values and the standard errors from Table 5 in Table 7 below.

10. STUDY OF Pu-241

So far Pu-241 has not been considered in detail. The α data (apart from Maxwellian averages) consist only of two points, so that only the ratio of the two is significant for our work. Consequently the "adjust" procedure is inapplicable and the fitting procedure depends mainly on the data for σ_a and σ_f. To obtain the weights for the σ_f points an "eye-ball" fit was used, as for the other isotopes, while for σ_a the most important data were known to be of similar quality (the CR 64C and MTR 61I values both used a BNL-type chopper and the same oxide sample material) so that the relative weights were estimated and an "absolute" weighting system derived from these aided by some mean-square deviation calculations. In fact, the accuracy for σ_a was quite high and that for σ_f relatively low, and the relative weights of total and fission cross-section data could be varied considerably without changing the fits (had there been no α data at all the fits would have been completely independent). The only alternative "cases" (i.e., sets of weights) used were obtained by varying the weights for some special sets of data (see App. V.F),

and for some fits by adding a "fictitious" point for α at 0.005 eV energy. This point was introduced, as discussed below and in the Appendix, to provide some way of including the qualitative knowledge which nuclear systematics provides as to what kinds of behaviour of $\sigma\sqrt{E}$ seem quite unlikely. The data from Harwell (Raffle, AERE-R 2998, and James (1965)) and Hanford (the HAN 58D set, with points in the energy range 2.5-4.7 milli eV), for all of which the authors' accuracy claims were known, all required a weight function varying with energy, or from point to point. The problems raised by these data sets is discussed fully in App. V.F--for James the fact that SCISRS contained a very large number of data, each of very low accuracy, introduced problems, while for HAN 58D the normalization accuracy of the data set required examination. Unfortunately this means that all the low-energy σ_f data are in some way problematical. The low energy σ_a data (especially the MTR 68L set) appeared very good in comparison, although the steep rise at low energies of $\sigma_a\sqrt{E}$ is also not so easily explained in terms of systematics (an unexpectedly narrow negative-energy resonance with a very small Γ_f/Γ_γ would be needed to explain this, since $\sigma_f\sqrt{E}$ does not show a similar rise).

The problem which arises is seen from Figs. 25-26; the $\sigma_a\sqrt{E}$ rise near E=0 seems well-determined but is increasingly steep as E=0 is approached, and many of the fits (at least without the "fictitious" α-datum) show σ_f/E falling in the $E < 0.015$ (approx.) eV region where the data become sparse. The only two α-points indicate only a small negative slope and a "flat" curve seems reasonable, but the fits rise steeply as $\alpha \to 0$. It is difficult to see what these trends can

represent in terms of the theory of neutron resonances; while multi-level analysis may yield curve-shapes (for σ/E) rather different from those expected from single-level theory, it seems unlikely that a definite rise of $\sigma_a\sqrt{E}$ for energies below 25-40 milli-eV would be accompanied by an even more sudden (concentrated below 0.02 eV) fall off of $\sigma_f\sqrt{E}$. But since the data below 0.015 eV are so poor, we have preferred to assume that $\sigma_f\sqrt{E}$ should be at least flat, if it does not rise slightly as $E \to 0$, and have performed fits to study what special assumptions would be needed to ensure this.

In the final set of fits (specified in the Appendix) are included cases with and without the James data (where the χ^2 shows that the "with" set give these points too much weight), with and without the downweighting applied to HAN 58D data, and with and without the single "fictitious" α datum. Table 6 gives the values of g-factors corresponding to the cases which were done and sample graphs are given in Fig. 25-26. To illustrate the changes due to different choices of weights, only curves for 0.1;5 fits are shown--considered as a set, the 0.1;5 are all "reasonable" fits, and more extreme differences (or, e.g. wiggliness) will occur for other indices and ranges of fit. On the question of which curve-shapes could be treated as acceptable, only the $\sigma_f\sqrt{E}$ curves are discussed below; as App. V makes clear all absorption, but none of the α curves, were "acceptable" if we apply nuclear systematics criteria. For the rest, the following general statements can be made: With neither HAN 58D nor James data included (case "N") we get typically a highly variable fit, with most influence from the extra α datum; practically all fits without this datum give σ_f curve shapes rejected on systematics ground (with it, most are OK).

TABLE 6

g-factors for Pu-241 Fits

		χ^2	g_a	g_f	g_η
0.1;4	A	1.478	1.03738 ± 69	1.04836 ± 232	1.01058 ± 233
	A+	1.485	1.03733 ± 69	1.05005 ± 226	1.01227 ± 228
	HD	1.474	1.03739 ± 69	1.04651 ± 246	1.00879 ± 246
	HD+	1.483	1.03733 ± 69	1.04889 ± 237	1.01114 ± 237
	NJ	1.158	1.03738 ± 69	1.05077 ± 251	1.01290 ± 250
	NJ+	1.169	1.03733 ± 69	1.05274 ± 241	1.01485 ± 241
0.1;5	A	1.480	1.03768 ± 86	1.04862 ± 383	1.01054 ± 376
	A+	1.486	1.03762 ± 86	1.05244 ± 364	1.01428 ± 359
	HD	1.475	1.03768 ± 86	1.04310 ± 442	1.00523 ± 432
	HD+	1.484	1.03761 ± 86	1.04984 ± 405	1.01179 ± 397
	NJ	1.158	1.03771 ± 86	1.05545 ± 413	1.01709 ± 405
	NJ+	1.166	1.03765 ± 86	1.05903 ± 389	1.02060 ± 382
	N	1.164	1.03771 ± 86	1.04296 ± 638	1.00506 ± 620
	N+	1.179	1.03765 ± 85	1.05680 ± 507	1.01846 ± 493
0.1;6	A	1.480	1.03762 ± 86	1.05117 ± 431	1.01306 ± 422
	A+	1.485	1.03757 ± 85	1.05556 ± 411	1.01734 ± 402
	HD	1.477	1.03760 ± 86	1.04401 ± 547	1.00617 ± 532
	HD+	1.485	1.03756 ± 86	1.05334 ± 483	1.01522 ± 470
	NJ	1.159	1.03765 ± 87	1.05789 ± 455	1.01950 ± 445
	NJ+	1.165	1.03761 ± 85	1.06177 ± 429	1.02329 ± 419
	N	1.166	1.03764 ± 86	1.03993 ± 920	1.00221 ± 889
	N+	1.179	1.03761 ± 86	1.06173 ± 638	1.02325 ± 617
0.14;4	HD	1.425	1.03644 ± 50	1.04735 ± 134	1.01054 ± 138
	NJ	1.120	1.03643 ± 50	1.04818 ± 138	1.01134 ± 141
0.14;5	A	1.426	1.03779 ± 77	1.04902 ± 266	1.01083 ± 266
	A+	1.432	1.03773 ± 77	1.05114 ± 258	1.01293 ± 258
	HD	1.423	1.03779 ± 77	1.04662 ± 287	1.00851 ± 286
	HD+	1.431	1.03772 ± 77	1.04974 ± 274	1.01158 ± 273
	NJ	1.114	1.03779 ± 77	1.05219 ± 287	1.01387 ± 286
	NJ+	1.123	1.03774 ± 77	1.05454 ± 272	1.01620 ± 274
	N	1.118	1.03782 ± 77	1.04636 ± 363	1.00824 ± 357
	N+	1.132	1.03773 ± 77	1.05244 ± 320	1.01417 ± 317
0.14;6	A	1.428	1.03775 ± 84	1.04779 ± 378	1.00968 ± 372
	A+	1.434	1.03768 ± 84	1.05168 ± 359	1.01349 ± 354
	HD	1.424	1.03774 ± 84	1.04194 ± 440	1.00404 ± 430
	HD+	1.432	1.03767 ± 84	1.04896 ± 403	1.01088 ± 395
	NJ	1.116	1.03777 ± 85	1.05437 ± 405	1.01600 ± 398
	NJ+	1.123	1.03772 ± 85	1.05800 ± 381	1.01955 ± 374
	N	1.119	1.03778 ± 84	1.04072 ± 640	1.00284 ± 622

(Cont'd)

(Cont'd)

		χ^2	g_a	g_f	g_η
0.14;7	A	1.427	1.03766 ± 86	1.05143 ± 425	1.01327 ± 416
	A+	1.432	1.03761 ± 86	1.05566 ± 399	1.01740 ± 391
	HD	1.424	1.03765 ± 81	1.04494 ± 530	1.00703 ± 515
	HD+	1.431	1.03760 ± 88	1.05369 ± 437	1.01551 ± 465
	NJ	1.113	1.03769 ± 79	1.05807 ± 469	1.01964 ± 457
	NJ+	1.120	1.03765 ± 85	1.06183 ± 413	1.02330 ± 404
	N	1.121	1.03768 ± 86	1.04308 ± 881	1.00521 ± 852
	N+	1.131	1.03765 ± 88	1.06240 ± 608	1.02385 ± 589
0.14;8	A	1.428	1.03715 ± 254	1.05162 ± 384	1.01395 ± 444
	HD	1.426	1.03714 ± 104	1.04492 ± 529	1.00751 ± 502
	HD+	1.432	1.03708 ± 207	1.05449 ± 816	1.01678 ± 810
	NJ	1.115	1.03720 ± 239	1.05808 ± 119	1.02013 ± 199
	NJ+	1.121	1.03714 ± 119	1.06179 ± 488	1.02377 ± 479
	N	1.121	1.03717 ± 225	1.03634 ± 1006	0.99920 ± 993
0.18;5	A	1.462	1.03702 ± 65	1.04654 ± 199	1.00918 ± 201
	A+	1.469	1.03697 ± 65	1.04790 ± 194	1.01054 ± 197
	HD	1.459	1.03703 ± 65	1.04505 ± 208	1.00773 ± 210
	HD+	1.467	1.03697 ± 65	1.04691 ± 202	1.00958 ± 204
	NJ	1.127	1.03702 ± 65	1.04864 ± 213	1.01120 ± 215
	N	1.128	1.03705 ± 65	1.04499 ± 243	1.00766 ± 243
	N+	1.145	1.03698 ± 65	1.04844 ± 226	1.01106 ± 226
0.18;6	A	1.461	1.03799 ± 81	1.04930 ± 316	1.01090 ± 314
	A+	1.467	1.03792 ± 81	1.05210 ± 303	1.01366 ± 301
	HD	1.458	1.03799 ± 81	1.04583 ± 353	1.00756 ± 348
	HD+	1.465	1.03792 ± 81	1.05030 ± 331	1.01193 ± 327
	NJ	1.121	1.03800 ± 81	1.05401 ± 343	1.01543 ± 339
	NJ+	1.129	1.03794 ± 81	1.05692 ± 325	1.01828 ± 322
	N	1.126	1.03802 ± 81	1.04585 ± 475	1.00754 ± 464
	N+	1.139	1.03794 ± 81	1.05480 ± 401	1.01625 ± 393
0.18;7	A	1.462	1.03783 ± 80	1.04963 ± 405	1.01137 ± 396
	A+	1.468	1.03777 ± 84	1.05361 ± 373	1.01526 ± 367
	HD	1.459	1.03782 ± 80	1.04362 ± 464	1.00558 ± 452
	HD+	1.466	1.03776 ± 85	1.05110 ± 436	1.01285 ± 426
	NJ	1.122	1.03785 ± 78	1.05618 ± 426	1.01766 ± 416
	NJ+	1.129	1.03780 ± 85	1.05982 ± 399	1.02121 ± 391
	N	1.127	1.03785 ± 83	1.04245 ± 715	1.00443 ± 693
	N+	1.139	1.03780 ± 86	1.05829 ± 539	1.01974 ± 524
0.18;8	A	1.463	1.03758 ± 85	1.05000 ± 313	1.01197 ± 288
	A+	1.468	1.03753 ± 77	1.05450 ± 349	1.01636 ± 342
	HD	1.460	1.03757 ± 144	1.04186 ± 453	1.00413 ± 456
	HD+	1.467	1.03752 ± 92	1.05179 ± 397	1.01376 ± 390
	NJ	1.123	1.03761 ± 71	1.05689 ± 360	1.01858 ± 351
	NJ+	1.129	1.03757 ± 80	1.06077 ± 354	1.02236 ± 347
	N	1.127	1.03760 ± 148	1.03655 ± 836	0.99899 ± 816
	N+	1.140	1.03757 ± 43	1.06007 ± 493	1.02169 ± 469

(All errors in g's are x 10^{-5})

With both these data sets at full weight, or with only James data excluded (cases A or NJ) most fits are acceptable and the α (extra) datum of much less importance.

If HAN 58D is downweighted but James retained (case HD) the sets with the fictitious α point are reasonably good (in σ_f curve shape) but most fits without it are rejects or at best borderline.

In Table 7 the attempt is made, in these difficult circumstances, to give ranges of g-factors selected from these fits either (A) applying the rejection criteria based on systematics as described above, or (B) being much more lenient concerning the shapes of the $\sigma_f\sqrt{E}$ curves. It is seen that this choice has a considerable effect on the "accuracy" which one could claim for the g_f and g_η factors.

As a result, it is felt desirable to present this situation without a definitive conclusion, except insofar as it is necessary to choose g-factor "best values" and accuracies for the IAEA 2200 m/s cross section evaluation. It does not appear likely that a further theoretical examination of the Pu-241 data will clarify the situation, though comments from measurers of data will be sought when this report has been circulated. However, the only way to resolve this question appears to be to obtain better σ_f or α data, as a function of neutron energy below about 0.02 eV, and it is hoped that this will be found to give values whose interpretation in terms of resonance theory of neutron-nucleus interactions is clear. In the meantime for the 2200 m/sec evaluation the "A" values of Table 7 will be used.

TABLE 7

Ranges of g-factors for Pu-241

	g_{abs}	g_{fiss}	g_{eta}
Max-Min (A)	1.03801 - 1.03697	1.05800 - 1.04494	1.01964 - 1.00703
Max-Min (B)	1.03801 - 1.03643	1.05982 - 1.04401	1.02121 - 1.00617
Max-Min (C)	1.03802 - 1.03643	1.00007 - 1.04072	1.02169 - 1.00284
Range (A+B mean)	131	1444	1388
Range (C)	159	1935	1885
Std. Dev'n (A/B)	±.00043	±.00481	±.00463
%	say 0.1	0.5	0.5
Std. Dev'n (C)	±.00053	±.00645	±.00628
%	*	0.7	0.7

Notes: All ranges are in units of 10^{-5}; A = acceptable, B = borderline (both using σ_f shapes); C = assuming wider limits (not systematics)

* If $\sigma_a\sqrt{E}$ low-energy measurement assumed not to have systematic error, ±0.125%, say, but if most recent measurements could be systematically high, then say ±0.2% or even more.

11. DISCUSSION AND CONCLUSIONS

From the foregoing it appears that the limits within which the curve shapes and g-factors are expected to lie, based on the existing experimental data, have been adequately explored, except that for Pu-241 the exploration extends only as far as seems justified in view of the limitations of the data. It seems less likely that more refined resonance theory, applied to these problems, would appreciably improve the situation.

It is, however, more difficult to define a "best" curve for $\sigma_a\sqrt{E}$, $\sigma_f\sqrt{E}$, or α as a function of energy. An attempt to estimate the actual values of g_a, g_f and g_η has been made, but the skewness of the distribution of some of our g's obtained by fitting has not made this easy--it is, for example, unlikely that the centre of our "acceptable" range of g's will generally be the most probable value. By examining the histograms (cf. App. V(E)) and curve shapes, and values from the "adjust" procedure, the "best" values given in Table 8 were obtained, but it is not claimed that an accuracy of better than perhaps 15-25% of the standard deviation is meaningful, so that in presenting these values only three decimal places have been generally given, and Pu-241 is only included in a tentative sense. Also given in the tables are the standard deviations of the g's (corresponding to the percentage errors of Table 5) as well as the (percentage) errors of three "independent" quantities which (with the relation $g_\eta = g_f/g_a$) together reproduce the total accuracies (cf. App. V.D.; these quantities are usually needed for least squares treatments of g-factors, as in the IAEA study already cited.)

TABLE 8

Estimated "Best" Values of $g(20.4_4\,^{\circ}C)$ and Their Accuracy

	g_{abs}	g_{fiss}	g_{eta}
U-233	0.966 ± .0012	0.966 ± .0020	1.000 ± .0016
(Indpt. errors)	(0.12%)	(∞%)	(0.16%)
U-235	0.979 ± .0009	0.977 ± .00151	0.998_5 ± .00174
(Indpt. errors)	(0.092%)	(0.164%)	(0.459%)
Pu-239	1.076 ± .00307	1.052 ± .00300	0.978 ± .00318
(Indpt. errors)	(0.285%)	(0.285%)	(0.325%)
Pu-241 (tentative)	1.037_5	1.050_5	1.012_5
(Choice of errors)	±0.1 or 0.2%	±0.5 or 0.7%	±0.5 or 0.7%

E R R A T U M

A STUDY OF THE ACCURACY OF g-FACTORS FOR ROOM-TEMPERATURE MAXWELLIAN SPECTRA FOR U AND Pu ISOTOPES

by

C.H. WESTCOTT

An unfortunate error occured in setting up Table 8 (p.40), where the errors in parentheses for Pu-239 (indpt. errors) are shown incorrectly. These values should be

	g_{abs}	g_{fiss}	g_{eta}
(indpt. errors)	(±0.331%)	(±0.331%)	(±0.452%)

The (unbracketed) errors shown in the previous line are correct.

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The next problem is two-fold; to define "best" curves (as a function of energy) and to deduce how the g-factors will behave at temperatures above 20.4_4 °C (there is seldom interest in practice in lower temperatures). Now if the g's are exactly known for all temperatures we can in theory define (apart from an arbitrary multiplier) the curve shapes, and vice versa, but if the g's are only known for one temperature, or a narrow range of temperatures, several different curves may be equally possible. Similarly, should a regression analysis (e.g., the IAEA study cited) show that g should be raised by, say, 0.3%, there is no unambiguous curve adjustment which can be justified as corresponding to this change. It may be possible in favourable cases where two clearly-differing alternative "recipes" have been identified (in our case R or LO for Pu-239 σ_a or R or SH for U-235 σ_f) to select a linear combination of the two in chosen proportions to duplicate quite closely the required g-factors, and suggest curves (from linear combinations of "adjusted" recipes) which correspond to these g's, but there is still no proof that such curves will be "correct" even if all three g's are reproduced. And in general no adjustment based on one recipe difference can reproduce the three g's exactly, since there are two degress of freedom involved in such a process. Nevertheless, in the actual case this single adjustment may be the best procedure available, and is likely to produce curve-shapes which are not unreasonable in the light of all available information, even if the g's are not exactly correct. We must emphasize, however, that no such recipe can give us any proof of the correctness of the resulting

curve-shapes. A similar problem arises if we find, on performing a regression analysis for all data relevant to 2200 m/sec constants (as in the concurrent IAEA study cited above) that the g-factors here proposed should be adjusted by up to 1 or 2 standard deviations to give a "best fit"--there is also here no unambiguous curve-shape adjustment which can be shown to correspond to the new g-factor values, or to be indicated by the totality of the information available.

A further related point is the temperature-variation of the g-factors for U-233, U-235 or Pu-239. As indicated in Table 1, the increments in the g's for an increment of, say, 120 centigrade degrees above 20.4_4°C, varies somewhat according to which "adjust" recipe is used. The "linear combination" suggested above may indicate, for any chosen g(20.4_4°C)'s, how the g's are likely to change with T, but this deduction also is not unambiguous--fortunately in practice these Δg changes are relatively similar for the different recipes, and the problem is seldom serious even though in principle ambiguity must arise (for Pu-239, the worst case, other uncertainties in the actual neutron spectrum may help to reduce the importance of this effect). The values which are finally obtained (for temperatures up to 160°C) are given in App. V.G.

Nevertheless, in spite of these reservations of principle, it seems useful to make available to the data centres values of $\sigma_a(E)$, $\sigma_f(E)$ and $\alpha(E)$ which are consistent with the present work; these will be sent initially to the Brookhaven NNCSC in a format of the ENDF/B type. A transition region near 0.2 eV will be needed in which our functions can be joined to the present evaluated data files, and

indications for this will also be sent to Brookhaven.

We therefore conclude with Table 8 (giving recommended g-values) and by arranging to communicate to the data centres typical curve-shapes at low energy, although with the reservations stated, whose importance must not be overlooked. It is also hoped that it will be clear that these are secondary to our main purpose, which was to study what accuracy it would seem reasonable to attribute to g-factors. Moreover for any reliable estimates of g's at higher temperatures than about 130°C, a further study concentrating more on data for neutron energies above 0.1 eV would be necessary.

12. ACKNOWLEDGMENTS

This work has been undertaken concurrently with a review of the 2200 m/sec constants on behalf of the IAEA and an indebtedness to those who supplied data or comments thereon for the IAEA study, must also be expressed in connection with this report. Discussions of more particular relevance to g-factor accuracy problems with Prof. E. Vogt, of the University of British Columbia, and Mr. G.C. Hanna are also acknowledged.

The contributions of Dr. D. McPherson and the staff of the Chalk River computation centre were much more direct, and some of the basic procedures adopted were chosen, and the early stages of the work programmed by Dr. McPherson; Miss C. Sprague also greatly assisted in arranging computer operations and graphical and tabular results and without their cooperation the present work might not have been possible.

NOTES ON FIGURES 1 - 12

Figs. 1-4 and 5(a) show the data together with "recipes" ("eye-ball" curves drawn through sets of data.)

Fig. 1 (U-233) has absorption (upper curve) and fission (lower) data.

Figs. 2 and 3 show three alternative U-235 (fission) recipes. The data which fit the "SH" curve best are (with that curve) drawn 3 inches low.

Fig. 4 also has those data fitting "LO" best drawn 3 inches low.

Figs. 5b and 6-9 are curves of "adjust" procedure--solid curves are the adjusted curves, dotted are the original recipes. The recipes used (in order, "abs, fiss, alpha") are indicated after the title.

Note, e.g., on Fig. 7(a) the "kink" near 0.02 eV due to change of weight in this region--this is acceptably reduced for the R.RSH.R or R.SH.R (cf. Fig. 8(a)) fits.

Figs. 10-12 are U-233 fitted curves (title still names three recipes, but the solid line is only the one--or two--recipes concerned). The dotted lines are the polynomial fits obtained.

Fig. 10 shows a good (0.15;5) fit, and a "wiggly" one (0.1;8).

Fig. 11 illustrates "even-odd" effects, for fits 0.2; 6 and 0.2;7.

Fig. 12(a) and (b) is an "over-rigid" fit (low-order,"limited to cubic") as discussed on p.19; the others (c)(d) are an "old" case giving unacceptable fits (σ_γ becomes negative as $E \to 0$).

SUMMARY OF U-233 FITS SHOWN IN GRAPHS

Fits rejected are those of Fig. 10(c,d), 12(a,b) and 12(c,d)--the last an extremely bad case. Fig. 11(a,b) is only moderately good but is deemed acceptable. The other two, 10(a,b) and 11(c,d), are good fits.

NOTES ON FIGURES 13-26

U-235 Fits (Figs. 13-18). Full line is recipe (which is shown in title). Dotted line is fitted curve.

Figs. 13-14 are one case in full (higher E range on smaller scale).

Figs. 15-16 and 17a are other cases but still for 0.15;5 fits, and illustrate MR vs SH differences, etc.

Figs. 17(b), 18(d) and 18(a,c) are fits which are too "wiggly". The upper end, 18(b), of Fig. 17(b) shows that wiggles are mainly at low E end, but also occur at upper end of E-range. For this case σ_a is well-behaved except just at upper end of range (like σ_f there).

Pu-239 Fits (Figs. 19-24)

Figs. 19-20 have one full-size σ_a and one full-size σ_f curves. Others are cut down and therefore do not show all data points (top left abs., top left and bottom right, fission).

Figs. 19-21 show B vs R contrast in fits for 0.15;6.

Fig. 24 shows case L (not exactly same order fit).

Pu-241 Fits (Figs. 25-26)

These are all 0.10;5 fits to illustrate difference between cases. Note the low tendency for $\sigma_f\sqrt{E}$ near E=0 for cases HD and N.

SUMMARY: The only curves corresponding to rejected cases are Fig. 17(b) and all on Fig. 18 and for Pu-241 the cases of Figs. 26(a,f) and 26(e); all others were deemed acceptable, except the fig. 26(d) case which is taken as borderline for wiggliness.

N.B. No data points for HAR 65C σ_f data appear on Figs. 25-26; they are so numerous that it seemed better to omit them, and their "scatter" is very large.

FIG 1.

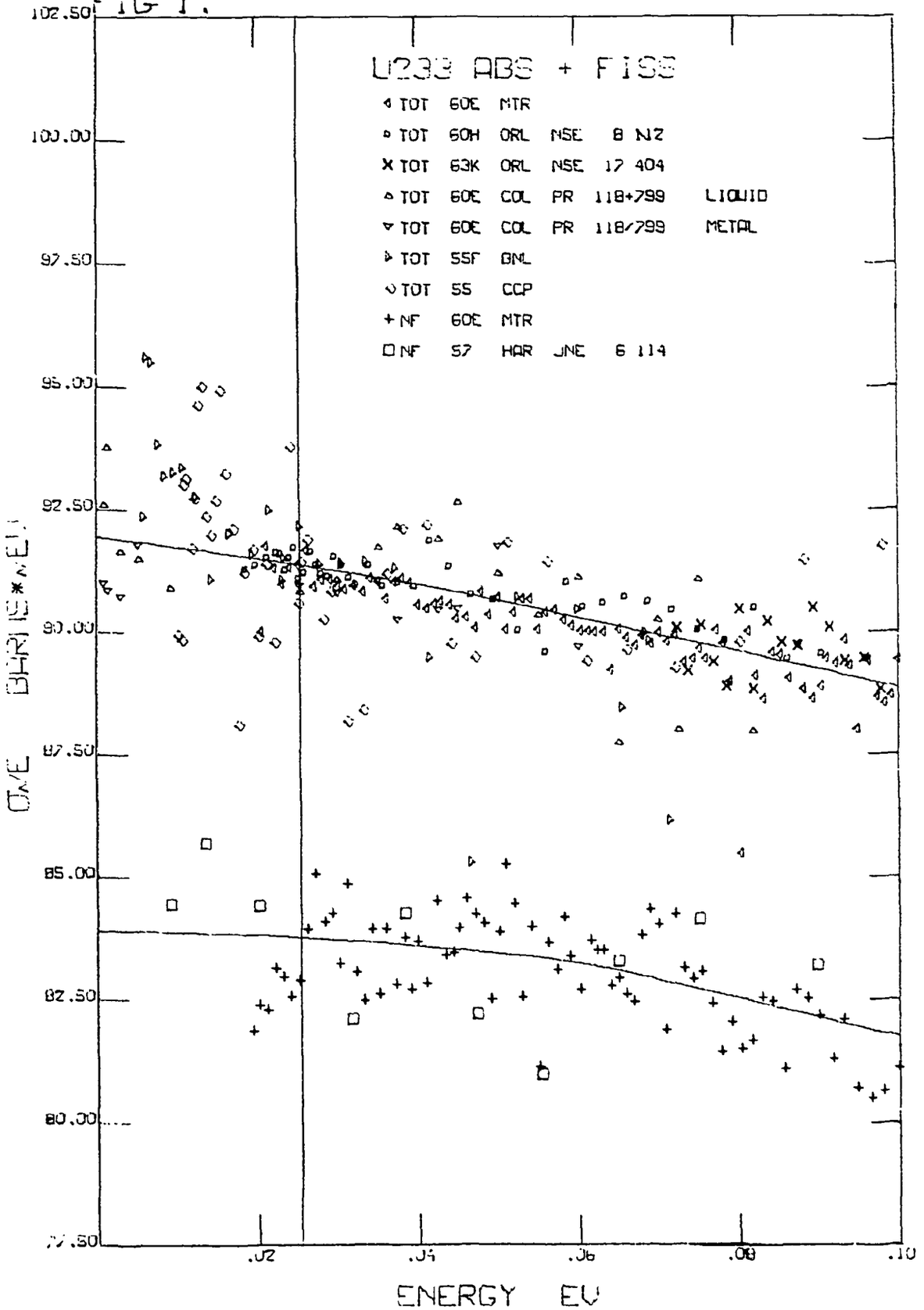

U233 ABS + FISS
TOT 60E MTR
TOT 60H ORL NSE 8 NZ
TOT 63K ORL NSE 17 404
TOT 60E COL PR 118+799 LIQUID
TOT 60E COL PR 118/799 METAL
TOT 55F BNL
TOT 55 CCP
NF 60E MTR
NF 57 HAR JNE 6 114
102.50
100.00
97.50
95.00
92.50
90.00
87.50
85.00
82.50
80.00
.02
.04
.06
.08
.10
ENERGY EV

FIG 2

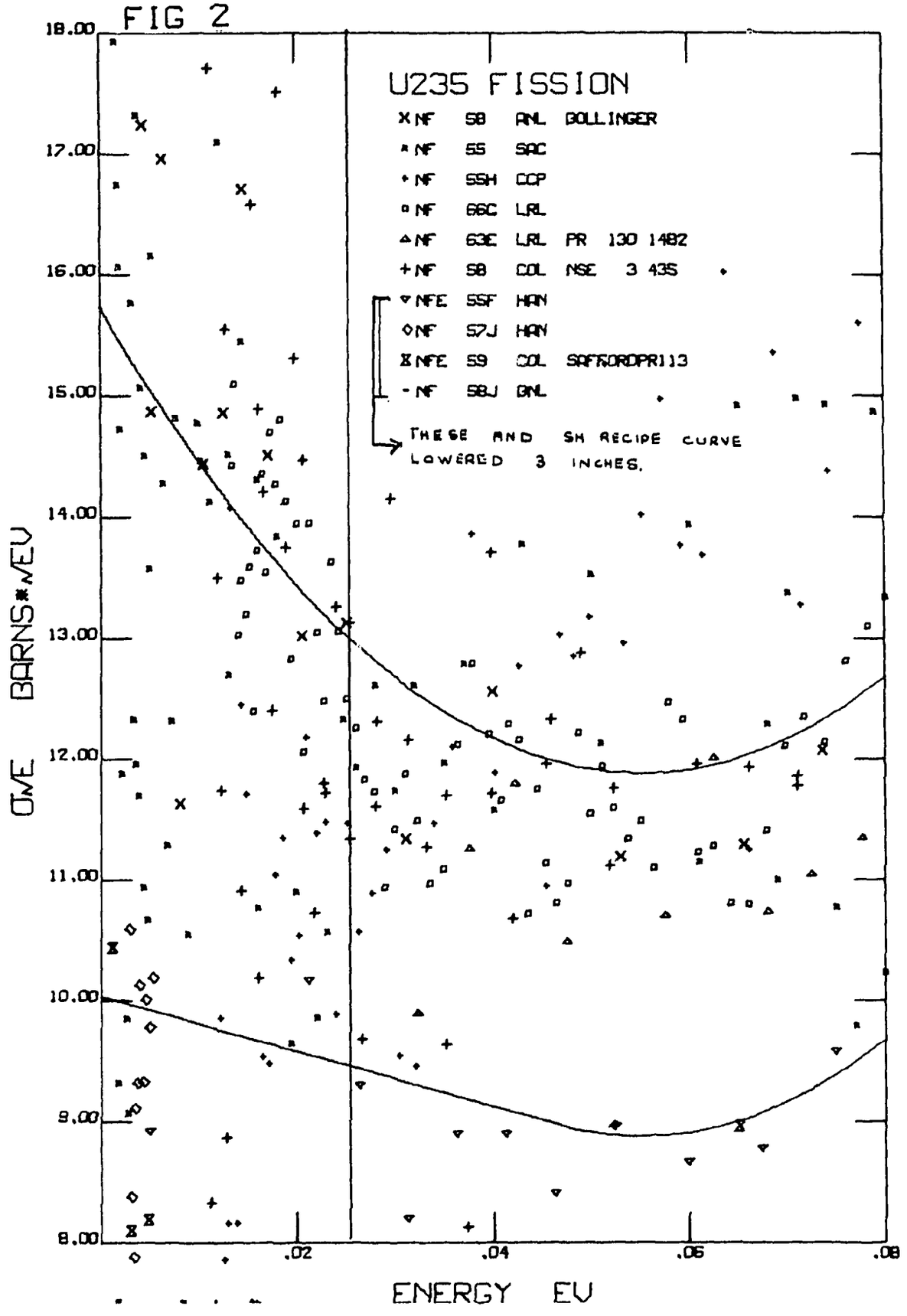

U235 FISSION
X NF 58 ANL BOLLINGER
* NF 55 SRC
+ NF 55H CCP
□ NF 66C LRL
△ NF 63E LRL PR 130 1482
+ NF 58 COL NSE 3 435
▽ NFE 55F HAN
◇ NF 57J HAN
⧖ NFE 59 COL SOFRORDPR113
- NF 58J BNL
THESE AND SH RECIPE CURVE LOWERED 3 INCHES.
18.00
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
.02
.04
.06
.08
ONE BARNS*N/EV
ENERGY EV

FIG 3.

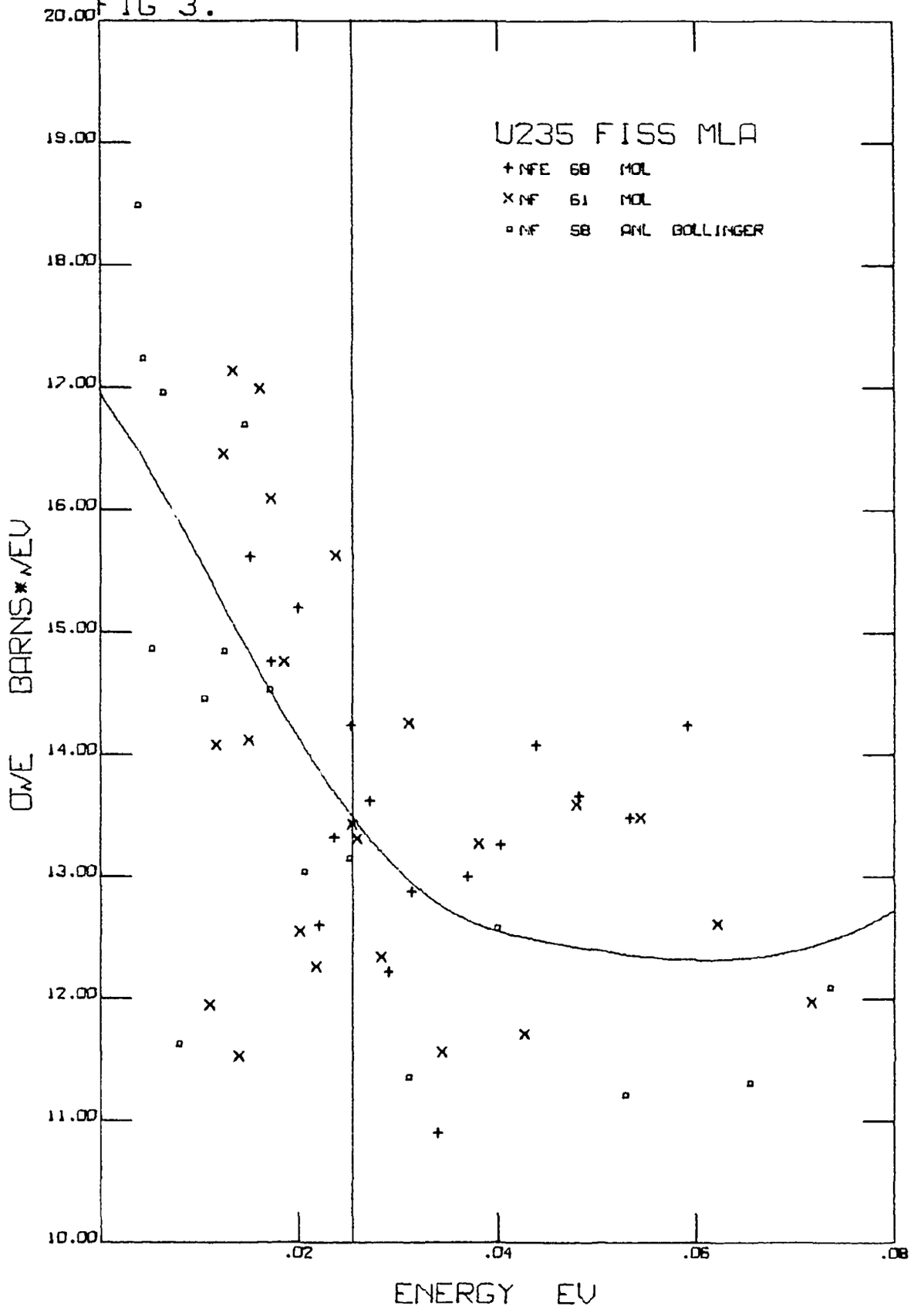

U235 FISS MLA
+ NFE 68 MOL
× NF 61 MOL
▫ NF 58 ANL BOLLINGER
20.00
19.00
18.00
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
.02
.04
.06
.08
ENERGY EV
BARNS*N/EV

FIG. 4

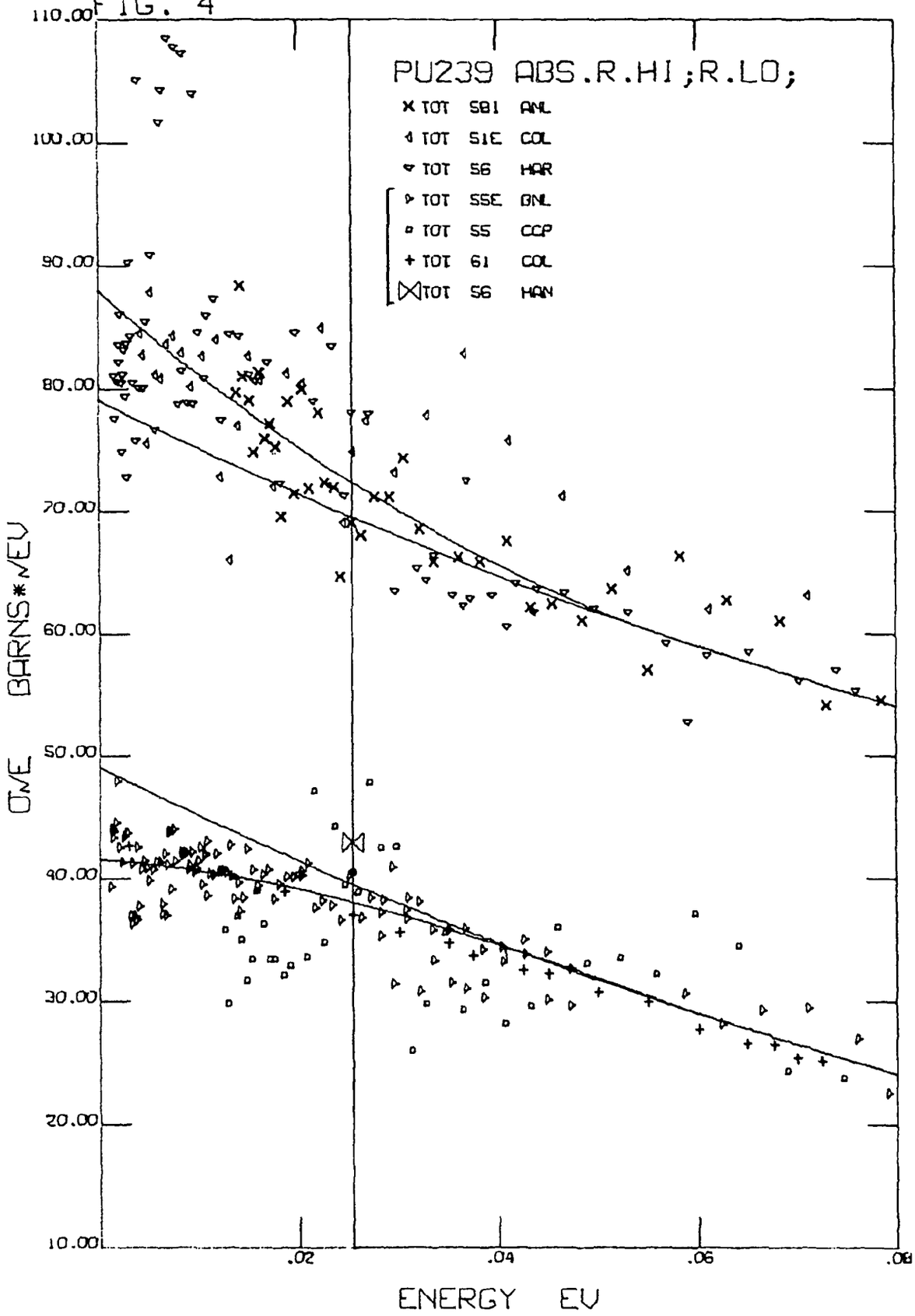

PU239 ABS.R.HI;R.LO;
TOT 581 ANL
TOT 51E COL
TOT 56 HAR
TOT 55E BNL
TOT 55 CCP
TOT 61 COL
TOT 56 HAN
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
BARNS*MEV
.02
.04
.06
.08
ENERGY EV

FIG. 5A

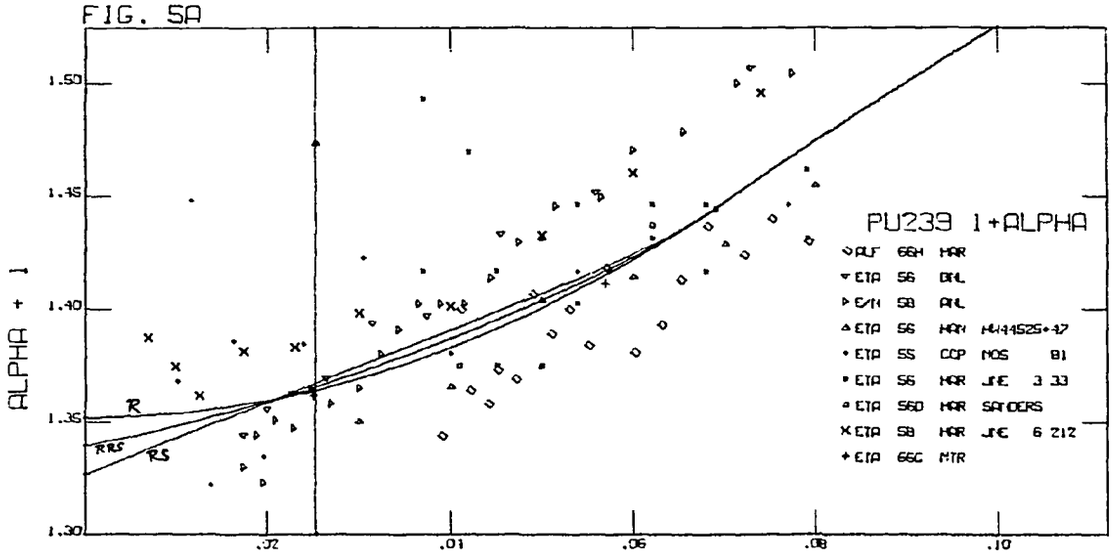
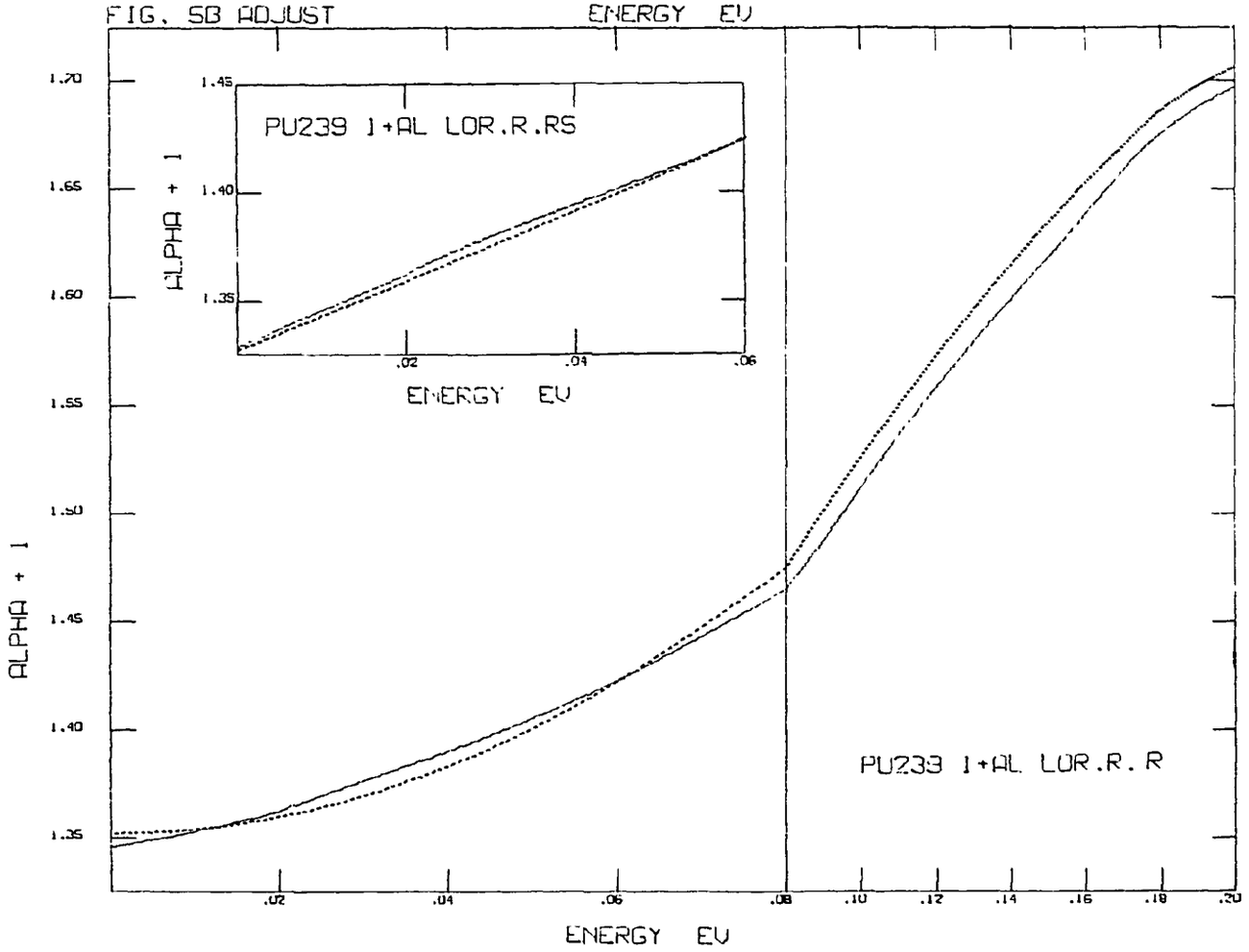


FIG. 5B ADJUST



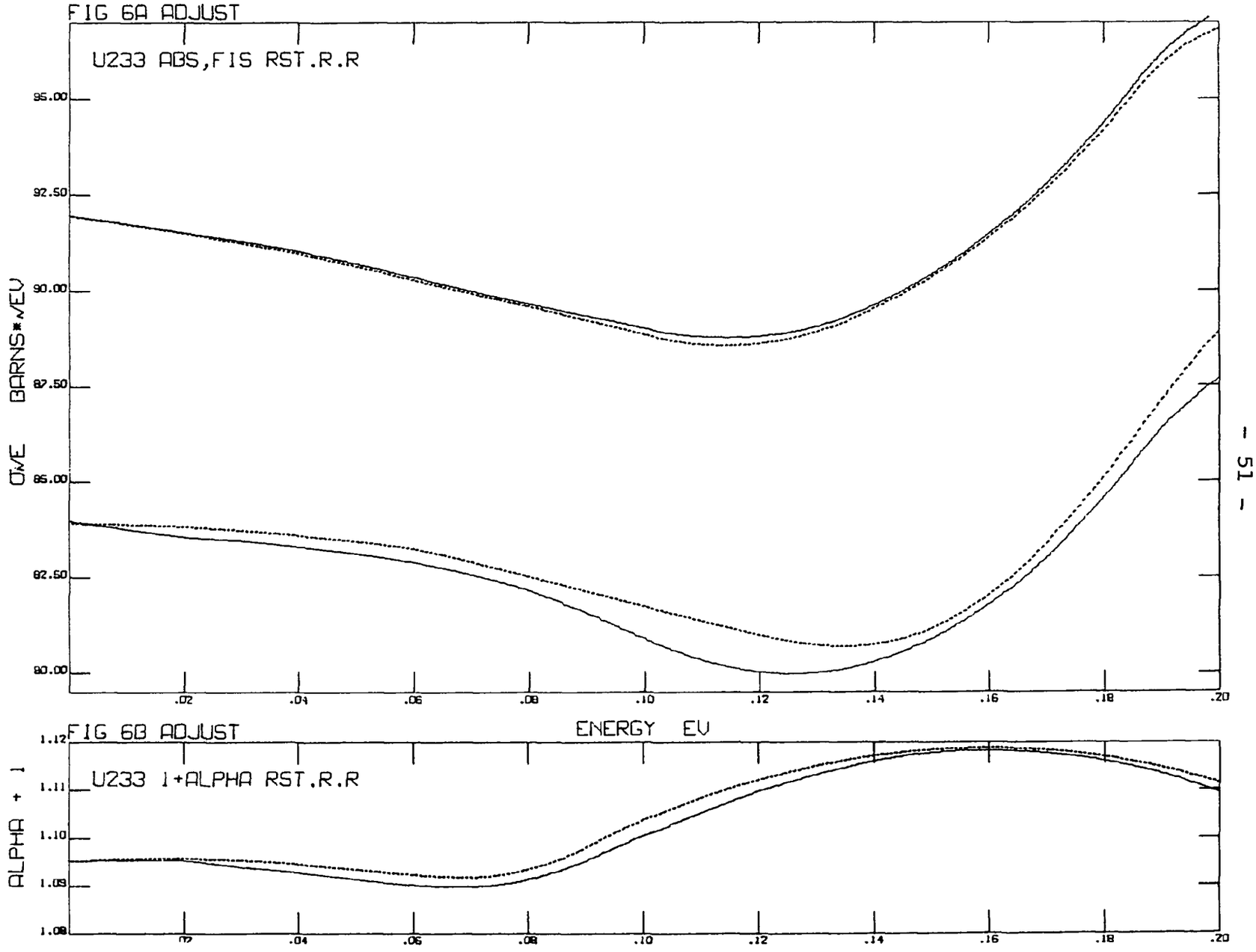


FIG 6A ADJUST
U233 ABS,FIS RST.R.R
95.00
92.50
90.00
87.50
85.00
82.50
80.00
σ/E BARNS*√EV
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
FIG 6B ADJUST
ENERGY EV
U233 1+ALPHA RST.R.R
1.12
1.11
1.10
1.09
1.08
ALPHA + 1

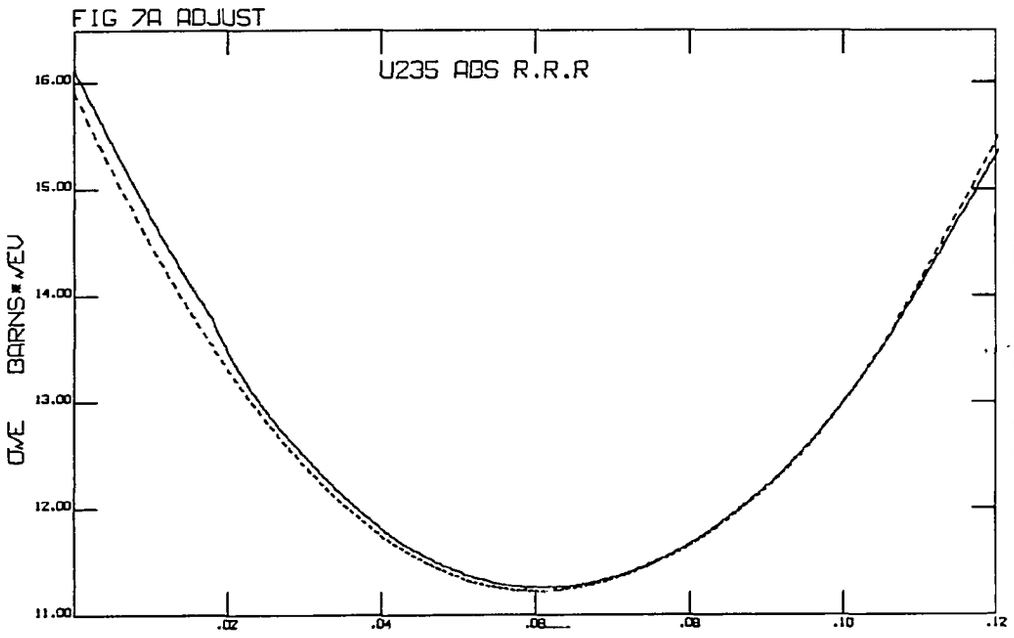


FIG 7A ADJUST
U235 ABS R.R.R
16.00
15.00
14.00
13.00
12.00
11.00
BARNS*√EV
σ√E
.02
.04
.06
.08
.10
.12
ENERGY EV

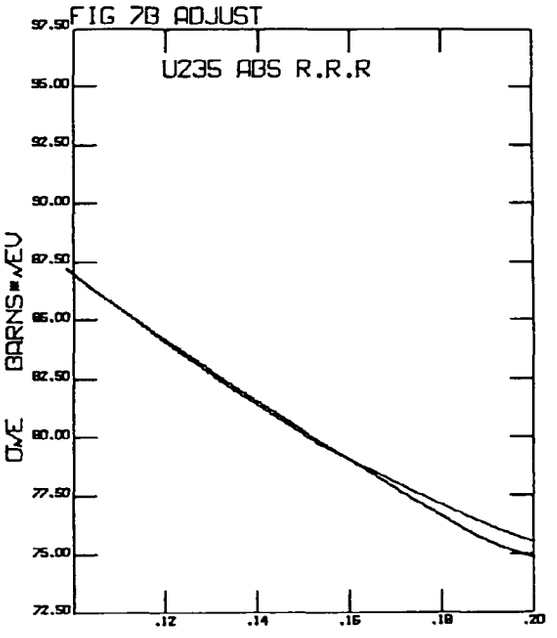


FIG 7B ADJUST
U235 ABS R.R.R
97.50
95.00
92.50
90.00
87.50
85.00
82.50
80.00
77.50
75.00
72.50
BARNS*√EV
σ√E
.12
.14
.16
.18
.20

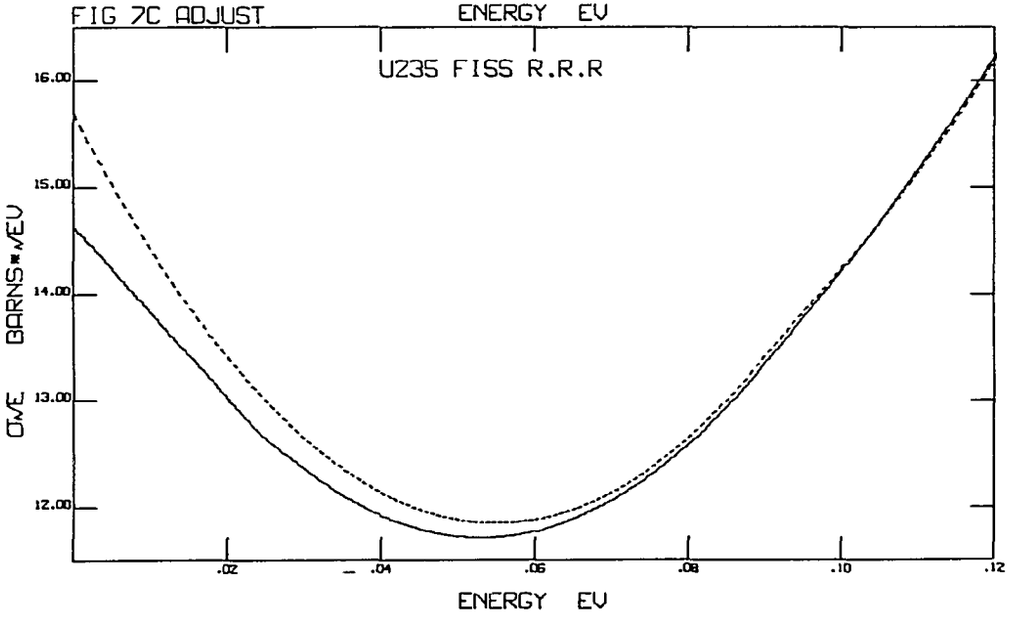


FIG 7C ADJUST
U235 FISS R.R.R
16.00
15.00
14.00
13.00
12.00
BARNS*√EV
σ√E
.02
.04
.06
.08
.10
.12
ENERGY EV

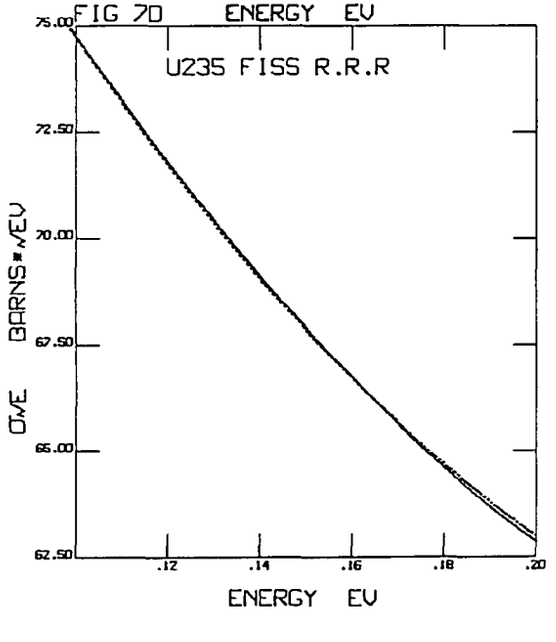


FIG 7D ENERGY EV
U235 FISS R.R.R
75.00
72.50
70.00
67.50
65.00
62.50
BARNS*√EV
σ√E
.12
.14
.16
.18
.20
ENERGY EV

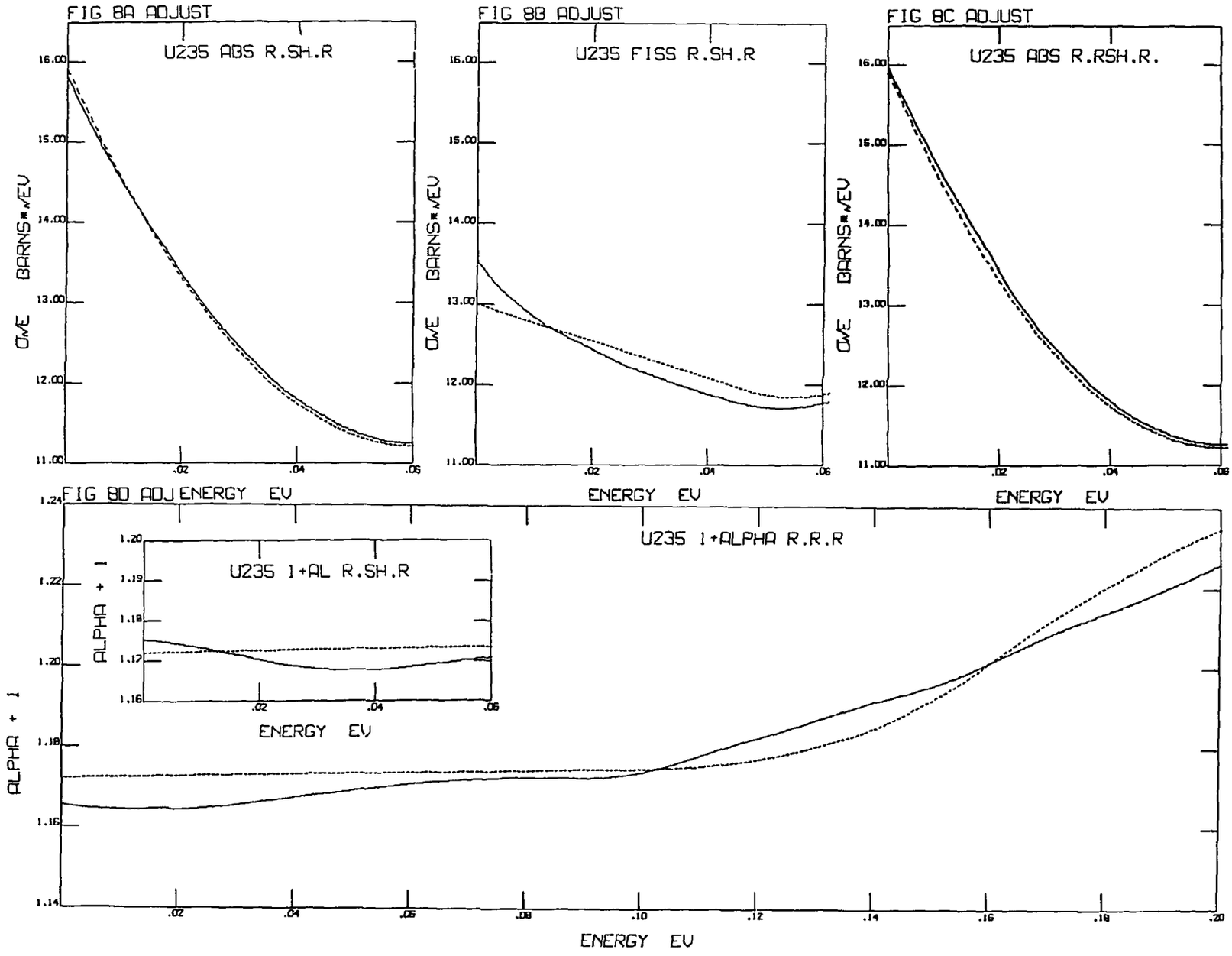


FIG 8A ADJUST
U235 ABS R.SH.R
FIG 8B ADJUST
U235 FISS R.SH.R
FIG 8C ADJUST
U235 ABS R.RSH.R.
BARNS*N/EV
ENERGY EV
FIG 8D ADJ ENERGY EV
U235 1+ALPHA R.R.R
U235 1+AL R.SH.R
ALPHA + 1

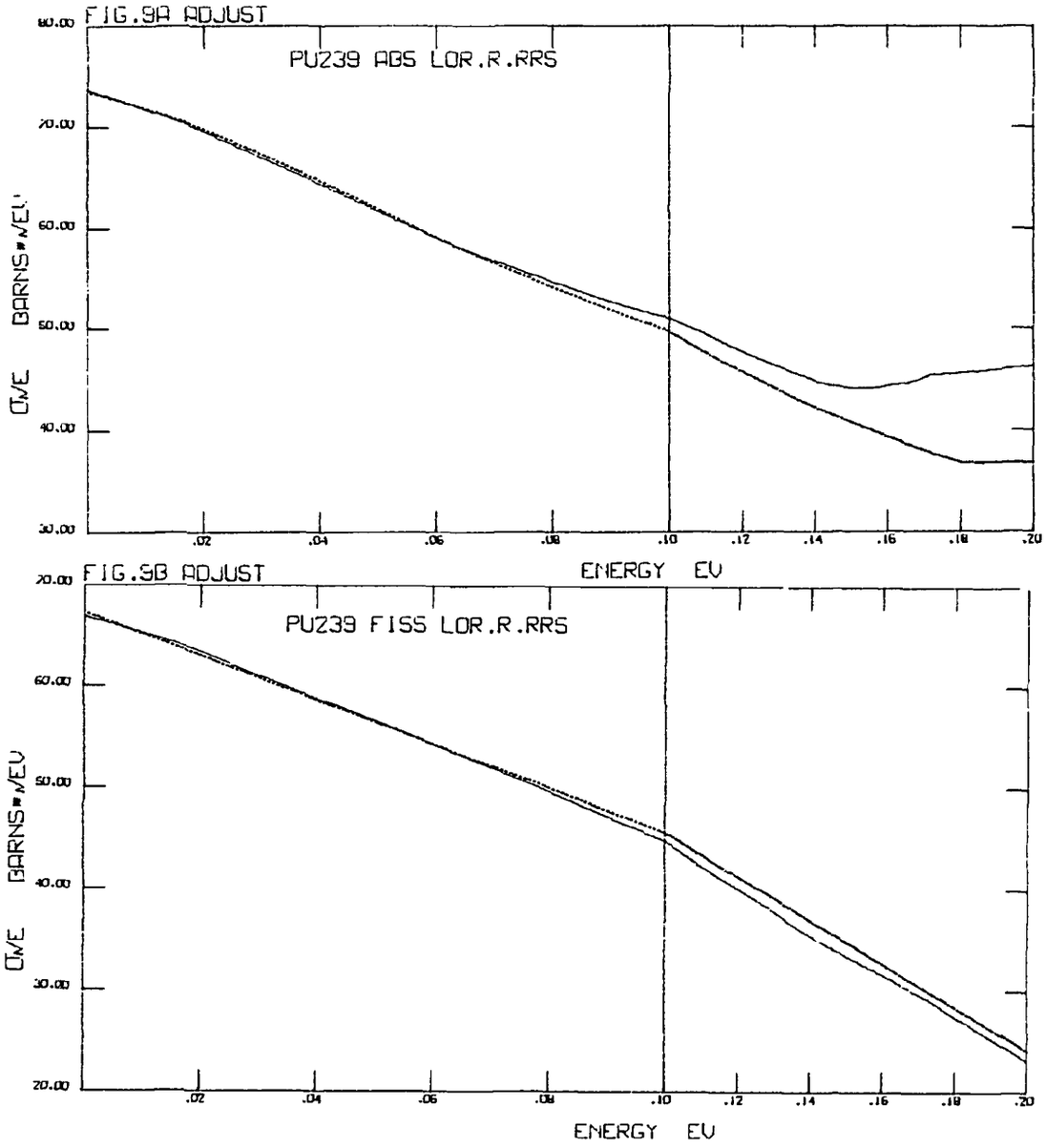


FIG.9A ADJUST
PU239 ABS LOR.R.RRS
σ/E BARNS*N/EV
ENERGY EV
FIG.9B ADJUST
PU239 FISS LOR.R.RRS
σ/E BARNS*N/EV
ENERGY EV

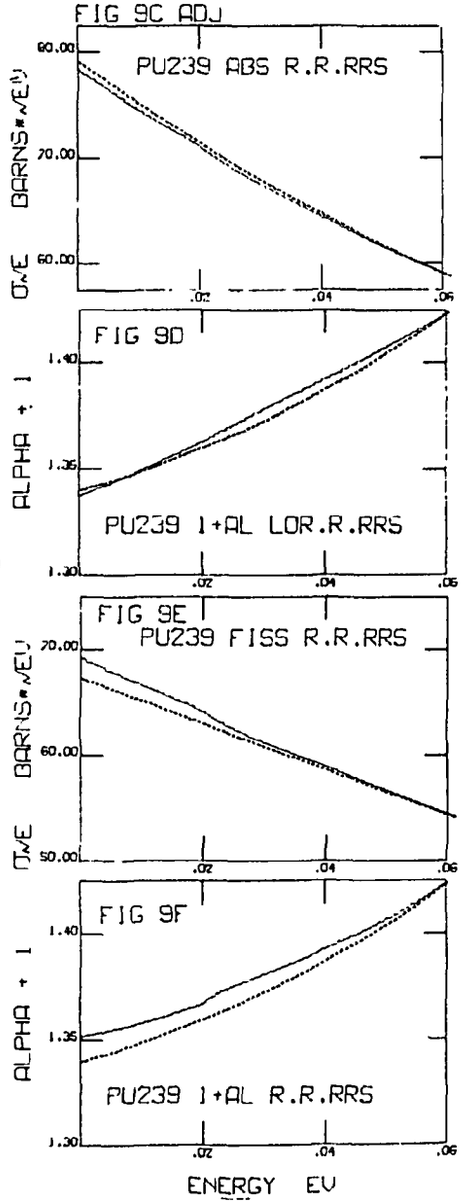


FIG 9C ADJ
PU239 ABS R.R.RRS
σ/E BARNS*N/EV
FIG 9D
PU239 1+AL LOR.R.RRS
ALPHA + 1
FIG 9E
PU239 FISS R.R.RRS
σ/E BARNS*N/EV
FIG 9F
PU239 1+AL R.R.RRS
ALPHA + 1
ENERGY EV

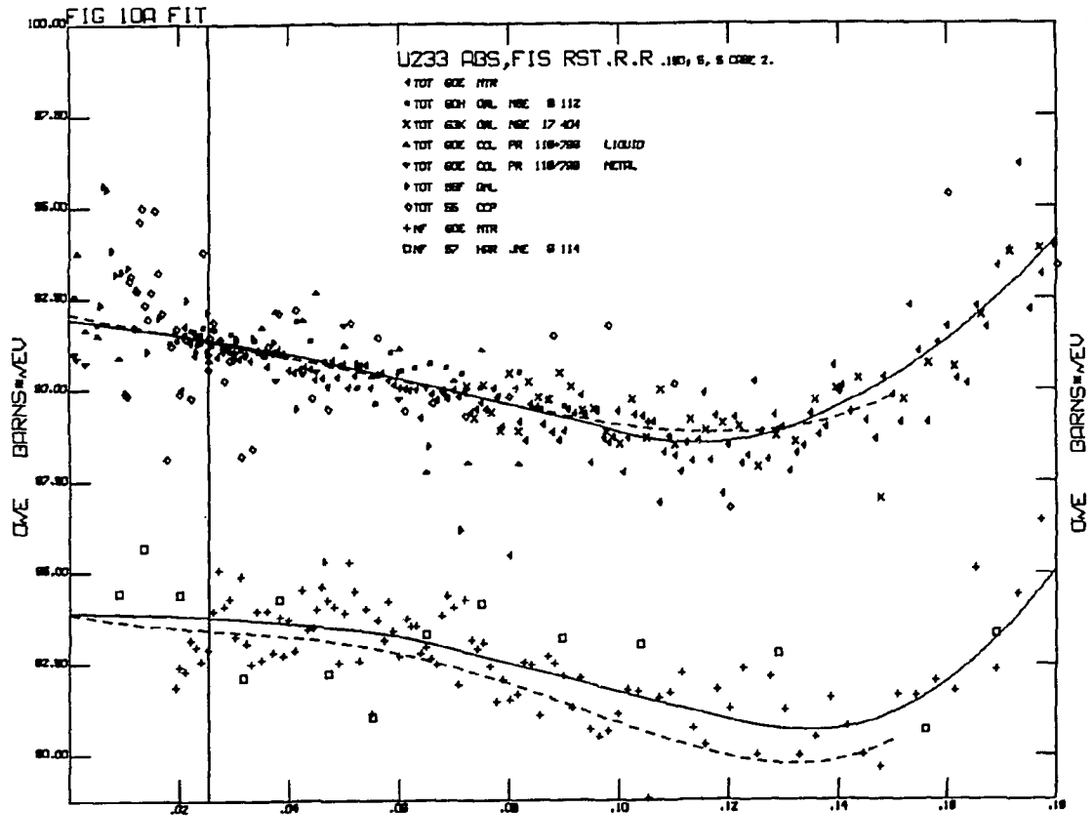


FIG 10A FIT
U233 ABS,FIS RST.R.R
BARNS/EV
ENERGY EV

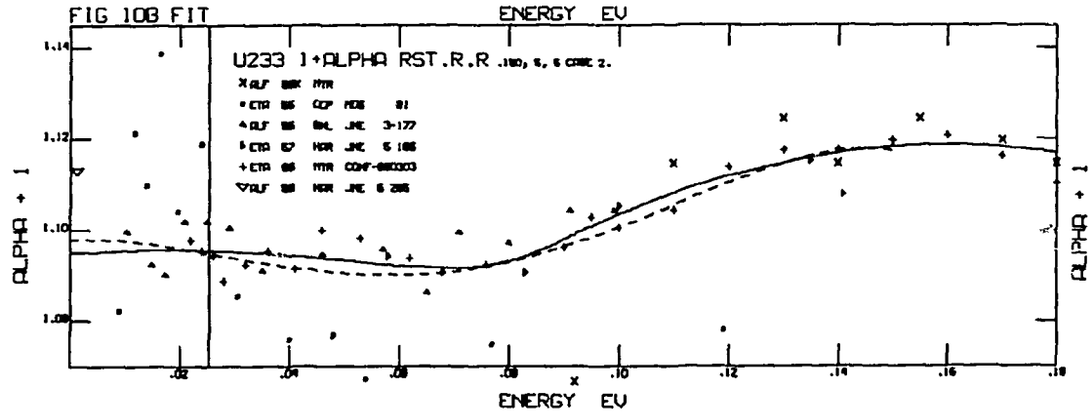


FIG 10B FIT
U233 1+ALPHA RST.R.R
ALPHA + 1
ENERGY EV

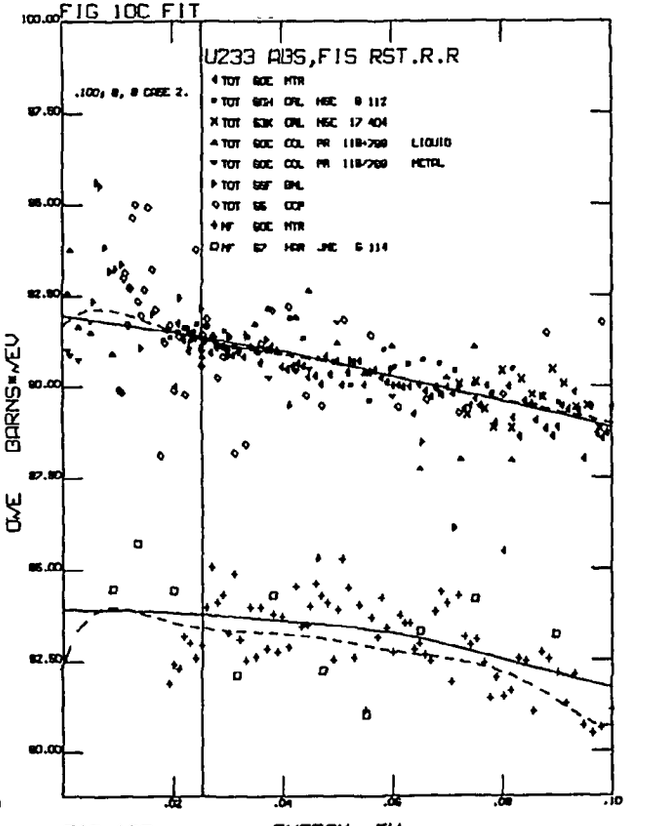


FIG 10C FIT
U233 ABS,FIS RST.R.R
BARNS/EV
ENERGY EV

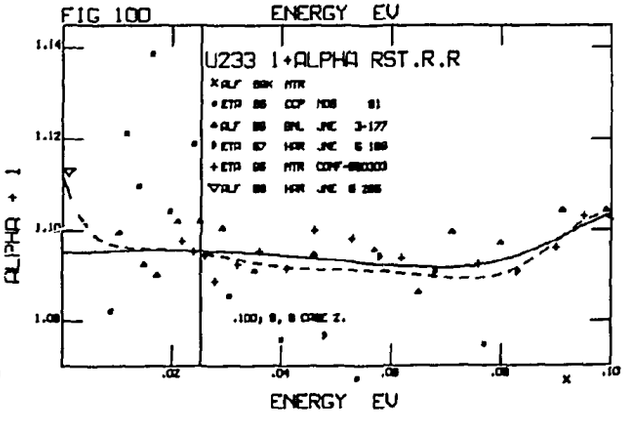


FIG 10D
U233 1+ALPHA RST.R.R
ALPHA + 1
ENERGY EV

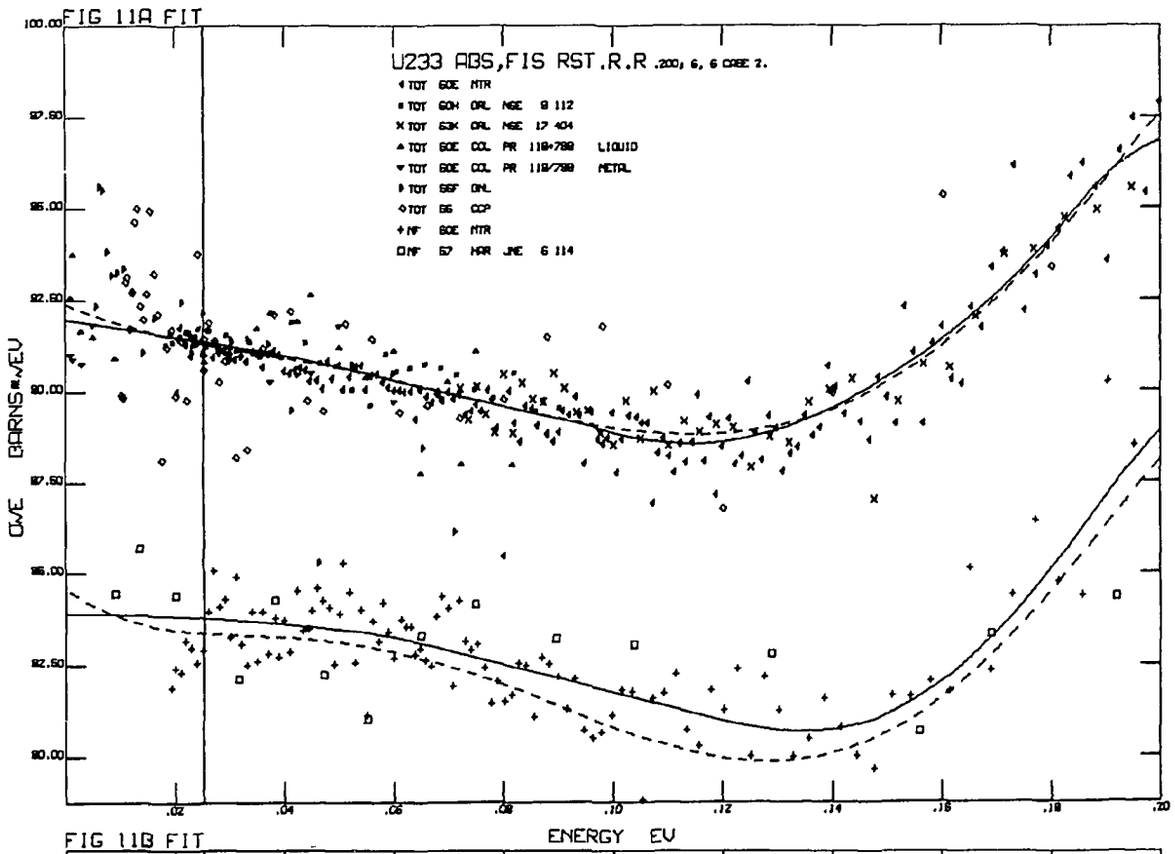


FIG 11A FIT
U233 ABS,FIS RST.R.R .200, 6, 6 CASE 2.
BARNS/EV
ENERGY EV

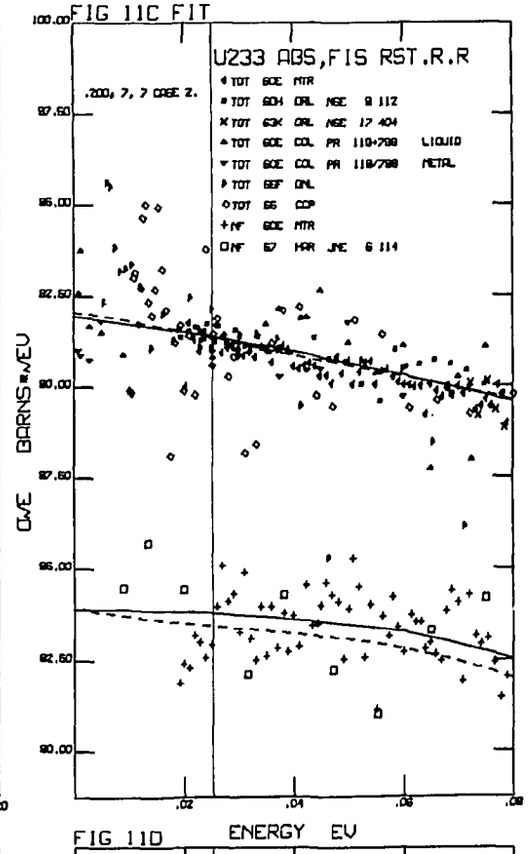


FIG 11C FIT
U233 ABS,FIS RST.R.R
.200, 7, 7 CASE 2.
BARNS/EV
ENERGY EV

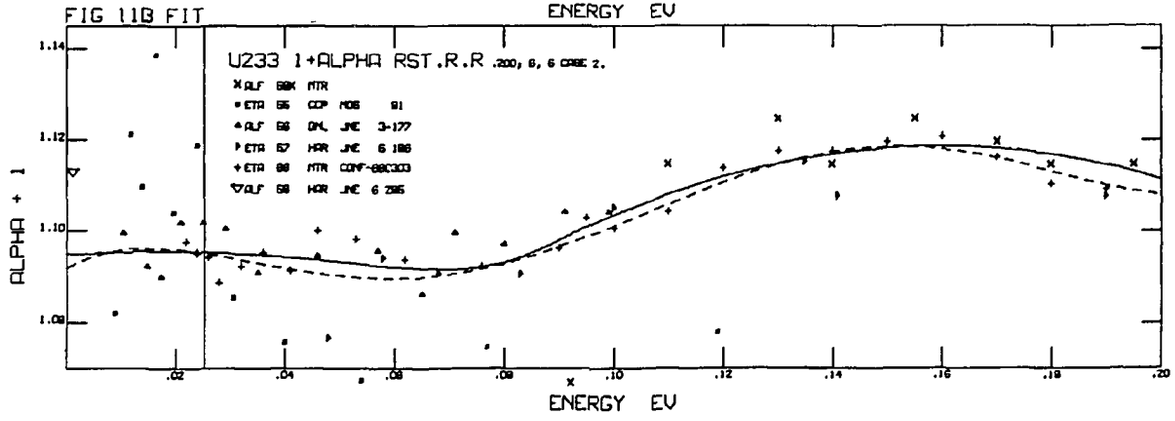


FIG 11B FIT
U233 1+ALPHA RST.R.R .200, 6, 6 CASE 2.
ALPHA + 1
ENERGY EV

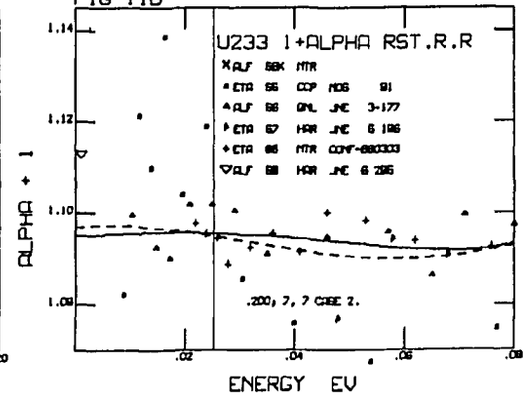


FIG 11D
U233 1+ALPHA RST.R.R
.200, 7, 7 CASE 2.
ALPHA + 1
ENERGY EV

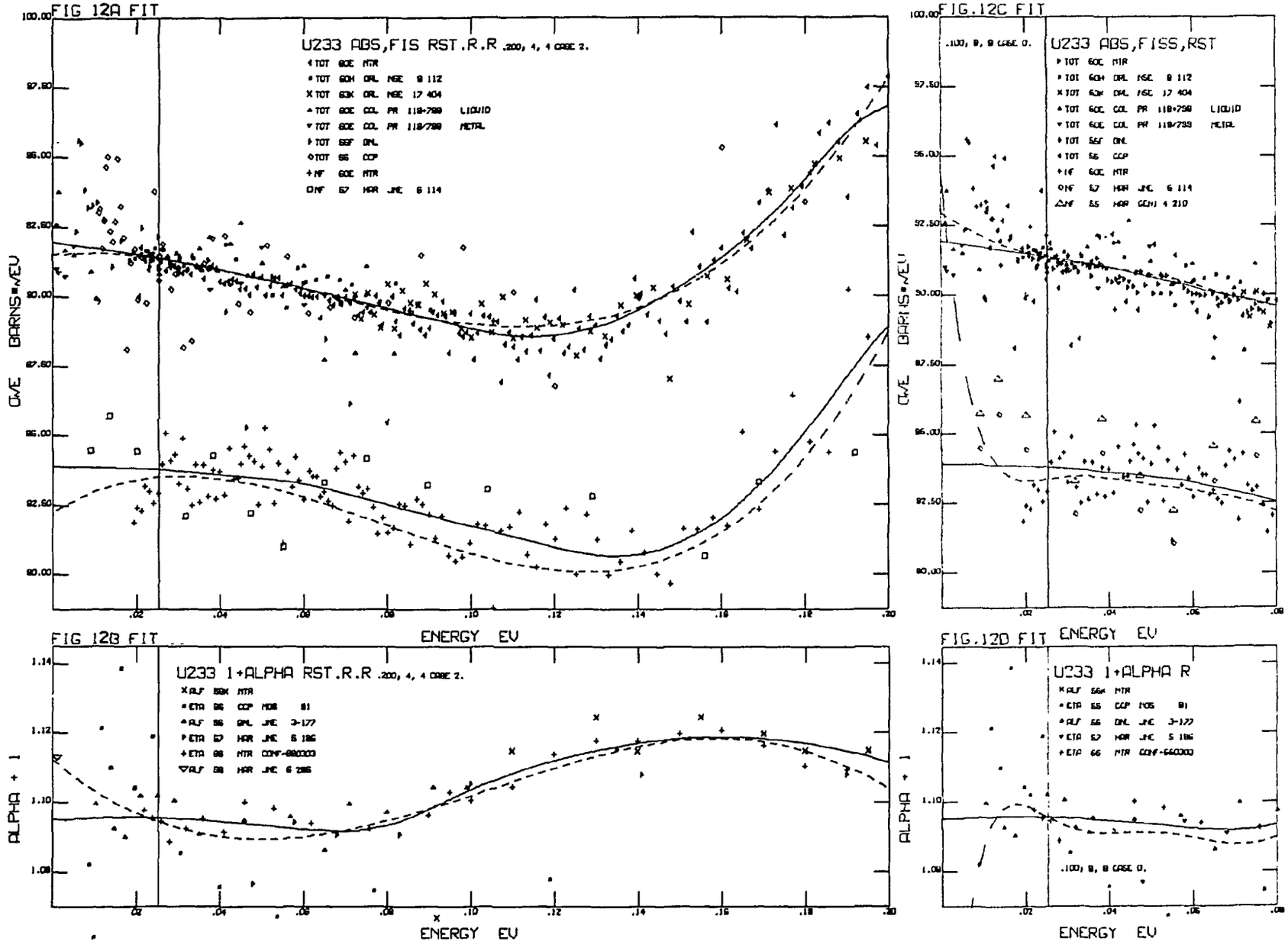


FIG 12A FIT
U233 ABS,FIS RST.R.R .200, 4, 4 CASE 2.
BARNS*MEV
ENERGY EV
FIG 12B FIT
U233 1+ALPHA RST.R.R .200, 4, 4 CASE 2.
ALPHA + 1
ENERGY EV
FIG.12C FIT
U233 ABS,FISS,RST
BARNS*MEV
ENERGY EV
FIG.12D FIT
U233 1+ALPHA R
ALPHA + 1
ENERGY EV

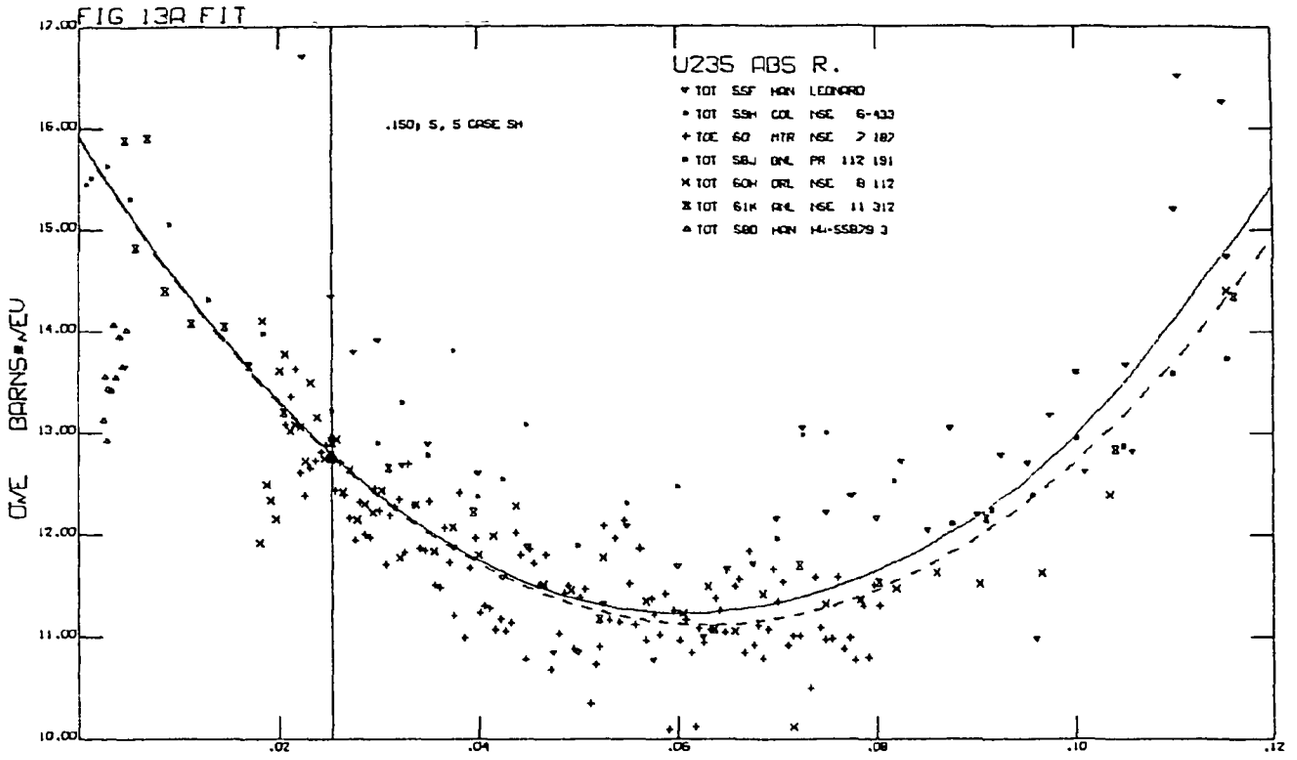


FIG 13A FIT
U235 ABS R.
.150; S, S CASE SH
BARNS#/EV
ENERGY EV

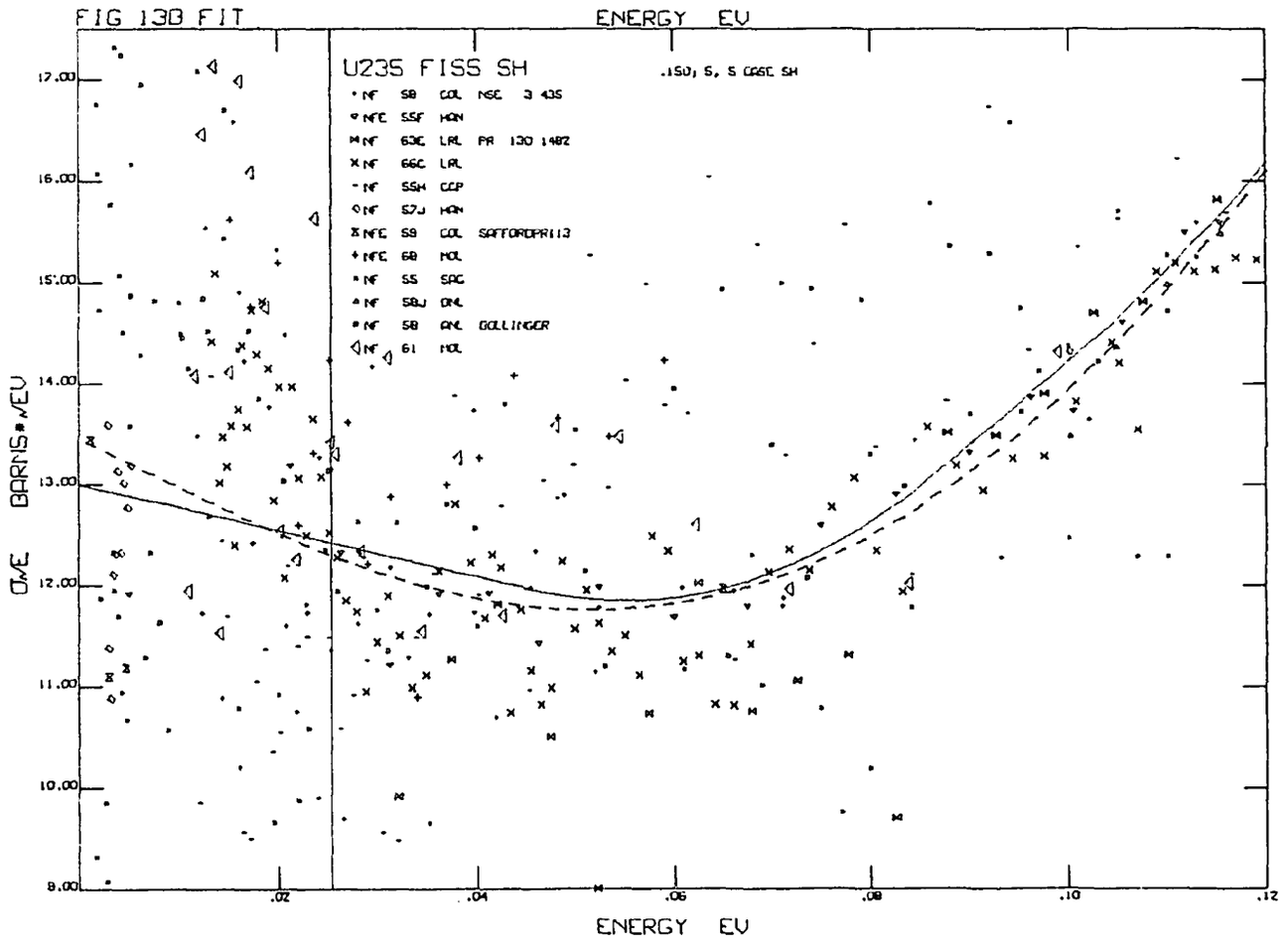


FIG 13B FIT
U235 FISS SH
.150; S, S CASE SH
BARNS#/EV
ENERGY EV

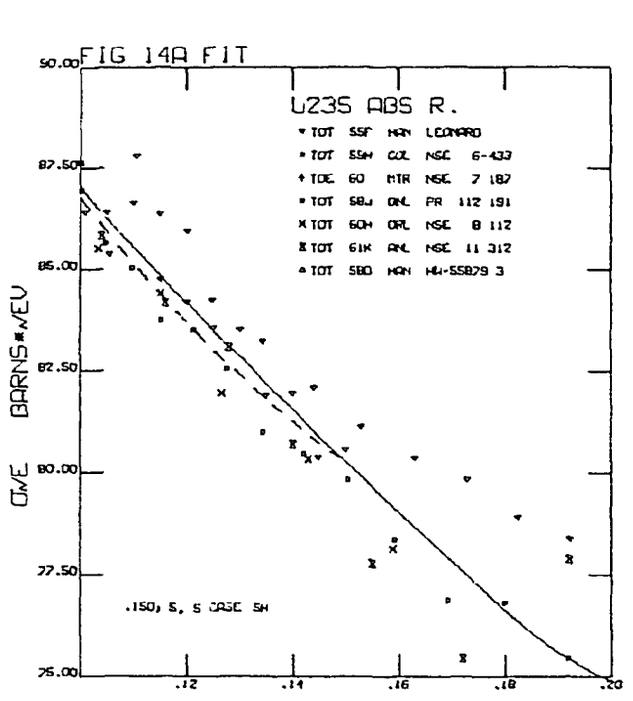


FIG 14A FIT
U235 ABS R.
.150, S, S CASE SH
BARNS#/EV
ENERGY EV

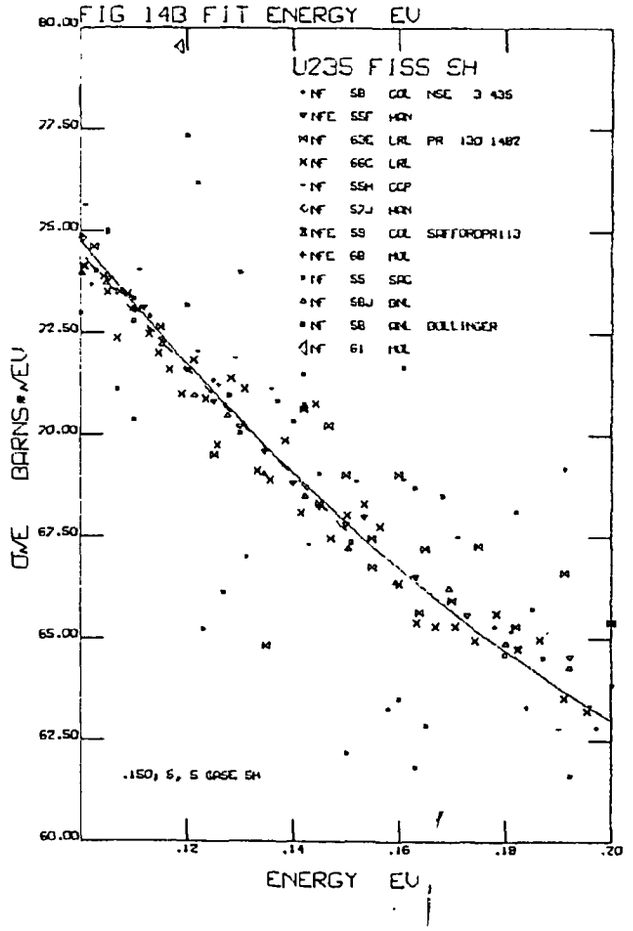


FIG 14B FIT ENERGY EV
U235 FISS SH
.150, S, S CASE SH
BARNS#/EV
ENERGY EV

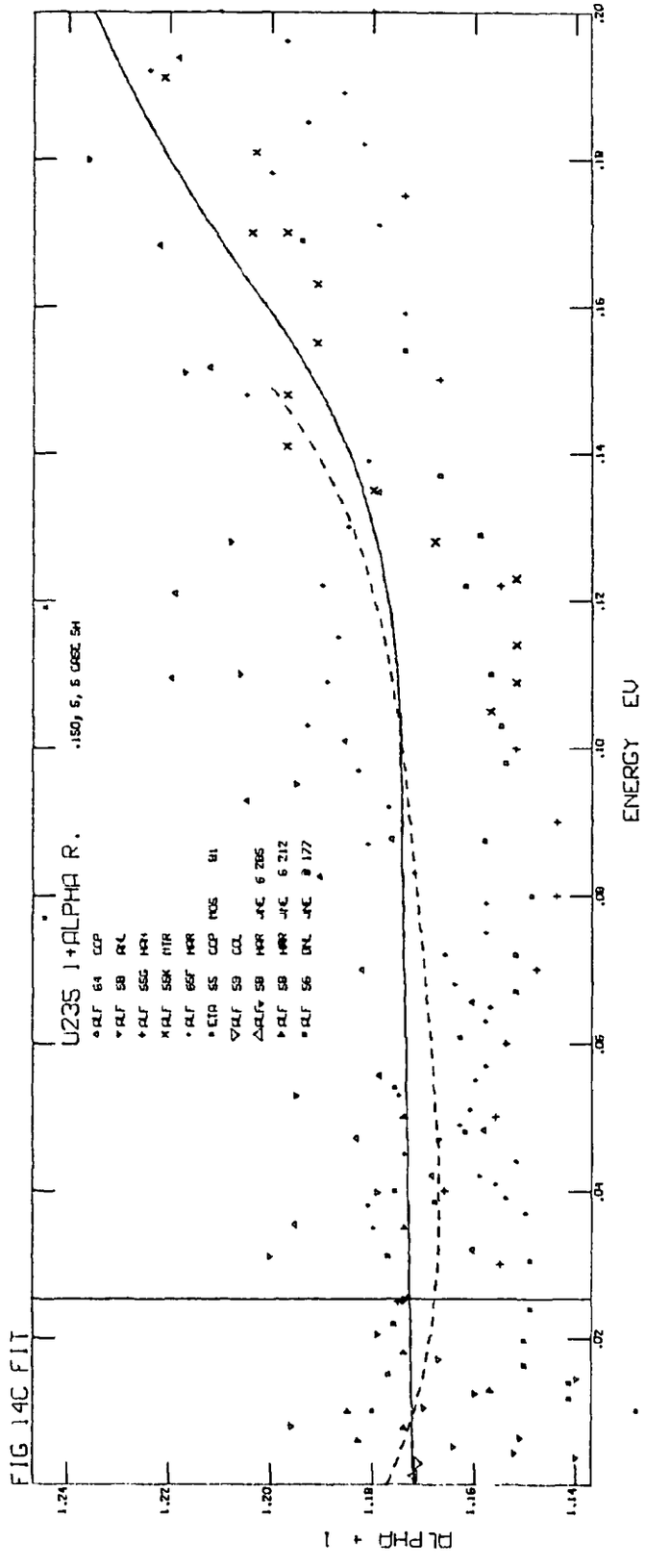


FIG 14C FIT
U235 1+ALPHA R.
.150, S, S CASE SH
DL PHO + 1
ENERGY EV

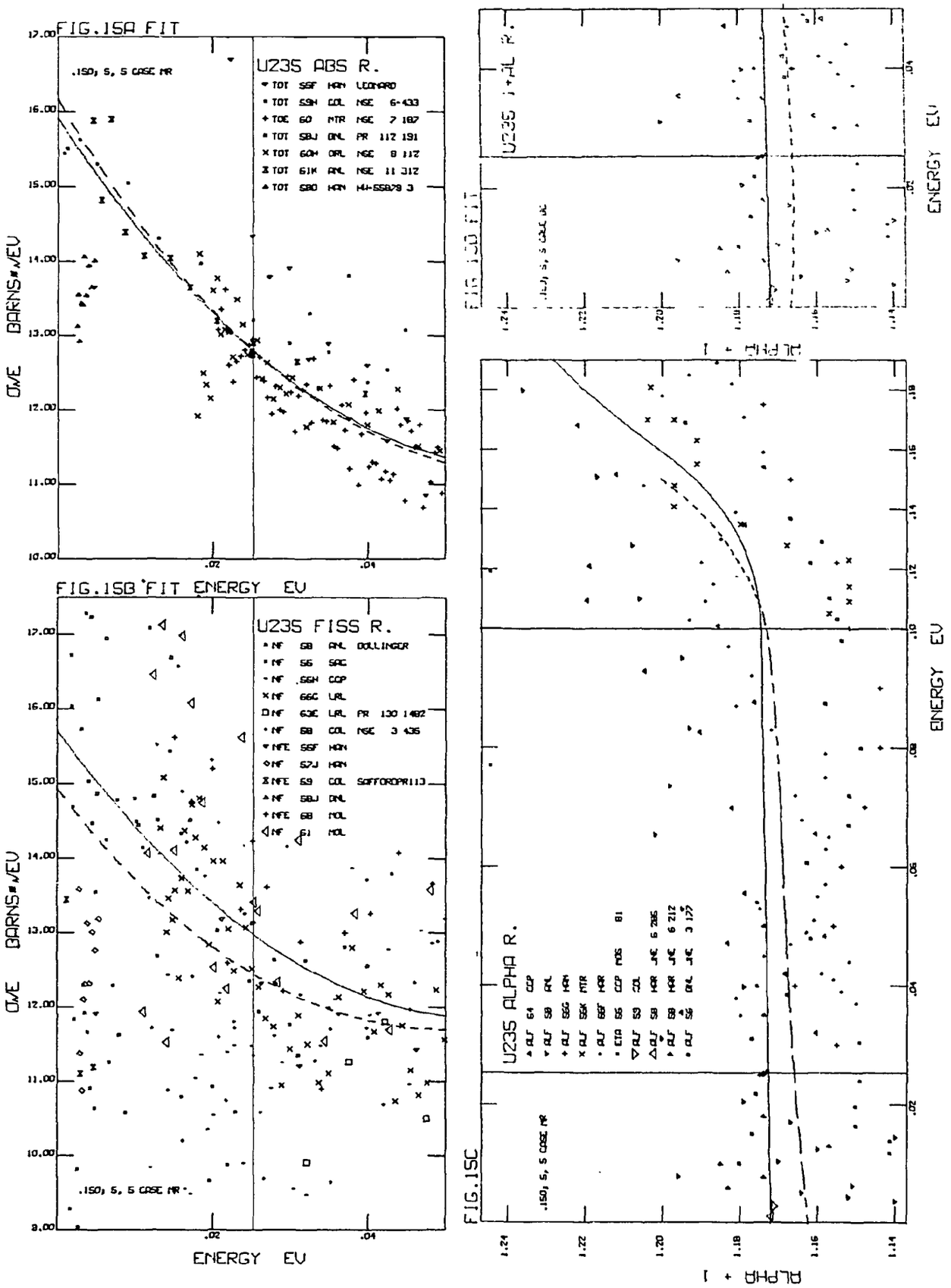


FIG.1SA FIT
U235 ABS R.
.150, S, S CASE MR
BARNS#/EV
FIG.1SB FIT ENERGY EV
U235 FISS R.
.150, S, S CASE MR
ENERGY EV
FIG.1SC
U235 ALPHA R.
.150, S, S CASE MR
ALPHA + 1
U235 ETA R.
ENERGY EV

FIG 16A FIT

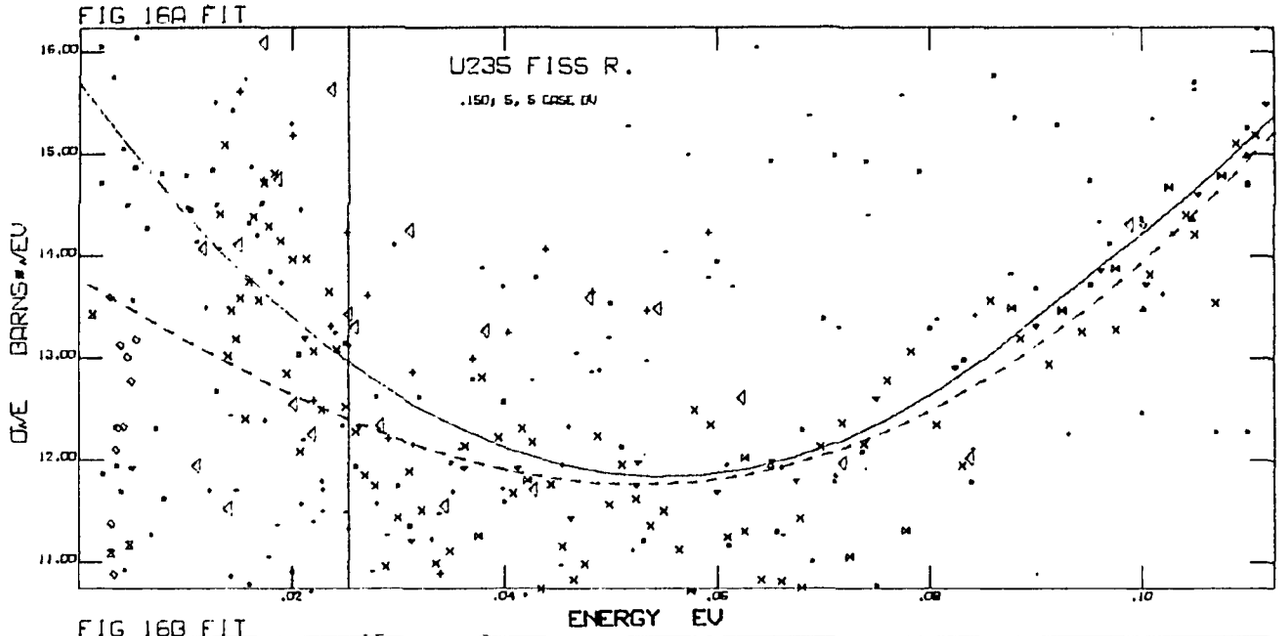
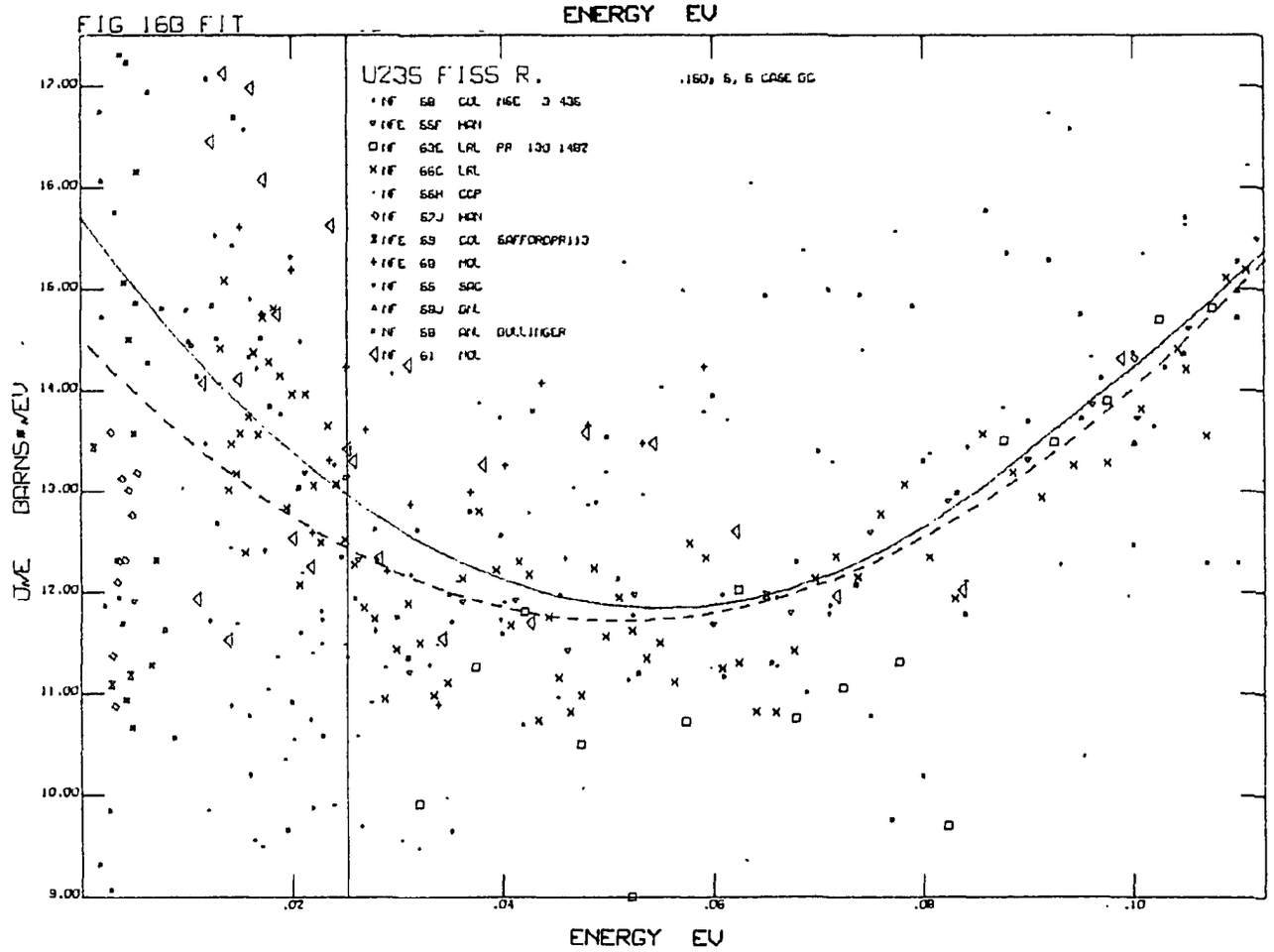


FIG 16B FIT



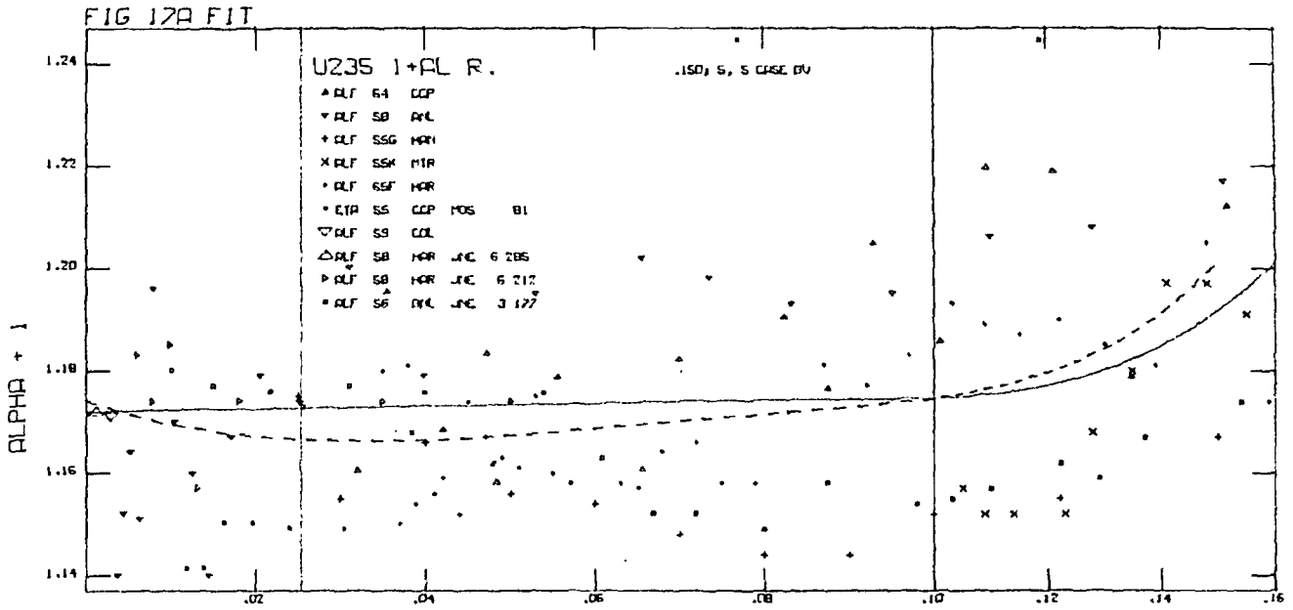


FIG 17A FIT
U235 1+AL R.
ALPHA + 1
ENERGY EV

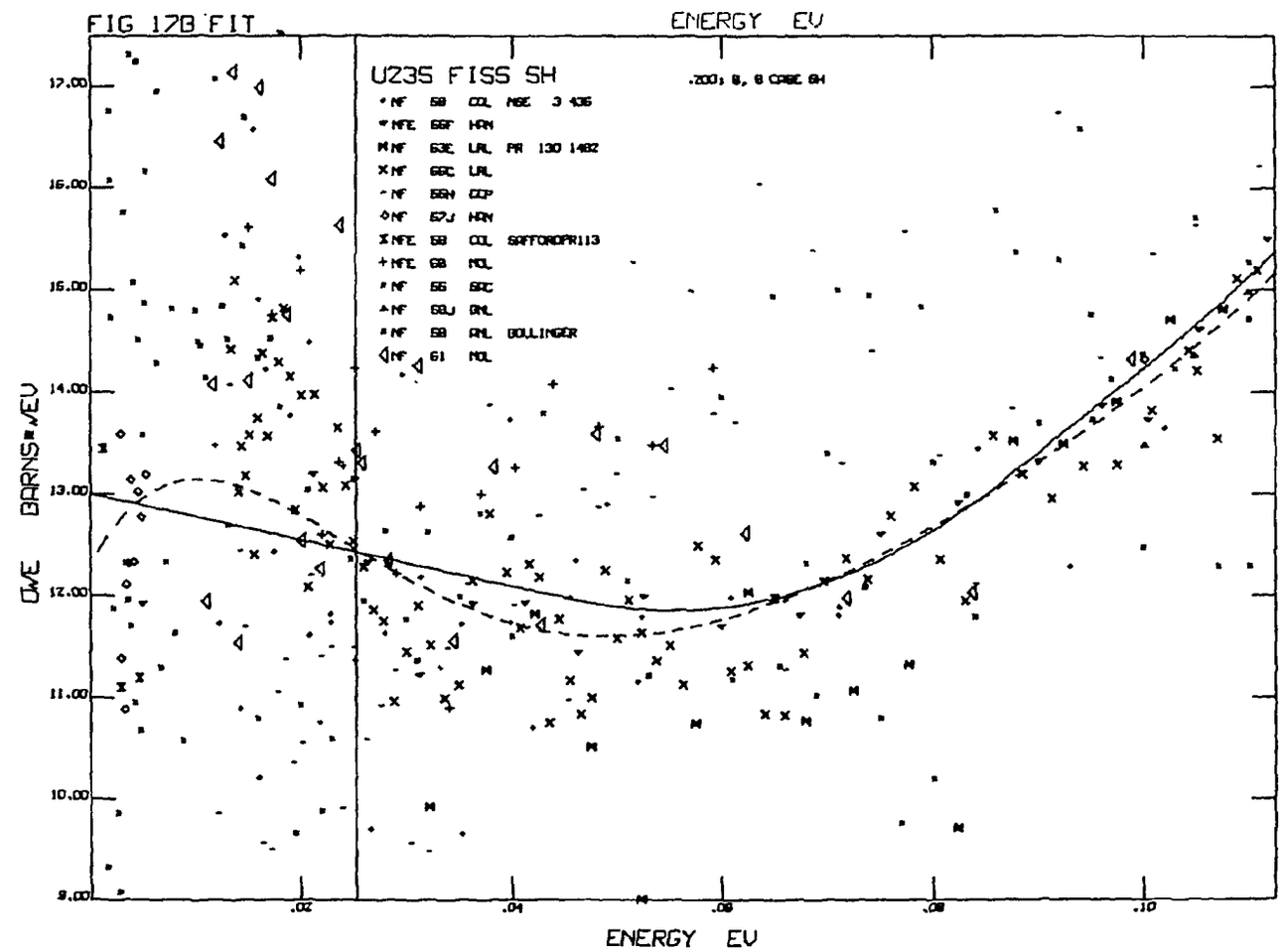


FIG 17B FIT
U235 FISS SH
BARNS/EV
ENERGY EV

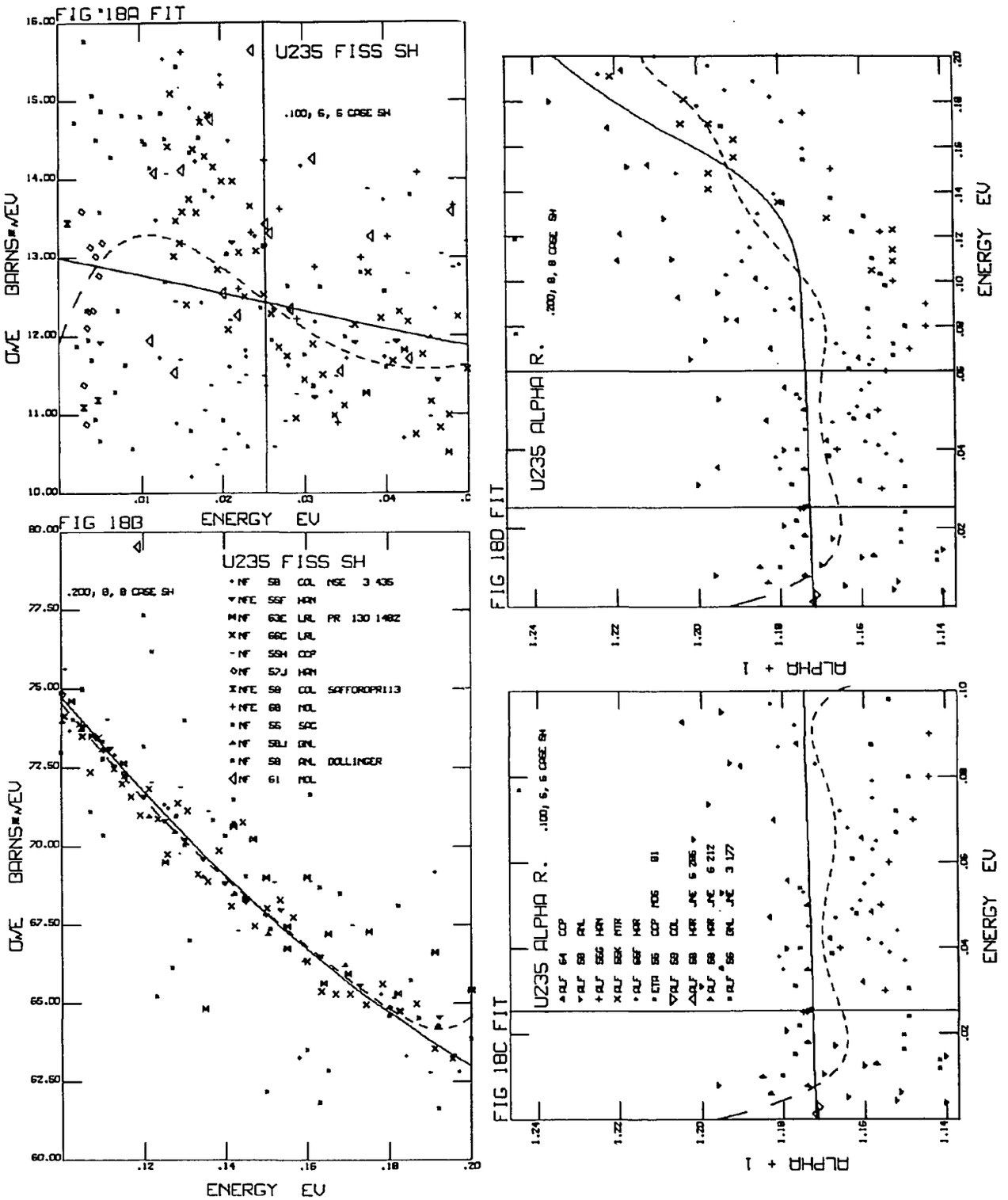


FIG 18A FIT
U235 FISS SH
.100, 6, 6 CASE SH
ENERGY EV
FIG 18B
U235 FISS SH
.200, 8, 8 CASE SH
ENERGY EV
FIG 18C FIT
U235 ALPHA R.
.100, 6, 6 CASE SH
ENERGY EV
FIG 18D FIT
U235 ALPHA R.
.200, 8, 8 CASE SH
ENERGY EV

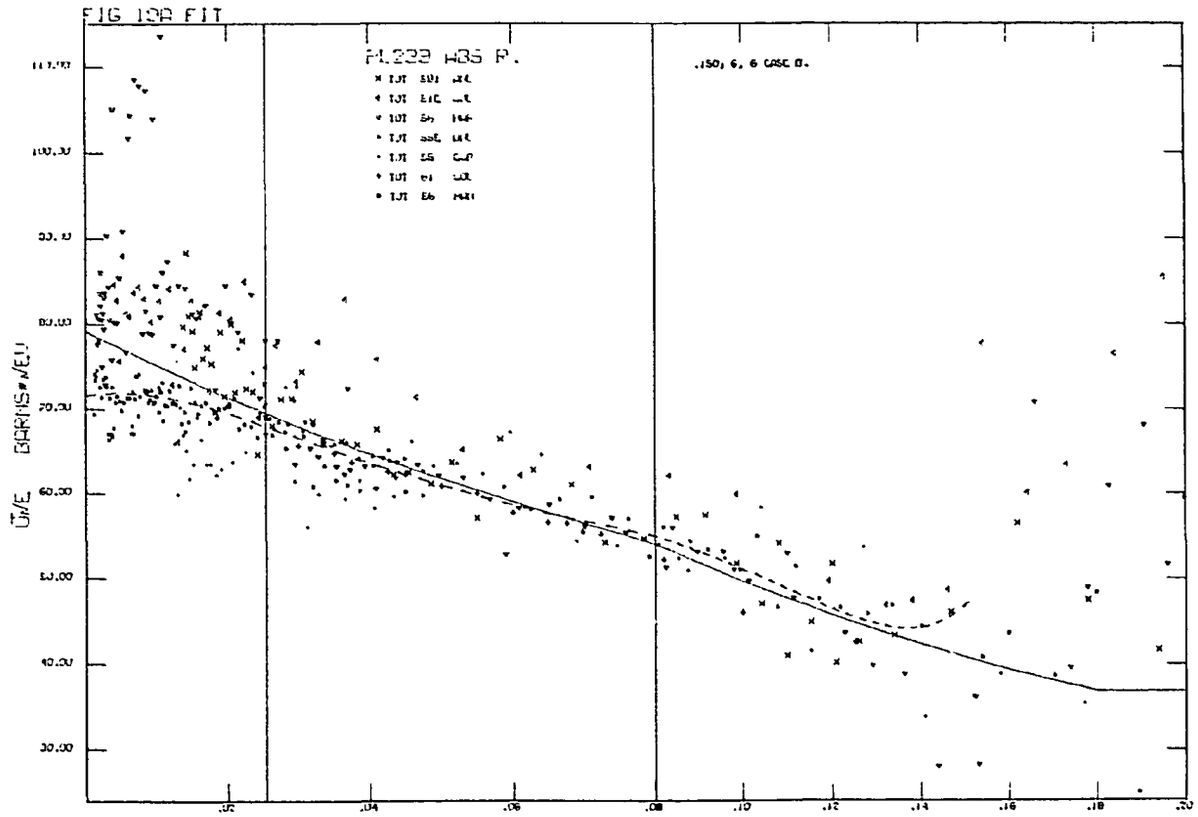


FIG 19A FIT
PU239 ABS R.
.150, 6, 6 CASE B.
σ/E BARNS#/EV
ENERGY EV

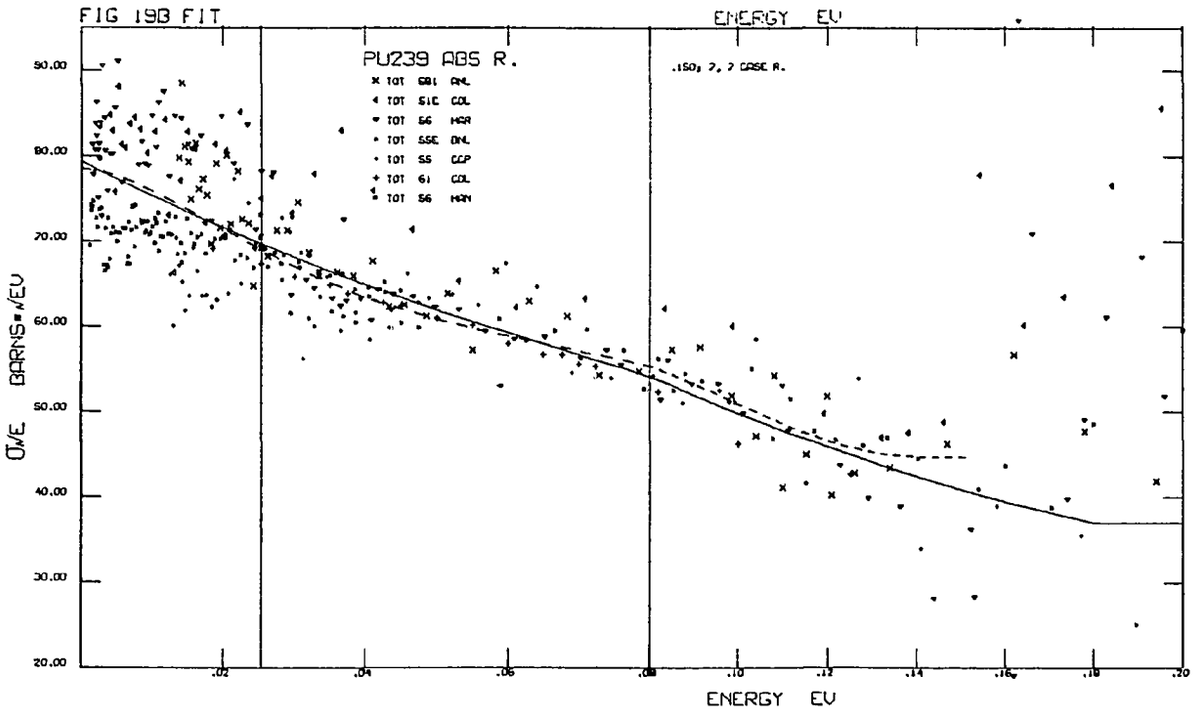


FIG 19B FIT
PU239 ABS R.
.150, 7, 7 CASE A.
σ/E BARNS#/EV
ENERGY EV

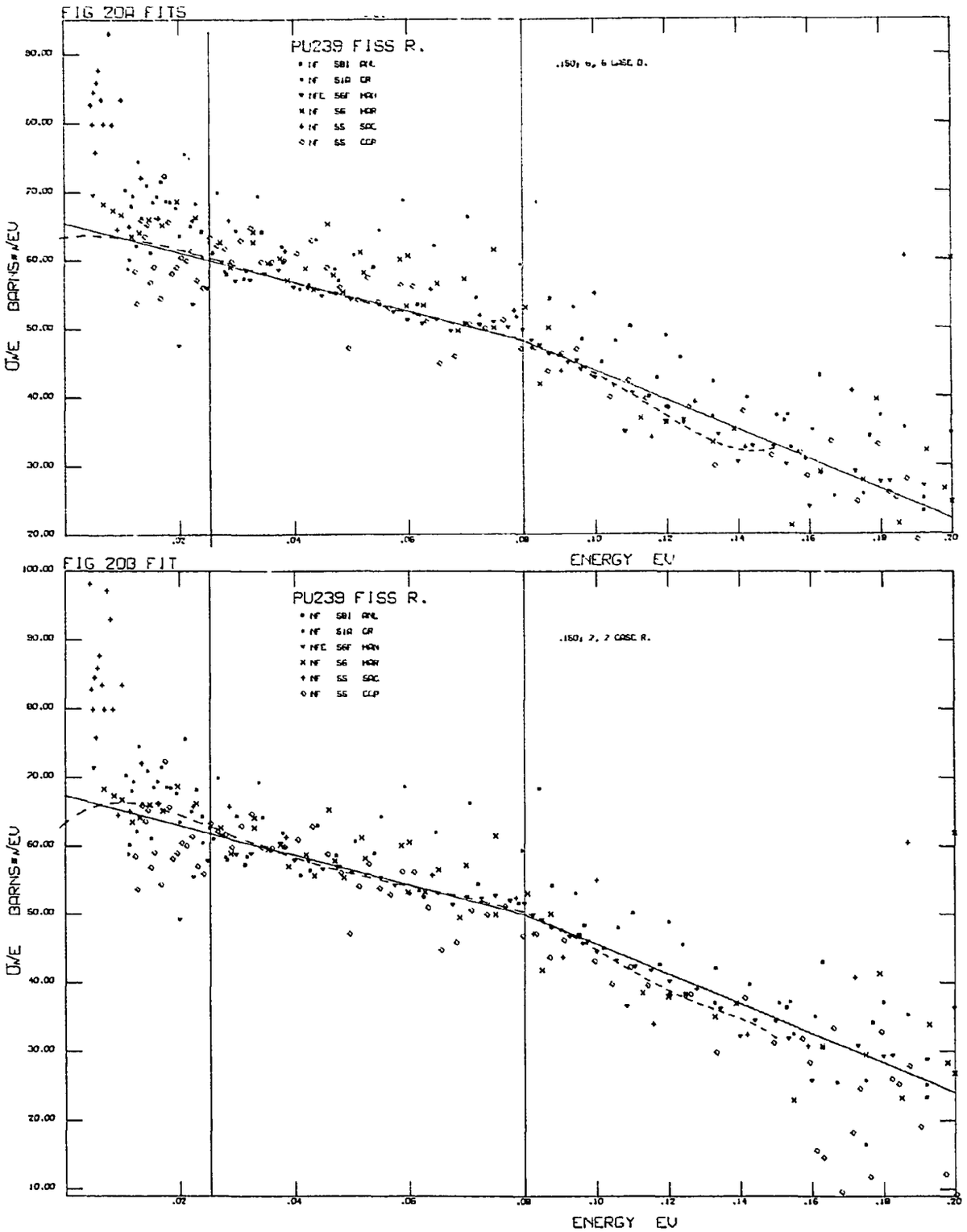


FIG 20A FITS
PU239 FISS R.
.150; 6, 6 CASE D.
σ/E BARNS/EV
ENERGY EV
FIG 20B FIT
PU239 FISS R.
.150; 2, 2 CASE R.
σ/E BARNS/EV
ENERGY EV

FIG 21A FIT

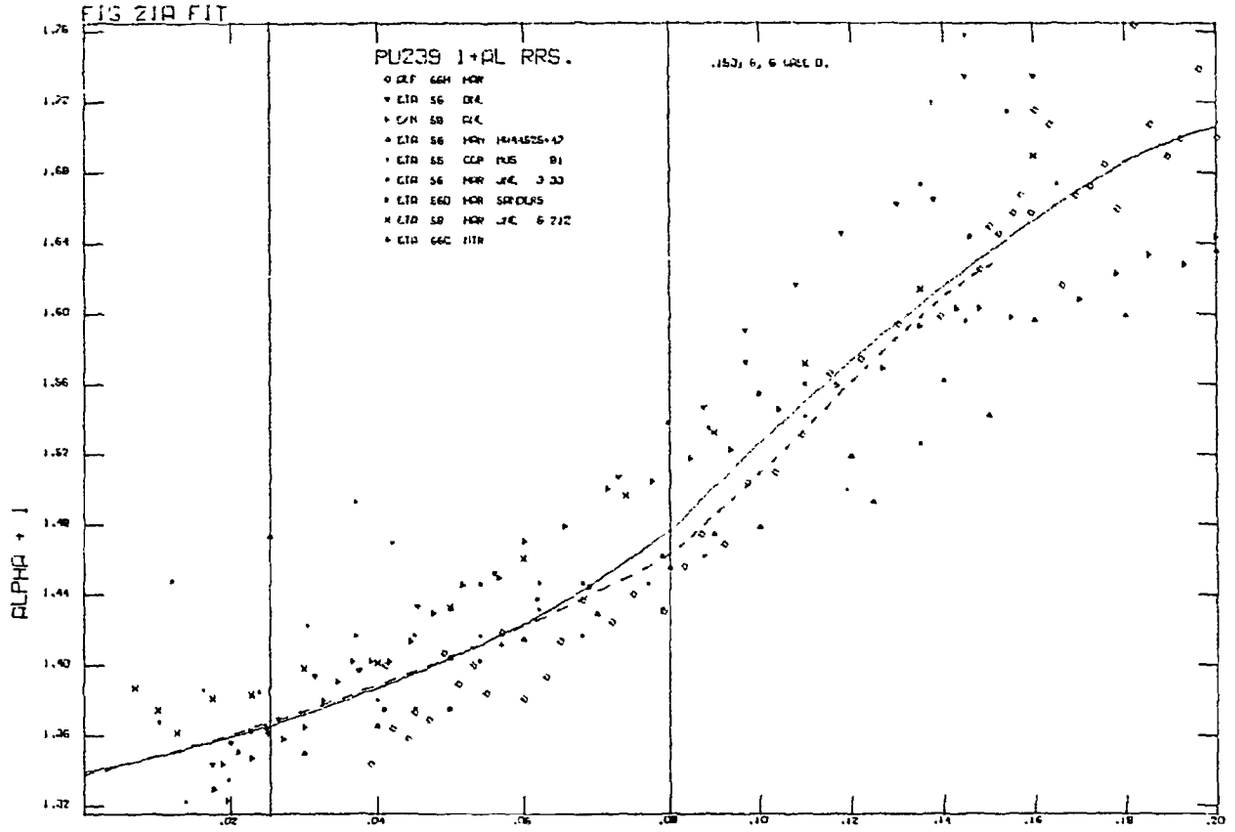
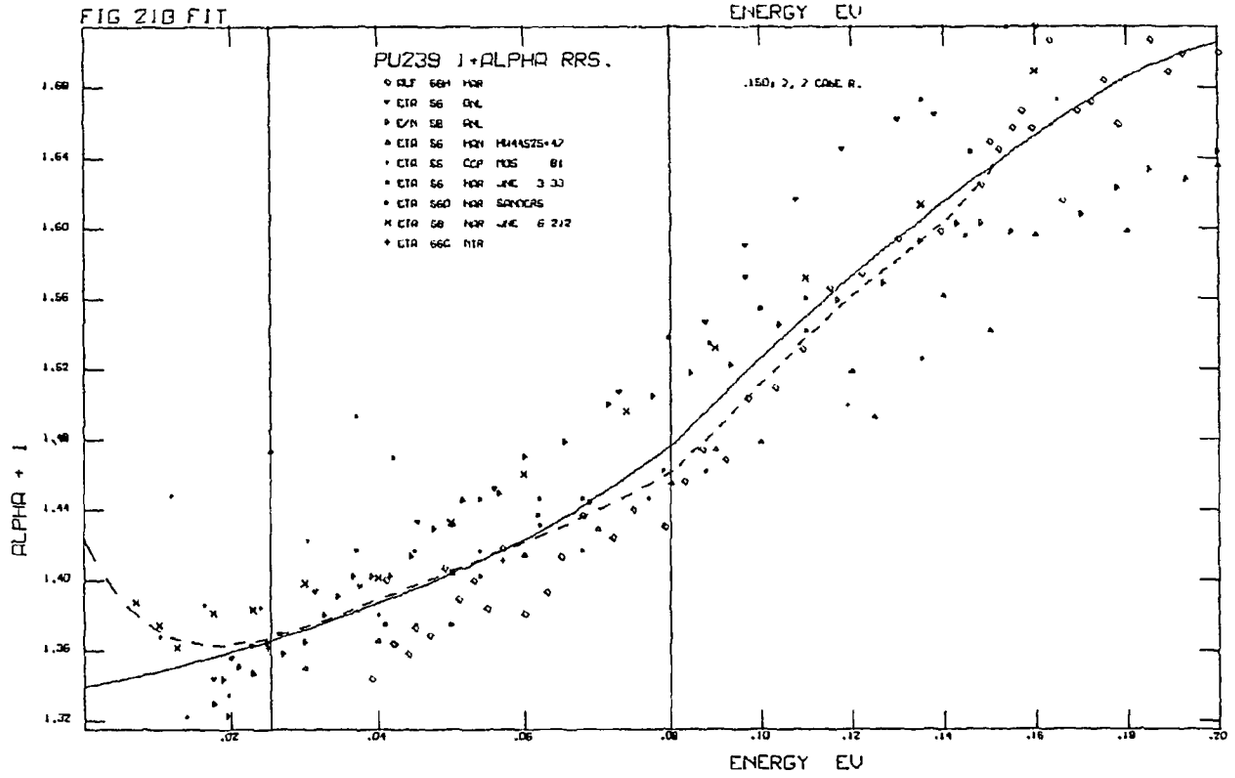


FIG 21B FIT



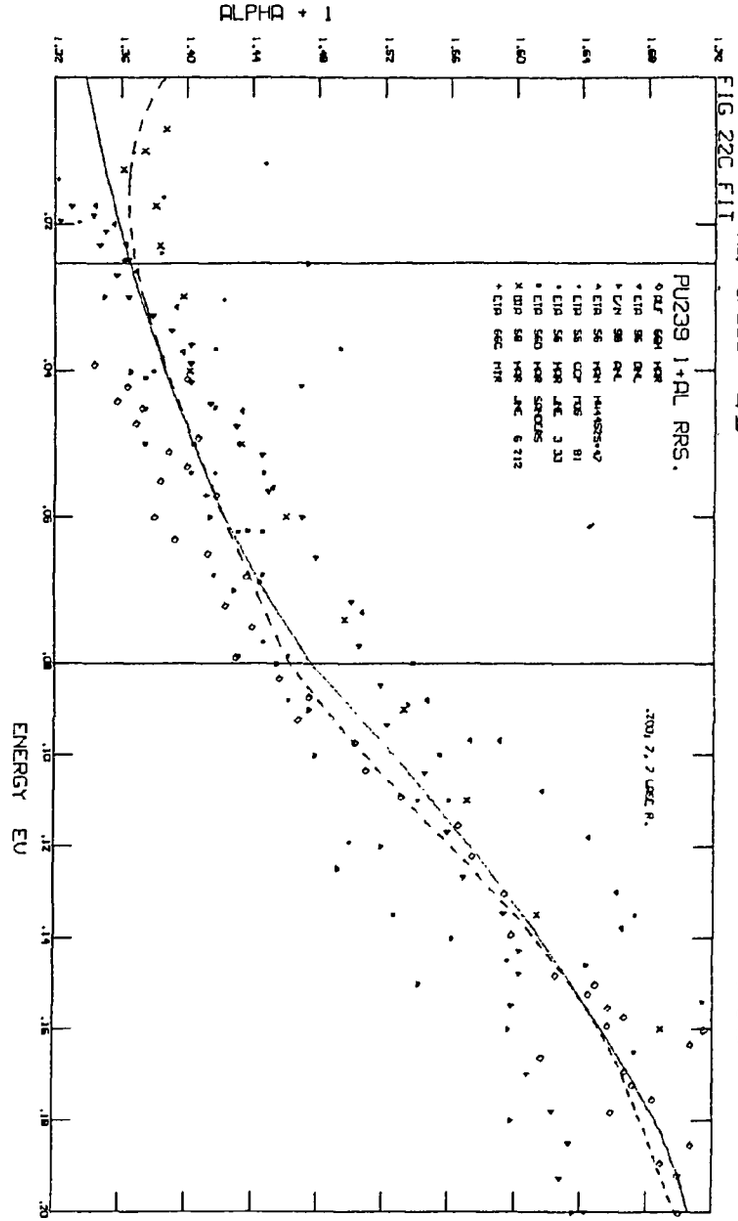


FIG 22C FIT

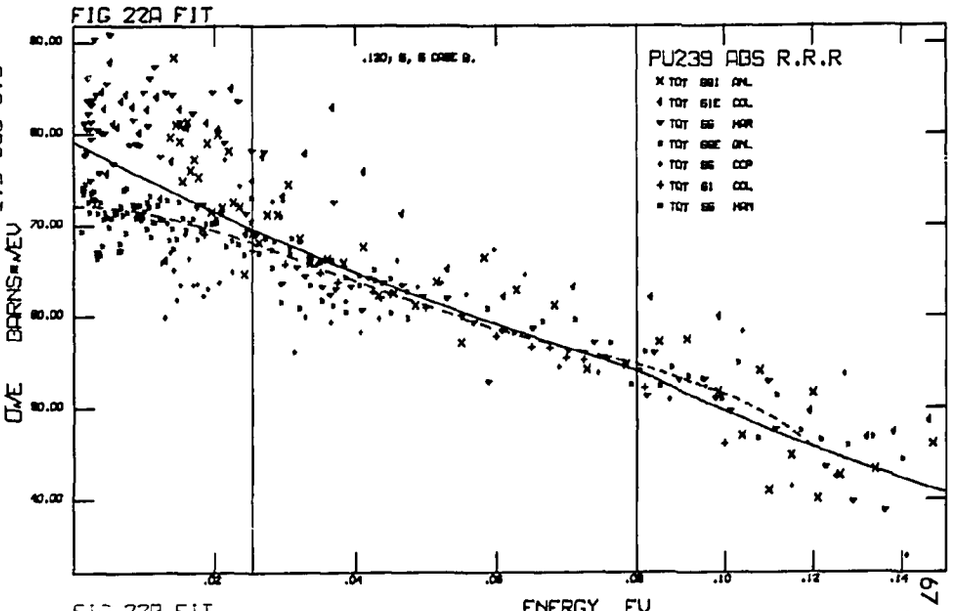


FIG 22A FIT

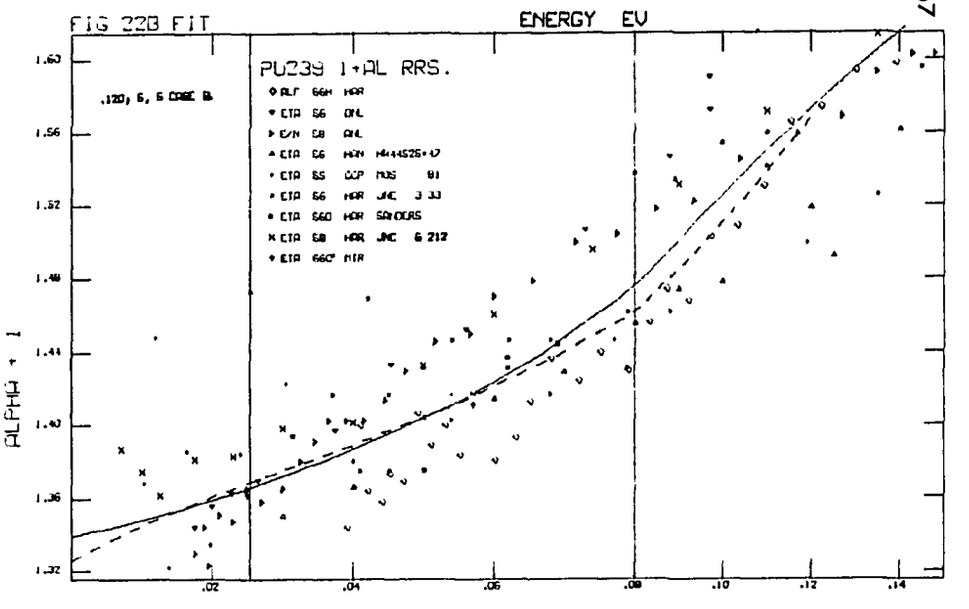


FIG 22B FIT

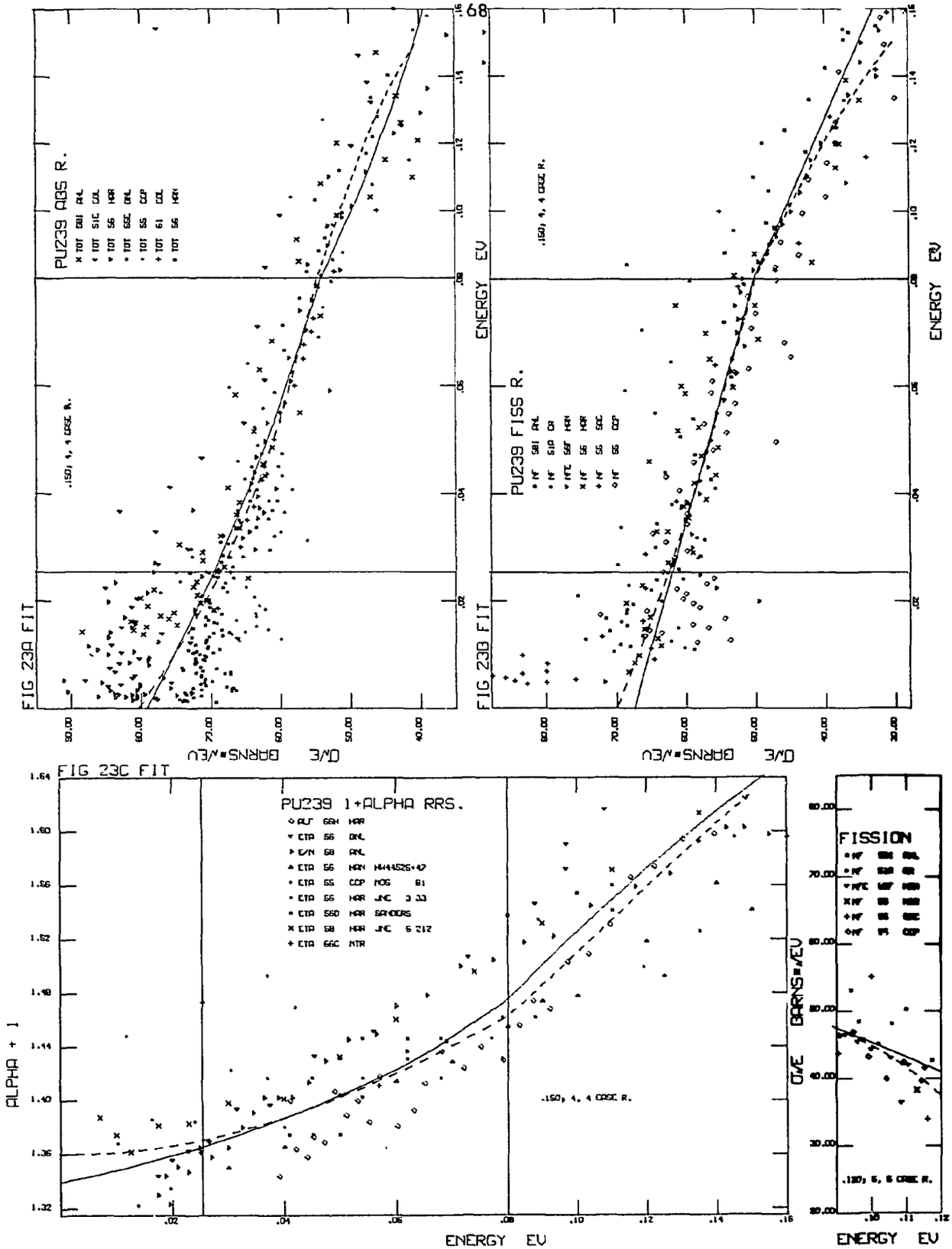
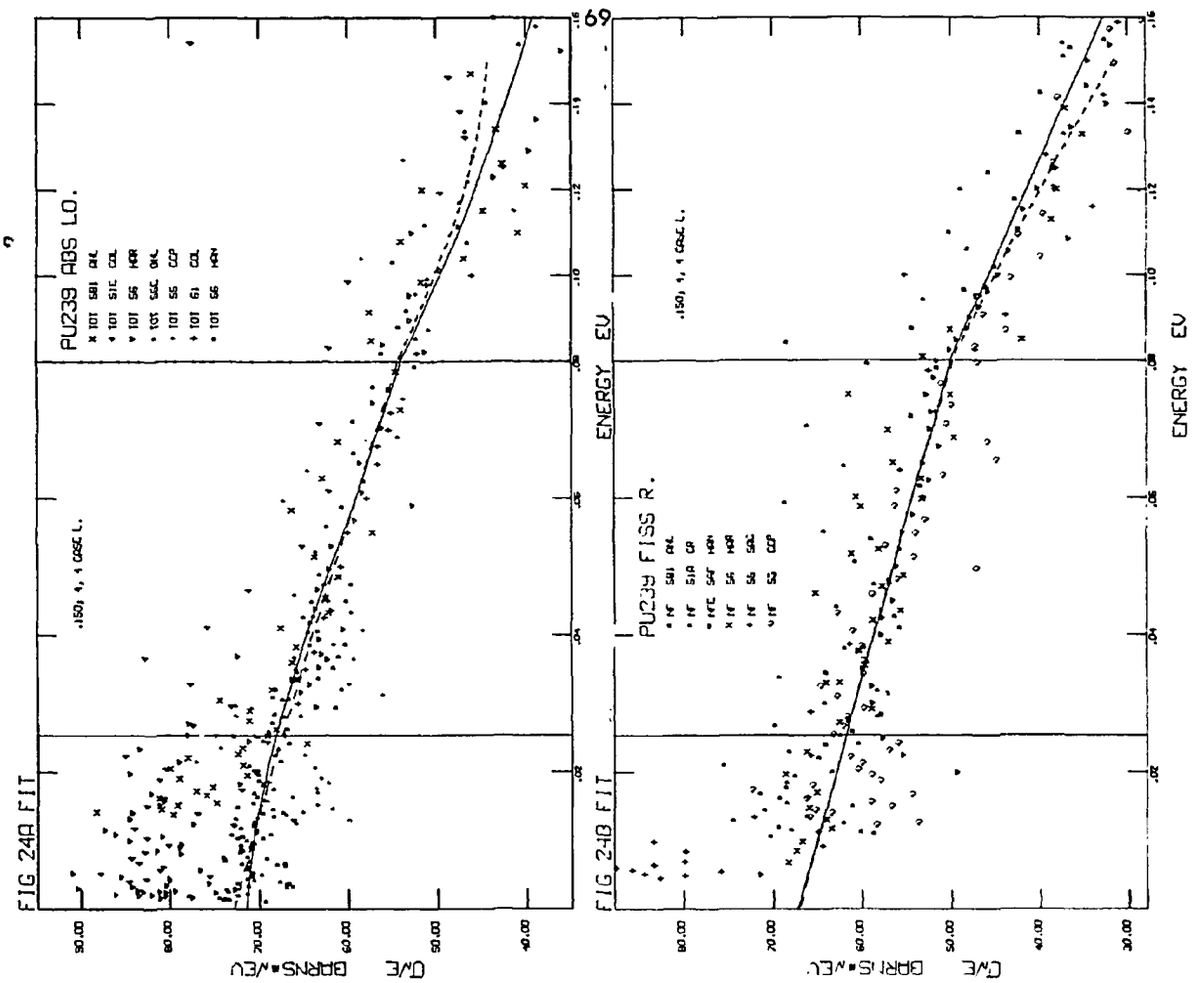


FIG 23A FIT
PU239 ABS R.
.150; 4, 4 CASE R.
ENERGY EV
FIG 23B FIT
PU239 FISS R.
.150; 4, 4 CASE R.
ENERGY EV
FIG 23C FIT
PU239 1+ALPHA RRS.
.150; 4, 4 CASE R.
ALPHA + 1
ENERGY EV
FISSION
.120; 5, 5 CASE R.
ENERGY EV


PU239 ABS LO.
FIG 24A FIT
.150; 4, 4 CASE L.
ENERGY EV
PU239 FISS R.
FIG 24B FIT
.150; 4, 4 CASE L.
ENERGY EV

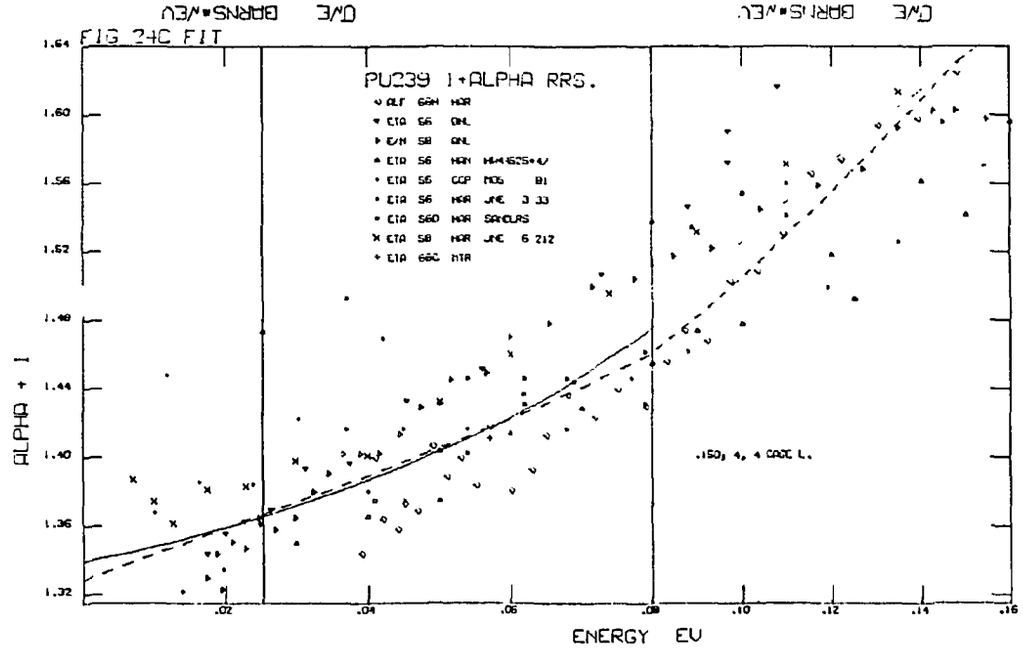


FIG 24C FIT
PU239 1+ALPHA RRS.
ALPHA + 1
.150; 4, 4 CASE L.
ENERGY EV

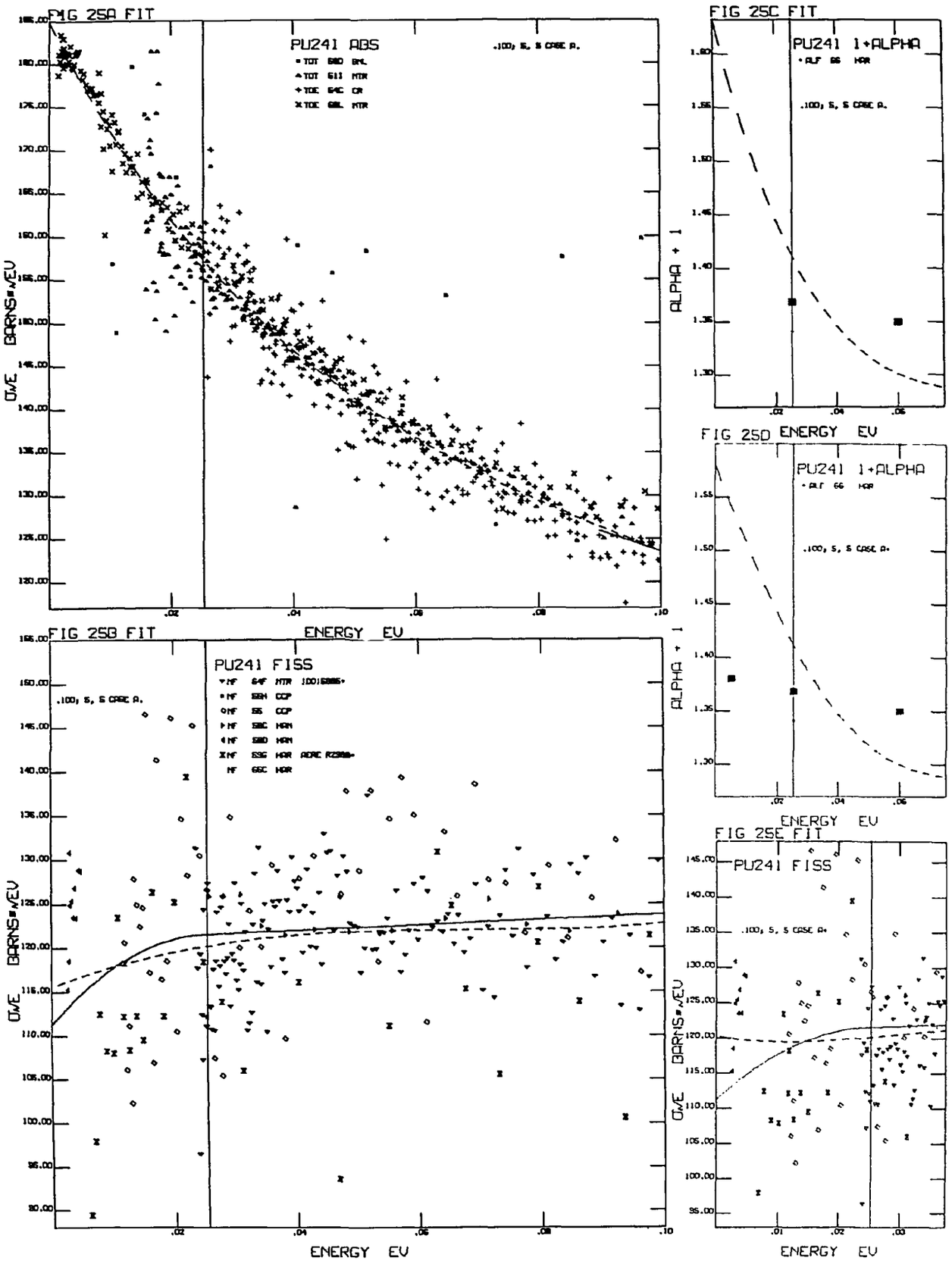


FIG 25A FIT
PU241 ABS
.100; S, S CASE A.
BARNS/EV
ENERGY EV
FIG 25B FIT
PU241 FISS
.100; S, S CASE A.
BARNS/EV
ENERGY EV
FIG 25C FIT
PU241 1+ALPHA
.100; S, S CASE A.
ALPHA + 1
FIG 25D ENERGY EV
PU241 1+ALPHA
.100; S, S CASE A.
ALPHA + 1
ENERGY EV
FIG 25E FIT
PU241 FISS
.100; S, S CASE A.
BARNS/EV
ENERGY EV

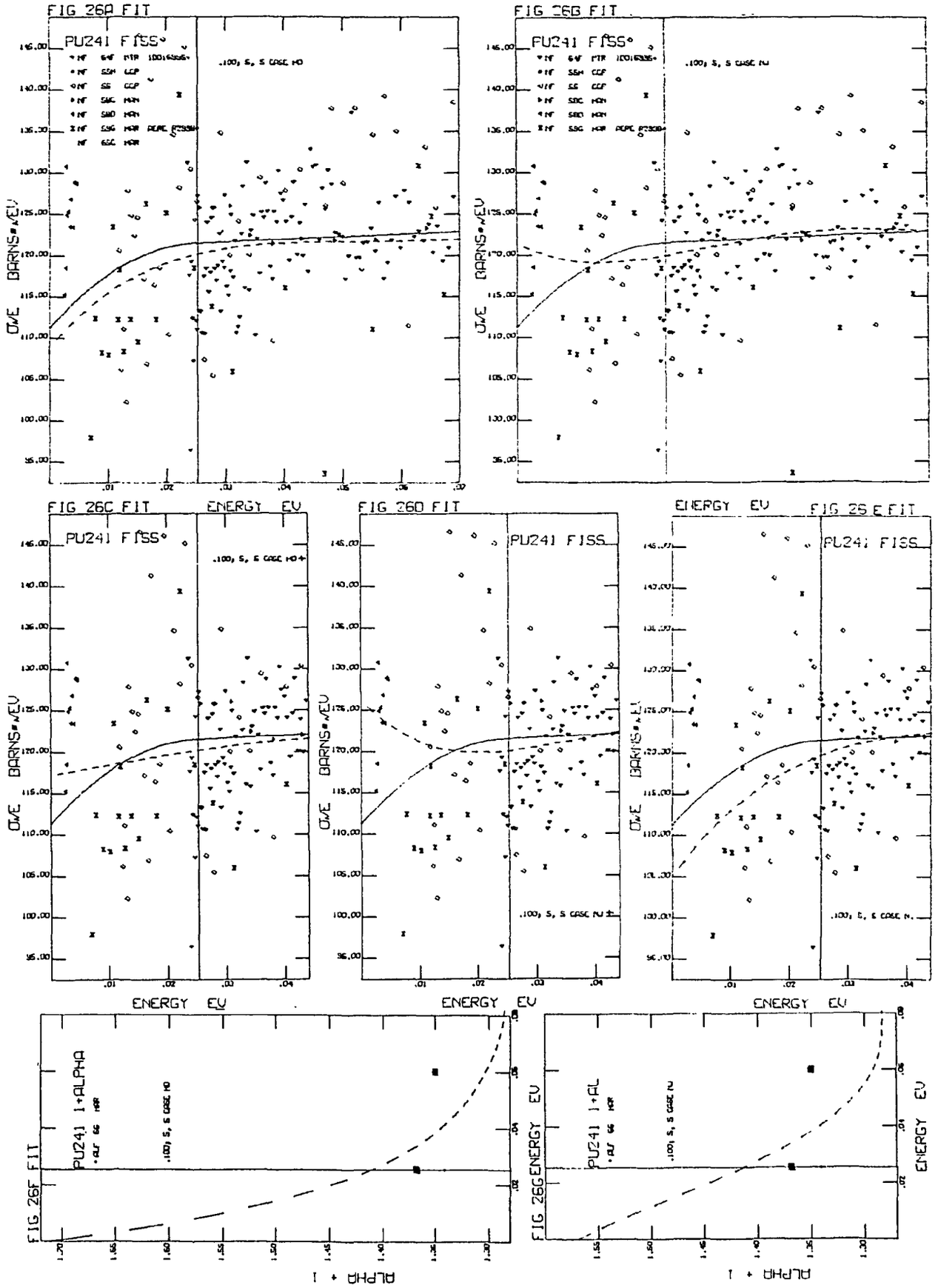


FIG 26A FIT
PU241 FISS
FIG 26B FIT
PU241 FISS
FIG 26C FIT
ENERGY EV
PU241 FISS
FIG 26D FIT
PU241 FISS
ENERGY EV
FIG 26E FIT
PU241 FISS
ENERGY EV
ENERGY EV
FIG 26F FIT
PU241 1+ALPHA
ALPHA + 1
ENERGY EV
ENERGY EV
FIG 26G
PU241 1+AL
ALPHA + 1
ENERGY EV

APPENDIX I

A. NUMERICAL COEFFICIENTS OF "RECIPES" FOR $\sigma_a\sqrt{E}$, $\sigma_f\sqrt{E}$ AND α

On the following sheets are listed the coefficients of the power series "recipes" (and Breit-Wigner term to be added) for absorption, fission and (1+α) for U-233, U-235 and Pu-239. The format of the listing is: (2 lines)

Quantity	Code	E_{min}	E_{max}	E_r	W	C_r
Card No.	C_o	C_1	C_2	C_3	C_4	C_5

The code digit is 1 for absorption, 2 for fission, 4 for 1+α. E_{min}, E_{max} (both in eV) are energy range of validity of the recipe given by this pair of cards. C_o, C_1, C_2 etc., are coefficients of power series, where the units of energy are 0.1 eV; E_r and W are the energy and $\Gamma^2/4$ of the resonance and C_r the numerator term (the units of E_r and $\sqrt{W}$ are also 0.1 eV, for convenience). The expressions to be evaluated are therefore (units for $\sigma\sqrt{E}$, barns $\sqrt{eV}$).

$$(\sigma\sqrt{E} \text{ or } 1+\alpha) = C_o + 10C_1E + 100C_2E^2 + 10^3C_3E^3 + \ldots + C_r\Big/\left[(10E - E_r)^2/W + 1\right] \quad \begin{cases} \text{between } E = E_{min} \\ \text{and} \quad E = E_{max} \end{cases}$$

Following the listing (for each isotope) of the recipes recommended, are listed alternatives. Such listings are partial, it being assumed that in the energy ranges for which alternative are not given, the "recommended" recipes listed at first will apply. Comments on alternative recipes follow.

URANIUM-233

ABSORPTION RECIPES

23ABS	1		.04		
RST1	91.94912	-2.0335	-1.05	-.017	
23ABS	1	.04	.1		
RST2	90.46763	8.33687	-26.60553	25.9084	-9.25925
23ABS	1	.1	.14		
RST3	107.7106	-33.5375	14.675		
23ABS	1	.14	.185		
RST4	76.6177	24.15	-20	6.6667	
23ABS	1	.185	.22		
RST5	-441.66938	734.8572	-334.026	50.61	
23ABS	1	.22	.4		
RST6	97.2259				

ALTERNATIVES (DIFFFRENCES SMALL)

23ABS	1		.04		
R1	91.61499	-2.0335	-2.1	-.035	
23ABS	1	.04	.1		
R2	88.6521	20.10873	-53.21106	51.8168	-18.51849
23ABS	1	.0	.1		
ST1	92.28326	-3.435			

FISSION RECIPE

23FIS	2	.0	.12	.6	.02	.15
R1	83.89307	-.145	-1.125	-2.15	1.25	
23FIS	2	.12	.19			
R2	-14.15961	293.48291	-322.49512	148.8	-24.0	
23FIS	2	.19	.28			
R3	-112.33374	225.63086	-82.65894	10. 7501		
23FIS	2	.28	.4			
R4	-157.32397	246.0443	-80.11938	8.61499		

ALPHA RECIPE

23ALF	4	.0	.07		
R1	1.095	.005	.0012	-.07202	.072
23ALF	4	.07	.09		
R2	1.16814	-.2184	.156		
23ALF	4	.09	.095		
R3	1.04395	.06			
23ALF	4	.095	.16		
R4	1.01118	.1344	-.042		
23ALF	4	.16	.24		
R5	1.00055	.14769	-.04615		
23ALF	4	.24	.4		
R6	3.2659	-2.46079	1.01683	-.18272	.012

NOTES ON RECIPE TABLES

Alternative recipes are partial; i.e., for ranges where no alternative recipe is given, the first-listed recipe applies.

For alternatives listed as "differences small" or "either could fit data", the main recipe was a compromise between R (used earlier) and a second recipe, but the change involved was of little significance.

The σ_f(U-235) and σ_a(Pu-239) alternatives are discussed at length in the text and appendices, although MLA was a recipe suggested by some data sets carrying relatively low weight, and was less important than the others. The HI σ_a(Pu-239) recipe was used for early weight determination (V, App II) but was dropped later when it was found that generally fits lay between R and LO (R was itself a compromise between LO and HI). The final LOR compromise was 75% LO, 25% R. other compromises were 50-50.

Recipes used in exploratory work but not listed included two σ_f(U-233) recipes trivially different in shape near 0.06 eV, and early α(U-235) recipes, one actually flat below 0.1 eV, and other independent of energy from 0.09 down to about 0.03 eV, and then "dipping" sharply as the energy axis was approached.

The LU σ_a(U-235) recipe was only used to test how much the g-factors depended on the curve shape above ~ 3 kT.

URANIUM-235

ABSORPTION RECIPES

25ABS	1	.0	.06			
R1	115.91	-35.6	13			
25ABS	1	.06	.09			
R2	115.03699	-32.69	10.575			
25ABS	1	.09	.105			
R3	119.7384	-43.192	16.44			
25ABS	1	.105	.18	2.9	.4556	53.29
R4	102.538	-17.088	1.5			
25ABS	1	.18	.4	2.9	.4556	53.29
R5	199.4895	-147.	56.35	-7.		

ALTERNATIVE (FOR TEST ONLY)

25ABS	1	.06	.1			
LU2	107.855	-3.125	-28.125	15.625		
25ABS	1	.1	.105			
LU3	144.63	-92.4	40			
NEXT RANGE 0.8 LESS THAN R (AS R BELOW .06 AND ABOVE .3)						
25ABS	1	.18	.22	2.9	.4556	53.29
LU5	150.7	-72.62012	17.25			
25ABS	1	.22	.3	2.9	.4556	53.29
LU6	67.82	2.94				

FISSION RECIPES

25FIS	2	.0	.09			
R1	100.702	-34.00739	12.73401			
25FIS	2	.09	.1			
R2	91.039	-11.81				
25FIS	2	.1	.2	2.9	.4556	39.97
R3	94.7	-24.05	4.1			
25FIS	2	.2	.4	2.9	.4556	39.97
R4	171.3	-120.65	43.25	-5.0		

ALTERNATIVES

25FIS	2	.0	.045		
SH1	98.0	-22.2725			
25FIS	2	.045	.09		
SH2	100.702	-34.0074	12.734		
25FIS	2	.0	.042		
MLA1	101.93527	-30.48417	-44.80433	160.95	-130.00
25FIS	2	.042	.09		
MLA2	96.81396	-12.40741	-20.86600	16.00000	

ALPHA RECIPE

25ALF	4	.0	.09		
R1	1.172	.00278			
25ALF	4	.09	.16		
R2	1.13667	.13509	-.1601	.063	
25ALF	4	.16	.4		
R3	.89572	.2756	-.053		

PLUTONIUM-239

ABSORPTION RECIPES

49ABS	1		.06	2.975	.25	2850.0
LOR1	73.45438	-13.9625	-26.9375	16.99305		
49ABS	1	.06	.18	2.975	.25	2850.0
LOR2	76.8999	-33.5	6.25			
49ABS	1	.18	.4	2.975	.25	2850.0
LOR3	36.85001					

ALTERNATIVES

49ABS	1		.06	2.975	.25	2850.0
R1	79.1499	-41	12.5			
49ABS	1	.0	.06	2.975	.25	2850.0
LO1	71.556	-4.95	-40.08334	22.65741		

ALTERNATIVE USED FOR WEIGHTS (EARLY)

49ABS	1	.0	.06	2.975	.25	2850.0
HI1	87.96997	-71.0	38.0			

FISSION RECIPE

49FIS	2		.4	2.975	.25	1700.0
R1	67.30005	-21.63				

ALPHA RECIPES

49ALF	4	.0	.04		
RRS1	1.3395	.08	.0975		
49ALF	4	.04	.07		
RRS2	1.35295	-.0544	.6015	-.84	.525
49ALF	4	.07	.18		
RRS3	1.22524	.3568	-.056		
49ALF	4	.18	.275		
RRS4	.99	.64444	-.14321		
49ALF	4	.2750	.325		
RRS5	3.15606	-.9366	.14321		
49ALF	4	.325	.4		
RRS6	1.6434				

ALTERNATIVES (EITHER COULD FIT DATA)

49ALF	4		.07		
R1	1.352		.195		
49ALF	4	.0	.04		
RS1	1.327	.16			
49ALF	4	.04	.07		
RS2	1.353RR	-.10RR	1.008	-1.68	1.05

B. RENORMALIZATION, DISPLACED ZERO GRAPHS AND σ_s CORRECTION

Several details should be explained briefly; as mentioned in Section 1, the g-factors depend on the shapes of the curves, so that renormalization is allowable*; these recipes are arbitrary to this extent but large renormalization changes are to be avoided, since then the "adjust" or "fitting" procedures may involve problems in resolving inconsistencies ($\sigma_f(1 + \alpha)/\sigma_a$ should equal unity). For the techniques commonly used for the measurement of σ_T, renormalization is somewhat dubious, but it may be appropriate if errors of sample assay are suspected--it is much less easy to adjust σ_T data for other types of systematic experimental errors, such as an incorrect estimate of background. For σ_f and η (used to give plots of α) measurements, renormalization is a more justifiable procedure, and this is also true for most techniques for measuring α directly. In general, however, only a few sets of data required renormalization to fall within the region of consensus, and only by factors slightly different from unity.

In obtaining data for σ_a an arbitrary (constant) value of σ_s was subtracted from the σ_T values in SCISRS. These σ_s values were initially, 13, 15 and 11 barns for U-233, U-235 and Pu-239 respectively, but, since their reassessment was part of the concurrent IAEA (2200 m/sec) study, provision was made for the "recipes" to be adjusted accordingly, by adding a term $\pm K\sqrt{E}$ to the $\sigma_a\sqrt{E}$ recipe.

Also, when only single data values appeared in SCISRS, they were usually ignored as giving no curve shape information, but if a special reason for their use existed, an "absolute"

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* Normalization multipliers used appear in Appendix II (Table); here the absence of a number means no renormalization; "x" with a number, indicates the multiplier used. A number followed by "÷" indicates that η (or, say, $\eta/\eta_{thermal}$) is stored in SCISRS, so that $1 + \alpha$ is obtained as a constant (that given) divided by the SCISRS datum (e.g. $1 + \alpha = \nu/\eta$).

value not otherwise normalized to our curves was down-weighted if necessary to allow for any possible normalization uncertainty in the rest of our data.

As explained at the beginning of Section 3 of the report, the absorption and fission graphs of this report are on an open scale with displaced zero. For U-233 the (constant) displacement indicated on the ordinate scales, and for α curve no displacement is used. The quantities subtracted from $\sigma\sqrt{E}$ before plotting are

U-235 (absorption) 100-200E (E < 0.12 eV), 53.29/Δ (E > 0.1 eV)
U-235 (fission) 85-200E (E < 0.12 eV), 39.97/Δ (E > 0.1 eV)
Where Δ = Breit Wigner denominator = $1 + (10E - 2.9)^2/0.4556$
Pu-239 (absorption) $2850/[1 + (10E - 2.975)^2/0.25]$
Pu-239 (fission) $1700/[1 + (10E - 2.975)^2/0.25]$

C. DISCUSSION OF ALTERNATIVE RECIPES AND SPECIAL POINTS

Figures 1-5 show, with the relevant data points, the low-energy portions of the more important alternative recipes. In Figure 2, where the SH recipe and the points associated with it are displaced downwards by 3" in an attempt to separate the two groups, we see most of the data for U-235 fission and the two main (R and SH) recipes--note the open scale used. Figure 3, shows the alternative MLA recipe (ANL data shown on this as well as on Figure 2), but these are relatively low-weight data*. In Figure 4 the Pu-239 σ_a points are in two groups, one fitting best to recipes HI or R--for the rest (also lowered 3" on the graph) curves R or LO fit better: in Figure 5 (α for Pu-239) it is seen that the data is scarce and different recipes are chosen to see what effects they have, rather than because the data indicate specific alternatives.

---

* The MOL authors used a linear fit vs time-of-flight, i.e. $\sigma = a + bE^{-\frac{1}{2}}$, and MLA is of somewhat similar shape, but there is no theoretical reason to expect a straight line on Mol coordinates. Note also on Figures 1-[illegible] some data sets listed have points only at higher energy than the graphs show.

C.1 Comments for U-235

Although generally the U-235 data are more accurate than for either U-233 or Pu-239, accuracy decreases above 0.1 eV and also at low energies α data become rather scarce. The two "single" points were added to the low-energy α region for this reason, downweighted as explained in "B" of this Appendix. For α also, the early recipes (flat and with a sharp dip near E = 0), mentioned in text on tables, were drawn (before the "single" points were used) to see whether a dip such as the ANL (1958) data alone might indicate would, if adopted, change g_α appreciably; only about 0.08 - 0.1% change resulted, and since the "dip" trend was not a serious suggestion, only a suggestion put up to test the point, no further use was made of these recipes. For σ_a(U-235) the low energy data are good, but a test (with recipe LU) was made of the influence of the exact curve above $\sim 3kT_o$. Below 0.6 eV LU and R coincide, while above 0.1 eV LU is some 0.8 barns-$\sqrt{\text{eV}}$ below R; the resulting 20°C g_a-factor was only 0.08% lower than for R, so that no further study of the effect of small recipe changes above ~0.08 eV seemed necessary.

Thus (MLA being a recipe of minor importance) only the SH vs R alternative recipes represent a serious difference, to be considered again in Appendix II and taken up in the body of this report. This is especially important since the Hanford and Columbia (Safford) measurements, which support SH, were careful measurements for which a high accuracy was claimed.

C.2 Comments for Pu-239

For Pu-239, α and σ_f both had some uncertainties at low energies, but the main discrepancy was for σ_a. For σ_f it was the old Saclay data which were discrepant (by a large amount, enough to change g_f by ~2%) but enquiries of Saclay led us to reject these data as unreliable. For α the R recipe was the first choice, based

on an examination of the log-log curves of BNL-325, but in fact on a linear scale R and RS are equally likely and RRS appears to be the recipe to be recommended. There is no serious discrepancy involved in this option; either recipe fits the data (Figure 5) equally well.

For σ_a(Pu-239) Figure 4 shows that about half the data favour HI or R, and half LO; the "adjust" procedure indicated some further preference,but not a clear-cut one, for LO. Only if the rejected Saclay σ_f data had been used as the basis of a recipe would HI have led to an "adjusted" α curve of the expected form. The discrepancy, now seen as one between the recipes R and LO, is significant and is taken up in Appendix II and the body of the report.

C.3 Comments for U-233

Accuracies of the data for U-233 were only modest, especially for σ_f, and for both this and α,low energy data were scanty; however, no divergent recipes were indicated for U-233. The low-energy α point of Cocking was downweighted (on the grounds given in B of this Appendix due to the α normalization uncertainty (the MTR 1966 data had had to be normalized upwards 0.3%, and all other data downwards by 0.3%, so a ±0.3% uncertainty was taken), but in fact even with this the point lies only about one standard deviation from the [illegible] (σ_a) difference, not shown in Figure 1, is quite [illegible], one can perhaps see in this figure that the MTR (two high) data fall nearer a straight line (ST) while the rest suggest concavity downwards. We therefore regard RST as the recipe to [illegible] (the α-factor difference between R and ST was quite small). As we see later, the main source of difficulty for U-233 is the lack of good data near zero energy.

APPENDIX II

A. EXPERIMENTAL DATA USED AND WEIGHTS ASSIGNED

In the tables which follow are listed the data sets used (SCISRS codes and short-form references) with the weights as used for "fitting" to a polynomial function as described in the text. A number (with x before or ÷ after it) indicates a renormalization, or deduction of $1 + \alpha$ from η, as explained in Appendix I. The weights are in units of $(\%)^{-2}$, being generally derived as explained in the text from the mean square deviations.

One important point will be clear from the tables; weights have been assigned over certain discrete energy ranges. In fact, from a general examination of the data curves initially plotted, it was clear that measurements were more accurate (and probably easier) in some energy ranges than others. For most types of measurement it was obvious that from 0.025 eV to 0.08 or 0.1 eV a better accuracy (and more plentiful data) was obtained, than for lower or higher energies. The decrease in accuracy has often occurred rather suddenly near 0.08 - 0.12 eV, with a gradual worsening (to a degree varying from data set to data set) up to 0.2 eV. Below 0.025 eV, the loss of data accuracy, or of number of points, was even more marked, and the onset of this effect was usually quite sudden and near to 0.025 eV, although for σ_T it was generally more gradual, but none the less definite.

It appears then that experimental techniques begin to fail below 0.025 eV; but the fact that experimenters have tended to concentrate their measurements in the energy range of kT_o to a few x kT_o, and have sometimes "pushed" their measurements down in energy so as just to include a 2200 m/sec point, has probably also been operative. For these reasons, it was certainly convenient to assign "weights" (usually constant but sometimes varying with

the form a + bE) separately for the ranges of energy 0 - 0.025 eV, 0.025 to 0.1 eV, 0.1 to 0.15 or 0.2 eV and if necessary 0.15 - 0.2 eV, with in special cases weight changes at other energy points. The format used in listing the weights is straightforward, footnotes being used whenever an energy boundary is other than at the energies just listed; a dash (-) indicates no weight assigned (equivalent to zero weight), often because there is no data in this range. An equals (=) sign indicates that the weight shown for the next lower energy range continues into the range concerned. See summary at the end of this appendix.

We should also note that a few data points were rejected as "fliers"; this (see Appendix V below) is indicated by a note "excluding" (i.e., giving zero weight) to certain short energy ranges, or sometimes by changing the lowest (or highest) limit of energy from (or to) which a weight is assigned. Usually these lay more than $\sqrt{10}$ (usually much more) standard deviations from the "consensus" or "eye-ball" curve, so that no precise rejection criterion was required; the cases were obvious ones and represented much less than 1% of the data used.

There were several alternative sets of weights for each isotope, as explained in the text. Since a preliminary use of the "adjust" procedure (using weights as explained in "B" below) served to improve the "eye-ball" recipes, the development of these weights had an iterative feature; the penultimate set of weights is indicated in the fits by code O (for "old")--these old values are not listed in this appendix--and the codes for more recent sets for the respective isotopes are as follows:

U-233: "O+" old weights plus a pseudo-point (see C.3 below)
"1" single Cocking point (v Appendix I) excluded
"2" Cocking point included, no pseudo-point
"3" adding a pseudo-point α = 0.095 at E = O, wt = 3.0

U-235 "BC", "BV", "SH" and "MR" (v Appendix II C)
Pu-239 "R", "LO" and "B" based on a preference for recipe R, for recipe LO, and for both treated equally (v Appendix I and II C below), respectively.

B. WEIGHTS USED FOR "ADJUST" PROCEDURE

In Table A II, 2 (last column of second page) are given the weights-per-unit-energy (in units of $(\%)^{-2}$ per $\frac{1}{2}kT_0$, an arbitrary but convenient choice) for the sum of all available information for σ_a, σ_f and $1 + \alpha$ respectively of each isotope. Only relative weights are needed (for these three quantities) and occasionally all three values have been (equally) normalized upwards as regions where all data deteriorate (e.g., near E = 0) are approached. These are made from the weights of Appendix II A by multiplying by the number of points of each set per $\frac{1}{2}kT_0$ energy range, and summing for all sets. As this is (see above) an iterative process, some of the "adjust" weights may have been deduced from an older set of separate-data weights, but the results are adequate for the purpose.

For the "adjust" procedure, the weight functions should be continuous. Trapezoidal (i.e., with alternately horizontal and sloping straight lines comprising the graph) functions are usually used, and in the tables are given E_a, E_b, E_c, W_f, W_g where the significance is that from E_a to E_b the weight is constant and equals W_f, changing linearly from this value to W_g from E_b to E_c; dashes (-) indicate cases where one or other of these sections is omitted.

C. COMMENTS ON THE WEIGHTS AND SPECIAL PROBLEMS

C.1 U-235

For U-235 the divergent recipes (Appendix I above) for σ_f corresponded to trends on which the alternative sets of weights

TABLE A.II.1

URANIUM-233 ABSORPTION

60E MTR PR 118 714
wt 2.25 5.0 1.25 0.6
Excluded region 0.079 - .0805 eV

60H ORL NSE 8 112
wt 10.0 4.9 - -

63K ORL NSE 17 404
wt - 2.1 1.2 =

60E COL PR 118+799 LIQUID
wt 1.0 0.56 - -

60E COL PR 118+799 METAL
wt 1.0 2.25 - -

55F BNL MUETHER x0.9868
wt 0.29 0.5 = =
Excluded region 0.043 - .048 eV

55 CCP GENEVA CONF x1.0135
wt 0.26 0.39 = 0.1

URANIUM-233 FISSION

60E MTR PR 118 714
wt 0.39 1.05 0.65 0.35

57 HAR JNE 6 114
wt 0.51 0.36 0.2 =

URANIUM-233 ALPHA

56K MTR BAPS 1-327 x0.997
wt - - 4.6 =

55 CCP MOS 81 1.0877÷
wt 0.131 0.34 - -

56 BNL JNE 3-177 x0.997
wt 4.2 5.0 - -

57 HAR JNE 5 186 2.4925÷
wt 0.4 V 5.0 3.0 =

66 MTR CONF-660303 2.5115÷
wt 1.0 9.5 1.0 8.0

58 HAR JNE 6 285
wt 0.3823 - (see note) -

URANIUM-235 FISSION

58 ANL BOLLINGER
wt SH 0.255 2.0 5.0 =
wt OTHER 0.28 2.0 5.0 =

58 COL NSE 3 435
wt SH 0.075 0.4 1.0 0.1
wt MR 0.082 0.35 1.0 0.1
wt OTHER 0.082 0.38 1.0 0.1

55F HAN LEONARD x0.994
wt SH 1.25 5.0 4.0 =
wt MR 0.19 3.0 4.0 =
wt OTHER 0.75 4.0 = =

63E LRL PR 130 1482 x0.9875
wt - 0.3 = 0.19

66C LRL CONF-660303 x1.1
wt SH 1.05 1.7 0.9 1.4
wt MR 1.5 1.35 0.9 1.4
wt OTHER 1.5 = 0.9 1.4

55H CCP GENEVA CONF x1.0732
wt SH 0.075 0.19 0.39 =
wt MR 0.045 0.19 0.39 =
wt OTHER 0.06 0.19 0.39 =

55 SAC
wt SH - 0.205 0.06 =

wt OTHER 0.035 0.205 0.06 =

58J BNL PR 112 191
wt - - 2.6 =

61 MOL JNE 15 165
wt 0.2 0.975 - -

68 MOL PRIV.COMM.
wt SH 0.565 0.4 - -
wt MR 0.8 0.5 - -
wt OTHER 0.9 0.5 - -

57J HAN LEONARD x1.05385
wt MR 0.425 - - -
wt BC 0.85 - (see notes)

59 COL SAFFORD
wt MR 0.08 - - -
wt BC 0.3 - (see notes)

(for notes see continuation page)

URANIUM-235 ABSORPTION

55F HAN LEONARD
wt 0 1.4 1.0 0.2

59H COL NSE 6-433
wt 4.0 0.9 - -

60 MTR NSE 7, 187
wt 9.4 5.8 - -

58J BNL PR 112 191
wt - 7.0 1.5 =

60H ORL NSE 8 112
wt 2.3 9.0 1.0 =

61K ANL NSE 11 312
wt 6.0 12.0 2.0 0.25

58D HAN HW-55879 No weight

URANIUM-235 ALPHA

64 CCP AT.EN. 16 110
wt - 0.616 0.22 =

58 ANL BOLLINGER
wt 0.36 0.326 0.24 =

55G HAN HW-38202 p.41
wt - 0.27 0.14 =

55K MTR PR 100 1266
wt - - 0.5 1.0

65F HAR BROOKS
wt - 0.78 = 0.16

55 CCP MOS 81 1.1722÷
wt 0.072 0.10 X 0.033 -

58 HAR JNE 6 212
wt 1.32 9.0 - -

56 BNL JNE 3 177
wt 2.5 = Y 0.4 =

58 HAR JNE 6 285
wt 0.2838 = = =

59 COL PR 113 1285
wt 1.6929 " = =

(Cont'd)

TABLE A.II.1 (Continued)

PLUTONIUM-239 ABSORPTION

58I ANL GENEVA CONF.

Case B	0.1			
Case R	0.14	0.32	=	0.15
Case L	0.04			

51E COL CUD-92

Case B	0.065			
Case R	0.085	0.04	0.158	-
Case L	0.025			

56 HAR JNE 2 187 x1.035

Case B	0.017			
Case R	0.02	0.275	0.19	-
Case L	0.01			

55E BNL PALEVSKY

Cases B,L	0.55	0.6	0.475	=
Case R	0.025	0.5	0.475	=

55 CCP GENEVA CONF.

Cases B,L	0.08			
Case R	0.05	0.125	0.21	=

61 COL NSE 11 65

Case B	1.2			
Case R	0.15	1.5	-	-
Case L	2.0	2.0	-	-

56 HAN HW44525 p.47

wt	-	-	0.11	=

PLUTONIUM-239 FISSION

58I ANL GENEVA CONF

wt	0.25	0.21	0.177	=

51A CR CRGP-458

wt	0.043	0.21	0.125	=

56F HAN LEONARD

wt	0.019	2.1	0.53	= W

56 HAR JNE 2 177 x1.057

wt	0.2	0.1	0.275	0.14 Z

Excluded regions 0.13-0.1325, 0.1-0.1115 and .16-.162 eV

55 SAC GENEVA CONF No Weight

55 CCP GENEVA CONF x1.1875

wt	0.045	0.15	=	P 0.05

PLUTONIUM-239 ALPHA

66H HAR BROOKS

wt	-	0.35	0.7	0.3

56 BNL JNE 3 177 2.79÷

wt	0.55 Q	0.12	0.03	=

58 ANL GENEVA CONF x1.0321

wt	0.42	0.3	0.22	0.08

56 HAN HW44525 p.47 1.3614÷

wt	0	R 0.66	0.05	=

55 CCP MOS 81 1.3886÷

wt	0.092	0.2	0.05	=

56 HAR JNE 3 33 1.3886÷

wt	-	0.113	0.059	=

56D HAR SANDERS 2.86÷

wt	-	0.213	0.4	0.05

58 HAR JNE 6 212 2.88÷

wt	0.35	0.25	0.35	=

66C MTR IDO-17140 2.871÷

wt	7.0	5.1	-	-

NOTES ON WEIGHTS

	eV
Reduced upper limits (instead of 0.2 eV) →	W 0.195 Z 0.199
Changed energy boundaries (instead of 0.1 eV) →	X 0.06 Y 0.065
(instead of 0.15 eV) →	P 0.16
(instead of 0.025 eV) →	Q 0.04 R 0.026 V 0.05

U-233 α 58 HAR JNE 6 285 was used in cases 2 and 3 only

Also used for case 3 only was an E=0 point α=0.095 weight 3.0

U-235 FISSION - 57J HAN
For cases SH/BV, weights were
0.0025 to 0.0047 0.3 to 2.5 L
0.0047 to 0.00515 2.5 to 2.0 L

also for 59 COL (SAFFORD)

E < 0.0024, weight 0.5 (Const.)
0.0024 to 0.0050 5.0 to 3.0 L
L indicates linearly interpolated
(For cases MR and BC, as in table)

TABLE A.II.2

	E_1	E_2	E_3	$W_{1,2} \rightarrow$	W_3
URANIUM-233					
ABS	0	0.08	0.12	2.0	1.5
	0.12	0.14	0.16	1.5	1.0
	0.16	0.2	-	1.0	-
FISS	0	0.02	0.03	0.1	0.363
	0.03	0.08	0.12	0.363	0.286
	0.12	0.14	0.16	0.283	0.333
	0.16	0.2	-	0.333	-
ALPHA	0	0.02	0.03	0.9	0.8
	0.03	0.05	0.09	0.8	0.9
	-	0.09	0.12	0.9	1.61
	0.12	0.14	0.16	1.61	2.5
	0.16	0.2	-	2.5	-
URANIUM-235					
ABS	0	0.018	0.025	1.2	3.8
	0.025	0.08	0.12	3.8	0.42
	0.12	0.14	0.16	0.42	0.245
	0.16	0.2	-	0.245	-
FISS	-	0.0	0.025	0.2	0.8
	-	0.025	0.03	0.8	1.0
	0.03	0.2	-	1.0	-
ALPHA	0	0.02	0.03	0.4	0.5
	0.03	0.08	0.12	0.5	0.13
	0.12	0.14	0.16	0.13	0.245
	0.16	0.2	-	0.245	-
PLUTONIUM-239					
ABS	0	0.0125	0.03	1.5	2.75
	0.03	0.09	0.11	2.75	2.4
	0.11	0.14	0.16	2.4	1.0
	-	0.16	0.172	1.0	0.55
	0.172	0.2	-	0.55	-
FISS	0	0.02	0.03	0.5	2.625
	0.03	0.09	0.11	2.625	2.5
	0.11	0.14	0.16	2.5	3.0
	0.16	0.2	-	3.0	-
ALPHA	0	0.02	0.03	0.9	1.22
	0.33	0.09	0.11	1.22	2.1
	0.11	0.14	0.16	2.1	1.6
	0.16	0.2	-	1.6	-

Table A.II.2 Weights used for "Adjust"

are based. The "O" (old) case was in effect a "whichever-is-best" weight based on SH or R (MLA was not then in final form). In the newer cases not only was the SH vs R choice involved, but also whether the authors' claimed accuracy was accepted for the two σ_f data sets (HAN 1957 and COL 1959) supporting the SH recipe, instead of using the (lower) weights given by the normal procedure based on the spread of the values. The authors' claims resulted in weights varying with energy (a form a + bE over certain energy ranges was an adequate approximation), or a constant weight over this range (giving a similar total weight) could also be used. Both were larger than the (constant) weight which was derived from the spread of the points. The reasons for considering this special treatment for these data sets were that both were measurements carefully made when it was known that absolute values were in doubt, and for which the authors' claims for the accuracy of each datum were available (for COL in a publication for HAN from SCISRS--also private communication); they were also the data primarily causing the R vs SH discrepancy, since all other (except MOL) values clustered around the R recipe as a consensus curve.

The cases (other than "O") used thus were:

"BC": based on a compromise (mean) of the weights deduced from a spread from recipes R and SH; COL and HAN with constant weights.

"BV": as BC above, but basing weights for COL and HAN σ_f data sets on authors' claims (varying with energy, see above).

"MR": based on spread from R recipe (or a compromise between R and MLA if better); constant for COL and HAN.

"SH": based on spread from SH recipe, with authors' claimed (variable with energy) weights for COL 1959 and HAN 1957 σ_f's.

Certainly using these sets, one expects the results of fitting using SH to yield a curve nearer the SH recipe, and using

MR the R recipe. The old set of weights was not very different from BC, but the low-energy Safford and Cocking α points were excluded; by accident this one omission and the lack of weights for MOL data seemed to tend to cancel one another.

C.2 Pu-239

As a point of interest, case "O" for Pu-239 did not exclude all the "fliers" excluded by the tabulated weights (it also gave some, but a small, weight to the Saclay 1955 σ_f data); in even earlier sets, with even more "fliers" in, the "fitting" procedure had failed to converge for ranges of fit up to $\geq$0.15 eV. This experience led us to look for "fliers" systematically, using the $\sqrt{10}$ standard deviation criterion mentioned above.

The other cases, corresponding to the alternative recipes for σ_a (v Appendix I) are:

B: weights using both recipes R and LO and using a compromise which is close to the value for whichever recipe gives the higher weight.

R: a set based on deviations from recipe R only.

L: a similar set based on recipe LO only.

There were no problems concerning σ_f, and the alternative α recipes for Pu-239 did not justify special treatment (v. App. I).

C.3 U-233

The cases 1, 2 and 3 differed only trivially as shown in "A" above. The main difficulty with U-233 was connected with the sparsity of data at low energies, and to meet this an additional "pseudo-point"(weight 7.1 units in case "O", a value chosen to equal one point from the best (MTR) α data set, but only 3.0 units in case 3) was added to the data, being α = 0.095 at E = O.

The use of this point is discussed in the text; it may be that an accident when case "O" was in use was really what led

to the use of such a point--though since the fits for U-233 all showed, to a greater degree than the other isotopes, the effects of a lack of good data below 0.02 eV, its use for this isotope was certainly instructive. The "accident" mentioned for case O--reinforced in its effects by the fact that at this date no "flier" exclusion had been made--was the use twice over of the 1957 Harwell σ_f data, once as now used and also, with source 1955 Geneva Conference, the same data with a different normalization. When the identity of these two sets of values was discovered, so that the accidental duplication of their weight disappeared, the fits certainly improved and an extreme case like the 0.1;8 case "O" fit (see Table 2 in text for notation) where σ_γ became negative for low energies, was not again encountered. Figure 12 includes a curve for this case, and Figure 10 the worst comparable curve obtained with the "new" weights.

SUMMARY OF FORMAT OF TABLE A.II.1

1st line: Code, Author or reference Normalization (if any)

2nd line: Code (if any) Weights .....

0-0.025 eV 0.025-0.1 eV 0.1-0.15 eV 0.15-0.2 eV
(unless modified by notes)

The entry "-" is equal to zero weight; "=" same as next lower energy range. "Exclusions" are also regions of zero weights, usually placed so as to include "fliers" to be rejected.

APPENDIX III

D. McPherson

Least Squares Fitting Program

An option in the SCISRS retrieval program provided for least squares fitting of the quantities $\sigma_a \sqrt{E}$, $\sigma_f \sqrt{E}$ and $1 + \alpha$ in the range $0 < E \leq E_c$ and the evaluation of the g-factors from the fitted quantities. The functional forms adopted were

$$\sigma_a \sqrt{E} = \left\{ \sum_{i=1}^{N_a} C_i \, E^{i-1} \right\}_{E \leq E_c} + Q_a \qquad (1a)$$

$$\sigma_f \sqrt{E} = \left\{ \sum_{i=N_a+1}^{N_a+N_f} C_i \, E^{i-N_a-1} \right\}_{E \leq E_c} + Q_f \qquad (1b)$$

$$1 + \alpha = \sigma_a / \sigma_f \qquad (1c)$$

where C_i are the parameters to be determined by the fit

N_a is the number of parameters used to describe the absorption curve

N_f is the number of parameters used to describe fission curve

Q_a is a Breit-Wigner resonance term plus, for $E > E_c$, a polynomial to describe absorption

Q_f analogous to Q_a, but for fission.

The polynomials in Q_a and Q_f are used only for $E > E_c$, and are the appropriate "eye-balled" recipes described in Appendix I; the polynomial contribution to the Q's are

not, of course, involved in the fit, but make a small contribution to the g-factors.

The quantities N_a, N_f, E_c were specified for each fit, the weights to be used for the data appeared as part of the data set specification (see Table A.II.1).

Trial values of the C_i were determined by fitting independently the linear systems 1a and 1b. The fit to the complete system of Eq. (1) was then obtained by iterating until the maximum change in any C_i was less than 1 part in 10^6. The output of the fitting program consisted of the set of C_i's and their variance-covariance matrix V.

The effective cross section in a Maxwellian spectrum of temperature $T = E_o/k$ ($=20.4_4^{\circ}C$) is defined by

$$\hat{\sigma} = \frac{2}{\sqrt{\pi}} \frac{1}{E_o^2} \int_o^{\infty} E\, e^{-E/E_o}\, \sigma(E)\, dE$$

In terms of the functions of Eq. (1),

$$\hat{\sigma}_a = \sum_{i=1}^{N_a} C_i\, I_i + R_a \qquad (2a)$$

$$\hat{\sigma}_f = \sum_{i=N_a+1}^{N_a+N_f} C_i\, I_{i-N_a} + R_f \qquad (2b)$$

where

$$I_i = \frac{4}{\sqrt{\pi}} \frac{1}{E_o^2} \int_o^{\sqrt{E_c}} E^i\, e^{-E/E_o}\, d(\sqrt{E})$$

$$= (i - \tfrac{1}{2}) E_o \, I_{i-1} - \frac{2e^{-E_c/E_o}}{E_o \sqrt{\pi}} \, E_c^{\,i-\frac{1}{2}} ,$$

$$I_o = \frac{2}{E_o^{\,3/2}} \, \mathrm{Erf} \, (\sqrt{E_c/E_o})$$

and

$$R_a = \frac{2}{\sqrt{\pi}} \, \frac{1}{E_o^{\,2}} \int_o^\infty Q_a(E) \, \sqrt{E} \, e^{-E/E_o} \, dE$$

with a similar expression for R_f.

The g-factors are defined by

$$g_a = \hat{\sigma}_a/\sigma_a(E_o) , \qquad g_f = \hat{\sigma}_f/\sigma_f(E_o) \quad \text{and} \quad g_\eta = g_f/g_a$$

The covariances of the effective cross sections and the g-factors are given in terms of the variance-covariance matrix (of the C_i's) V by:

$$\mathrm{var}(\hat{\sigma}_a) = \sum_{i,j=1}^{N_a} I_i I_j \, V_{ij}$$

$$\mathrm{var}(\hat{\sigma}_f) = \sum_{i,j=N_a+1}^{N_a+N_f} I_{i-N_a} \, I_{j-N_a} \, V_{ij}$$

$$\mathrm{var}(g_a) = \sum_{i,j=1}^{N_a} \frac{\partial g_a}{\partial c_i} \frac{\partial g_a}{\partial c_j} V_{ij}$$

$$\mathrm{var}(g_f) = \sum_{i,j=N_a+1}^{N_a+N_f} \frac{\partial g_f}{\partial c_i} \frac{\partial g_f}{\partial c_j} V_{ij}$$

$$\mathrm{var}(g_\eta) = \sum_{i,j=1}^{N_a+N_f} \frac{\partial g_\eta}{\partial c_i} \frac{\partial g_\eta}{\partial c_j} V_{ij}$$

where the $\partial g/\partial c_i$ are obtained from the definition of the g-factors and Eq. (2).

As used in this study, $N_a=N_f$ except where otherwise stated. The computer output includes, in addition to values previously indicated, the values and standard deviations of $\hat{\sigma}$, $\sigma(E_o)$ and $g(20.44^\circ C)$ for both absorption and fission, and g_η and its standard deviation; it also includes χ^2, defined by

$$\chi^2 = \frac{10^4}{M-(N_a+N_f)} \sum_{j=1}^{M} \frac{W_j}{x_j^2} (x_j - x_e)^2$$

Where M is the number of data points, x is the j-th datum ($\sigma\sqrt{E}$ or $1 + \alpha$), x_e is the value calculated for the energy E_j of the j-th datum, and W_j is the weight (in our units, so that $10^{-4}\, x_j^2/W_j$ is the variance) of the j-th datum.

APPENDIX IV

Data in SCISRS Not Used

The following (SCISRS codes given) data were not used for reasons listed below, although more than one datum for them were in SCISRS.

U-233

TOT	HAR	56	Pattenden*	
NFE	HAR	59G	R-2998	***
all	HAR	66H	Brooks	*
NF	CR	51A	CRGP-458	* **

U-235

NFE	HAR	59G	R-2998	****
NF	HAR	65F	Brooks	*
TOT	CCP	55H	Geneva	*
TOT	HAR	55	Brooks	*
TOT	HAR	55	Lynn	*
NF	SAC	55	Auclair	*

Pu-239

NF	HAN	58D	HW-55879,3*	
NFE	HAR	59G	R-2998	* **
NF	( )	65C	Salzburg SM60**	

Pu-241

TOT	BNL	58D	Low%-241	*

Others listed in Table A.II.1 as "no weights" were initially given weights, which turned out to be low, and discarded after enquiries from authors or representatives of laboratories involved. Such enquiries were usually also made for data marked * or ** in above table. Note also that deduced values (e.g. σ_f from α) were not generally included, nor data sets which started near or above 0.2 eV.

Code of Remarks

* Unacceptably large spread of data values.

* Unreliable shape--evidence of systematic errors--no satisfactory explanation available. (for NF HAN 58D cf App. V.F, first para.)

** Cld values--enquiries difficult or replies not encouraging.

** Spread of values not good, very small numbers of data, not worth inclusion in view of other data available.

APPENDIX V

A. RELATION OF SPREAD TO STANDARD DEVIATION

Fundamentally the only reason for stating our results as standard deviations is because they are to be used in a least squares regression analysis--our real conclusions are the range within which it seems that a given g-factor is likely to vary. Curves which were obtained in our fits and which would correspond to g's outside this range (g_{min} to g_{max}, say), have been rejected as physically implausible. We therefore choose as the standard deviation that for which the assumption of a normal distribution would lead to about a unit expectation for the number of fits giving $g > g_{max}$, and also for $g < g_{min}$, from among the N (say) acceptable fits obtained. Most of this expectation (for the normal distribution) would represent cases giving g only slightly outside our range, with a similar liklihood of g's just within our range occurring. The more normal approach of deducing a standard deviation from a sum of squares of deviations is more sensitive to the incorrect rejection or acceptance of extreme values, so in spite of its logicality we have chosen not to use it for this work; we have really been searching as much for the limits of unacceptability as to produce a representative sample of fits of all types with the "correct" frequency of occurrence. However, for σ_f (Pu-239) we have also calculated the standard deviation of g's from our sample in a conventional manner; the values obtained was $\pm$ 266 x 10^{-5} in excellent agreement with the value (Table 5) obtained from the spread using a x 1.1 factor of safety. Note: this was a case for which no rejection on account of curve shape was necessary.

We consider first a presumed Gaussian ("normal" distribution for N=40, say; beyond the 95% confidence limits at each end of the range (at $\pm 2\sigma$, where σ = standard deviation) $\sim$ 1 datum is expected; then σ = one-quarter of the spread. A second distribution may have two components, one "normal" and the other a distribution where two discrete values (differing by x, say) are presumed equally probable, folded together. If $x = 2\sigma$, say, we can form the combined distribution of the average of two Gaussians centered on $\pm x$ from the centre of the whole--the 95% confidence limits are then at $\pm$ 2.644 σ(for $x = \sigma$ it would be $\pm$ 2.18σ) whereas the standard deviation is in fact $\sqrt{2\sigma}$ (or $\sqrt{1.25\sigma}$ for $x = \sigma$), so that the full width of the spread is 3.74 (or 3.90) times the standard deviation, instead of 4 times. This alternative corresponds for example, to the σ_T (Pu-239) LOR-R alternative folded with a Gaussian (cf. second paragraph of section 9 of text).

It seems in our cases that at most half of the total spread is from a two-discrete-value distribution, but the rest of the distribution may be a somewhat truncated normal distribution, so that we should probably reduce the factor (4 or 3.74 as above) by which we divide the "spread" to estimate the standard deviation, to a value of 3.33; this adjustment covers the truncation possibility and other contingencies.

The "factors of safety" mentioned in section 8 (and listed in Table 5) also contain some adjustments but are used with the 3.33 factor just quoted. For U-233, where the two-value distribution effect is probably absent, 3.50 might have

been more appropriate than 3.33, so the factors of safety have been adjusted downwards (from the original estimate of $\sqrt{3}$, or more for g_{abs}) to the values shown.

B. REJECTION FOR CURVE SHAPE REASONS: SUMMARY

The general question of rejection has been dealt with in section 8; apart from unacceptable anomalous behaviour near E=0, curves may be rejected for general "wiggliness" if too high an order or fit gives too sinuous a curve. An extreme case is that of case "0" U-233 for the 0.1;8 fit (fig.12c), when σ_γ becomes negative. Less serious cases (rejected or categorized as "borderline") may have faults as follows

R rises suddenly (too much to be acceptable) near E=0
F falls suddenly (too much to be acceptable) near E=0
W generally too wiggly

In what follows, RB, FB and WB denote borderline effects of a similar type; a, f or α preceding these symbols denote which quantities misbehave.

B.1 For U-233

The cases "0" and "0+" are taken separately--all but the low-order fits show large or at least appreciable wiggliness; the ranges in Table 5 are taken for the remaining ("new") cases but 0.2;4 is rejected as the "too rigid fit"* and 0.1;7 and 0.1;8 fits are also rejected for wiggliness. The case "1" (single HAR 58 point omitted) also becomes borderline for many of the fits. This isotope is discussed again below.

* In the sense described in section 6, p. 19-20 ("low order fits")

B.2 For U-235

No fits for 0.1;7 or 0.1;8 and only case "0" for 0.15;8 was done, and this reduced the number of rejections for curve shape reasons. For the older weights (case "0") 0.1;6, 0.15;7 and 0.2;8 all gave fF, αR rejections with (especially for 0.1;6) also a general wiggliness and 0.15;8 case "0" was rejected even more definitely, while 0.1;5 0.15;6 and 0.2;7 were all treated as borderline cases. By contrast for case "MR" all fits done were acceptable, with 0.1;6 being still acceptable but the nearest of the "MR" cases to the borderline (fFB, αRB). The other cases were intermediate (see below). Since (apart from wiggliness for low-range high-order fits) the most frequent fault was fF, αR, it is perhaps not surprising that case SH, which gives the lowest fission curve for $E \approx 0$, should be more liable, and case MR less liable, to give curves rejected for these reasons. Physically, a quite sudden rise of α near $E = 0$ (in the last ≈ 8 meV) seems unlikely, since for this isotope $\Gamma_\gamma \approx 40$ meV, for even a small capture-only resonance would probably not give as sharp a rise as our fits indicate--this would still leave the fall in $\sigma_f\sqrt{E}$ to be explained. It is almost certain that accidental features in the few data for α and σ_f at low energies cause the fF, αR tendency, and we feel that beyond a certain point this should be taken as a ground for rejection of the fit as physically unreasonable.

For case "SH", to complete the story in detail, 0.1;6, 0.15;7 and 0.2;8 are rejected, though on the basis of the fission curve shape alone the 0.2;8 case might be accepted but the αR fault is definitely bad--indeed 0.1;6 and 0.2;8

are rejected also for BV and the former for BC (the latter was not done for this case); for 0.15;7 case BV and BC both give wiggly but acceptable fission curves, but BV gives an αR characteristic and is treated as rejected, while BC is deemed borderline since its α rise is less marked. The only other cases near the borderline are (for αRB reasons) 0.2;7 "SH" and "BV" 0.15;6 "SH" and 0.1;5 "BV", but these are all treated as acceptable cases.

B.3 For Pu-239

For E_{max} = 0.1 eV only 4- and 5-term fits were done, but a set for E_{max} = 0.12 eV (up to 6 terms, or 7 for case "0") was included. The 0.12;7 "0" fit was rejected (reason code: fF, αWR) but all others were either borderline or acceptable. For case "0" the borderline fits were 0.12;5 and 0.1;4 (reason codes: αFB) but these were both close to acceptable and the "borderline" designation reflects as much a lack of confidence in the "old" weight set as any really dubious curve shapes. For the 0.2;8 fits, case "R" showed a borderline trend (fFB, αRB) while for 0.15;7 fits a similar trend for case "R" was rather more marked, while cases "B" and "L" also showed this trend, in the latter case the fission curves being rather more, and the α curves less affected than for case "R". For 0.12;6 cases "R" and "L" showed a similar trend (α curves being satisfactory for "L" and fission for "R") but the cases were deemed acceptable.

B.4 General

In some cases odd/even effects were seen, where the behaviour at low energies depended on whether the order of fit was odd or even (perhaps due to data peculiarities at the high end of the range) but generally a good variation of curves was obtained. The number of acceptable fits for U-235 was about 45 (plus borderline), and for Pu-239 slightly more, so that statistically the sample seems adequate. For U-233 the new fits, for cases 2 and 3 only (case 1 being near borderline rather often) we have only 28 good fits, or say 38 with most case 1 fits included; these are rather uniform fits (within the spreads shown in Table 5) but as already explained are based on a narrow choice of weights. The rather large factor of safety (/3, corrected as explained in A above to 1.64) used brings the overall claimed errors up to the point where the case "0" curve shapes correspond to g-values within the errors proposed in cases where the shapes are not unreasonable.

We also tend to use larger "factors of safety" when the computed error is small--this occurs for absorption of U-235 and U-233, being particularly marked for the former as seen in Table 5. In any case it is felt that a claim of much better accuracy than 0.1% for a g-factor cannot be sustained, and for U-233, where the causes of the larger spreads obtained using "old weights" is not fully understood, the larger factor of safety listed for absorption is felt to be appropriate. There was one other consideration for

U-235, which led to the factors of safety in Table 5 being increased a little over what would have been used otherwise; this was that in the course of preliminary work some cases had been fitted with somewhat different weights and a few of the curves which resulted had shapes which would be deemed acceptable, but gave g-factors outside the limits for fits in Table 5. These were for cases discarded or superseded, but it was nevertheless felt desirable to make a token upward adjustment to safety factors on this account.

A few other points re Table 5 can also be clarified here. Where two borderline cases are shown bracketed (with an asterisk*) the mean of the two is used as a borderline figure, to be averaged with the "acceptable" limit shown in the line above. This has been done where the outer limit for the "borderline" case is felt to be only marginally acceptable, even as borderline, and the next highest (or lowest) value for another borderline case in given also. Note that the limits from "adjust" are obtained (from those of Table 1) by adding for Pu^{239} at each end of the range a quantity $\frac{1}{2}|\Delta(R-RS)|$ to allow for the possible extra spread in adjust due to the α recipe alternatives.

Figures 10 - 24 have been chosen so as to include borderline and unacceptable cases as well as a set of acceptable fits for each isotope--these can be identified from the foregoing by the fitting "code" given for each graph; see also remarks on pages 45 and 46.

C. TEMPERATURE EFFECTS ON g-FACTORS

Especially for differences in recipes like R-LO (cf. Fig. 4) there is the possibility of two effects cancelling when a room-temperature g-factor is computed. Thus the integral of σ/E times the Maxwellian function will be lower for LO than for R, but so will σ_{2200}. Thus it may be that g will be insensitive to such a recipe difference "by accident"; however at higher temperatures the cancellation may diminish. It is therefore dangerous to take the "spread" or variation of g's at one temperature only. For U-233 any such effect can only be conjectured, since no clear alternative recipes were seen; for Δ(RS-R) for Pu-239 all Δ g's diminish (arithmetically) with rising temperature, so the effect would be unimportant. But for Δ(R-LO) Pu-239 or Δ(R-SH) U-235 differences it is found that the corresponding Δg's are only arithmetically decreasing (for positive ΔT) for one of the three g's for either isotope; for one other g in each case Δg increases without change of sign and for the third, g passes through a sign change and then increases with increasing T. For such cases it is felt desirable to add the additional* $|\Delta g|$ to the existing spread of g's calculated at 20°C to give the range used in Table 5 to calculate the total inaccuracy of g. For this purpose we use the changes in g possible for temperatures up to 140°C--this somewhat arbitrary figure is chosen to include the range of neutron temperatures which actually occur

* We take the excess over the 20°C Δg when the sign does not change, and the 140°C $|\Delta g|$ plus half of the 20°C $|\Delta g|$ when it does.

in measurements of the type used in the 2200 m/sec study already mentioned.

D. TOTAL ACCURACY AND INDEPENDENT ERRORS

For the least squares analysis of 2200 m/sec constants the g-factor accuracies are required as <u>independent</u> errors, say $g_a \pm h_a$, $g_f \pm h_f$ and $g_\eta \pm h_\eta$, the total accuracy of g_f, say, being the direct accuracy taken together with an accuracy deduced from $g_f = g_\eta\, g_a$, and similarly for the other quantities. Writing for the $(\%^2)$ variances of the g's, v_a, v_f and v_η, and the corresponding independent quantities μ_a, μ_f and μ_η (where for example, $\mu_f = 10^4 h_f^2/g_f^2$, so that the total weights are $1/v_a$, $1/v_f$, $1/v_\eta$ (and similarly for the independent weights), we see that the equations defining the total weight in terms of the independent accuracies are $1/v_f = 1/\mu_f + (\mu_a + \mu_\eta)^{-1}$ and similarly. G.C. Hanna has shown that the solutions are of the form, writing $v = v_a + v_f + v_\eta$ and $t_a = v - 2v_a$, $t_f = v - 2v_f$, $t_\eta = v - 2v_\eta$,

$$\mu_a = \frac{t_f t_\eta}{2}\left(\frac{1}{t_a} + \frac{1}{t_f} + \frac{1}{t_\eta}\right)$$

$$\mu_f = \frac{t_\eta t_a}{2}\left(\frac{1}{t_a} + \frac{1}{t_f} + \frac{1}{t_\eta}\right)$$

$$\mu_\eta = \frac{t_a t_f}{2}\left(\frac{1}{t_a} + \frac{1}{t_f} + \frac{1}{t_\eta}\right)$$

Hence the h's can be found using $\mu_i = 10^4\, h_i^2/g_i^2$ (see above).

E. ADDITIONAL COMMENTS

It should be recorded that, as an additional aid in studying curve-shapes in "B" above, histograms were constructed giving the distribution of slopes of curves (expressed by C_1/C_0, v. App. I) near the origin. These were found very helpful--especially in correlating the more extreme values with particular cases or orders of fit--but it seems unnecessary to discuss this in detail. They also provided warning of any skewness of the distributions (giving a mid-range value, e.g. of g's, considerably different from means or most probable values) which were used in considering the "best value" problem for g--see section 11 of this report.

F. SPECIAL QUESTIONS ARISING FOR Pu-241

As mentioned in the text above, the fission data for Pu-241 are of low accuracy, being especially poor below 0.015 eV, while for α (or η) the only two points which exist (J.R. Smith and S.D. Reeder, NBS (Spec. Pub.) 299, p.590) were absolute η measurements, not intended to give information on the energy-variations. These have been downweighted (from 0.9 % to 1.15% error in η, or $(1+\alpha)$) following our usual rules for using absolute values, due to having to regard all other curves as renormalizable in fitting curve shapes. The use of authors' claimed accuracies for the Seppi, Friesen and Leonard (HW-55879, p. 3) σ_f data, without allowance for the 2% error of the 514-barn normalization (at E = 0.1 eV) point, also represents an over-weighting,

discussed further below, since it could be claimed that the total weight of all these points (correlated by the normalization) should correspond to not less than a 2% error, which would require a rather large downweighting factor. The Raffle data were also taken with the author's claimed accuracy, and the James (Nucl. Phys. 65, 353, 1965) data (given in SCISRS as almost 1000 points of individual accuracy varying from 8 to over 40%) had also to be specially treated, to fit the computing code used.

As stated in the text, the main difficulty is that the α curve derived from separate σ_a and σ_f fits rises steeply as E approaches zero, while the Smith and Reeder points and nuclear systematics, indicate a flat trend in α (since this is found in fact above about 0.035 eV, systematics suggest not too great a change in α-slope should occur below $\sim$0.02 eV).

In order to study the "spread" of g-factors, several different alternative bases for fitting were used. For a preliminary study the James data were excluded (see below, remarks re biased averaging), especially since these numerous data slowed down the computation process considerably--some fits were also made excluding also the Seppi et al (HAN 58D) points, as representing an extreme form of "downweighting". In these exploratory runs the tendency of the $\sigma_f\sqrt{E}$ fitted curve to fall off sharply near E = 0 was almost universal, and in order to combat this tendency (to see how much the g's would be changed), an arbitrary extra datum (for α at E = 0.005 eV) was added as a "fictitious" point to the input. Initially this extra point was given an error 5 times, and later 3.5 times, larger than the error of either Smith and

Reeder α point, since as low a weight as would suffice was felt to be desirable for this fictitious datum, in a desire to perturb the fits as little as possible (the weights were 0.03 and 0.06122 units); the value of α used for this point was $\alpha = 0.380$, (a rough extrapolation to 0.005 eV from the two other α points). Although the use of a nearly-constant α curve would tend, with the actual σ_a curve, to produce a definitely-rising $\sigma_f\sqrt{E}$ curve, the accuracies ($\pm$ 0.0795 or $\pm$ 0.0557 in α, corresponding to about $\pm$ 135 or $\pm$ 95 barns in σ_f at 0.005 eV) were so low that the upward-pull on the fission curve was relatively weak. It did, however, act as a counterbalance to the existing tendency of $\sigma_f\sqrt{E}$ to fall. Since this tendency seems to be due not to adequate data but to fluctuations in what (relatively inaccurate) data there are, this idea of a "fictitious" point may not be unreasonable.

The problem which arose for the James data (cited above as "biased averaging"), and which was largely overcome by modifying the least squares code to use the percentage error specified in SCISRS for each point, was that because initially fixed percentage accuracies (or %-accuracies dependent only on E) were used, any points actually fluctuating downwards received a too high weight, while upward fluctuations gave a downweighting. If was near E = 0 that, with $\sim$ 40% standard deviations for single data points, this became serious, and the "average" $\sigma\sqrt{E}$ deduced for the James data dropped off, exactly where other data tended to cause the curves to "dip" in an unacceptable (for systematics) way.

Even with the modified computing code taking the accuracy of each point from SCISRS this effect seem not to have disappeared entirely.

In the later, definitive, curve-fitting studies for Pu-241, four options were used, each without and usually also with the extra 0.005 eV fictitious α point discussed above. The four options are (a "+" is added to the code if the extra α point is used).

A	all data included at indicated weights (v. Table A.V.1)
HD	HAN '58D data downweighted for uncertain normalization, James data at indicated weight
NJ	James data excluded, HAN '58D with indicated weight
N	Both James and HAN '58D data excluded, others with indicated weights.

In fact, when the James data were included (with errors from SCISRS) the result was a definite increase in χ^2, indicating that the weight given James data was too large (by about 1.8 times). Without further computer code changes this was not correctable, so, remembering also that some biased averaging effect appeared to remain, the "with James" and "no James" fits were felt to be equally likely representations which should "bracket" the most acceptable choice. The HAN 58D downweighting for uncertain normalization (by a factor of 3.2) was also felt to be problematical, so that "A" and "HD" can also be considered as fits to be taken on an equal footing. Case N is included to show how much shapes can change if both these "special" sets of data are rejected, but in fact N+ seems more reasonable than N (in the absence of the HAN 58D data the $\sigma_f\sqrt{E}$ dip near E = 0 is accentuated).

TABLE A.V.1

Pu-241 DATA : WEIGHTS IN $(\%)^{-2}$

(In brackets are energy limits in eV, between are given weights in $(\%)^{-2}$. The code (T) indicates 0.025 eV, L indicates a linear variation of the weight with energy in the range indicated, E "exclusion" (i.e., wt = 0), ";" indicates discontinuity in weight, when linear variation in use, at end of range).

Total Cross Sections

MTR 61I (0)0.25(T,L,0.04)1.0(0.1)0.5(0.159,E,0.160)0.5(0.2).

CR 64C (0.02)0.5(0.1)0.025(0.18) - Craig et al

MTR 68L (0)0.5(0.1) - Young et al, Priv. Comm.

Fission Cross Sections

MTR 64F (0)0.0186(T)0.113(0.1)0.284(0.2) IDO-16995

CCP 55H (0.05)0.06(0.105)0.16(0.15)0.06(0.2)

CCP 55 (0)0.015(T)0.037(0.1)

HAN 58C (0.02)0.165(0.0325)2.0(0.1)0.4(0.15)0.2(0.2) HW-63492

HAN 58D *(indicated)0.004(0.0025,L,0.0035)0.094(0.0035,L,0.00475)0.315

*(downw'td) 0.0013 (same) 0.030 (same) 0.1

HAR 59G 0.005(0.006,L,0.0075)0.015(0.0075,L,0.09)0.02;(0.09)0.03(0.105)

HAR 65C (James) - either % errors as given in SCISRS or no weight*

* options - see mid-page A.V.13

Alpha Data

MTR 68 wt. 0.75 (fictitious point, if used, wt = 0.06122).

N.B. For fuller references CINDA should be consulted (Above codes are from SCISRS)

No full list of rejections or rejection criteria are given; simply, the situation is that if an α-curve shape (based on systematics) were used as a basis, essentially all fits would be rejects, since all give an abrupt rise near $E = 0$. On the basis of systematics, indicating that $\sigma_f\sqrt{E}$ should not fall too sharply at low energies, a rejection criterion can be chosen (excluding about half of the fitted curves) which seems not unreasonable. The ranges shown in Table 7 for Pu-241 marked "A" are made on this basis--for "B" the rejection of $\sigma_f\sqrt{E}$ dips is restricted to one or two of the worst cases. Thus we see that whether or not we feel able to apply some limit based on the idea that a narrow low-energy capture-only resonance in Pu-241 is possible, but a sharp dip in $\sigma_f\sqrt{E}$ is not, may affect the accuracy attributable to the Pu-241 g's by a factor of almost 1.5. The only real answer to this situation is more data--for either σ_f or α as a function of energy below 0.02 eV--and preferably also more accurate data in this energy region.

G. TABLE OF g-VALUES FROM "ADJUST" FOR VARIOUS TEMPERATURES

To conclude this appendix we list the g-factors obtained from an "adjust" operation for temperatures up to $\sim$ 140°C, for U-233, U-235 and Pu-239, choosing the recipes used to give 20°C g's close to those of Table 8 (actually a small constant increment has been added to all tabulated values to bring the 20.4_4°C values exactly to agree with those given in that table).

Earlier it was mentioned that provisional values for σ_s (used in $\sigma_a = \sigma_T - \sigma_s$) were used, and these seemed adequate for all the earlier work on the "spread" (i.e., the accuracy) of g-factors.

TABLE A.V.2

Low-Temperature g-Factors for U-233 (Based on RST.R.R)

T(°C)	g_a	g_f	g_η
20.4_4	0.9963	0.9961	0.9998
40.4_4	0.9959	0.9955_5	0.9997
60.4_4	0.9955_6	0.9951	0.9995
80.4_4	0.9952_6	0.9946_5	0.9994
100.4_4	0.9950_5	0.9943	0.9992
120.4_4	0.9949	0.9940	0.9991
140.4_4	0.9948	0.9937	0.9989

For U-235 (Based on R.RSH.R)

20.4_4	0.9787	0.9772	0.9984
40.4_4	0.9740_5	0.9723_5	0.9982
60.4_4	0.9696_5	0.9671	0.9979_5
80.4_4	0.9655	0.9627	0.9977
100.4_4	0.9616_5	0.9586	0.9974
120.4_4	0.9580	0.9546	0.9970_5
140.4_4	0.9546	0.9509	0.9967

For Pu-239 (Based on LR.R.R)

20.4_4	1.0762	1.0522	0.9777
40.4_4	1.0948	1.0654	0.9731
60.4_4	1.1159	1.0805	0.9683
80.4_4	1.1396	1.0977_5	0.9632_5
100.4_4	1.1662	1.1172	0.9580
120.4_4	1.1958	1.1391	0.9526
140.4_4	1.2284_5	1.1634_5	0.9471

N.B. For the table above the σ_a recipes were altered to correspond to σ_s values of 11, 16 and 8 barns respectively for U-233, U-235 and Pu-239.

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