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O.A.P. TAVARES and M.L. TERRANOVA[*]

Centro Brasileiro de Pesquisas Físicas - CBPF/CNPq
Rua Dr. Xavier Sigaud, 150
22290 - Rio de Janeiro, RJ - Brasil

[*]Dipartimento di Scienze e Tecnologie Chimiche
Università degli Studi di Roma "Tor Vergata",
Via E. Carnevale, 00173 Roma, Italy
Istituto Nazionale di Fisica Nucleare-INFN,
Sezione di Roma II, Roma, Italy.

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O.A.P.TAVARES* and M.L.TERRANOVA

Dipartimento di Scienze e Tecnologie Chimiche,Universita` degli
Studi di Roma "Tor Vergata",Via E.Carnevale, 00173 Roma, Italy
Istituto Nazionale di Fisica Nucleare-INFN, Sezione di Roma II,
Roma, Italy.

ABSTRACT. - A general fit has been performed to the data on most probable fragment total kinetic energy release in fission, $\langle E_k^t \rangle$, for values of parameter $Z^2/A^{1/3}$ of the fissioning nucleus ranging between 50 and 2150 . The data result to be rather well fitted by an expression of the type: $\langle E_k^t \rangle = Z^2/(aA^{1/3}+bA^{-1/3}+cA^{-1})$ with a = 9.02, b = -34.5 and c = 45.9 (all values expressed in MeV^{-1}). For light fissioning systems the present result provides a trend of $\langle E_k^t \rangle$ which gives vanishing $\langle E_k^t \rangle$-values for Z approaching zero, as predicted in liquid drop model calculations.

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* Permanent address: Centro Brasileiro de Pesquisas Fisicas-CBPF/CNPq, Rua Dr.Xavier Sigaud 150, 22290 Rio de Janeiro-RJ, Brasil.

1. INTRODUCTION

Recently a systematic experimental study on fission of complex nuclei induced by monochromatic and polarized photons of energies between 30 and 80 MeV has been undertaken with the aim of searching for shell effects on fissility of nuclei located near ^{208}Pb [1,2]. The fission yield of these reactions has been measured by using solid-state nuclear-track detectors (mostly plastic detectors) placed in intimate contact with thick target samples. The present work originated in an attempt to evaluate for various fissioning systems the most probable total kinetic energy of the fission fragments in order to calculate fragment energy-loss-rate and residual ranges in a number of target and detector materials[3].

During the sixties Viola,Jr.[4,5] succeeded in obtaining a quite comprehensive systematics of most probable fragment total kinetic energy release in fission, $\langle E_k^t \rangle$, and it was shown that the data could be rather accurately described by a simple model which predicts a linear correlation of $\langle E_k^t \rangle$ on the Coulomb parameter $Z^2/A^{1/3}$ of the fissioning nucleus. Expressions for $\langle E_k^t \rangle$ as a function of $Z^2/A^{1/3}$ have been thus derived according to the available set of experimental data [5,6]. Later a new correlation was found[7] based on further data obtained at the lower ($^{46}_{23}$V) and upper ($^{302}_{120}$X) extremes of $Z^2/A^{1/3}$ values, and it is reported as

$$\langle E_k^t \rangle = (0.1189 \pm 0.0011)\, Z^2/A^{1/3} + 7.3\ (\pm 1.5)\ \text{MeV}\ . \qquad (1.1)$$

Eq.(1.1) provides a significant improvement in the description of the data if compared with previous correlations (for details see Ref.[7]).

However, as pointed out by Viola et al.[7], consideration of the diffuse nature of light nuclei and the associated perturbations to the necking degree of freedom in liquid drop model calculations predict a change in slope at low values of $Z^2/A^{1/3}$ leading to vanishing $<E_k^t>$ values as Z approaches zero.

Since Eq.(1.1) does not provide for such a behaviour and at the same time we are interested in obtaining intermediate-energy photofission yield measurements for target nuclei lighter than vanadium, we felt therefore worthwhile to perform a new systematics of $<E_k^t>$. The aim of the present paper was to search for an analytical form of $<E_k>$ that could give a better prediction for the $<E_k^t>$-values, particularly in the case of low Z nuclei.

The present study, although not developed within a rigorous phenomenological treatment, has shown, however, to be capable at predicting $<E_k^t>$-values for fissioning systems of $Z^2/A^{1/3} < 150$.

2. SYSTEMATICS

The fragment total kinetic energy release in fission, E_k^t, is calculated from the Coulomb repulsion between the primary fission fragments in the configuration at contact. Let (Z_1,A_1) and (Z_2,A_2) be the atomic number and the mass number of the primary fission fragments, where a particular mode of division from an initial fissioning nucleus (Z,A) is defined by the quantity $0 < x \leq 1/2$ such that $Z_1 = xZ$, $A_1 = xA$, $Z_2 = (1 - x)Z$ and $A_2 = (1-x) A$.

The fission fragments are assumed to be spherical ones, and the extension of their charge distributions from the charge centers, R_i (i =1,2), is supposed to have an A-dependence of the same type as the equivalent root-mean-square radius of the nuclear charge distribution [8], i.e.,

$$R_i = a_1 A_i^{1/3} + a_2 A_i^{-1/3} + a_3 A_i^{-1} , \qquad (2.1)$$

where the a's are constant. The E_k^t-value for the mode of division x is given by

$$E_k^t = \frac{Z_1 Z_2\ e^2}{R_1 + R_2} =$$

$$= Z^2 e^2 x(1-x)\{a_1 A^{1/3}[x^{1/3}+(1-x)^{1/3}]+a_2 A^{-1/3}[x^{-1/3} +$$

$$+(1-x)^{-1/3}]+a_3 A^{-1}[x^{-1}+(1-x)^{-1}]\}^{-1} \quad . \qquad (2.2)$$

The most probable fragment total kinetic energy is obtained by inserting the x-value corresponding to the most probable mode of division, <x>. It follows from (2.2) therefore that

$$\langle E_k^t \rangle = \frac{Z^2}{aA^{1/3} + bA^{-1/3} + cA^{-1}} \quad , \qquad (2.3)$$

where a, b and c are fitting parameters to be determined by applying the general method of weighted least-squares-fit to the available $\langle E_k \rangle$ data.

These later have been taken from the compilation of Ref.[5], from the table reported in Ref.[7], and from Ref.[9] : this last one reports data on $\langle E_k^t \rangle$ for a number of fissioning systems in the intermediate-mass region. To these data we have added also the $\langle E_k^t \rangle$-value for the ^{24}Mg fissioning system derived from the experiment carried out by Sherman[10] who detected the ^{12}C photofission fragments by a special nuclear-track emulsion technique. By using appropriate range-energy relations [11] it was possible to deduce a value $\langle E_k^t \rangle = 8.6 \pm 0.4$ MeV for the photofission of ^{24}Mg. A total of 109 measured $\langle E_k^t \rangle$-values have been entered in the present systematics.

3. RESULTS and DISCUSSION

The least-squares treatment performed over all reported $\langle E_k^t \rangle$ data (expressed in MeV) yielded the following values for the parameters of Eq.(2.3):

$a = 9.02\ \mathrm{MeV}^{-1}$, $b = -34.5\ \mathrm{MeV}^{-1}$, $c = 45.9\ \mathrm{MeV}^{-1}$. (3.1)

In the fitting procedure none of the data has been rejected, and where several experimental values of $\langle E_k^t \rangle$ existed for a given fissioning nucleus all these data have been entered. In addition, no corrections have been applied to the original $\langle E_k^t \rangle$ values reported by the authors.

For heavy fissioning systems ($Z \gtrsim 80$, $A \gtrsim 200$, $Z^2/A^{1/3} \gtrsim 1100$), the systematic behaviour of $\langle E_k^t \rangle$ expressed by Eq.(2.3) turns out to be proportional to $Z^2/A^{1/3}$ with a slope approximately equal to $a^{-1} = 0.11$ MeV, which value compares well with the slope of ~ 0.12 of Eq.(1.1). For heavy fissioning nuclei indeed the $\langle E_k^t \rangle$-values obtained by means of Eq.(1.1) are found to differ by less than 2% from those predicted by means of Eq.(2.3) with the numerical set of parameters given in (3.1). For intermediate-mass and lighter nuclei, however, the trend of $\langle E_k^t \rangle$ predicted by the present systematics differs significantly from that described by Eq.(1.1), mainly as one goes towards systems of low $Z^2/A^{1/3}$. Such a difference is illustrated in Fig.1, where the dashed line represents the trend of $\langle E_k^t \rangle$ as calculated by Eq.(1.1), and the full line the one predicted according to Eqs.(2.3)(3.1) . As one can appreciate from inspection of the inserted graph , the curve arising from the present systematics exhibits a trend of vanishing $\langle E_k^t \rangle$ with Z approaching zero, as expected on the basis of the liquid drop model. In addition, it is seen from Fig.1 that the present systematics represents an improved description of the

$<E_k^t>$ data down to $Z^2/A^{1/3} = 50$.

The goodness of the present fitting procedure has been examined by calculating some standard statistical quantities. Fig.2 shows the frequency distribution of $<E_k^t>_c - <E_k^t>_e$ between calculated and experimental $<E_k^t>$ values, with the former being obtained from Eqs.(2.3)(3.1) (Fig.2a) and Eq.(1.1) (Fig.2b) for the whole set of fission cases considered. It is readily seen that the systematics by Viola et al.[7] gives a somewhat positive mean deviation (~1.6 MeV), whereas in the present analysis the quantity $<E_k^t>_c - <E_k^t>_e$ exhibits a normal distribution about a mean value of -90 keV. The χ-squared per degree of freedom for the present fitting procedure was calculated as 1.16. Tab.1 reports the main statistical fitting quantities of both systematics in order to allow a direct comparison.

4. SUMMARY and CONCLUSION

A new description of the available experimental data on fragment total kinetic energy release in fission has been undertaken, based on a semi-empirical three-parameter formula which has shown to be rather adequate in reproducing the data. Eqs.(2.3) (3.1) may be considered as a general systematics of $<E_k^t>$.

From inspection of Fig.2 and Tab.1 we are led to conclude that the present systematics is not only useful in reproducing the measured $<E_k^t>$ values for both very light and very heavy fissioning systems, but also in predicting those not available from experiment. In particular, the correlation expressed by Eqs.(2.3) and (3.1) provides a trend towards vanishing $<E_k^t>$ with Z approaching zero, as predicted in liquid drop model calculations.

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FIGURE CAPTIONS

Fig.1.- Most probable fragment total kinetic energy release in fission, $<E_k^t>$, plotted against parameter $Z^2/A^{1/3}$ of fissioning nucleus (a log-scale has been chosen to show clearly the trend of $<E_k^t>$ at low values of $Z^2/A^{1/3}$). The data points have been taken from : ○,Ref.[5]; □,Ref.[7] ; △,Ref.[9] ; ▽, deduced value from the experiment reported in Ref.[10]. The dashed line is the trend predicted by Eq.(1.1) and the full line the one predicted by the systematics of this work (Eqs.(2.3) (3.1)). The inserted graph shows the trend of $<E_k^t>$ near the origin.

Fig.2.- Distribution of $<E_k^t>_c - <E_k^t>_e$ obtained from the systematics of the present work (a) and from the statistical treatment of Ref.[7](b) (for details see text).

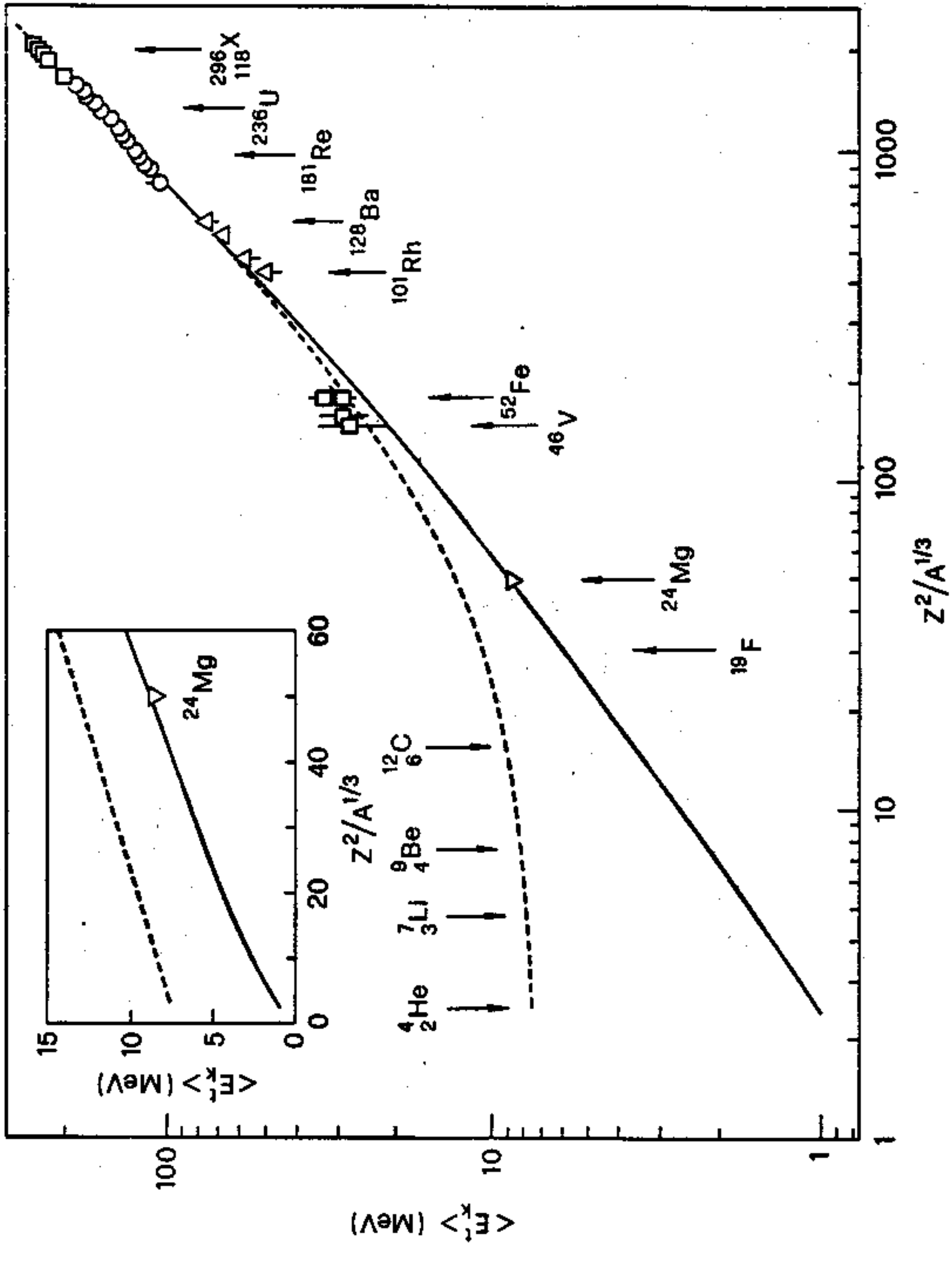
$\langle E_t^k \rangle$ (MeV)
100
10
1
$Z^2/A^{1/3}$
1
10
100
1000
$^{296}_{118}X$
^{236}U
^{181}Re
^{128}Ba
^{101}Rh
^{52}Fe
^{46}V
^{24}Mg
^{19}F
$^{12}_{6}C$
$^{9}_{4}Be$
$^{7}_{3}Li$
$^{4}_{2}He$
$\langle E_t^k \rangle$ (MeV)
15
10
5
0
$Z^2/A^{1/3}$
0
20
40
60
^{24}Mg

Fig. 1

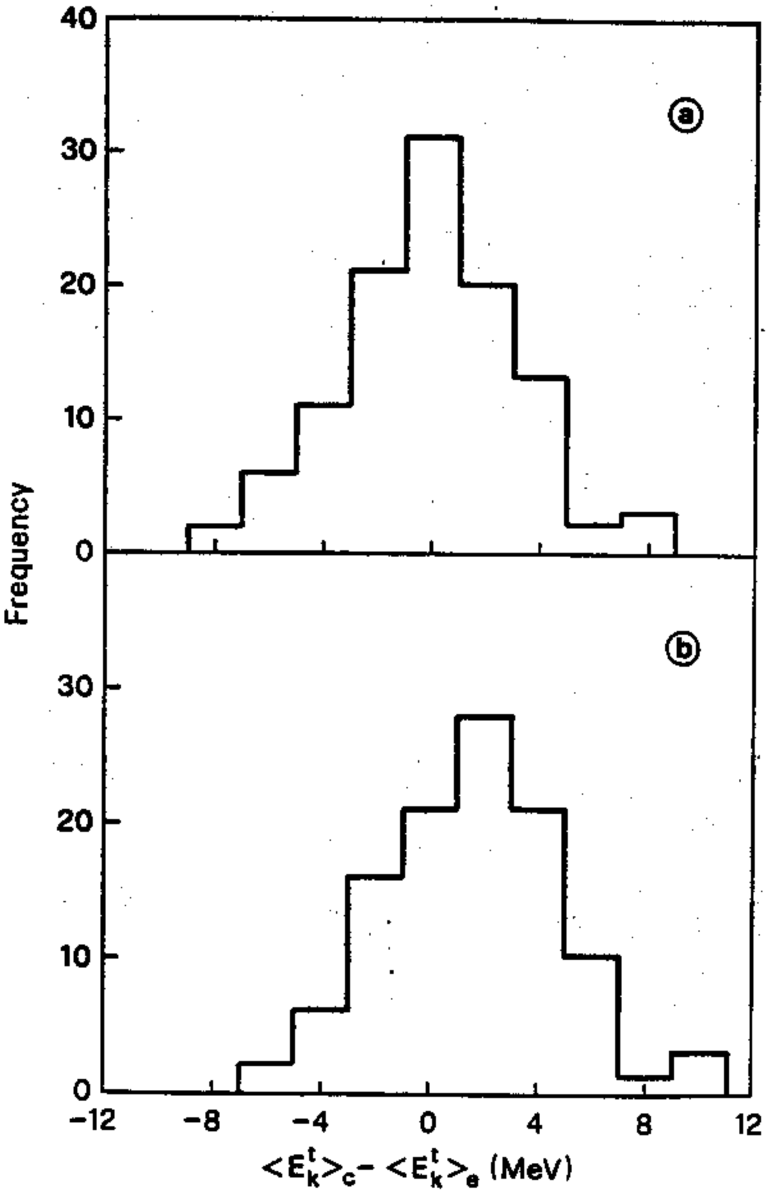

Fig. 2

Please reduce to 73

TABLE I.- Values of some statistical quantities for the systematics of $<E_k^t>$ discussed in the present work.

SYSTEMATICS	DISTRIBUTION of $<E_k^t>_c - <E_k^t>_e$		
	Mean value (MeV)	Standard deviation (MeV)	Chi-squared per degree of freedom χ_ν^2
Ref.[7]	1.57	3.27	1.54
Present work	-0.09	3.29	1.16

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