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EQUILIBRIUM CHARGE FRACTION OF IONS OF Z=4–92 (0.02–6 MeV/u) AND Z=4–20 (UP TO 40 MeV/u) EMERGING FROM A CARBON FOIL

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(abstract)

Based on recent finding that the variation of charge fractions, mean charges and charge distribution widths with ion energy E and projectile atomic number Z is strongly dependent on the shell structure of ions, systematic reanalysis of the charge distributions of ions has been performed. Graphs are presented for equilibrium charge fractions thus obtained of ions emerging from a carbon foil as a function of E ranging from 0.02 to 6 MeV/u. Each graph pertains to one ion species from Z=4 to 83 and Z=92. Tables of the mean charges and charge distribution widths are also given for each ion species in the same range of Z and E. For fast ions of Z=4 to 20 up to 40 MeV/u, charge fractions of fully stripped ions, H-like ions and He-like ions are tabulated.

[key words ; charge-distribution, heavy-ion, carbon-foil]

CONTENTS

INTRODUCTION

1. Preface

The knowledge on the equilibrium charge distribution of ions emerging from a matter is important not only from the view of atomic collision physics but also from practical point of designing nuclear instruments and accelerators. There exist some approaches to estimate the equilibrium charge fraction of ions, $F(q)$, when charge state q, projectile atomic number Z, ion velocity v, and target material are given. For light ions of $1 \leq Z \leq 10$, Zaidins[1] performed theoretical calculation and presented graphs of $F(q)$ vs v of ions after passage through a carbon foil at the energy less than 5 MeV/u. His calculation is known[2] to agree rather well with the observed values[3,4,5], as is shown in Fig.I for B and F ions. On the other hand, empirical formulas of $F(q)$ have been proposed by Sayer[6] for heavier ions having passed through gas and carbon foil, and by Baudinet-Robinet[7] for ions of $Z \leq 36$ emerging from a carbon foil. However, through recent systematic data accumulation, it turns out that the observed values have not always been reproduced well with these formulas[5]. Furthermore, for ions heavier than Z=36, there is no way to estimate even very crude values of $F(q)$.

Recently, Shima et al.[8] reported an oscillatory behavior of the mean charge $\bar{q}$ of ions versus Z when equilibrium mean charges are compared at an equal velocity of ions passing through a carbon foil. Here, $\bar{q}$ is defined by

$$\bar{q} = \Sigma_q \{qF(q)\}. \qquad (1)$$

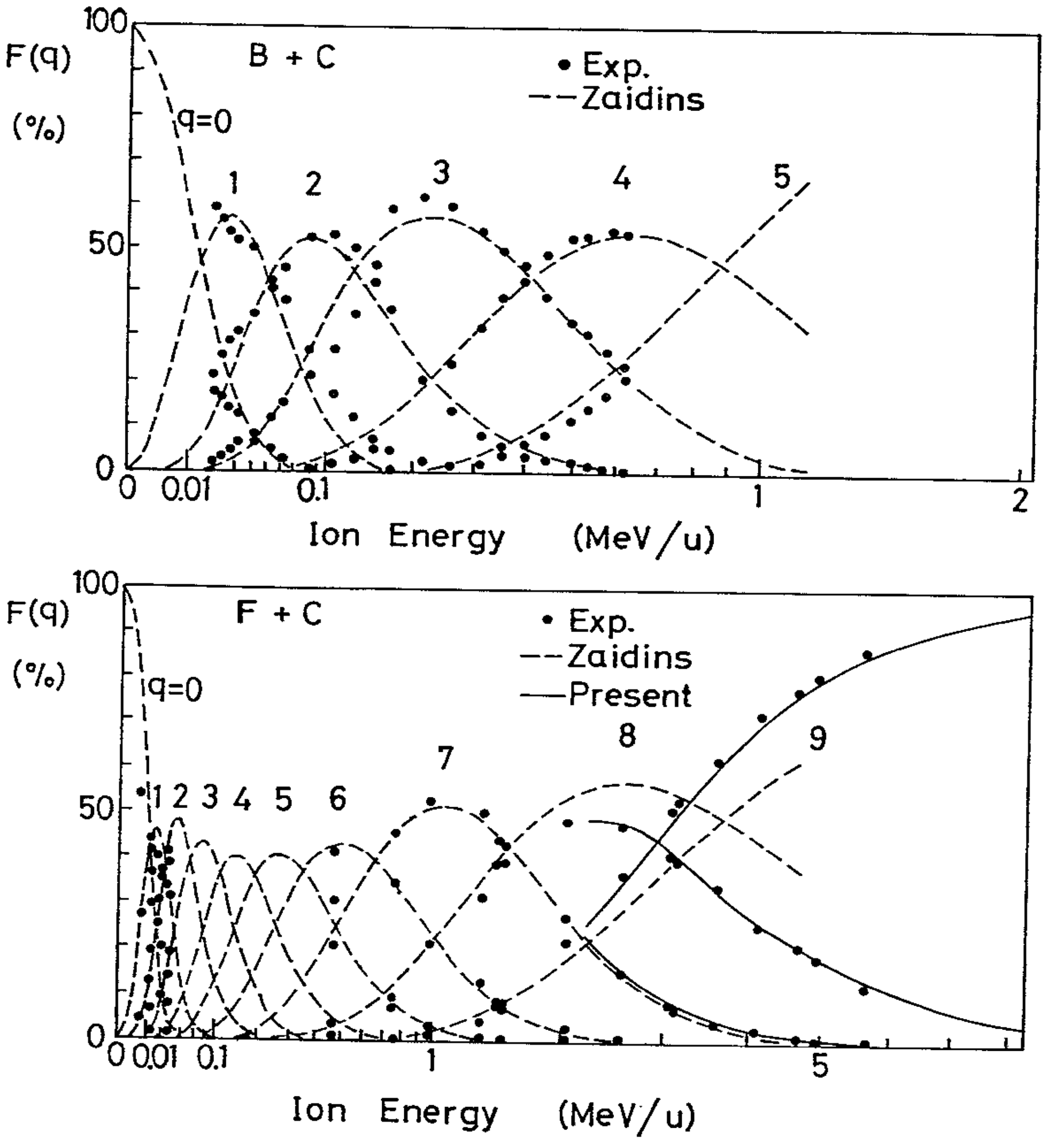

Fig. I. Equilibrium charge fractions of B and F ions after passage through a carbon foil. Solid circles represent experimental values reported[3,4,5], and the broken curves are theoretical calculation by Zaidins. The solid curves for F ions are based on the present estimation as described in 3.2 in the text.

Such Z-oscillatory behavior can be observed for ion energies up to a few MeV/u. Furthermore, the charge distribution width d defined by

$$d = (\Sigma_q\{(q-\bar{q})^2F(q)\})^{1/2} \quad , \qquad (2)$$

was also shown to oscillate[9] as a function of Z.

The Z-oscillations of $\bar{q}$ as well as of d are surprising because the scaling work of F(q) that is basically a function of $\bar{q}$ and d, had been empirically done[6,7] by assuming that both $\bar{q}$ and d are monotonously varying functions of Z. Considering recent increasing applications of heavier and faster ions in various fields, it is worthwhile to present more reliable values of F(q) for lower Z, as well as for higher Z ions over a wide range of v.

In this article, by taking account of the Z-oscillation of $\bar{q}$ and d, F(q) values of ions passing through a carbon foil are empirically deduced. For each ion species ranging from Z=4 to 92, the evaluated results of F(q) are graphically displayed as a function of ion energy E in the range from 0.02 to 6 MeV/u. Tables of $\bar{q}$ and d for these Z and E are separately presented.

In addition to these tables and graphs, the charge fractions of highly charged (few-electron) ions that are dominated with fully stripped ions, are also tabulated for ions from Z=4 to 20 and energies up to 40 MeV/u.

2. Variation of Ionic Charge States vs Z and v

Equilibrium charge distribution data have been reported most frequently for ions having passed through a carbon foil. Fig.II displays the combination of ion Z and its energy E (MeV/u) where data

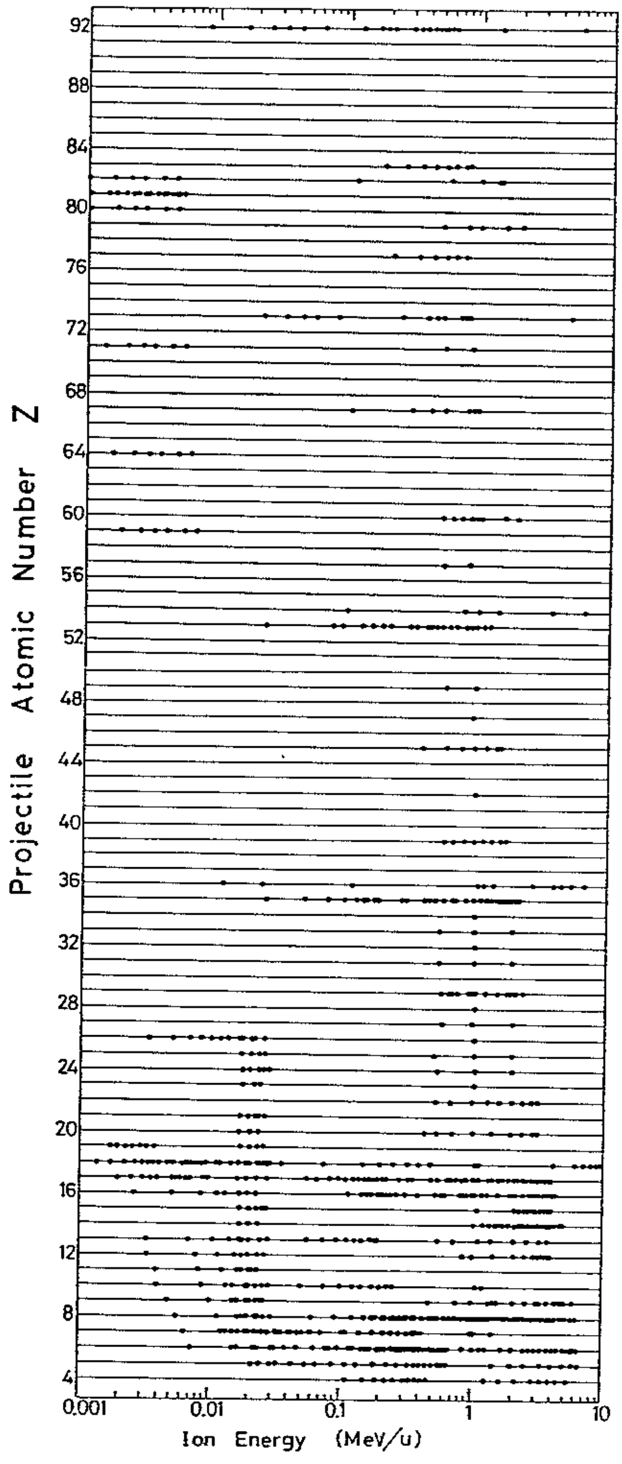

Fig.II. Combination of projectile atomic number Z versus ion energy for existing data of equilibrium charge distributions of ions after passage through a carbon foil.

are available. The data reported before 1972 are summarized by Wittkower and Betz[3], those between 1972 and 1985 are compiled by Shima et al.[4], and more recent data after 1985 have been given in refs.5, and 9 to 20. By comparing all these data, some systematic trends have been verified in ref.5 for F(q), $\bar{q}$, d against Z and E. These results can be summarized as follows.

(1) The mean charges, $\bar{q}$, oscillate with Z for a given value of v as shown in Fig.III where the ordinate denotes the reduced mean charge $\bar{q}/Z$. Similarly, they also oscillate with v for a given value of Z. The amplitudes of the oscillatory behavior are seen to decrease with increasing ion energy (MeV/u) or v.

(2) The phase of the Z-oscillation of $\bar{q}$ varies with E, and the enhancement of q takes place when the mean charge $\bar{q}$ of ions is close to the charge of closed shell ions, i.e., $\bar{q}$ is enhanced along the three curves of $\bar{q}/Z$ = Z-2 (He-like ions having 2×1^2 electrons), Z-10 (Ne-like ions having $2\times(1^2+2^2)$ electrons) and Z-28 (Ni-like ions having $2\times(1^2+2^2+3^2)$ electrons) as shown in Fig.III. (With the addition of electrons, the stability of ions is provided when outermost shell has $2n^2$ electrons (n is the principal quantum number) as is seen for instance in Fig.1 of ref.5. This behavior slightly differs from the formation of neutral atoms).

(3) The charge distribution widths, d , oscillate as a function of Z for a fixed ion velocity[7]. As is shown in Fig.IV, the scaling of d can be found by plotting the values $d/Z^{0.27}$ as a function of the mean number of electrons, $\bar{n}_e = Z-\bar{q}$, remaining in the ion. Fig.IV demonstrates that the values $d/Z^{0.27}$ fall on a universal curve regardless of Z or v. Under the choice of the coordinates in Fig.IV, the regularity above

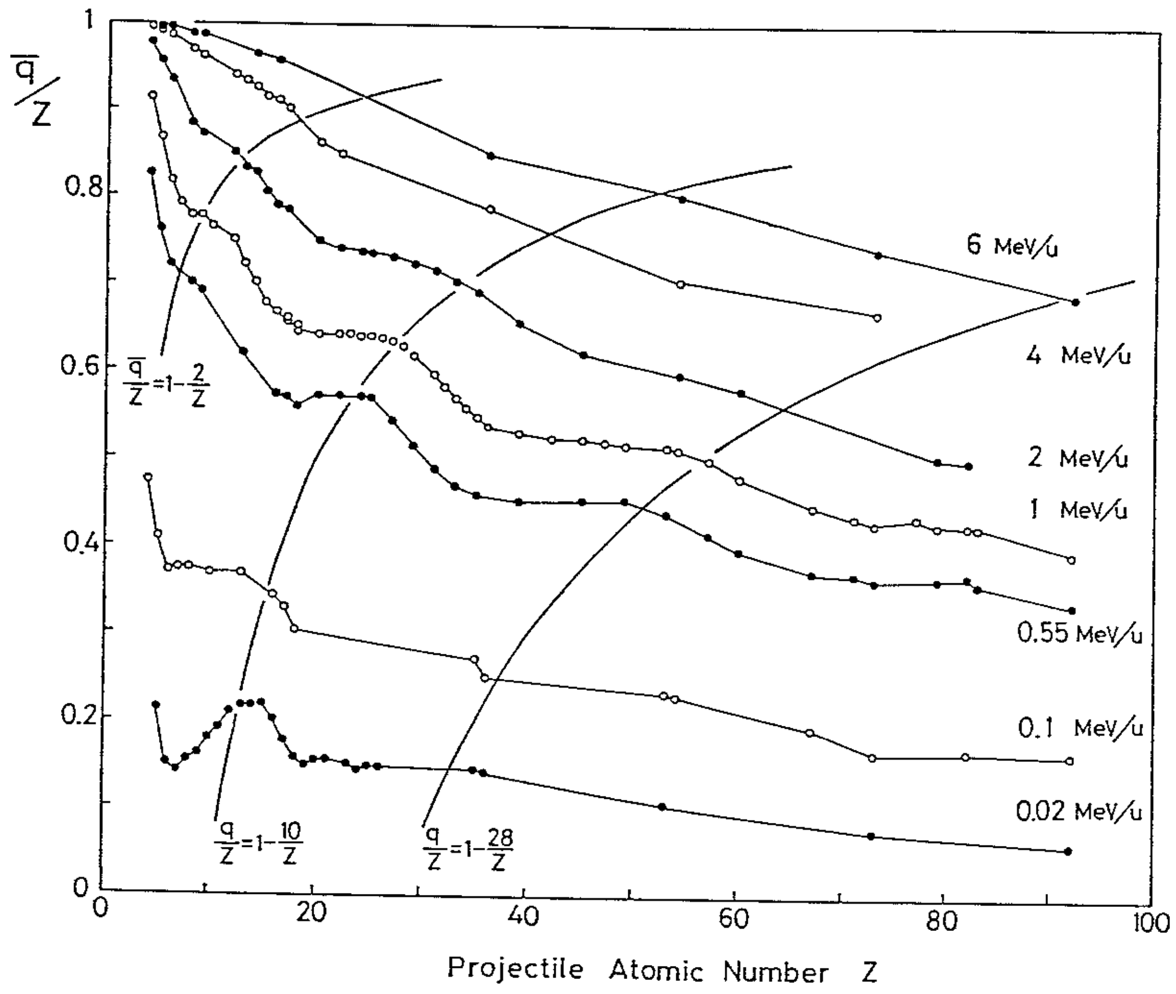

Fig.III. Equilibrium mean charges $\bar{q}$ divided by atomic number of ions Z plotted against Z for ions after passage through a carbon foil. Thin solid lines connecting the data points are drawn to guide the eye. Explanation for thick solid curves denoted with $\bar{q}/Z$ = 1-2/Z, 1-10/Z, and 1-28/Z is given in the text.

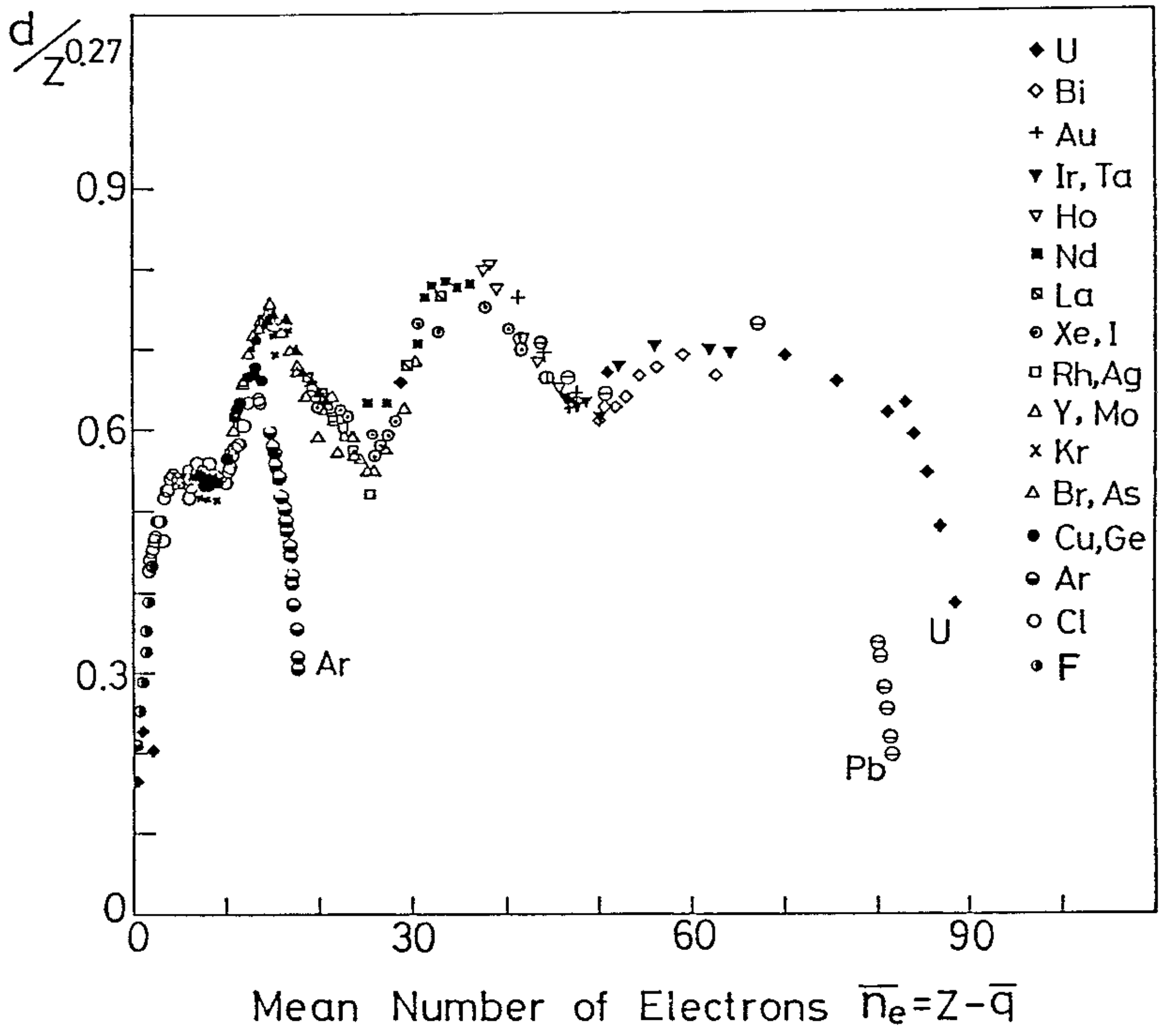

Fig.IV. Universal plot of charge distribution width for various ions as a function of the mean number of electrons remaining in the ions, $\overline{n}_e$ = $Z-\overline{q}$.

mentioned is found to break down when the ion approaches neutral ($\overline{n}_e \cong Z$) or ion velocity approaches zero. Fig.IV shows examples for Ar, Pb and U ions, where the d value clearly has an onset at $\overline{n}_e = Z$ and rises up sharply with decreasing $\overline{n}_e$ values or increasing ion velocity until they join the universal curve.

(4) Charge distribution function is not always symmetric. When the outermost electrons of ions are distributed among the shell belonging to the single-n, the distribution function can be approximated with a single Gaussian distribution. On the other hand, when the outermost electrons are distributed among two adjacent-n shells, the charge distributions are asymmetric and are represented with two Gaussian having different distribution widths or standard deviations[21]. This phenomenon, known as the shell effect in F(q)[22], takes place at the charge states of ions having the closed shell electron structure like He-like, Ne-like or Ni-like ions[5].

3. Evaluation of F(q)

3.1 Medium charge ions

Sayer[6] and Baudinet-Robinet[7] tried to find suitable asymmetric functions for expressing F(q) at given values of E and Z. However, in order that the actual charge distribution is reproduced with some distribution function over a wide range of Z and E, the proper choice of $\overline{q}$ and d is more important than the choice of distribution function. Namely, the first priority lies in the correct choice of $\overline{q}$ that is directly connected to the determination of F(q) around $q \cong \overline{q}$, and then, the second one lies in the correct choice of d that is related to the determination of F(q) of charge states away from $\bar{q}$, meanwhile the choice of the distribution function is less important over that of $\bar{q}$ and d. Based on this concept, F(q) values of ions after passage through a carbon foil have been evaluated in the range of Z=4-92 and E=0.02-6 MeV/u. For this purpose, efforts were made to obtain accurate values of $\bar{q}$ and d, meanwhile the asymmetric feature of F(q) was not taken into account for the present evaluation of F(q). Our procedure is as follows:

(i) For ions whose data have been already reported over a wide range of v, the relation q vs v has been numerically determined using the expression $\bar{q} = Z\{1 - \exp(-\Sigma_i a_i v^i))\}$, where a_i is constant. For ion species whose data are scarce or missing, similar expression of $\bar{q}$ vs v has been deduced by utilizing the existing data points in Fig.II and the interpolated values of $\bar{q}$ in the Z-oscillatory trend of $\bar{q}$ in Fig.III. Values of $\bar{q}$ are given in Table 1.

(ii) Once the $\bar{q}$ value is determined, the corresponding distribution width d is automatically determined from Fig.IV where $d/Z^{0.27}$ values are shown as a function of $\bar{n}_e = Z-\bar{q}$. Values of d are given in Table 1.

(iii) The charge distribution F(q) is deduced from $\bar{q}$ and d above by adopting the following Gaussian distribution,

$$F(q) = 1/(\sqrt{2\pi}\ d) \times \exp\{-(q-\bar{q})^2/(2d^2)\} \ . \qquad (3)$$

Values of F(q) vs ion energy E in units of MeV/u and MeV are respectively displayed in Figs.1 to 81, and Figs.82 to 158.

An example of F(q) values for 1 MeV/u Fe ions thus evaluated is shown in Fig.V with a dashed curve together with the observed values[9]. For comparison, an empirical relation by Baudinet-Robinet[4] is also drawn with a solid curve. For other light ions or medium ions, the agreement between experiment and present evaluation is more or less of the same degree as that in Fig.V. On the other hand, for ions heavier than $Z \cong 40$, the existing data are not sufficient enough (see Fig.II) to obtain the accurate relationships between $\overline{q}$ vs Z or v from procedure (i) and d vs $\overline{n}_e$ from procedure (ii), and hence, the degree of agreement between the observed and evaluated values is expected to be worse than that for light ions.

3.2 Few electron ions

For such highly charged ions as the charge distribution is dominated by fully stripped ions (q=Z), Gaussian distribution is not appropriate for the expression of F(q). In addition, since most of the charge exchange processes in this case involve K-shell electrons, the characteristic of ionic shell structure disappears in $\overline{q}$ and d. In order to find some trends of $\overline{q}$ and d vs Z, v or $\overline{n}_e$ for these few-electron ions, existing data[3,4,5,15,17,19,20] of $\overline{q}$ and d are plotted in Figs.VI and VII, respectively. Fig.VI shows the values $\overline{n}_e = Z - \overline{q}$ divided by Z against ion velocity parameter $X = v/(v' Z^{0.45})$ where $v' = 3.6 \times 10^8$ cm/sec. This parameter X has been adopted by several authors[23-27] for the scaling of $\overline{q}$ values at less than about X=2.3. In Fig.VI, only the results of empirical formulas using X by Nikolaev and Dmitriev (ND)[23], To and Drouin (TD)[24] or Shima et al. (SIM)[27] are drawn, and the observed values are known to focus well along these curves. On the other hand,

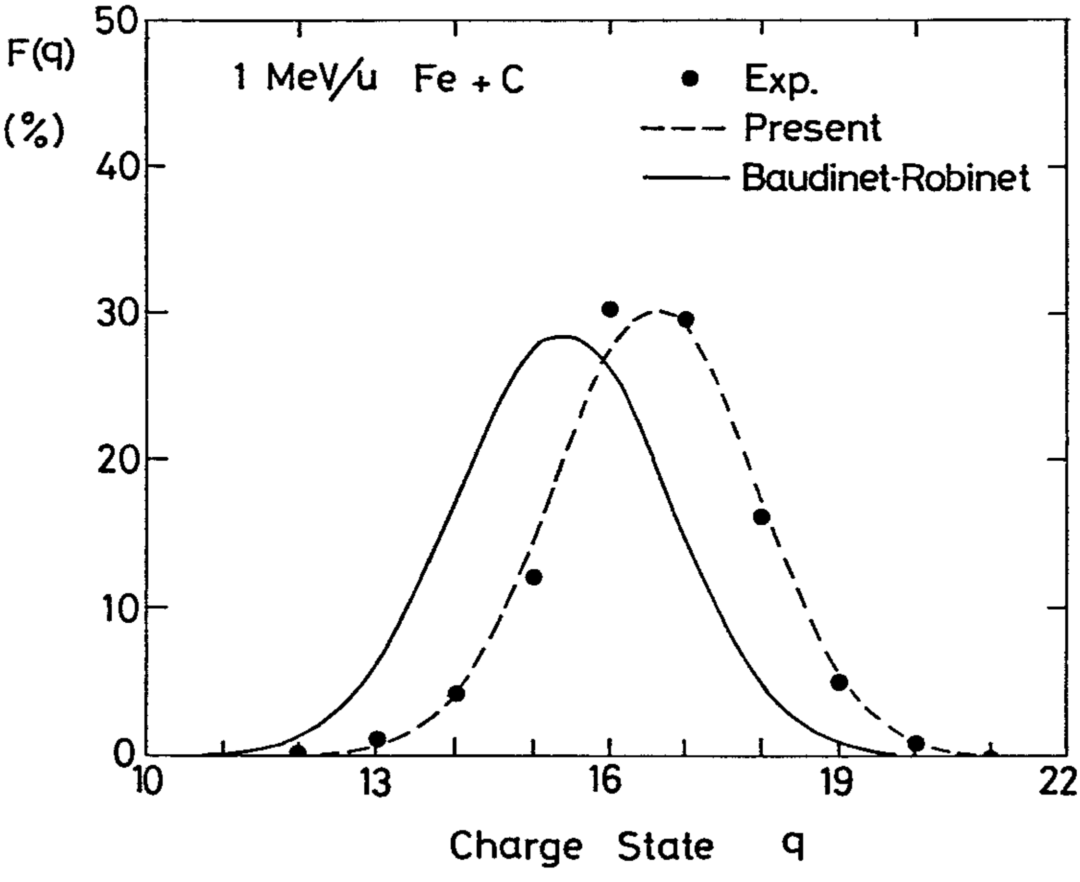

Fig.V. Equilibrium charge distribution of 1 MeV/u Fe ions after passage through a carbon foil. The observed values (solid circles)[4], calculation by Baudinet-Robinet[7] (solid curve), and the result of present calculation (dashed curve) are drawn.

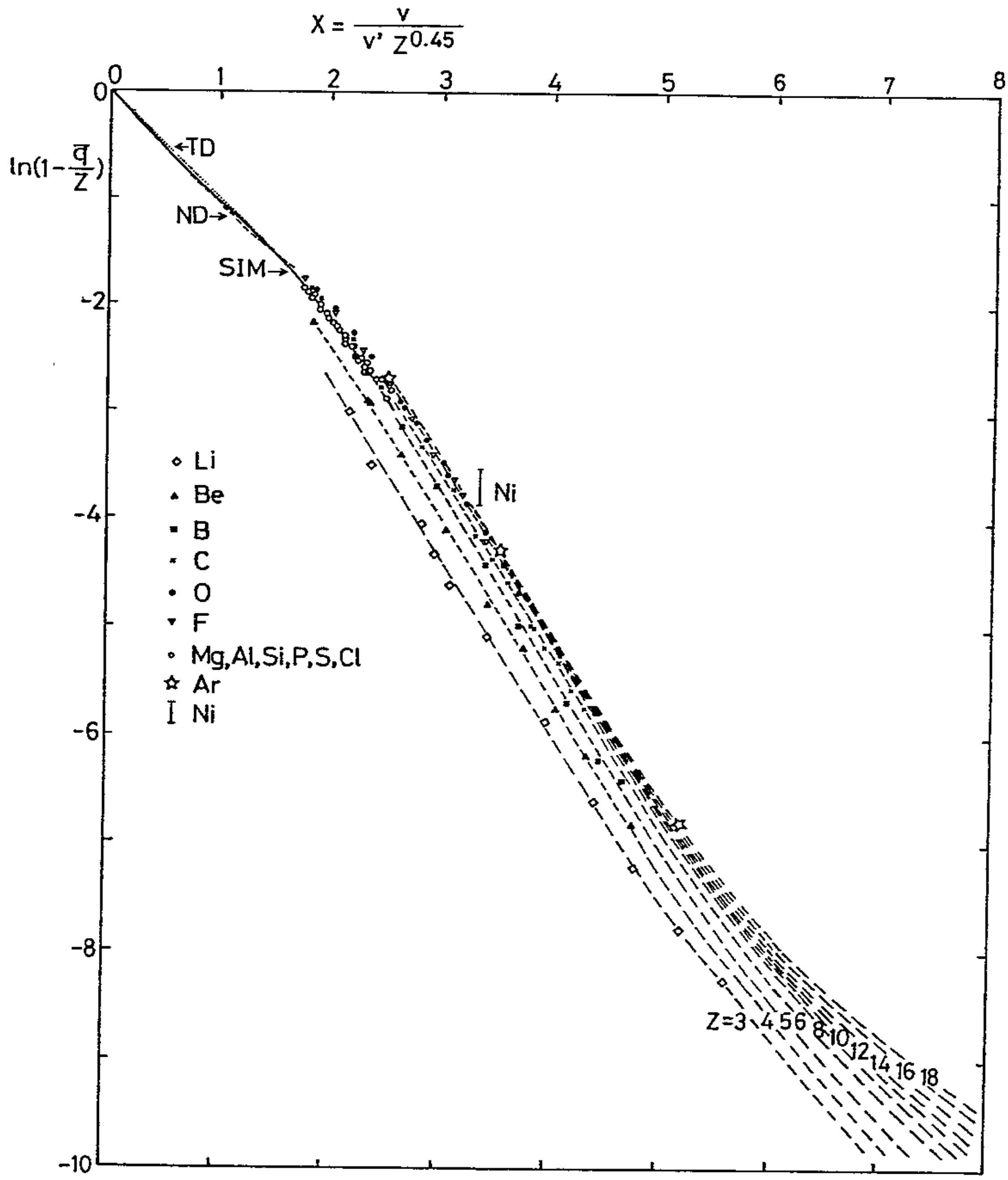

Fig.VI. Plot of experimental $(1-\bar{q}/Z)=\bar{n}_e/Z$ values as a function of scaling parameter $X = v/(v'Z^{0.45})$ for few-electron ions after passage through a carbon foil where v means the ion velocity and $v'=3.6\times10^8$ cm/sec. Dashed curves represent the exterpolated values considering the data of few-electron ions from He (data are outside the scale of the figure) to Kr. ND, TD, and SIM respectively stand for empirical formulae by Nikolaev and Dmitriev, by To and Drouin, and by Shima et al., applicable to the ions of X<2.3.

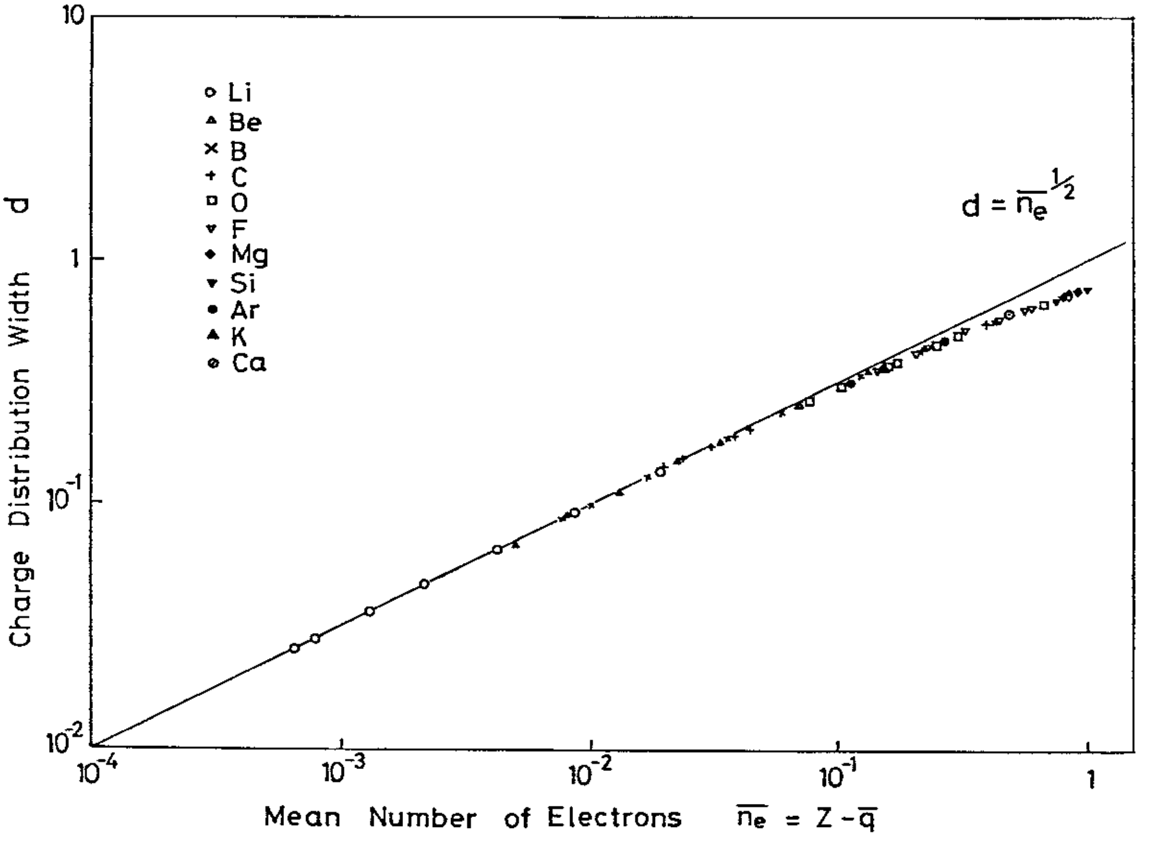

Fig.VII. Universal plot of charge distribution width of few-electron ions as a function of the mean number of electrons remaining in the ions, $\overline{n}_e = Z - \overline{q}$. The straight line $d = \overline{n}_e^{1/2}$ drawn in the figure means an asymptotic line of d corresponding to the charge distribution being composed of only two states of q=Z and Z-1.

at the present fast ion velocity region of X>3, the data are seen to diverge systematically with increasing X and Z. Fig.VII shows d vs n_e where data for ions with $\overline{n}_e$ less than unity. As $\overline{n}_e$ decreases, the observed values of d are seen to focus along an asymptotic line of $d = \overline{n}_e^{1/2}$ which corresponds to the d values when the ions have only two charge components of q = Z and q = Z-1. If we assume three charge components of q = Z, Z-1, and Z-2, F(q) values of these few-electron ions can be evaluated from Fig.VI and VII with the aid of eqs.(1) and (2).[28] The results are tabulated in Table 2 for ion species Z = 4 to 20 where the ion energy goes up to 40 MeV/u.

An example of F(q) values thus evaluated is drawn in Fig.I for F ions with solid curves. The agreement between experiment and the present evaluation for other Z ions is expected to be of the same degree as is shown in Fig.I.

3.3 Target species dependence

Although the equilibrium charge distribution of ions after passage through foils other than a carbon foil is outside the scope of this article, its general trend with respect to the target species is briefly described in the following.

When equilibrium q values observed behind different foils are compared at fixed Z and v, they are known to oscillate as a function of target atomic number[29,30]. Oscillation of $\overline{q}$ is reported to occur at ion energies less than several MeV/u. The amplitude of the oscillation increases with decreasing energy, meanwhile the phase of the oscillation varies with ion energy and also depends upon Z. For the limited number of target species dependent data for F, Si Cl or Cu ions up to several MeV/u[29,30], the difference of mean charges between the highest and the lowest values for given Z and v, $(\bar{q}_{high}-\bar{q}_{low})/\bar{q}$, is found to be at most 12 %.

On the other hand, at ion energies above several MeV/u, the oscillatory behavior of $\bar{q}$ gradually disappears, and the ions after passage through foils with lower atomic number generally exhibit higher $\bar{q}$ values, In fact, the reported data suggest that the use of Be foil provides the highest equilibrium mean charges for 1 to 3 MeV/u F, Si, Cl or Cu ions. This tendency appears to be preserved for ions at least up to several tens MeV/u although investigated data are very limited[17,20]. With further increase of ion energies up to about 200-1000 MeV/u, the foils taking the maximum of $\bar{q}$ values move from those with intermediate atomic number to higher atomic number[31,32]. Evaluation of equilibrium $\bar{q}$, d, or F(q) values with respect to the target atomic number is to be done after more data accumulation and theoretical analysis.

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EXPLANATION OF TABLE

TABLE 1. Equilibrium Mean Charges $\bar{q}$ and Distribution Widths d of Ions after Passage through a Carbon Foil in Ion Energies E=0.02 to 6 MeV/u.

Equilibrium mean charge and charge distribution width of 0.02, 0.04, 0.1, 0.2, 0.4, 1, 2, 4 and 6 MeV/u ions after passage through a carbon foil are ordered by increasing the atomic number of ions. Tabulated values are evaluated based on the procedure (i) to (iii) described in 3.1 in the text. Charge fraction of ions F(q) for given charge state q and energy can be estimated approximately by applying $\bar{q}$ and d values given in this table to Gaussian distribution in eq.(3).

Z Atomic number of ions

$\bar{q}$ Mean charge of ions after passage through a carbon foil, Eq.(1)

d Distribution width of ions after passage through a carbon foil, Eq.(2)

Table 1. Equilibrium mean charges $\bar{q}$ and charge distribution widths d of ions after passage through a carbon foil.

Atomic number Z	$\bar{q}$ and d	Ion energy (MeV/u)								
		0.02	0.04	0.1	0.2	0.4	1	2	4	6
4	$\bar{q}$	0.934	1.23	1.86	2.45	3.07	3.665	3.915	3.988	3.997
	d	0.545	0.605	0.640	0.654	0.662	0.528	0.282	0.108	0.0519
5	$\bar{q}$	1.04	1.41	2.05	2.70	3.53	4.29	4.780	4.966	4.991
	d	0.680	0.730	0.710	0.691	0.678	0.678	0.441	0.182	0.094
6	$\bar{q}$	0.885	1.32	2.25	3.15	3.92	4.91	5.606	5.920	5.976
	d	0.735	0.763	0.775	0.700	0.630	0.701	0.557	0.271	0.153
7	$\bar{q}$	0.942	1.39	2.56	3.76	4.76	5.70	6.41	6.850	6.960
	d	0.286	0.423	0.776	0.846	0.767	0.686	0.579	0.386	0.239
8	$\bar{q}$	1.24	1.89	3.03	4.11	5.27	6.22	7.08	7.756	7.921
	d	0.840	0.885	0.885	0.853	0.770	0.754	0.729	0.463	0.274
9	$\bar{q}$	1.37	2.02	3.37	4.65	5.83	6.96	7.85	8.670	8.890
	d	0.444	0.657	0.975	0.975	0.899	0.804	0.717	0.531	0.372
10	$\bar{q}$	1.69	2.40	3.68	4.85	6.09	7.62	8.64	9.540	9.600
	d	0.563	0.802	1.00	1.00	0.994	0.857	0.763	0.598	0.576
11	$\bar{q}$	2.09	2.80	4.05	5.25	6.60	8.27	9.39	10.43	10.73
	d	0.716	0.959	1.03	1.03	1.03	0.909	0.809	0.649	0.531
12	$\bar{q}$	2.55	3.34	4.44	5.42	6.86	9.01	10.10	11.28	11.62
	d	0.897	1.05	1.05	1.05	1.05	0.955	0.856	0.701	0.598
13	$\bar{q}$	2.75	3.20	4.73	6.44	7.69	9.24	10.82	12.13	12.59
	d	1.01	1.08	1.08	1.08	1.08	1.05	0.901	0.748	0.624
14	$\bar{q}$	3.04	3.81	5.04	6.23	7.70	9.92	11.61	12.96	13.38
	d	1.21	1.12	1.10	1.10	1.10	1.10	0.940	0.791	0.705
15	$\bar{q}$	3.25	4.05	5.33	6.55	8.03	10.18	12.06	13.73	14.24
	d	1.33	1.23	1.12	1.12	1.12	1.12	1.01	0.840	0.753
16	$\bar{q}$	3.19	4.03	5.56	7.00	8.46	10.69	12.63	14.64	15.26
	d	1.49	1.38	1.19	1.14	1.14	1.14	1.07	0.865	0.764
17	$\bar{q}$	3.06	3.99	5.64	7.29	9.13	11.12	13.13	15.29	16.01
	d	1.65	1.54	1.33	1.16	1.16	1.16	1.14	0.921	0.825
18	$\bar{q}$	2.82	3.89	5.73	7.37	9.15	11.78	13.90	15.53	16.70
	d	1.54	1.68	1.47	1.26	1.18	1.18	1.18	1.01	0.886
19	$\bar{q}$	2.86	4.09	6.28	8.20	10.05	12.28	14.48	16.69	17.56
	d	1.55	1.68	1.55	1.30	1.19	1.19	1.19	1.01	0.918
20	$\bar{q}$	3.07	4.05	6.05	8.23	10.54	12.87	15.01	17.21	18.57
	d	1.62	1.66	1.73	1.44	1.21	1.21	1.21	1.07	0.928
21	$\bar{q}$	3.23	4.29	6.35	8.54	11.00	13.49	15.64	17.96	19.15
	d	1.60	1.65	1.73	1.55	1.23	1.23	1.23	1.12	0.990
22	$\bar{q}$	3.31	4.33	6.49	8.91	11.54	14.16	16.30	18.83	20.23
	d	1.59	1.63	1.72	1.66	1.30	1.24	1.24	1.14	0.994
23	$\bar{q}$	3.35	4.55	6.88	9.33	12.05	14.84	16.98	19.44	20.78
	d	1.57	1.62	1.71	1.76	1.39	1.26	1.26	1.20	1.06
24	$\bar{q}$	3.36	4.62	7.08	9.66	12.51	15.42	17.68	20.35	21.60
	d	1.54	1.60	1.70	1.81	1.48	1.27	1.27	1.23	1.09
25	$\bar{q}$	3.53	4.79	7.25	9.90	12.91	16.04	18.38	20.90	22.39
	d	1.52	1.58	1.68	1.80	1.58	1.28	1.28	1.28	1.12
26	$\bar{q}$	3.61	4.79	7.28	10.11	13.33	16.62	19.05	21.68	23.17
	d	1.50	1.55	1.66	1.78	1.68	1.30	1.30	1.30	1.16
27	$\bar{q}$	4.00	5.32	7.78	10.32	13.32	17.12	19.73	22.41	23.95
	d	1.49	1.55	1.65	1.77	1.84	1.31	1.31	1.31	1.19
28	$\bar{q}$	4.13	5.26	7.42	9.95	13.26	17.52	20.38	23.18	24.68
	d	1.46	1.51	1.61	1.72	1.87	1.39	1.32	1.32	1.24
29	$\bar{q}$	4.25	5.41	7.63	10.15	13.38	17.92	21.04	23.90	25.46
	d	1.44	1.49	1.59	1.70	1.85	1.49	1.34	1.34	1.28
30	$\bar{q}$	4.37	5.62	7.80	10.17	13.42	18.38	21.54	24.60	26.26
	d	1.48	1.47	1.57	1.67	1.82	1.59	1.35	1.35	1.32

(Table 1 continued)

Atomic number Z	$\bar{q}$ and d	Ion energy (MeV/u)								
		0.02	0.04	0.1	0.2	0.4	1	2	4	6
31	$\bar{q}$	4.50	5.82	8.06	10.37	13.51	18.48	22.16	25.40	26.98
	d	1.54	1.46	1.55	1.65	1.80	1.73	1.36	1.36	1.36
32	$\bar{q}$	4.64	6.04	8.42	10.78	13.78	18.63	22.72	26.05	27.71
	d	1.60	1.52	1.53	1.64	1.78	1.88	1.37	1.37	1.37
33	$\bar{q}$	4.79	6.29	8.81	11.71	14.02	18.78	23.13	26.78	28.50
	d	1.66	1.58	1.52	1.63	1.76	1.98	1.38	1.38	1.38
34	$\bar{q}$	4.92	6.49	9.11	11.54	14.36	18.98	23.63	27.46	29.00
	d	1.73	1.64	1.50	1.61	1.74	1.96	1.45	1.40	1.40
35	$\bar{q}$	5.22	6.88	9.60	12.03	14.72	19.14	24.10	27.86	29.90
	d	1.78	1.69	1.53	1.60	1.72	1.93	1.54	1.41	1.41
36	$\bar{q}$	4.13	5.79	8.86	11.82	14.99	19.19	23.88	28.88	30.43
	d	1.92	1.82	1.64	1.55	1.70	1.90	1.75	1.42	1.42
37	$\bar{q}$	5.20	6.58	9.25	12.14	15.38	19.74	25.01	29.45	31.38
	d	1.93	1.85	1.69	1.53	1.69	1.89	1.74	1.43	1.43
38	$\bar{q}$	5.24	6.72	9.48	12.41	15.75	20.20	25.38	30.13	32.00
	d	2.00	1.91	1.75	1.57	1.67	1.88	1.85	1.44	1.44
39	$\bar{q}$	5.28	6.82	9.72	12.80	16.32	20.65	25.91	30.79	32.71
	d	2.07	1.98	1.81	1.62	1.66	1.87	1.94	1.45	1.45
40	$\bar{q}$	5.38	7.11	9.83	12.37	15.92	22.16	26.24	31.16	33.60
	d	2.14	2.04	1.87	1.72	1.60	1.91	2.06	1.46	1.46
41	$\bar{q}$	5.40	7.16	10.05	12.79	16.47	22.50	26.57	31.73	34.24
	d	2.22	2.11	1.93	1.76	1.59	1.89	2.09	1.47	1.47
42	$\bar{q}$	5.46	7.11	10.29	13.65	17.40	22.03	27.09	32.26	34.86
	d	2.29	2.19	1.99	1.79	1.60	1.83	2.08	1.48	1.48
43	$\bar{q}$	5.48	7.15	10.54	14.14	17.94	22.45	27.63	32.80	35.67
	d	2.25	2.24	2.05	1.82	1.61	1.81	2.07	1.54	1.49
44	$\bar{q}$	5.50	7.20	10.78	14.64	18.54	22.88	28.16	33.35	36.48
	d	2.22	2.30	2.11	1.87	1.63	1.79	2.06	1.60	1.50
45	$\bar{q}$	5.52	7.28	10.91	14.79	18.87	23.40	28.62	33.84	37.18
	d	2.18	2.27	2.18	1.94	1.68	1.77	2.04	1.69	1.50
46	$\bar{q}$	5.53	7.37	11.04	14.95	19.20	23.92	29.09	34.34	37.88
	d	2.15	2.24	2.25	2.00	1.73	1.76	2.03	1.79	1.51
47	$\bar{q}$	5.55	7.46	11.23	15.21	19.56	24.52	29.56	34.85	38.56
	d	2.11	2.21	2.31	2.06	1.78	1.76	2.01	1.88	1.52
48	$\bar{q}$	5.54	7.51	11.42	15.54	20.00	24.96	30.00	35.33	39.25
	d	2.08	2.17	2.37	2.11	1.83	1.74	1.99	1.98	1.53
49	$\bar{q}$	5.60	7.54	11.61	16.00	20.56	25.33	30.48	35.82	39.94
	d	2.04	2.14	2.34	2.16	1.87	1.71	1.98	2.07	1.54
50	$\bar{q}$	5.59	7.61	11.78	16.18	20.80	25.90	30.98	36.30	40.65
	d	2.00	2.10	2.31	2.22	1.93	1.70	1.96	2.17	1.55
51	$\bar{q}$	5.61	7.73	11.99	16.36	20.97	26.39	31.37	36.72	41.31
	d	1.96	2.07	2.28	2.29	1.99	1.68	1.94	2.22	1.56
52	$\bar{q}$	5.58	7.84	12.21	16.55	21.15	26.83	31.72	37.18	41.96
	d	1.92	2.04	2.26	2.36	2.05	1.68	1.92	2.20	1.57
53	$\bar{q}$	5.61	7.89	12.43	16.96	21.54	26.87	32.17	37.63	42.67
	d	1.88	2.00	2.23	2.41	2.10	1.75	1.90	2.19	1.63
54	$\bar{q}$	5.62	8.06	12.42	16.49	21.14	28.08	32.56	38.02	43.31
	d	1.84	1.97	2.19	2.40	2.21	1.75	1.88	2.17	1.70
55	$\bar{q}$	5.61	8.12	12.54	16.59	21.23	28.22	32.70	38.63	43.89
	d	1.88	1.93	2.16	2.36	2.28	1.82	1.84	2.16	1.78
56	$\bar{q}$	5.60	8.13	12.60	16.66	21.27	28.39	33.32	39.26	44.52
	d	1.93	1.89	2.12	2.33	2.35	1.88	1.83	2.15	1.85
57	$\bar{q}$	5.64	8.12	12.65	16.89	21.50	28.28	33.80	39.82	45.09
	d	1.97	1.88	2.08	2.30	2.42	1.96	1.81	2.13	1.94

(Table 1 continued)

Atomic number Z	$\bar{q}$ and d	Ion energy (MeV/u)								
		0.02	0.04	0.1	0.2	0.4	1	2	4	6
58	$\bar{q}$	5.68	8.23	12.76	16.87	21.44	28.65	34.16	40.37	45.76
	d	2.01	1.92	2.04	2.26	2.49	2.01	1.78	2.12	2.01
59	$\bar{q}$	5.61	8.16	12.77	16.99	21.60	28.73	34.52	41.01	46.37
	d	2.05	1.97	2.00	2.22	2.46	2.09	1.76	2.11	2.08
60	$\bar{q}$	5.70	8.28	12.87	17.01	21.54	28.79	34.77	41.58	46.92
	d	2.08	2.01	1.96	2.18	2.42	2.16	1.75	2.10	2.17
61	$\bar{q}$	5.67	8.23	12.88	17.17	21.81	28.96	35.18	42.15	47.50
	d	2.11	2.05	1.94	2.15	2.39	2.22	1.80	2.08	2.25
62	$\bar{q}$	5.64	8.18	12.90	17.33	22.07	29.13	35.59	42.72	48.08
	d	2.14	2.09	1.93	2.11	2.36	2.29	1.85	2.07	2.34
63	$\bar{q}$	5.61	8.12	12.92	17.49	22.33	29.23	35.91	43.30	48.67
	d	2.17	2.12	1.98	2.07	2.33	2.36	1.90	2.05	2.35
64	$\bar{q}$	5.67	8.20	12.93	17.34	22.00	29.31	36.22	43.84	48.58
	d	2.19	2.15	2.02	2.02	2.27	2.44	1.96	2.04	2.30
65	$\bar{q}$	5.66	8.13	13.00	17.81	22.83	29.45	36.47	44.43	49.76
	d	2.21	2.18	2.06	2.00	2.27	2.51	2.02	2.02	2.32
66	$\bar{q}$	5.62	8.05	12.94	17.88	23.02	29.54	36.80	44.98	50.42
	d	2.23	2.21	2.10	1.96	2.24	2.58	2.08	2.00	2.31
67	$\bar{q}$	5.63	7.97	12.71	17.61	22.81	29.49	37.05	45.56	50 92
	d	2.24	2.23	2.14	1.98	2.18	2.54	2.14	1.99	2.29
68	$\bar{q}$	5.58	7.98	12.85	17.84	23.14	29.99	37.33	46.10	51.41
	d	2.25	2.24	2.17	2.02	2.15	2.52	2.20	1.97	2.27
69	$\bar{q}$	5.55	7.88	12.70	17.78	23.31	30.29	37.61	46.58	52.03
	d	2.26	2.26	2.20	2.07	2.11	2.50	2.26	1.95	2.26
70	$\bar{q}$	5.55	7.79	12.53	17.71	23.47	30.63	37.84	47.18	52.50
	d	2.27	2.27	2.23	2.11	2.08	2.47	2.32	1.93	2.24
71	$\bar{q}$	5.51	7.65	12.39	17.81	23.85	30.40	38.06	47.71	52.97
	d	2.27	2.28	2.26	2.15	2.05	2.41	2.38	1.92	2.21
72	$\bar{q}$	5.54	7.69	12.23	17.36	23.51	31.09	38.30	48.24	53.61
	d	2.27	2.29	2.28	2.19	1.98	2.40	2.45	1.90	2.20
73	$\bar{q}$	5.61	7.67	12.23	17.56	23.65	30.50	38.54	48.76	54.02
	d	2.27	2.29	2.29	2.22	2.03	2.32	2.51	1.88	2.18
74	$\bar{q}$	5.48	7.59	12.21	17.61	24.05	31.52	38.78	49.21	54.61
	d	2.26	2.29	2.31	2.25	2.06	2.33	2.57	1.85	2.16
75	$\bar{q}$	5.47	7.65	12.41	17.96	24.48	31.91	39.00	49.63	55.31
	d	2.25	2.29	2.31	2.27	2.09	2.31	2.64	1.87	2.15
76	$\bar{q}$	5.47	7.68	12.54	18.21	24.88	32.28	39.14	50.16	55.63
	d	2.24	2.28	2.32	2.29	2.12	2.28	2.67	1.91	2.12
77	$\bar{q}$	5.47	7.73	12.78	18.68	25.41	32.17	39.35	50.57	56.21
	d	2.23	2.27	2.33	2.30	2.41	2.23	2.63	1.96	2.10
78	$\bar{q}$	5.48	7.85	12.98	18.79	25.58	32.92	39.55	51.01	56.67
	d	2.22	2.27	2.33	2.32	2.18	2.22	2.59	2.01	2.08
79	$\bar{q}$	5.53	7.91	13.22	19.28	25.97	32.56	39.89	51.35	57.24
	d	2.21	2.26	2.33	2.34	2.21	2.15	2.57	2.07	2.06
80	$\bar{q}$	5.56	8.04	13.40	19.47	26.46	33.76	40.12	51.80	57.68
	d	2.19	2.25	2.33	2.35	2.23	2.17	2.53	2.11	2.04
81	$\bar{q}$	5.59	8.17	13.65	19.78	26.90	34.34	40.50	52.25	58.24
	d	2.17	2.24	2.33	2.36	2.25	2.15	2.50	2.16	2.02
82	$\bar{q}$	5.58	7.50	13.50	21.01	28.23	35.00	41.00	52.64	58.71
	d	2.15	2.20	2.33	2.37	2.25	2.14	2.48	2.21	1.99
83	$\bar{q}$	5.60	8.50	14.51	20.69	27.13	33.99	41.50	52.95	59.26
	d	2.14	2.21	2.33	2.38	2.31	2.09	2.46	2.27	1.97
92	$\bar{q}$	5.78	8.27	14.40	21.38	28.46	36.80	46.46	57.50	63.53
	d	1.98	2.03	2.19	2.36	2.44	2.36	2.29	2.67	2.21

TABLE 2. Equilibrium Charge Fractions of Few-Electron Ions for Z=4 to 20 in Ion Energies less than 40 MeV/u after Passage through a Carbon Foil.

Equilibrium charge fractions of few-electron ions after passage through a carbon foil are orderd by increasing the projectile atomic number for charge states q = Z, Z-1 and Z-2. Tabulated values are evaluated according to the procedure described in 3.2 in the text.

Z   Atomic number of ions

F(q)   Charge fraction of ions having charge state q

Table 2. Equilibrium charge fractions of highly charged ions after passage through a carbon foil. F(Z-2), F(Z-1) and F(Z) mean the charge fractions of He-like ions, H-like ions, and fully stripped ions. The notation (-n) stands for 10^{-n}.

Ion	Energy (MeV/u)	Charge fraction F(Z-2)	F(Z-1)	F(Z)
Be	2	1.71(-3)	0.0792	0.919
	3	2.01(-4)	0.0279	0.972
	5	7.40(-6)	5.43(-3)	0.9946
	7	5.84(-7)	1.53(-3)	0.9985
	10	4.60(-8)	4.29(-4)	0.99957
	15	2.25(-9)	9.48(-5)	0.999905
B	2	0.0117	0.193	0.796
	3	1.60(-3)	0.0768	0.922
	5	7.27(-5)	0.0169	0.983
	7	6.09(-6)	4.92(-3)	0.9951
	10	4.62(-7)	1.36(-3)	0.9986
	15	2.44(-8)	3.13(-4)	0.99969
	20	3.24(-9)	1.14(-4)	0.99989
C	2	0.0398	0.320	0.641
	3	6.72(-3)	0.151	0.843
	5	4.34(-4)	0.0408	0.959
	7	4.71(-5)	0.0136	0.986
	10	3.10(-6)	3.52(-3)	0.9965
	15	1.74(-7)	8.35(-4)	0.99917
	20	2.56(-8)	3.20(-4)	0.99968
N	3	0.0220	0.253	0.725
	4	5.57(-3)	0.139	0.855
	5	1.57(-3)	0.0762	0.922
	7	1.93(-4)	0.0274	0.972
	10	1.58(-5)	7.92(-3)	0.9921
	15	8.04(-7)	1.79(-3)	0.9982
	20	1.25(-7)	7.07(-4)	0.99929
O	3	0.0514	0.351	0.578
	5	4.57(-3)	0.126	0.869
	7	5.71(-4)	0.0467	0.953
	10	5.40(-4)	0.0146	0.985
	15	2.48(-6)	3.14(-3)	0.9969
	20	4.18(-7)	1.29(-3)	0.9987
	30	3.50(-8)	3.74(-4)	0.99963
F	4	0.0281	0.279	0.693
	5	0.0101	0.181	0.809
	7	1.49(-3)	0.0741	0.924
	10	1.66(-4)	0.0255	0.974
	15	8.12(-6)	5.68(-3)	0.9943
	20	1.15(-6)	2.15(-3)	0.9979
	30	1.09(-7)	6.60(-4)	0.99934
Ne	5	0.0202	0.244	0.756
	7	2.88(-3)	0.102	0.896
	10	3.70(-4)	0.0378	0.962
	15	2.00(-5)	8.90(-3)	0.9911
	20	2.66(-6)	3.26(-3)	0.9967
	30	2.26(-7)	9.51(-4)	0.99905
Na	5	0.0365	0.309	0.654
	7	6.54(-3)	0.149	0.845
	10	8.38(-4)	0.0561	0.943
	15	5.07(-5)	0.0141	0.986
	20	6.33(-6)	5.02(-3)	0.9950
	30	5.52(-7)	1.48(-3)	0.9985
Mg	5	0.0623	0.375	0.563
	7	0.0121	0.196	0.792
	10	1.56(-3)	0.0759	0.923
	15	1.08(-4)	0.0205	0.979
	20	1.27(-5)	7.09(-3)	0.9929
	30	1.04(-6)	2.04(-3)	0.9980
Al	7	0.0211	0.249	0.730
	10	2.92(-3)	0.102	0.895
	15	2.21(-4)	0.0293	0.971
	20	2.66(-5)	0.0103	0.9897
	30	1.93(-6)	2.78(-3)	0.9972
	40	4.06(-7)	1.27(-3)	0.9987
Si	7	0.0331	0.298	0.669
	10	5.05(-3)	0.132	0.863
	15	4.15(-4)	0.0399	0.960
	20	5.08(-5)	0.0142	0.986
	30	3.48(-6)	3.73(-3)	0.9963
	40	7.03(-7)	1.68(-3)	0.9983
P	7	0.0567	0.363	0.581
	10	8.82(-3)	0.170	0.821
	15	7.69(-4)	0.0539	0.945
	20	1.04(-4)	0.0202	0.9797
	30	6.33(-6)	5.02(-3)	0.9950
	40	1.25(-6)	2.24(-3)	0.9978
S	7	0.082	0.409	0.509
	10	0.0147	0.213	0.772
	15	1.56(-3)	0.0759	0.923
	20	1.91(-4)	0.0273	0.973
	30	1.12(-5)	6.67(-3)	0.9933
	40	2.26(-6)	3.00(-3)	0.9970
Cl	10	0.0219	0.252	0.726
	15	2.24(-3)	0.0902	0.909
	20	3.22(-4)	0.0353	0.964
	30	1.85(-5)	8.56(-3)	0.9914
	40	3.65(-6)	3.82(-3)	0.9962
Ar	10	0.0325	0.296	0.672
	15	3.46(-3)	0.111	0.886
	20	5.35(-3)	0.0452	0.954
	30	3.03(-5)	0.0109	0.989
	40	5.87(-6)	4.83(-3)	0.9952
K	10	0.0509	0.349	0.560
	15	5.64(-3)	0.139	0.855
	20	8.96(-4)	0.0581	0.941
	30	5.13(-5)	0.0142	0.986
	40	1.02(-5)	6.35(-3)	0.9936
Ca	10	0.0703	0.390	0.540
	15	8.96(-3)	0.171	0.820
	20	1.29(-3)	0.0692	0.929
	30	7.83(-5)	0.0175	0.982
	40	1.37(-5)	7.39(-3)	0.9926

EXPLANATION OF FIGURES

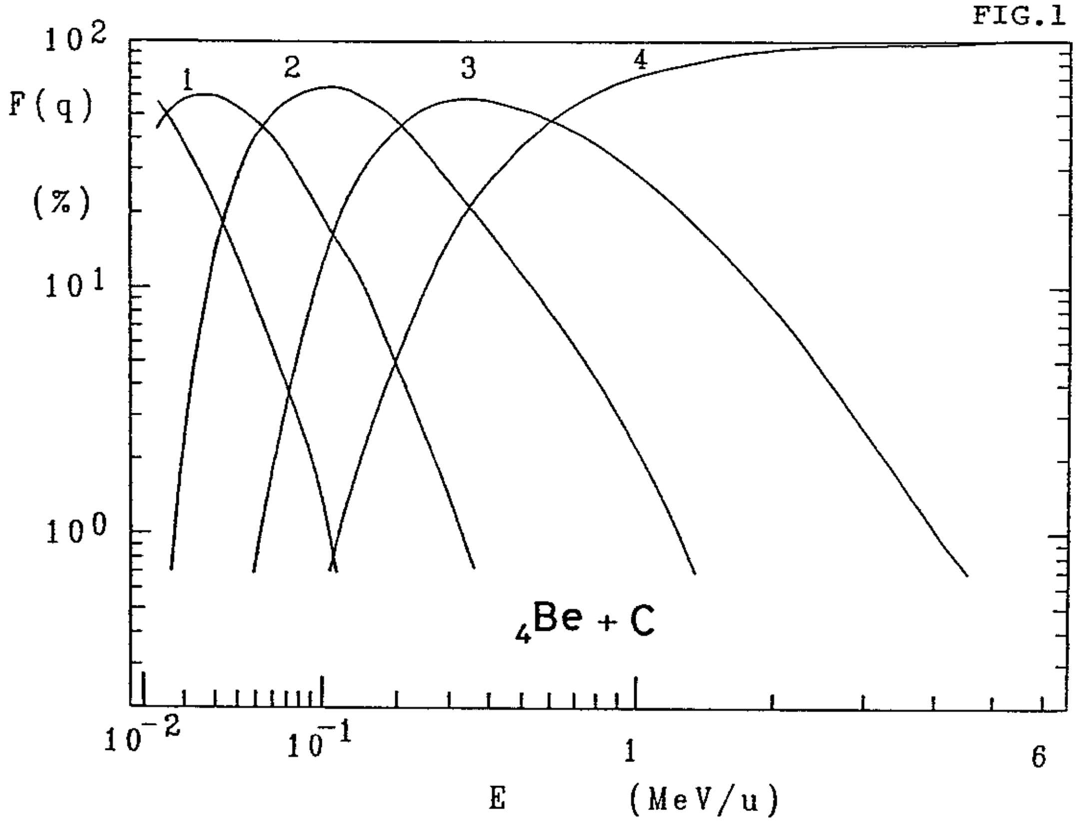
FIGURES 1-81. Equilibrium Charge Fraction of Ions for Z=4 to 83 and 92 after Passage through a Carbon Foil as a Function of Ion Energy between 0.02 and 6 MeV/u.

Equilibrium charge fractions of ions after passage through a carbon foil are shown as a function of ion energy from 0.02 to 6 MeV/u. Each figure pertains to one ion species whose atomic number ranges from Z=4 to 83 and Z=92. These values are evaluated based on the procedure (i) to (iii) described in 3.1 in the text. The numbers attached above the curves represent the charge states of ions.

F(q) Charge fraction of ions having charge state q.

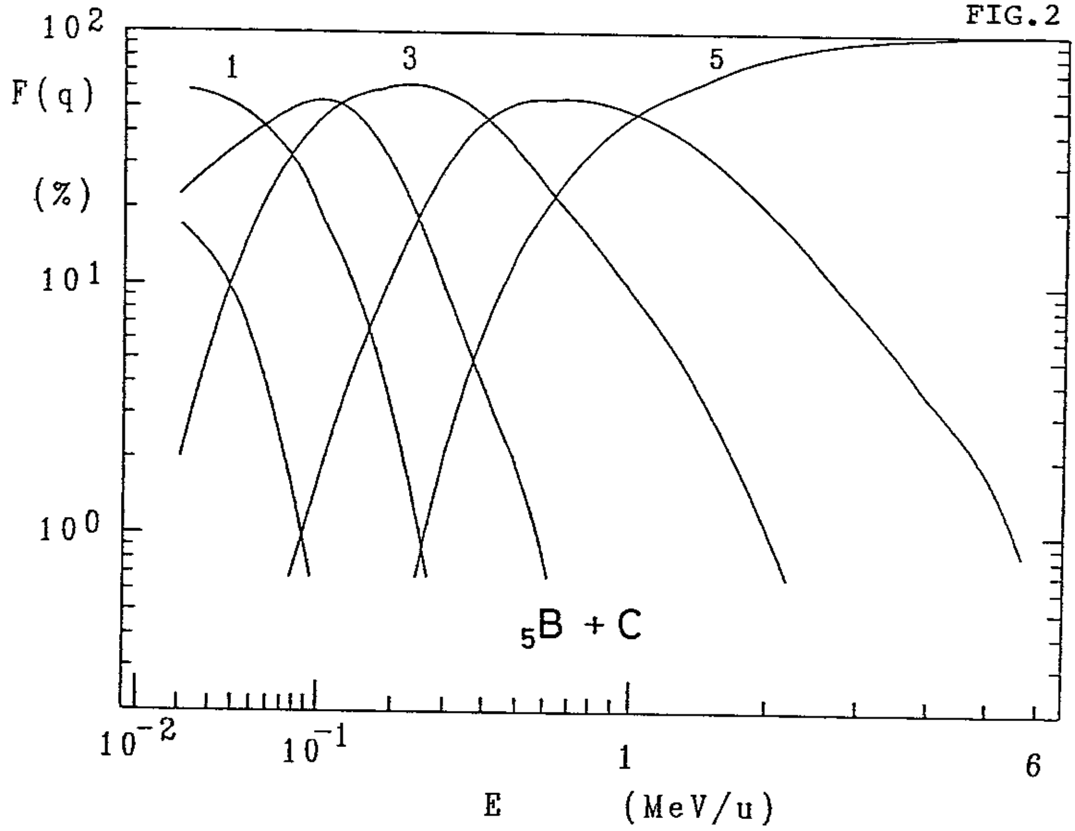
E Ion energy at emergence from a carbon foil, in MeV/u.

FIG.1



10^2
F(q)
(%)
10^1
10^0
1
2
3
4
$_4$Be + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.2



10^2
F(q)
(%)
10^1
10^0
1
3
5
$_5$B + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.3

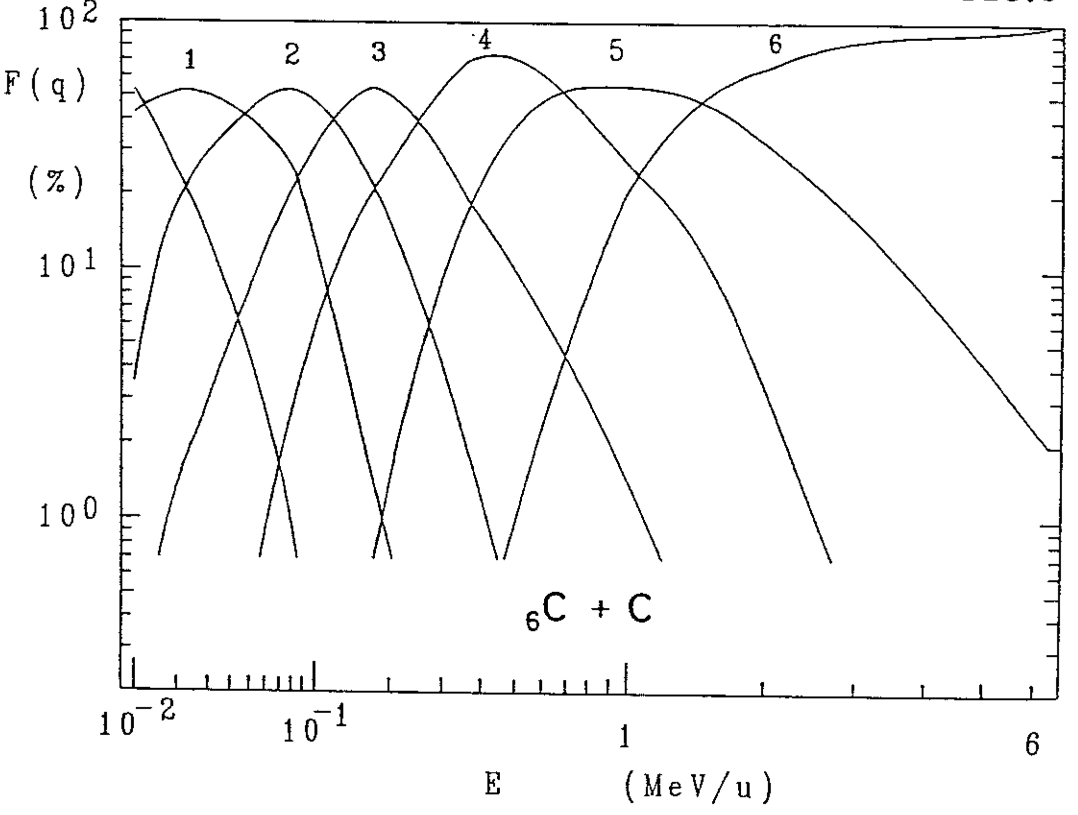

10^2
F(q)
(%)
10^1
10^0
1
2
3
4
5
6
6C + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.4

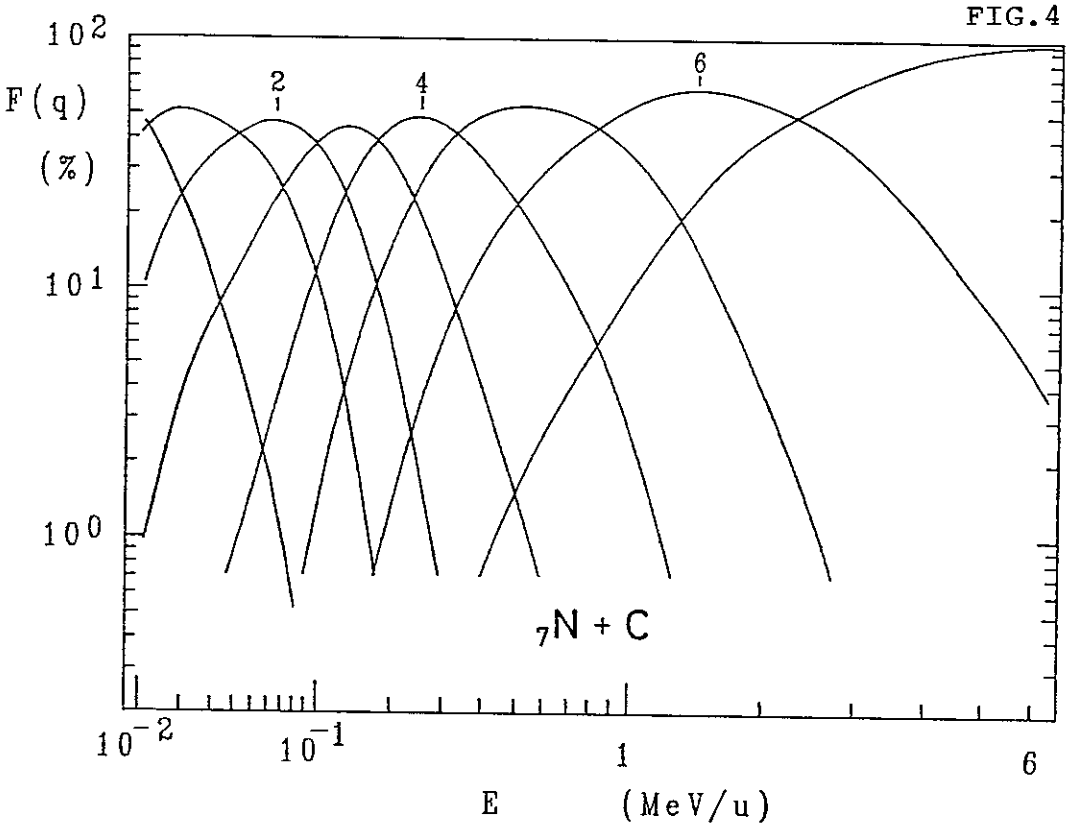
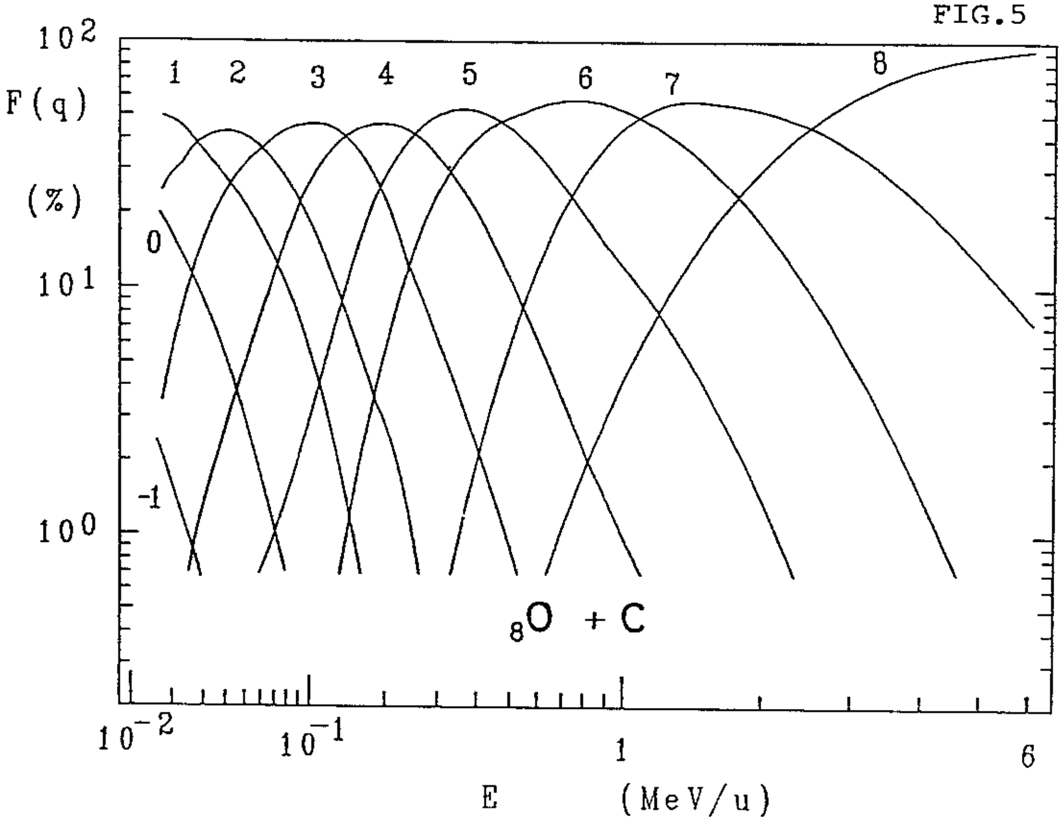
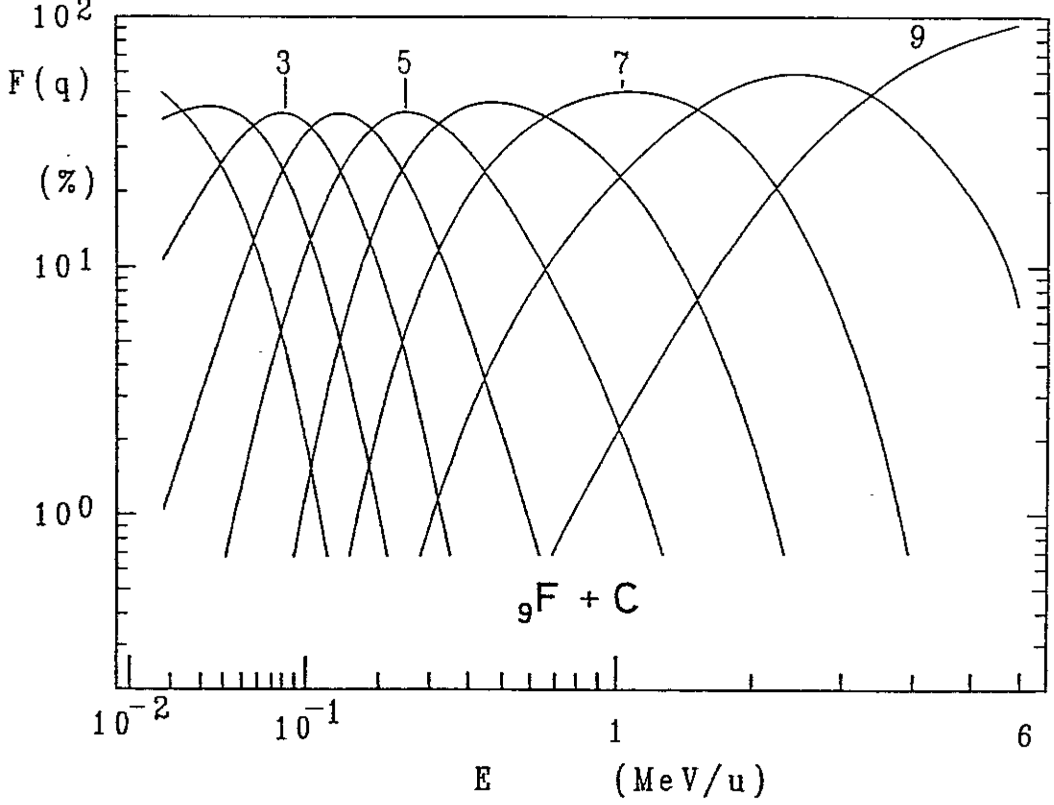

10^2
F(q)
(%)
10^1
10^0
2
4
6
7N + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.5



10^2
F(q)
(%)
10^1
10^0
1
2
3
4
5
6
7
8
0
-1
$_8$O + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.6



10^2
F(q)
(%)
10^1
10^0
3
5
7
9
$_9$F + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

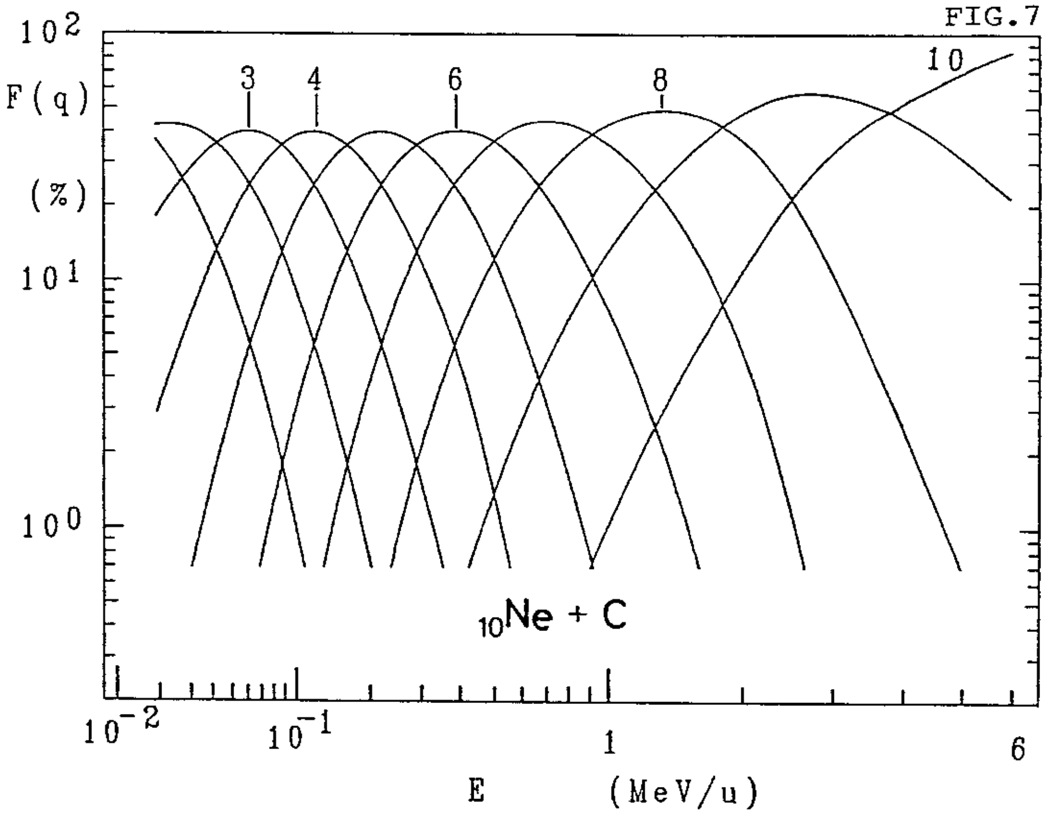


FIG.7
10^2
F(q)
(%)
10^1
10^0
3
4
6
8
10
$_{10}$Ne + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

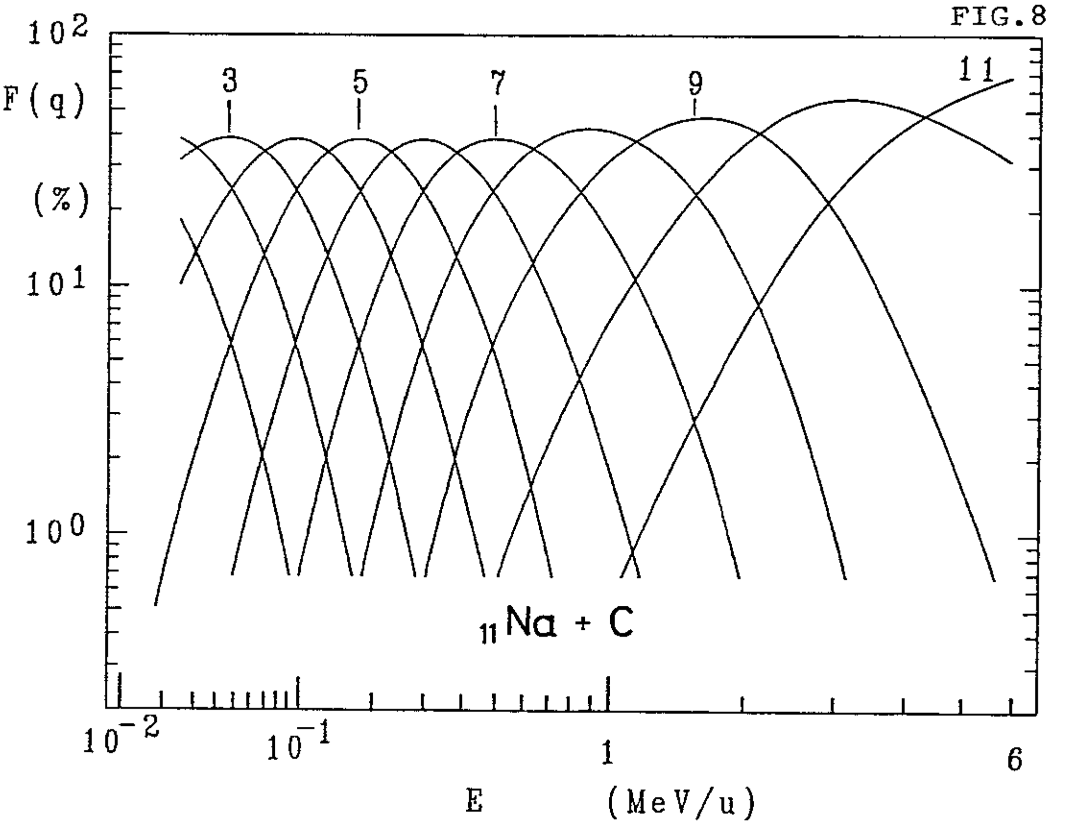
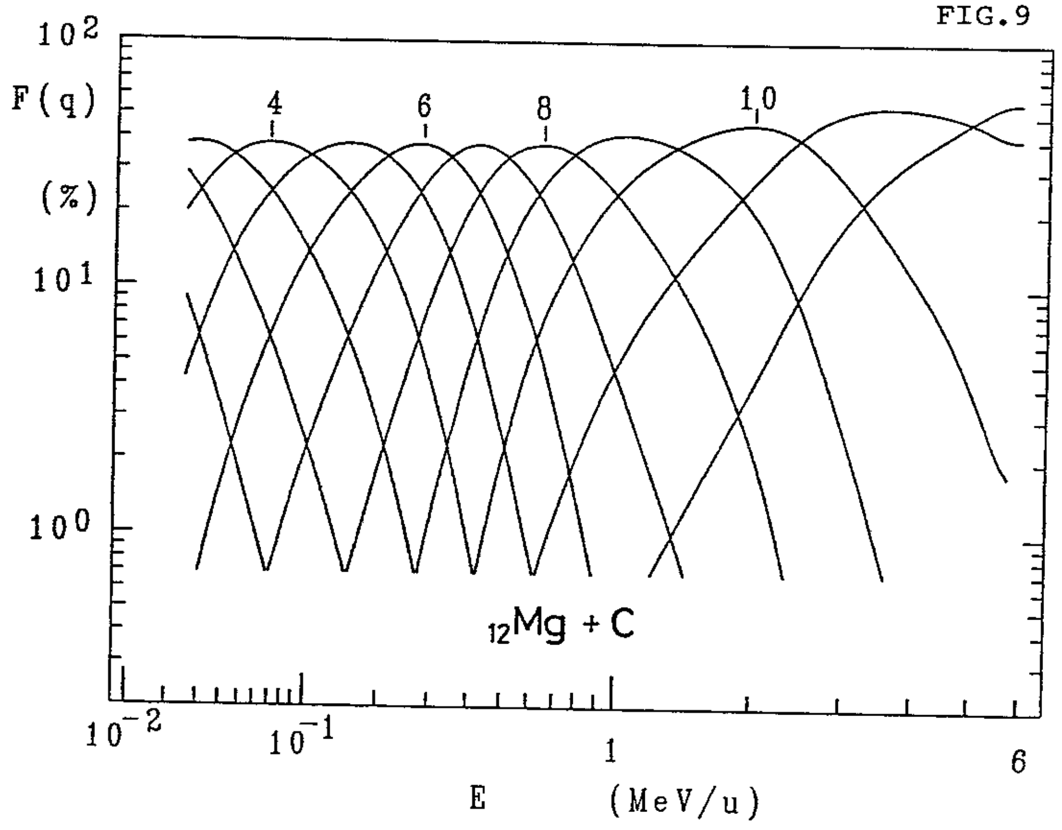


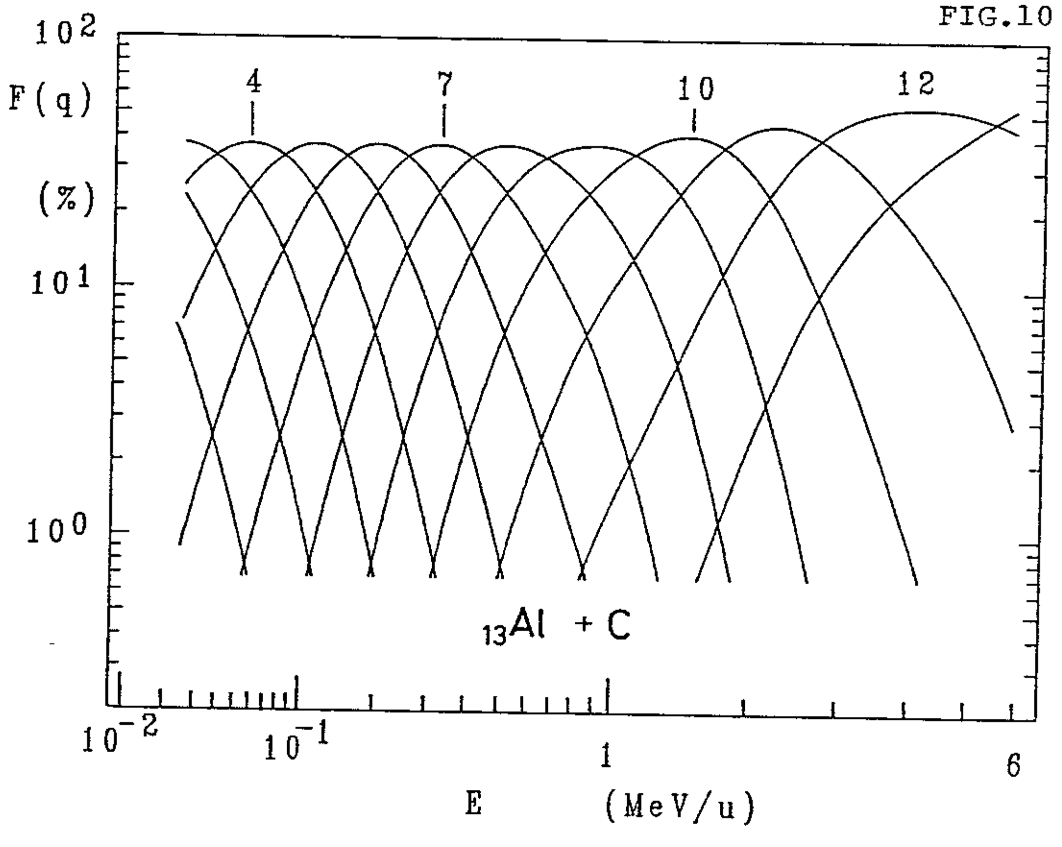
FIG.8
10^2
F(q)
(%)
10^1
10^0
3
5
7
9
11
$_{11}$Na + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.9



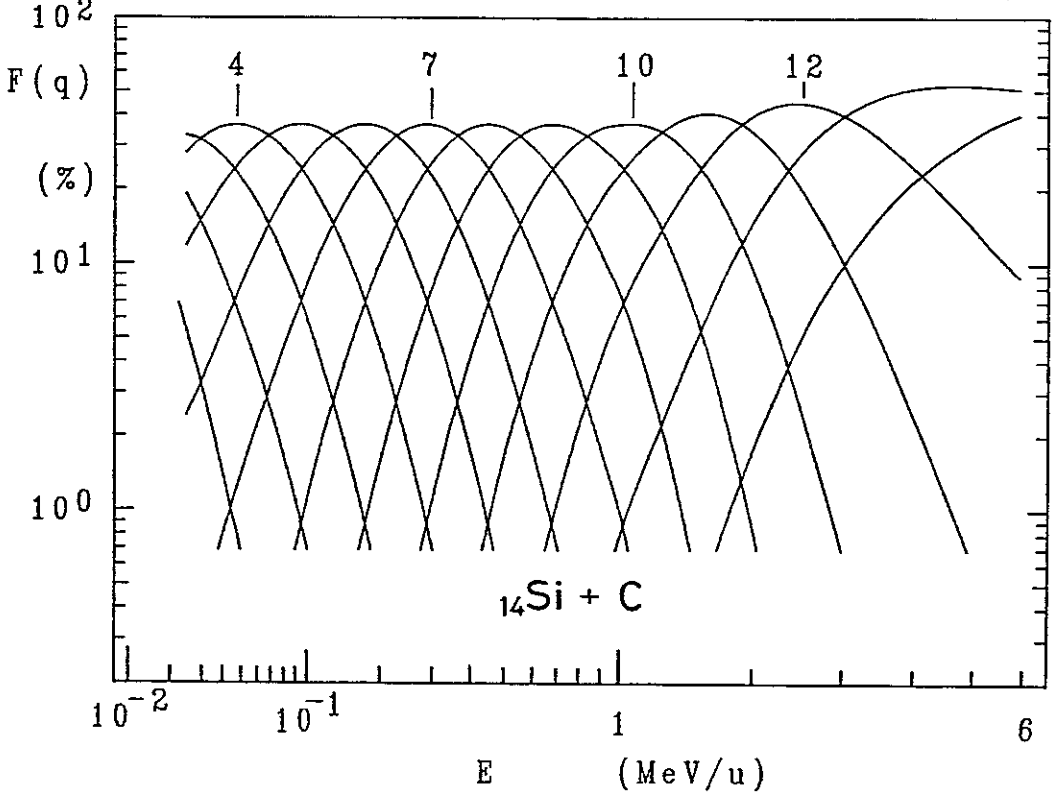
10^2
F(q)
(%)
10^1
10^0
4
6
8
10
$_{12}$Mg + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.10



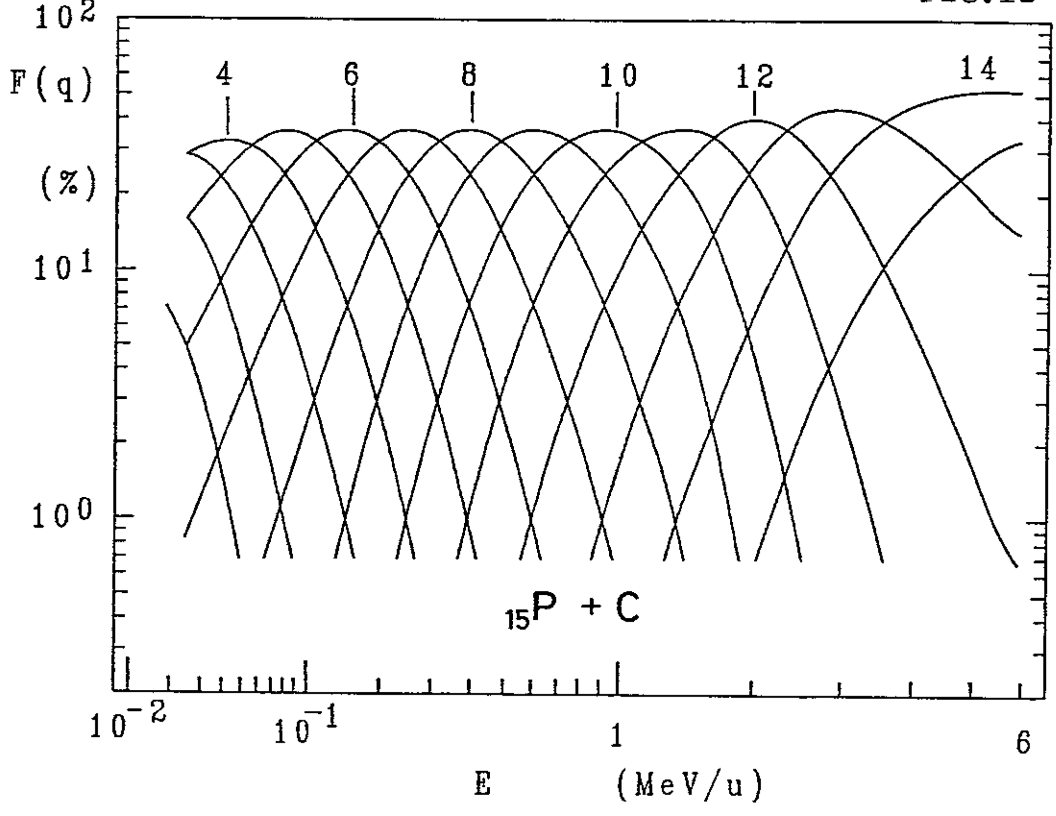
10^2
F(q)
(%)
10^1
10^0
4
7
10
12
$_{13}$Al + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.11



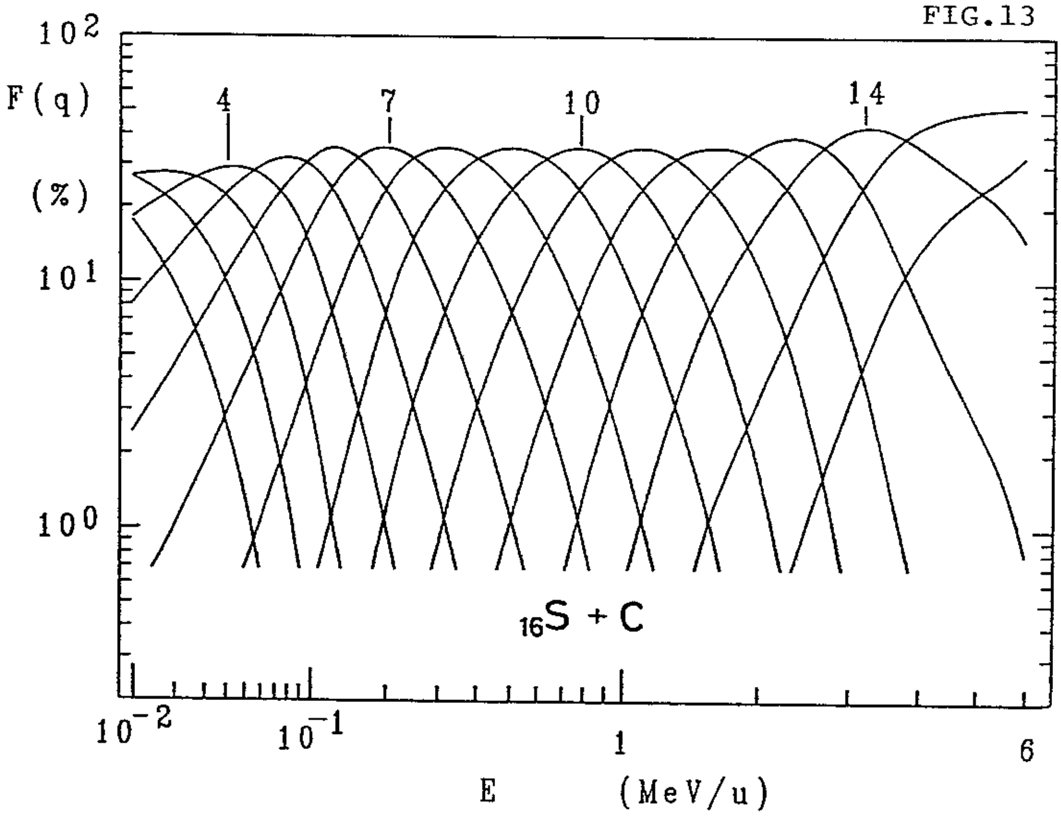
10^2
F(q)
(%)
10^1
10^0
4
7
10
12
$_{14}$Si + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.12



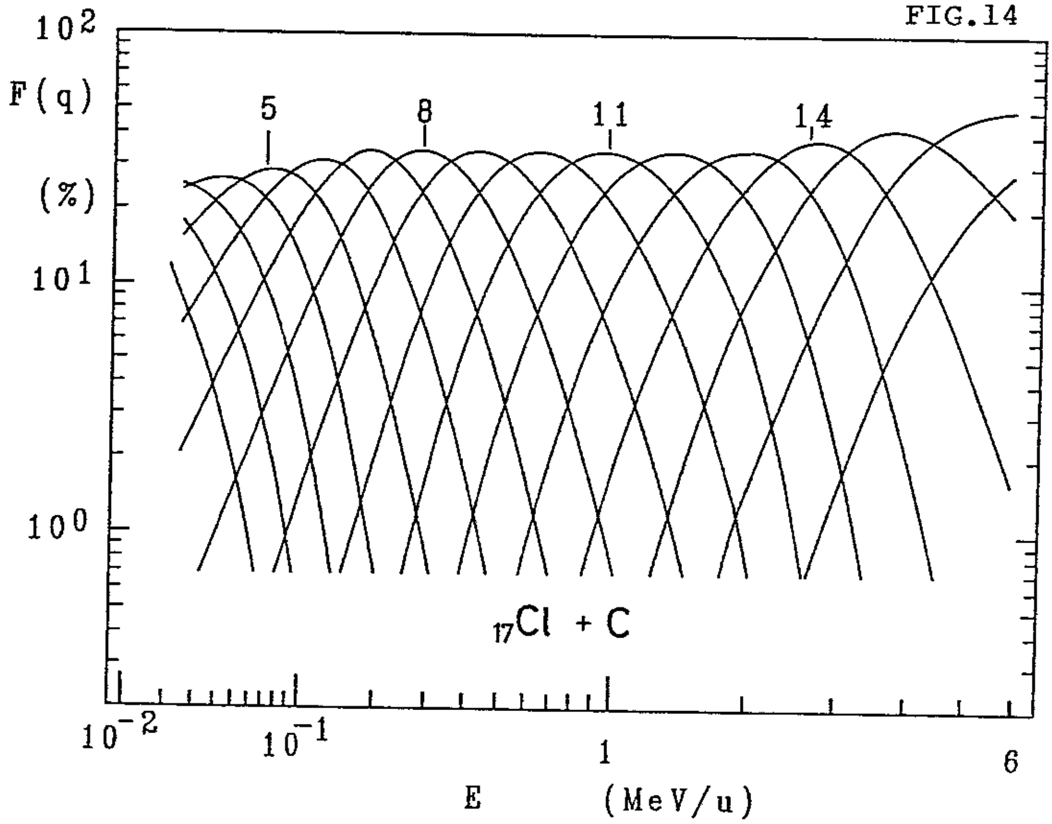
10^2
F(q)
(%)
10^1
10^0
4
6
8
10
12
14
$_{15}$P + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.13



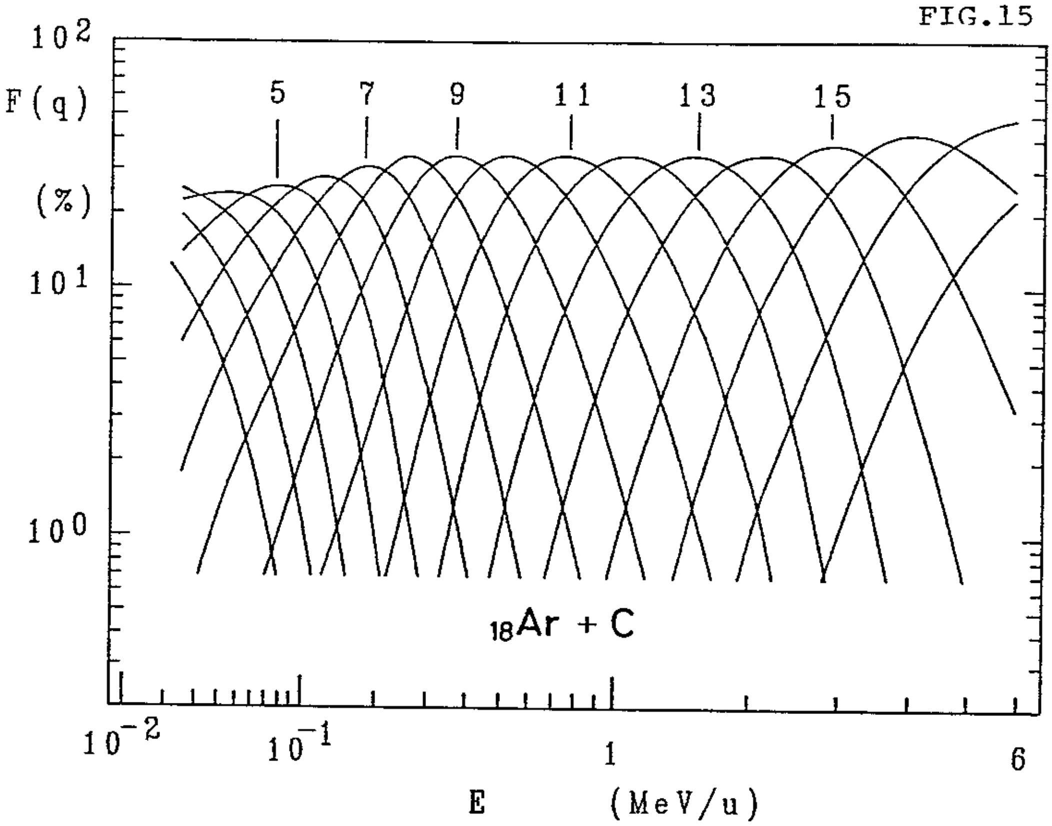
10^2
F(q)
(%)
10^1
10^0
4
7
10
14
$_{16}S + C$
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.14



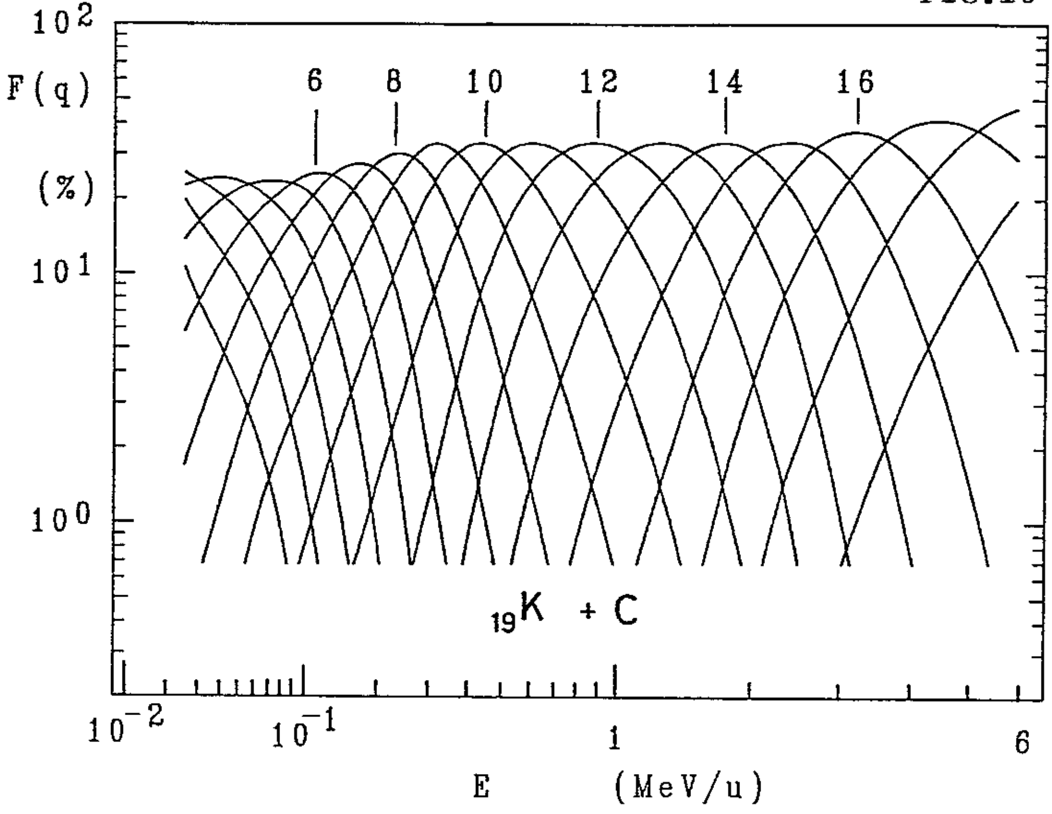
10^2
F(q)
(%)
10^1
10^0
5
8
11
14
$_{17}Cl + C$
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.15



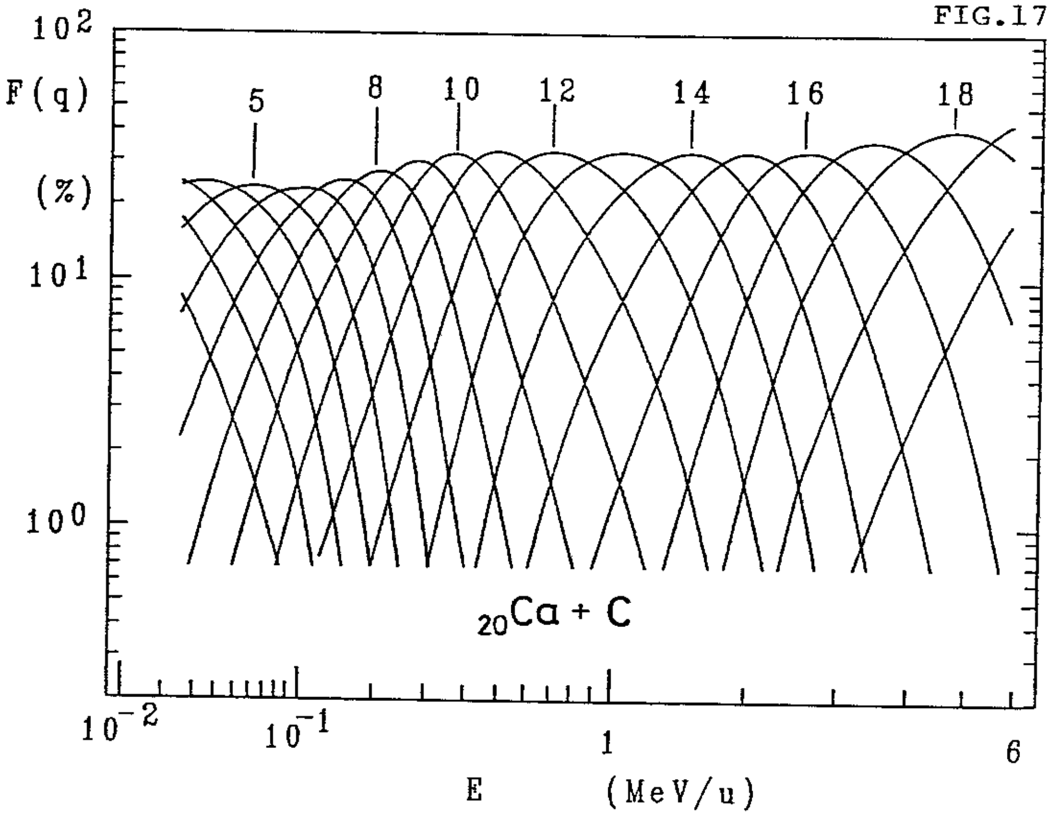
10^2
F(q)
(%)
10^1
10^0
5
7
9
11
13
15
$_{18}$Ar + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.16



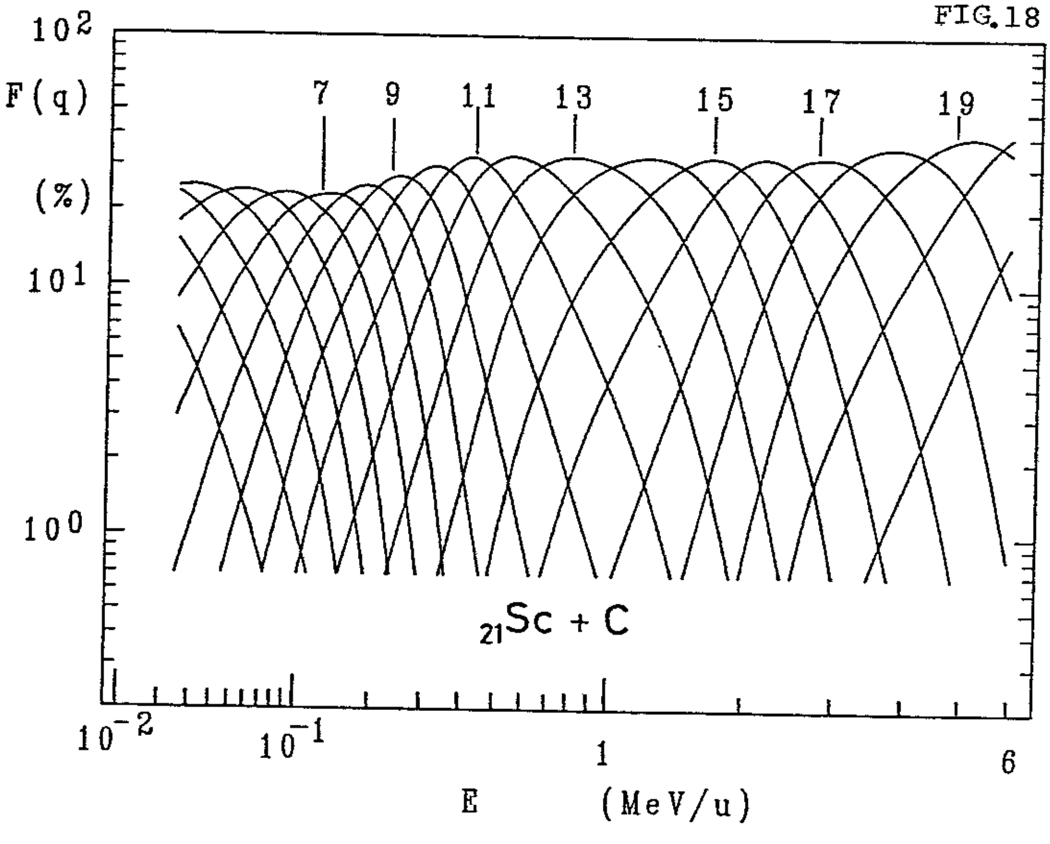
10^2
F(q)
(%)
10^1
10^0
6
8
10
12
14
16
$_{19}$K + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.17



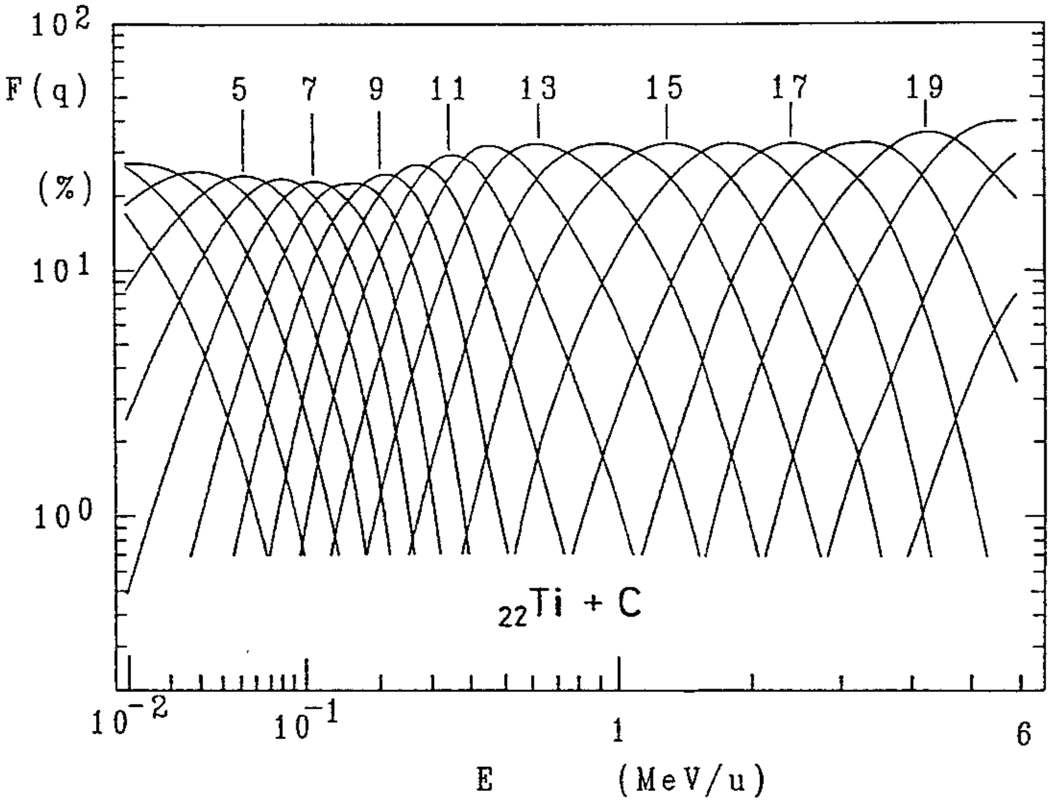
10^2
F(q)
(%)
10^1
10^0
5
8
10
12
14
16
18
$_{20}$Ca + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.18



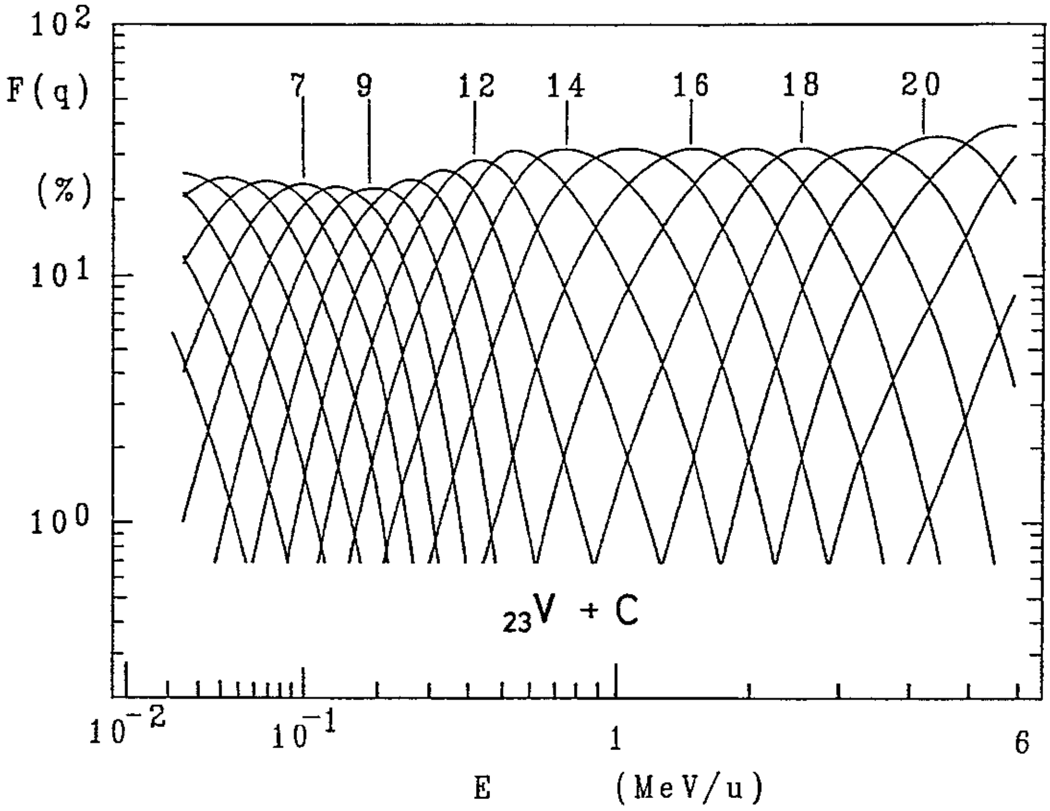
10^2
F(q)
(%)
10^1
10^0
7
9
11
13
15
17
19
$_{21}$Sc + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.19

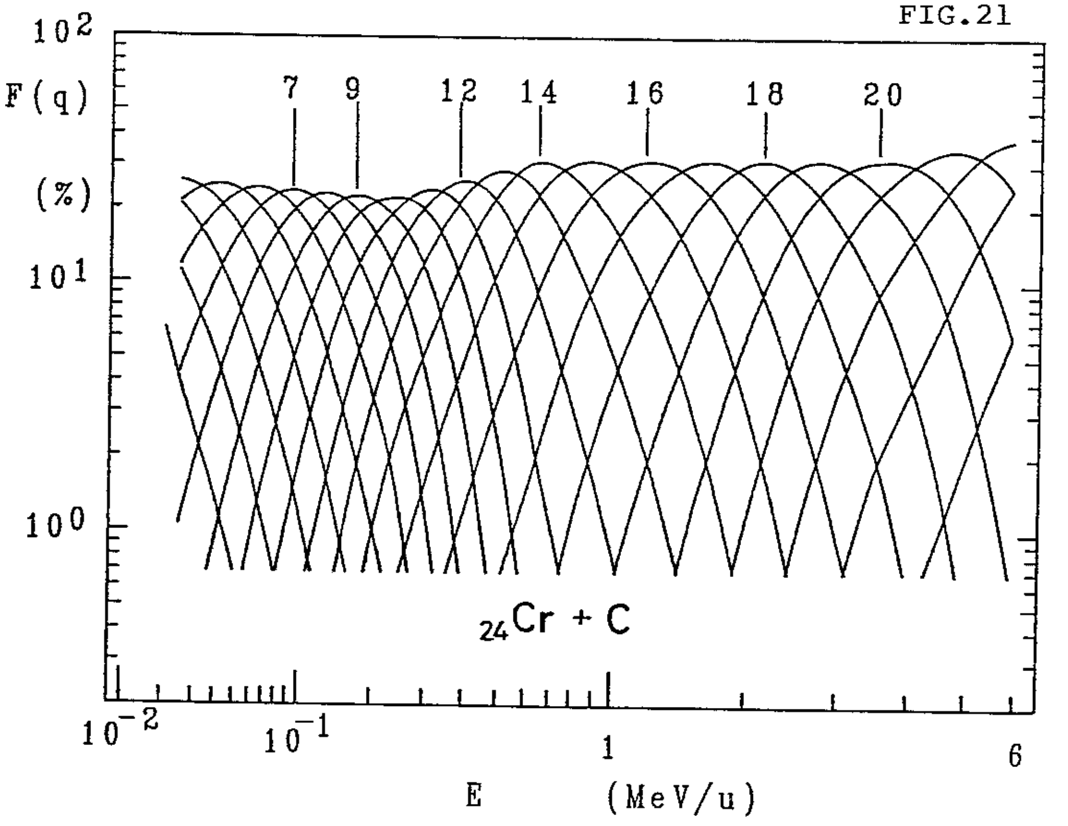


10^2
F(q)
(%)
10^1
10^0
5
7
9
11
13
15
17
19
$_{22}$Ti + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.20

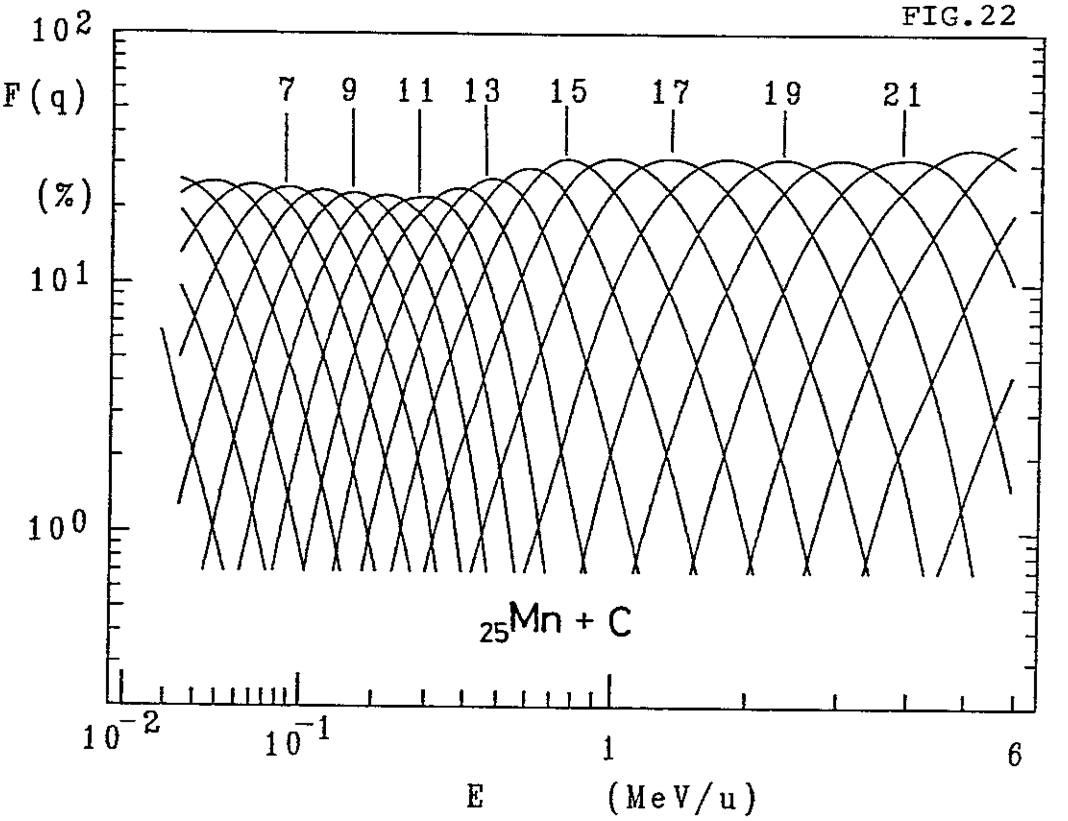


10^2
F(q)
(%)
10^1
10^0
7
9
12
14
16
18
20
$_{23}$V + C
10^{-2}
10^{-1}
1
6
E (MeV/u)



10^2
F(q)
(%)
10^1
10^0
7 9 12 14 16 18 20
$_{24}$Cr + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.21



10^2
F(q)
(%)
10^1
10^0
7 9 11 13 15 17 19 21
$_{25}$Mn + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.22

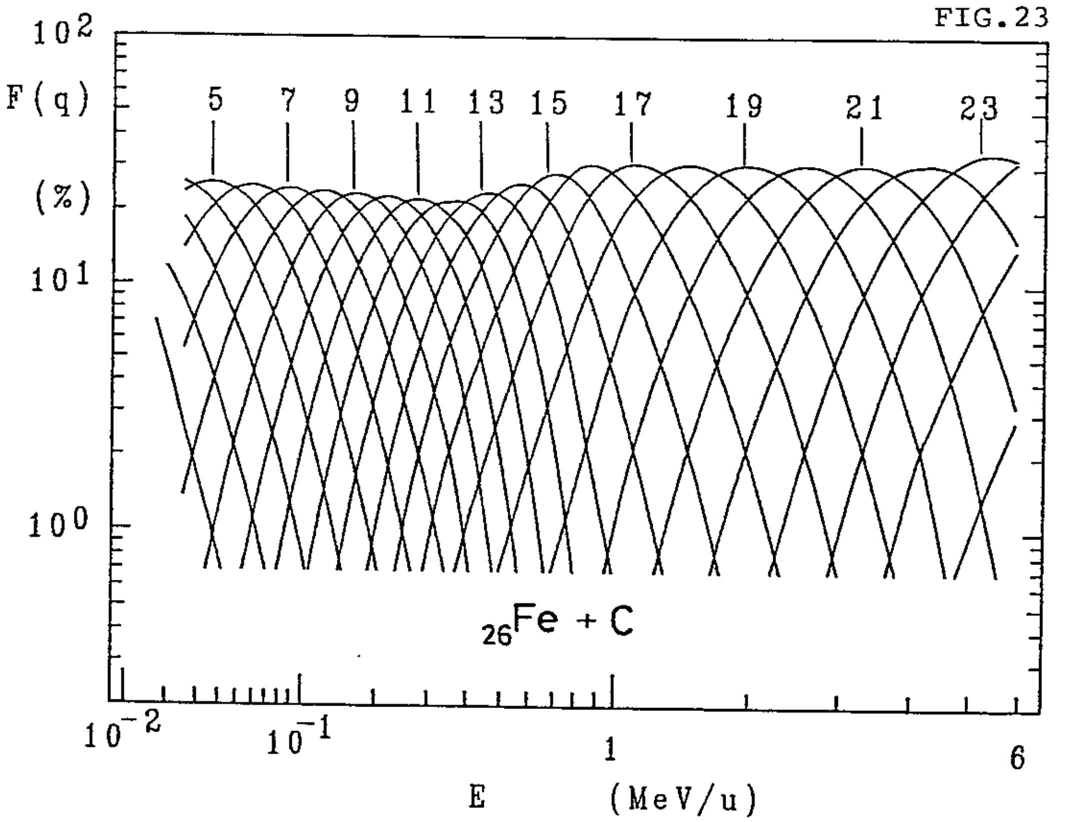


FIG.23
10^2
F(q)
(%)
10^1
10^0
5
7
9
11
13
15
17
19
21
23
$_{26}Fe + C$
10^{-2}
10^{-1}
1
6
E (MeV/u)

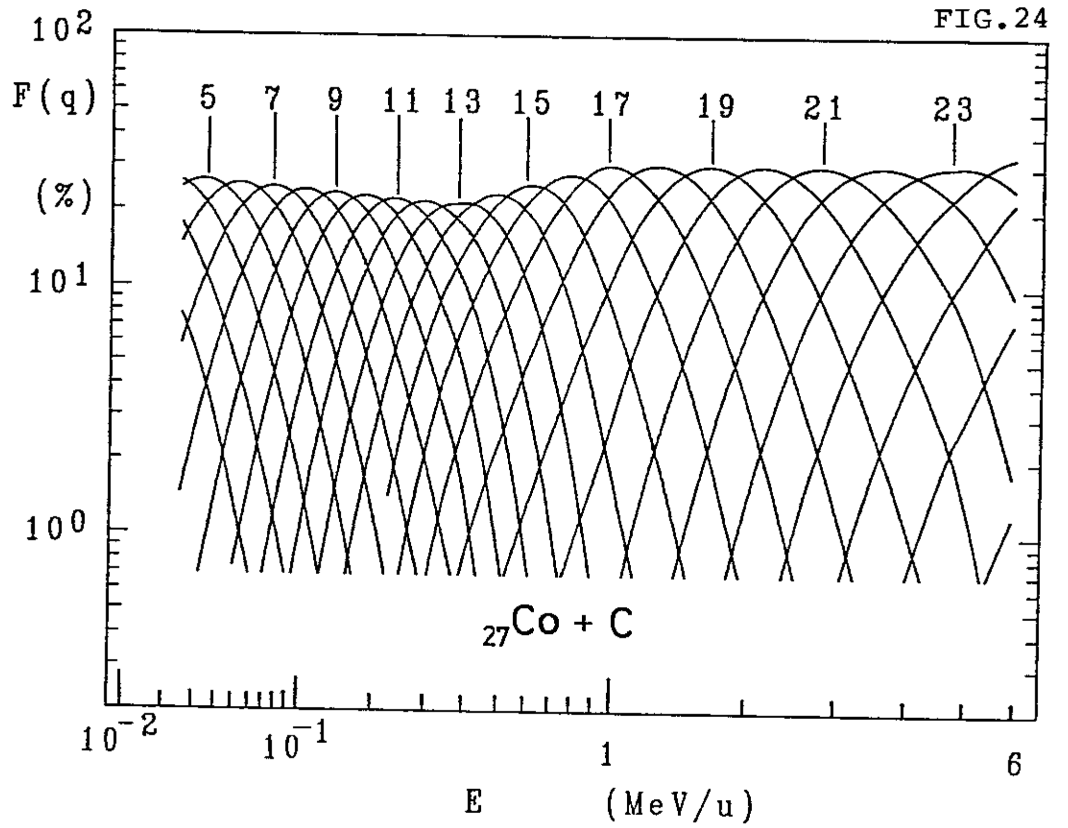
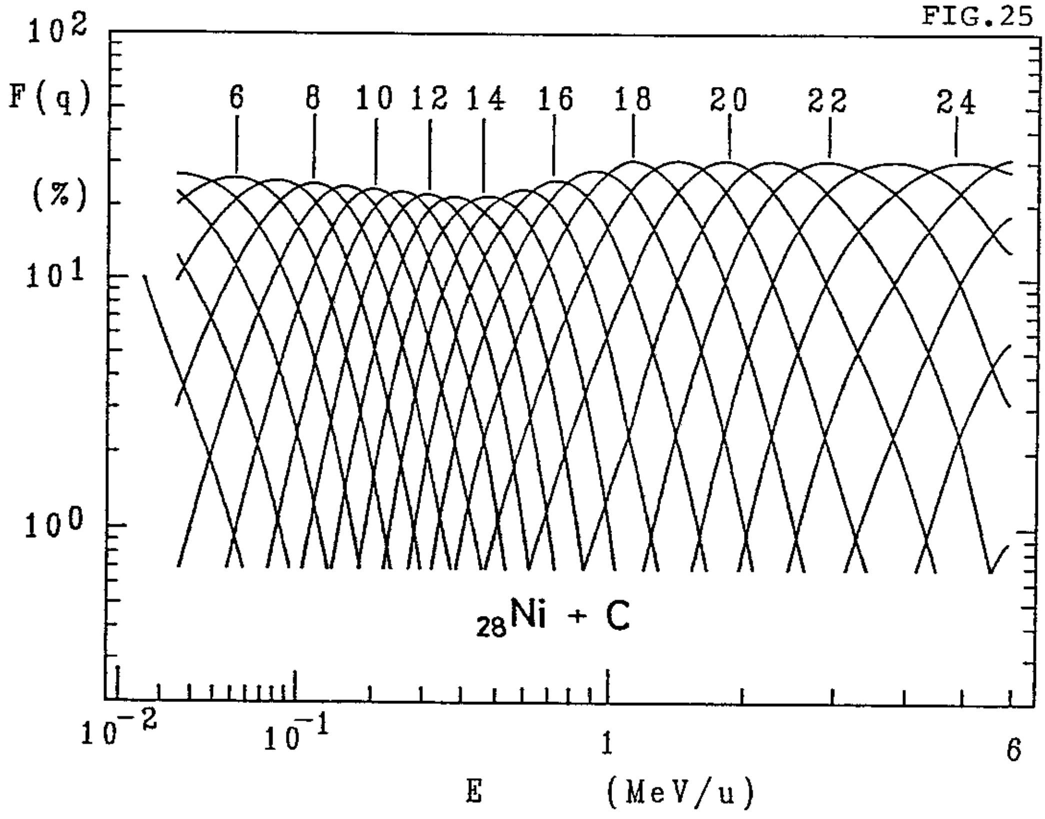


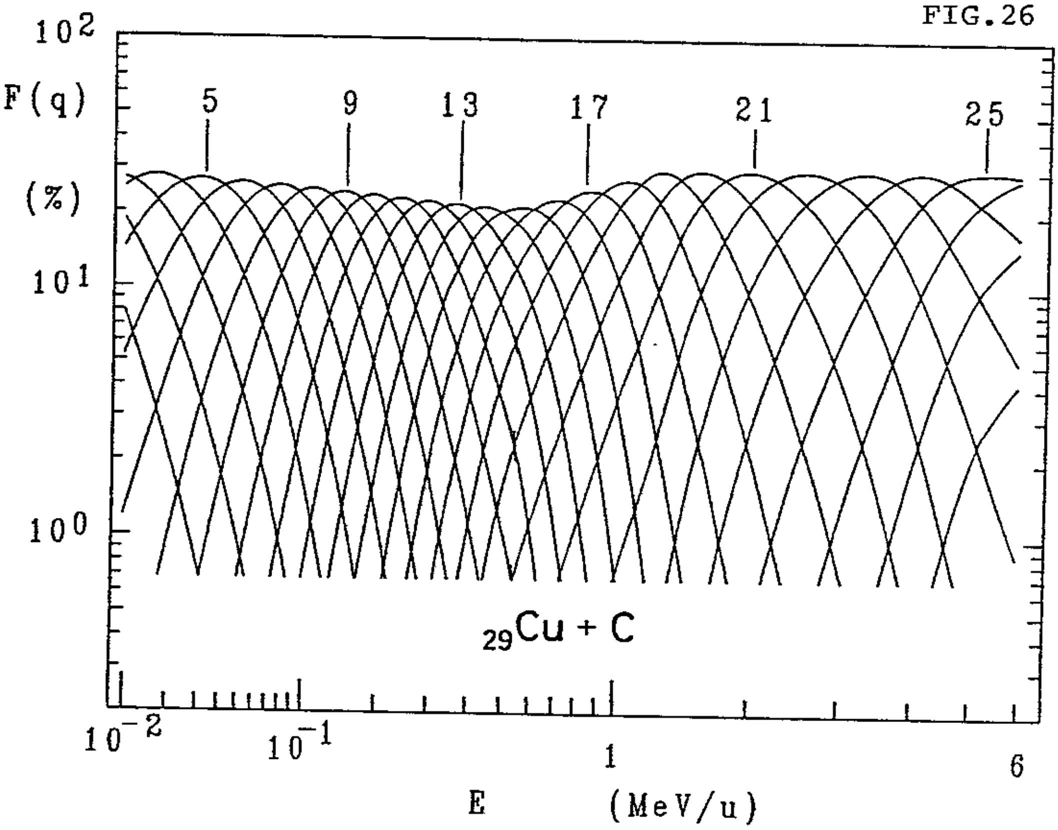
FIG.24
10^2
F(q)
(%)
10^1
10^0
5
7
9
11
13
15
17
19
21
23
$_{27}Co + C$
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.25



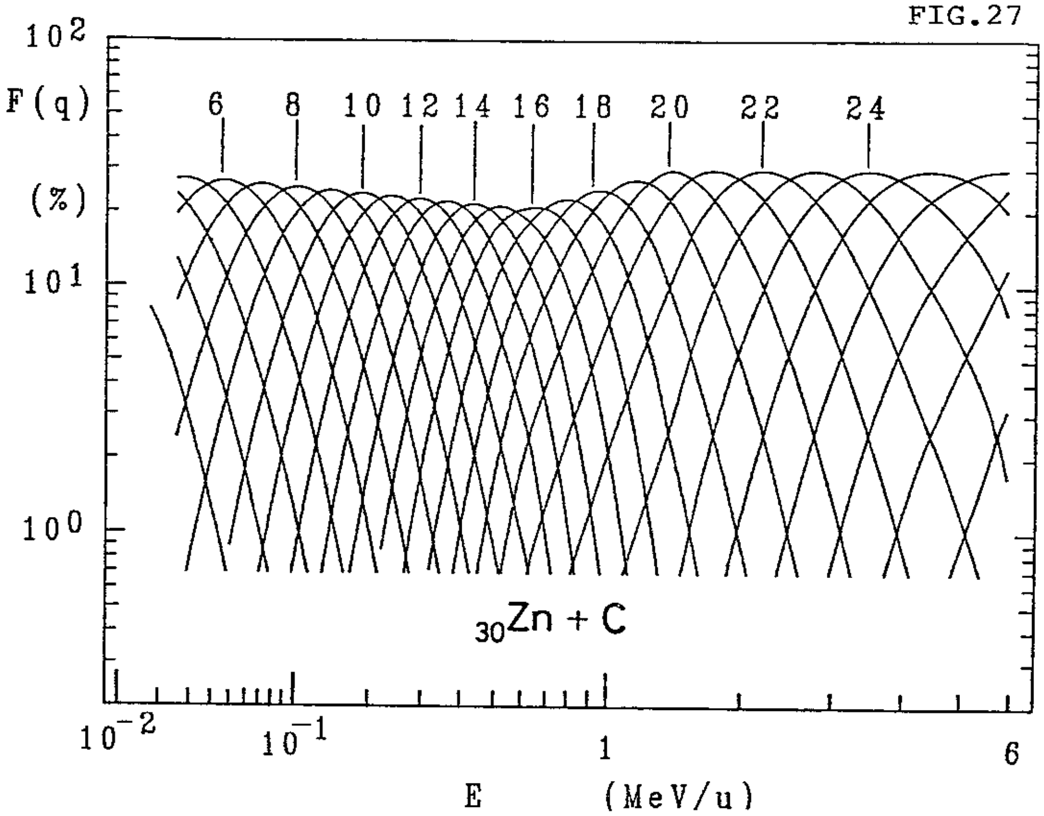
10^2
F(q)
(%)
10^1
10^0
6 8 10 12 14 16 18 20 22 24
$_{28}$Ni + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.26



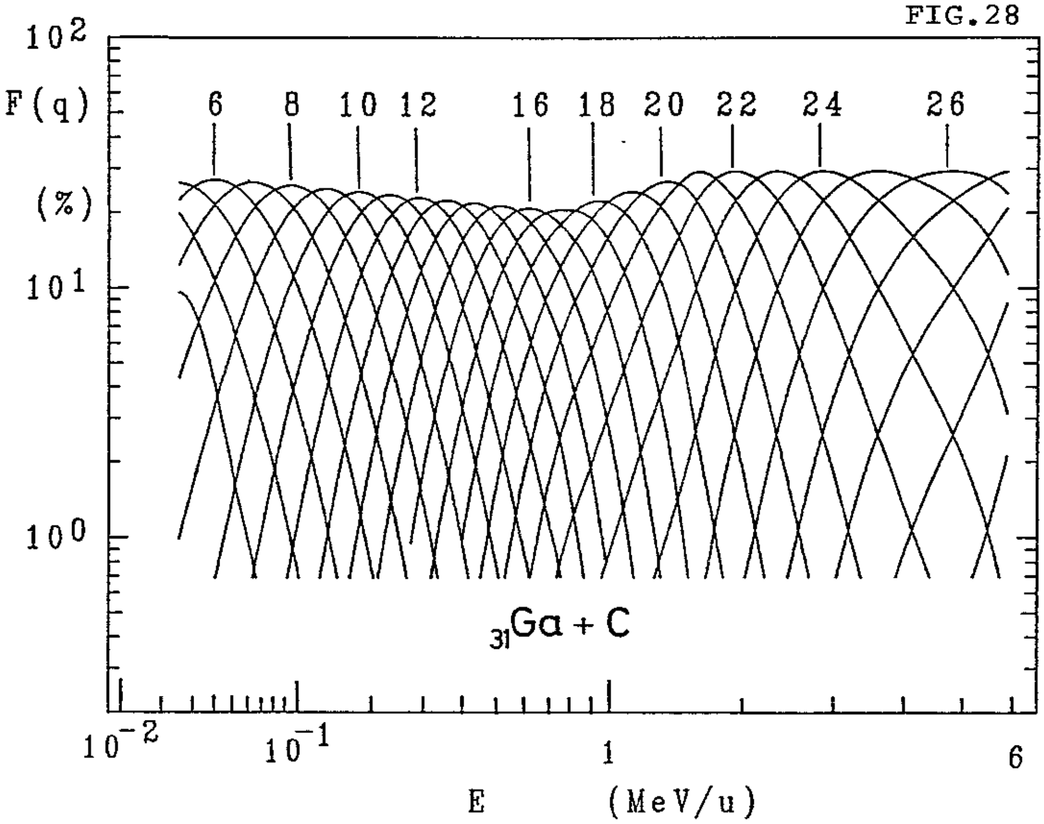
10^2
F(q)
(%)
10^1
10^0
5 9 13 17 21 25
$_{29}$Cu + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.27



10^2
F(q)
(%)
10^1
10^0
6 8 10 12 14 16 18 20 22 24
30Zn + C
10^-2 10^-1 1 6
E (MeV/u)

FIG.28



10^2
F(q)
(%)
10^1
10^0
6 8 10 12 16 18 20 22 24 26
31Ga + C
10^-2 10^-1 1 6
E (MeV/u)

FIG.29

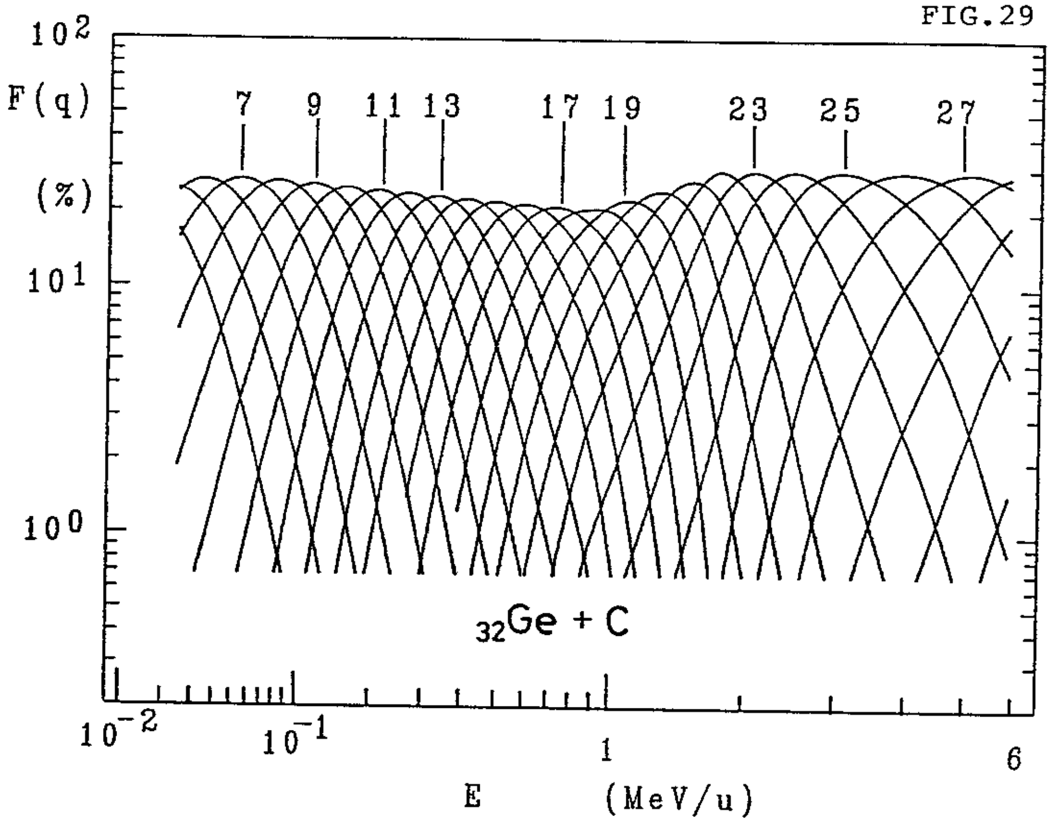

10^2
F(q)
(%)
10^1
10^0
7
9
11
13
17
19
23
25
27
32Ge + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.30

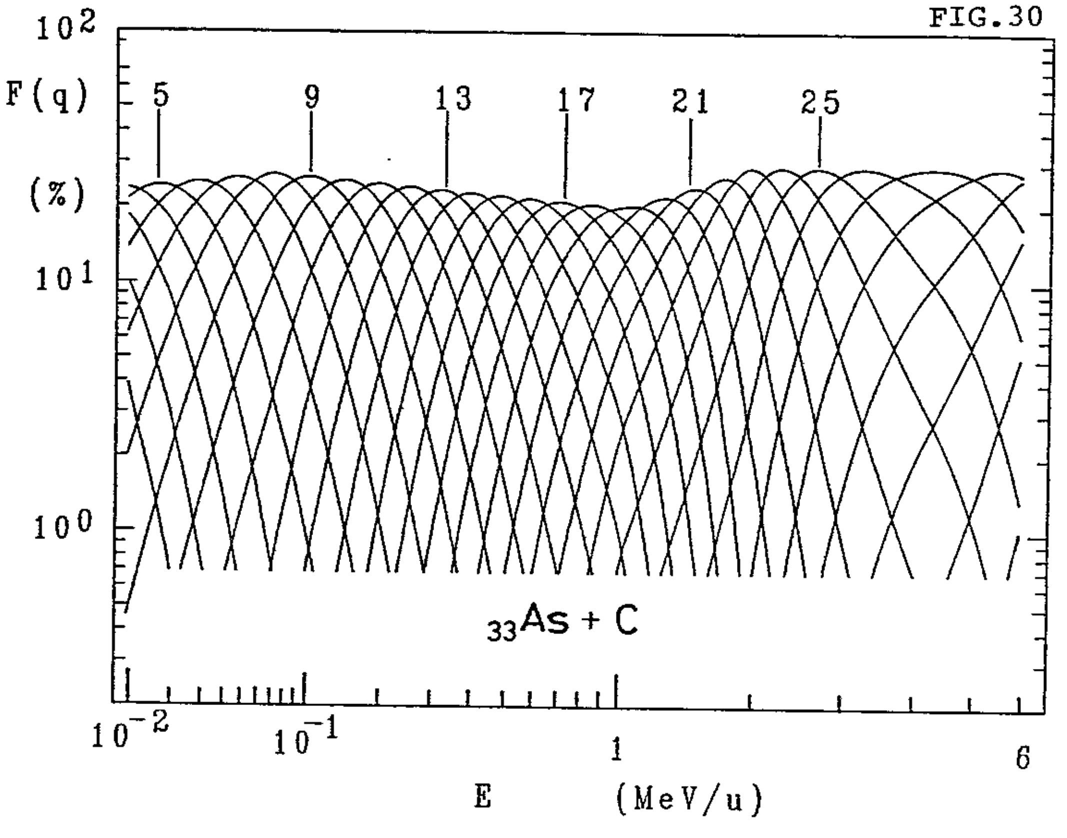

10^2
F(q)
(%)
10^1
10^0
5
9
13
17
21
25
33As + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.31

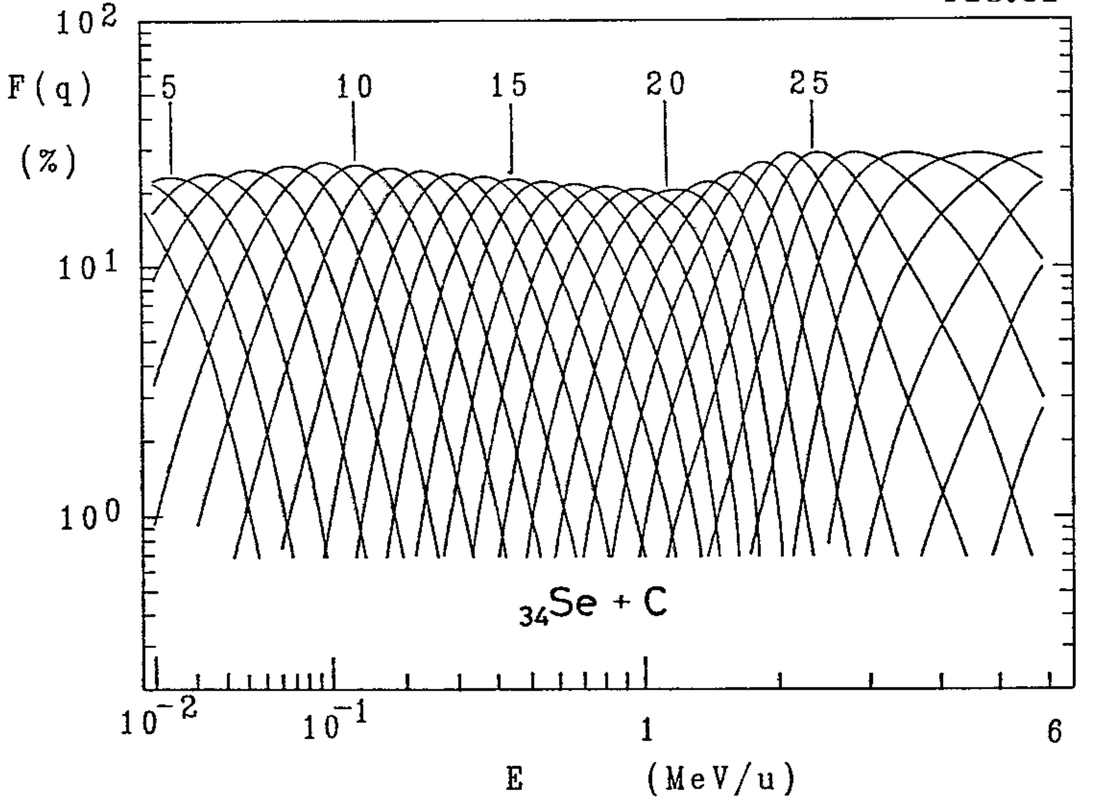

10^2
F(q)
(%)
10^1
10^0
5
10
15
20
25
34Se + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.32

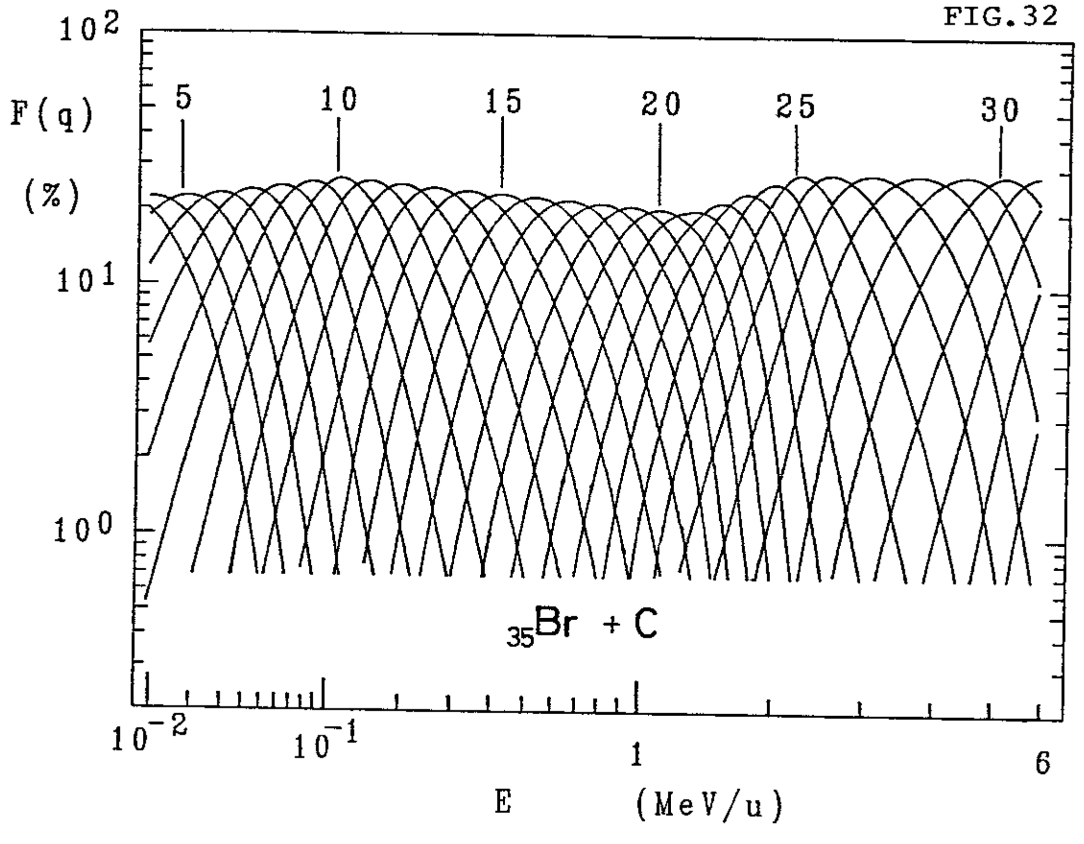
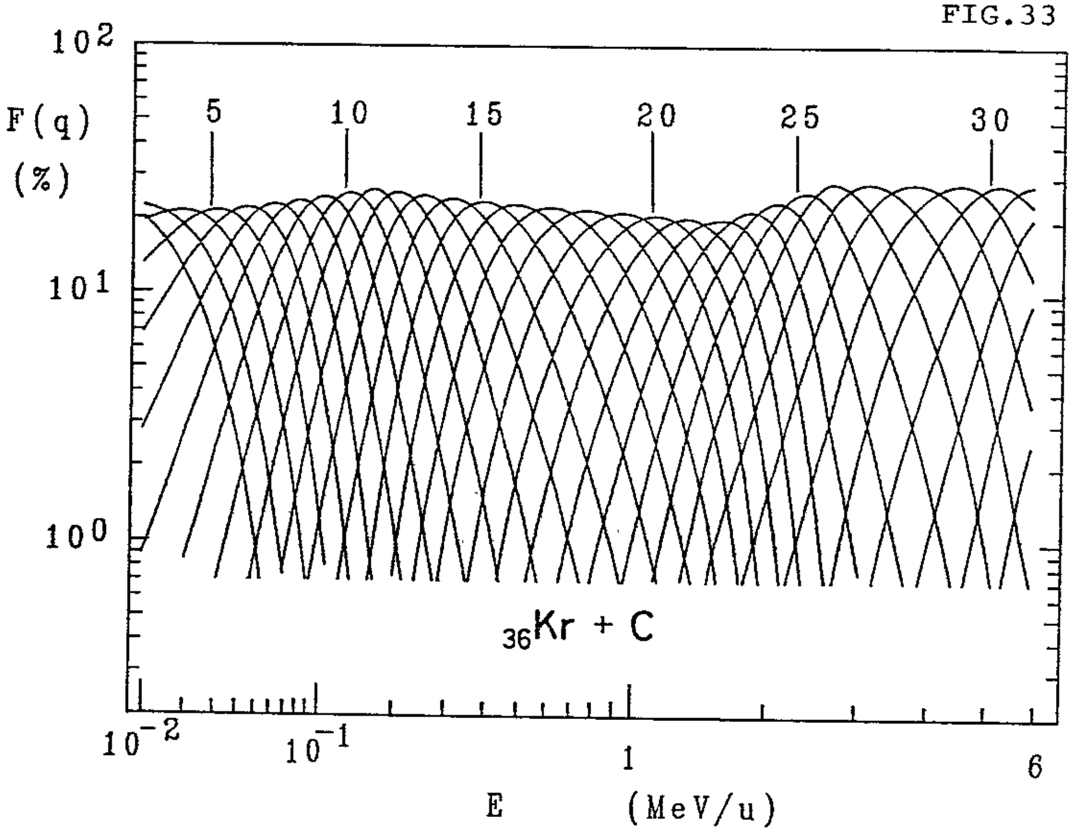
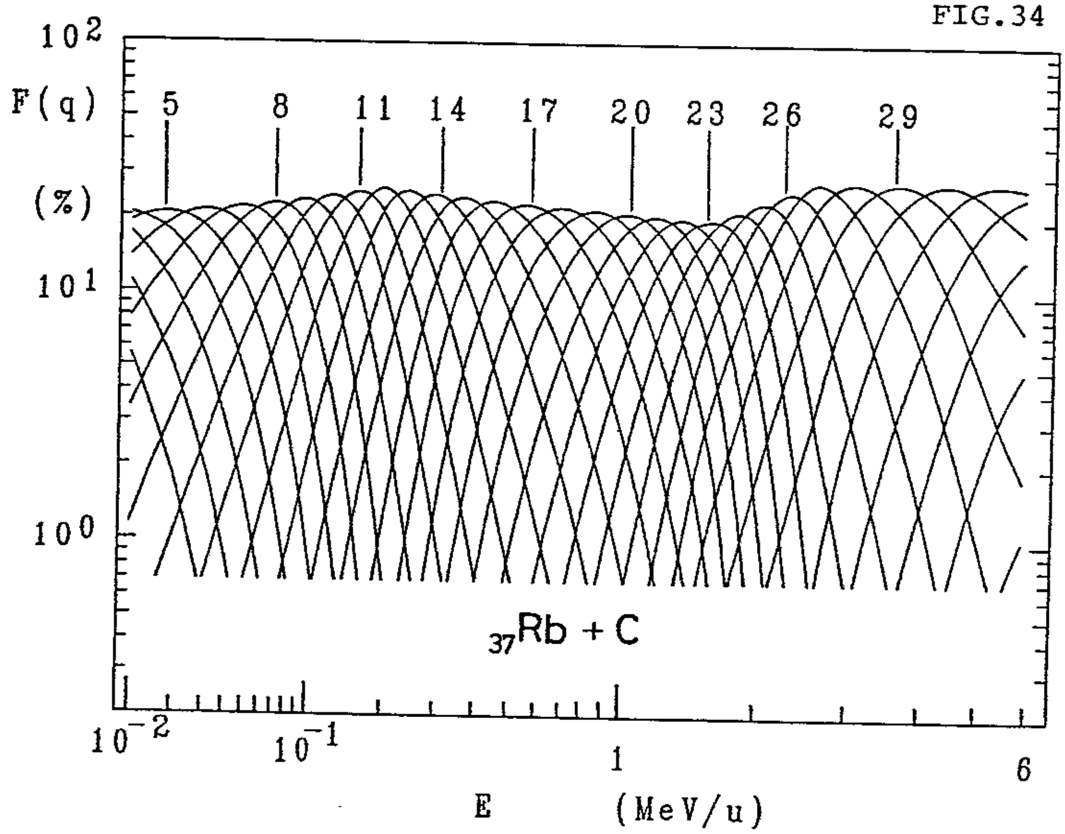

10^2
F(q)
(%)
10^1
10^0
5
10
15
20
25
30
35Br + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.33



10^2
F(q)
(%)
10^1
10^0
5
10
15
20
25
30
$_{36}$Kr + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.34



10^2
F(q)
(%)
10^1
10^0
5
8
11
14
17
20
23
26
29
$_{37}$Rb + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.35

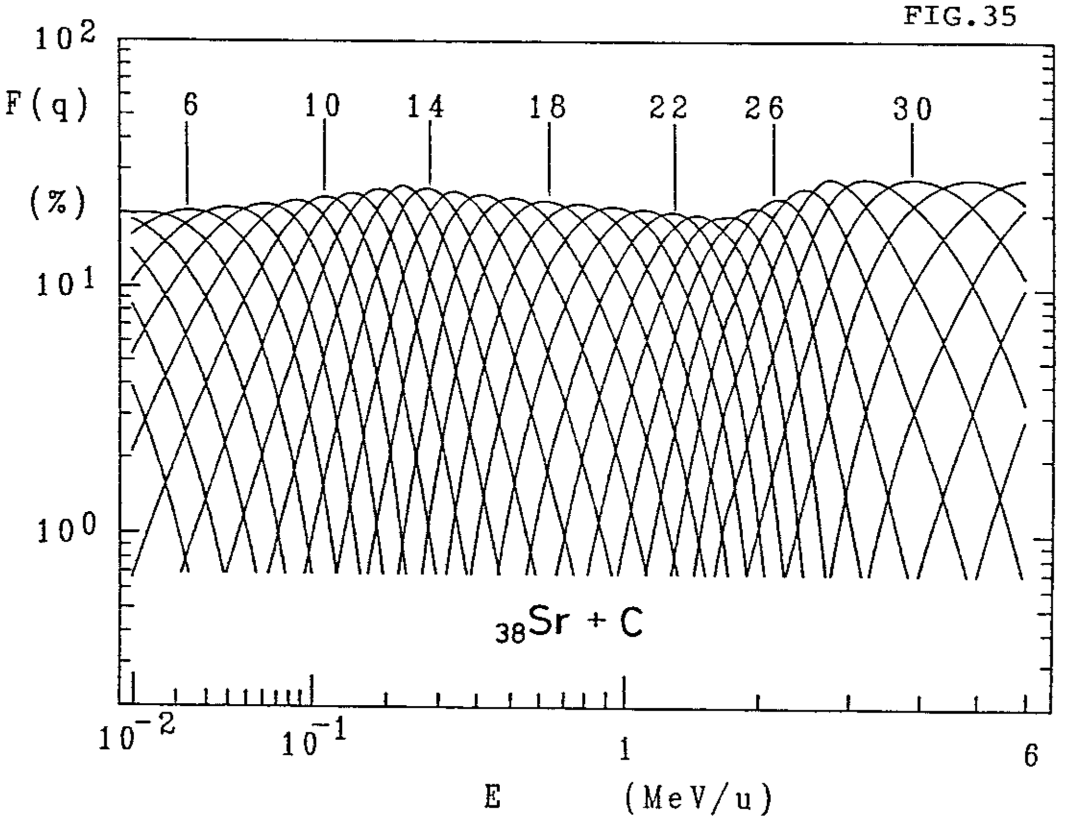

10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
38Sr + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.36

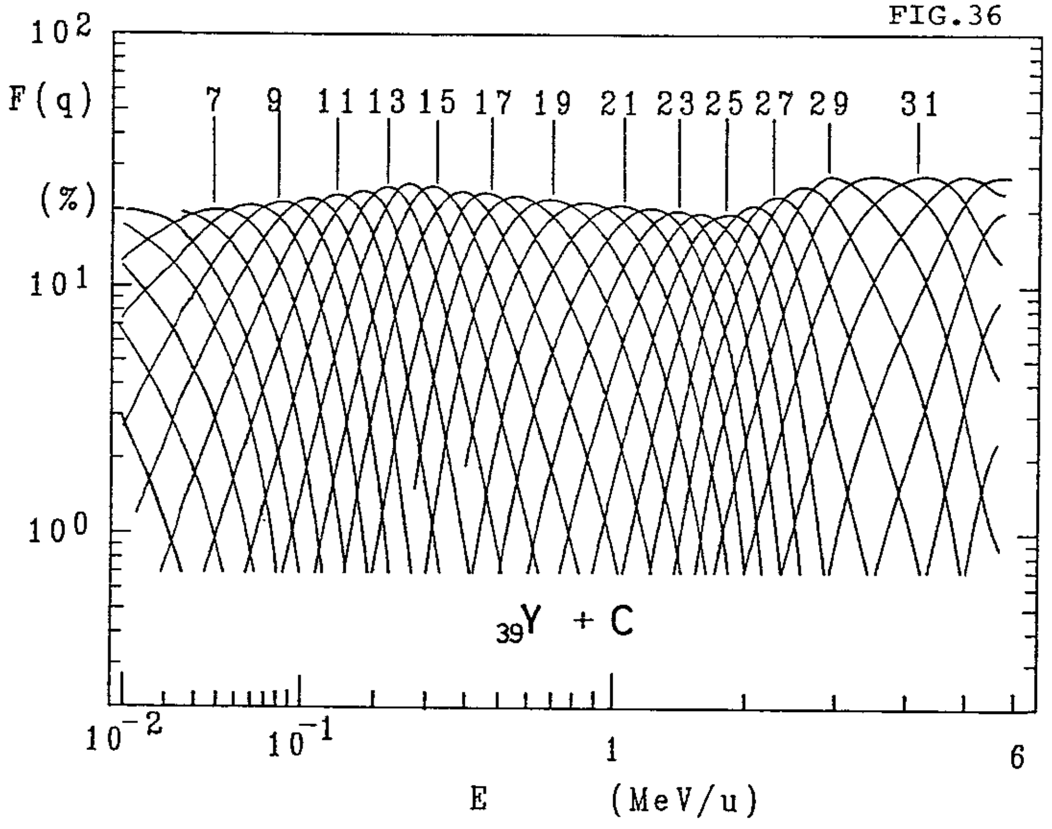
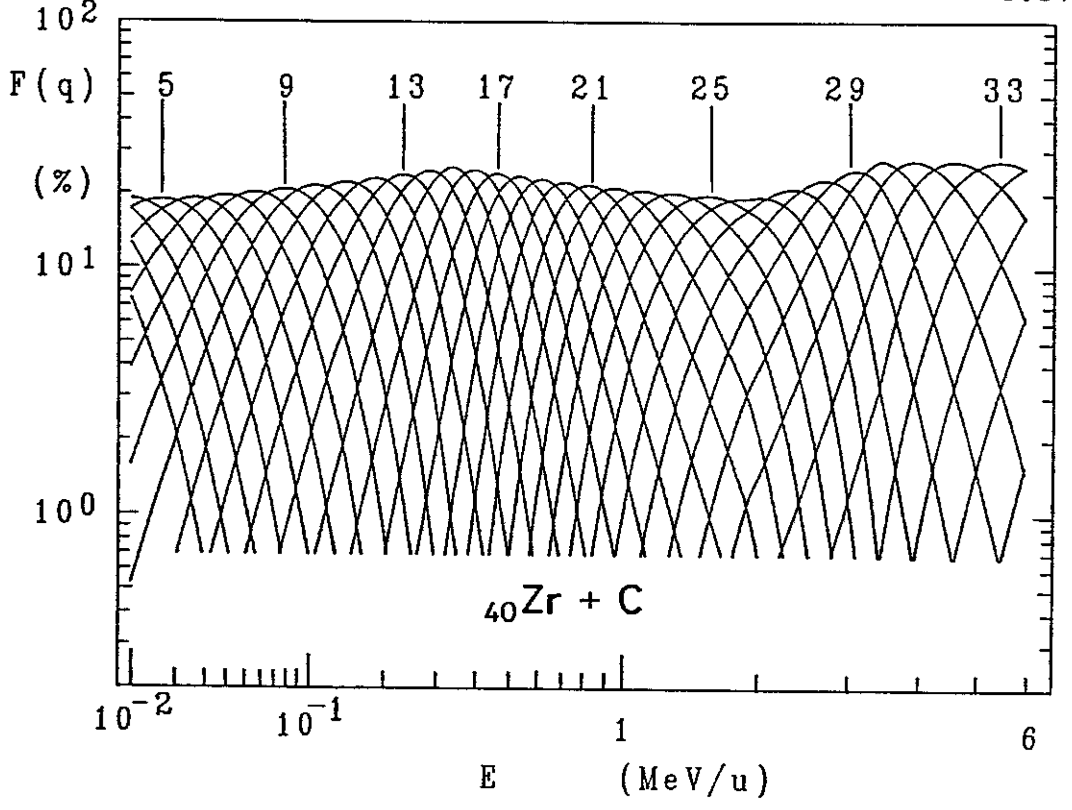
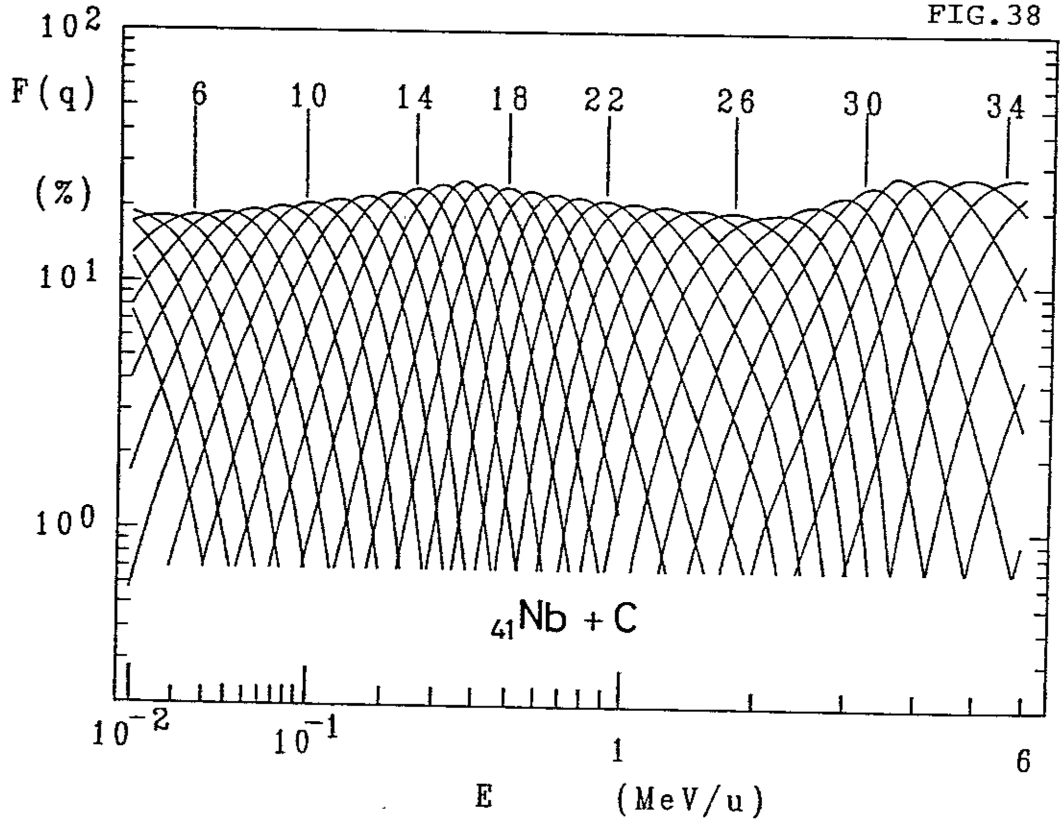

10^2
F(q)
(%)
10^1
10^0
7
9
11
13
15
17
19
21
23
25
27
29
31
39Y + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.37



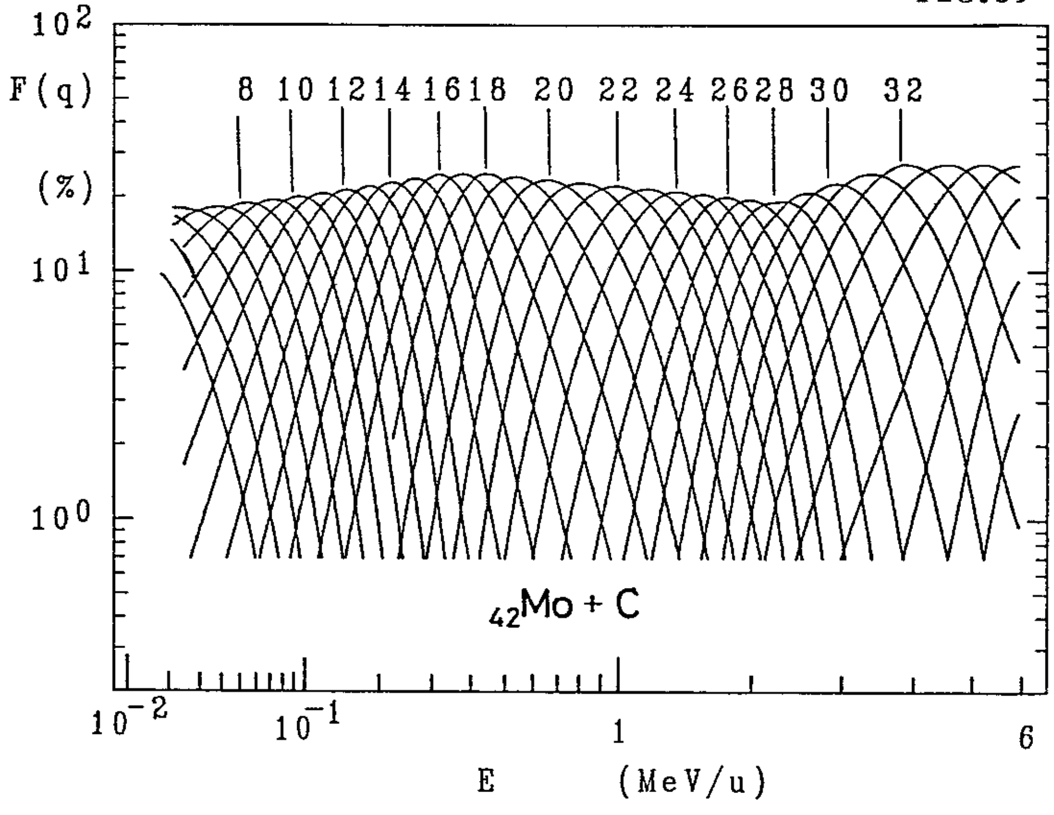
10^2
F(q)
(%)
10^1
10^0
5
9
13
17
21
25
29
33
$_{40}Zr + C$
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.38



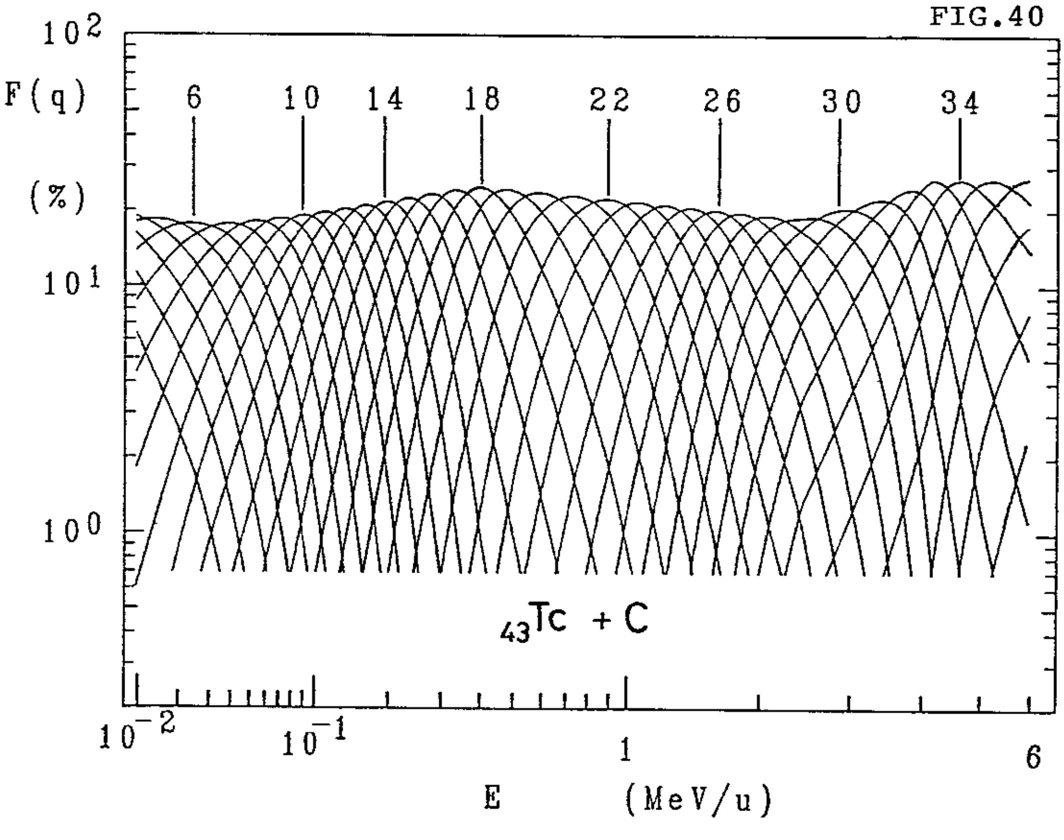
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
$_{41}Nb + C$
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.39



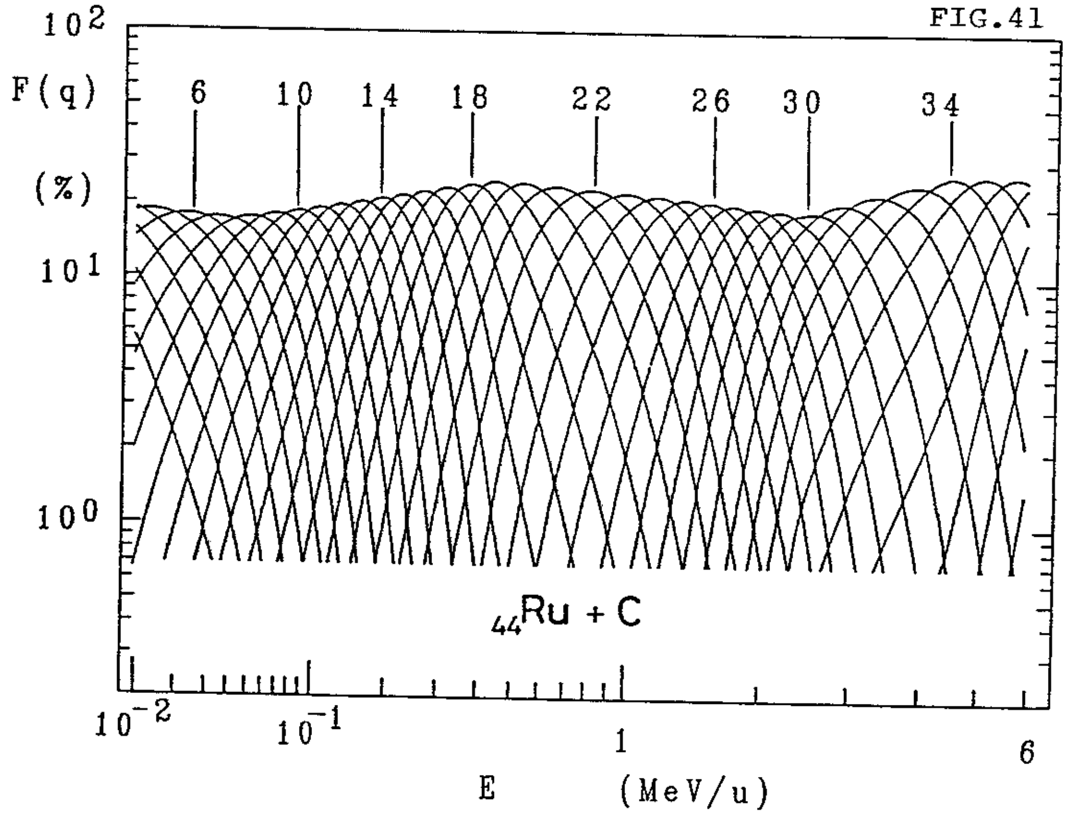
10^2
F(q)
(%)
10^1
10^0
8 10 12 14 16 18 20 22 24 26 28 30 32
$_{42}$Mo + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.40



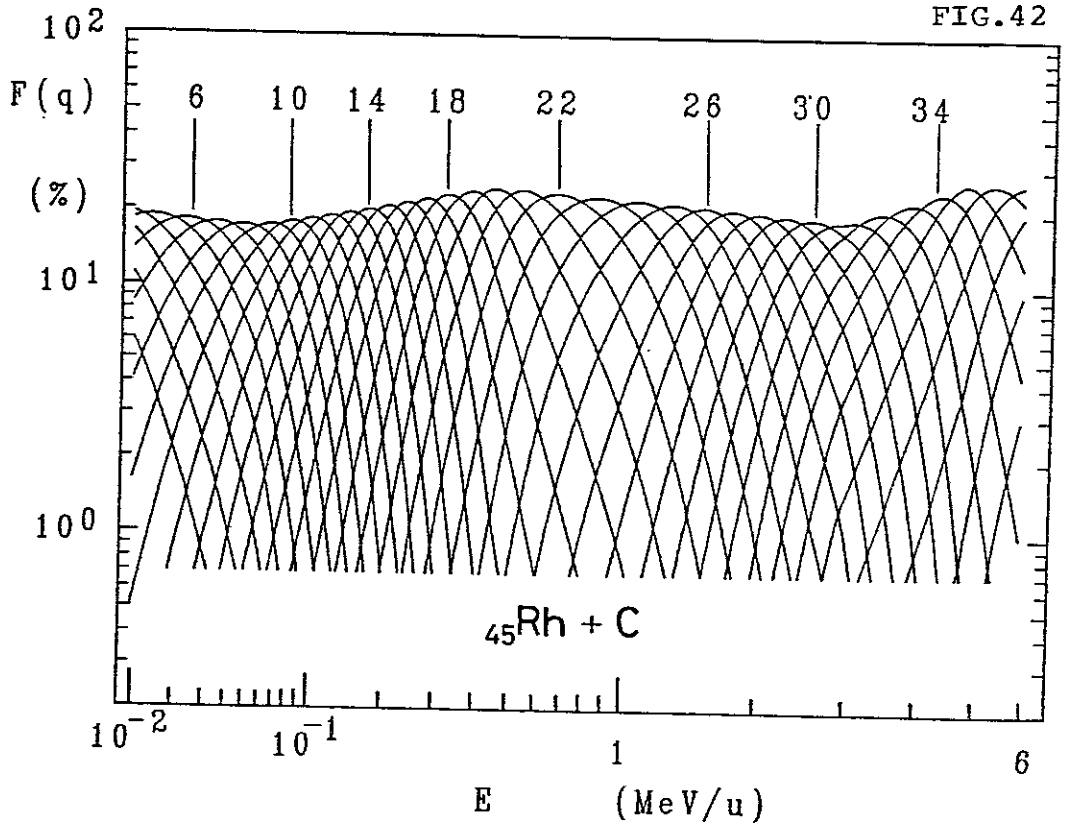
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34
$_{43}$Tc + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.41



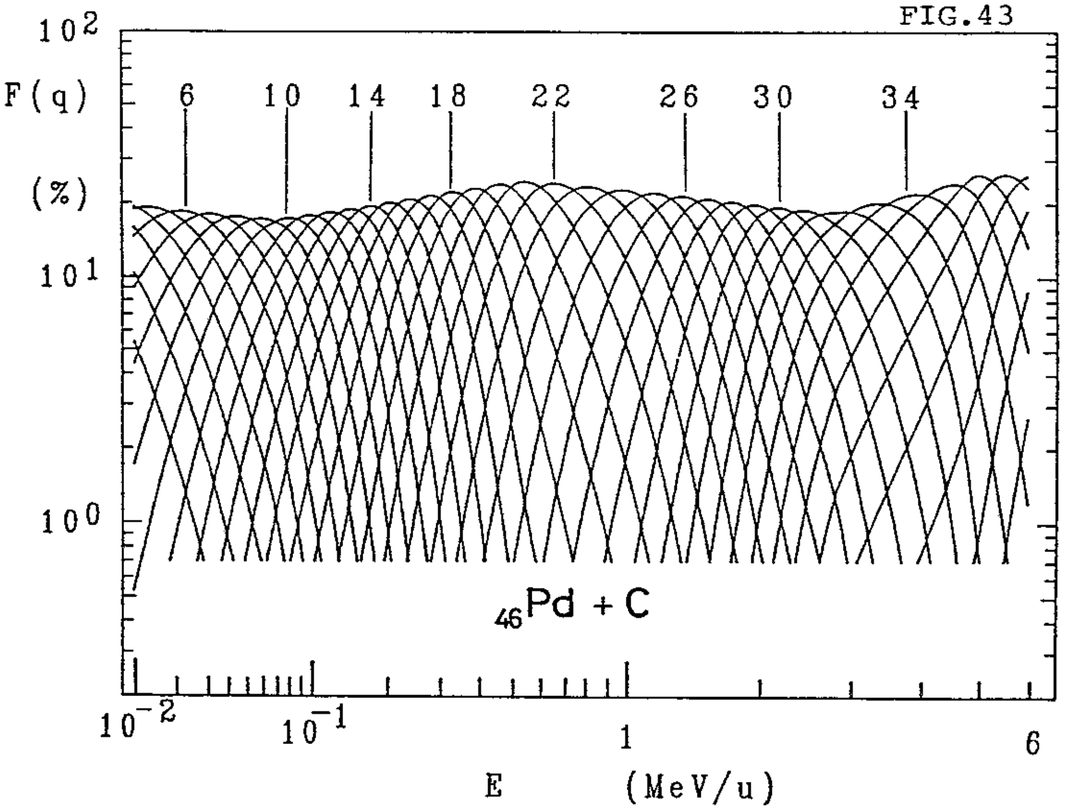
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
$_{44}$Ru + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.42



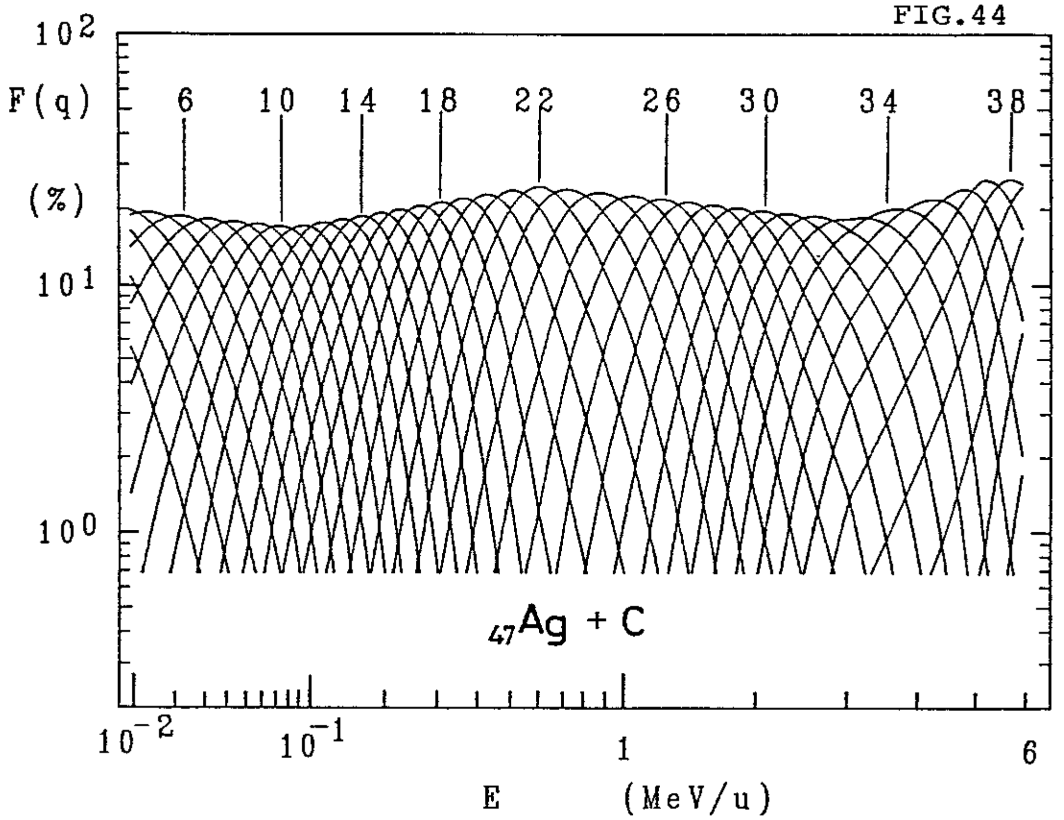
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
$_{45}$Rh + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.43



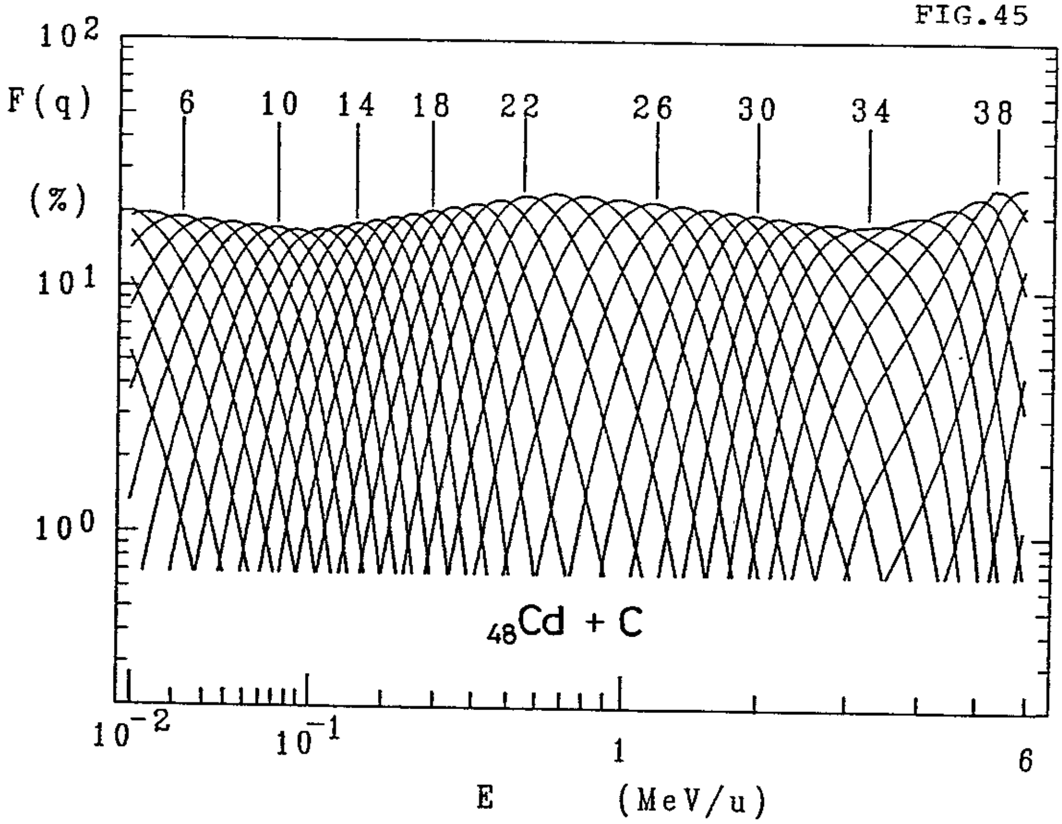
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
$_{46}$Pd + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.44



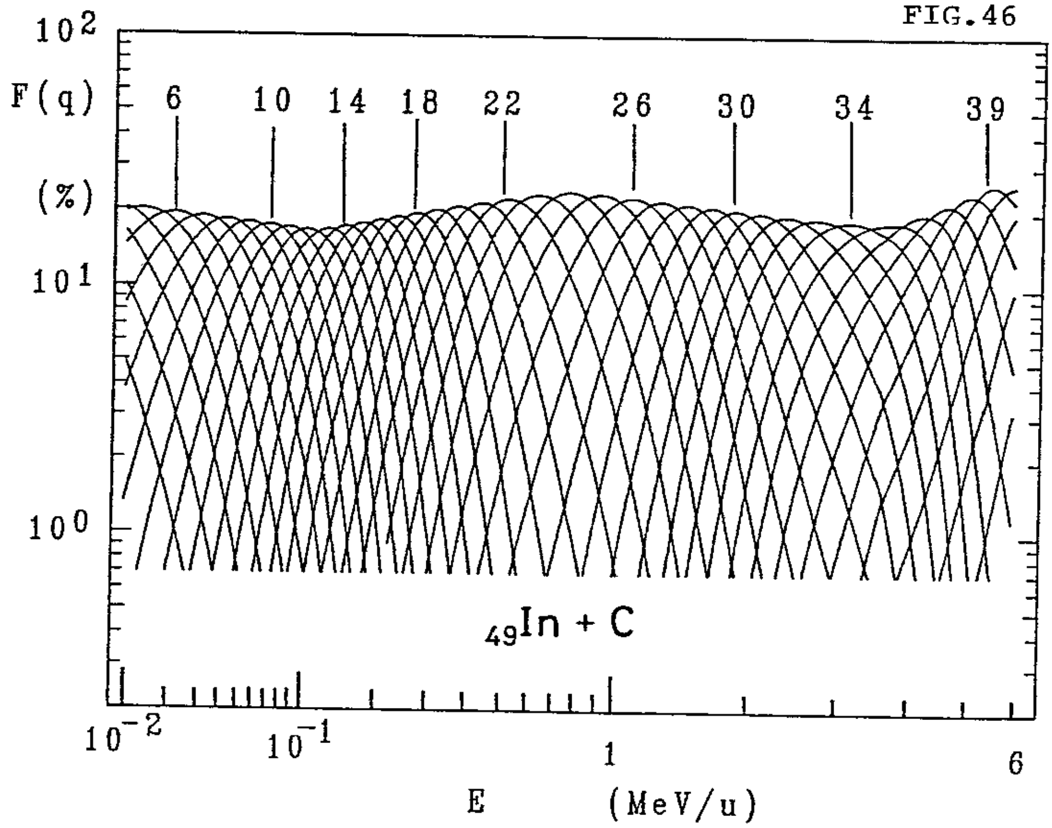
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
$_{47}$Ag + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.45



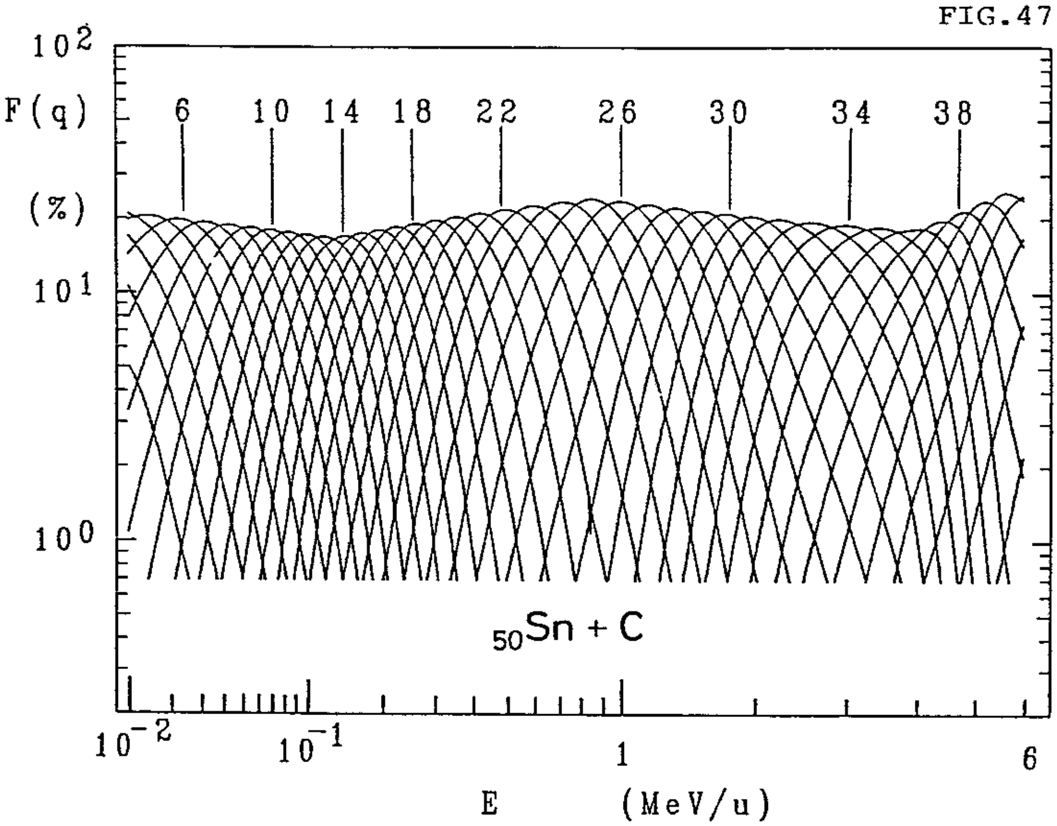
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
$_{48}$Cd + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.46



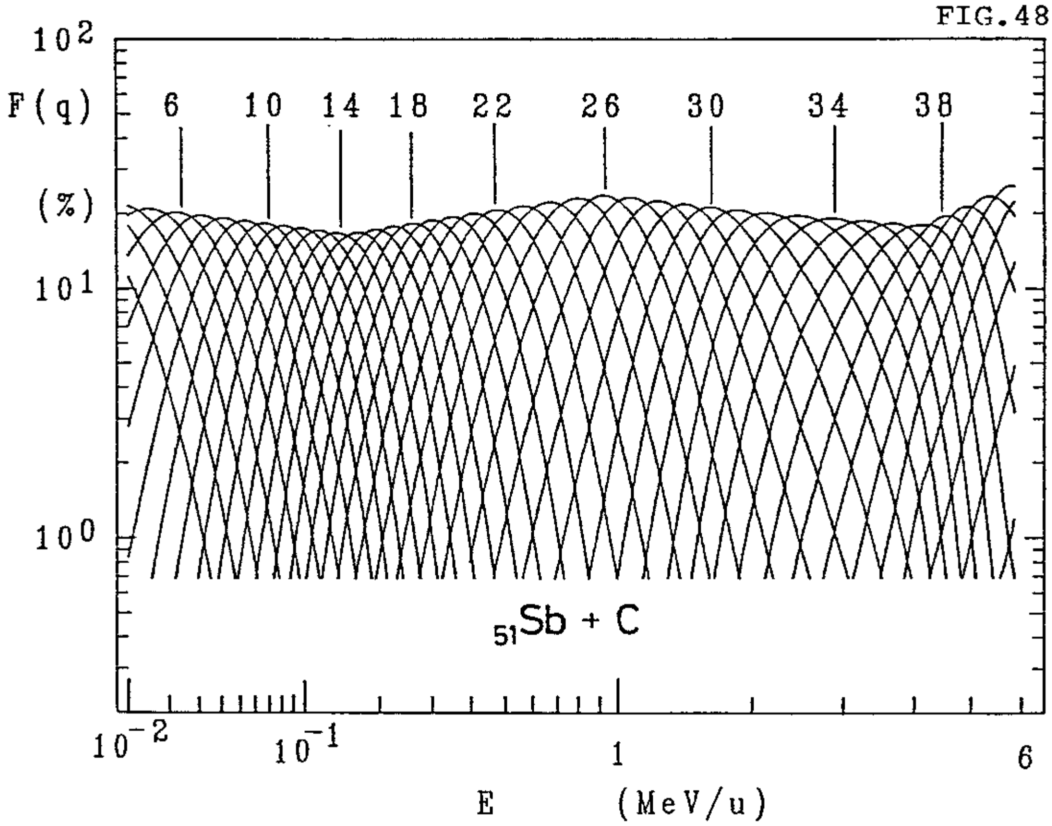
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
39
$_{49}$In + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.47



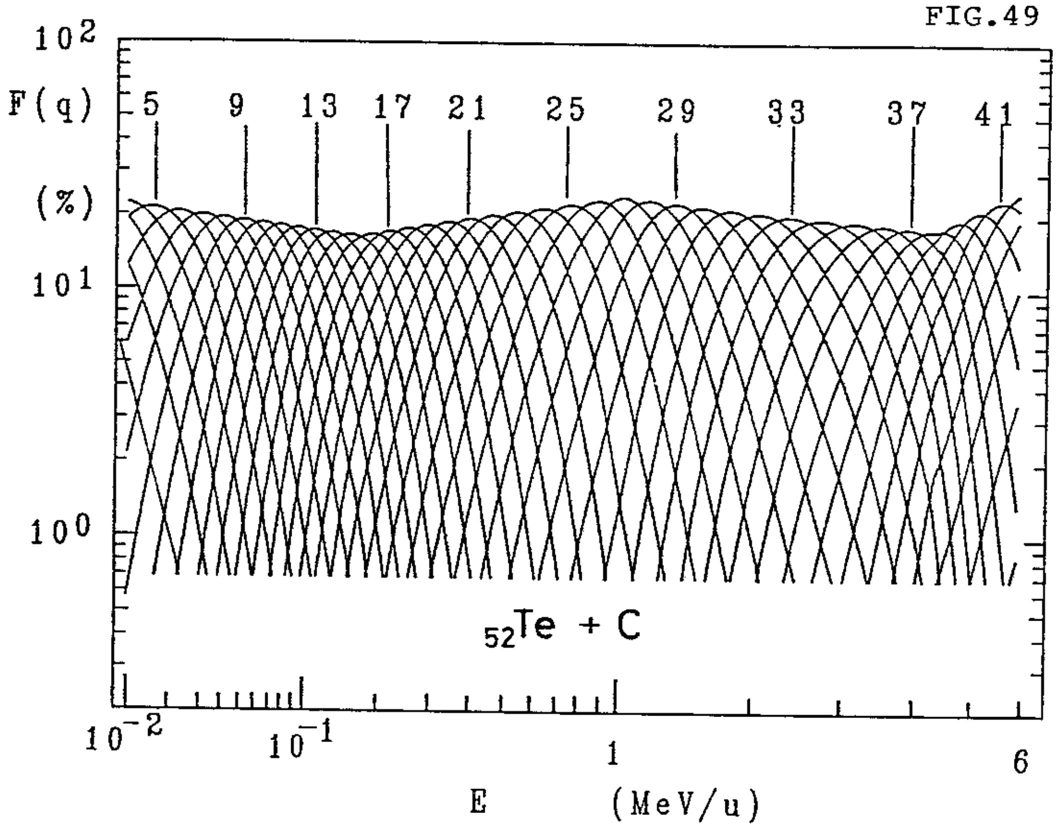
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
50Sn + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.48



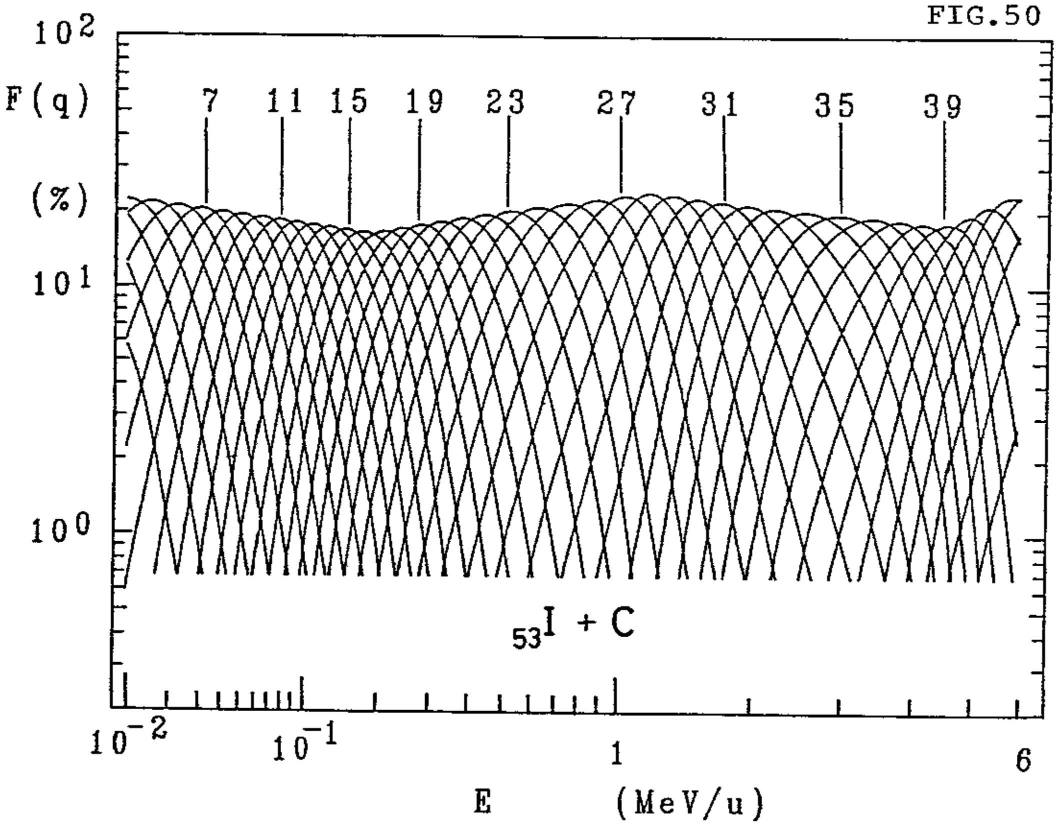
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
51Sb + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.49



10^2
F(q)
(%)
10^1
10^0
5 9 13 17 21 25 29 33 37 41
$_{52}$Te + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.50



10^2
F(q)
(%)
10^1
10^0
7 11 15 19 23 27 31 35 39
$_{53}$I + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.51

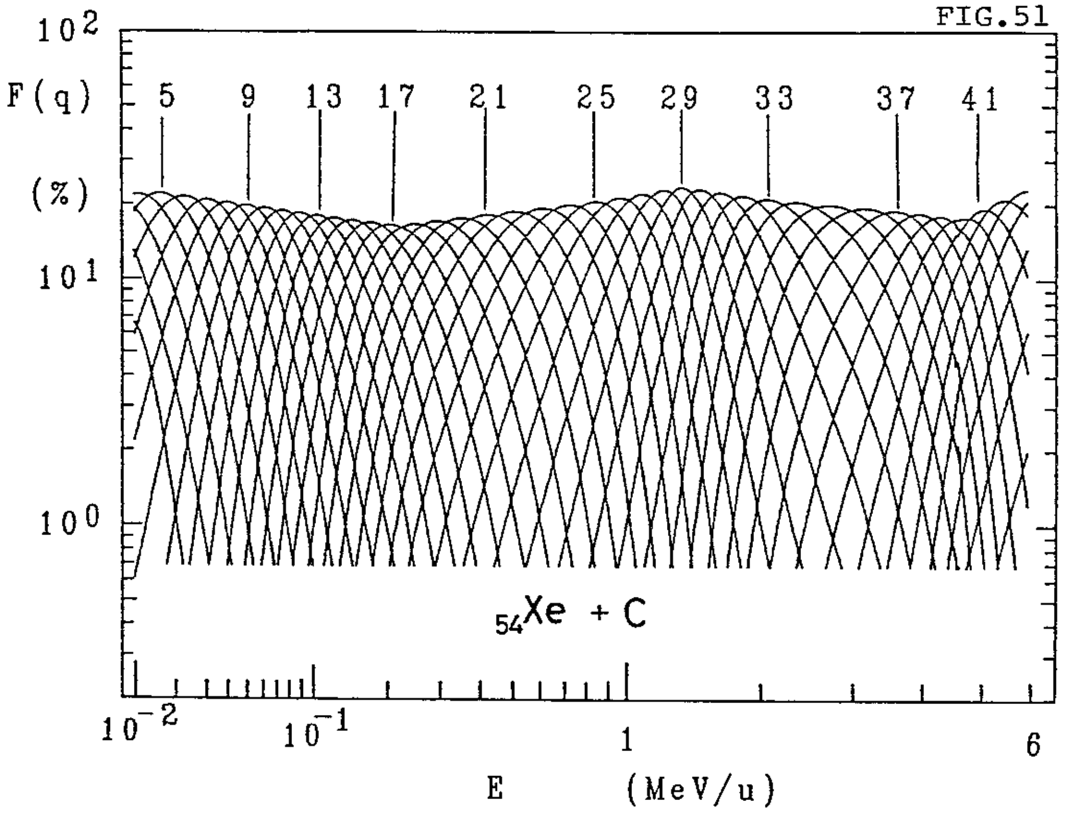

10^2
F(q)
(%)
10^1
10^0
5
9
13
17
21
25
29
33
37
41
54Xe + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.52

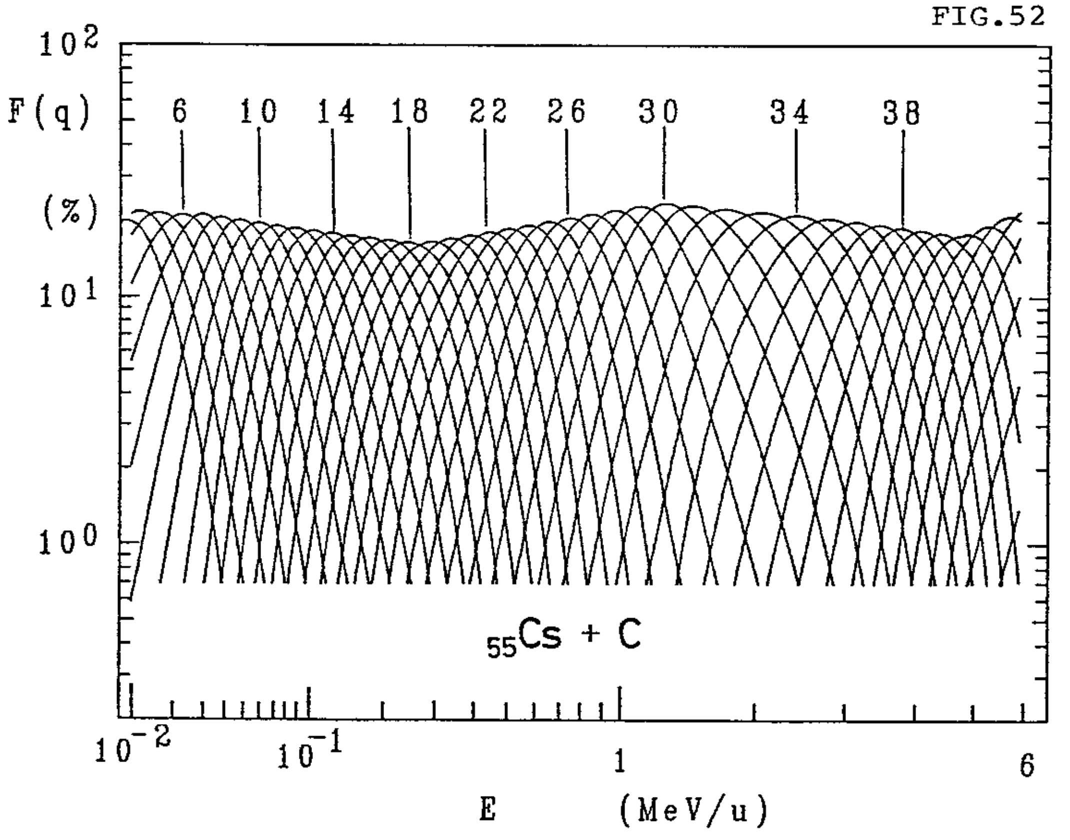
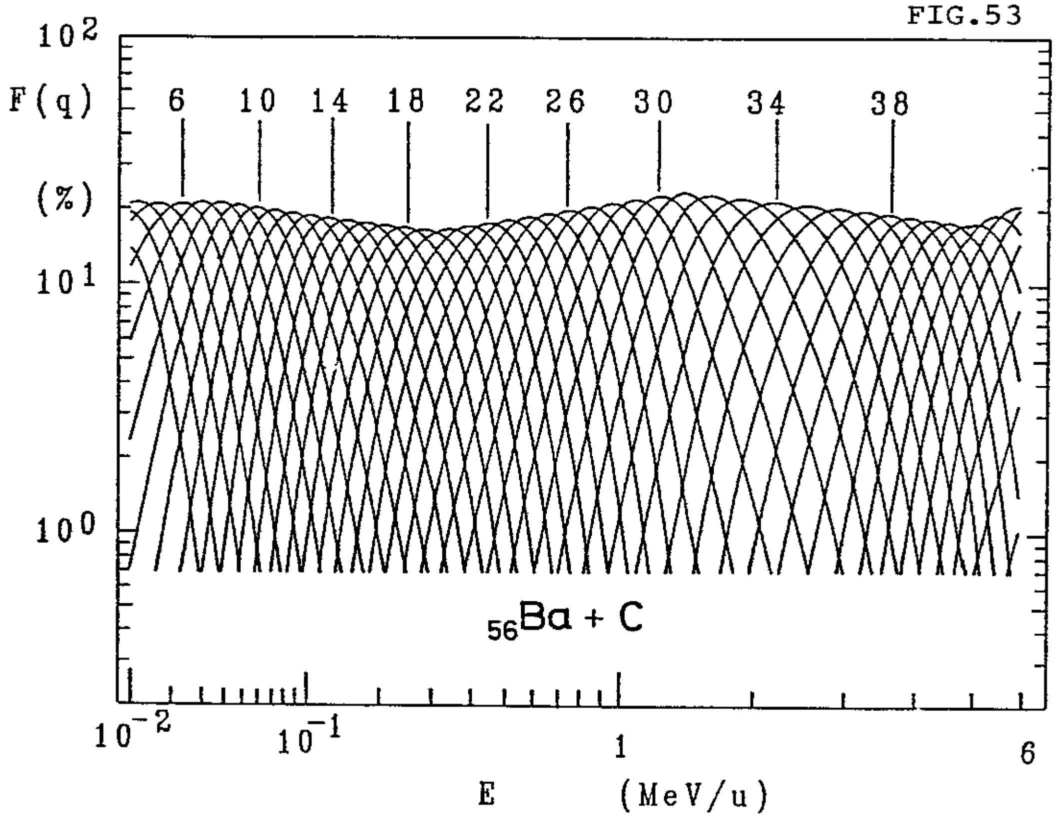
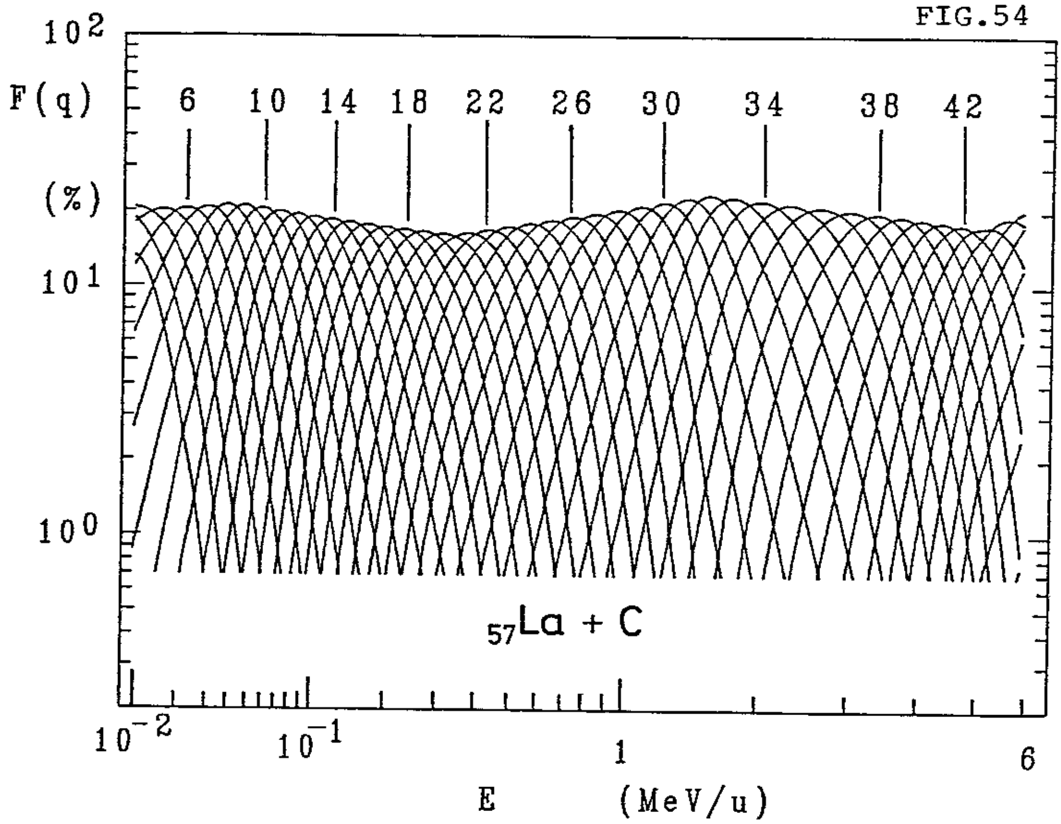

10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
55Cs + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.53



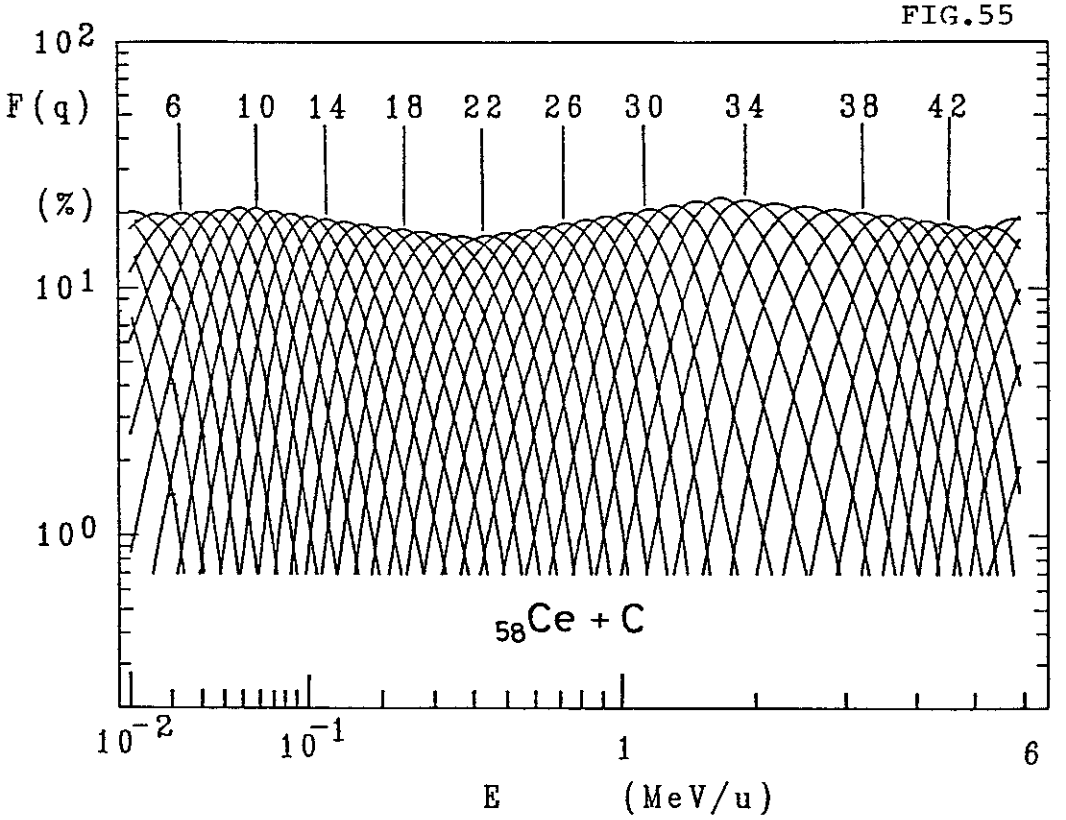
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38
56Ba + C
10^-2 10^-1 1 6
E (MeV/u)

FIG.54



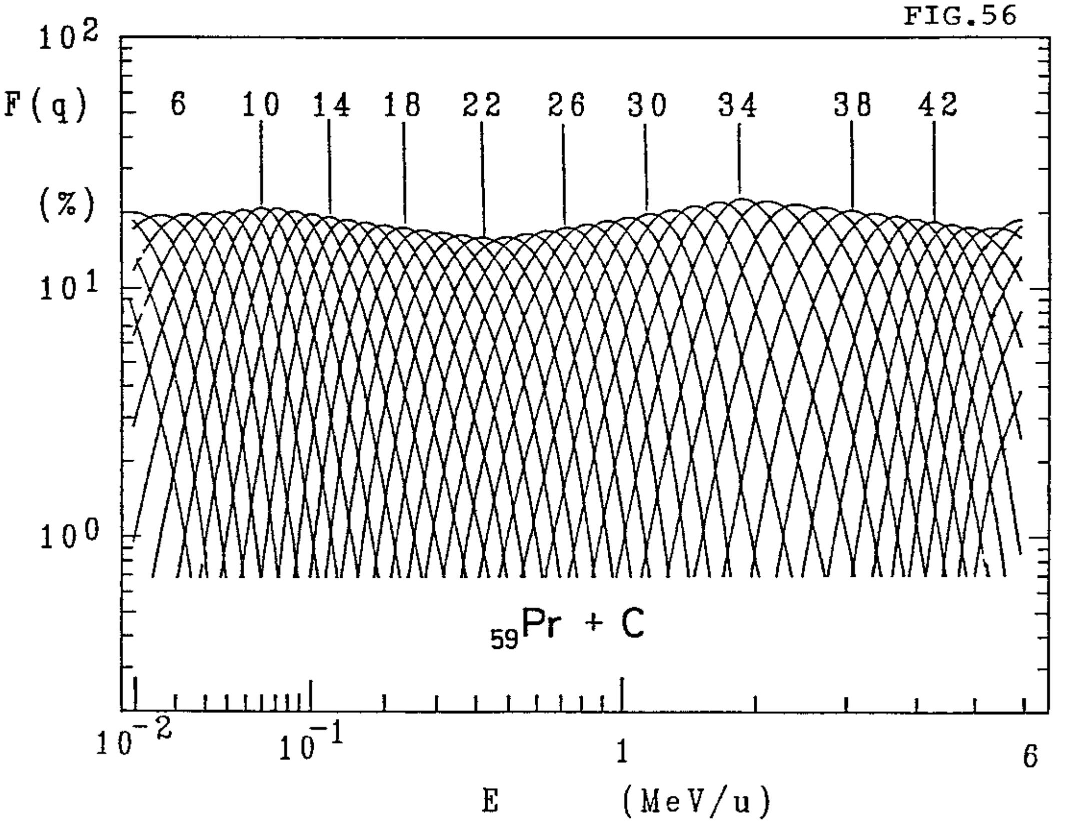
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42
57La + C
10^-2 10^-1 1 6
E (MeV/u)

FIG.55



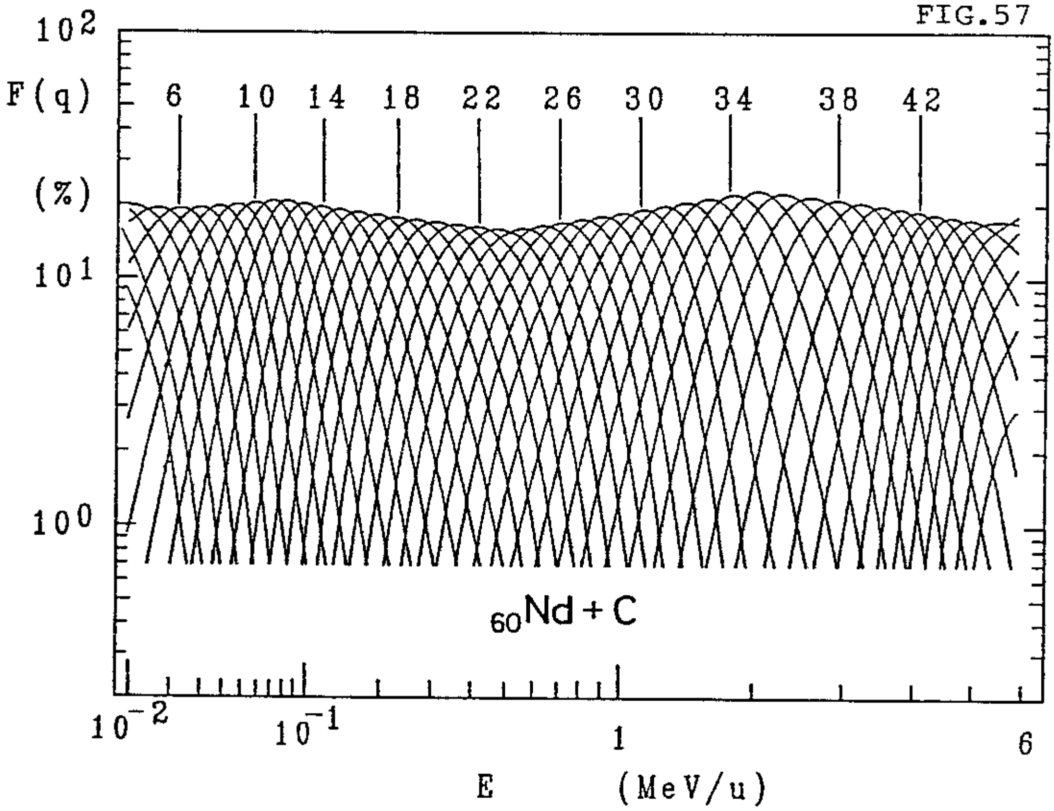
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42
$_{58}$Ce + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.56



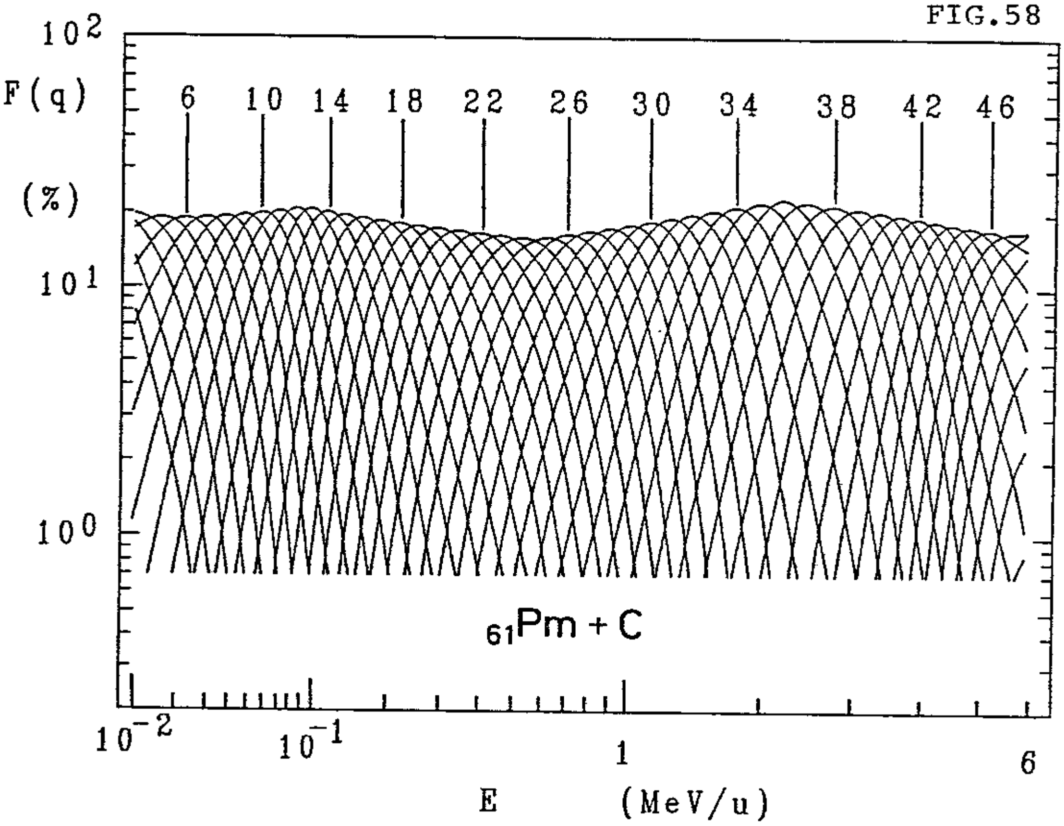
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42
$_{59}$Pr + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.57



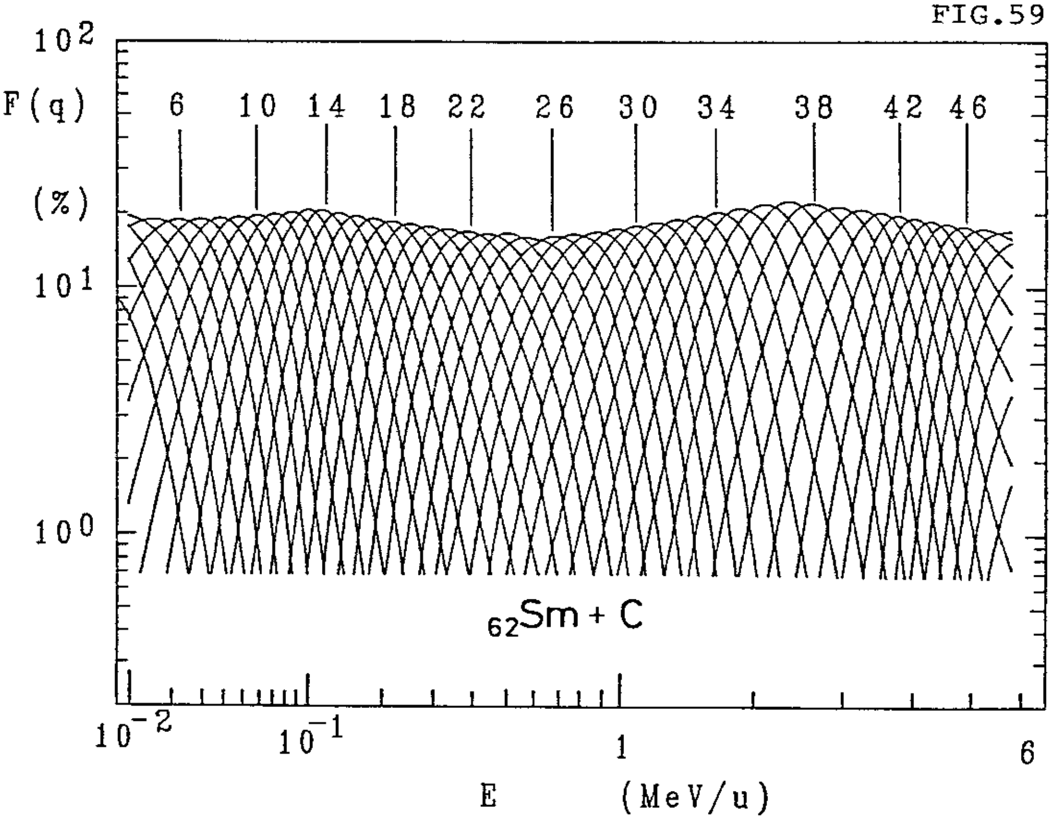
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
$_{60}$Nd + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.58



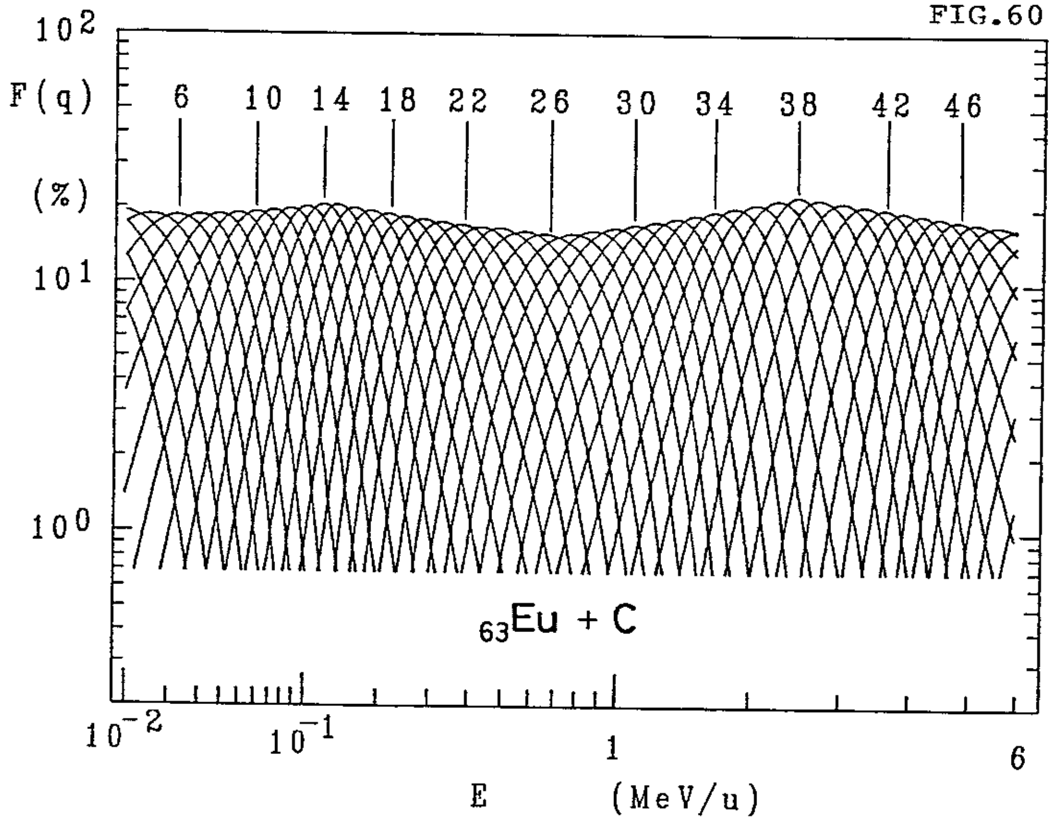
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
46
$_{61}$Pm + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.59



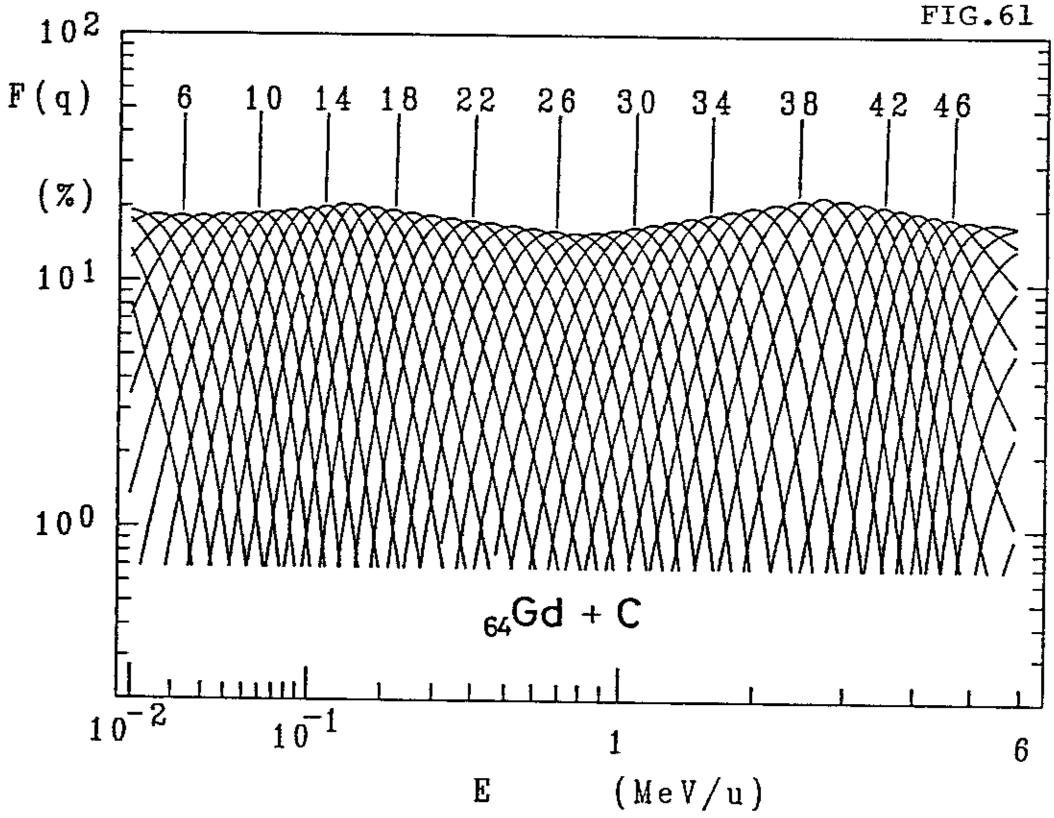
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
46
$_{62}$Sm + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.60



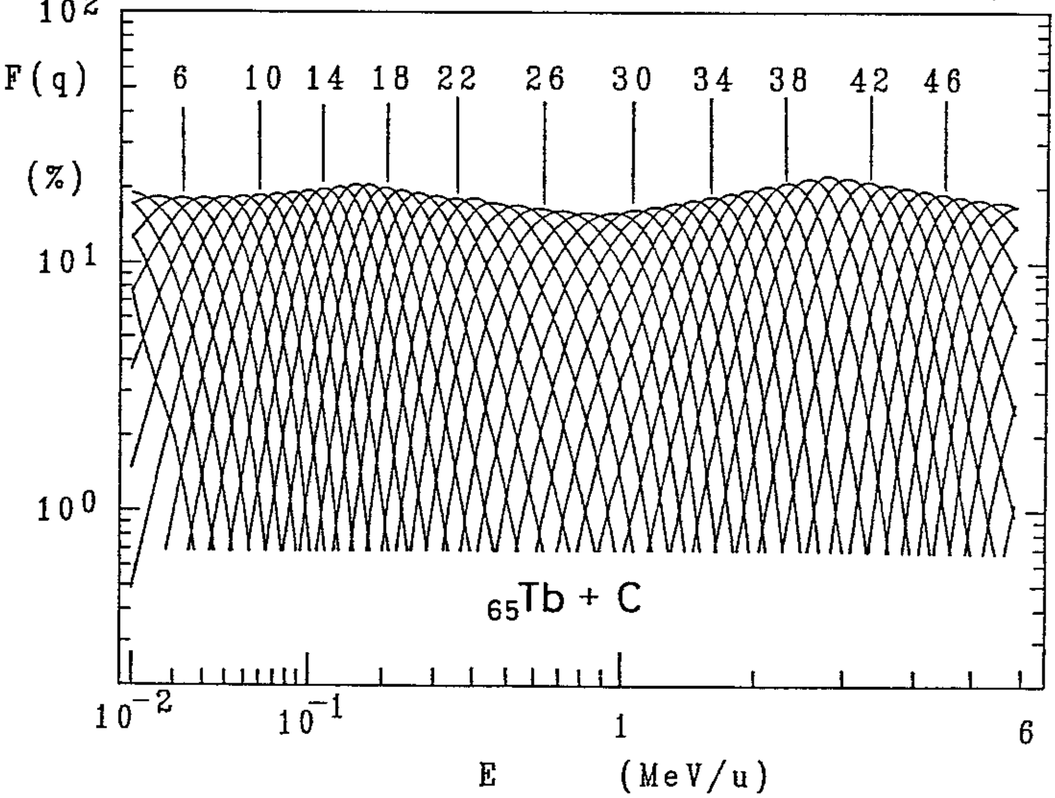
10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
46
$_{63}$Eu + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.61



10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46
64Gd + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.62



10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46
65Tb + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.63

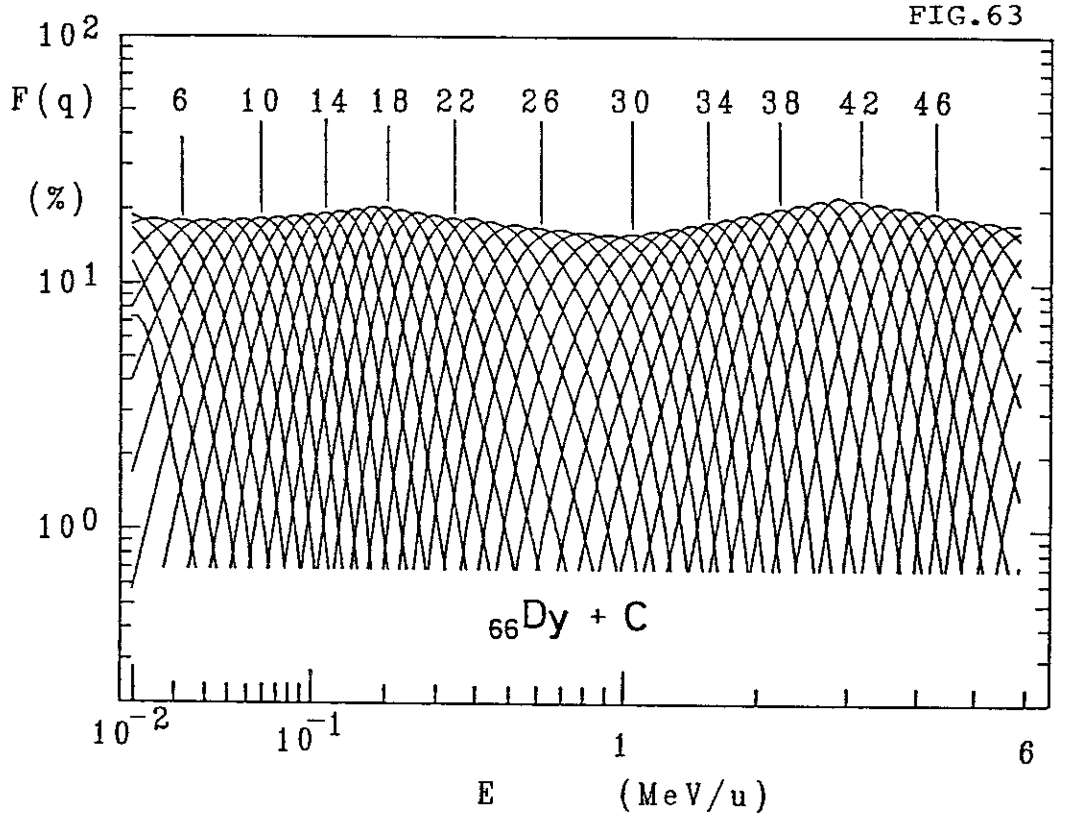

10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
46
66Dy + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.64

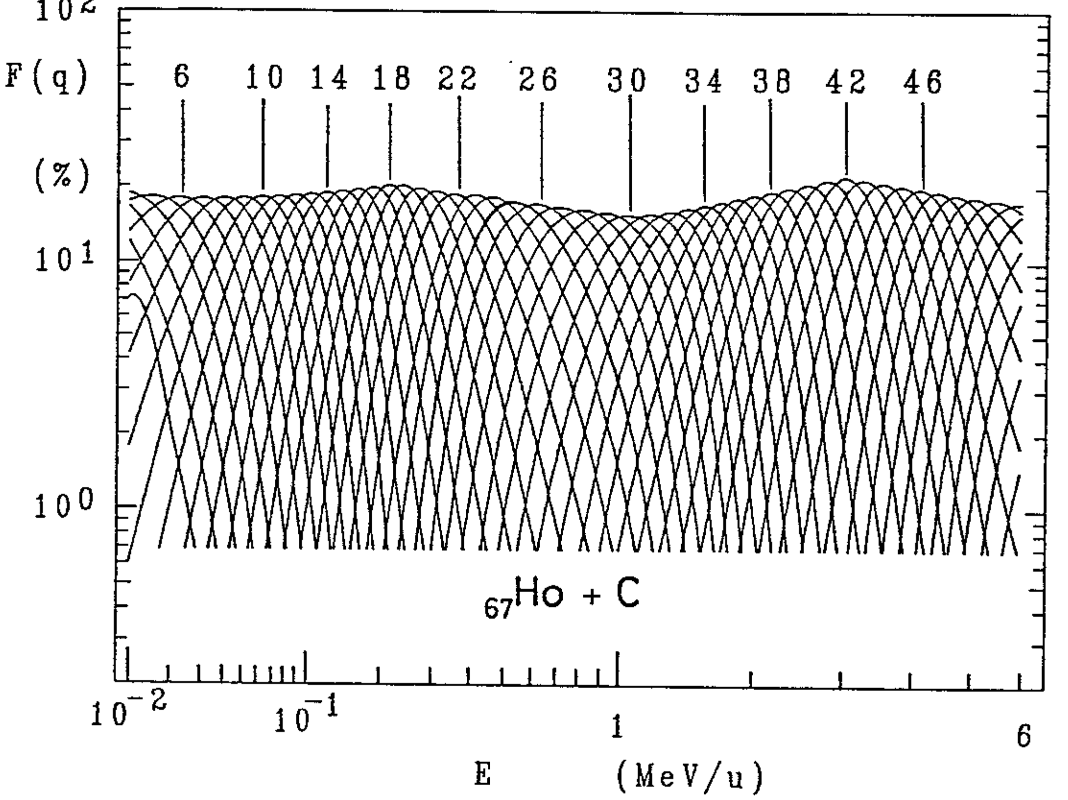
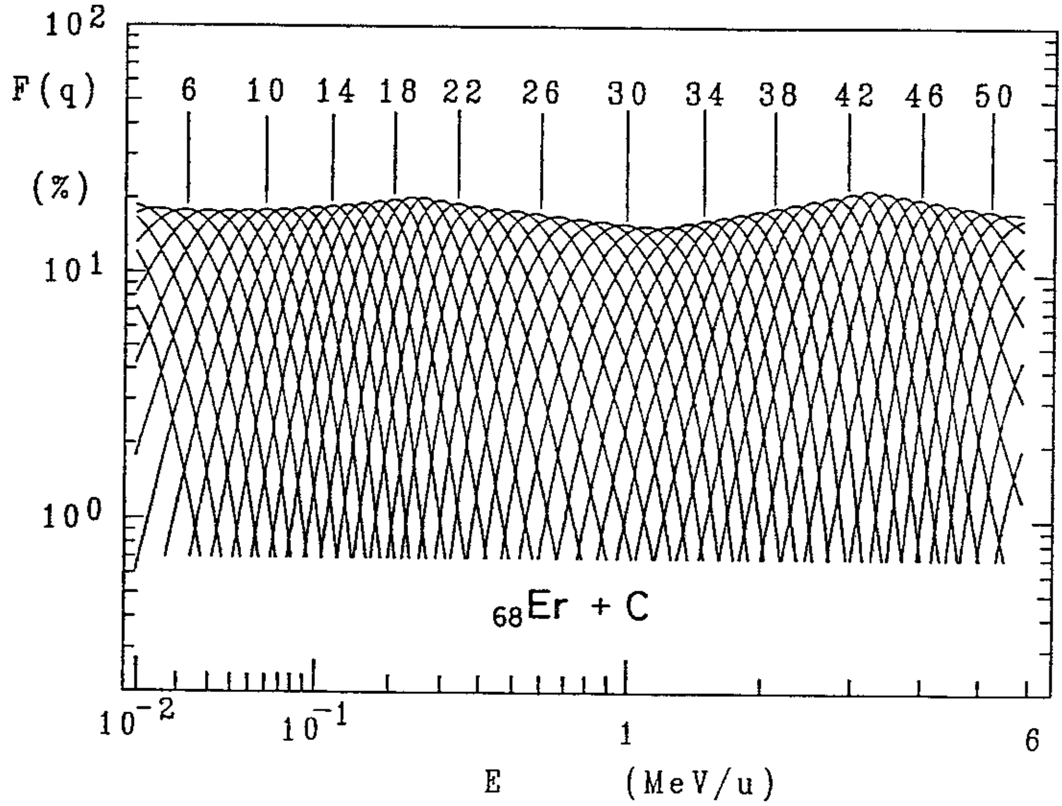
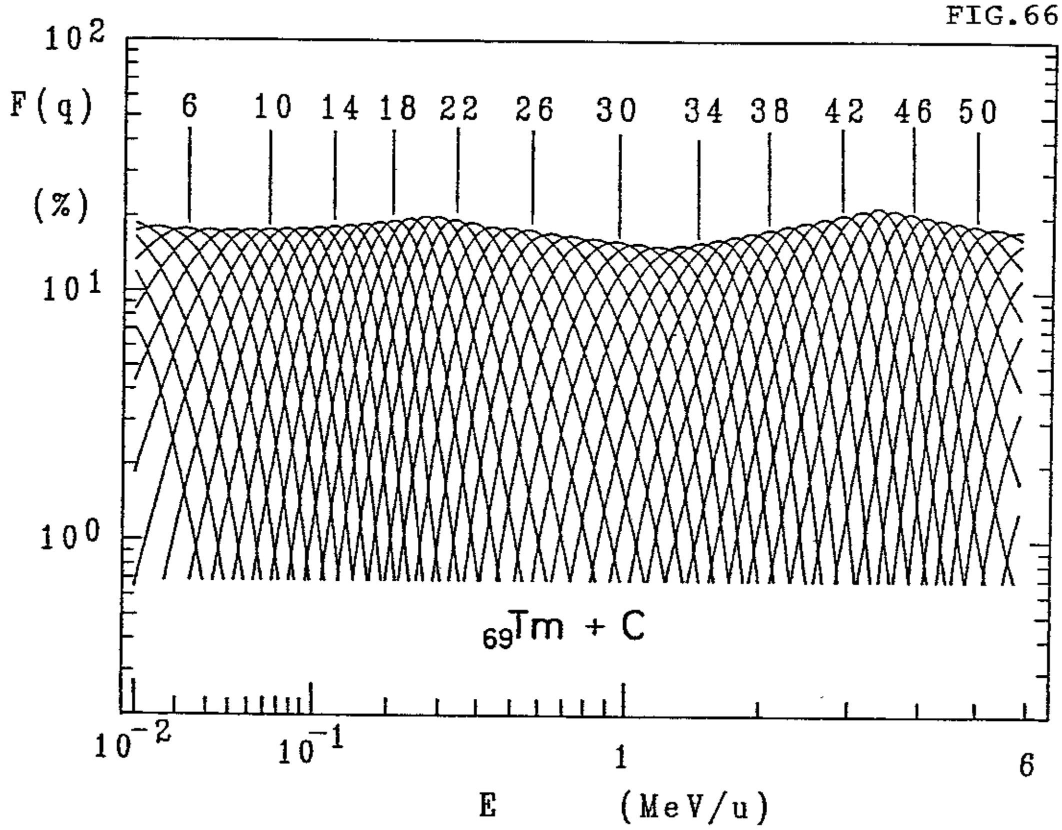

10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
46
67Ho + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.65



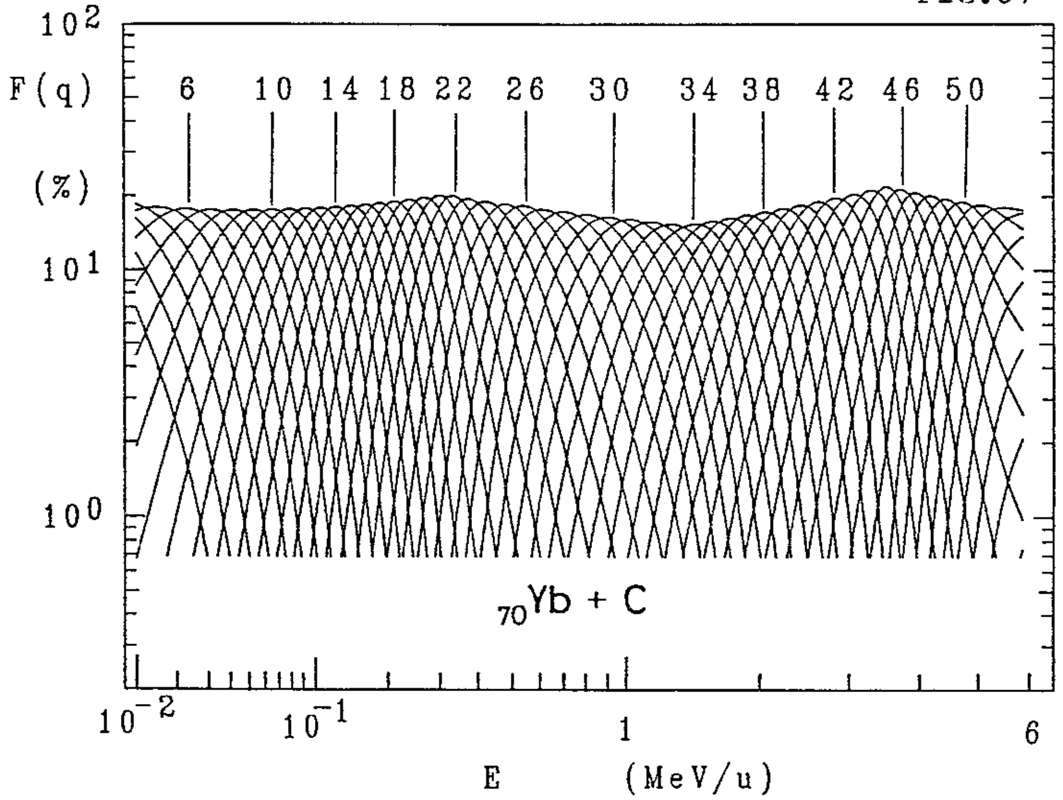
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50
$_{68}$Er + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.66



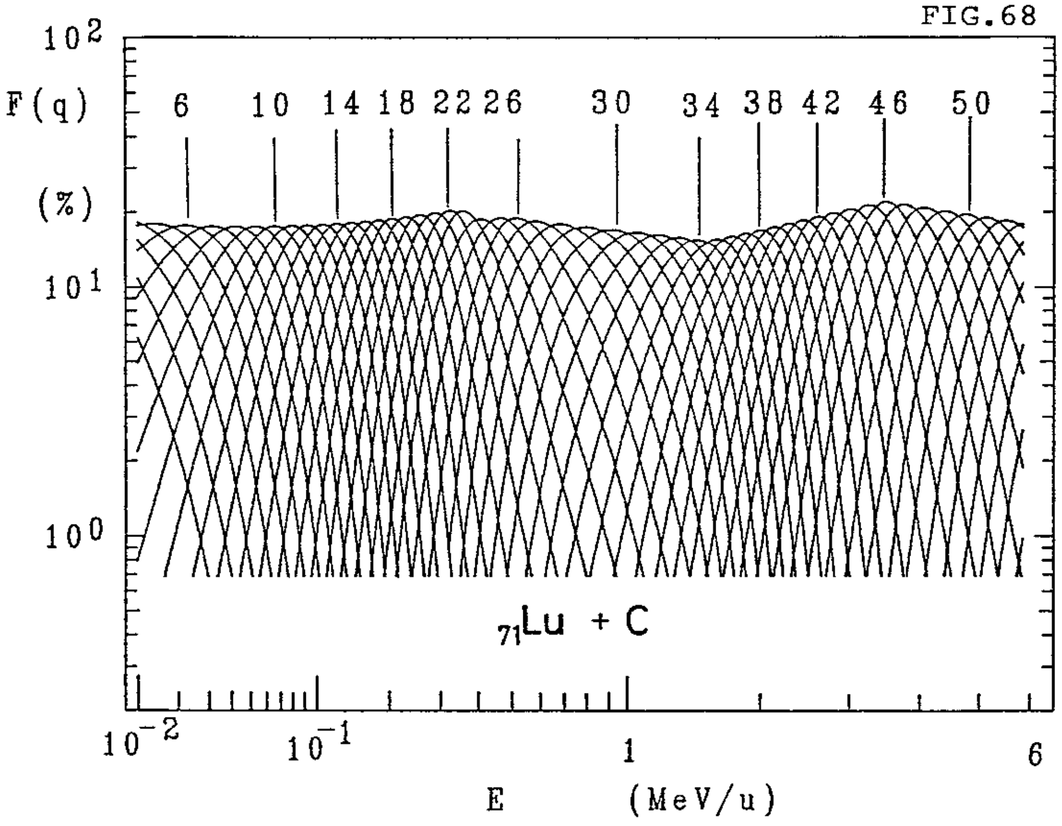
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50
$_{69}$Tm + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.67



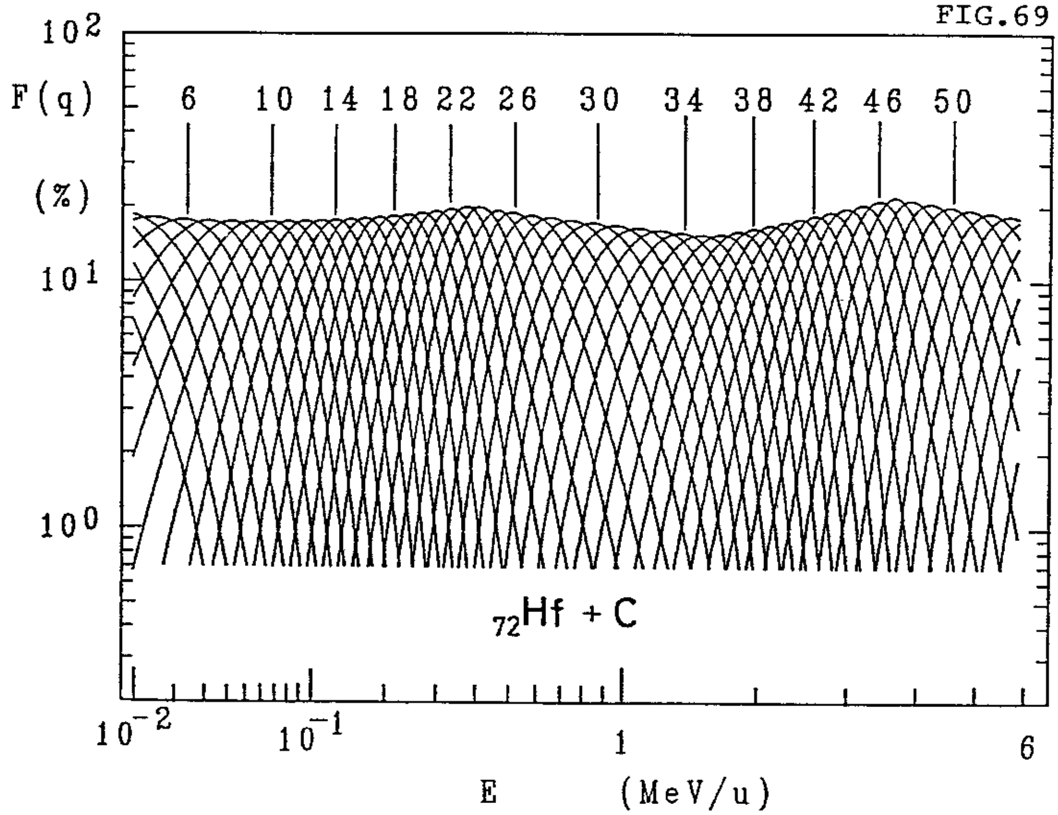
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50
$_{70}$Yb + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.68



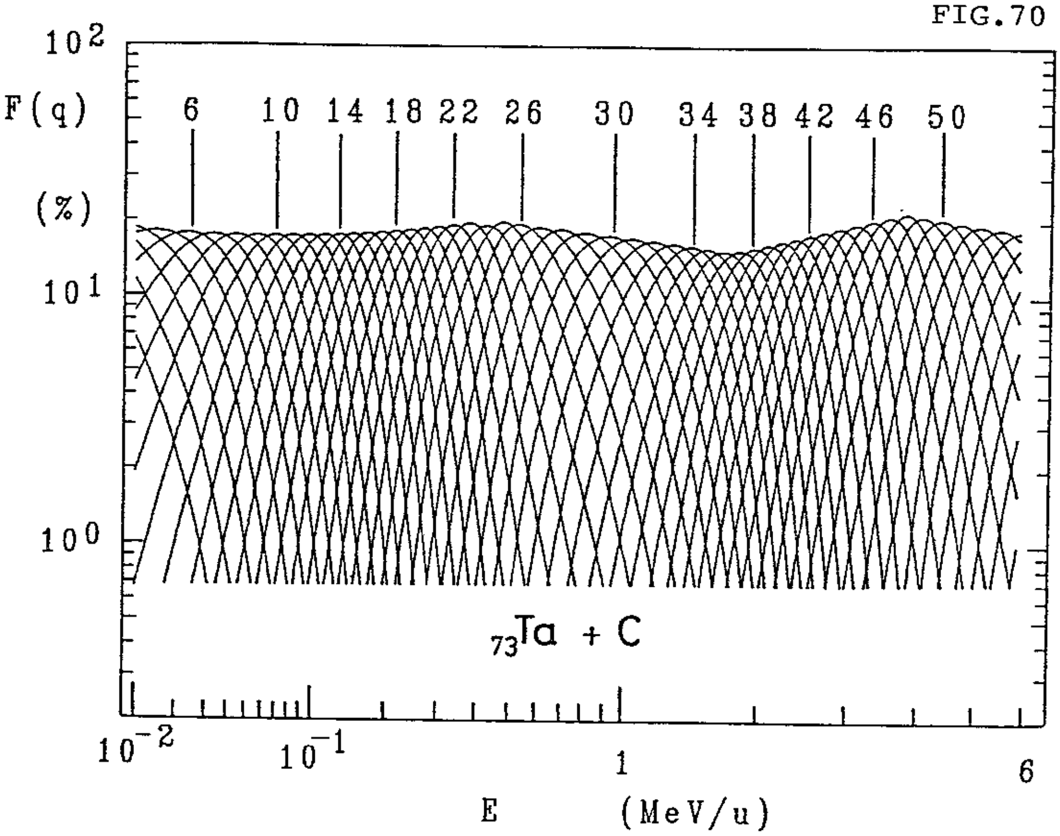
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50
$_{71}$Lu + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.69



10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50
$_{72}$Hf + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.70



10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50
$_{73}$Ta + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.71

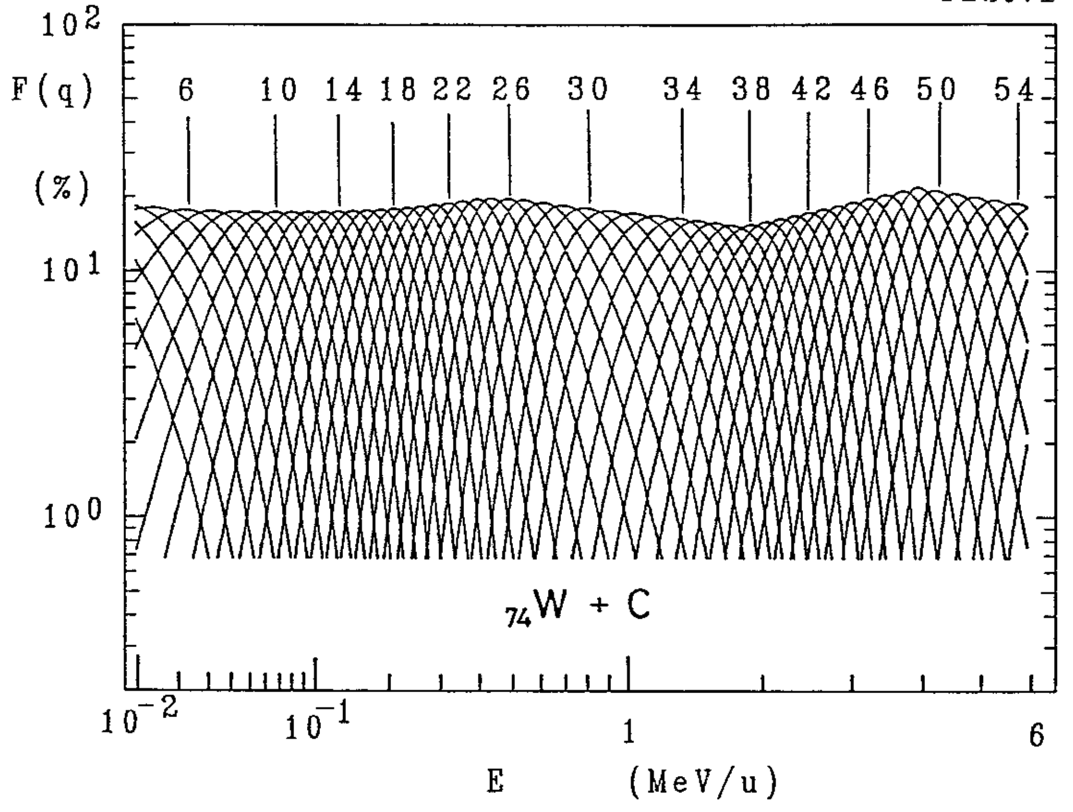

10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
46
50
54
74W + C
10^-2
10^-1
1
6
E
(MeV/u)

FIG.72

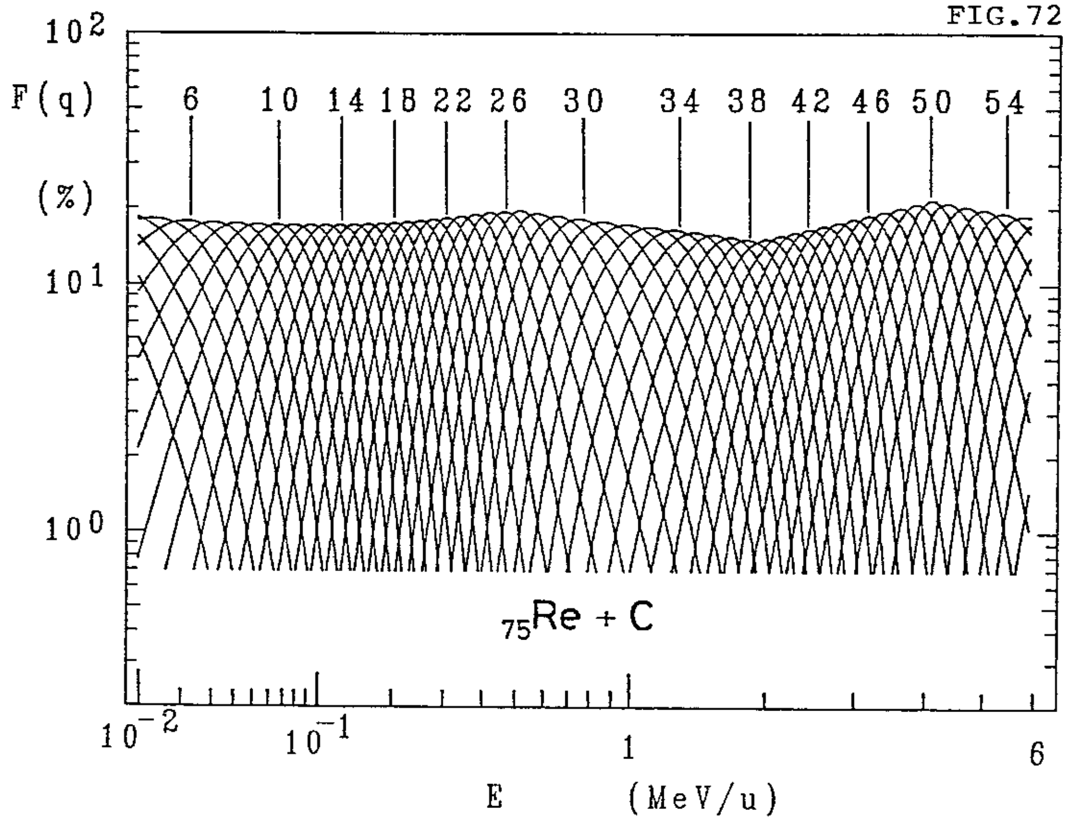
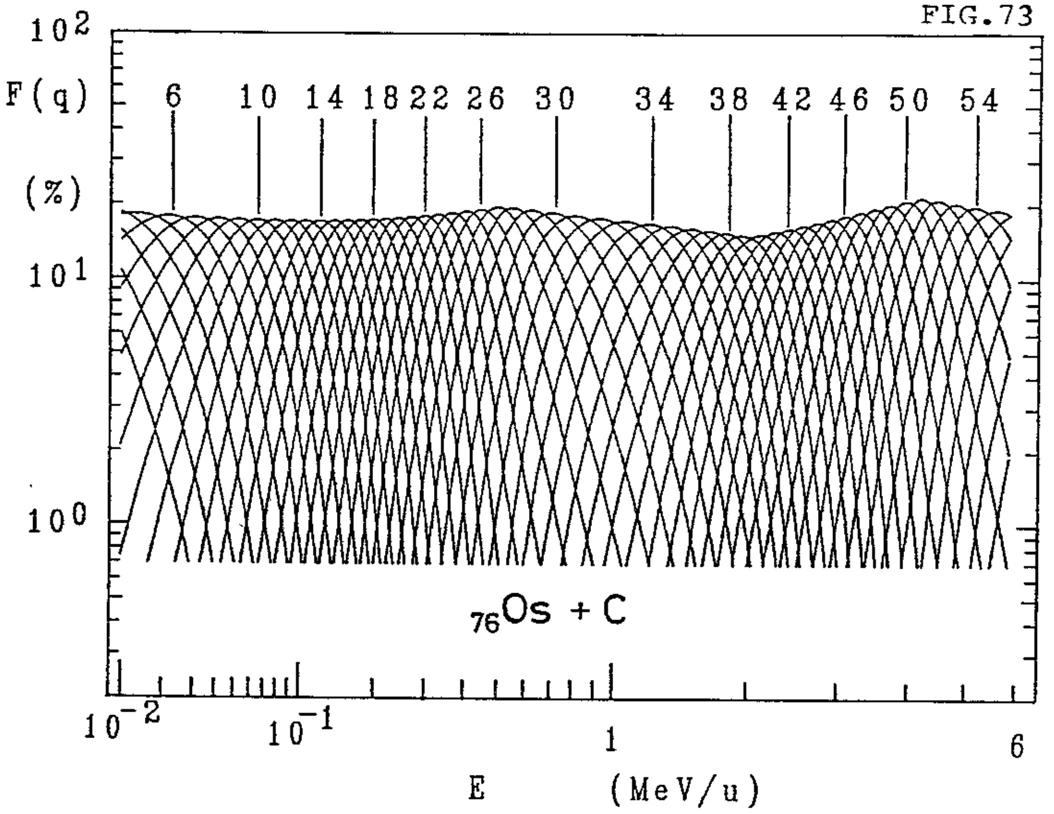
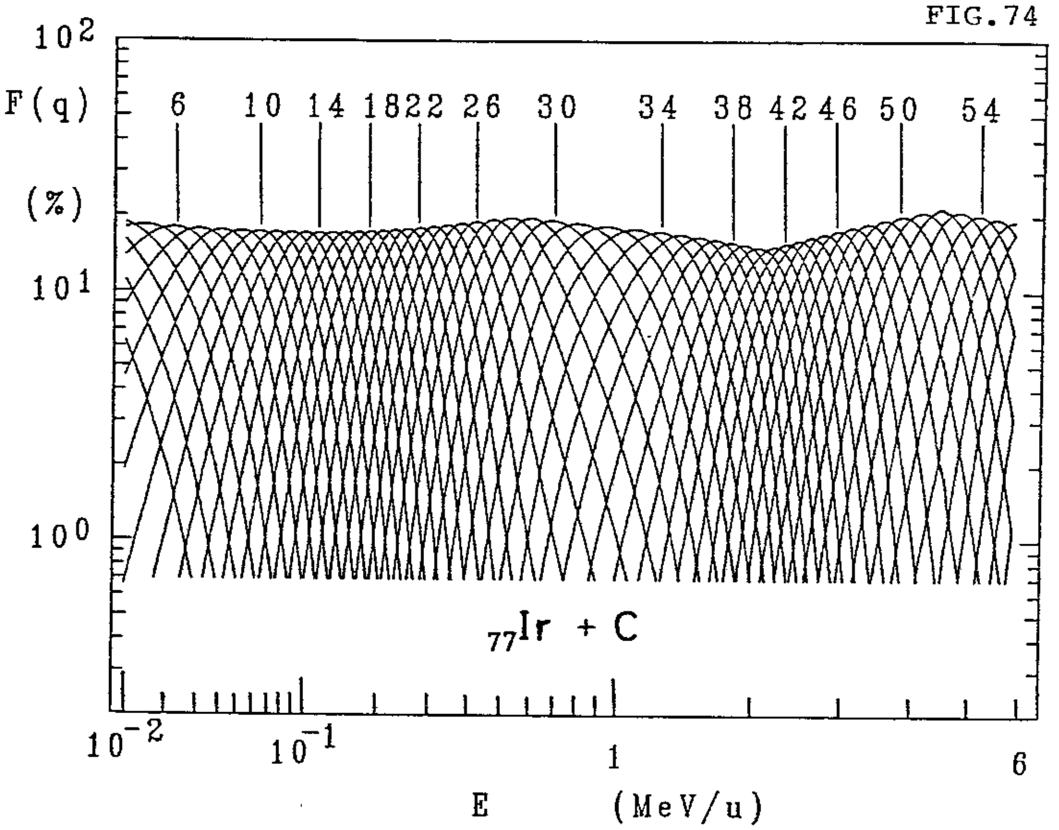

10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
46
50
54
75Re + C
10^-2
10^-1
1
6
E
(MeV/u)

FIG.73



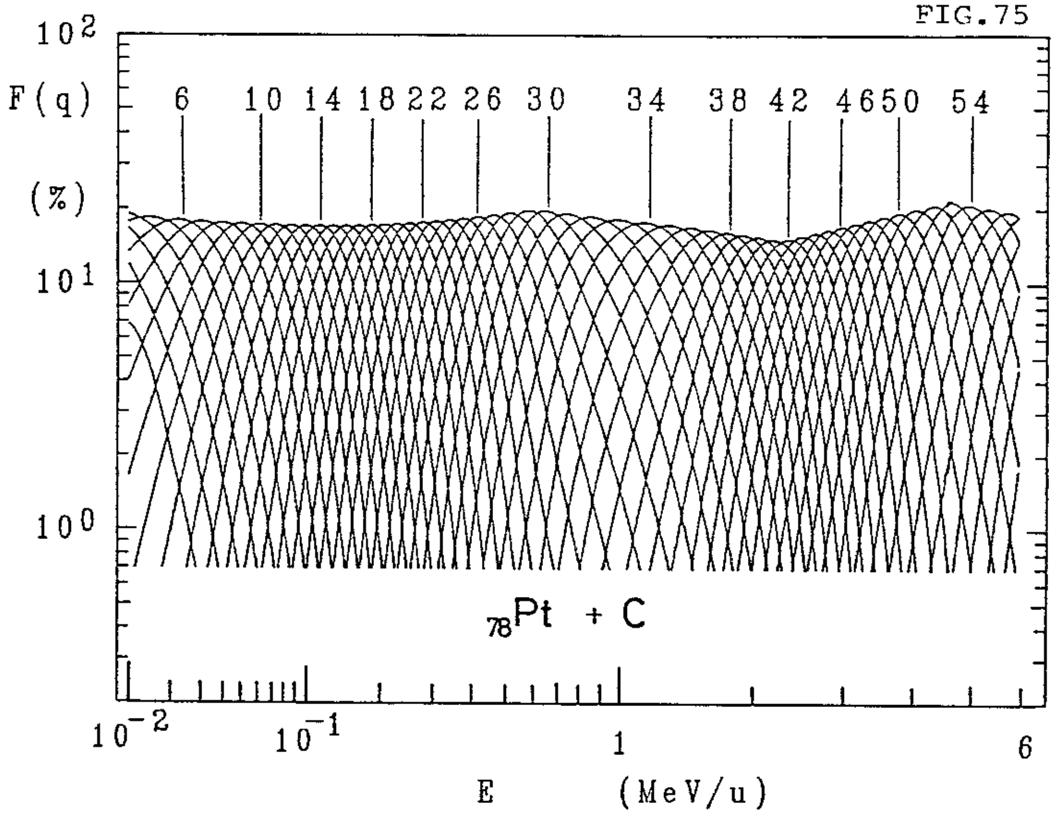
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50 54
$_{76}$Os + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.74



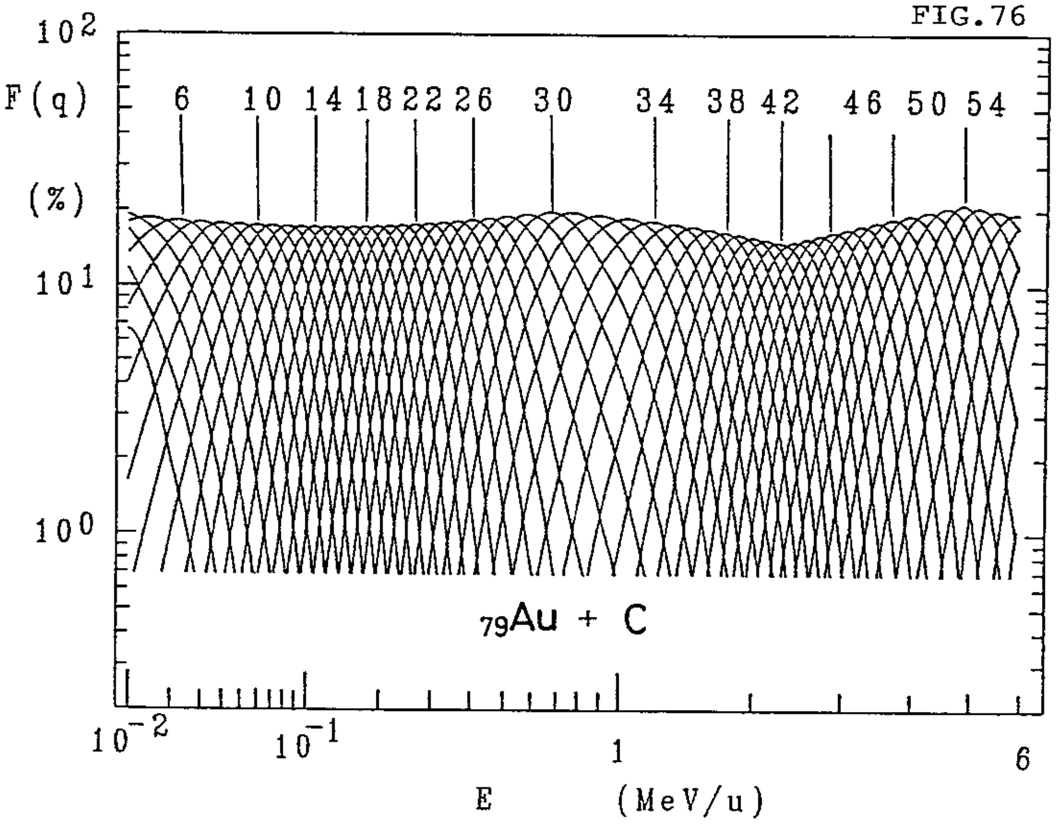
10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50 54
$_{77}$Ir + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.75



F(q)
(%)
10^2
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50 54
$_{78}$Pt + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.76



F(q)
(%)
10^2
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50 54
$_{79}$Au + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIG.77

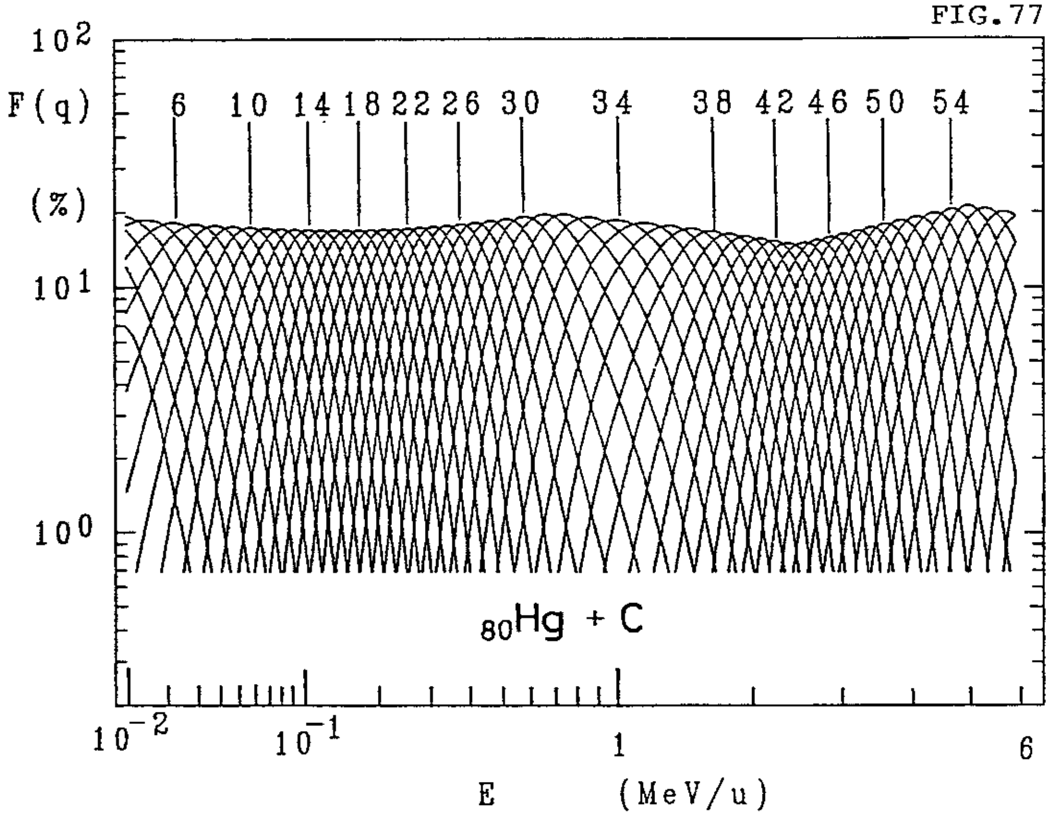

10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
46
50
54
80Hg + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.78

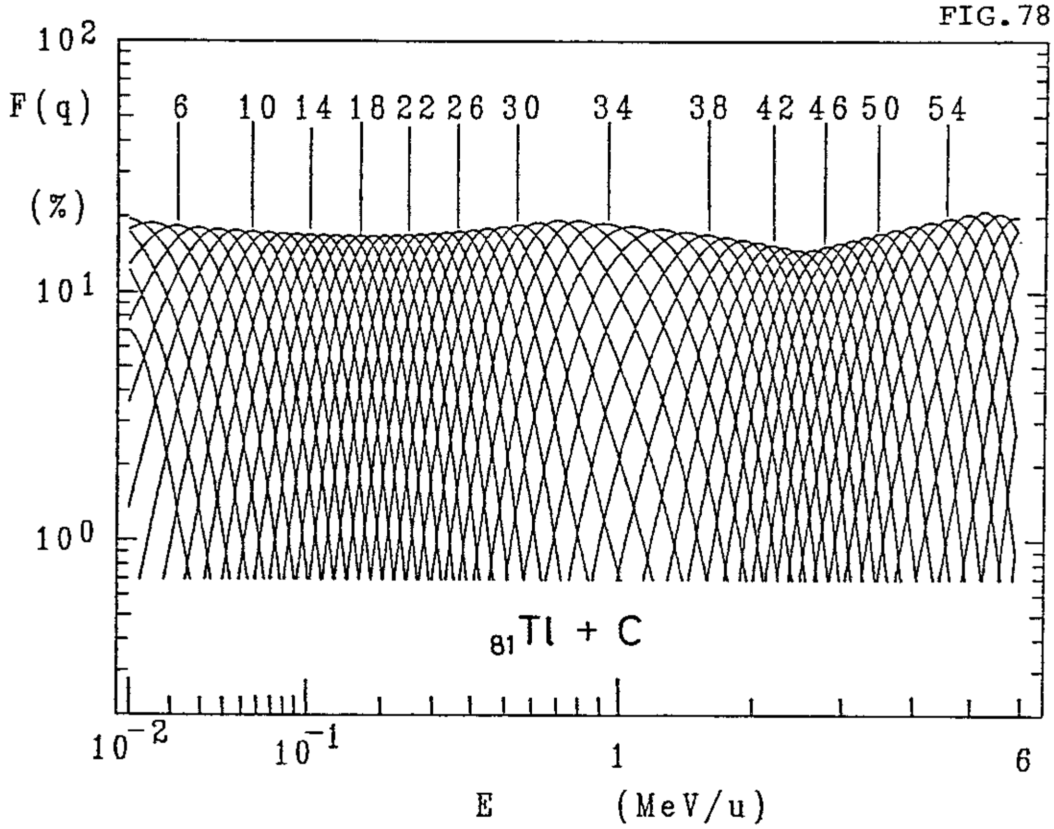

10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
46
50
54
81Tl + C
10^-2
10^-1
1
6
E (MeV/u)

FIG.79

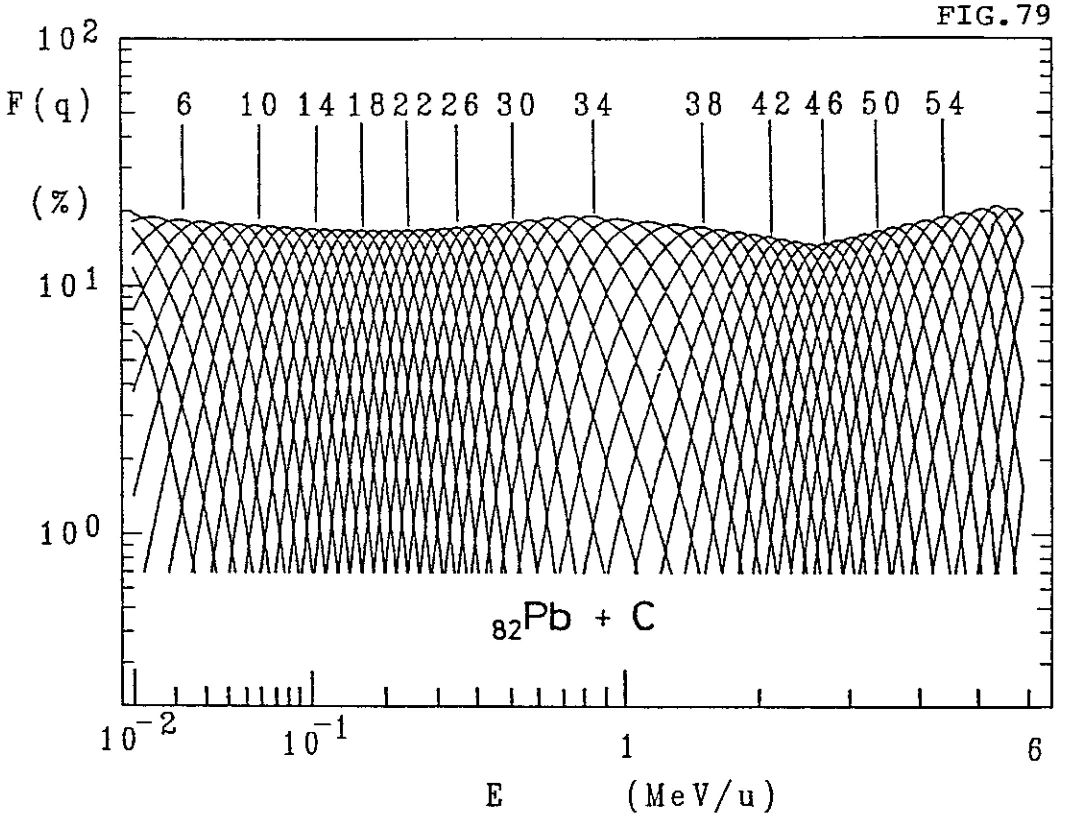

10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50 54
82Pb + C
10^-2 10^-1 1 6
E (MeV/u)

FIG.80

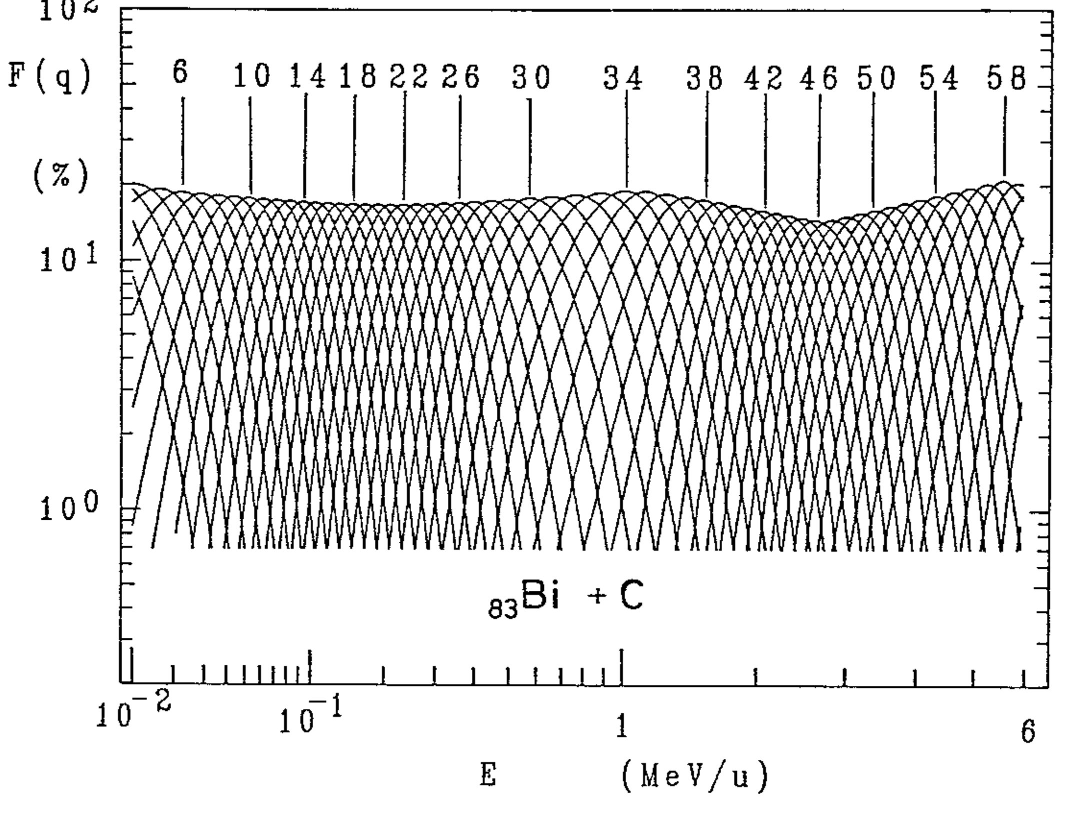
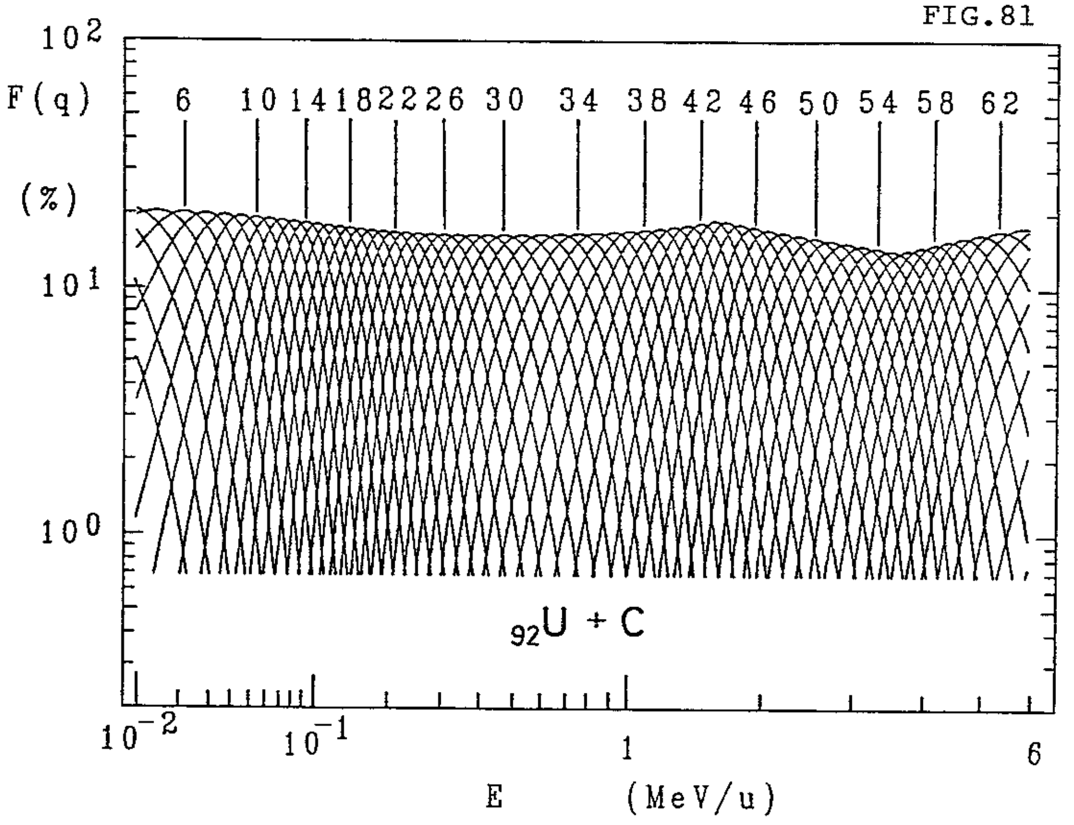

10^2
F(q)
(%)
10^1
10^0
6 10 14 18 22 26 30 34 38 42 46 50 54 58
83Bi + C
10^-2 10^-1 1 6
E (MeV/u)

FIG.81



10^2
F(q)
(%)
10^1
10^0
6
10
14
18
22
26
30
34
38
42
46
50
54
58
62
$_{92}$U + C
10^{-2}
10^{-1}
1
6
E (MeV/u)

FIGURES 82-158. Equilibrium Charge Fraction of Ions for Z=5 to 83 after Passage through a Carbon Foil as a Function of Ion Energy between 1 and 12 MeV.

Equilibrium charge fractions of ions after passage through a carbon foil are shown as a function of ion energy from 1 to 12 MeV. Each figure pertains to one ion species whose atomic number ranges from Z=5 to 83. These values are evaluated based on the procedure (i) to (iii) described in 3.1 in the text. The numbers attached above the curves represent the charge states of ions. Evaluation is done for ions of the mass number having the highest abundance of isotope ratio.

F(q) Charge fraction of ions having charge state q.

E Ion energy at emergence from a carbon foil, in units of MeV.

FIG.82

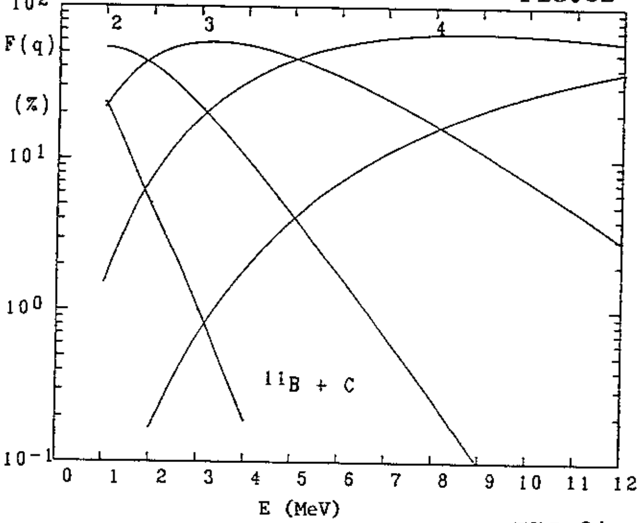


FIG.83

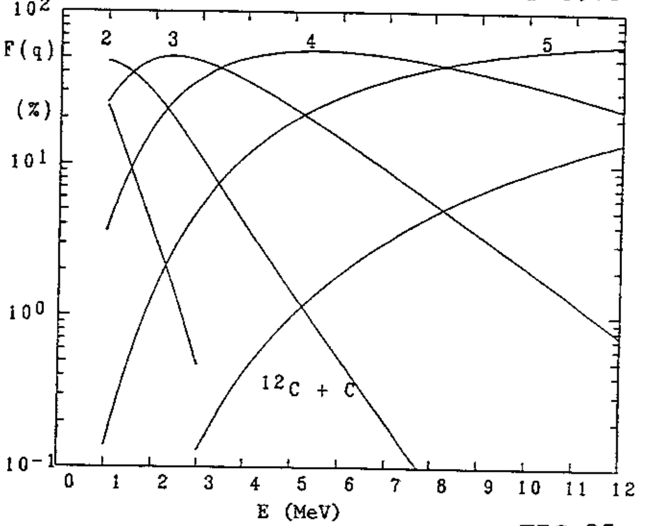


FIG.84

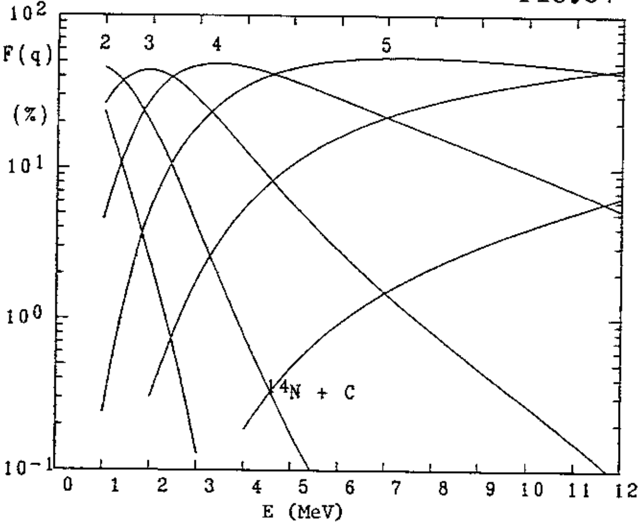


FIG.85

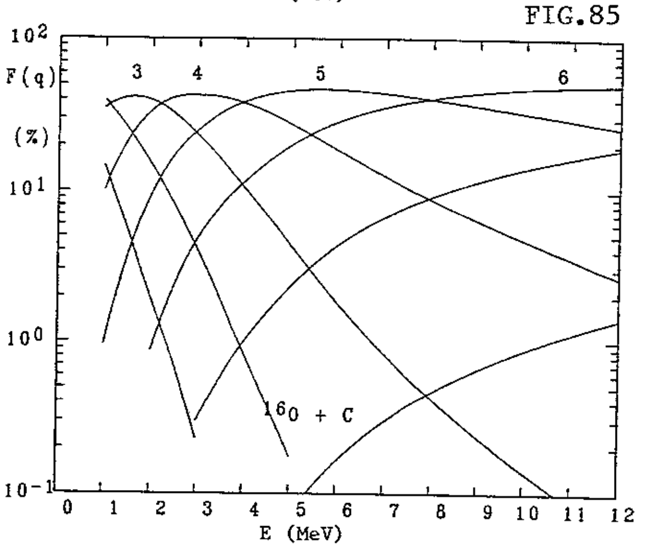


FIG.86

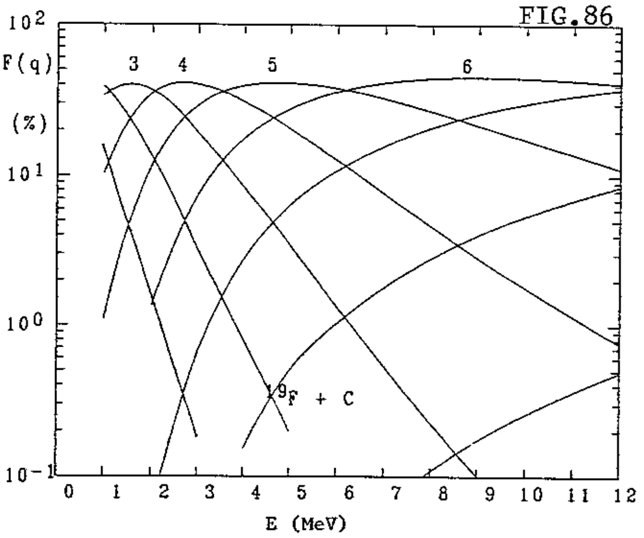


FIG.87

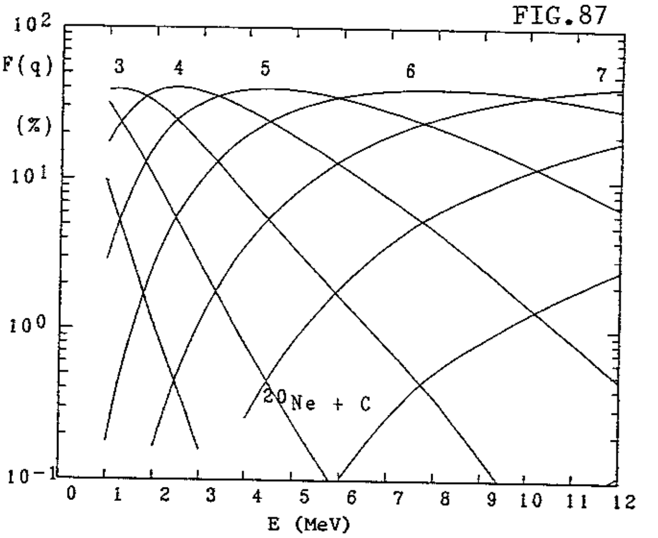


FIG.88

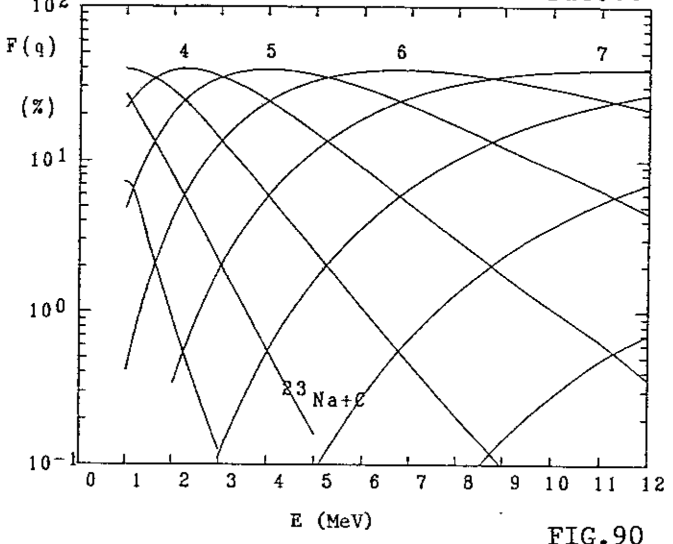


FIG.89

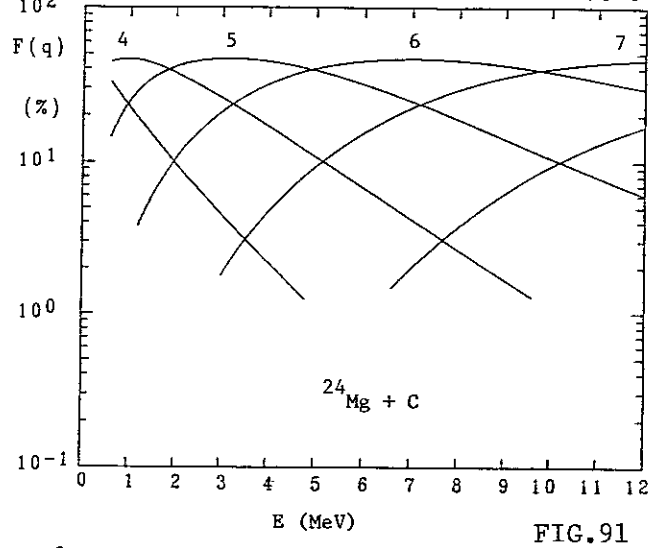


FIG.90

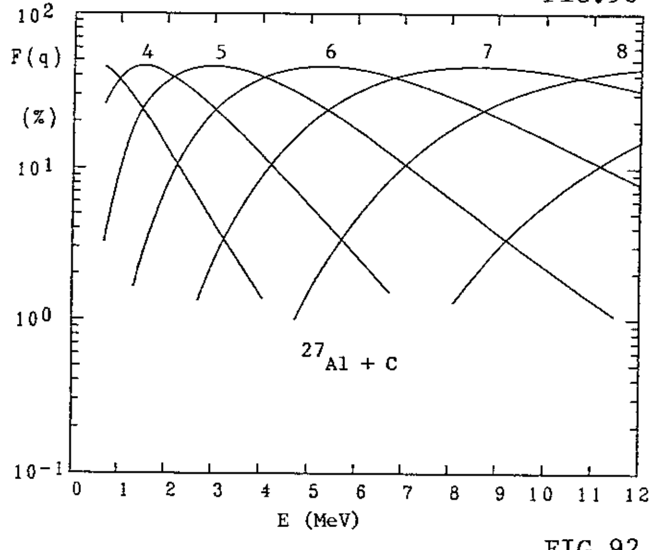


FIG.91

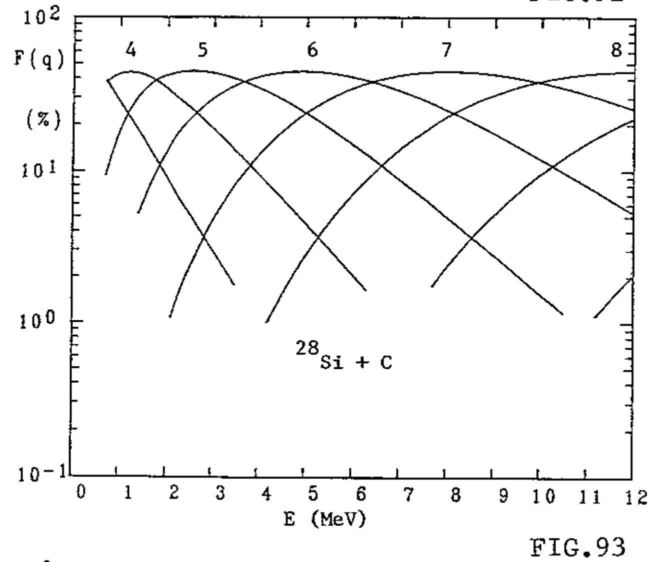


FIG.92

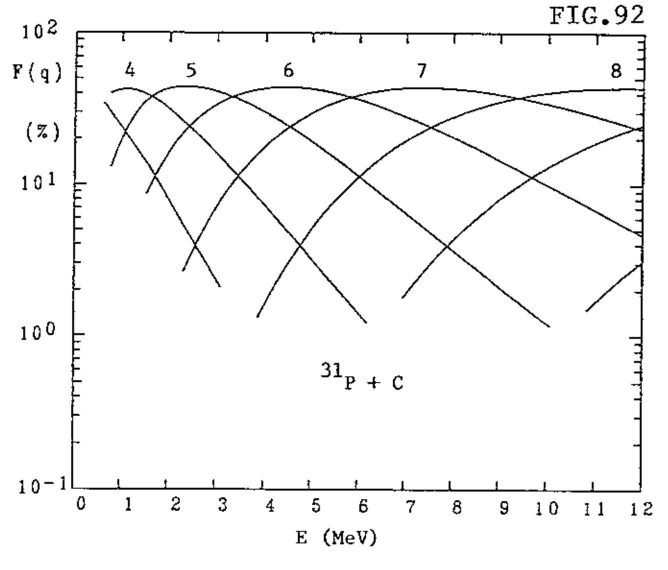


FIG.93

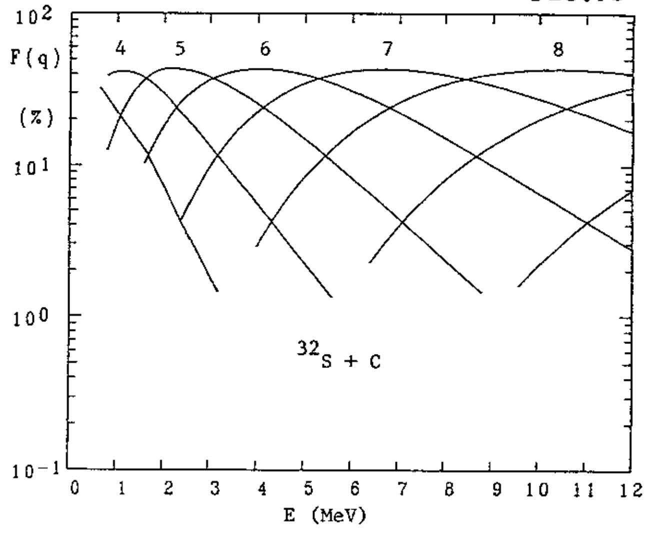


FIG.94

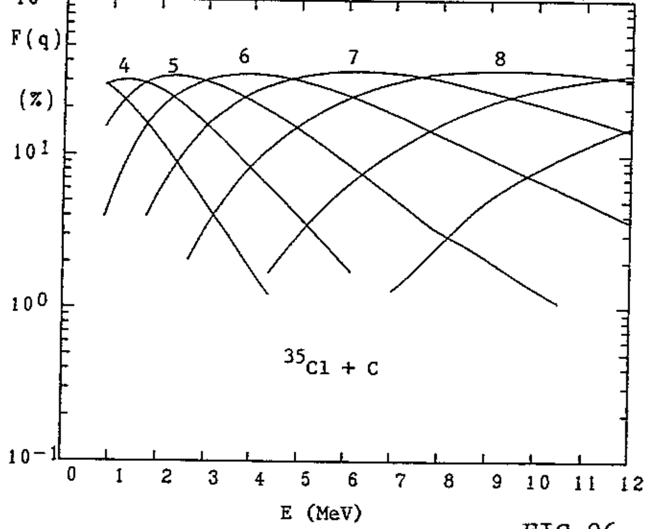


FIG.95

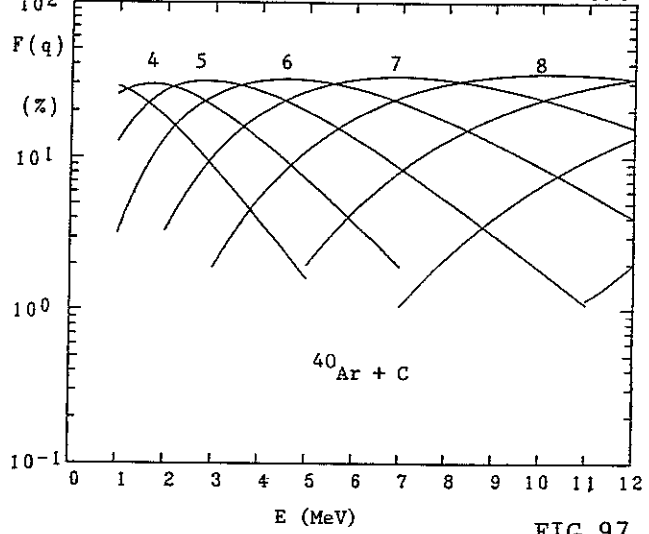


FIG.96

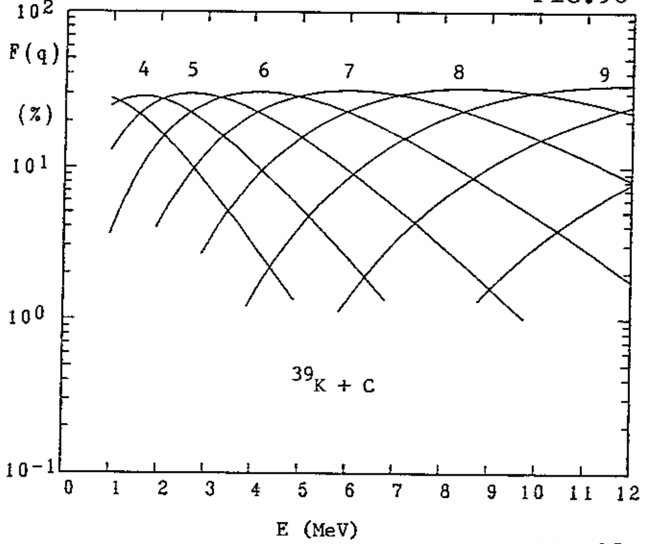


FIG.97

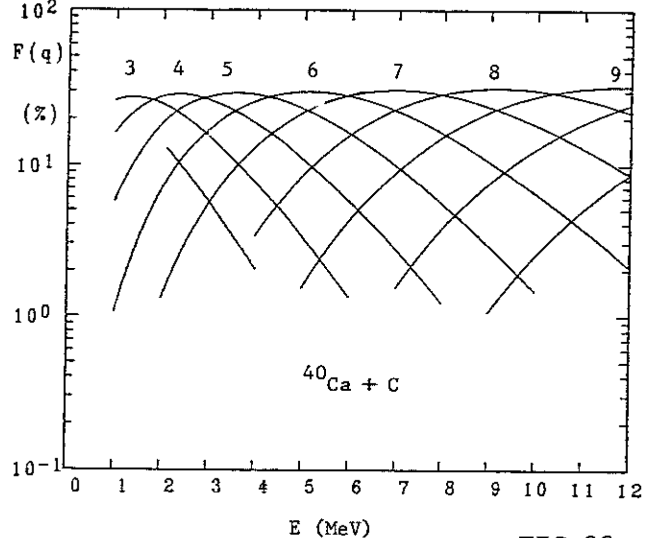


FIG.98

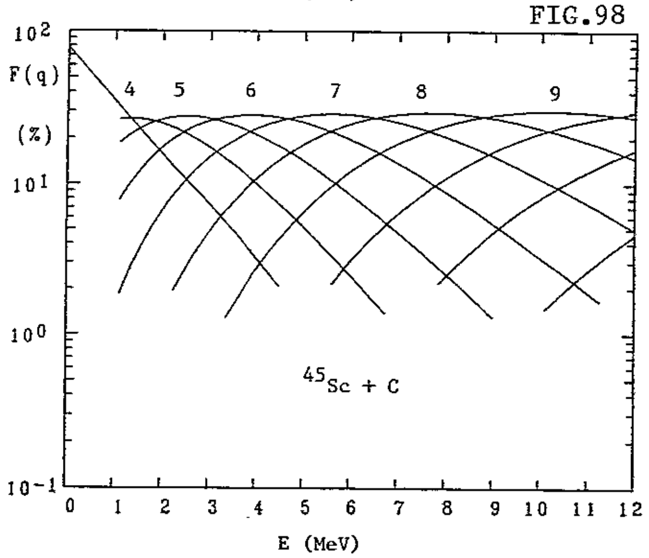


FIG.99

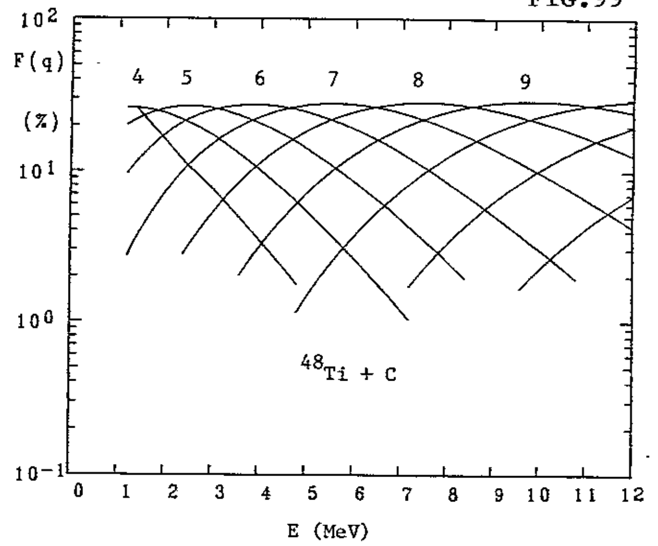


FIG.100

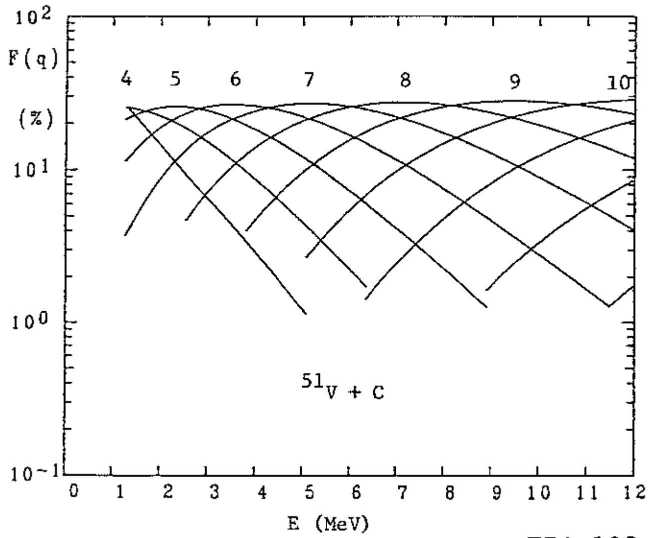


FIG.101

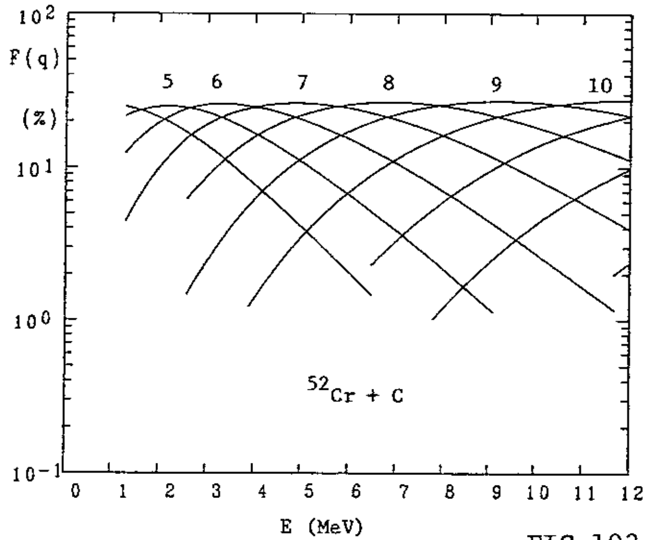


FIG.102

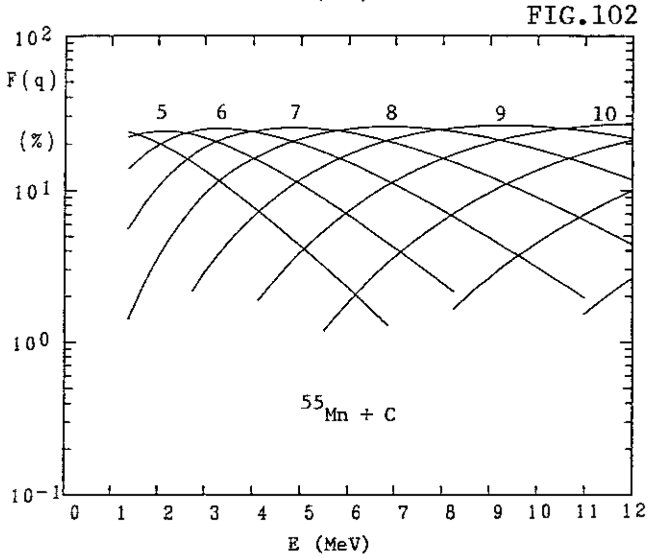


FIG.103

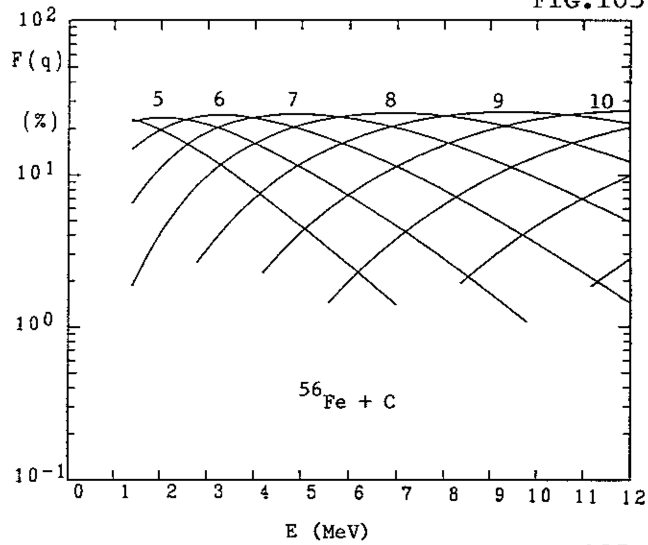


FIG.104

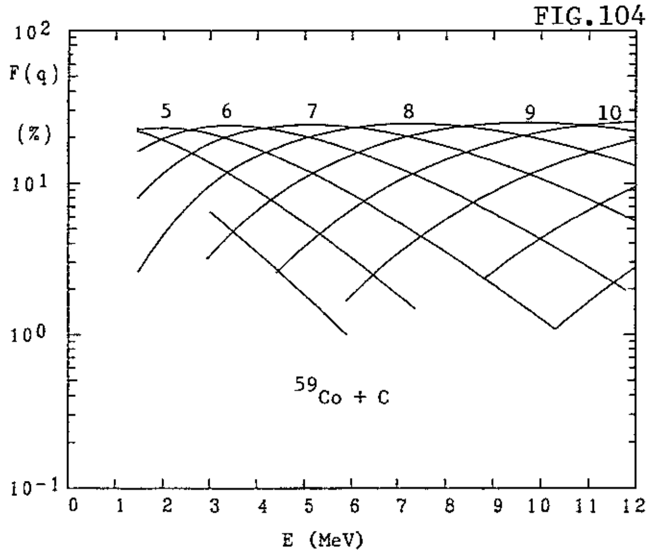


FIG.105

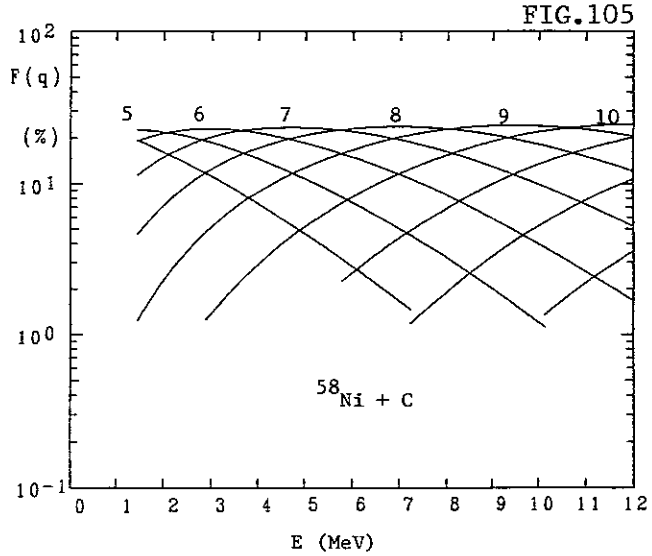


FIG.106

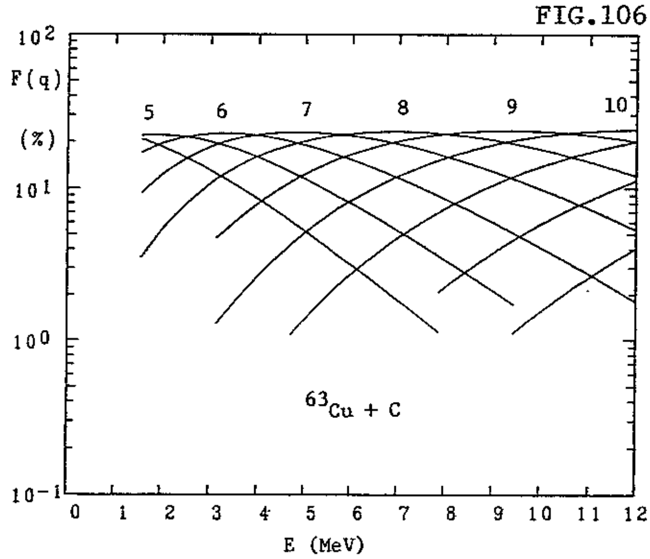


FIG.107

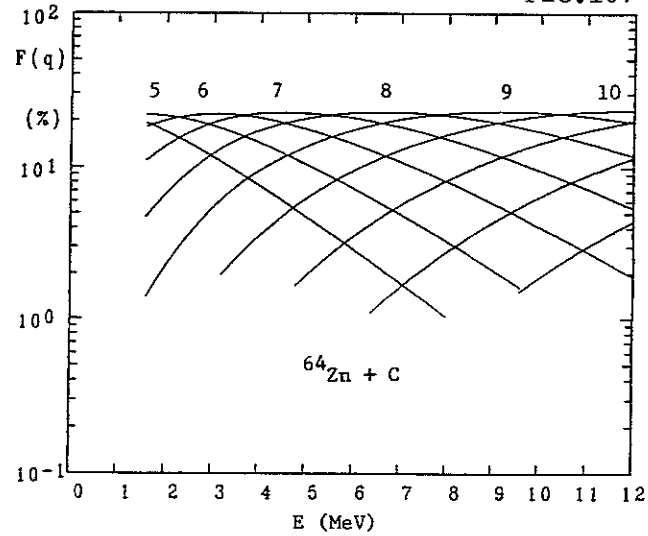


FIG.108

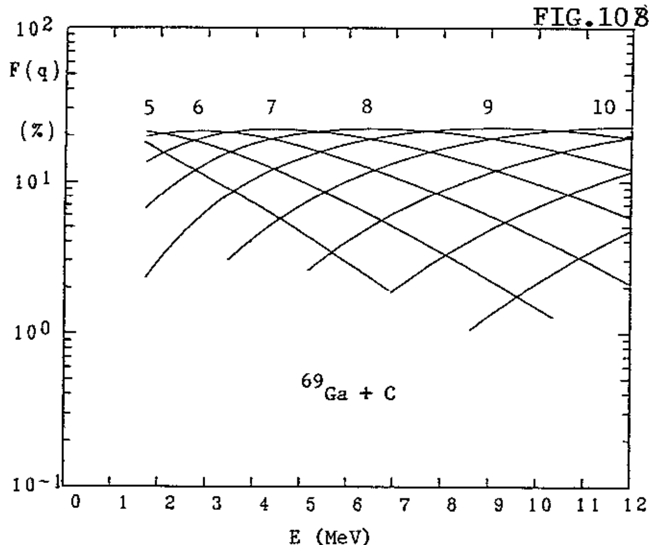


FIG.109

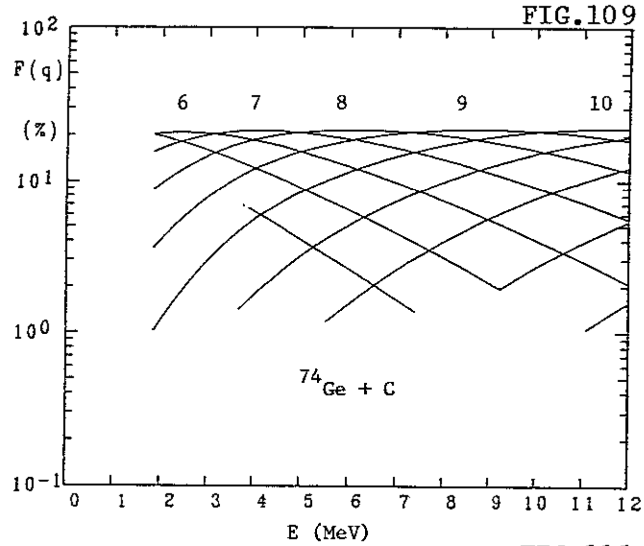


FIG.110

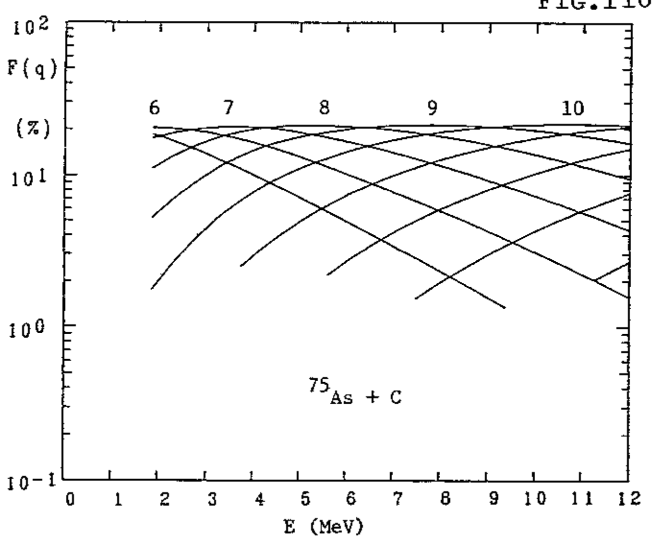


FIG.111

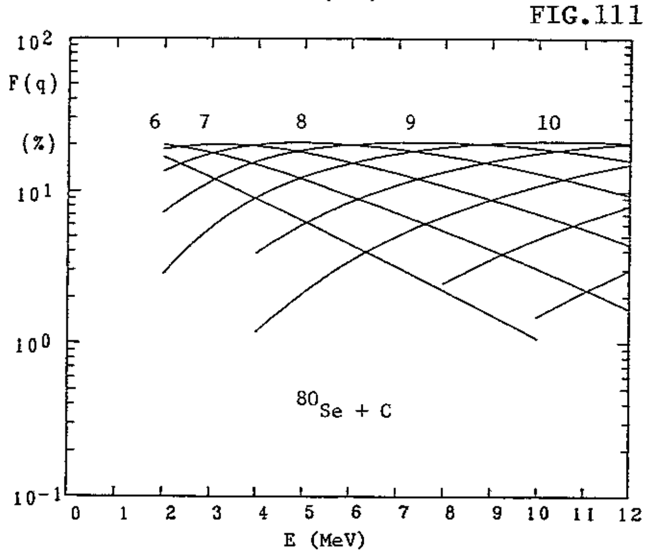


FIG.112

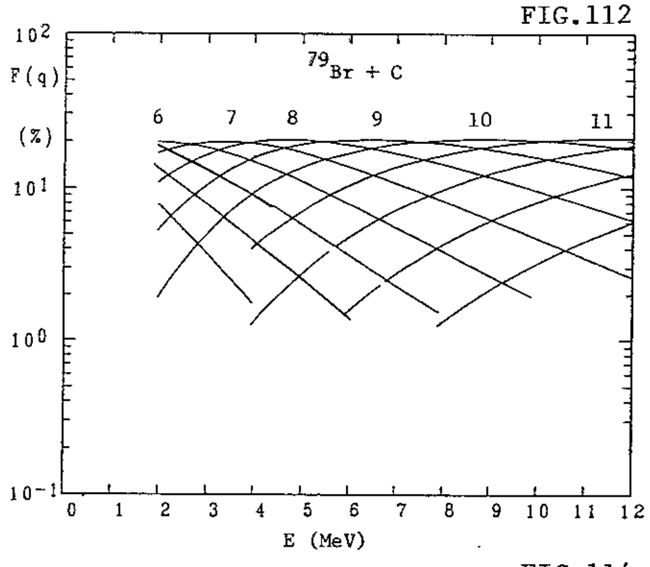


FIG.113

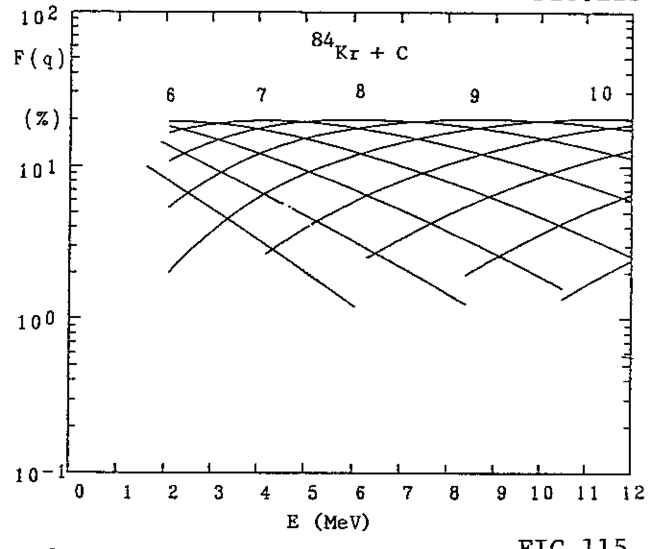


FIG.114

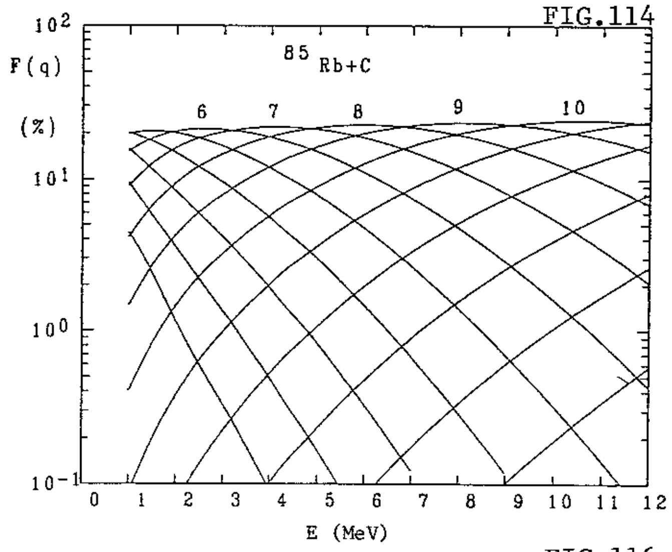


FIG.115

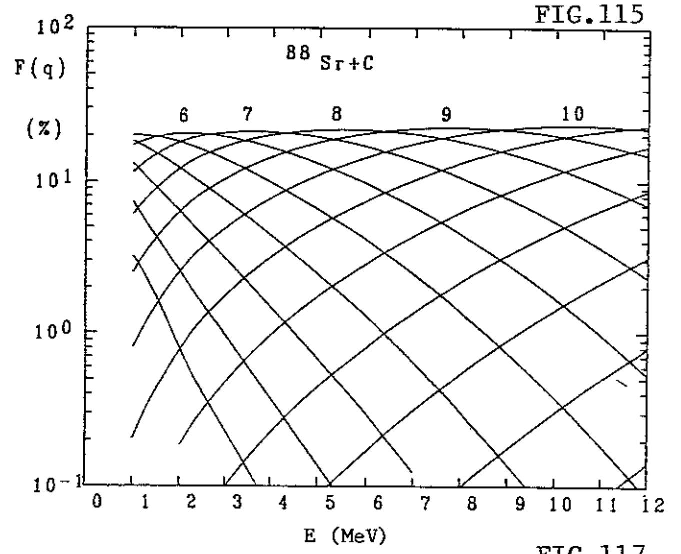


FIG.116

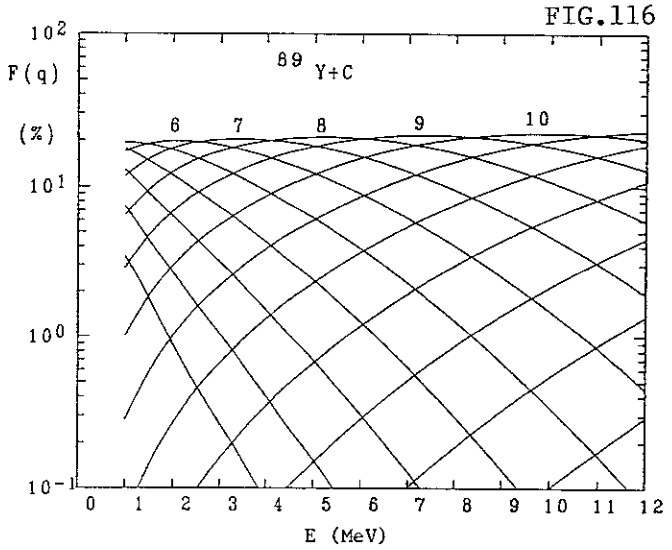
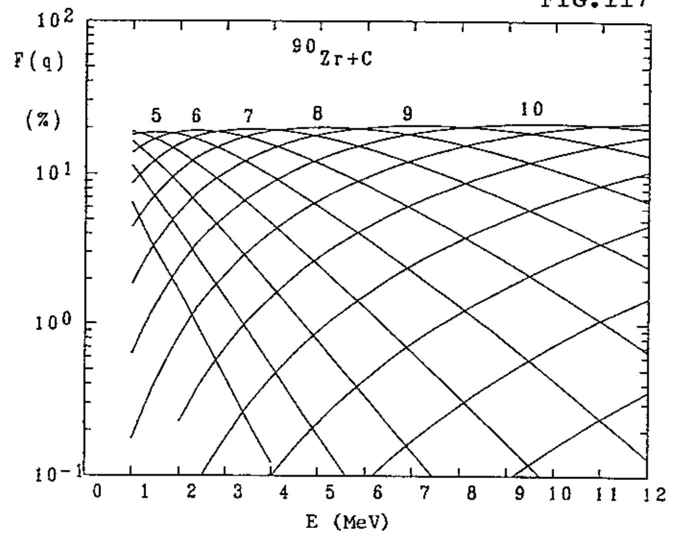


FIG.117



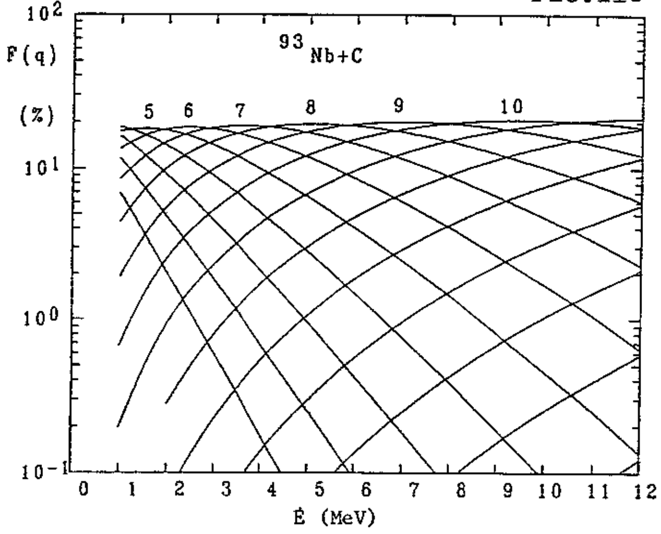


FIG.118

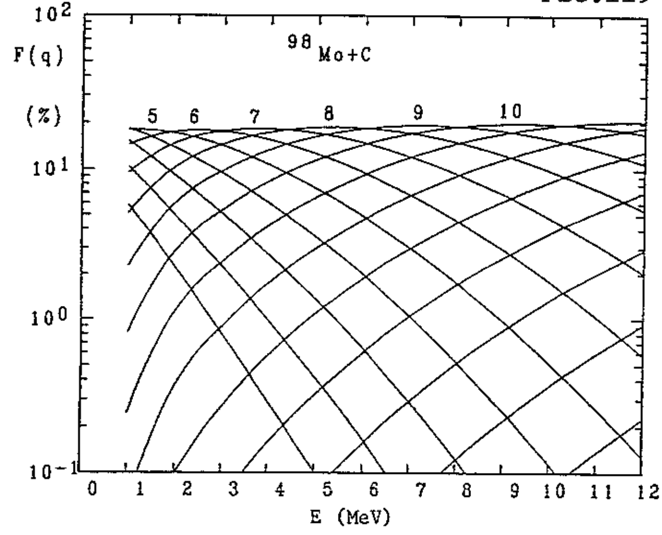


FIG.119

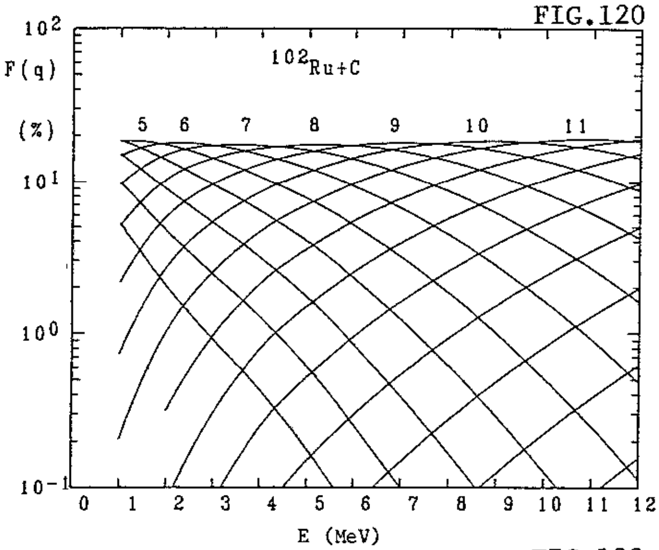


FIG.120

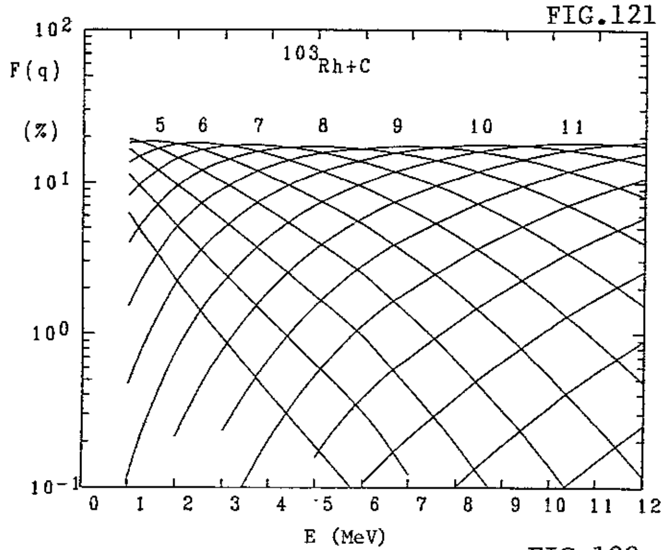


FIG.121

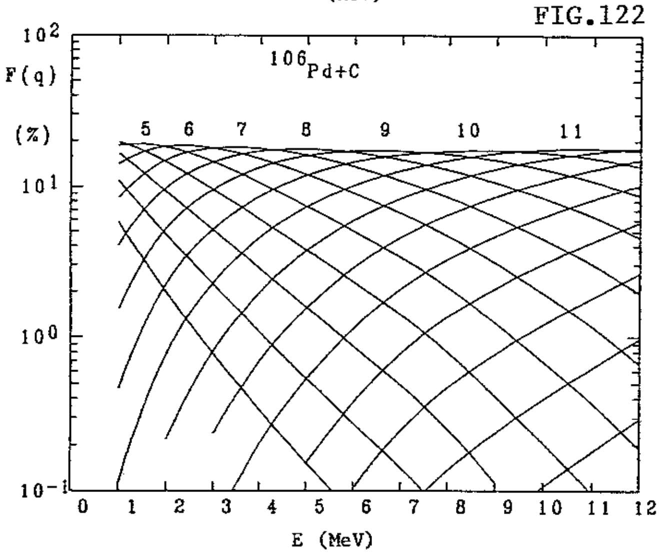


FIG.122

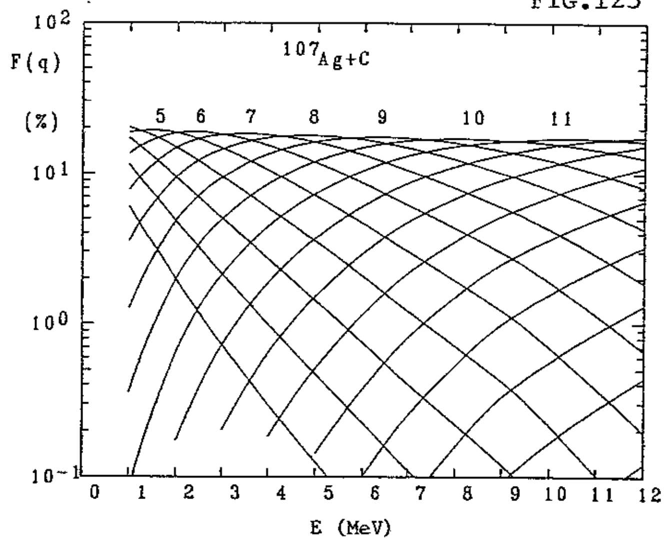


FIG.123

FIG.124

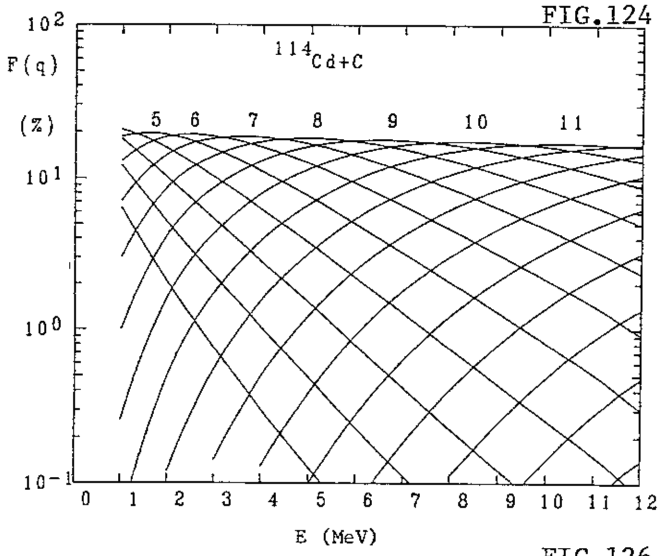


FIG.125

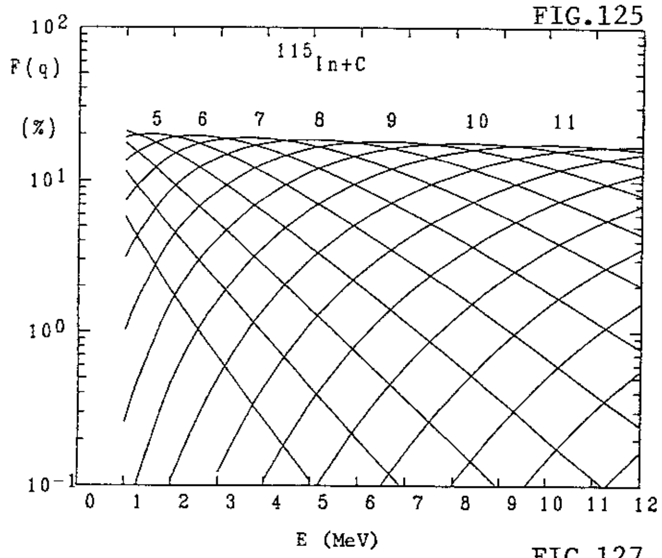


FIG.126

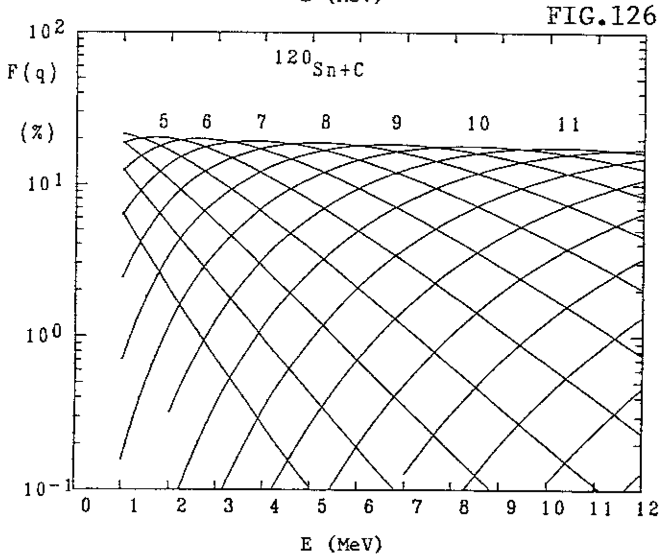


FIG.127

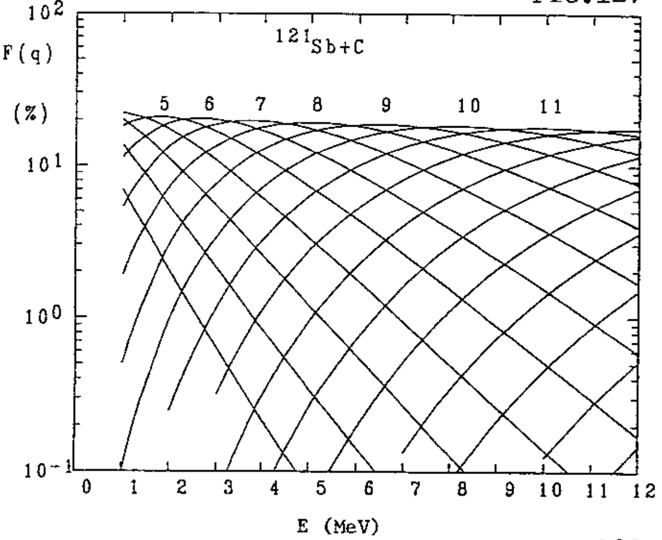


FIG.128

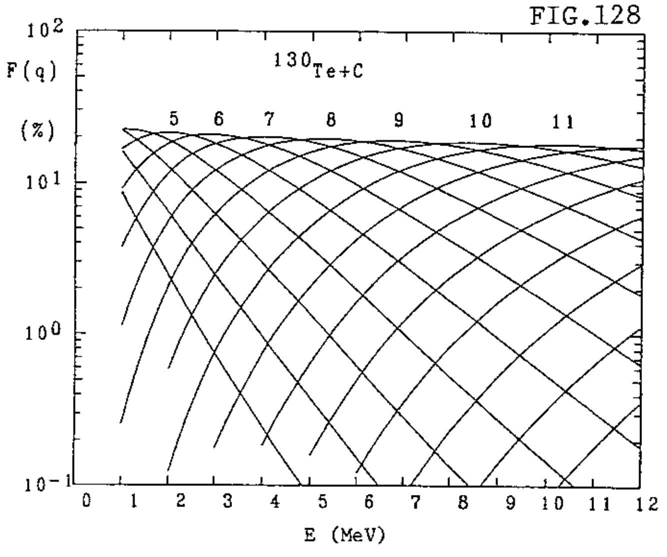


FIG.129

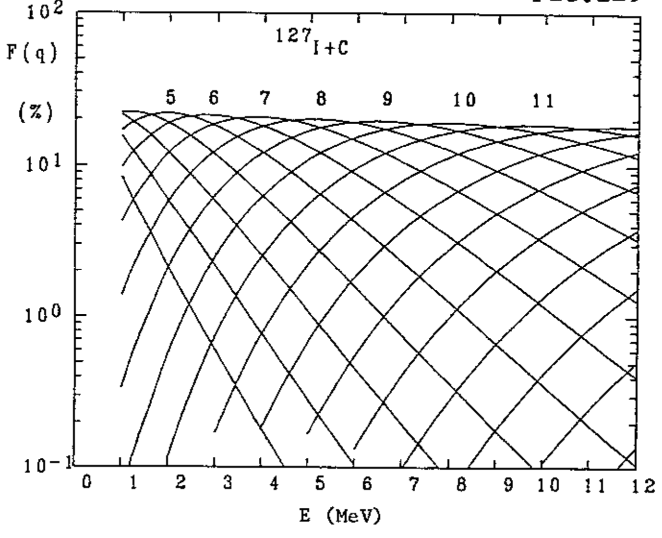


FIG.130

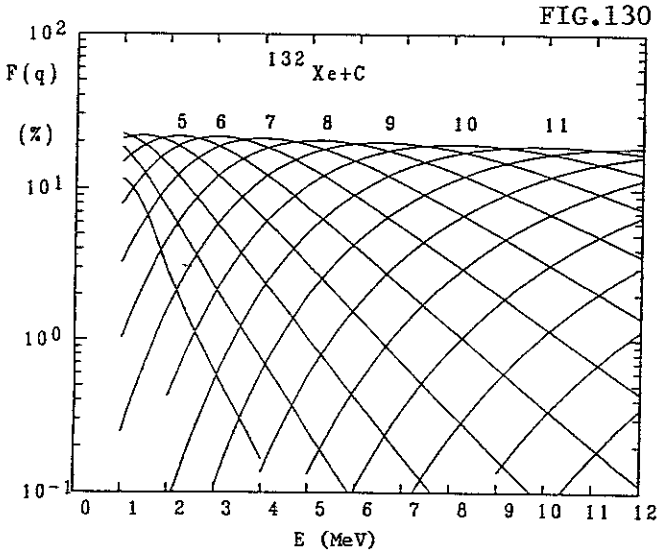


FIG.131

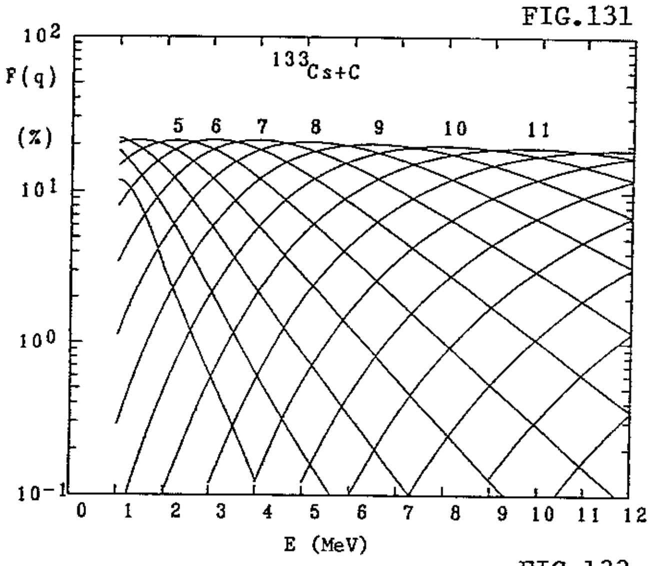


FIG.132

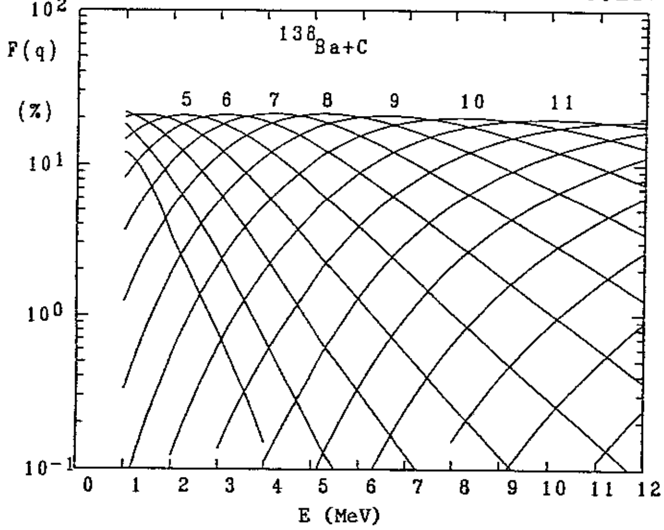


FIG.133

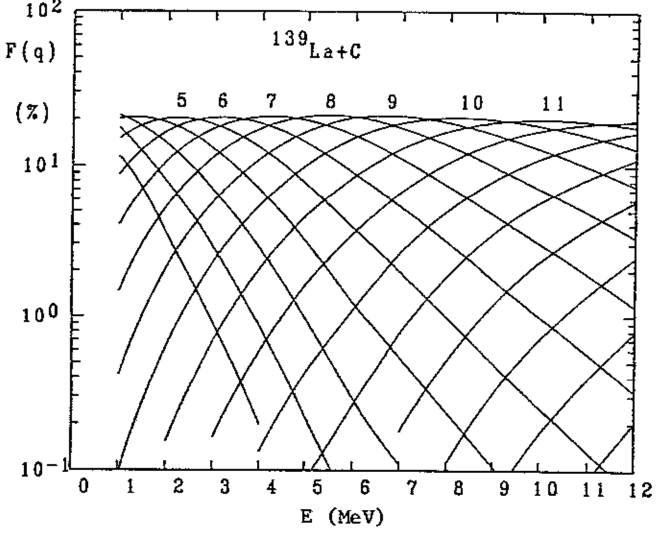


FIG.134

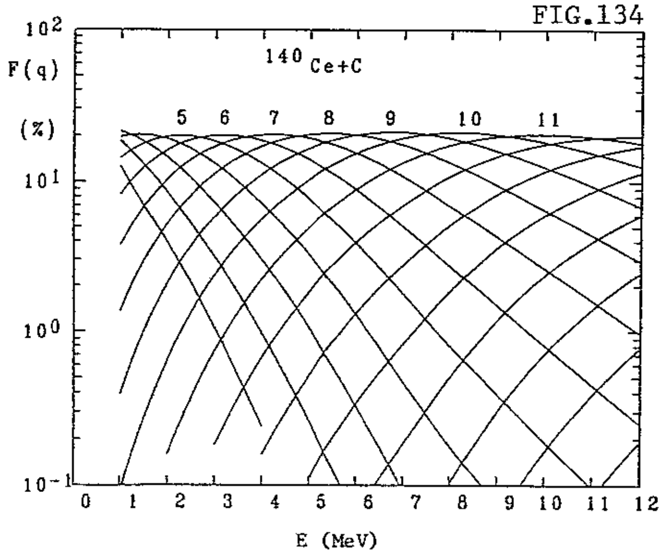


FIG.135

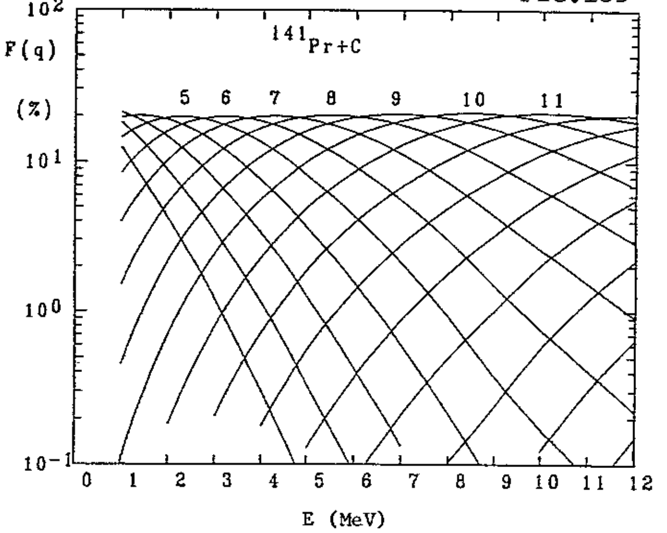


FIG.136

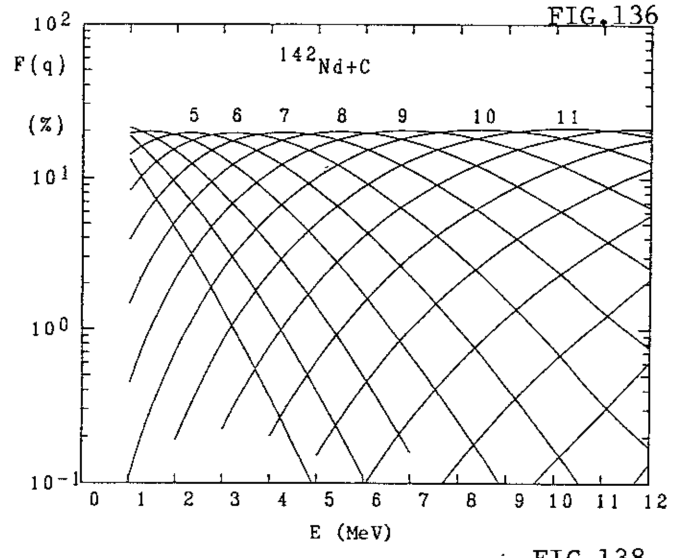


FIG.137

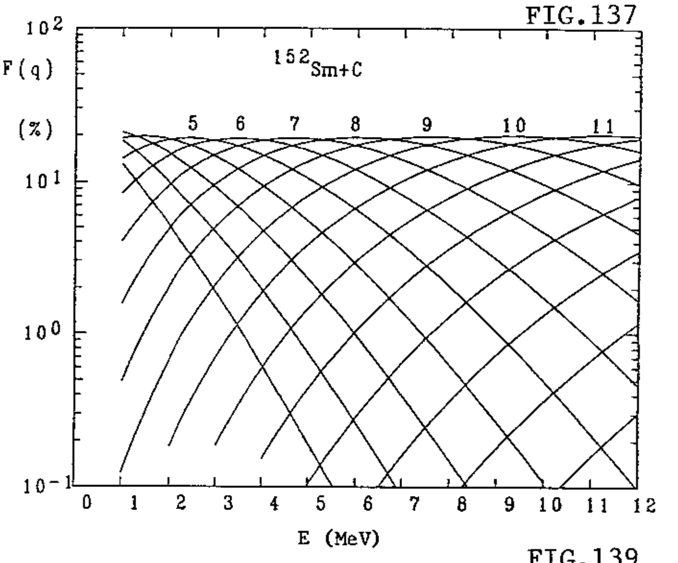


FIG.138

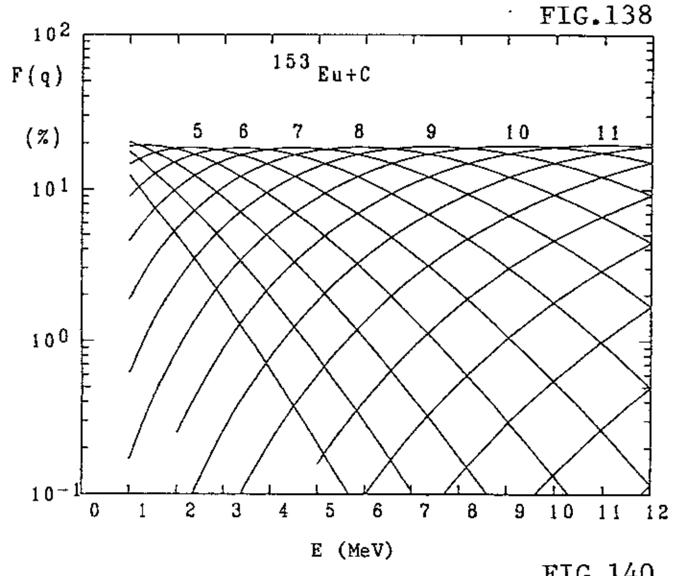


FIG.139

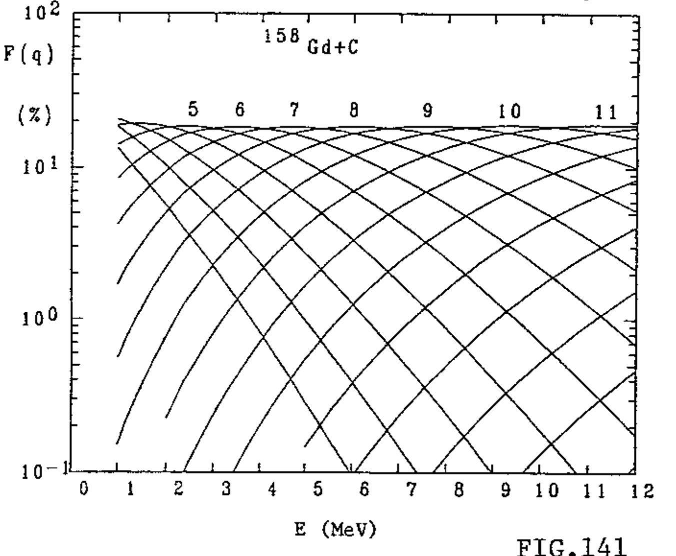


FIG.140

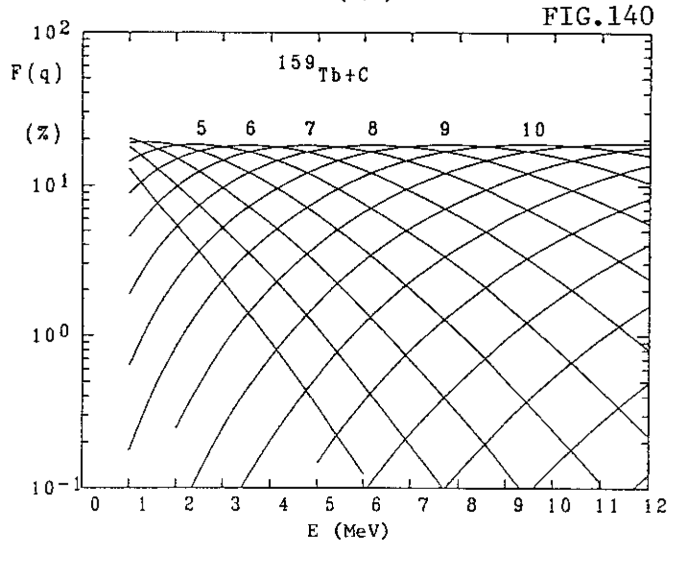


FIG.141

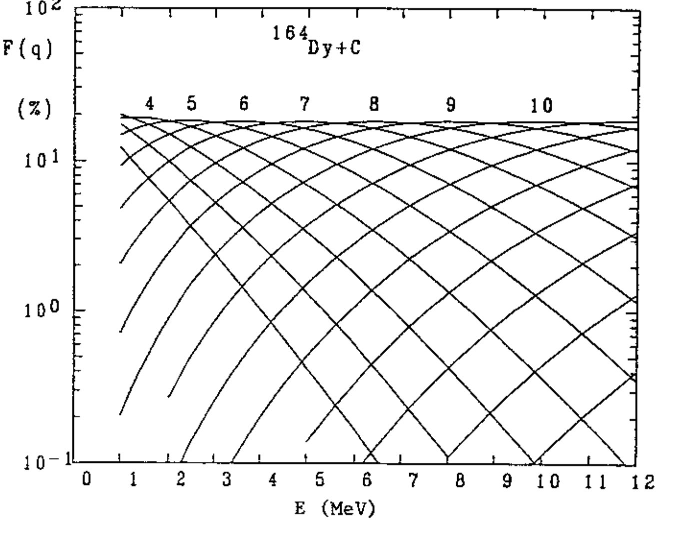


FIG.142

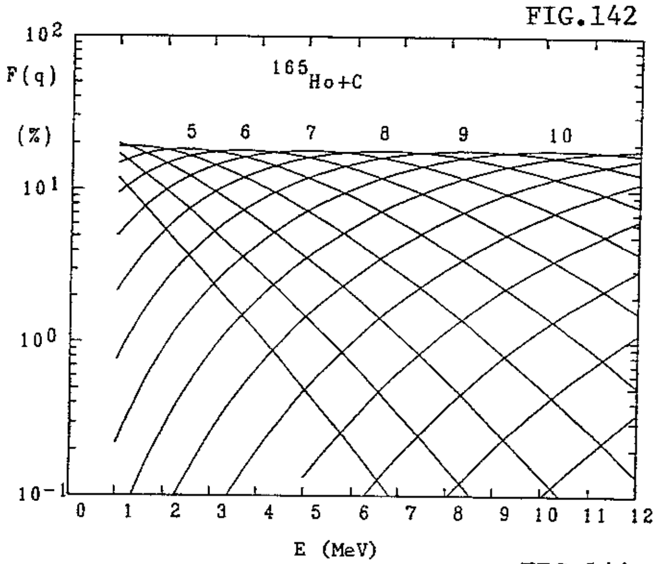


FIG.143

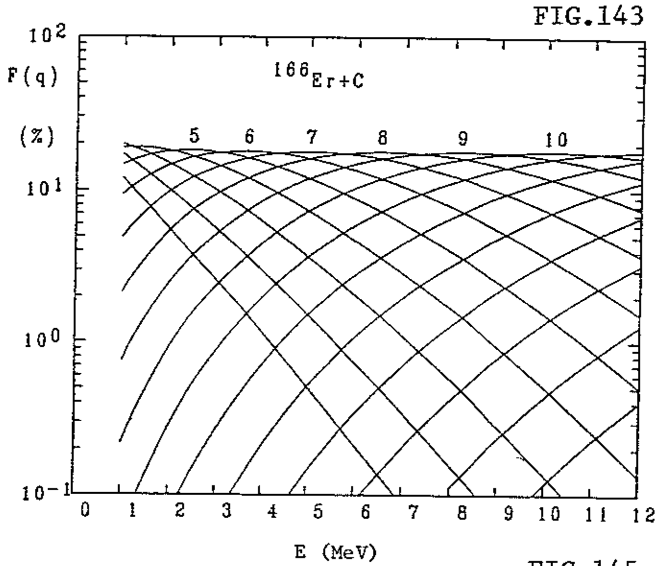


FIG.144

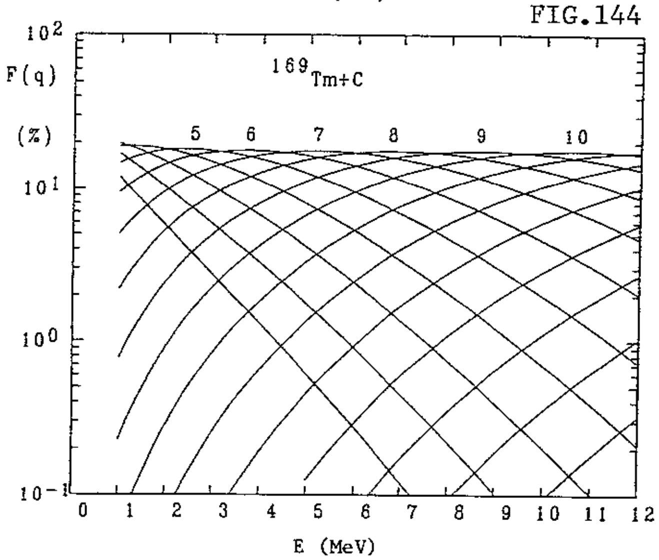


FIG.145

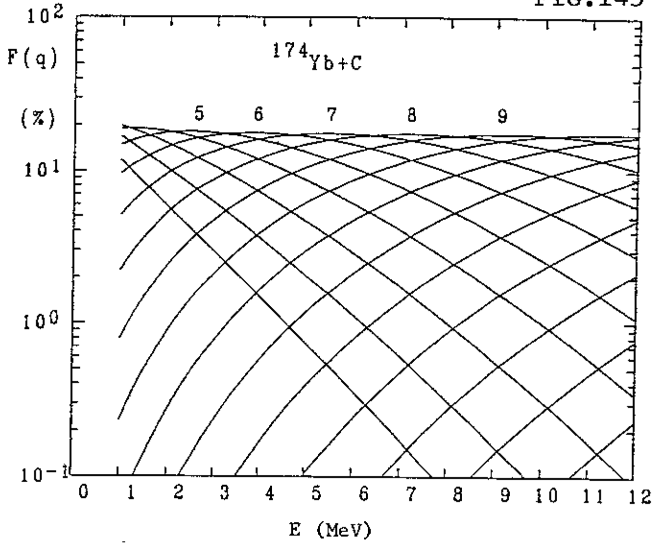


FIG.146

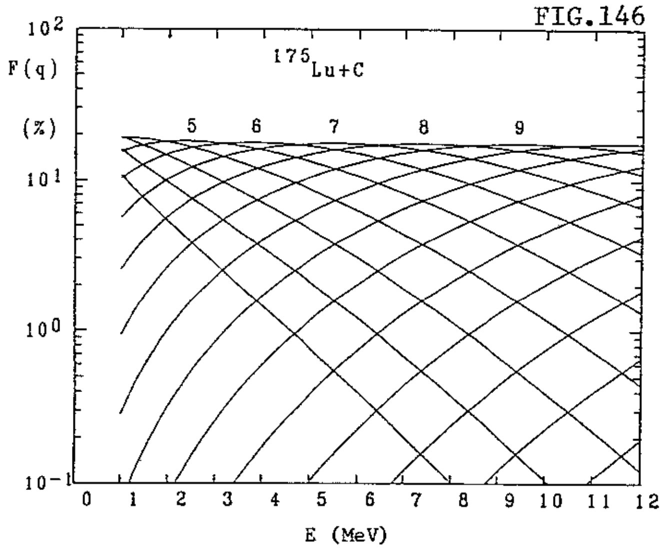


FIG.147

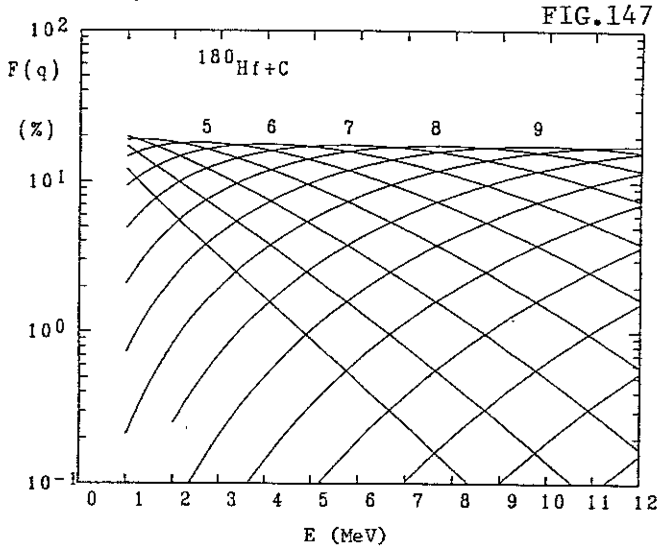


FIG.148

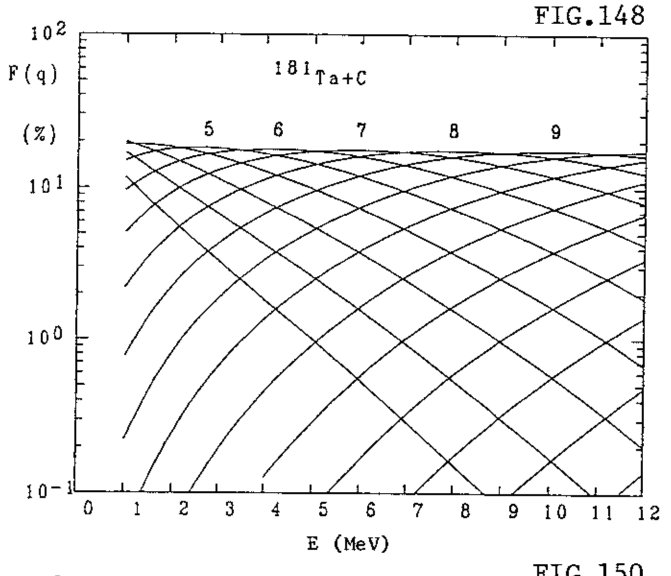


FIG.149

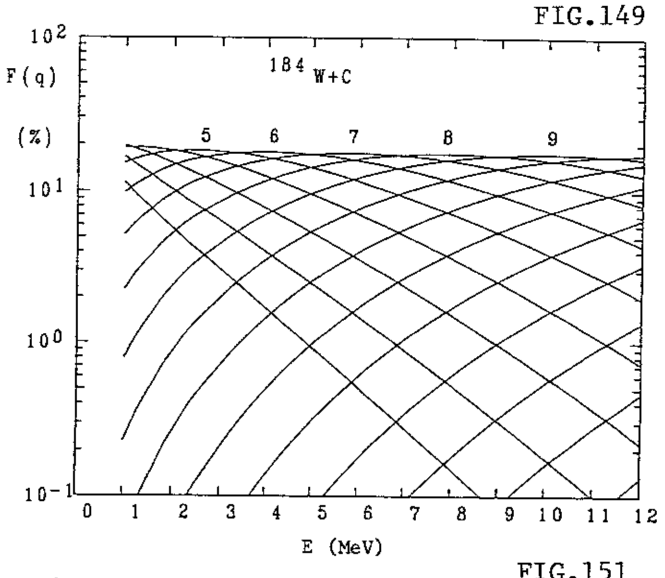


FIG.150

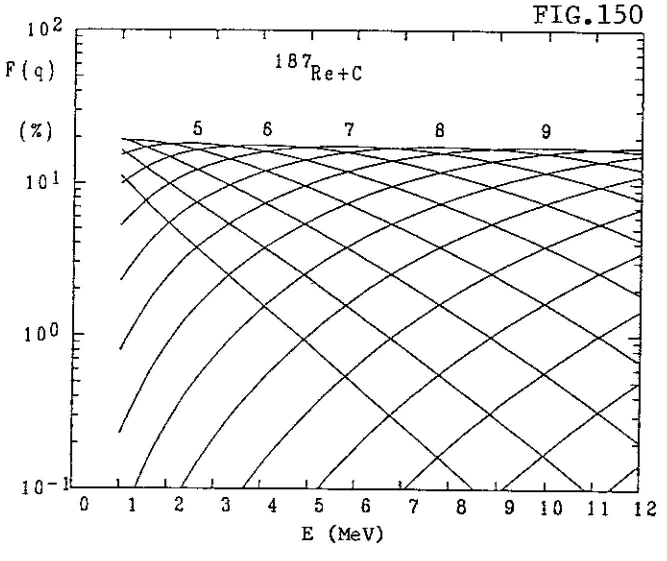


FIG.151

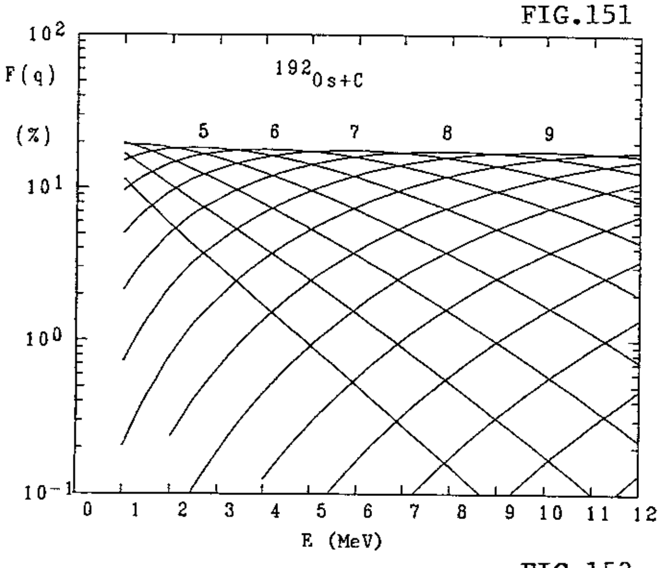


FIG.152

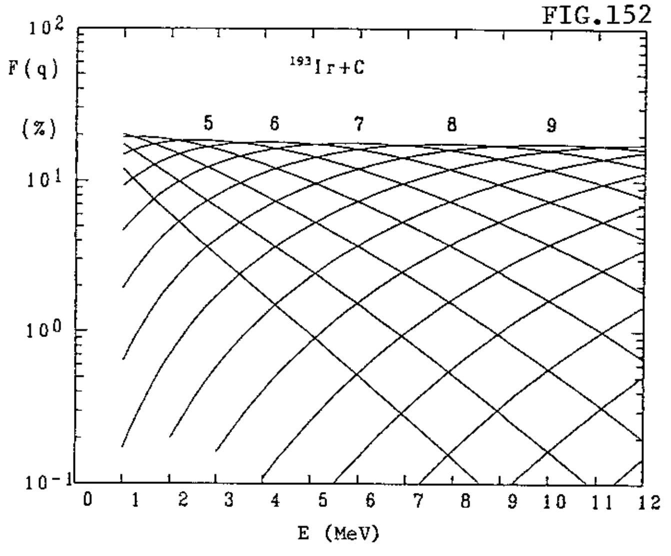


FIG.153

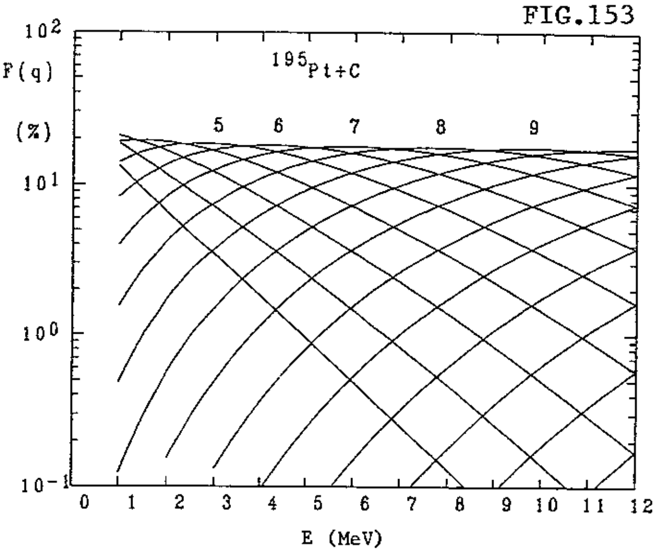


FIG.154

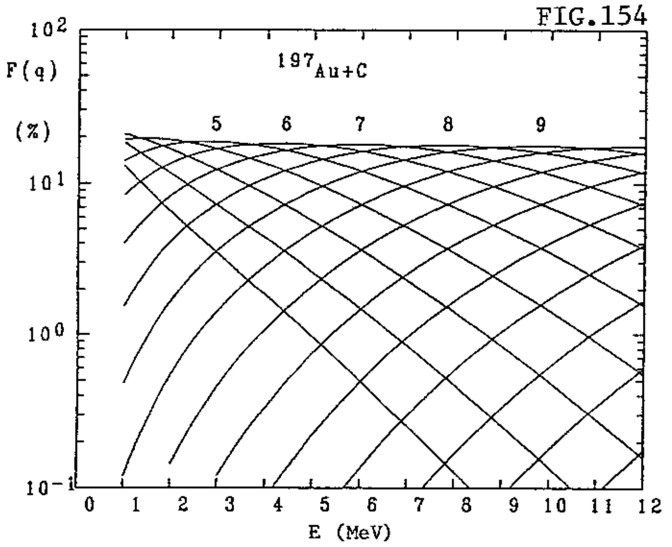


FIG.155

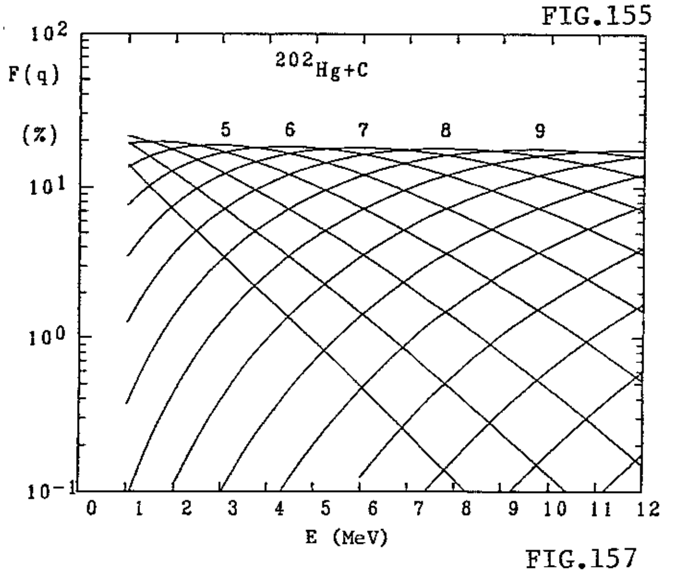


FIG.156

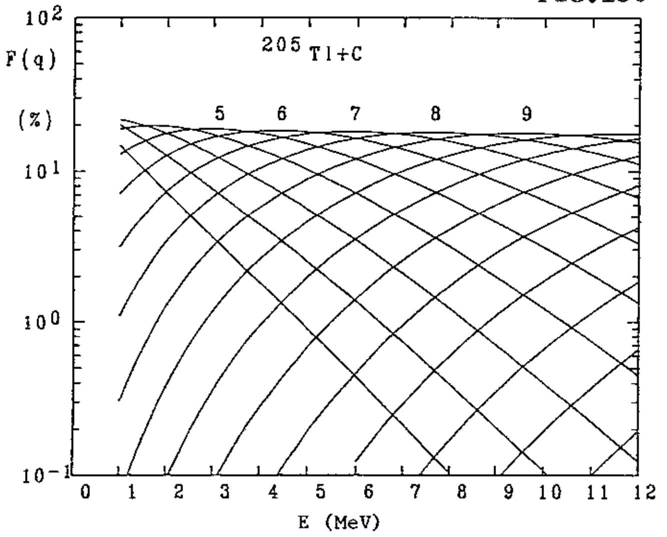


FIG.157

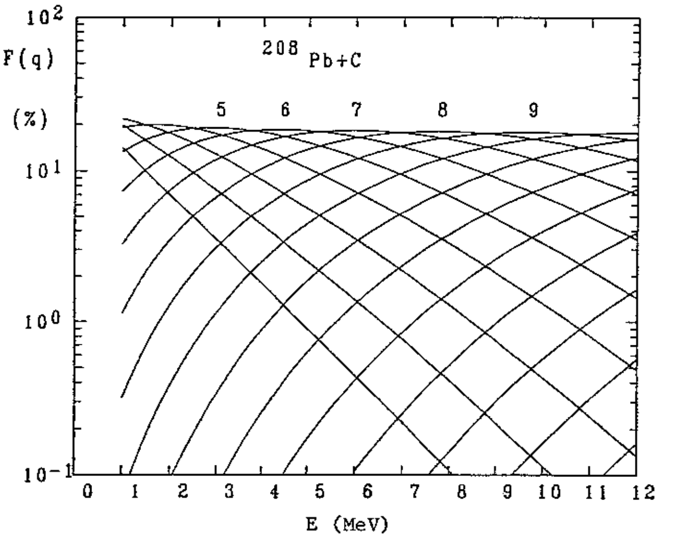
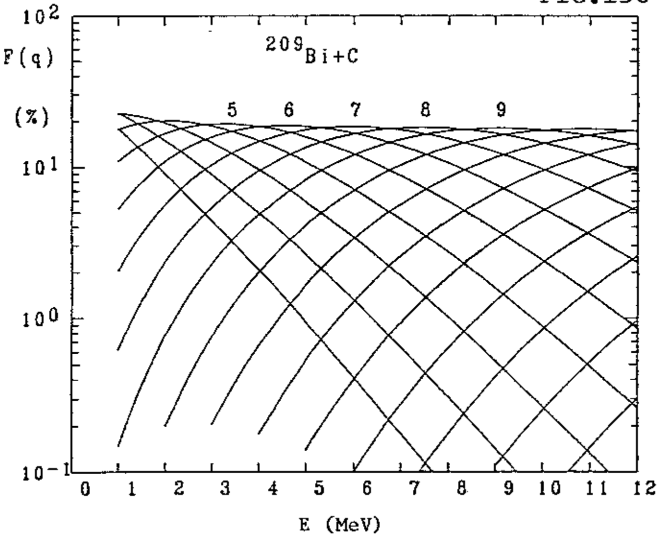


FIG.158



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