ОБЪЕДИНЕННЫЙ
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W. Neubert

EXPERIMENTAL DATA ON (H.I., xn)-REACTIONS

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1. Energetic Relations

In this paper a compilation of measured excitation function data for heavy ion induced compound nucleus reactions is presented. A projectile with the kinetic energy E_{lab} interacts with a target nucleus and forms an excited compound nucleus of excitation energy E_{exc}, which decays by emission of particles and gamma quanta. Here, only reactions with emission of neutrons are dealt with. The excitation functions of such reactions show sharp maxima, the positions of which depend on the number x of emitted neutrons. The large body of experimental (HI, xn) reaction data, presented in the succeeding tables, offers the possibility to look for a simple and reliable way for optimizing the experimental conditions of such type of reactions. Only the tabulated values of mass excess and neutron separation energy are used to formulate an empirical relation for the peak position of the excitation functions.

As it is suggested by Alexander and Simonoff [20], the relation

$$(\langle E \rangle_x - \sum_{i=1}^{x} B_{in})/x \sim 5.0 \ldots 6.5\ MeV \qquad /1/$$

is valid, regardless of the number of the evaporated neutrons and the projectile mass, which has been proved correct for a number of reactions leading to the product nuclei $^{149,150,151}Dy$. In this notation B_{in} is the neutron separation energy of the compound nucleus or the intermediate nuclei formed in the neutron evaporation cascade. $\langle E \rangle_x$ designates the mean value of the compound nucleus excitation energy, which corresponds to the centre of gravity of the measured excitation function. In case of a symmetric shape of the excitation function this quantity coincides with the peak position $\bar{E}_{exc}$, which will further be used by us as a fairly good approximation in order to simplify the analysis of the experimental data. The excitation energy consists of the mass excess difference of the ingoing target and projectile nuclei and the outgoing compound nucleus, added to the kinetic energy (in the centre-of-mass system) brought in by the projectile.

$$\bar{E}_{exc} = E_{lab} \frac{A_T}{A_C} + (M-A)_T + (M-A)_I - (M-A)_C , \qquad /2/$$

where $(M-A)$ denote the mass excesses of target (T), ion (I) and compound nucleus (c). In analogy to the expression /1/ we define a quantity

$$\bar{\epsilon} = (E_{exc} - \sum_{i=1}^{x} B_{in}) / x \quad , \qquad /3/$$

representing the average energy value, which is carried away by each step of the evaporation cascade in form of gamma radiation and kinetic energy of the emitted neutron.

2. Compilation of Experimental Data

Data characterizing the excitation functions of (HI, xn) reactions, available in the literature were arranged in tables 1-12 in order to get statistical material for the characteristic quantity $\bar{\epsilon}$ and its dependence of the mass number. The compilation covers HI reactions with B, C, N, O, F, Ne, P and Ar as incoming particles.

In the first column of the tables the compound nucleus reaction is specified, ordered with increasing mass numbers of reaction products.

The second column contains the energy position E_{lab} of the peak of the excitation function, measured in the laboratory system. Reactions with the heaviest ions show very broad excitation functions, causing uncertainly determined peak positions, e.g. ± 6MeV in case of Ar.

The calculation of the excitation energy values E_{exc}, cited in the third column, is based on the tables of experimentally determined mass excess values (23). In the rare cases, where for the compound nucleus no experimental value was available, the $(M-A)_c$ value was taken from Seegers' mass formula (11) and corresponding target and projectile values (based also on ^{16}O -mass scale) from the tables of Everling et al. (9). In some few cases values from Zeldes' table (36) were used.

In the fourth column $B_n = \sum_{i=1}^{x} B_{in}$ denotes the neutron separation energies summed over the whole evaporation cascade. The B_{in} values were taken from (11).

The fifth column contains the quantity $\bar{\epsilon}$, derived from equation /3/.

The peak cross section σ is given in the sixth column in units of $10^{-27} cm^2$. For smaller values the exponent is given in parentheses, e.g. $6(-4) = 6.10^{-4}$ mb. A stroke is given if the cross section has not been quantitatively determined or was only given as a branching ratio or the σ / σ_{total} ratio.

The remarks in column seven imply LSI-low spin isomers, HSI-high spin isomers, i.e. states which form independent isomeric pairs without or with very weak gamma branching. S and Z indicate that the mass excess values were taken from Seegers' table (11) or Zeldes' table (36), respectively. Values marked by an asterisk * were included into the least square fit. The $\bar{\epsilon}$ value is shifted to higher energies, if the peak of the excitation function is less than 10 MeV above the Coulomb barrier, which takes place mainly for *(HI, 3n)* reactions and, in case of heavy nuclei, even for *(HI, 4n)* reactions. Such data were excluded from the fit.

The references cited in the last column consider the literature till March 1972.

3. Conclusions

In figure 1 the $\bar{\epsilon}$ values are plotted vs. the mass number A of the product nucleus. At first sight quite large deviations from the data of Alexander and Simonoff are noticeable. Major sources of the fluctuations may be inaccurately known initial energies and day-to-day variations of the different accelerators used by the investigators. The evaluation of the energy loss in the target material may cause further fluctuations, if different energy-range relations were used. Emerging from these fluctuations $\bar{\epsilon}$ decreases with increasing mass number. Such trend is to be expected, because the kinetic energy of the emitted neutrons as well as the residual excitation energy of the system dissipated by photon emission decrease with increasing mass number, as follows from model predictions. Assuming a linear dependence, a least square fit leads for the interval $110 \le A \le 260$ to the relation

$$\bar{\epsilon}_{fit} = (8.8 - \frac{2.3}{100} A)\ MeV. \qquad /4/$$

In order to check its validity the standard deviations S of the experimental points $\bar{\epsilon}$ in fig. 1 from $\bar{\epsilon}_{fit}$ were calculated for mass number intervals of each $\Delta A = 10$. The result drawn in fig. 2 shows no striking deviations. The distribution function for the whole mass region $110 \le A \le 260$ (fig. 3) fulfills the requirements of a normal distribution and may be described by a Gaussian distribution with a standard deviation of $S = 0.7$ MeV. Equation /4/ may, therefore, be used as a first approximation for the estimation of $\bar{\epsilon}$. The equations /2/ and /3/ are useful to find out the optimum projectile energy E_{lab} which gives maximum yield of a desired reaction product. In fig. 1 groups of experimental points show considerable deviations and were, therefore, excluded from the fit. One of these groups are the nuclei $^{149,150,151}Dy$, produced by irradiation of enriched Gd targets with argon ions[18]. The corresponding values may possibly be influenced by the uncertainly known incident energy of the heavy ions, because the internal beam of the cyclotron was used. This is supported by the fact, that other data for these reactions[49] give much lower $\bar{\epsilon}$ values.

A large dispersion of the $\bar{\epsilon}$ values is also observed for the group of the heaviest nuclei, where the cross-sections are extremely small, causing large statistical errors.

For the low-spin ground states of the nuclei ^{149}Tb, $^{151,152,154}Ho$ small $\bar{\epsilon}$ values were obtained, which lie outside the expected deviations. In each of these nuclei a high-spin isomeric state exists, which decays by α -emission without gamma branching to the ground state, leading to a "screening" of the low-spin state. With increasing bombarding energy higher angular momenta are transferred to the product nucleus, and preferably the high-spin level is populated, whereas the direct population of the low-spin level diminishes. The peak position of the excitation function of the "screened" low-spin state is found at lower beam energy. The quantity $\bar{\epsilon}$ derived from the excitation function of the high-spin state coincides with the bulk of the other data. In the ordinary cases of strong gamma branching no screening takes place, and the excitation of the low-spin state is mainly affected by that of the high-spin state. Usually, the shifts of the excitation functions owing to different spin values are, therefore, not very significant and are smaller than the shifts, caused by one additionally evaporated neutron.

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References

(1) A.S.Baraboschkin et al. Zh.Eksperim. i Teor. Fiz., 32, 1294 (1957).
(2) T.Sikkeland, S.C.Thompson, A.Ghiorso. Phys.Rev., 112, 453 (1958).
(3) L.I.Guseva et al. Zh. Eksperim. i Teor. Fiz., 37, 973 (1959).
(4) A.S. Karamyan et al. Zh. Eksperim. i Teor. Fiz., 36, 621 (1959).
(5) A.S.Karamyan, A.A.Pleve. Zh. Eksperim. i Teor. Fiz., 37, 654 (1959).
(6) A.S.Karamyan, L.I.Rusinov, V.A.Fomicev. Zh. Eksperim. i Teor. Fiz., 36, 1374(1959).
(7) V.V.Volkov et al. Zh. Eksperim. i Teor. Fiz., 37, 1207 (1959).
(8) V.V.Volkov et al. Zh. Eksperim. i Teor. Fiz., 36, 762 (1959).
(9) F.Everling, L.A.Konig, J.H.E.Mattauch and A.H.Wapstra. Nucl. Phys., 18, 529 (1960).
(10) A.S.Karamyan, A.A.Pleve. Zh.Eksperim. i Teor. Fiz., 40, 1541 (1961).
(11) P.A.Seeger. Nucl.Phys., 25, 1 (1961).
(12) T.D.Thomas, G.E.Gordon, R.M.Latimer, G.T.Seaborg. Phys.Rev., 126, 1805 (1962).
(13) J.M.Alexander and G.N.Simonoff. Phys.Rev., 130, 2383 (1963).
(14) T.J.Klingen and G.R.Choppin. Phys.Rev., 130, 1990 (1963).
(15) R.D.Macfarlane. Phys.Rev., 131, 2176 (1963).
(16) R.D.Macfarlane, R.Griffionen. Phys.Rev., 130, 1491 (1963).
(17) R.M.Griffionen, R.D.Macfarlane. Phys.Rev., B133, 1373 (1964).
(18) H.Kumpf, V.A.Karnaukhov, Zh. Eksperim. i Teor. Fiz., 46, 1545 (1964).
(19) R.D.Macfarlane. Phys.Rev., B136, 941 (1964).
(20) J.M.Alexander, G.N.Simonoff. Phys.Rev., 133, B93 (1964).
(21) H.F.Brinckmann, C.Heiser, K.F.Alexander, W.Neubert, H.Rotter. Nucl. Phys., 81, 233 (1965).

(22) R.D.Macfarlane. Phys.Rev., B137, 1448 (1965).
(23) J.H.E.Mattauch, W.Thiele, A.H.Wapstra. Nucl.Phys., 67, 1 (1965).
(24) H.Rotter, A.G.Demin, L.P.Pashenko, H.F.Brinckmann. Yad. Fiz., 4, 246 (1966).
(25) E.D.Donets, V.A.Shegolev, V.A.Ermakov. Yad. Energ., 20, 223 (1966), E.D.Donets, JINR, 2919, Dubna, 1966.
(26) M.Kaplan. Phys.Rev., 143, 894 (1966).
(27) V.I.Mikheev, S.M.Polikanov. Proceedings Int. Conf. Heavy Ion Physics, Dubna 1966, part 2.
(28) A.A.Siivola. Nucl.Phys., 84, 385 (1966).
(29) K.Valli, E.K.Hyde, W.Treytl. UCRL-17272 (1966) and J.Inorg. Nucl. Chem., 29, 2503 (1967).
(30) K.F.Alexander, W.Neubert, H.Rotter. JINR P7-3185, Dubna, 1967.
(31) D.D.Bogdanov, S.Daroczy, V.A.Karnaukhov, L.A.Petrov, G.M.Ter-Akopyan. JINR E6-3142, Dubna, 1967.
(32) A.Siivola. Nucl.Phys., A101, 129 (1967).
(33) W.Treytl, K.Valli. Nucl.Phys., A97, 405 (1967).
(34) W.Treytl, E.K.Hyde, K.Valli. UCRL-17405 (1967).
(35) K. Valli, M.J.Nurmia, E.K.Hyde. Phys.Rev., 159, 1013 (1967) and K.Valli, W.Treytl, E.K.Hyde. Phys.Rev., 161, 1284 (1967).
(36) N.Zeldes, A.Grill, A.Simievic. Mat.Fiz.Skr.Dan.Vid.Selsk., 3, no. 5 (1967).
(37) W.Neubert, K.F.Alexander. JINR Preprint P7-3657, Dubna, 1968.
(38) T.Sikkeland, A.Ghiorso, M.J.Nurmia. Phys.Rev., 172, 1232 (1968).
(39) A.Siivola. Nucl.Phys., A109, 231 (1968).
(40) D.F.Togerson, R.A.Gough, R.D.Macfarlane. Phys.Rev., 174, 1494 (1968).
(41) K.Valli, W.Treytl, E.K.Hyde. UCRL-17322 and Phys.Rev., 176, 1377 (1968).
(42) K.F.Alexander, W.Neubert, H.Rotter et al. Nucl.Phys., A133, 77 (1969).
(43) M.Barbier. Induced Radioactivity. North-Holland Publishing Co., 1969, chapter VI.
(44) Ch.Droste, W.Neubert, T.Morek et al. Comm. JINR P6-4539, Dubna, 1969 and Comm. JINR P6-4592, Dubna, 1969.
(45) R.A.Gough and R.D.Macfarlane. Proceedings Int.Conf.Nucl.Reactions. Induced by Heavy Ions, Heidelberg, 1969.
(46) C.Heiser, K.F.Alexander, H.F.Brinckmann, N.Nenov, W.Neubert, H.Rotter. Nucl. Phys., A96, 327 (1967).
(47) T.Morek, W.Neubert et al. Comm. JINR P6-4868, Dubna, 1969.
(48) T.Morek, W.Neubert, Ch.Droste et al. Comm. JINR P6-4553, Dubna, 1969.
(49) J.B.Natowitz, J.M.Alexander. Phys.Rev., 188, 1734 (1969).
(50) W.Neubert, K.F.Alexander et al. Nucl.Phys., A131, 225 (1969).
(51) V.A.Shegolev. JINR 7-4596, Dubna, 1969.
(52) J.Borgreen, K.Valli, E.K.Hyde. Phys.Rev., C2, 1841 (1970).
(53) Ch.Droste et al. Nucl.Phys., A152, 579 (1970) and Comm. JINR P6-4597, Dubna, 1969.

(54) G.N.Flerov, Yu.Ts.Oganesyan, Yu.V.Lobanov et al. Preprint JINR P7-5174, Dubna, 1970 and Nucl.Phys., A160, 181 (1971).
(55) R.J.Silva et al. Phys.Rev., C2, 1948 (1970).
(56) T.Sikkeland, R.J.Silva, A.Ghiorso, M.J.Nurmia. Phys.Rev., C1, 1564 (1970).
(57) D.F.Togerson, R.D.Macfarlane. Nucl.Phys., A149 (1970), 641.
(58) D.F.Togerson, R.D.Macfarlane. Phys.Rev., C2, 2309 (1970).
(59) K.Valli, E.K.Hyde, J.Borgreen. Phys.Rev., C1, 2115 (1970).
(60) Y.Le Beyec, M.Lefort, A.Vigny. Phys.Rev., C3, 1268 (1971).
(61) H.Delagrange et al. Phys.Lett., 37B, 355 (1971).
(62) K.Eskola et al. Phys.Rev., C4, 632 (1971).
(63) W.Neubert. Nucl.Instr. and Meth., 93, 473 (1971).
(64) Yu.Ts.Oganesyan, Yu.E.Penionshkevic, A.O.Schamsutdinov, Nguen Tak An. Comm. JINR P7-5912, Dubna, 1971.
(65) G.Ya. Sun-Tsin-Yan, V.A.Druin, A.S. Trofimov. Preprint JINR P7-5920, Dubna, 1971, Yad.Fiz., 14, 1297 (1971).
(66) K.S.Toth, R.L.Hahn. Phys.Rev., C3, 854 (1971).
(67) R.Broda et al. Acta Physica Polonica, B3, 263 (1972).

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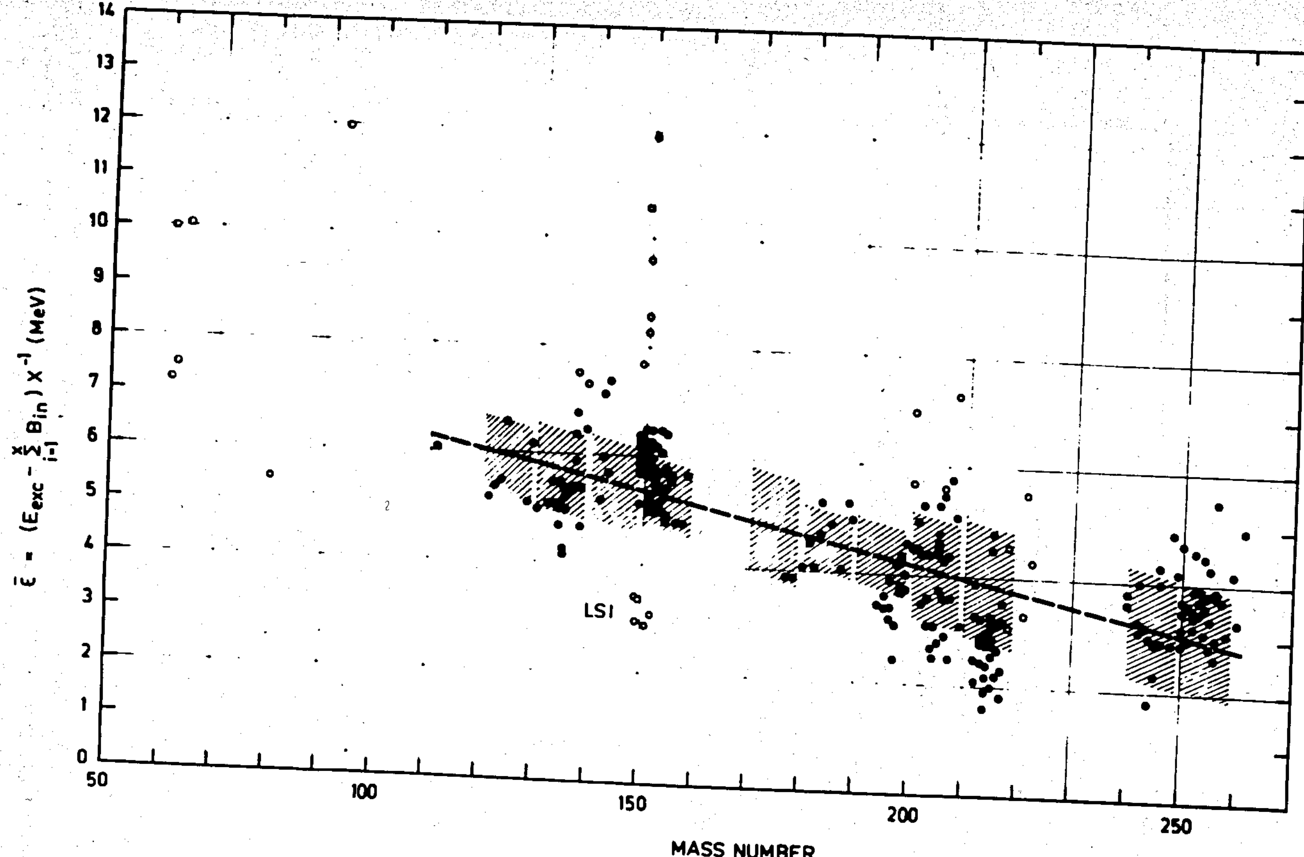


Fig. 1. Plot of the experimentally determined values $\bar{\epsilon}$ vs. mass number of the product nucleus. The dashed line represents the fit-equation /4/; the hatched band covers the standard deviation. Open circles (o) are not included in the least-square fit.

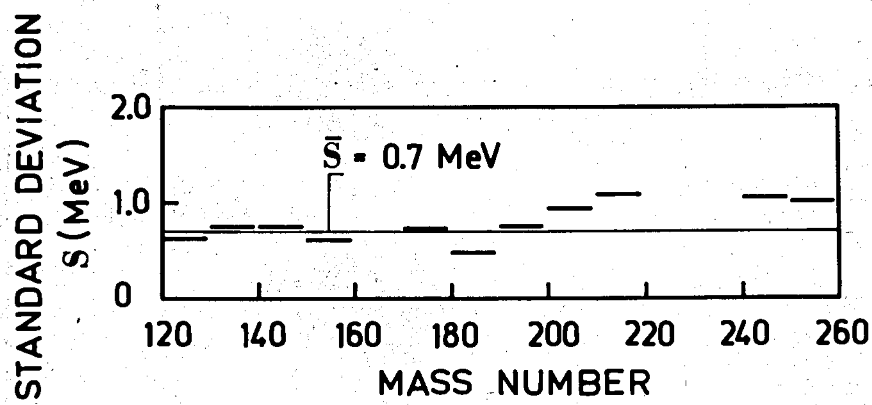
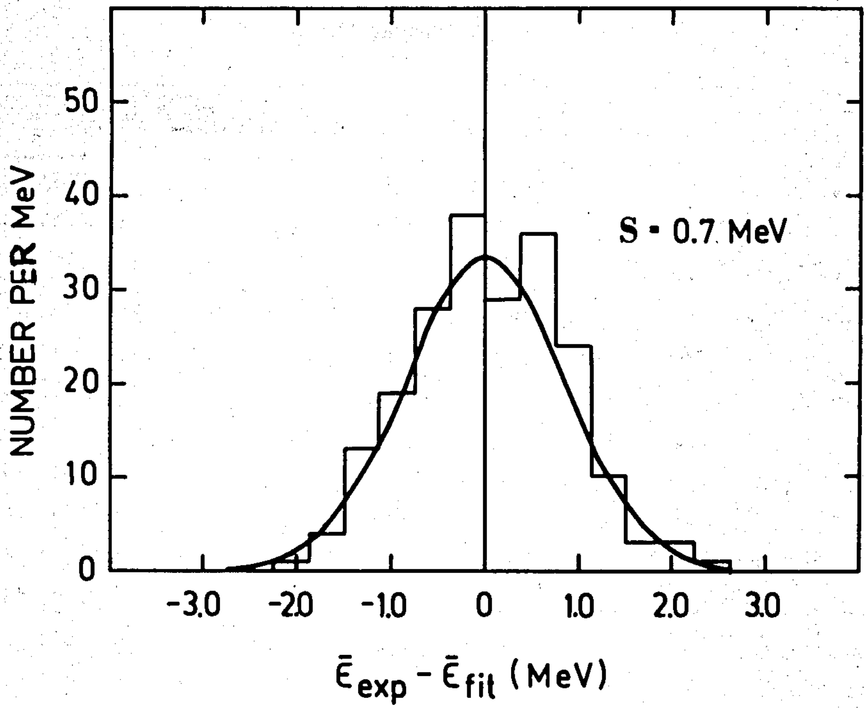


Fig. 2. Standard deviations of the experimental values $\bar{\epsilon}$ from the values $\bar{\epsilon}_{fit}$ obtained from equation /4/ averaged over mass number intervals ΔA =10.

Fig. 3. Distribution function for the differences between the experimental values $\bar{\epsilon}_{exp}$ and the values $\bar{\epsilon}_{fit}$ obtained from equation /4/. The lower part shows the respective distribution around the mean value for reactions leading to $^{149,150,151}Dy$ (20).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10
20
30
40
50
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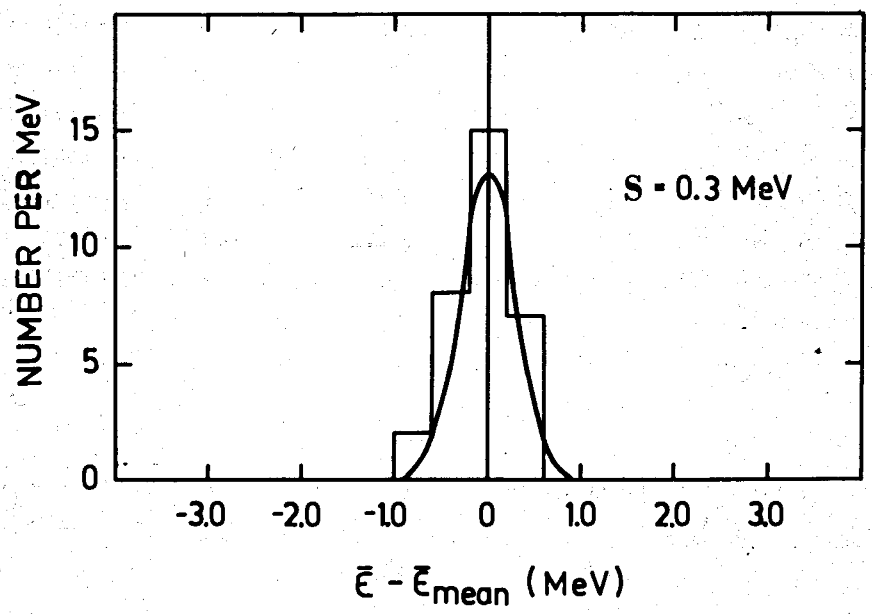
-2.0
-1.0
0
1.0
2.0
3.0
$\bar{\varepsilon}_{exp} - \bar{\varepsilon}_{fit}$ (MeV)


NUMBER PER MeV
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5
10
15
S = 0.3 MeV
-3.0
-2.0
-1.0
0
1.0
2.0
3.0
$\bar{\varepsilon} - \bar{\varepsilon}_{mean}$ (MeV)

Z = 5 BORON INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_nMeV)	$\bar{\varepsilon}$(MeV)	σ(mb)	REMARKS	REFERENCES
$^{139}La(^{10}B,7n)^{142}Sm$	97	92.4	55.8	5.2	524	* (26)	66 Ka 4
$^{146}Nd(^{11}B,8n)^{149}Tb$	100	91.4	63.6	3.5	12.4	LSI (13)	63 Al 1
$^{144}Nd(^{10}B,5n)^{149}Tb$	60	54.6	40.1	3.2	41.4	LSI (13)	63 Al 1
$^{142}Nd(^{11}B,4n)^{149}Tb$	53	45.4	33.3	3.0	51.6	LSI (13)	63 Al 1
$^{144}Nd(^{11}B,6n)^{149}Tb$	78	68.5	48.8	3.3	28	LSI (13)	63 Al 1
$^{146}Nd(^{10}B,7n)^{149}Tb$	82	78.0	55.3	3.4	19.6	LSI (13)	63 Al 1
$^{181}Ta(^{11}B,4n)^{188}Pt$	60	53.0	31.7	5.3	400	* (61)	71 De 1
$^{197}Au(^{10}B,7n)^{200}Po$	90	83.8	57.2	3.8	–	* (51)	69 Sh 1
$^{197}Au(^{10}B,6n)^{201}Po$	82	76.2	49.1	4.5	–	* (51)	69 Sh 1
$^{197}Au(^{10}B,5n)^{202}Po$	67	61.9	39.8	4.4	–	* (51)	69 Sh 1
$^{197}Au(^{11}B,5n)^{203}Po$	71	62.0	40.3	4.4	–	* (47)	69 Mo 2
$^{209}Bi(^{10}B,7n)^{212}Ra$	92	72.1	49.3	3.3	–	* (51)	69 Sh 1
$^{208}Pb(^{11}B,7n)^{212}Fr$	91	63.5	46.6	2.5	–	* (40)	68 To 1
$^{208}Pb(^{11}B,6n)^{213}Fr$	80	53.0	38.2	2.5	–	* (40)	68 TO 1
$^{208}Pb(^{11}B,6n)^{213}Fr$	82	55.0	38.2	2.8	–	* (17)	64 Gr 1
$^{209}Bi(^{10}B,6n)^{213}Ra$	81	61.6	42.0	3.3	–	* (51)	69 Sh 1
$^{209}Bi(^{10}B,5n)^{214}Ra$	67	48.4	33.5	3.0	–	* (51)	69 Sh 1
$^{208}Pb(^{11}B,5n)^{214}Fr$	68	41.6	32.1	1.9	–	* (40)	68 To 1
$^{209}Bi(^{11}B,6n)^{214}Ra$	81	57.8	40.5	2.9	–	* (57)	70 To 2
$^{209}Bi(^{11}B,5n)^{215}Ra$	70	46.8	34.0	2. 6	–	* (57)	70 TO 2
$^{249}Cf(^{11}B,4n)^{256}103$	63	41.6	25.9	3.9	–	S* (62)	71 Es 1

Z = 6 CARBON INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	$\bar{\epsilon}$(MeV)	σ(mb)	REMARKS	REFERENCES
$^{51}V(^{13}C,3n)^{61}Cu$	54	59	27.6	10.0	300		(4) 59 Ka 1
$^{51}V(^{12}C,2n)^{61}Cu$	42	49.8	19.8	15.0	<10		(10) 61 Ka 1
$^{71}Ga(^{12}C,4n)^{79}Rb$	62.5	62.7	41.2	5.4	–		(67) 72 Br 1
$^{102}Pd(^{12}C,3n)^{111}Te$	64	51.2	33.0	6.1	–	*	(31) 67 Bo 1
$^{113}In(^{12}C,4n)^{121}Cs$	73	60.6	39.7	5.2	–	Z *	(30) 67 Al 1
$^{115}In(^{12}C,3n)^{124}Cs$	59	49	29.2	6.6	–	*	(44) 69 Dr 1
$^{121}Sb(^{12}C,4n)^{129}La$	72	62.2	37.5	6.2	75	*	(42) 69 Al 1
$^{122}Sn(^{12}C,4n)^{130}Ba$	60.5	54.5	34.4	5.0	–	*	(63) 71 Ne 1
$^{130}Te(^{12}C,10n)^{132}Ce$	150	134.3	83.5	5.1	69	*	(64) 71 Og 1
$^{130}Te(^{12}C,9n)^{133}Ce$	140	124.5	74.9	5.5	100	*	(64) 71 Og 1
$^{130}Te(^{13}C,10n)^{133}Ce$	142	131	79.9	5.1	70	*	(64) 71 Og 1
$^{128}Te(^{12}C,6n)^{134}Ce$	94	85	51.8	5.5	358		(14) 63 Kl 1
$^{130}Te(^{12}C,8n)^{134}Ce$	117	104.5	64.5	5.0	596		(14) 63 Kl 1
$^{128}Te(^{12}C,5n)^{135}Ce$	77.5	70	43.7	5.4	240	*	(14) 63 Kl 1
$^{130}Te(^{12}C,7n)^{135}Ce$	96	85.9	56.4	4.2	390	*	(14) 63 Kl 1
$^{130}Te(^{12}C,7n)^{135}Ce$	105	93	56.4	5.2	210	*	(64) 71 Og 1
$^{130}Te(^{13}C,8n)^{135}Ce$	109	101	61.4	5.0	140	*	(64) 71 Og 1
$^{130}Te(^{12}C,5n)^{137}Ce$	75	65.7	38.7	5.4	532		(64) 71 Og 1
$^{128}Te(^{12}C,3n)^{137}Ce$	54	48.4	26.0	7.5	68		(14) 63 Kl 1
$^{130}Te(^{12}C,5n)^{137}Ce$	77.5	68.4	38.7	5.9	275	*	(14) 63 Kl 1
$^{130}Te(^{13}C,6n)^{137}Ce$	82	76.0	43.7	5.4	249	*	(64) 71 Og 1
$^{130}Te(^{12}C,4n)^{138}Ce$	55	48	29.2	4.7	48	*	(21) 65 Br 1
$^{130}Te(^{12}C,3n)^{139}Ce$	51	44	21.9	7.3	55		(64) 71 Og 1
$^{130}Te(^{13}C,4n)^{139}Ce$	56	53	26.9	6.5	237	*	(64) 71 Og 1
$^{137}Ba(^{12}C,7n)^{142}Sm$	112	92.2	55.8	5.2	550	*	(43) 69 Ba 1
$^{136}Ba(^{12}C,6n)^{142}Sm$	103.7	85.8	49.7	6.0	589	*	(26) 66 Ka 4
$^{144}Nd(^{12}C,7n)^{149}Dy$	119	97.0	60.9	5.2	–	*	(20) 64 Al 2

Z = 6 CARBON INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	ε(MeV)	σ(mb)	REMARKS	REFERENCES
$^{141}Pr(^{12}C,4n)^{149}Tb$	65	45.1	33.3	3.0	35	LSI	(13) 63 Al 1
$^{142}Nd(^{12}C,5n)^{149}Dy$	94.3	75.6	44.8	6.2	446	*	(20) 64 Al 2
$^{142}Nd(^{12}C,4n)^{150}Dy$	78.8	59.8	34.6	6.3	934	*	(20) 64 Al 2
$^{144}Nd(^{12}C,6n)^{150}Dy$	106.1	85.2	50.7	5.7	830	*	(20) 64 Al 2
$^{142}Nd(^{12}C,3n)^{151}Dy$	67.2	45.4	26.7	6.2	445	*	(20) 64 Al 2
$^{144}Nd(^{12}C,5n)^{151}Dy$	90.0	68.6	42.8	5.1	590	*	(20) 64 Al 2
$^{181}Ta(^{12}C,4n)^{189}Au$	72.5	53.0	33.0	5.0	290	*	(46) 69 He 1
$^{197}Au(^{12}C,7n)^{202}At$	108	83.1	58.4	3.5	40	*	(12) 62 Th 1
$^{197}Au(^{12}C,6n)^{203}At$	92	67.6	48.9	3.1	200	*	(12) 62 Th 1
$^{197}Au(^{12}C,5n)^{204}At$	78	54.5	41.0	2.7	100	*	(12) 62 Th 1
$^{197}Au(^{12}C,4n)^{205}At$	70	47.0	31.9	3.8	90	*	(12) 62 Th 1
$^{197}Au(^{12}C,4n)^{205}At$	72.5	49.4	31.9	4.4	-	*	(47) 69 Me 2
$^{197}Au(^{12}C,3n)^{206}At$	64.0	41.4	24.4	5.6	-		(47) 69 Me 2
$^{203}Tl(^{12}C,8n)^{207}Rn$	112	82	62.0	2.5	-	*	(17) 64 Gr 1
$^{205}Tl(^{12}C,5n)^{212}Fr$	87	54.0	34.5	3.9	-	*	(17) 64 Gr 1
$^{206}Pb(^{12}C,6n)^{212}Ra$	96	56.9	43.4	2.1	-		(35) 67 Va 2
$^{206}Pb(^{12}C,5n)^{213}Ra$	84	50.0	36.1	2.8	-	*	(35) 67 Va 2
$^{209}Bi(^{12}C,7n)^{214}Ac$	107	68.3	51.3	2.4	-	*	(33) 67 Tr 1
$^{209}Bi(^{12}C,7n)^{214}Ac$	110	71	51.3	2.8	8	*	(45) 69 Ge 1
$^{206}Pb(^{12}C,4n)^{214}Ra$	72	39.0	27.6	2.9	-	*	(35) 67 Va 2
$^{209}Bi(^{12}C,6n)^{215}Ac$	98	59.8	42.7	2.8	-	*	(34) 67 Tr 2
$^{209}Bi(^{12}C,6n)^{215}Ac$	99	61.5	42.7	3.1	40	*	(45) 69 Ge 1
$^{209}Bi(^{12}C,6n)^{215}Ac$	96	62.4	42.7	3.3	-	*	(57) 70 To 2
$^{209}Bi(^{12}C,5n)^{216}Ac$	89	51.5	35.8	3.1	92	*	(45) 69 Ge 1
$^{209}Bi(^{12}C,5n)^{216}Ac$	83	49.5	35.8	2.7	-	HBI *	(57) 70 To 2
$^{209}Bi(^{12}C,4n)^{217}Ac$	80	42.0	27.8	3.5	86	*	(45) 69 Ge 1
$^{209}Bi(^{12}C,4n)^{217}Ac$	77	40.5	27.8	3.2	-	*	(24) 65 Re 1
$^{209}Bi(^{12}C,3n)^{218}Ac$	67	30.8	21.3	3.1	-		(24) 65 Re 1

Z = 6 CARBON INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	$\bar{\varepsilon}$(MeV)	σ(mb)	REMARKS	REFERENCES
^{209}Bi(^{12}C,3n)^{218}Ac	72	35	21.3	4.6	110	■ (45)	69 Ge 1
^{232}Th(^{12}C,4n)^{240}Cm	67	40.7	25.6	3.8	7.5(-2)	■ (3)	59 Gu 1
^{232}Th(^{13}C,5n)^{240}Cm	74	48.8	30.9	3.6	1.8(-1)	■ (3)	59 Gu 1
^{235}U (^{12}C,5n)^{242}Cf	79	49.9	33.4	3.3	–	■ (55)	70 Si 7
^{234}U(^{12}C,4n)^{242}Cf	73	43.6	27.6	4.0	–	■ (55)	70 Si 7
^{238}U(^{12}C,8n)^{242}Cf	106	77.2	52.5	3.1	–	■ (51)	69 Sh 1
^{238}U(^{12}C,7n)^{243}Cf	97	68.5	46.0	3.2	–	■ (51)	69 Sh 1
^{238}U(^{12}C,6n)^{244}Cf	84	56.2	38.3	3.0	–	■ (51)	69 Sh 1
^{238}U(^{12}C,6n)^{244}Cf	76	49.2	38.3	1.8	6.0(-3)	■ (2)	58 Si 1
^{238}U(^{13}C,6n)^{245}Cf	78	50.8	37.3	2.3	–	(43)	69 Ba 1
^{238}U(^{12}C,5n)^{245}Cf	74	46.7	32.2	2.9	1.0(-1)	(51)	69 Sh 1
^{238}U(^{12}C,4n)^{246}Cf	62.5	36.3	24.9	2.9	3. (-2)	■ (2)	58 Si 1
^{238}U(^{12}C,4n)^{246}Cf	67	40.9	24.9	4.0	6. (-2)	■ (8)	59 Vo 2
^{238}U(^{13}C,5n)^{246}Cf	78	51.5	30.0	4.3	1.2(-1)	■ (8)	59 Vo 2
^{241}Pu(^{13}C,4n)^{250}Fm	67	40.0	25.3	3.7	5.0(-3)	■ (7)	59 Vo 1
^{242}Pu(^{12}C,4n)^{250}Fm	65	37	25.3	2.9	1 (- 2)	■ (2)	58 Si 1
^{244}Cm(^{12}C,5n)^{251}102	83	50.1	34.9	3.0	9 (- 5)	■ (38)	68 Si 5
^{244}Cm(^{12}C,4n)^{252}102	73.3	40.9	27.0	3.5	2.5(-4)	■ (38)	68 Si 5
^{244}Cm(^{13}C,5n)^{252}102	82	49.9	32.6	3.5	1.6(-4)	Z ■ (38)	68 Si 5
^{246}Cm(^{12}C,5n)^{253}102	83	50.4	33.2	3.4	2.4(-4)	Z ■ (38)	68 Si 5
^{244}Cm(^{13}C,4n)^{253}102	73	41.2	26.3	3.7	3(- 4)	Z ■ (38)	68 Si 5
^{246}Cm(^{12}C,4n)^{254}102	72	40	25.7	3.6	1.0(-3)	Z ■ (38)	68 Si 5
^{246}Cm(^{13}C,5n)^{254}102	78.5	46.5	31.0	3.1	5.6(-4)	Z ■ (38)	68 Si 5
^{246}Cm(^{13}C,4n)^{255}102	70	38.4	25.0	3.3	6.2(-4)	Z ■ (38)	68 Si 5
^{248}Cm(^{12}C,5n)^{255}102	77.8	45.8	31.6	2.8	5.8(-4)	Z ■ (38)	68 Si 5
^{248}Cm(^{12}C,4n)^{256}102	71.2	39.4	24.4	3.7	1.0(-3)	Z ■ (38)	68 Si 5
^{248}Cm(^{13}C,5n)^{256}102	74.8	42.7	29.4	2.7	6.6(-4)	Z ■ (38)	68 Si 5
^{248}Cm(^{13}C,4n)^{257}102	70.5	38.7	23.8	3.7	1.1(-3)	Z ■ (38)	68 Si 5

Z = 7 NITROGEN INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	$\bar{\varepsilon}$(MeV)	σ(mb)	REMARKS	REFERENCES	
$^{51}V(^{15}N,5n)^{61}Zn$	94	89	53.0	7.2	60		(4)	59 Ka 1
$^{51}V(^{14}N,3n)^{62}Zn$	45	52	29.5	7.5	15		(4)	59 Ka 1
$^{133}Cs(^{14}N,5n)^{142}Sm$	92	77	41.2	7.2	770	*	(26)	66 Ka 4
$^{141}Pr(^{14}N,6n)^{149}Dy$	107	86.1	51.9	5.7	280	*	(20)	64 Al 2
$^{141}Pr(^{15}N,7n)^{149}Dy$	126	100.8	60.9	5.7	243	*	(20)	64 Al 2
$^{141}Pr(^{14}N,5n)^{150}Dy$	88	70.2	41.7	5.7	650	*	(20)	64 Al 2
$^{141}Pr(^{15}N,6n)^{150}Dy$	113	85.5	50.7	5.8	660	*	(20)	64 Al 2
$^{141}Pr(^{14}N,4n)^{151}Dy$	75	54.0	33.8	5.0	325	*	(20)	64 Al 2
$^{142}Nd(^{14}N,4n)^{152}Ho$	82	57.5	35.1	5.6	-	S,HSI *	(66)	71 Te 4
$^{142}Nd(^{14}N,4n)^{152}Ho$	74	50.2	35.1	3.8	-	S,LSI	(66)	71 Te 4
$^{142}Nd(^{14}N,3n)^{153}Ho$	69	45.7	25.0	6.9	-	S, HSI *	(66)	71 Te 4
$^{144}Nd(^{14}N,4n)^{154}Ho$	73	51.9	33.6	4.6	-	LSI	(66)	71 Te 4
$^{144}Nd(^{14}N,4n)^{154}Ho$	81	59.4	33.6	6.4	-	HSI *	(66)	71 TO 4
$^{179}Hf(^{14}N,6n)^{187}Au$	95	74.6	50.5	4.1	140	*	(46)	69 He 1
$^{197}Au(^{14}N,8n)^{203}Rn$	123	95.4	66.5	3.6	-	*	(35)	67 Va 2
$^{197}Au(^{14}N,7n)^{204}Rn$	105	78.5	56.9	3.1	-	*	(35)	67 Va 2
$^{196}Pt(^{14}N,6n)^{204}At$	88	62.8	47.9	2.5	150	*	(12)	62 Th 1
$^{195}Pt(^{14}N,4n)^{205}At$	72	50.2	31.9	4.6	50	*	(12)	62 Th 1
$^{196}Pt(^{14}N,5n)^{205}At$	80	55.2	38.8	5.3	100	*	(12)	62 Th 1
$^{198}Pt(^{14}N,7n)^{205}At$	97	71.7	52.2	2.8	60	*	(12)	62 Th 1
$^{197}Au(^{14}N,6n)^{205}Rn$	104	77.5	48.8	4.8	230	*	(4)	59 Ka 1

Z = 7 NITROGEN INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	$\bar{\varepsilon}$(MeV)	σ(mb)	REMARKS	REFERENCES
$^{197}Au(^{14}N,6n)^{205}Rn$	111	84.1	48.8	5.9	350		(1) 57 Ba 1
$^{197}Au(^{14}N,5n)^{206}Rn$	97	80.4	39.5	8.2	850		(1) 57 Ba 1
$^{198}Pt(^{14}N,6n)^{206}At$	87	62.2	44.6	2.9	230	*	(12) 62 Th 1
$^{197}Au(^{14}N,5n)^{206}Rn$	92.5	67.0	39.5	5.5	270	*	(4) 59 Ka 1
$^{196}Pt(^{14}N,4n)^{206}At$	68	45.8	31.3	3.6	60	*	(43) 69 Ba 1
$^{197}Au(^{14}N,4n)^{207}Rn$	87	71.0	31.8	9.8	200		(1) 57 Ba 1
$^{197}Au(^{14}N,4n)^{207}Rn$	74	49.5	31.8	4.4	-	*	(35) 67 Va 2
$^{197}Au(^{14}N,4n)^{207}Rn$	79	55.0	31.8	5.8	125	*	(4) 59 Ka 1
$^{198}Pt(^{14}N,5n)^{207}At$	78	53.7	41.0	3.6	100	*	(12) 62 Th 1
$^{198}Pt(^{14}N,4n)^{208}At$	73	48.9	31.9	5.1	50	*	(12) 62 Th 1
$^{238}U\ (^{14}N,6n)^{246}Es$	91	59.6	38.7	3.7	0.8(-3)	S	(43) 69 Ba 1
$^{248}Cm(^{15}N,5n)^{258}103$	87	46.7	31.1	3.1	-	* S	(62) 71 Es 1
$^{248}Cm(^{15}N,4n)^{259}103$	81	41.0	24.0	4.2	-	* S	(62) 71 Es 1

Z = 8 OXYGEN INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	$\bar{\varepsilon}$(MeV)	σ(mb)	REMARKS	REFERENCES
^{51}V(^{16}O,3n)^{64}Ga	70	63	32.6	10.1	70		(5) 59 Ka 2
^{51}V(^{16}O,2n)^{65}Ga	59	53	20.3	16.3	50		(5) 59 Ka 2
^{80}Se(^{16}O,3n)^{93}Mo	68	63	27.6	12.0	250		(6) 59 Ka 3
^{109}Ag(^{18}O,5n)^{122}Cs	92	76	49.1	5.4	-	■	(44) 69 Dr 1
^{109}Ag(^{18}O,4n)^{123}Cs	73	60	37.9	5.5	-	■	(44) 69 Dr 1
^{115}In(^{18}O,5n)^{128}La	92	74	48.4	5.1	-	■	(63) 71 Ne 1
^{124}Sn(^{16}O,6n)^{134}Ce	96	80	51.8	4.7	333	■	(14) 63 Kl 1
^{124}Sn(^{18}O,8n)^{134}Ce	126	105.5	64.5	5.1	-	■	(64) 71 Og 1
^{124}Sn(^{16}O,5n)^{135}Ce	79	65	43.7	4.3	190	■	(14) 63 Kl 1
^{124}Sn(^{18}O,6n)^{136}Ce	95	78.5	46.4	5.3	-	■	(64) 71 Og 1
^{139}La(^{16}O,6n)^{149}Tb	100	68.6	48.8	3.4	14	LSI	(13) 63 Al 1
^{140}Ce(^{16}O,7n)^{149}Dy	134	102.3	60.9	5.9	250	■	(20) 64 Al 2
^{140}Ce(^{16}O,6n)^{150}Dy	120	87.2	50.7	6.1	690	■	(20) 64 Al 2
^{140}Ce(^{16}O,6n)^{150}Dy	119	86.5	50.7	6.0	450	■	(16) 63 Ma 2
^{140}Ce(^{16}O,5n)^{151}Dy	103	71.4	42.8	5.7	620	■	(20) 64 Al 2
^{140}Ce(^{18}O,7n)^{151}Dy	129	100.4	58.3	6.0	410	■	(20) 64 Al 2
^{140}Ce(^{16}O,5n)^{151}Dy	102	71	42.8	5.7	550	■	(16) 63 Ma 2
^{141}Pr(^{16}O,6n)^{151}Ho	121	84	52.6	5.2	-	HSI■	(16) 63 Ma 2
^{141}Pr(^{16}O,6n)^{151}Ho	103	70	52.6	2.9	-	S,LSI	(16) 63 Ma 2
^{142}Nd(^{16}O,6n)^{152}Er	125	85	54.4	5.1	-	S ■	(15) 63 Ma 1
^{140}Ce(^{16}O,4n)^{152}Dy	83	53	33.0	5.0	200	■	(16) 63 Ma 2
^{141}Pr(^{16}O,5n)^{152}Ho	107	72	44.4	5.5	-	S,HSI■	(16) 63 Ma 2
^{141}Pr(^{16}O,5n)^{152}Ho	93	60	44.4	3.1	-	S,LSI	(16) 63 Ma 2
^{142}Nd(^{16}O,6n)^{152}Er	120	82	51.5	5.1	-	S ■	(16) 63 Ma 2
^{142}Nd(^{16}O,6n)^{152}Er	125	85	54.4	5.1	-	S ■	(15) 63 Ma 1
^{142}Nd(^{16}O,5n)^{153}Er	108	71	45.9	5.0	-	S ■	(15) 63 Ma 1
^{142}Nd(^{16}O,4n)^{154}Er	89	55	35.5	4.9	-	S ■	(15) 63 Ma 1
^{144}Sm(^{16}O,6n)^{154}Yb	130	87	57.9	4.8	9	S ■	(19) 64 Ma 3
^{144}Sm(^{16}O,5n)^{155}Yb	119	77	48.8	5.6	42	S ■	(19) 64 Ma 3
^{168}Yb(^{16}O,7n)^{177}Pt	141	94	66.6	3.9	-	S ■	(28) 66 Si 3

Z = 8   OXYGEN INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	ε(MeV)	σ(mb)	REMARKS	REFERENCES
^{172}Yb(^{16}O,8n)^{180}Pt	144	104	71.2	4.1	–	■	(28) 66 Si 3
^{172}Yb(^{16}O,6n)^{182}Pt	118	77	52.5	4.1	–	■	(28) 66 Si 3
^{175}Lu(^{16}O,8n)^{183}Au	146	109	71.1	4.7	–	■	(39) 68 Si 6
^{175}Lu(^{16}O,6n)^{185}Au	117	82	52.4	4.9	–	■	(39) 68 Si 6
^{197}Au(^{16}O,8n)^{205}Fr	145	102	66.3	4.5	–	■	(17) 64 Gr 1
^{205}Tl(^{16}O,7n)^{214}Ac	118	66.4	51.3	2.2	–	■	(34) 67 Tr 2
^{203}Tl(^{16}O,5n)^{214}Ac	95	45.5	37.7	1.6	–	S ■	(34) 67 Tr 2
^{203}Tl(^{16}O,4n)^{215}Ac	85	37.2	29.1	2.0	–	S ■	(34) 67 Tr 2
^{205}Tl(^{16}O,6n)^{215}Ac	112	61.0	42.7	3.1	–	■	(34) 67 Tr 2
^{206}Pb(^{16}O,7n)^{215}Th	128	73.1	53.6	2.8	–	S ■	(41) 68 Va 3
^{206}Pb(^{16}O,6n)^{216}Th	112	58.3	44.9	2.2	–	S ■	(41) 68 Va 3
^{206}Pb(^{16}O,5n)^{217}Th	102	49.0	37.6	2.3	–	S ■	(41) 68 Va 3
^{208}Pb(^{16}O,3n)^{221}Th	84	31.4	21.4	3.3	–	■	(57) 70 Te 2
^{208}Pb(^{16}O,3n)^{221}Th	87	38.0	21.4	5.5	–		(59) 70 Va 4
^{209}Bi(^{16}O,3n)^{222}Pa	89	35.2	22.4	4.3	–		(52) 70 Be 2
^{238}U(^{18}O,8n)^{248}Fm	120	74.2	50.7	2.9	1.3(–4)	S ■	(25) 66 De 1
^{238}U(^{16}O,6n)^{248}Fm	102.5	68.0	39.0	4.9	3.5(–4)	■	(25) 66 De 1
^{238}U(^{16}O,5n)^{249}Fm	93	53.5	32.7	4.2	2.7(–4)	■	(25) 66 De 1
^{238}U(^{18}O,6n)^{250}Fm	101	56.2	37.0	3.2	1.9(–3)	S ■	(25) 666 De 1
^{238}U(^{16}O,4n)^{250}Fm	88	44.0	25.3	4.7	1.0(–3)	■	(7) 59 Vo 1
^{238}U(^{18}O,5n)^{251}Fm	93	49.2	31.1	3.6	4.0(–3)	S ■	(25) 66 De 1
^{239}Pu(^{18}O,5n)^{252}102	96	48.9	32.7	3.2	1.6(–5)	S ■	(27) 66 Mi 1
^{239}Pu(^{18}O,4n)^{253}102	90	41.9	26.4	3.9	5.1(–5)	S ■	(27) 66 Mi 1
^{242}Pu(^{16}O,5n)^{253}102	96	50.6	33.2	3.5	4.4(–5)	S ■	(27) 66 Mi 1
^{242}Pu(^{16}O,4n)^{254}102	89	43.6	25.7	4.5	3.4(–5)	S ■	(27) 66 Mi 1
^{242}Pu(^{18}O,5n)^{255}102	98	50.6	31.6	3.8	6.0(–5)	S	(43) 69 Ba 1
^{242}Pu(^{18}O,4n)^{256}102	88	41.7	24.4	4.3	2.3(–5)	S ■	(27) 66 Mi 1
^{243}Am(^{18}O,5n)^{256}103	95	47.5	32.7	3.0	6.0(–5)	S ■	(25) 66 De 1

Z = 9 FLOURINE INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	$\bar{\varepsilon}$(MeV)	σ(mb)	REMARKS	REFERENCES
^{138}Ba(^{19}F,8n)^{149}Tb	125	90.5	63.6	3.4	10		(13) 63 Al 1
^{139}La(^{19}F,9n)^{149}Dy	165	129.0	76.4	5.9	144	*	(20) 64 Al 2
^{139}La(^{19}F,8n)^{150}Dy	149	114.5	66.2	6.0	450	*	(20) 64 Al 2
^{139}La(^{19}F,7n)^{151}Dy	132	99.8	58.3	5.9	350	*	(20) 64 Al 2
^{141}Pr(^{19}F,8n)^{152}Er	158.5	117	71.1	5.7	55	*	(19) 64 Ma 3
^{141}Pr(^{19}F,7n)^{153}Er	145	105	62.6	6.1	83	*	(19) 64 Ma 3
^{142}Nd(^{19}F,8n)^{153}Tm	160	115	73.5	5.2	10	*	(19) 64 Ma 3
^{142}Nd(^{19}F,7n)^{154}Tm	149	105	64.7	5.8	45	*	(19) 64 Ma 3
^{144}Sm(^{19}F,7n)^{156}Lu	151	103	68.6	4.8	-	*	(22) 65 Ma 4
^{169}Tm(^{19}F,10n)^{178}Pt	170	129	90.3	3.9	-	S*	(28) 66 Si 3
^{185}Re(^{19}F,10n)^{194}Po	167	125	90.6	3.4	-	*	(32) 67 Si 4
^{185}Re(^{19}F,9n)^{195}Po	152	112	81.5	3.4	-	*	(32) 67 Si 4
^{185}Re(^{19}F,8n)^{196}Po	135	97	71.1	3.2	-	*	(32) 67 Si 4
^{185}Re(^{19}F,7n)^{197}Po	123	84	62.3	3.1	-	*	(32) 67 Si 4
^{187}Re(^{19}F,8n)^{198}Po	135	98	68.3	3.7	-	*	(32) 67 Si 4
^{187}Re(^{19}F,7n)^{199}Po	122	86	59.8	3.7	-	*	(32) 67 Si 4
^{197}Au(^{19}F,10n)^{206}Ra	172	124.2	81.6	4.3	-	*	(35) 67 Va 2
^{197}Au(^{19}F,3n)^{213}Ra	96	51.6	22.6	9.6	-		(35) 67 Va 2
^{208}Pb(^{19}F,3n)^{224}Pa	102	43.3	21.4	7.3	-		(52) 70 Bo 2
^{238}U(^{19}F,7n)^{250}Mv	121	70.2	45.9	3.5	1.9(-4)	S **	(25) 66 Do 1
^{238}U(^{19}F,5n)^{252}Mv	105	55.5	32.2	4.6	5(-4)	S	(25) 66 Do 1

Z = 10 NEON INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	ε(MeV)	σ(mb)	REMARKS	REFERENCES
$^{122}Sn(^{20}Ne,5n)^{137}Nd$	107	81	46.9	6.8	–	* (53)	70 Dr 2
$^{119}Sn(^{22}Ne,4n)^{137}Nd$	90	62.7	37.1	6.4	–	* (53)	70 Dr 2
$^{126}Te(^{22}Ne,5n)^{143}Sm$	113	78.2	41.2	7.4	–	* (50)	69 Ne 1
$^{130}Te(^{20}Ne,7n)^{143}Sm$	130	95	55.3	5.7	–	* (50)	69 Ne 1
$^{136}Ba(^{20}Ne,7n)^{149}Dy$	147	102.5	60.9	6.0	230	* (20)	64 Al 2
$^{137}Ba(^{20}Ne,8n)^{149}Dy$	160	116.9	67.7	6.4	160	* (20)	64 Al 2
$^{138}Ba(^{20}Ne,9n)^{149}Dy$	168	129.4	76.5	5.9	150	* (20)	64 Al 2
$^{136}Ba(^{20}Ne,6n)^{150}Dy$	131	88.0	50.7	6.2	610	* (20)	64 Al 2
$^{137}Ba(^{20}Ne,7n)^{150}Dy$	146	102.0	57.5	6.3	440	* (20)	64 Al 2
$^{138}Ba(^{20}Ne,8n)^{150}Dy$	154	115.5	66.2	6.2	460	* (20)	64 Al 2
$^{137}Ba(^{22}Ne,9n)^{150}Dy$	176	131.0	72.7	6.5	280	* (20)	64 Al 2
$^{136}Ba(^{20}Ne,5n)^{151}Dy$	115	73.0	42.8	6.0	380	* (20)	64 Al 2
$^{137}Ba(^{20}Ne,6n)^{151}Dy$	129	88.2	49.6	6.3	340	* (20)	64 Al 2
$^{138}Ba(^{20}Ne,7n)^{151}Dy$	140	100.1	58.3	6.0	400	* (20)	64 Al 2
$^{137}Ba(^{22}Ne,8n)^{151}Dy$	163	117.0	64.8	6.5	260	* (20)	64 Al 2
$^{138}Ba(^{22}Ne,9n)^{151}Dy$	184	128.7	73.1	6.2	220	* (20)	64 Al 2
$^{140}Ce(^{20}Ne,8n)^{152}Er$	174	121	71.1	6.2	40	S * (19)	64 Ma 3
$^{140}Ce(^{20}Ne,7n)^{153}Er$	158	108	62.6	6.5	50	S * (19)	64 Ma 3
$^{141}Pr(^{20}Ne,8n)^{153}Tm$	170	116.5	73.5	5.4	10	* (19)	64 Ma 3
$^{141}Pr(^{20}Ne,7n)^{154}Tm$	156	105	64.7	5.8	38	* (19)	64 Ma 3
$^{142}Nd(^{20}Ne,8n)^{154}Yb$	176	119.5	75.8	5.5	1.5	S * (19)	64 Ma 3
$^{142}Nd(^{20}Ne,7n)^{155}Yb$	160	105.7	66.7	5.6	9	S * (19)	64 Ma 3
$^{144}Sm(^{20}Ne,7n)^{157}Hf$	164	105	70.5	4.8	1.8	S * (22)	65 Ma 4
$^{144}Sm(^{20}Ne,6n)^{158}Hf$	150	92	59.0	5.7	1.8	S * (22)	65 Ma 4
$^{169}Tm(^{20}Ne,8n)^{181}Au$	160	110	73.5	4.6	–	* (39)	68 Si 6
$^{169}Tm(^{20}Ne,6n)^{183}Au$	134	86	54.3	5.3	–	* (39)	68 Si 6
$^{185}Re(^{20}Ne,9n)^{196}At$	176	118	83.1	3.9	–	* (33)	67 Tr 1
$^{185}Re(^{20}Ne,8n)^{197}At$	163	106	72.5	4.2	–	* (33)	67 Tr 1

Z = 10 NEON INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	$\bar{\epsilon}$ (MeV)	σ(mb)	REMARKS	REFERENCES
$^{185}Re(^{20}Ne,7n)^{198}At$	150	94	63.5	4.4	-	∗ (33)	67 Tr 1
$^{185}Re(^{20}Ne,6n)^{199}At$	135	81	53.3	4.6	-	∗ (33)	67 Tr 1
$^{185}Re(^{20}Ne,5n)^{200}At$	120	67	44.6	4.5	-	∗ (33)	67 Tr 1
$^{185}Re(^{20}Ne,4n)^{201}At$	103	54.9	34.8	5.0	-	∗ (33)	67 Tr 1
$^{185}Re(^{22}Ne,5n)^{202}At$	120	69.1	42.8	5.3	-	∗ (47)	69 Mo 2
$^{197}Au(^{20}Ne,8n)^{209}Ac$	152	90.3	65.3	3.1	-	∗ (34)	67 Tr 2
$^{235}U(^{22}Ne,5n)^{252}102$	118	52.0	32.6	3.9	1.6(-2)	S ∗ (54)	70 Fl 1
$^{238}U(^{22}Ne,6n)^{254}102$	126	60.2	37.6	3.8	6.(-5)	S ∗ (25)	66 Do 1
$^{238}U(^{22}Ne,5n)^{255}102$	118	53.0	31.6	4.3	2.2(-4)	S ∗ (25)	66 Do 1
$^{238}U(^{22}Ne,4n)^{256}102$	111	46.5	24.4	5.5	4.5(-5)	S ∗ (25)	66 Do 1
$^{243}Am(^{22}Ne,4n)^{261}105$	117	46.0	25.7	5.0	5.(-3)	S ∗ (54)	70 Fl 1
$^{243}Am(^{22}Ne,5n)^{260}105$	121	50.0	33.2	3.3	4.(-3)	S ∗ (54)	70 Fl 1

Z = 15 PHOSPHOR INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	$\bar{\epsilon}$(MeV)	σ(mb)	REMARKS	REFERENCES
$^{189}Os(^{31}P,5n)^{215}Pa$	175	62.6	40.2	4.5	3.5(-3)	S	✱(65) 71 Su 1
$^{189}Os(^{31}P,4n)^{216}Pa$	162	51.6	32.4	4.8	1.0(-3)	S	(65) 71 Su 1

Z = 18 ARGON INDUCED REACTIONS

REACTION	E_{lab}(MeV)	E_{exc}(MeV)	B_n(MeV)	$\bar{\epsilon}$(MeV)	σ(mb)	REMARKS	REFERENCES
$^{116}Cd(^{40}Ar,7n)^{149}Dy$	212±10	105	60.9	6.3	33		(49) 69 Na 1
$^{116}Cd(^{40}Ar,7n)^{149}Dy$	225	115	60.9	7.7	-		(18) 64 Ku 1
$^{114}Cd(^{40}Ar,5n)^{149}Dy$	206	98	44.8	10.6	-		(18) 64 Ku 1
$^{114}Cd(^{40}Ar,5n)^{149}Dy$	173	73.5	44.8	5.7	29.5		(49) 69 Na 1
$^{116}Cd(^{40}Ar,6n)^{150}Dy$	209	102	50.7	8.6	-		(18) 64 Ku 1
$^{116}Cd(^{40}Ar,6n)^{150}Dy$	187	86.8	50.7	6.0	154		(49) 69 Na 1
$^{114}Cd(^{40}Ar,4n)^{150}Dy$	165	67.6	34.6	8.3	143		(49) 69 Na 1
$^{114}Cd(^{40}Ar,4n)^{150}Dy$	172	73	34.6	9.6	-		(18) 64 Ku 1
$^{114}Cd(^{40}Ar,3n)^{151}Dy$	158	62.4	26.6	11.9	20.4		(49) 69 Na 1
$^{164}Dy(^{40}Ar,9n)^{195}Po$	245±10	115.2	82.4	3.6	2		✱(56) 70 Si 8
$^{164}Dy(^{40}Ar,8n)^{196}Po$	225±10	98.5	71.1	3.4	8		✱(56) 70 Si 8
$^{164}Dy(^{40}Ar,7n)^{197}Po$	215±6	79.5	62.3	2.5	35		✱(56) 70 Si 8
$^{164}Dy(^{40}Ar,6n)^{198}Po$	196±4	75.0	52.3	3.8	45		✱(56) 70 Si 8
$^{164}Dy(^{40}Ar,5n)^{199}Po$	182±4	63.7	43.8	4.0	55		✱(56) 70 Si 8
$^{164}Dy(^{40}Ar,4n)^{200}Po$	173±5	57.0	34.1	5.7	20		(56) 70 Si 8
$^{164}Dy(^{40}Ar,4n)^{200}Po$	180±4	62.2	34.1	7.0	20		(60) 71 Be 1