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ABSTRACT

The cross section data of /n,2n/ reactions predicted by different empirical formulae are compared with each other and with the experimental data. The predictions from the Ádám-Jéki formula with refitted parameters show an improved agreement with the measured cross section values.

РЕЗЮМЕ

В работе обобщены эмпирические формулы, служащие для расчета сечения реакций /n,2n/. Вычисленные значения сечений сравниваются с эксперементальными данными. Показано, что применением видоизмененных параметров, значения сечений, вычисляемые с помощью формул Адам - Йеки, хорошо совпадают с измеренными значениями.

KIVONAT

Összehasonlitjuk az /n,2n/ reakciók hatáskeresztmetszetének számitására szolgáló empirikus formulákat, a számitott hatáskeresztmetszet-értékeket összehasonlitjuk a kisérleti adatokkal. Megállapitjuk, hogy a módositott paramétereket használva az Ádám-Jéki formulával számitható hatáskeresztmetszetek jól egyeznek a mért értékekkel.

The (n,2n) reaction cross sections are of interest in many fields of applied physics concerned with neutron energies from 10 to 15 MeV. These cross sections are usually evaluated from activation analytical data. The available experimental values show unfortunately a very large spread owing to the limitations of activation analysis and in many cases to poor knowledge of the level scheme involved. There are still a number of nuclei for which the cross section data need to be determined in addition to these more or less known from the reported experiments. The latest edition of World Request List for Neutron Data Measurements /WRENDA/ [1] specifies more than 30 nuclei with reaction cross sections which would be of interest to know for experiments in dosimetry, activation analysis, neutron yield monitor, breeder reactor design or for the study of cross section systematics. In a more recent publication [2] again more than 30 nuclei /most of them not included in the WRENDA specification/ are listed. Apart from the applications cited above, the (n,2n) cross sections have to be known also for the design of fusion reactors.

Csikai and Pető [4] have shown an N-Z dependence to exist in the values of the (n,2n) cross sections. At energies exceeding the threshold energy for reaction by the same energy i.e. at constant excess energy, the cross section versus N-Z plots yield a straight line if N or Z is constant, the cross section varies linearly with /N-Z/. This dependence permits also unknown cross sections to be evaluated. The values of cross sections estimated by making use of this N-Z systematics were published by Bődy and Csikai [3] along with cross section values predicted by other formulae. These formulae include the expression referred to by the authors as the Ádám-Jéki phenomenological formula [5].

$$\sigma_{emp} = \left[1 - C_1 \cdot f(A) \cdot \exp\left(-C_2 \cdot \frac{N-Z}{A}\right)\right] \cdot C_3$$

$$f(A) = \left(A^{\frac{1}{3}} + 1\right)^2$$

The Ádám-Jéki expression has been originally formulated in order to show the non-existence of the shell effect observed by several workers. The three parameters of the equation were fitted to 35 experimental data. Later an attempt was made to use this formula for the prediction of unknown cross sections. For this reason a new fit was made with the use of more than 120 experimental points and also the application limits of the parameters were evaluated [6] as

	c_1	c_2	c_3 mbarn
$N \leq 28$	0.085	20.0	550
$28 < N \leq 50$	0.06	8.45	1900
$50 < N \leq 82$	0.06	9.5	2600
$82 < N$	0.15	14.0	3500

Bődy and Csikai [3] have found in their comparison that the Ádám-Jéki formula gives usually an overestimate of the cross section as compared with the experimental values and that the deviation from the experiment is not symmetrical around 0 /Fig. 1 broken line/. Their calculation showed a much better agreement for the predictions obtained with the Pearlstein formula [7] /Fig. 1 dotted line/. The predictions from the Ádám-Jéki formula with the refitted parameters [6] show an improved agreement and the deviations become symmetrical around 0. These predictions were compared with the experimental data referred to in [3] and the result is shown in Fig. 1 by a solid line. It is apparent from the figure that both the Pearlstein and the Ádám-Jéki expressions show symmetrical distributions of the deviations around 0 while the former gives a slightly underestimated, the later a slightly overestimated cross section as compared with experiment.

In Table 1 the values predicted from the N-Z systematics [3], the Pearlstein formula [7] and the refitted Ádám-Jéki formula [6] are listed in columns 1, 2 and 3 respectively. The experimental data available to date do not permit the confidence limits for the three formulae to be established. The maximum deviations arise for the nuclei far from the stability line but for these species the experimental data are scarce.

The cross sections for Mo(n,2n) and Nb(n,2n) reactions required for the design of fusion reactors as calculated from the above formulae [8] are compared in Fig. 2 with the most recent measurements reported by D.S.Mather et al. [9]. It is of interest to note that the Ádám-Jéki and the Pearlstein predictions agree very well with experimental data.

	BŐDY-CSIKAI	PEARLSTEIN	ÁDÁM-JÉKI
^{42}Ca	290	129	201
^{43}Ca	595	566	475
^{44}Ca	470	398	545
^{46}Ca	740	670	619
^{47}Ti	380	502	394
^{48}Ti	320	338	367
^{49}Ti	660	877	607
^{50}Ti	655	595	542
^{51}V	565	507	468
^{53}Cr	890	851	1049
^{54}Cr	1120	764	1186
^{57}Fe	900	834	868
^{58}Fe	1060	727	1002
^{60}Ni	408	296	359
^{61}Ni	780	802	457
^{62}Ni	900	627	808
^{64}Ni	1095	773	1188
^{67}Zn	1000	1047	914
^{68}Zn	1120	730	1013
^{72}Ge	788	640	840
^{73}Ge	1010	1240	1054
^{74}Ge	1100	991	1131
^{77}Se	1135	1476	931
^{78}Se	1085	965	990
^{80}Se	1200	1169	1234
^{82}Kr	795	849	834
^{83}Kr	1130	1371	1044
^{84}Kr	1280	1052	1081
^{86}Kr	2010	1247	1296

	BŐDY-CSIKAI	PEARLSTEIN	ÁDÁM-JÉKI
^{87}Sr	1525	1298	937
^{88}Sr	1465	854	921
^{91}Zr	1160	1366	1351
^{92}Zr	1235	1491	1517
^{94}Zr	1350	1449	1763
^{93}Nb	1080	1281	1295
^{94}Mo	865	1148	1037
^{95}Mo	980	1382	1207
^{96}Mo	1125	1337	1369
^{97}Mo	1295	1519	1476
^{98}Mo	1370	1485	1631
^{99}Ru	940	1374	1031
^{100}Ru	960	1275	1217
^{101}Ru	1120	1522	1341
^{102}Ru	1225	1441	1495
^{104}Pd	945	1226	1070
^{105}Pd	1275	1517	1214
^{106}Pd	1430	1410	1358
^{108}Pd	1740	1538	1591
^{109}Ag	1440	1506	1421
^{111}Cd	1260	1630	1334
^{112}Cd	1590	1526	1468
^{113}Cd	1370	1723	1531
^{114}Cd	1450	1639	1668
^{115}Sn	1565	1611	1223
^{116}Sn	1560	1489	1347
^{117}Sn	1530	1719	1428
^{118}Sn	1465	1596	1553
^{119}Sn	1480	1800	1597
^{120}Sn	1495	1685	1726

	BŐDY-CSIKAI	PEARLSTEIN	ÁDÁM-JÉKI
^{122}Sn	1470	1770	1871
^{123}Te	1290	1795	1504
^{124}Te	1345	1631	1619
^{125}Te	1340	1866	1654
^{126}Te	1495	1730	1773
^{130}Te	1590	1825	2006
^{129}Xe	1525	1861	1564
^{130}Xe	1580	1663	1674
^{131}Xe	1565	1912	1698
^{132}Xe	1630	1708	1810
^{134}Ba	1550	1668	1577
^{135}Ba	1570	1889	1621
^{136}Ba	1660	1665	1718
^{137}Ba	1655	1959	1742
^{138}Ba	1720	1874	1835
^{139}La	1730	1846	1735
^{138}Ce	1520	1635	1479
^{143}Nd	1720	1983	1488
^{144}Nd	1800	1970	1705
^{145}Nd	1775	1940	1810
^{146}Nd	1845	1804	2008
^{147}Sm	1580	1996	1300
^{148}Sm	1625	1980	1522
^{149}Sm	1585	2056	1640
^{150}Sm	1645	2019	1847
^{152}Sm	1790	2050	2127
^{151}Eu	1675	2023	1599
^{153}Eu	1885	2038	1918
^{152}Gd	1790	1970	1334
^{155}Gd	1785	2114	1788

	BŐDY-CSIKAI	PEARLSTEIN	ÁDÁM-JÉKI
^{156}Gd	1800	2065	1974
^{157}Gd	1725	2148	2045
^{158}Gd	1740	2139	2206
^{159}Tb	1875	2115	2018
^{156}Dy	1790	1819	1137
^{158}Dy	1910	2008	1507
^{161}Dy	2050	2171	1898
^{162}Dy	2160	2141	2065
^{163}Dy	2180	2213	2125
^{164}Dy	2350	2195	2271
^{164}Er	1995	2070	1649
^{167}Er	1910	2228	1992
^{168}Er	1930	2211	2138
^{168}Yb	1850	2066	1481
^{171}Yb	1970	2235	1857
^{172}Yb	1970	2196	2006
^{173}Yb	1900	2273	2073
^{174}Yb	1890	2257	2199
^{177}Hf	1955	2293	1937
^{178}Hf	1975	2282	2073
^{179}Hf	2075	2263	2131
^{180}Hf	2235	2104	2256
^{183}W	2180	2353	2010
^{184}W	2230	2233	2137
^{186}Os	2175	2277	1816
^{187}Os	2130	2364	1883
^{188}Os	2175	2340	2021
^{189}Os	2125	2377	2073
^{190}Os	2185	2331	2204
^{192}Os	2190	2253	2362

	BŐDY-CSIKAI	PEARLSTEIN	ÁDÁM-JÉKI
^{193}Ir	2130	2384	2174
^{190}Pt	2045	2228	1681
^{192}Pt	2030	2297	1902
^{194}Pt	2010	2328	2098
^{195}Pt	1960	2443	2135
^{196}Pt	1990	2395	2259
^{196}Hg	2060	2226	1776
^{198}Hg	2010	2283	1980
^{199}Hg	2020	2440	2033
^{200}Hg	2090	2380	2149
^{201}Hg	2085	2482	2189
^{202}Hg	2160	2429	2301
^{206}Pb	1915	2444	2201
^{207}Pb	1930	2517	2246
^{208}Pb	1985	2491	2332

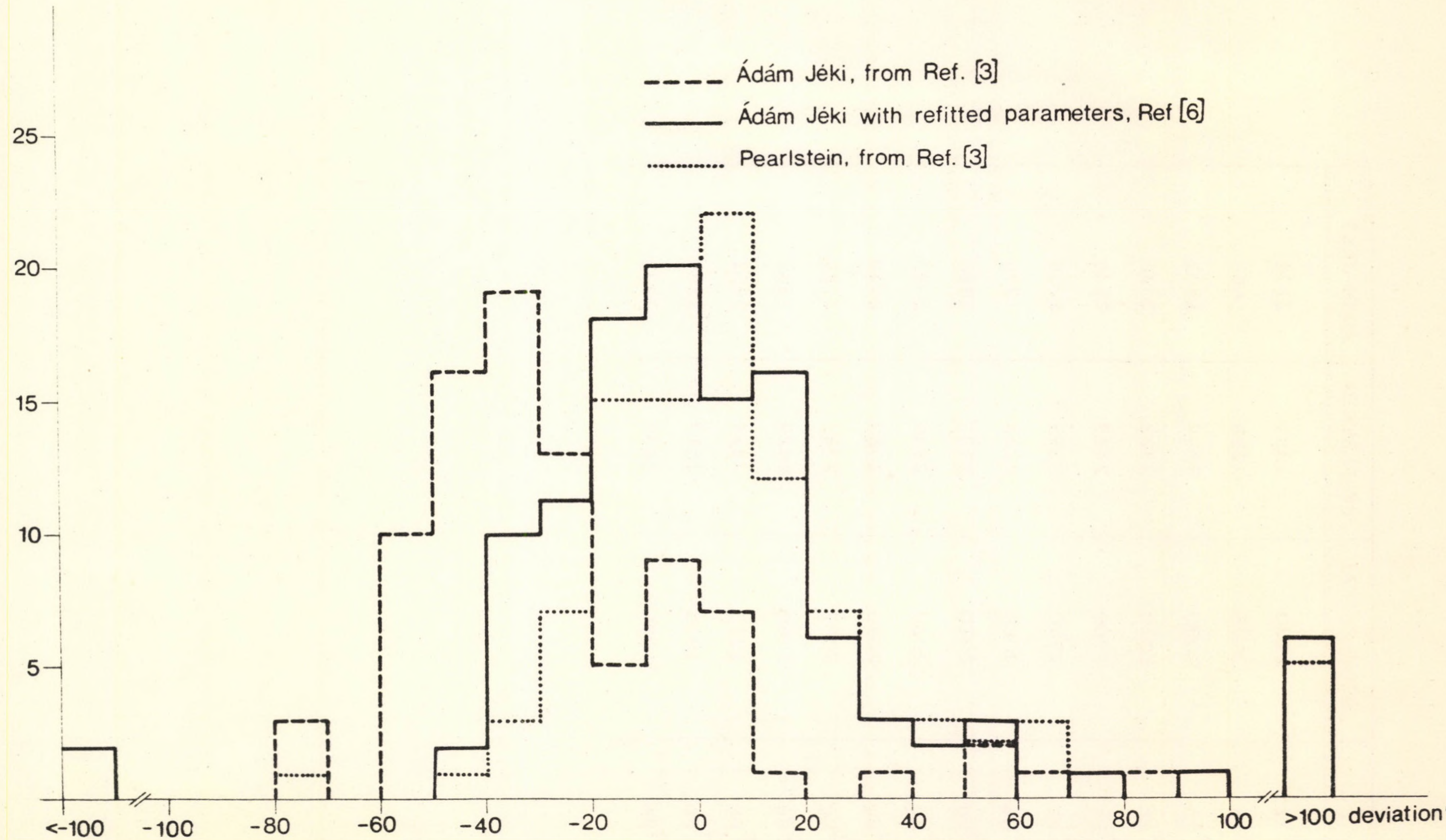
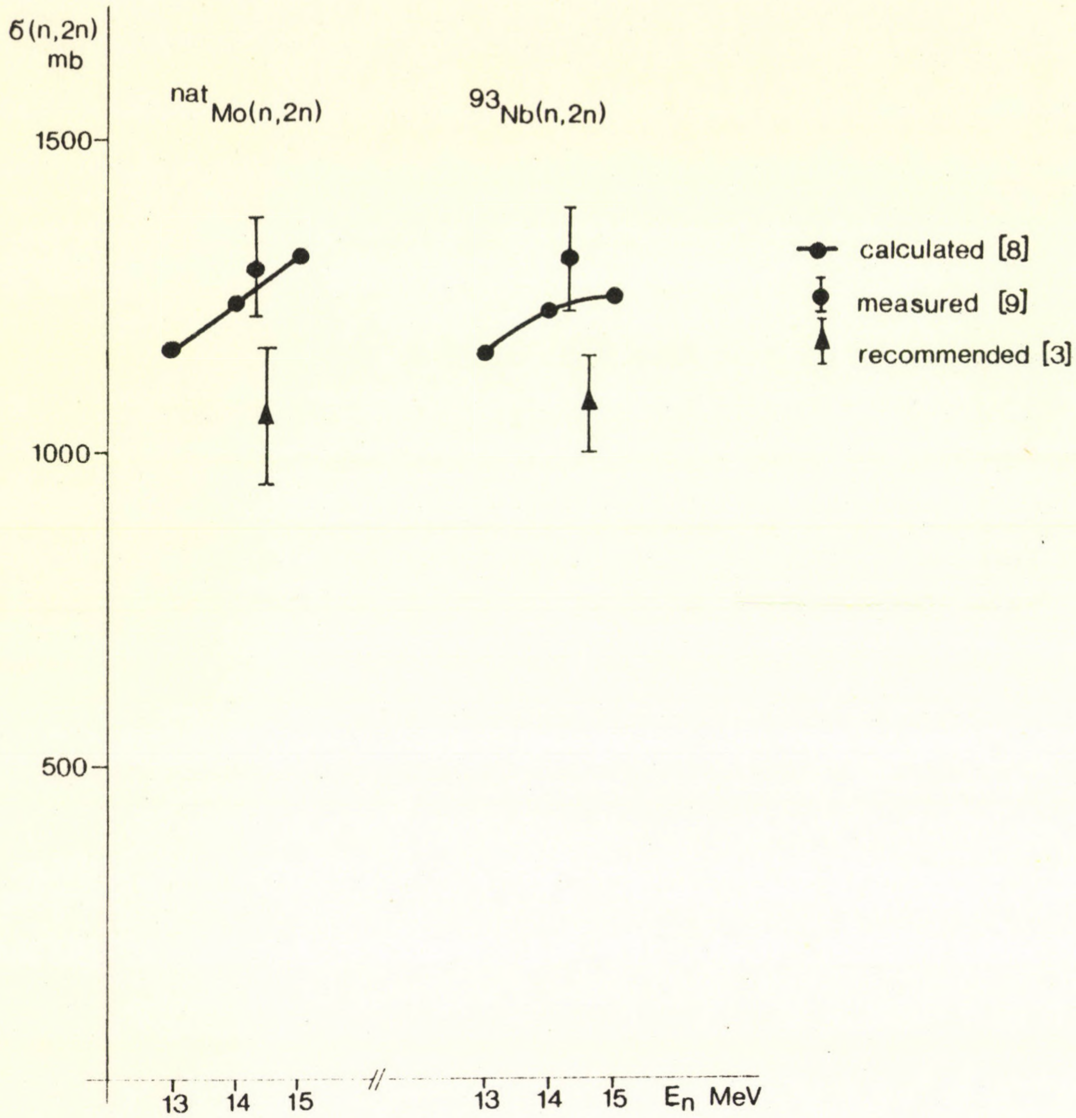

Ádám Jéki, from Ref. [3]
Ádám Jéki with refitted parameters, Ref [6]
Pearlstein, from Ref. [3]
25
20
15
10
5
<-100
-100
-80
-60
-40
-20
0
20
40
60
80
100
>100 deviation%

Fig. 1



σ(n,2n)
mb
1500
1000
500
natMo(n,2n)
93Nb(n,2n)
calculated [8]
measured [9]
recommended [3]
13
14
15
13
14
15
En MeV

Fig. 2

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Kiadja a Központi Fizikai Kutató Intézet
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