

# FRAGMENT MASS DISTRIBUTION FOR $^{238}\text{U}$ FISSION BY NEUTRONS IN THE ENERGY REGION FROM 2 TO 200 MeV.

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The detailed analysis of experimental data for actinide nuclei fission at medium excitation energies shows that at formation of angular, mass and energy distributions of fission fragments the essential role is played by the spectrum of transition states above the fission barrier. The basic characteristics of transition states are the collective energy and the total angular momentum of the fissioning nucleus. Thus, the process of formation and scission of fragments is influenced not only by the temperature but also by the total angular momentum of the fissioning nucleus [1,2].

The double-peak structure of a fission barrier and the dependence of the transition states shapes of fissioning nuclei on excitation energy complicates the analysis and makes difficult the calculations of fragments yield for particular excitation energy of a fissioning nucleus. It is shown [3] that in the excitation energy range of 40 - 45 MeV the shell effects disappear and the nucleus "feels" medium properties only described by liquid-drop model. It means that the effective transition states of fissioning nuclei are gradually shifted from the shape of the second barrier to the liquid-drop saddle shape with increasing of excitation energy. Thus, the shape of mass and charge fission fragment distributions should change from the asymmetric shape corresponding to the double-peak fission barrier to the symmetric shape corresponding to the liquid-drop barrier.

To describe Zöller's data [4] for pre-neutron-emission fragment mass distributions of  $^{238}\text{U}$  fission by neutrons in the energy interval from 2 to 200 MeV the five-gaussian model was used.

$$Y(A) = \sum_{i=1}^{i=5} \frac{y_i}{\sigma_i \sqrt{2\pi}} \exp\left(-\frac{(A - A_i)^2}{2\sigma_i^2}\right), \quad (1)$$

where parameters subscripts 1 and 2 refer to light-peak components, 4 and 5 to heavy-peak components, and 3 to the central peak.

$A_f = A_0 - \bar{\nu}_{pre}$  is the mass of fissioning nucleus after emission of prefission neutrons.

$$\bar{\nu}_{pre} = 6.77 \left( \frac{(0.02 \cdot E^*)^2}{1 + (0.02 \cdot E^*)^2} + \exp\left[-\frac{(22.9 - E^*)^2}{2.625^2}\right] \right), \quad (2)$$

where  $E^*$  is the excitation energy of compound nucleus,  $A_0$ .

$$A_3 = A_f / 2; \quad (3)$$

$$A_{1,5} = A_3 \mp 20.56; \quad (4)$$

$$A_{2,4} = A_3 \mp \begin{cases} 17.18 & \ell \leq \ell_{cr} \\ 0 & \ell > \ell_{cr} \end{cases}, \quad (5)$$

where  $\ell_{cr} = 7\hbar$  is the critical value of angular momentum, above which the asymmetric components 2 and 4 is converted into symmetric component 3 in all excitation energy range.

$$\sigma_{1,5} = 5.29 + (1 - P_{LD}) \cdot 5.14; \quad (6)$$

$$\sigma_{2,4} = 2.81 + (1 - P_{LD}) \cdot 7.25; \quad (7)$$

$$\sigma_3 = 5.28 + (1 - P_{LD}) \cdot 13.07; \quad (8)$$

$$Y_{1,5} = 100 \cdot P_{LD}; \quad (9)$$

$$Y_{2,4} = 100(1 - P_{LD}) \cdot s_1; \quad (10)$$

$$Y_3 = 200(1 - P_{LD}) \cdot s_2; \quad (11)$$

Here  $P_{LD}$  is the function, which describes converting of asymmetric mass fragment distribution into symmetric form with increasing of excitation energy of a fissioning nucleus.  $s_1$  and  $s_2$  are functions, which take into account a dependence of fragment mass distributions on angular momentum of fissioning nucleus.

$$P_{LD} = \left[ 1 + \exp\left(\frac{E^* - 44.7}{91.2}\right) \right]^{-1}; \quad (12)$$

$$s_1 = \sum_{\ell=0}^{\ell=\ell_{cr}} (2\ell + 1)T_{\ell} / \sum_{\ell=0}^{\ell=\infty} (2\ell + 1)T_{\ell}; \quad (13)$$

$$s_2 = 1 - s_1; \quad (14)$$

Here  $T_{\ell}$  are transmission coefficients in the input channel of reaction [5].

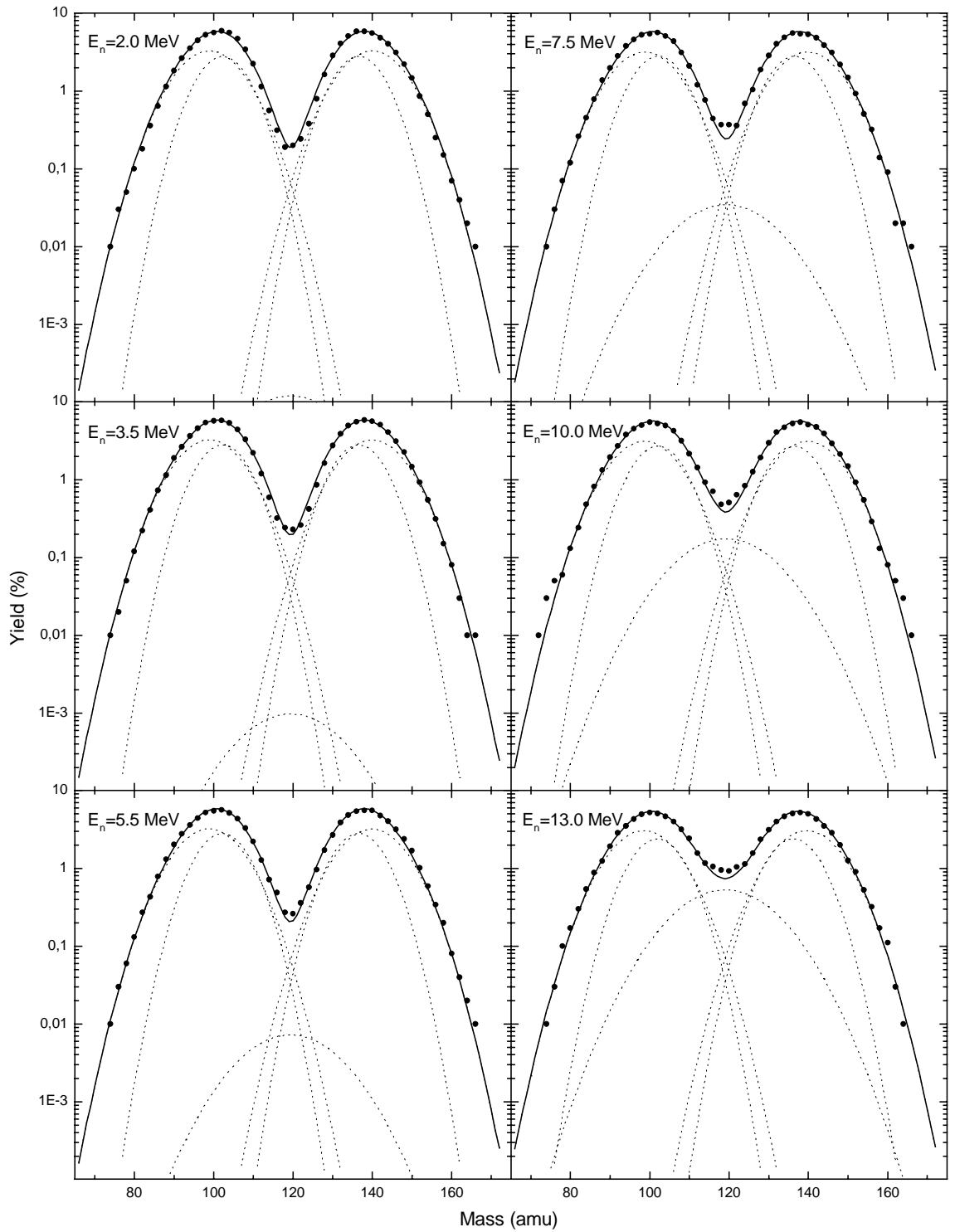
The results of description of Zöller's data [4] for pre-neutron-emission fragment mass distributions of  $^{238}\text{U}$  fission by neutrons in the energy region from 2 to 200 MeV are summarized in Figs. 1 – 3 and Tables 1 – 3.

The results of calculations of pre-neutron-emission fragment mass distributions for  $^{238}\text{U}$  fission by neutrons for other energies ( $E_n=1.6$  MeV, 8 MeV, 14.5 MeV, 21 MeV, 28 MeV and 100 MeV) are shown in Fig.4 and Table 4.

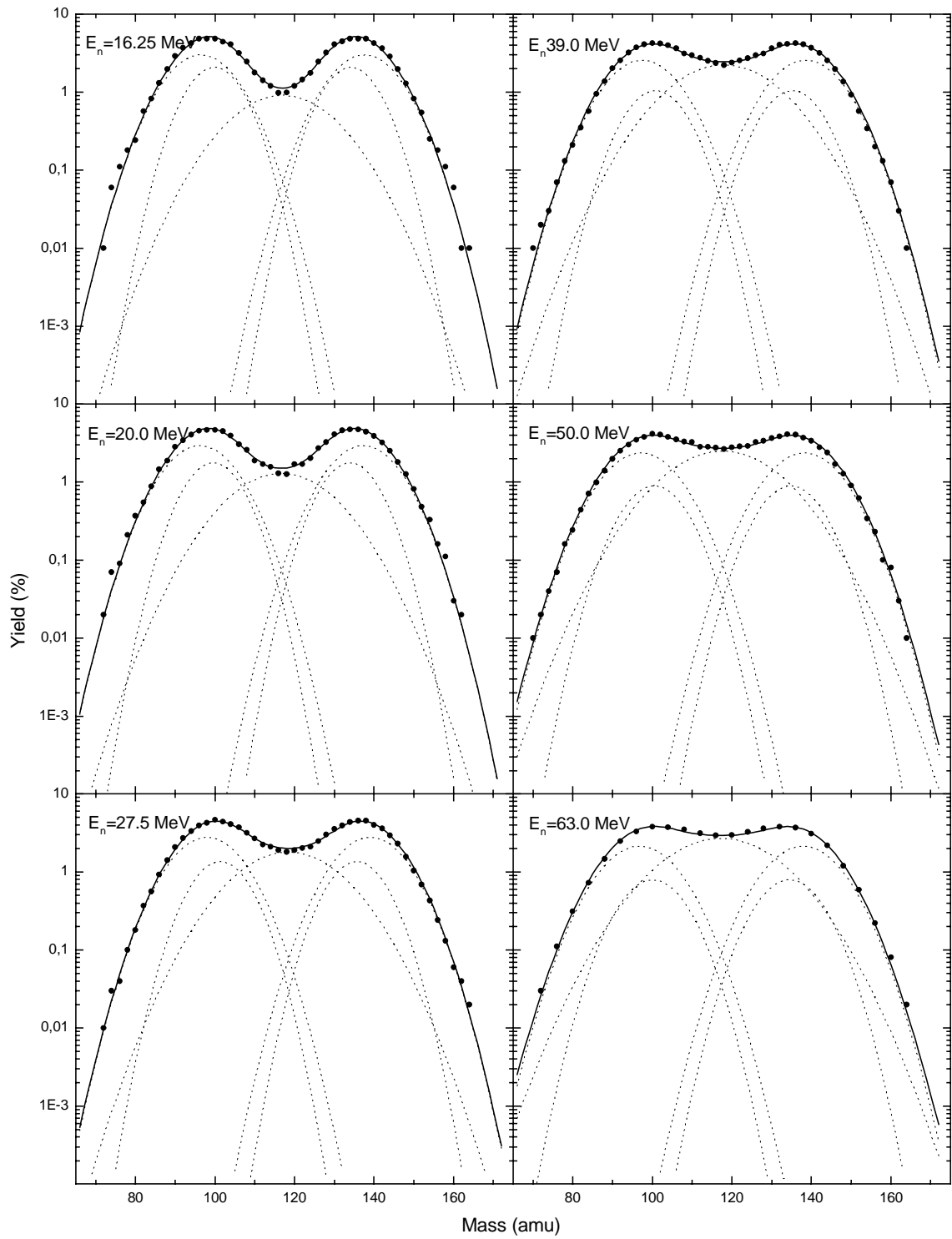
The authors are indebted to Dr. M.Lammer for supporting the work and partial translations of Zöller's thesis and to Dr. V.M.Maslov for providing numerical data of transmission coefficients.

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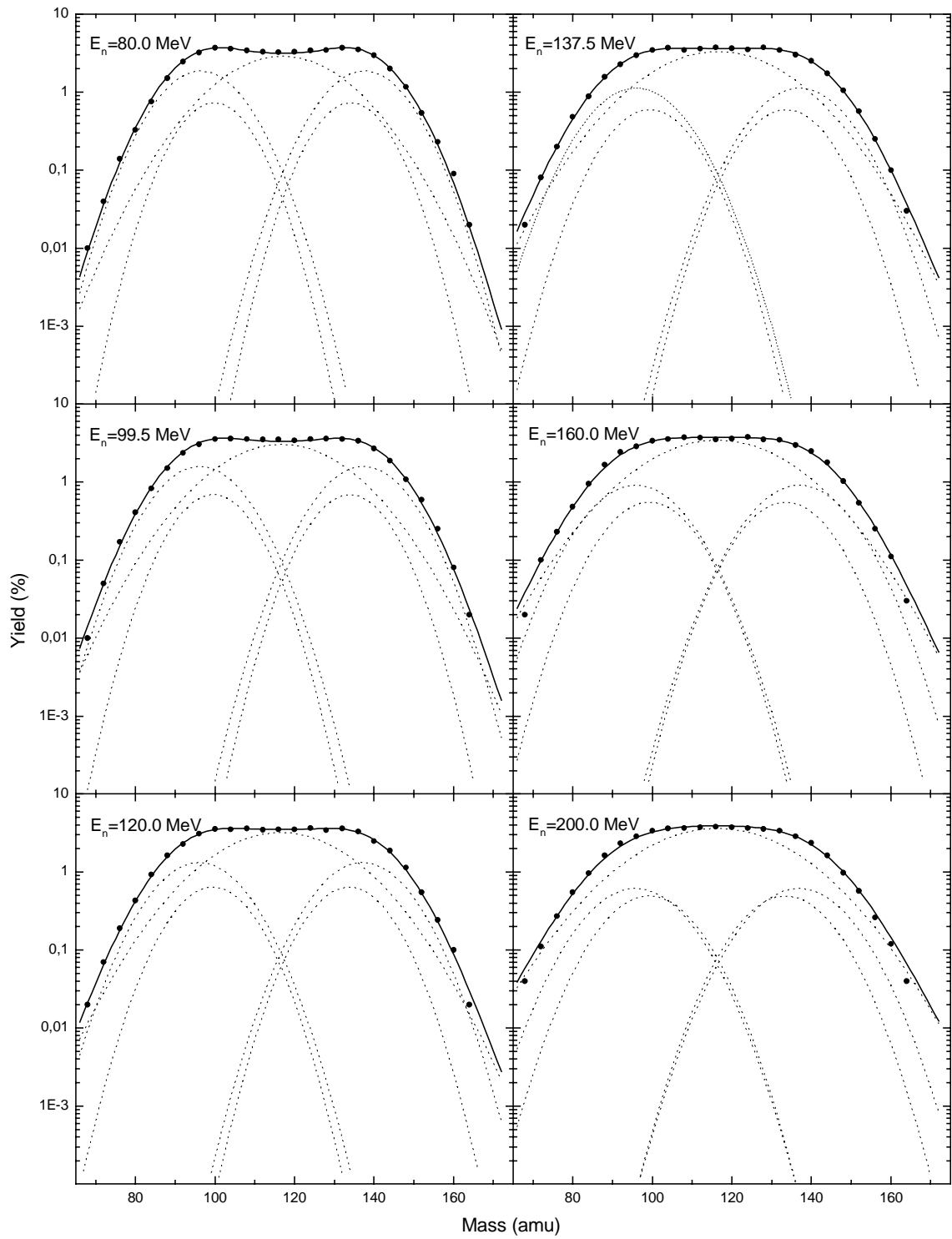
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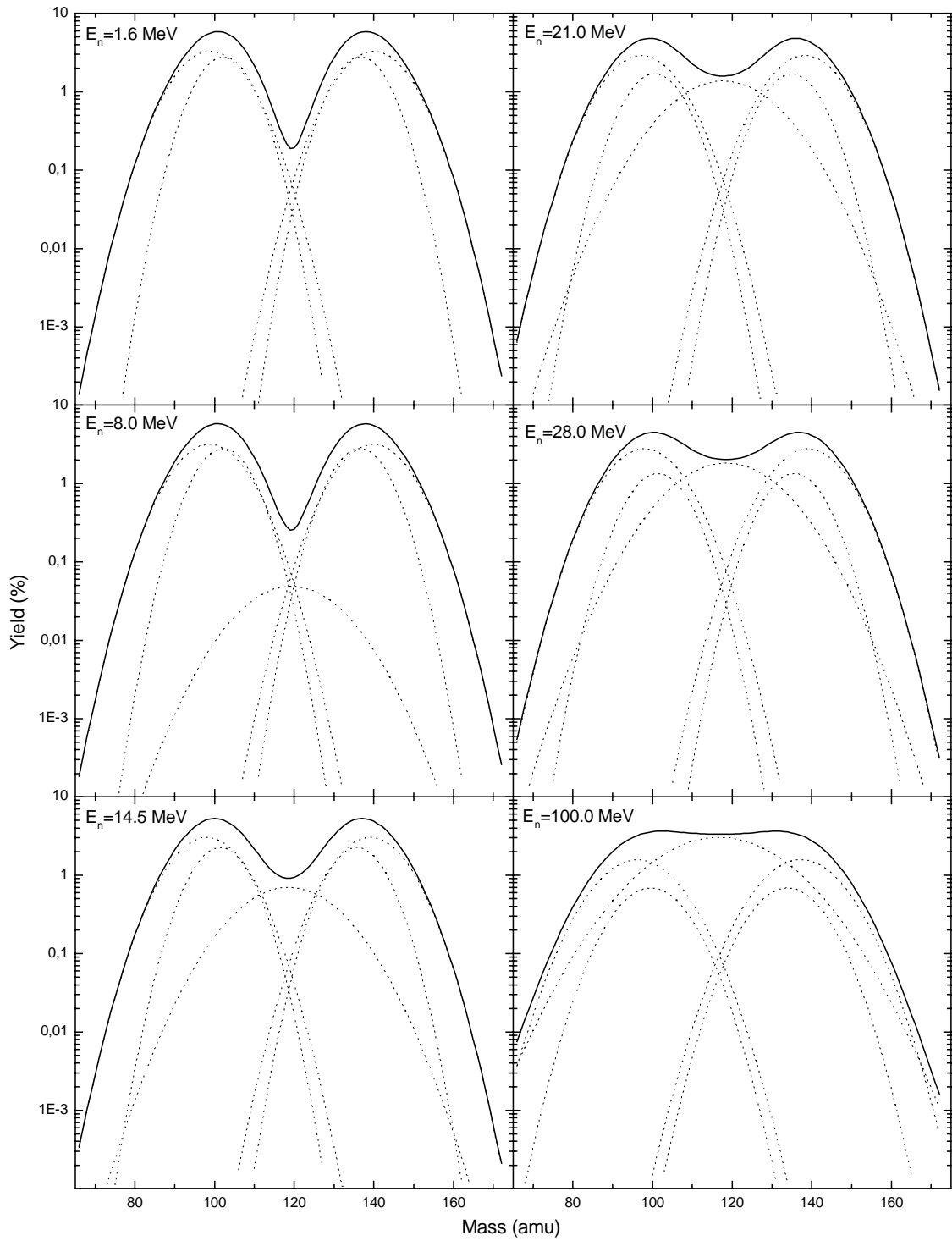
**Fig.1.** The pre-neutron-emission mass distributions in  $^{238}\text{U}$  fission induced by neutrons. The points are experimental data [4]; the lines are our calculations. The neutron energies are indicated in the figure.



**Fig.2.** Same as Fig.1.



**Fig.3.** Same as Fig.1.



**Fig.4.** The pre-neutron-emission mass distributions in  $^{238}\text{U}$  fission induced by neutrons. The lines are our calculations. The neutron energies are indicated in the figure.

**Table 1**  
 Pre-Neutron-Emission Mass Chain Yields  
 for Fission  $^{238}\text{U}$  by neutrons

MASS	2.0 MeV	3.5 MeV	5.5 MeV	7.5 MeV	10.0 MeV	13.0 MeV
66	0.000142	0.000151	0.000165	0.000181	0.000205	0.000250
67	0.000258	0.000274	0.000298	0.000326	0.000366	0.000442
68	0.000463	0.000490	0.000530	0.000575	0.000642	0.000768
69	0.000815	0.000859	0.000924	0.000998	0.001106	0.001311
70	0.001407	0.001478	0.001582	0.001701	0.001873	0.002198
71	0.002385	0.002496	0.002661	0.002847	0.003115	0.003622
72	0.003969	0.004140	0.004393	0.004679	0.005088	0.005863
73	0.006484	0.006741	0.007123	0.007551	0.008164	0.009325
74	0.010398	0.010777	0.011340	0.011970	0.012867	0.014575
75	0.016371	0.016918	0.017728	0.018635	0.019924	0.022386
76	0.025307	0.026078	0.027220	0.028498	0.030310	0.033788
77	0.038413	0.039476	0.041052	0.042814	0.045309	0.050125
78	0.057260	0.058694	0.060821	0.063200	0.066561	0.073096
79	0.083837	0.085726	0.088536	0.091680	0.096115	0.104801
80	0.120591	0.123027	0.126659	0.130727	0.136454	0.147761
81	0.170450	0.173522	0.178118	0.183275	0.190513	0.204920
82	0.236816	0.240607	0.246304	0.252709	0.261657	0.279613
83	0.323521	0.328102	0.335025	0.342823	0.353637	0.375499
84	0.434742	0.440168	0.448419	0.457729	0.470492	0.496453
85	0.574874	0.581179	0.590832	0.601731	0.616415	0.646397
86	0.748341	0.755533	0.766622	0.779134	0.795549	0.829089
87	0.959352	0.967406	0.979914	0.993985	1.011724	1.047829
88	1.211570	1.220420	1.234263	1.249731	1.268109	1.305110
89	1.507695	1.517221	1.532217	1.548784	1.566763	1.602177
90	1.848930	1.858934	1.874777	1.891963	1.908101	1.938523
91	2.234340	2.244528	2.260747	2.277856	2.290269	2.311350
92	2.660139	2.670095	2.686030	2.702123	2.708501	2.715029
93	3.118969	3.128152	3.142936	3.156835	3.154528	3.140676
94	3.599321	3.607071	3.619656	3.629987	3.616180	3.575929
95	4.085252	4.090834	4.100055	4.105350	4.077337	4.005076
96	4.556606	4.559285	4.563976	4.562827	4.518361	4.409626
97	4.989892	4.989038	4.988186	4.979437	4.917124	4.769388
98	5.359890	5.355087	5.348005	5.330964	5.250640	5.064036
99	5.641901	5.633059	5.619543	5.594158	5.497171	5.275012
100	5.814426	5.801840	5.782273	5.749251	5.638583	5.387559
101	5.861858	5.846223	5.821593	5.782409	5.662585	5.392557
102	5.776743	5.759093	5.730919	5.687708	5.564489	5.287861
103	5.561161	5.542744	5.512903	5.468251	5.348135	5.078868
104	5.226902	5.209019	5.179517	5.136169	5.025778	4.778179
105	4.794354	4.778187	4.750904	4.711459	4.616904	4.404369
106	4.290249	4.276715	4.253186	4.219817	4.146147	3.980034
107	3.744657	3.734312	3.715574	3.689830	3.640645	3.529441
108	3.187728	3.180739	3.167268	3.149988	3.127254	3.076129
109	2.646722	2.642906	2.634652	2.625977	2.630066	2.640822
110	2.143757	2.142670	2.139159	2.138643	2.168540	2.239926
111	1.694534	1.695579	1.696062	1.702840	1.756472	1.884746
112	1.308067	1.310609	1.314224	1.327197	1.401805	1.581435
113	0.987301	0.990766	0.996673	1.014683	1.107182	1.331559
114	0.730349	0.734286	0.741774	0.763740	0.871014	1.133087
115	0.532038	0.536155	0.544707	0.569718	0.688837	0.981610
116	0.385504	0.389677	0.398993	0.426361	0.554706	0.871581
117	0.283617	0.287881	0.297879	0.327152	0.462474	0.797437
118	0.220130	0.224659	0.235461	0.266414	0.406828	0.754516
119	0.190502	0.195589	0.207493	0.240105	0.384054	0.739712

120	0.192419	0.198455	0.211907	0.246327	0.392505	0.751875
121	0.226036	0.233481	0.249036	0.285538	0.432800	0.791953
122	0.293957	0.303309	0.321583	0.360502	0.507753	0.862874
123	0.400967	0.412712	0.434310	0.475964	0.622023	0.969175
124	0.553474	0.568026	0.593451	0.638037	0.781490	1.116367
125	0.758642	0.776265	0.805808	0.853283	0.992336	1.310044
126	1.023210	1.043932	1.077548	1.127509	1.259871	1.554782
127	1.352032	1.375568	1.412773	1.464354	1.587171	1.852895
128	1.746484	1.772181	1.811975	1.863793	1.973681	2.203219
129	2.202931	2.229760	2.270620	2.320786	2.413983	2.600078
130	2.711553	2.738157	2.778109	2.824338	2.896978	3.032679
131	3.255829	3.280634	3.317412	3.357210	3.405716	3.485089
132	3.812917	3.834297	3.865573	3.896505	3.918037	3.936949
133	4.355063	4.371530	4.395189	4.415176	4.408068	4.364911
134	4.851957	4.862350	4.876754	4.884349	4.848464	4.744676
135	5.273764	5.277401	5.281598	5.276194	5.213100	5.053377
136	5.594379	5.591133	5.584975	5.566903	5.479840	5.271954
137	5.794371	5.784669	5.768809	5.739299	5.632920	5.387158
138	5.863108	5.847849	5.823624	5.784650	5.664579	5.392859
139	5.799718	5.780131	5.749366	5.703391	5.575666	5.290481
140	5.612753	5.590225	5.554988	5.504678	5.375177	5.088512
141	5.318677	5.294591	5.256956	5.204899	5.078835	4.801238
142	4.939536	4.915135	4.876984	4.825464	4.707028	4.446932
143	4.500227	4.476534	4.439428	4.390282	4.282456	4.045838
144	4.025870	4.003650	3.968770	3.923328	3.827874	3.618235
145	3.539619	3.519383	3.487533	3.446634	3.364219	3.182836
146	3.061143	3.043185	3.014833	2.978888	2.909308	2.755656
147	2.605840	2.590281	2.565621	2.534704	2.477133	2.349394
148	2.184687	2.171517	2.150539	2.124477	2.077711	1.973268
149	1.804567	1.793680	1.776224	1.754686	1.717344	1.633207
150	1.468876	1.460103	1.445908	1.428461	1.399134	1.332264
151	1.178247	1.171374	1.160112	1.146274	1.123623	1.071142
152	0.931263	0.926048	0.917351	0.906621	0.889429	0.848744
153	0.725079	0.721265	0.714749	0.706633	0.693830	0.662680
154	0.555943	0.553275	0.548557	0.542585	0.533248	0.509709
155	0.419604	0.417838	0.414555	0.410296	0.403646	0.386106
156	0.311630	0.310546	0.308368	0.305435	0.300824	0.287952
157	0.227645	0.227050	0.225690	0.223753	0.220653	0.211362
158	0.163506	0.163244	0.162463	0.161246	0.159238	0.152649
159	0.115431	0.115379	0.114987	0.114271	0.113026	0.108443
160	0.080076	0.080143	0.079997	0.079613	0.078884	0.075761
161	0.054571	0.054695	0.054690	0.054516	0.054122	0.052038
162	0.036528	0.036667	0.036735	0.036683	0.036495	0.035137
163	0.024011	0.024143	0.024238	0.024251	0.024183	0.023319
164	0.015498	0.015611	0.015708	0.015749	0.015744	0.015208
165	0.009821	0.009912	0.009998	0.010046	0.010071	0.009747
166	0.006110	0.006180	0.006249	0.006294	0.006328	0.006138
167	0.003732	0.003782	0.003835	0.003873	0.003906	0.003798
168	0.002238	0.002273	0.002311	0.002340	0.002368	0.002309
169	0.001317	0.001341	0.001368	0.001389	0.001410	0.001379
170	0.000761	0.000777	0.000795	0.000809	0.000825	0.000810
171	0.000432	0.000442	0.000453	0.000463	0.000474	0.000467
172	0.000240	0.000246	0.000254	0.000260	0.000267	0.000265



**Table 2**  
 Pre-Neutron-Emission Mass Chain Yields  
 for Fission  $^{238}\text{U}$  by neutrons

MASS	16.25 MeV	20 MeV	27.5 MeV	39 MeV	50 MeV	63 MeV
66	0.000861	0.001088	0.000531	0.000946	0.001536	0.002524
67	0.001457	0.001818	0.000896	0.001539	0.002418	0.003831
68	0.002423	0.002987	0.001488	0.002470	0.003763	0.005760
69	0.003963	0.004826	0.002435	0.003910	0.005784	0.008572
70	0.006370	0.007667	0.003922	0.006102	0.008779	0.012619
71	0.010063	0.011976	0.006217	0.009388	0.013151	0.018368
72	0.015625	0.018395	0.009699	0.014231	0.019439	0.026421
73	0.023848	0.027782	0.014888	0.021255	0.028344	0.037545
74	0.035782	0.041260	0.022489	0.031273	0.040761	0.052693
75	0.052780	0.060262	0.033427	0.045326	0.057805	0.073023
76	0.076547	0.086566	0.048888	0.064711	0.080832	0.099906
77	0.109174	0.122321	0.070361	0.091003	0.111448	0.134930
78	0.153149	0.170048	0.099656	0.126066	0.151505	0.179874
79	0.211354	0.232618	0.138919	0.172038	0.203073	0.236675
80	0.287019	0.313190	0.190618	0.231295	0.268387	0.307363
81	0.383647	0.415108	0.257497	0.306384	0.349762	0.393968
82	0.504881	0.541757	0.342493	0.399913	0.449481	0.498408
83	0.654336	0.696359	0.448616	0.514413	0.569646	0.622344
84	0.835365	0.881733	0.578784	0.652155	0.712001	0.767018
85	1.050768	1.099991	0.735605	0.814941	0.877736	0.933082
86	1.302449	1.352203	0.921136	1.003866	1.067275	1.120424
87	1.591006	1.638018	1.136592	1.219070	1.280077	1.328008
88	1.915286	1.955287	1.382048	1.459504	1.514450	1.553754
89	2.271931	2.299708	1.656134	1.722716	1.767417	1.794460
90	2.654966	2.664550	1.955762	2.004708	2.034652	2.045801
91	3.055502	3.040525	2.275916	2.299873	2.310509	2.302415
92	3.461660	3.415882	2.609549	2.601058	2.588158	2.558077
93	3.858796	3.776782	2.947635	2.899768	2.859854	2.805980
94	4.230118	4.108001	3.279420	3.186535	3.117317	3.039094
95	4.557717	4.393953	3.592895	3.451431	3.352230	3.250600
96	4.823965	4.619968	3.875502	3.684727	3.556801	3.434345
97	5.013167	4.773692	4.115029	3.877621	3.724352	3.585300
98	5.113257	4.846436	4.300631	4.022982	3.849869	3.699952
99	5.117279	4.834261	4.423858	4.116015	3.930453	3.776594
100	5.024417	4.738618	4.479559	4.154755	3.965604	3.815473
101	4.840353	4.566403	4.466521	4.140332	3.957297	3.818780
102	4.576866	4.329385	4.387739	4.076928	3.909843	3.790456
103	4.250697	4.043072	4.250240	3.971438	3.829509	3.735857
104	3.881836	3.725170	4.064471	3.832862	3.723977	3.661294
105	3.491500	3.393858	3.843320	3.671489	3.601676	3.573508
106	3.100098	3.066132	3.600897	3.497991	3.471075	3.479137
107	2.725473	2.756437	3.351240	3.322523	3.340019	3.384224
108	2.381654	2.475742	3.107127	3.153950	3.215182	3.293836
109	2.078205	2.231138	2.879128	2.999278	3.101687	3.211804
110	1.820205	2.025932	2.675003	2.863338	3.002924	3.140623
111	1.608747	1.860162	2.499485	2.748743	2.920571	3.081486
112	1.441801	1.731384	2.354422	2.656076	2.854782	3.034458
113	1.315281	1.635601	2.239221	2.584274	2.804515	2.998743
114	1.224132	1.568208	2.151482	2.531138	2.767948	2.972997
115	1.163328	1.524822	2.087739	2.493880	2.742910	2.955676
116	1.128682	1.501971	2.044186	2.469671	2.727306	2.945343
117	1.117447	1.497571	2.017344	2.456107	2.719469	2.940934
118	1.128667	1.511199	2.004580	2.451577	2.718425	2.941933
119	1.163296	1.544143	2.004480	2.455489	2.724033	2.948462

120	1.224083	1.599240	2.017033	2.468355	2.737015	2.961254
121	1.315210	1.680500	2.043632	2.491720	2.758840	2.981541
122	1.441705	1.792514	2.086891	2.527940	2.791501	3.010832
123	1.608622	1.939693	2.150280	2.579829	2.837188	3.050637
124	1.820050	2.125359	2.237605	2.650194	2.897882	3.102132
125	2.078019	2.350807	2.352342	2.741298	2.974920	3.165829
126	2.381439	2.614420	2.496916	2.854302	3.068568	3.241269
127	2.725235	2.911005	2.671953	2.988757	3.177661	3.326784
128	3.099843	3.231481	2.875648	3.142207	3.299366	3.419380
129	3.491240	3.563024	3.103317	3.309984	3.429100	3.514743
130	3.881583	3.889747	3.347248	3.485230	3.560650	3.607404
131	4.250465	4.193857	3.596912	3.659201	3.686492	3.691046
132	4.576669	4.457199	3.839561	3.821809	3.798287	3.758932
133	4.840203	4.662977	4.061166	3.962392	3.887517	3.804419
134	5.024323	4.797412	4.247608	4.070602	3.946187	3.821492
135	5.117248	4.851107	4.385972	4.137316	3.967513	3.805276
136	5.113291	4.819904	4.465762	4.155463	3.946513	3.752451
137	5.013263	4.705141	4.479889	4.120649	3.880441	3.661540
138	4.824116	4.513285	4.425292	4.031520	3.769009	3.533031
139	4.557914	4.255048	4.303118	3.889819	3.614375	3.369333
140	4.230350	3.944138	4.118457	3.700153	3.420922	3.174565
141	3.859051	3.595864	3.879715	3.469504	3.194854	2.954225
142	3.461926	3.225772	3.597705	3.206577	2.943674	2.714770
143	3.055770	2.848490	3.284626	2.921060	2.675595	2.463151
144	2.655226	2.476861	2.953037	2.622888	2.398964	2.206361
145	2.272176	2.121412	2.614963	2.321583	2.121747	1.951029
146	1.915511	1.790124	2.281183	2.025724	1.851097	1.703085
147	1.591209	1.488466	1.960752	1.742570	1.593059	1.467518
148	1.302628	1.219604	1.660750	1.477844	1.352387	1.248240
149	1.050923	0.984724	1.386225	1.235660	1.132483	1.048028
150	0.835496	0.783407	1.140295	1.018577	0.935435	0.868563
151	0.654445	0.614007	0.924355	0.827741	0.762134	0.710517
152	0.504970	0.474014	0.738351	0.663088	0.612441	0.573698
153	0.383719	0.360367	0.581083	0.523585	0.485386	0.457213
154	0.287076	0.269736	0.450508	0.407474	0.379380	0.359644
155	0.211398	0.198733	0.344021	0.312509	0.292413	0.279215
156	0.153183	0.144095	0.258710	0.236172	0.222244	0.213952
157	0.109199	0.102798	0.191564	0.175854	0.166552	0.161812
158	0.076566	0.072144	0.139643	0.129003	0.123068	0.120791
159	0.052793	0.049801	0.100201	0.093225	0.089662	0.089006
160	0.035791	0.033809	0.070764	0.066363	0.064408	0.064744
161	0.023855	0.022571	0.049181	0.046534	0.045620	0.046498
162	0.015629	0.014817	0.033636	0.032142	0.031864	0.032976
163	0.010066	0.009564	0.022636	0.021869	0.021949	0.023100
164	0.006372	0.006070	0.014989	0.014658	0.014913	0.015987
165	0.003964	0.003788	0.009767	0.009680	0.009997	0.010937
166	0.002424	0.002325	0.006262	0.006299	0.006614	0.007398
167	0.001457	0.001403	0.003951	0.004040	0.004320	0.004952
168	0.000861	0.000833	0.002454	0.002554	0.002787	0.003281
169	0.000500	0.000486	0.001500	0.001593	0.001777	0.002155
170	0.000285	0.000279	0.000903	0.000980	0.001121	0.001403
171	0.000160	0.000158	0.000535	0.000595	0.000699	0.000907
172	0.000088	0.000088	0.000313	0.000357	0.000433	0.000583

**Table 3**  
 Pre-Neutron-Emission Mass Chain Yields  
 for Fission  $^{238}\text{U}$  by neutrons

MASS	80 MeV	99.5 MeV	120 MeV	137.5 MeV	160 MeV	200 MeV
66	0.004373	0.007421	0.011869	0.016676	0.023992	0.038707
67	0.006358	0.010336	0.015920	0.021786	0.030511	0.047619
68	0.009179	0.014325	0.021277	0.028379	0.038706	0.058448
69	0.013147	0.019740	0.028317	0.036842	0.048963	0.071566
70	0.018669	0.027026	0.037504	0.047642	0.061741	0.087397
71	0.026266	0.036737	0.049403	0.061335	0.077575	0.106423
72	0.036594	0.049554	0.064687	0.078575	0.097082	0.129188
73	0.050463	0.066291	0.084146	0.100116	0.120958	0.156287
74	0.068850	0.087909	0.108688	0.126808	0.149978	0.188371
75	0.092911	0.115514	0.139340	0.159599	0.184987	0.226131
76	0.123983	0.150354	0.177228	0.199511	0.226884	0.270286
77	0.163564	0.193795	0.223563	0.247624	0.276601	0.321567
78	0.213295	0.247290	0.279601	0.305042	0.335072	0.380690
79	0.274905	0.312332	0.346600	0.372848	0.403199	0.448329
80	0.350147	0.390388	0.425762	0.452056	0.481804	0.525083
81	0.440711	0.482817	0.518159	0.543543	0.571581	0.611440
82	0.548112	0.590777	0.624657	0.647991	0.673040	0.707741
83	0.673563	0.715117	0.745828	0.765808	0.786455	0.814140
84	0.817842	0.856265	0.881865	0.897064	0.911810	0.930572
85	0.981145	1.014125	1.032504	1.041429	1.048752	1.056725
86	1.162962	1.187975	1.196952	1.198122	1.196559	1.192017
87	1.361959	1.376400	1.373849	1.365882	1.354124	1.335589
88	1.575909	1.577252	1.561247	1.542963	1.519949	1.486311
89	1.801668	1.787652	1.756629	1.727156	1.692178	1.642792
90	2.035208	2.004049	1.956970	1.915847	1.868634	1.803425
91	2.271735	2.222328	2.158836	2.106097	2.046897	1.966425
92	2.505866	2.437977	2.358518	2.294764	2.224388	2.129893
93	2.731883	2.646296	2.552204	2.478635	2.398483	2.291884
94	2.944046	2.842650	2.736173	2.654585	2.566621	2.450485
95	3.136936	3.022727	2.906985	2.819725	2.726425	2.603884
96	3.305804	3.182807	3.061682	2.971558	2.875812	2.750450
97	3.446906	3.319989	3.197946	3.108101	3.013088	2.888786
98	3.557761	3.432378	3.314234	3.227986	3.137018	3.017783
99	3.637338	3.519198	3.409844	3.330512	3.246870	3.136645
100	3.686118	3.580823	3.484940	3.415659	3.342423	3.244908
101	3.706042	3.618720	3.540500	3.484053	3.423948	3.342425
102	3.700335	3.635309	3.578215	3.536885	3.492149	3.429342
103	3.673232	3.633755	3.600336	3.575802	3.548089	3.506057
104	3.629618	3.617712	3.609495	3.602764	3.593091	3.573167
105	3.574647	3.591037	3.608499	3.619899	3.628634	3.631405
106	3.513351	3.557516	3.600142	3.629355	3.656247	3.681585
107	3.450294	3.520623	3.587025	3.633164	3.677413	3.724534
108	3.389308	3.483323	3.571421	3.633140	3.693490	3.761053
109	3.333316	3.447950	3.555183	3.630802	3.705657	3.791871
110	3.284269	3.416158	3.539702	3.627339	3.714873	3.817618
111	3.243183	3.388945	3.525916	3.623610	3.721880	3.838817
112	3.210268	3.366731	3.514356	3.620169	3.727204	3.855877
113	3.185122	3.349498	3.505235	3.617323	3.731193	3.869101
114	3.166966	3.336940	3.498542	3.615199	3.734054	3.878704
115	3.154878	3.328630	3.494153	3.613814	3.735894	3.884825
116	3.148024	3.324165	3.491919	3.613139	3.736759	3.887543
117	3.145827	3.323282	3.491743	3.613146	3.736666	3.886893
118	3.148085	3.325923	3.493616	3.613836	3.735612	3.882867
119	3.155004	3.332254	3.497623	3.615236	3.733578	3.875414

120	3.167168	3.342620	3.503907	3.617375	3.730508	3.864433
121	3.185413	3.357450	3.512604	3.620235	3.726278	3.849757
122	3.210658	3.377134	3.523750	3.623686	3.720658	3.831140
123	3.243681	3.401853	3.537179	3.627416	3.713268	3.808239
124	3.284878	3.431426	3.552422	3.630865	3.703541	3.780602
125	3.334027	3.465161	3.568615	3.633168	3.690694	3.747663
126	3.390102	3.501741	3.584449	3.633130	3.673722	3.708751
127	3.451137	3.539172	3.598147	3.629224	3.651410	3.663106
128	3.514197	3.574796	3.607506	3.619630	3.622369	3.609913
129	3.575440	3.605375	3.609970	3.602313	3.585101	3.548341
130	3.630292	3.627252	3.602769	3.575125	3.538077	3.477602
131	3.673718	3.636573	3.583083	3.535940	3.479842	3.397008
132	3.700565	3.629546	3.548237	3.482801	3.409115	3.306032
133	3.705953	3.602727	3.495900	3.414070	3.324896	3.204367
134	3.685659	3.553290	3.424271	3.328568	3.226559	3.091975
135	3.636474	3.479266	3.332241	3.225680	3.113927	2.969125
136	3.556476	3.379719	3.219502	3.105441	2.987319	2.836409
137	3.445203	3.254845	3.086602	2.968565	2.847568	2.694746
138	3.303709	3.105985	2.934946	2.816435	2.696003	2.545362
139	3.134489	2.935552	2.766723	2.651044	2.534399	2.389748
140	2.941307	2.746882	2.584793	2.474900	2.364905	2.229617
141	2.728920	2.544019	2.392525	2.290897	2.189942	2.066825
142	2.502755	2.331469	2.193607	2.102165	2.012094	1.903308
143	2.268555	2.113932	1.991849	1.911916	1.833985	1.741002
144	2.032033	1.896045	1.790989	1.723290	1.658170	1.581769
145	1.798567	1.682145	1.594520	1.539218	1.487029	1.427333
146	1.572943	1.476084	1.405548	1.362309	1.322680	1.279222
147	1.359175	1.281090	1.226681	1.194762	1.166914	1.138728
148	1.160397	1.099683	1.059967	1.038313	1.021152	1.006880
149	0.978823	0.933645	0.906870	0.894213	0.886426	0.884428
150	0.815773	0.784038	0.768277	0.763233	0.763384	0.771848
151	0.671751	0.651263	0.644538	0.645695	0.652310	0.669354
152	0.546549	0.535142	0.535536	0.541521	0.553160	0.576923
153	0.439384	0.435025	0.440757	0.450295	0.465610	0.494324
154	0.349036	0.349896	0.359380	0.371333	0.389108	0.421155
155	0.273989	0.278484	0.290362	0.303753	0.322933	0.356881
156	0.212551	0.219365	0.232518	0.246538	0.266242	0.300870
157	0.162968	0.171050	0.184597	0.198606	0.218125	0.252427
158	0.123511	0.132059	0.145338	0.158852	0.177644	0.210828
159	0.092544	0.100977	0.113519	0.126198	0.143873	0.175345
160	0.068567	0.076493	0.087997	0.099621	0.115921	0.145266
161	0.050248	0.057429	0.067728	0.078178	0.092956	0.119915
162	0.036434	0.042751	0.051782	0.061018	0.074218	0.098663
163	0.026148	0.031570	0.039349	0.047391	0.059026	0.080931
164	0.018583	0.023140	0.029737	0.036645	0.046779	0.066203
165	0.013085	0.016846	0.022361	0.028225	0.036958	0.054016
166	0.009134	0.012189	0.016743	0.021667	0.029119	0.043968
167	0.006327	0.008772	0.012489	0.016584	0.022887	0.035710
168	0.004351	0.006284	0.009288	0.012662	0.017950	0.028941
169	0.002974	0.004485	0.006890	0.009648	0.014051	0.023407
170	0.002022	0.003191	0.005100	0.007338	0.010979	0.018893
171	0.001369	0.002265	0.003770	0.005573	0.008565	0.015218
172	0.000924	0.001605	0.002783	0.004226	0.006670	0.012233

**Table 4**  
 Pre-Neutron-Emission Mass Chain Yields  
 for Fission  $^{238}\text{U}$  by neutrons

MASS	1.6 MeV	8 MeV	14.5 MeV	21 MeV	28 MeV	100 MeV
66	0.000139	0.000185	0.000344	0.000667	0.000545	0.007513
67	0.000254	0.000333	0.000600	0.001130	0.000918	0.010455
68	0.000456	0.000588	0.001030	0.001882	0.001523	0.014476
69	0.000804	0.001018	0.001738	0.003085	0.002489	0.019929
70	0.001389	0.001733	0.002881	0.004972	0.004003	0.027261
71	0.002357	0.002897	0.004694	0.007882	0.006337	0.037026
72	0.003926	0.004756	0.007515	0.012285	0.009873	0.049905
73	0.006419	0.007666	0.011822	0.018830	0.015137	0.066712
74	0.010303	0.012138	0.018279	0.028382	0.022838	0.088406
75	0.016234	0.018878	0.027776	0.042071	0.033906	0.116094
76	0.025113	0.028840	0.041486	0.061334	0.049535	0.151019
77	0.038146	0.043285	0.060912	0.087951	0.071216	0.194543
78	0.056901	0.063835	0.087930	0.124067	0.100765	0.248115
79	0.083364	0.092520	0.124821	0.172196	0.140328	0.313222
80	0.119983	0.131813	0.174279	0.235188	0.192372	0.391323
81	0.169686	0.184651	0.239395	0.316168	0.259631	0.483772
82	0.235877	0.254416	0.323607	0.418436	0.345030	0.591717
83	0.322390	0.344898	0.430605	0.545306	0.451558	0.715998
84	0.433410	0.460199	0.564192	0.699917	0.582102	0.857039
85	0.573334	0.604610	0.728094	0.884977	0.739232	1.014734
86	0.746597	0.782414	0.925701	1.102468	0.924957	1.188362
87	0.957412	0.997631	1.159758	1.353315	1.140434	1.376506
88	1.209455	1.253672	1.431973	1.637018	1.385679	1.577022
89	1.505439	1.552898	1.742570	1.951288	1.659258	1.787040
90	1.846583	1.896072	2.089792	2.291718	1.958027	2.003021
91	2.231977	2.281713	2.469399	2.651529	2.276927	2.220867
92	2.657863	2.705408	2.874228	3.021478	2.608892	2.436088
93	3.116915	3.159165	3.293910	3.389973	2.944909	2.644008
94	3.597650	3.630933	3.714847	3.743466	3.274279	2.840016
95	4.084142	4.104474	4.120566	4.067155	3.585095	3.019826
96	4.556233	4.559730	4.492528	4.345992	3.864943	3.179738
97	4.990405	4.973821	4.811383	4.565914	4.101798	3.316870
98	5.361379	5.322694	5.058628	4.715186	4.285024	3.429338
99	5.644375	5.583311	5.218460	4.785679	4.406385	3.516368
100	5.817792	5.736144	5.279605	4.773878	4.460924	3.578329
101	5.865925	5.767595	5.236805	4.681468	4.447581	3.616678
102	5.781238	5.671940	5.091712	4.515346	4.369440	3.633813
103	5.565759	5.452408	4.852985	4.287051	4.233543	3.632877
104	5.231273	5.121171	4.535539	4.011652	4.050274	3.617493
105	4.798205	4.698168	4.159034	3.706262	3.832388	3.591490
106	4.293362	4.208954	3.745830	3.388387	3.593807	3.558628
107	3.746912	3.681914	3.318730	3.074347	3.348353	3.522354
108	3.189105	3.145305	2.898848	2.777967	3.108577	3.485616
109	2.647292	2.624588	2.503890	2.509715	2.884839	3.450735
110	2.143658	2.140413	2.147068	2.276316	2.684723	3.419359
111	1.693933	1.707490	1.836686	2.080859	2.512830	3.392483
112	1.307138	1.334357	1.576377	1.923289	2.370922	3.370534
113	0.986198	1.023950	1.365845	1.801175	2.258370	3.353499
114	0.729186	0.774718	1.201915	1.710607	2.172774	3.341084
115	0.530886	0.582052	1.079712	1.647097	2.110696	3.332869
116	0.384388	0.439752	0.993797	1.606396	2.068380	3.328462
117	0.282522	0.341367	0.939154	1.585147	2.042399	3.327603
118	0.219001	0.281281	0.911957	1.581355	2.030176	3.330239
119	0.189258	0.255513	0.910080	1.594645	2.030342	3.336532

120	0.190955	0.262207	0.933371	1.626306	2.042916	3.346821
121	0.224228	0.301856	0.983668	1.679132	2.069304	3.361529
122	0.291674	0.377237	1.064569	1.757044	2.112111	3.381030
123	0.398083	0.493087	1.180954	1.864515	2.174781	3.405498
124	0.549879	0.655482	1.338256	2.005821	2.261070	3.434740
125	0.754269	0.870918	1.541504	2.184169	2.374398	3.468056
126	1.018050	1.145107	1.794205	2.400782	2.517124	3.504126
127	1.346159	1.481571	2.097165	2.654057	2.689824	3.540960
128	1.740065	1.880161	2.447398	2.938934	2.890659	3.575909
129	2.196230	2.335728	2.837332	3.246601	3.114948	3.605752
130	2.704918	2.837201	3.254489	3.564656	3.355028	3.626855
131	3.249662	3.367328	3.681785	3.877755	3.600469	3.635392
132	3.807634	3.903272	4.098525	4.168741	3.838672	3.627601
133	4.351039	4.418124	4.482031	4.420120	4.055796	3.600070
134	4.849482	4.883225	4.809730	4.615709	4.237933	3.550003
135	5.273003	5.271001	5.061416	4.742227	4.372379	3.475457
136	5.595354	5.557918	5.221345	4.790596	4.448828	3.375514
137	5.796959	5.727045	5.279846	4.756768	4.460341	3.250383
138	5.867071	5.769844	5.234198	4.641971	4.403946	3.101409
139	5.804735	5.686863	5.088654	4.452376	4.280815	2.930999
140	5.618467	5.487280	4.853667	4.198252	4.096003	2.742478
141	5.324738	5.187426	4.544468	3.892786	3.857825	2.539872
142	4.945631	4.808592	4.179274	3.550749	3.576969	2.327667
143	4.506106	4.374528	3.777421	3.187193	3.265483	2.110538
144	4.031349	3.909042	3.357662	2.816332	2.935777	1.893096
145	3.544577	3.434006	2.936844	2.450700	2.599735	1.679656
146	3.065515	2.967976	2.529031	2.100620	2.268016	1.474050
147	2.609604	2.525466	2.145087	1.773971	1.949580	1.279488
148	2.187851	2.116804	1.792644	1.476198	1.651440	1.098476
149	1.807161	1.748426	1.476358	1.210500	1.378601	0.932788
150	1.470946	1.423446	1.198328	0.978132	1.134157	0.783481
151	1.179849	1.142331	0.958597	0.778761	0.919498	0.650954
152	0.932459	0.903582	0.755650	0.610835	0.734573	0.535031
153	0.725934	0.704341	0.586872	0.471929	0.578198	0.435064
154	0.556521	0.540898	0.448949	0.359065	0.448346	0.350043
155	0.419968	0.409087	0.338186	0.268979	0.342433	0.278702
156	0.311835	0.304595	0.250780	0.198344	0.257569	0.219625
157	0.227737	0.223189	0.183012	0.143940	0.190763	0.171329
158	0.163525	0.160883	0.131401	0.102784	0.139095	0.132338
159	0.115407	0.114049	0.092798	0.072207	0.099836	0.101243
160	0.080030	0.079486	0.064448	0.049897	0.070529	0.076739
161	0.054519	0.054450	0.044007	0.033913	0.049036	0.057650
162	0.036477	0.036654	0.029540	0.022669	0.033550	0.042944
163	0.023966	0.024243	0.019491	0.014901	0.022588	0.031735
164	0.015462	0.015752	0.012639	0.009632	0.014965	0.023280
165	0.009793	0.010054	0.008055	0.006122	0.009756	0.016962
166	0.006089	0.006303	0.005045	0.003827	0.006259	0.012284
167	0.003717	0.003880	0.003105	0.002352	0.003952	0.008848
168	0.002227	0.002346	0.001878	0.001422	0.002456	0.006345
169	0.001310	0.001393	0.001116	0.000846	0.001503	0.004533
170	0.000756	0.000813	0.000652	0.000495	0.000905	0.003228
171	0.000429	0.000465	0.000374	0.000285	0.000537	0.002294
172	0.000238	0.000262	0.000211	0.000161	0.000314	0.001628