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8-GROUP MODEL ENERGY SPECTRA OF DELAYED NEUTRONS FROM THERMAL FISSION OF ^{235}U

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May 2022

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Abstract
The energy spectra of delayed neutrons from neutron-induced fission of ^{235}U are estimated in the 8-group model using the Kalman filtering method. The spectra are available for viewing and downloading on the IAEA Reference database for beta-delayed neutrons.

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Contents

1. Introduction

The macroscopic section of the new IAEA beta-delayed neutron (bDN) reference database produced by an IAEA Coordinated Research Project (2013-2018) is continuously updated to provide up-to-date and reliable aggregate delayed neutron (DN) data for energy applications (Ref. [1]). The database contains high-resolution experimental DN spectra from thermal neutron-induced fission of ^{235}U that can be used to validate microscopic beta-delayed neutron data as well as group spectra obtained both experimentally and by the summation method. To date, however, there is no experimental information on DN group spectra in the IAEA database or in the evaluated data libraries. The existing group spectra in the evaluated libraries were obtained by summing the spectra of individual precursors without any consideration of the corresponding uncertainties.

The purpose of this work is to estimate the group energy spectra of DNs emitted in thermal neutron-induced fission of ^{235}U. We use the 8-group model (Ref. [2]) and the integral DN spectra measured with high energy resolution in different time intervals after the irradiation of a ^{235}U sample (Ref. [3]). These experimental data are already available in the IAEA bDN database (Ref. [4]). The 8-group spectra are estimated using the Kalman filter methodology (Ref. [5]). To carry out calculations using the Kalman filter method, the availability of information on the uncertainties of the initial data is a prerequisite.

The experimental integral DN energy spectra available in the IAEA database (Ref. [4]) do not have any associated uncertainties. Therefore, in the first stage of this work, we estimate the uncertainties of the integral DN spectra, and then use this data to derive the 8-group DN spectra and their uncertainties. The data obtained in this work are presented in numerical and graphical form. The estimated 8-group DN spectra are compared with appropriate 8-group spectra in the JEFF decay-data file. The next step in the development of the DN group spectra will be to estimate the spectra in the 6-group model.

2. Estimation of uncertainties of integral/composite delayed neutron spectra for ^{235}U

For the estimation of the uncertainties of the integral spectra the following sources of errors were considered:

1) statistical uncertainties ΔN_c;
2) neutron background uncertainties ΔN_b;
3) uncertainties of the spectrum of recoil nuclei ^{3}He - $\Delta N_{He\text{-}3}$ and recoil protons - ΔN_p, as well as the uncertainties of thermal peak ΔN_T;
4) uncertainties of the efficiency of the neutron spectrometer ΔN_{eff} and the attenuation function of the neutron flux in the lead filter ΔN_{Pb}.

In Fig. 1 we show an example of the instrumental integral DN spectrum measured in the time interval dt_c=0.12-152 s. The figure shows the spectrum of ^{3}He recoil nuclei and proton recoils, as well as the resulting instrumental DN spectrum after taking into account the contribution of the recoil effect of ^{3}He nuclei and recoil protons. In the calculations, it was assumed that the uncertainty in the spectrum of recoil nuclei is due to the error in the cross section for the elastic scattering of neutrons by ^{3}He nuclei.

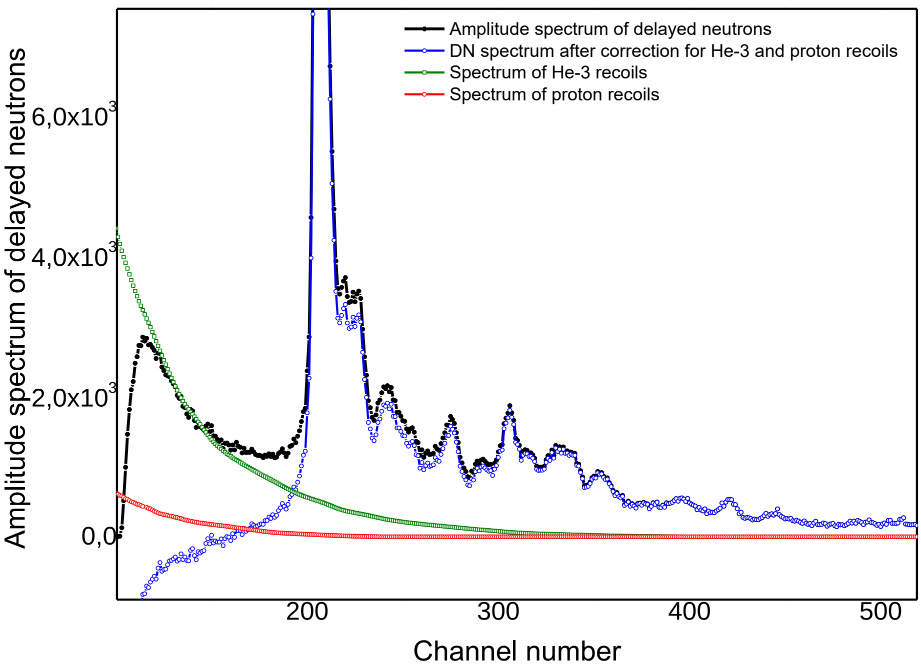

FIG. 1. The instrumental DN spectrum measured in the time interval dt_c=0.12-152 s and the procedure for taking into account the effect of recoil nuclei.

The thermal peak was approximated by a Gaussian distribution (see Fig. 2). The approximation errors were determined by the uncertainties in the distribution parameters estimated by the least squares method.

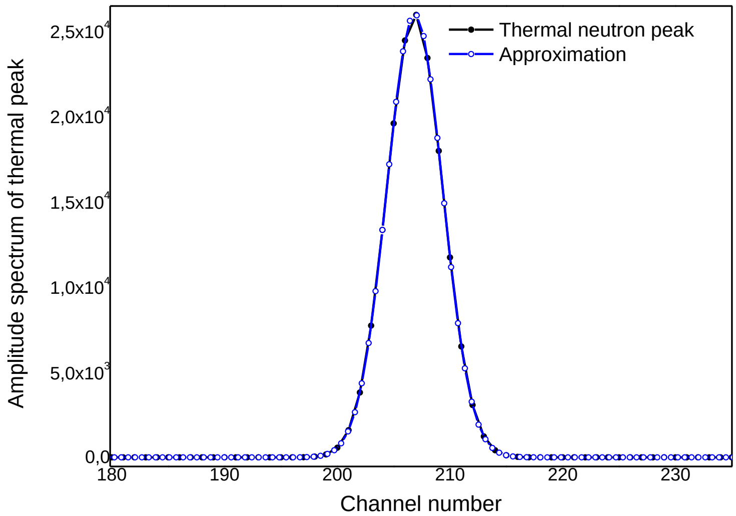

FIG. 2. The instrumental spectrum of the thermal peak and its approximation by a Gaussian.

The resulting instrumental DN spectrum, obtained as a result of taking into account the recoil nuclei and the thermal peak corrections, is shown in Fig. 3. The measurement uncertainties of the integral DN spectrum resulting from the corrections for the neutron background, the effect of recoil nuclei and subtraction of the thermal peak, were determined using the expression

$$\Delta N_{res} = \sqrt{(\Delta N_c)^2 + (\Delta N_b)^2 + (\Delta N_{He-3})^2 + (\Delta N_p)^2 + (\Delta N_T)^2} \ .$$

The DN amplitude spectrum with associated uncertainties ΔN_{res} obtained for the counting interval dt_c=0.12-152 s are shown in Fig. 3.

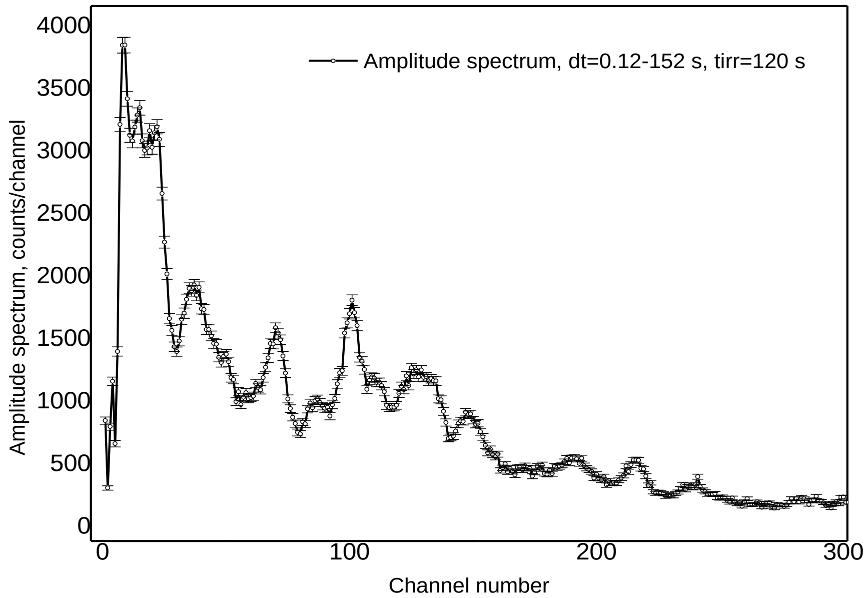

FIG. 3. Amplitude DN spectrum obtained after corrections for background, recoils and thermal peak.

The resulting spectrum was further processed by taking into account the efficiency of the spectrometer and the attenuation function of the neutron flux in the lead filter. The uncertainties in the DN spectrum due to errors in the efficiency of the neutron spectrometer $\Delta N_{eff}/ N_{eff}$ (4.7% over the whole energy range (Ref. [6])) and in the neutron attenuation function in a lead filter $\Delta N_{Pb}/N_{Pb}$ (1%) were obtained using the error propagation formula

$$\frac{\Delta N}{N} = \sqrt{\left(\frac{\Delta N_{res}}{N_{res}}\right)^2 + \left(\frac{\Delta N_{eff}}{N_{eff}}\right)^2 + \left(\frac{\Delta N_{Pb}}{N_{Pb}}\right)^2}$$

where $\Delta N_{res}/ N_{res}$ are the uncertainties due to statistics, subtraction of the background, ^{3}He and proton recoils, and the thermal peak (see Fig. 3).

The obtained DN spectrum and its uncertainties for 0.12-152 s counting time interval is presented in Fig. 4. The uncertainties are shown before and after inclusion of the uncertainties associated with the efficiency and transmission data.

The numerical data of the uncertainties of the DN spectra measured in different time intervals after two irradiation sessions of the ^{235}U sample of 20 and 120 s, respectively, are presented in Tables 2 and 3. In Table 2, the uncertainties of the integral DN spectra do not include uncertainties associated with efficiency and transmission data. In Table 3, the uncertainties of the integral DN spectra include uncertainties associated with efficiency and transmission data.

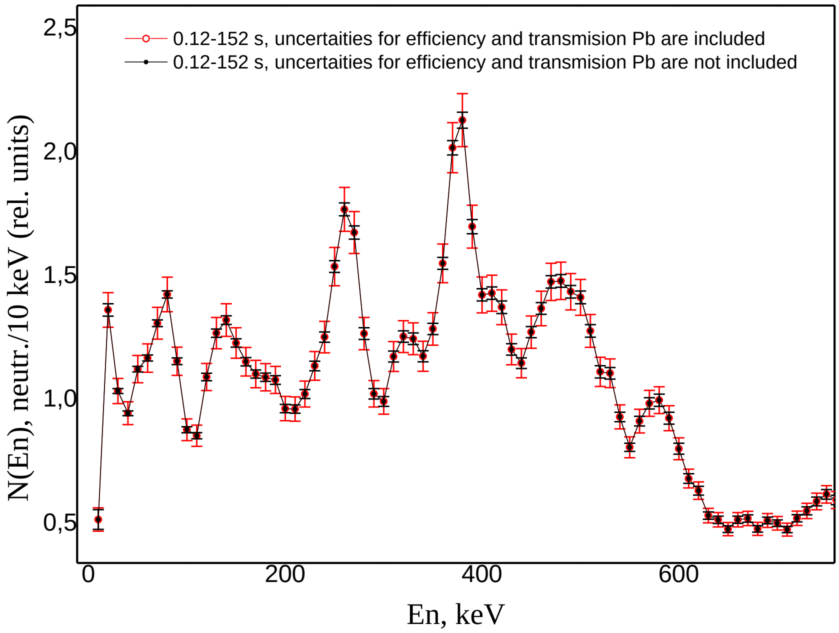

FIG. 4. Energy distribution of DN from fission of ^{235}U by thermal neutrons in the interval of 0.12-152 s after the end of the irradiation session with t_{irr} = 120 s.

TABLE 1. Composite DN spectra from thermal neutron-induced fission of ^{235}U measured in different time intervals dt_c (normalized to 100). Data with interval dt_c=0.12-1, 1-2, 2-3, 3-4, 4-44, 0.12-44 s correspond to irradiation interval t_{irr}=20 s. Data with intervals dt_c=0.12-2, 2-12, 12-22, 22-32, 32-152, 0.12-152 s correspond to irradiation interval t_{irr}=120 s.

E_n (keV)	N(t), 0.12-1 s	N(t), 1-2 s	N(t), 2-3 s	N(t), 3-4 s	N(t), 4-44 s	N(t), 0.12-2 s	N(t), 2-12 s	N(t), 12-22 s	N(t), 22-32 s	N(t), 32-152 s	N(t), 0.12-44 s	N(t), 0.12-152 s
10	0.246	0.357	0.262	0.485	0.610	0.471	0.312	0.344	0.402	0.889	0.655	0.514
20	0.599	0.741	0.624	0.979	1.420	0.803	0.965	1.148	1.256	2.042	1.167	1.362
30	0.799	0.911	0.885	0.997	1.085	0.908	0.920	0.976	1.006	1.291	1.075	1.034
40	0.816	0.944	0.969	0.972	1.038	0.905	0.929	0.982	0.948	1.041	1.022	0.944
50	0.839	0.974	0.970	0.952	1.086	0.899	0.968	1.084	1.114	1.446	1.046	1.122
60	0.902	1.032	1.061	0.953	1.135	0.961	1.024	1.126	1.131	1.501	1.098	1.167
70	0.932	1.080	1.169	1.059	1.308	1.044	1.227	1.372	1.368	1.496	1.244	1.308
80	0.963	1.101	1.191	1.196	1.528	1.098	1.376	1.502	1.486	1.595	1.358	1.424
90	0.979	1.124	1.178	1.239	1.330	1.081	1.220	1.184	1.294	1.153	1.273	1.154
100	1.032	1.180	1.184	1.192	1.068	1.044	1.004	0.951	0.901	0.806	1.106	0.877
110	1.085	1.270	1.232	1.152	0.998	1.092	0.962	0.859	0.798	0.820	1.060	0.853
120	1.132	1.350	1.276	1.184	1.193	1.186	1.161	1.122	1.153	1.114	1.184	1.090
130	1.197	1.329	1.297	1.247	1.335	1.215	1.247	1.270	1.313	1.412	1.297	1.268
140	1.221	1.276	1.266	1.291	1.343	1.208	1.279	1.325	1.261	1.555	1.304	1.321
150	1.219	1.244	1.230	1.293	1.276	1.206	1.162	1.179	1.092	1.479	1.259	1.228
160	1.277	1.262	1.300	1.284	1.225	1.225	1.163	1.208	1.171	1.240	1.210	1.152
170	1.311	1.258	1.322	1.215	1.126	1.251	1.157	1.099	0.963	1.151	1.162	1.102
180	1.219	1.167	1.216	1.247	1.119	1.217	1.129	0.998	0.998	1.249	1.140	1.089
190	1.130	1.126	1.172	1.266	1.069	1.160	1.084	0.970	0.940	1.220	1.090	1.078

E_n (keV)	N(t), 0.12-1 s	N(t), 1-2 s	N(t), 2-3 s	N(t), 3-4 s	N(t), 4-44 s	N(t), 0.12-2 s	N(t), 2-12 s	N(t), 12-22 s	N(t), 22-32 s	N(t), 32-152 s	N(t), 0.12-44 s	N(t), 0.12-152 s
200	1.174	1.109	1.206	1.194	1.031	1.170	1.011	0.909	0.883	1.043	1.052	0.963
210	1.200	1.160	1.261	1.241	1.045	1.203	1.032	0.983	0.851	0.979	1.081	0.961
220	1.223	1.265	1.317	1.268	1.146	1.214	1.083	1.023	0.942	1.075	1.152	1.022
230	1.379	1.288	1.385	1.324	1.207	1.247	1.202	1.156	1.067	1.184	1.216	1.135
240	1.514	1.343	1.480	1.352	1.316	1.367	1.224	1.299	1.202	1.393	1.301	1.252
250	1.471	1.421	1.535	1.410	1.518	1.438	1.436	1.492	1.541	1.796	1.459	1.537
260	1.396	1.421	1.502	1.545	1.728	1.528	1.689	1.790	1.714	2.107	1.611	1.768
270	1.377	1.331	1.402	1.563	1.703	1.539	1.619	1.730	1.601	1.905	1.616	1.674
280	1.338	1.215	1.367	1.460	1.423	1.359	1.315	1.255	1.203	1.264	1.395	1.266
290	1.338	1.244	1.419	1.321	1.106	1.212	1.122	1.046	0.976	0.993	1.171	1.023
300	1.352	1.335	1.488	1.275	1.053	1.191	1.145	1.015	0.958	0.859	1.136	0.992
310	1.330	1.370	1.438	1.367	1.241	1.300	1.301	1.149	1.040	1.140	1.246	1.173
320	1.377	1.372	1.355	1.555	1.310	1.401	1.366	1.341	1.289	1.186	1.326	1.254
330	1.470	1.373	1.373	1.513	1.365	1.374	1.280	1.297	1.308	1.200	1.336	1.245
340	1.462	1.411	1.441	1.400	1.265	1.357	1.315	1.244	1.169	1.036	1.293	1.174
350	1.451	1.477	1.604	1.423	1.277	1.486	1.428	1.420	1.264	1.133	1.303	1.285
360	1.556	1.568	1.753	1.568	1.480	1.586	1.616	1.701	1.529	1.482	1.482	1.550
370	1.601	1.560	1.778	1.767	1.885	1.647	2.001	2.209	2.265	2.025	1.793	2.017
380	1.528	1.436	1.657	1.754	2.180	1.621	2.072	2.345	2.376	2.151	1.955	2.129
390	1.469	1.372	1.490	1.601	1.860	1.536	1.723	1.754	1.848	1.712	1.783	1.698
400	1.404	1.333	1.419	1.441	1.624	1.386	1.455	1.490	1.535	1.425	1.558	1.422
410	1.355	1.247	1.326	1.369	1.494	1.277	1.454	1.453	1.592	1.398	1.450	1.429
420	1.286	1.198	1.223	1.341	1.436	1.289	1.427	1.473	1.407	1.340	1.392	1.372
430	1.162	1.167	1.172	1.340	1.369	1.234	1.209	1.347	1.318	1.157	1.310	1.202
440	1.095	1.134	1.183	1.294	1.166	1.171	1.156	1.209	1.081	1.184	1.206	1.146
450	1.113	1.181	1.244	1.209	1.241	1.155	1.315	1.340	1.134	1.308	1.206	1.272
460	1.187	1.268	1.306	1.225	1.328	1.225	1.399	1.461	1.399	1.435	1.306	1.367
470	1.217	1.308	1.359	1.262	1.490	1.272	1.422	1.562	1.610	1.527	1.415	1.475
480	1.174	1.346	1.320	1.302	1.485	1.284	1.396	1.714	1.585	1.493	1.421	1.479
490	1.210	1.286	1.260	1.334	1.397	1.327	1.477	1.513	1.506	1.419	1.392	1.435
500	1.258	1.107	1.134	1.417	1.455	1.262	1.397	1.443	1.615	1.429	1.373	1.412
510	1.247	1.030	1.003	1.360	1.313	1.135	1.267	1.353	1.398	1.230	1.247	1.277
520	1.171	1.028	1.021	1.097	1.018	1.028	1.190	1.180	1.080	1.040	1.037	1.111
530	1.071	0.989	1.043	1.052	0.949	1.024	1.191	1.175	1.058	1.034	1.008	1.105
540	0.977	0.934	0.962	1.005	0.917	0.960	1.030	0.987	0.883	0.855	0.972	0.929
550	0.920	0.965	0.914	0.829	0.823	0.920	0.879	0.843	0.824	0.731	0.857	0.806
560	0.935	0.981	0.977	0.866	0.904	0.965	0.928	0.999	0.944	0.847	0.888	0.912
570	0.934	0.974	0.980	0.884	1.008	0.978	1.020	1.139	0.912	0.955	0.972	0.984
580	0.945	0.982	0.914	0.876	1.006	0.913	1.005	1.083	1.051	1.027	0.981	0.997
590	0.985	0.954	0.911	0.903	0.930	0.833	0.933	1.068	1.042	0.884	0.927	0.924
600	0.975	0.898	0.915	0.890	0.895	0.858	0.850	0.874	0.862	0.716	0.863	0.800
610	0.922	0.846	0.913	0.884	0.719	0.806	0.798	0.746	0.725	0.570	0.782	0.680
620	0.844	0.820	0.834	0.784	0.705	0.742	0.700	0.646	0.574	0.558	0.718	0.631
630	0.781	0.808	0.726	0.632	0.609	0.789	0.654	0.574	0.439	0.391	0.657	0.530

E_n (keV)	N(t), 0.12-1 s	N(t), 1-2 s	N(t), 2-3 s	N(t), 3-4 s	N(t), 4-44 s	N(t), 0.12-2 s	N(t), 2-12 s	N(t), 12-22 s	N(t), 22-32 s	N(t), 32-152 s	N(t), 0.12-44 s	N(t), 0.12-152 s
640	0.743	0.808	0.714	0.579	0.594	0.724	0.645	0.476	0.496	0.391	0.608	0.513
650	0.712	0.771	0.726	0.621	0.559	0.644	0.605	0.520	0.392	0.366	0.586	0.475
660	0.712	0.690	0.717	0.613	0.518	0.680	0.621	0.502	0.416	0.469	0.568	0.513
670	0.733	0.666	0.697	0.635	0.560	0.669	0.641	0.555	0.484	0.406	0.578	0.518
680	0.703	0.680	0.594	0.694	0.568	0.646	0.581	0.473	0.434	0.403	0.590	0.476
690	0.676	0.690	0.563	0.633	0.573	0.631	0.590	0.521	0.530	0.447	0.580	0.510
700	0.697	0.659	0.659	0.547	0.560	0.598	0.636	0.473	0.474	0.414	0.557	0.499
710	0.692	0.614	0.647	0.524	0.503	0.569	0.574	0.453	0.524	0.379	0.534	0.473
720	0.655	0.567	0.644	0.562	0.519	0.598	0.613	0.554	0.511	0.458	0.542	0.519
730	0.620	0.557	0.693	0.612	0.560	0.620	0.596	0.584	0.512	0.525	0.563	0.549
740	0.603	0.597	0.665	0.600	0.606	0.586	0.611	0.674	0.624	0.518	0.592	0.587
750	0.597	0.579	0.640	0.600	0.655	0.586	0.620	0.655	0.702	0.583	0.626	0.616
760	0.572	0.541	0.598	0.643	0.632	0.594	0.641	0.613	0.619	0.551	0.622	0.593
770	0.569	0.531	0.543	0.599	0.594	0.575	0.557	0.570	0.578	0.496	0.586	0.526
780	0.557	0.531	0.581	0.569	0.574	0.529	0.488	0.459	0.553	0.432	0.546	0.469
790	0.526	0.520	0.605	0.520	0.473	0.456	0.479	0.455	0.492	0.355	0.493	0.441
800	0.512	0.472	0.559	0.428	0.431	0.402	0.429	0.445	0.373	0.346	0.445	0.410
810	0.481	0.481	0.502	0.376	0.407	0.421	0.409	0.433	0.427	0.332	0.422	0.394
820	0.439	0.501	0.451	0.396	0.418	0.462	0.451	0.344	0.476	0.352	0.422	0.397
830	0.423	0.449	0.422	0.388	0.406	0.424	0.435	0.466	0.500	0.449	0.422	0.460
840	0.390	0.422	0.417	0.350	0.442	0.393	0.466	0.612	0.736	0.529	0.431	0.541
850	0.386	0.446	0.452	0.364	0.518	0.464	0.580	0.697	0.788	0.607	0.479	0.617
860	0.415	0.443	0.438	0.371	0.574	0.456	0.553	0.550	0.713	0.560	0.504	0.568
870	0.419	0.419	0.392	0.376	0.455	0.382	0.440	0.443	0.467	0.422	0.453	0.438
880	0.393	0.375	0.343	0.395	0.383	0.380	0.345	0.359	0.294	0.317	0.374	0.343
890	0.411	0.337	0.339	0.367	0.302	0.383	0.319	0.327	0.304	0.256	0.314	0.308
900	0.421	0.363	0.383	0.319	0.287	0.383	0.300	0.342	0.249	0.239	0.293	0.283
910	0.355	0.395	0.345	0.390	0.280	0.393	0.286	0.272	0.242	0.255	0.303	0.279
920	0.307	0.400	0.320	0.416	0.296	0.385	0.356	0.248	0.308	0.258	0.313	0.317
930	0.309	0.405	0.370	0.357	0.318	0.358	0.375	0.351	0.355	0.350	0.328	0.368
940	0.350	0.406	0.390	0.366	0.358	0.341	0.341	0.478	0.391	0.326	0.350	0.381
950	0.351	0.395	0.355	0.321	0.374	0.339	0.377	0.442	0.435	0.422	0.371	0.421
960	0.305	0.364	0.316	0.280	0.384	0.358	0.358	0.399	0.432	0.334	0.364	0.369
970	0.289	0.322	0.332	0.297	0.334	0.364	0.313	0.356	0.349	0.281	0.325	0.313
980	0.296	0.305	0.322	0.277	0.277	0.319	0.312	0.328	0.326	0.235	0.289	0.305
990	0.310	0.306	0.295	0.258	0.271	0.298	0.290	0.263	0.273	0.221	0.256	0.271
1000	0.303	0.281	0.300	0.251	0.233	0.298	0.256	0.261	0.238	0.217	0.241	0.257
1010	0.306	0.271	0.306	0.286	0.248	0.282	0.217	0.284	0.271	0.202	0.244	0.243
1020	0.317	0.276	0.288	0.293	0.222	0.265	0.219	0.227	0.205	0.158	0.232	0.214
1030	0.307	0.276	0.270	0.235	0.177	0.248	0.198	0.244	0.238	0.191	0.203	0.221
1040	0.259	0.266	0.247	0.213	0.208	0.238	0.226	0.246	0.187	0.154	0.202	0.214
1050	0.224	0.244	0.208	0.213	0.202	0.206	0.207	0.238	0.203	0.199	0.212	0.222
1060	0.236	0.217	0.201	0.200	0.225	0.182	0.185	0.158	0.209	0.167	0.198	0.194
1070	0.218	0.199	0.234	0.216	0.164	0.192	0.222	0.188	0.192	0.162	0.171	0.216

E_n (keV)	N(t), 0.12-1 s	N(t), 1-2 s	N(t), 2-3 s	N(t), 3-4 s	N(t), 4-44 s	N(t), 0.12-2 s	N(t), 2-12 s	N(t), 12-22 s	N(t), 22-32 s	N(t), 32-152 s	N(t), 0.12-44 s	N(t), 0.12-152 s
1080	0.188	0.179	0.233	0.215	0.128	0.184	0.183	0.150	0.205	0.152	0.157	0.186
1090	0.203	0.184	0.212	0.168	0.159	0.193	0.185	0.207	0.200	0.144	0.163	0.203
1100	0.225	0.204	0.146	0.187	0.192	0.234	0.161	0.118	0.201	0.195	0.178	0.210
1110	0.220	0.200	0.136	0.206	0.188	0.196	0.240	0.110	0.211	0.254	0.195	0.263
1120	0.210	0.180	0.159	0.203	0.209	0.219	0.259	0.156	0.331	0.232	0.207	0.270
1130	0.218	0.189	0.082	0.226	0.257	0.280	0.248	0.112	0.297	0.227	0.226	0.270
1140	0.178	0.215	0.095	0.220	0.247	0.247	0.251	0.133	0.229	0.217	0.236	0.250
1150	0.208	0.239	0.200	0.203	0.238	0.203	0.248	0.120	0.254	0.253	0.229	0.284
1160	0.217	0.262	0.210	0.199	0.231	0.219	0.204	0.101	0.326	0.206	0.214	0.237
1170	0.133	0.229	0.152	0.181	0.169	0.220	0.188	0.120	0.177	0.162	0.184	0.202
1180	0.178	0.164	0.113	0.151	0.149	0.209	0.145	0.123	0.254	0.214	0.185	0.242
1190	0.208	0.226	0.120	0.136	0.119	0.214	0.171	0.122	0.250	0.237	0.165	0.296
1200	0.132	0.140	0.152	0.099	0.098	0.167	0.154	0.106	0.211	0.176	0.147	0.251
1210	0.103	0.161	0.115	0.069	0.085	0.242	0.147	0.083	0.119	0.187	0.122	0.287
1220	0.098	0.141	0.069	0.086	0.067	0.144	0.096	0.112	0.119	0.140	0.108	0.342
1230	0.199	0.130	0.092	0.084	0.070	0.093	0.096	0.051	0.085	0.145	0.087	0.233
1240	0.106	0.130	0.036	0.093	0.054	0.149	0.063	0.026	0.078	0.099	0.076	0.225
1250	0.167	0.088	0.049	0.064	0.065	0.150	0.062	0.034	0.114	0.072	0.067	0.208
1260	0.091	0.100	0.085	0.073	0.039	0.124	0.059	0.060	0.159	0.071	0.061	0.161
1270	0.066	0.091	0.058	0.042	0.037	0.101	0.046	0.028	0.059	0.065	0.055	0.134
1280	0.135	0.063	0.090	0.058	0.042	0.136	0.049	0.049	0.051	0.035	0.069	0.124
1290	0.217	0.094	0.055	0.040	0.030	0.036	0.060	0.053	0.022	0.094	0.062	0.113
1300	0.175	0.091	0.027	0.057	0.037	0.154	0.061	0.038	0.085	0.075	0.059	0.103
1310	0.084	0.076	0.090	0.012	0.049	0.057	0.046	0.016	0.029	0.056	0.067	0.090
1320	0.119	0.158	0.031	0.036	0.040	0.035	0.071	0.030	0.069	0.061	0.073	0.092
1330	0.096	0.066	0.078	0.039	0.037	0.129	0.043	0.039	0.026	0.060	0.084	0.106
1340	0.114	0.052	0.074	0.064	0.047	0.102	0.052	0.054	0.017	0.046	0.090	0.089
1350	0.115	0.070	0.078	0.041	0.048	0.127	0.056	0.050	0.139	0.035	0.093	0.087
1360	0.098	0.142	0.105	0.016	0.057	0.067	0.031	0.041	0.042	0.043	0.086	0.096
1370	0.173	0.133	0.072	0.042	0.043	0.068	0.039	0.042	0.061	0.083	0.092	0.095
1380	0.102	0.069	0.061	0.059	0.046	0.148	0.044	0.024	0.048	0.068	0.097	0.105
1390	0.141	0.031	0.051	0.067	0.047	0.198	0.060	0.025	0.119	0.085	0.102	0.103
1400	0.140	0.047	0.035	0.054	0.030	0.228	0.064	0.032	0.101	0.069	0.105	0.109
1410	0.141	0.117	0.030	0.088	0.030	0.180	0.061	0.033	0.040	0.087	0.109	0.119
1420	0.177	0.141	0.018	0.061	0.034	0.067	0.060	0.017	0.070	0.053	0.113	0.088
1430	0.165	0.124	0.032	0.104	0.036	0.098	0.065	0.055	0.131	0.101	0.098	0.091
1440	0.170	0.153	0.044	0.068	0.043	0.103	0.069	0.057	0.109	0.116	0.086	0.084
1450	0.132	0.149	0.045	0.092	0.065	0.105	0.064	0.057	0.061	0.080	0.085	0.091
1460	0.121	0.139	0.043	0.090	0.065	0.102	0.065	0.077	0.079	0.098	0.083	0.077
1470	0.121	0.140	0.043	0.091	0.065	0.102	0.065	0.073	0.075	0.092	0.080	0.097
1480	0.104	0.120	0.035	0.079	0.055	0.083	0.059	0.072	0.073	0.090	0.087	0.089
1490	0.082	0.095	0.026	0.063	0.042	0.062	0.052	0.065	0.065	0.079	0.089	0.078
1500	0.069	0.080	0.020	0.054	0.034	0.083	0.069	0.067	0.067	0.081	0.074	0.062
1510	0.064	0.075	0.018	0.051	0.032	0.116	0.095	0.096	0.103	0.129	0.058	0.043

E_n (keV)	N(t), 0.12-1 s	N(t), 1-2 s	N(t), 2-3 s	N(t), 3-4 s	N(t), 4-44 s	N(t), 0.12-2 s	N(t), 2-12 s	N(t), 12-22 s	N(t), 22-32 s	N(t), 32-152 s	N(t), 0.12-44 s	N(t), 0.12-152 s
1520	0.057	0.067	0.015	0.046	0.028	0.102	0.084	0.098	0.105	0.131	0.038	0.039
1530	0.054	0.063	0.013	0.043	0.026	0.094	0.078	0.092	0.097	0.121	0.026	0.026
1540	0.047	0.055	0.010	0.039	0.022	0.079	0.066	0.081	0.085	0.105	0.016	0.021
1550	0.043	0.050	0.008	0.045	0.019	0.070	0.059	0.070	0.070	0.086	0.009	0.039
1560	0.046	0.054	0.010	0.049	0.021	0.076	0.064	0.069	0.069	0.085	0.020	0.043
1570	0.052	0.061	0.012	0.055	0.025	0.090	0.075	0.081	0.083	0.103	0.028	0.022
1580	0.044	0.052	0.009	0.048	0.020	0.072	0.060	0.079	0.081	0.100	0.014	0.019
1590	0.040	0.048	0.007	0.045	0.018	0.065	0.055	0.064	0.062	0.076	0.005	0.033
1600	0.045	0.053	0.009	0.048	0.020	0.074	0.062	0.067	0.067	0.081	0.012	0.025

TABLE 2. The uncertainties of the integral DN spectra from thermal neutron-induced fission of ^{235}U, measured in different time intervals dt_c. Uncertainties associated with efficiency and transmission data are not included.

E_n (keV)	ΔN(t), % 0.12-1s	ΔN(t), % 1-2 s	ΔN(t), % 2-3 s	ΔN(t), % 3-4 s	ΔN(t), % 4-44 s	ΔN(t), % 0.12-2s	ΔN(t), % 2-12 s	ΔN(t), % 12-22 s	ΔN(t), % 22-32 s	ΔN(t), % 32-152s	ΔN(t), % 0.12-44 s	ΔN(t), % 0.12-152 s
10	26.04	24.44	17.92	16.86	6.67	15.44	6.86	10.86	14.98	5.67	13.36	7.76
20	8.09	8.69	6.85	7.89	2.64	4.92	2.59	4.31	5.54	2.21	2.58	1.82
30	4.66	4.46	4.43	4.96	1.64	3.11	1.76	2.71	3.38	1.55	1.29	0.96
40	3.96	3.57	3.94	4.29	1.34	2.89	1.67	2.36	2.91	1.53	1.08	1.01
50	4.19	3.69	4.07	4.53	1.31	3.14	1.77	2.42	2.91	1.54	1.13	1.01
60	4.44	3.87	4.33	4.78	1.34	3.25	1.82	2.45	2.96	1.53	1.19	1.04
70	4.43	3.97	4.43	4.85	1.33	3.27	1.80	2.42	2.94	1.59	1.18	1.04
80	4.52	4.08	4.40	4.75	1.31	3.33	1.78	2.43	2.93	1.65	1.14	1.03
90	4.68	4.21	4.53	4.82	1.39	3.46	1.89	2.66	3.16	1.88	1.23	1.15
100	4.81	4.28	4.75	5.09	1.58	3.67	2.12	3.06	3.71	2.27	1.37	1.36
110	4.83	4.39	4.85	5.41	1.71	3.76	2.28	3.32	4.10	2.43	1.48	1.48
120	4.91	4.42	4.95	5.53	1.68	3.76	2.24	3.23	3.91	2.27	1.44	1.38
130	4.98	4.41	5.07	5.55	1.64	3.82	2.21	3.11	3.73	2.11	1.41	1.32
140	4.92	4.54	5.15	5.57	1.67	3.93	2.25	3.14	3.86	2.05	1.44	1.32
150	4.98	4.74	5.24	5.67	1.73	4.01	2.34	3.27	4.07	2.13	1.49	1.39
160	5.16	4.85	5.43	5.80	1.80	4.04	2.41	3.35	4.19	2.30	1.55	1.46
170	5.19	4.96	5.37	6.06	1.88	4.08	2.46	3.56	4.45	2.42	1.61	1.52
180	5.18	5.13	5.43	6.12	1.96	4.23	2.54	3.78	4.62	2.43	1.67	1.56
190	5.40	5.40	5.78	6.29	2.04	4.43	2.65	3.94	4.79	2.53	1.75	1.61
200	5.72	5.59	6.12	6.57	2.12	4.52	2.79	4.09	5.08	2.74	1.81	1.74
210	5.70	5.71	6.27	6.61	2.13	4.57	2.84	4.08	5.18	2.85	1.83	1.77
220	5.82	5.63	6.28	6.71	2.11	4.67	2.83	4.05	5.09	2.83	1.81	1.77
230	5.92	5.64	6.28	6.74	2.10	4.69	2.82	3.96	4.98	2.75	1.82	1.72
240	5.77	5.79	6.31	6.84	2.04	4.60	2.76	3.83	4.73	2.57	1.79	1.66
250	5.76	5.78	6.33	6.68	1.95	4.60	2.63	3.63	4.41	2.37	1.71	1.54
260	5.99	5.61	6.24	6.58	1.92	4.53	2.56	3.53	4.36	2.31	1.67	1.49
270	6.12	5.70	6.28	6.77	2.01	4.68	2.70	3.75	4.64	2.53	1.73	1.60
280	6.18	6.03	6.55	7.14	2.24	5.04	2.98	4.24	5.24	3.01	1.95	1.87

E_n (keV)	ΔN(t), % 0.12-1s	ΔN(t), % 1-2 s	ΔN(t), % 2-3 s	ΔN(t), % 3-4 s	ΔN(t), % 4-44 s	ΔN(t), % 0.12-2s	ΔN(t), % 2-12 s	ΔN(t), % 12-22 s	ΔN(t), % 22-32 s	ΔN(t), % 32-152s	ΔN(t), % 0.12-44 s	ΔN(t), % 0.12-152 s
290	6.31	6.19	6.70	7.48	2.43	5.30	3.14	4.61	5.70	3.38	2.08	2.04
300	6.31	6.08	6.65	7.47	2.39	5.31	3.09	4.59	5.73	3.36	2.03	2.00
310	6.34	6.04	6.61	7.04	2.29	5.07	2.98	4.36	5.40	3.15	1.95	1.87
320	6.31	6.19	6.66	6.96	2.24	5.00	2.99	4.20	5.19	3.10	1.92	1.84
330	6.18	6.14	6.66	7.19	2.27	5.11	3.01	4.26	5.22	3.18	1.95	1.88
340	6.12	6.09	6.64	7.25	2.29	5.00	2.95	4.21	5.27	3.24	1.97	1.91
350	6.14	6.08	6.47	7.04	2.18	4.80	2.80	3.92	4.97	2.99	1.92	1.76
360	6.13	5.84	6.23	6.59	1.96	4.69	2.59	3.53	4.32	2.59	1.71	1.57
370	5.95	5.71	6.06	6.43	1.82	4.63	2.45	3.29	3.95	2.39	1.59	1.44
380	5.96	5.91	6.01	6.71	1.86	4.71	2.53	3.45	4.14	2.48	1.64	1.52
390	6.02	6.13	6.39	7.09	2.01	4.92	2.75	3.86	4.55	2.74	1.78	1.69
400	6.17	6.12	6.62	7.31	2.10	5.15	2.85	4.02	4.70	2.87	1.84	1.74
410	6.41	6.27	6.80	7.36	2.14	5.19	2.88	4.01	4.83	2.90	1.88	1.75
420	6.62	6.35	7.00	7.38	2.21	5.25	3.01	4.10	5.04	3.05	1.92	1.83
430	6.81	6.37	7.10	7.47	2.32	5.37	3.13	4.32	5.38	3.11	2.02	1.93
440	6.84	6.53	7.34	7.76	2.32	5.47	3.05	4.28	5.46	3.01	2.03	1.88
450	6.87	6.36	7.07	7.74	2.23	5.37	2.93	4.06	5.10	2.87	1.96	1.77
460	6.68	6.10	6.86	7.64	2.14	5.25	2.90	3.93	4.76	2.78	1.87	1.73
470	6.57	6.10	6.83	7.53	2.14	5.24	2.90	3.84	4.70	2.79	1.86	1.71
480	6.75	6.05	6.95	7.46	2.18	5.15	2.88	3.90	4.77	2.84	1.91	1.73
490	6.76	6.34	7.25	7.25	2.19	5.25	2.91	4.07	4.77	2.88	1.89	1.76
500	6.73	6.69	7.65	7.42	2.29	5.52	3.05	4.23	4.97	3.05	2.01	1.82
510	6.83	6.77	7.78	8.23	2.52	5.82	3.26	4.59	5.66	3.39	2.19	2.01
520	7.11	7.23	8.05	9.09	2.69	5.97	3.46	5.00	6.15	3.69	2.37	2.24
530	7.52	7.08	8.09	8.85	2.61	5.87	3.46	4.78	5.98	3.60	2.27	2.12
540	7.48	6.89	7.66	8.85	2.51	5.82	3.34	4.54	5.88	3.38	2.15	2.04
550	7.42	7.01	7.91	8.90	2.54	6.04	3.37	4.55	5.67	3.32	2.20	2.03
560	7.39	7.16	8.17	8.78	2.63	6.29	3.50	4.74	5.79	3.56	2.28	2.12
570	7.30	7.36	7.99	8.87	2.80	6.26	3.65	5.19	6.28	3.96	2.41	2.32
580	7.49	7.42	8.07	9.20	2.97	6.51	3.84	5.61	6.97	4.26	2.50	2.47
590	7.85	7.62	8.51	10.23	3.10	6.59	4.02	6.01	7.72	4.62	2.65	2.61
600	8.19	7.89	9.21	10.88	3.22	6.60	4.12	6.44	8.16	5.04	2.74	2.77
610	8.53	7.80	9.16	10.57	3.33	7.06	4.23	6.53	8.53	5.06	2.78	2.85
620	8.86	8.04	9.19	10.63	3.38	7.02	4.23	6.52	8.66	4.90	2.85	2.83
630	8.97	8.54	9.15	10.34	3.32	7.02	4.21	6.46	8.31	4.88	2.80	2.79
640	8.90	8.44	9.35	10.13	3.29	7.14	4.30	6.65	8.32	4.93	2.81	2.89
650	8.96	8.36	9.92	10.86	3.31	7.25	4.29	6.71	8.08	4.85	2.84	2.81
660	8.71	8.60	9.98	11.56	3.41	7.49	4.29	6.76	7.97	4.99	2.93	2.87
670	8.63	8.66	9.98	11.25	3.44	7.57	4.33	6.70	7.99	4.98	2.94	2.88
680	9.12	9.05	9.99	10.80	3.36	7.40	4.32	6.36	7.99	4.65	2.88	2.77
690	9.61	9.48	9.36	10.80	3.26	7.42	4.30	6.06	7.57	4.50	2.82	2.66
700	9.55	9.07	9.59	10.82	3.15	7.59	4.29	5.88	7.18	4.40	2.72	2.63
710	9.70	9.25	9.81	10.60	3.18	7.52	4.29	6.03	7.21	4.37	2.77	2.64

E_n (keV)	$\Delta N(t)$, % 0.12-1s	$\Delta N(t)$, % 1-2 s	$\Delta N(t)$, % 2-3 s	$\Delta N(t)$, % 3-4 s	$\Delta N(t)$, % 4-44 s	$\Delta N(t)$, % 0.12-2s	$\Delta N(t)$, % 2-12 s	$\Delta N(t)$, % 12-22 s	$\Delta N(t)$, % 22-32 s	$\Delta N(t)$, % 32-152s	$\Delta N(t)$, % 0.12-44 s	$\Delta N(t)$, % 0.12-152 s
720	10.00	9.63	10.05	11.08	3.27	7.61	4.42	6.35	7.52	4.55	2.87	2.74
730	9.99	9.94	10.49	11.26	3.43	7.96	4.72	6.77	7.88	4.90	2.96	2.94
740	10.33	9.89	10.18	12.01	3.68	8.54	4.90	7.14	8.34	5.23	3.15	3.07
750	10.53	9.97	10.44	13.40	3.85	9.09	5.09	7.21	8.89	5.45	3.31	3.18
760	10.47	10.21	11.11	13.58	3.89	8.86	5.15	7.43	8.82	5.49	3.34	3.24
770	10.98	9.84	11.55	13.22	3.89	8.62	5.09	7.51	8.49	5.18	3.33	3.19
780	11.55	10.63	12.18	14.12	3.80	9.14	5.04	6.72	7.54	4.75	3.35	2.91
790	12.12	11.05	12.49	14.12	3.57	8.97	4.73	6.11	6.90	4.43	3.20	2.74
800	12.31	10.57	12.15	14.04	3.49	8.55	4.58	6.26	6.98	4.43	3.04	2.69
810	12.40	10.85	12.61	13.77	3.76	9.23	4.95	7.03	8.01	4.83	3.34	2.98
820	12.38	11.19	13.54	13.61	4.20	9.58	5.58	7.80	9.81	5.54	3.65	3.44
830	12.33	11.94	13.94	14.46	4.58	9.46	5.97	8.25	10.76	6.13	3.99	3.70
840	11.92	11.95	13.45	14.41	4.68	9.49	6.06	8.51	11.03	6.33	3.95	3.83
850	12.54	11.48	13.78	13.35	4.64	9.42	6.04	9.03	11.31	6.37	3.91	3.87
860	13.72	11.58	13.80	14.03	4.51	9.60	5.79	8.96	10.43	5.97	3.86	3.62
870	14.00	11.75	13.20	14.31	4.34	9.98	5.73	7.88	9.73	5.66	3.73	3.43
880	12.78	11.95	12.87	15.00	4.19	10.20	5.73	7.39	9.35	5.50	3.65	3.39
890	12.90	12.15	13.15	16.09	4.21	10.09	5.71	7.60	9.10	5.44	3.67	3.26
900	14.17	12.40	13.82	16.06	4.48	9.76	5.98	8.01	9.64	5.93	3.85	3.67
910	14.24	13.13	14.62	16.58	4.78	10.41	6.17	8.49	10.33	6.39	4.19	3.78
920	13.98	13.42	16.06	17.17	5.00	10.84	6.32	9.09	10.98	6.68	4.37	3.98
930	14.47	13.67	16.45	16.33	5.13	10.86	6.68	9.42	11.71	6.83	4.47	4.09
940	14.62	14.07	15.37	16.08	5.18	11.26	7.15	9.39	11.67	7.08	4.35	4.24
950	14.26	14.34	15.52	17.05	5.53	11.54	7.35	9.80	12.31	7.40	4.67	4.52
960	14.27	14.92	16.05	18.18	5.60	11.83	7.26	9.93	12.34	7.40	4.87	4.33
970	15.81	14.88	17.05	18.92	5.45	12.24	7.25	9.85	12.73	7.34	4.70	4.60
980	17.69	15.26	19.09	19.15	5.54	13.33	7.56	10.69	12.93	7.32	4.72	4.50
990	17.59	16.35	18.61	18.78	6.01	13.36	7.49	11.23	12.82	7.59	5.18	4.61
1000	17.34	16.90	16.61	18.62	6.31	13.26	7.61	11.23	13.14	7.73	5.36	4.78
1010	16.47	16.47	17.90	21.12	6.01	13.49	7.84	11.18	13.06	7.77	5.28	4.62
1020	16.24	16.02	19.81	19.69	5.78	12.61	7.93	10.06	12.84	7.29	4.97	4.67
1030	16.70	16.70	17.15	19.21	5.63	12.59	7.28	9.72	12.58	6.78	4.85	4.23
1040	16.66	16.85	18.31	18.93	5.34	12.97	6.92	10.07	11.16	6.78	4.78	4.15
1050	16.72	16.54	17.92	19.76	5.75	13.68	6.94	10.24	12.80	7.09	4.85	4.74
1060	16.26	17.52	18.21	20.41	5.45	14.52	7.34	12.56	12.64	7.74	5.02	5.07
1070	16.93	18.28	16.88	19.64	6.37	14.16	6.71	11.53	13.18	7.85	5.41	4.81
1080	18.25	19.32	16.93	19.67	7.22	14.48	7.39	12.92	12.77	8.10	5.64	5.18
1090	17.53	19.02	17.72	22.30	6.48	14.13	7.35	10.98	12.91	8.33	5.53	4.96
1100	16.67	18.07	21.34	21.12	5.90	12.81	7.88	14.54	12.87	7.16	5.31	4.87
1110	16.85	18.26	22.11	20.11	5.95	14.00	6.46	15.10	12.56	6.27	5.06	4.36
1120	17.26	19.24	20.50	20.28	5.64	13.24	6.21	12.65	10.04	6.56	4.91	4.30
1130	16.92	18.78	28.54	19.19	5.10	11.71	6.35	14.93	10.59	6.64	4.71	4.30
1140	18.75	17.62	26.50	19.47	5.19	12.48	6.32	13.71	12.06	6.79	4.60	4.47

E_n (keV)	ΔN(t), % 0.12-1s	ΔN(t), % 1-2 s	ΔN(t), % 2-3 s	ΔN(t), % 3-4 s	ΔN(t), % 4-44 s	ΔN(t), % 0.12-2s	ΔN(t), % 2-12 s	ΔN(t), % 12-22 s	ΔN(t), % 22-32 s	ΔN(t), % 32-152s	ΔN(t), % 0.12-44 s	ΔN(t), % 0.12-152 s
1150	17.36	16.71	18.27	20.28	5.29	13.76	6.35	14.41	11.45	6.29	4.68	4.20
1160	16.98	15.96	17.80	20.44	5.37	13.25	7.00	15.77	10.11	6.97	4.83	4.59
1170	21.66	17.07	20.92	21.48	6.29	13.21	7.30	14.42	13.73	7.86	5.22	4.97
1180	18.76	20.18	24.31	23.51	6.70	13.56	8.31	14.27	11.45	6.83	5.20	4.54
1190	17.33	17.16	23.57	24.75	7.50	13.40	7.64	14.31	11.54	6.49	5.51	4.11
1200	21.78	21.84	20.91	28.95	8.26	15.19	8.06	15.37	12.55	7.54	5.83	4.46
1210	24.60	20.38	24.06	34.80	8.87	12.61	8.23	17.32	16.71	7.32	6.39	4.17
1220	25.23	21.72	31.04	31.17	9.97	16.37	10.20	14.91	16.71	8.45	6.80	3.82
1230	17.70	22.62	26.98	31.47	9.72	20.34	10.18	22.14	19.83	8.30	7.59	4.63
1240	24.27	22.68	42.95	29.98	11.16	16.09	12.59	31.11	20.68	10.05	8.10	4.71
1250	19.35	27.55	36.75	36.08	10.15	16.04	12.71	27.30	17.12	11.78	8.66	4.90
1260	26.27	25.86	28.01	33.89	13.05	17.62	13.01	20.50	14.47	11.89	9.08	5.57
1270	30.68	27.05	33.94	44.74	13.34	19.48	14.77	29.84	23.76	12.41	9.50	6.12
1280	21.53	32.62	27.15	37.90	12.60	16.83	14.24	22.64	25.68	16.91	8.53	6.36
1290	16.96	26.61	34.68	45.50	14.90	32.53	12.88	21.81	39.24	10.30	8.96	6.66
1300	18.91	27.14	50.06	38.11	13.43	15.83	12.86	25.66	19.80	11.54	9.19	6.97
1310	27.28	29.53	27.16	84.50	11.69	25.96	14.68	39.11	33.72	13.35	8.66	7.47
1320	22.92	20.56	46.48	48.07	12.90	33.36	11.86	29.05	22.05	12.85	8.25	7.37
1330	25.47	31.87	29.25	46.25	13.40	17.25	15.18	25.28	35.81	12.88	7.73	6.88
1340	23.37	35.85	30.05	36.14	11.93	19.43	13.85	21.49	43.81	14.73	7.43	7.50
1350	23.33	30.85	29.21	44.86	11.75	17.43	13.40	22.36	15.47	16.96	7.35	7.59
1360	25.30	21.63	25.25	72.52	10.87	23.98	18.08	24.58	28.20	15.24	7.61	7.21
1370	19.03	22.38	30.51	44.43	12.47	23.73	16.06	24.40	23.40	10.99	7.36	7.26
1380	24.73	31.03	33.12	37.50	12.11	16.14	15.02	32.57	26.45	12.15	7.19	6.91
1390	21.06	46.44	36.29	35.34	11.97	13.95	12.88	31.35	16.70	10.85	7.01	6.97
1400	21.14	37.50	43.64	39.35	15.02	12.99	12.54	27.77	18.15	12.03	6.89	6.78
1410	21.08	23.89	46.94	30.85	14.93	14.63	12.79	27.46	28.96	10.72	6.76	6.49
1420	18.78	21.72	61.60	36.83	14.06	23.89	12.90	38.19	21.79	13.80	6.64	7.55
1430	19.44	23.23	45.72	28.30	13.54	19.85	12.42	21.42	15.98	9.93	7.15	7.41
1440	19.19	20.85	38.74	35.11	12.48	19.36	12.06	20.99	17.45	9.30	7.64	7.71
1450	21.75	21.18	38.56	30.08	10.15	19.17	12.48	20.96	23.39	11.17	7.68	7.43
1460	22.77	21.92	39.57	30.35	10.16	19.44	12.42	18.06	20.52	10.11	7.76	8.09
1470	22.69	21.85	39.43	30.25	10.12	19.39	12.39	18.46	21.08	10.41	7.91	7.18
1480	24.54	23.60	43.54	32.57	11.03	21.55	12.97	18.68	21.38	10.57	7.60	7.51
1490	27.58	26.46	50.87	36.29	12.58	24.99	13.85	19.60	22.69	11.25	7.50	8.00
1500	30.19	28.89	57.93	39.40	13.93	21.51	12.03	19.37	22.39	11.10	8.20	8.98
1510	31.23	29.86	61.13	40.60	14.52	18.20	10.26	16.11	17.98	8.81	9.31	10.73
1520	33.01	31.49	66.98	42.65	15.50	19.44	10.93	15.97	17.81	8.73	11.44	11.35
1530	34.03	32.44	70.74	43.79	16.10	20.19	11.34	16.53	18.54	9.10	13.77	13.88
1540	36.51	34.71	80.80	46.22	17.55	22.05	12.32	17.51	19.86	9.78	17.83	15.45
1550	38.33	36.37	89.73	42.91	18.71	23.50	13.06	18.92	21.81	10.81	23.56	11.29
1560	37.06	35.18	83.70	41.25	17.95	22.48	12.53	19.00	21.93	10.87	15.88	10.81
1570	34.61	32.96	73.56	39.04	16.48	20.67	11.57	17.58	19.98	9.84	13.37	15.14

E_n (keV)	ΔN(t), % 0.12-1s	ΔN(t), % 1-2 s	ΔN(t), % 2-3 s	ΔN(t), % 3-4 s	ΔN(t), % 4-44 s	ΔN(t), % 0.12-2s	ΔN(t), % 2-12 s	ΔN(t), % 12-22 s	ΔN(t), % 22-32 s	ΔN(t), % 32-152s	ΔN(t), % 0.12-44 s	ΔN(t), % 0.12-152 s
1580	37.75	35.82	87.76	41.83	18.39	23.18	12.89	17.81	20.31	10.02	18.79	16.27
1590	39.29	37.22	96.50	43.10	19.38	24.35	13.49	19.76	23.10	11.49	33.19	12.40
1600	37.46	35.55	86.78	41.52	18.23	22.86	12.72	19.25	22.36	11.10	20.15	14.22

TABLE 3. The uncertainties of the integral DN spectra from thermal neutron-induced fission of ^{235}U, measured in different time intervals dt_c. Uncertainties associated with efficiency and transmission data are included.

E_n (keV)	ΔN(t), % 0.12-1s	ΔN(t), % 1-2 s	ΔN(t), % 2-3 s	ΔN(t), % 3-4 s	ΔN(t), % 4-44 s	ΔN(t), % 0.12-2s	ΔN(t), % 2-12 s	ΔN(t), % 12-22 s	ΔN(t), % 22-32 s	ΔN(t), % 32-152s	ΔN(t), % 0.12-44 s	ΔN(t), % 0.12-152 s
10	26.49	24.91	18.55	17.53	8.22	16.18	8.38	11.88	15.73	7.43	14.20	9.13
20	9.41	9.93	8.36	9.24	5.48	6.88	5.46	6.45	7.33	5.29	5.46	5.14
30	6.69	6.56	6.54	6.90	5.08	5.72	5.12	5.52	5.88	5.05	4.98	4.90
40	6.23	5.98	6.22	6.44	4.99	5.61	5.09	5.36	5.62	5.04	4.93	4.91
50	6.38	6.06	6.30	6.60	4.98	5.74	5.12	5.38	5.62	5.05	4.94	4.91
60	6.54	6.17	6.47	6.78	4.99	5.80	5.14	5.40	5.64	5.04	4.95	4.92
70	6.54	6.23	6.54	6.83	4.98	5.81	5.13	5.38	5.64	5.06	4.95	4.92
80	6.60	6.31	6.52	6.76	4.98	5.85	5.12	5.38	5.63	5.08	4.94	4.92
90	6.70	6.39	6.61	6.80	5.00	5.92	5.16	5.49	5.75	5.16	4.96	4.94
100	6.80	6.44	6.76	7.00	5.06	6.05	5.25	5.70	6.07	5.31	5.00	5.00
110	6.81	6.51	6.83	7.24	5.10	6.10	5.32	5.84	6.32	5.39	5.03	5.03
120	6.87	6.53	6.90	7.33	5.09	6.10	5.30	5.79	6.20	5.31	5.02	5.00
130	6.92	6.52	6.99	7.34	5.08	6.14	5.29	5.73	6.08	5.25	5.01	4.98
140	6.88	6.61	7.04	7.36	5.09	6.21	5.31	5.74	6.16	5.22	5.02	4.98
150	6.92	6.75	7.11	7.43	5.11	6.26	5.35	5.81	6.30	5.25	5.03	5.00
160	7.05	6.82	7.25	7.53	5.13	6.28	5.38	5.86	6.37	5.33	5.05	5.02
170	7.07	6.91	7.21	7.74	5.16	6.31	5.40	5.98	6.55	5.38	5.07	5.04
180	7.06	7.03	7.25	7.78	5.19	6.40	5.44	6.11	6.67	5.39	5.09	5.05
190	7.23	7.23	7.51	7.91	5.22	6.54	5.49	6.21	6.78	5.43	5.11	5.07
200	7.47	7.37	7.78	8.14	5.25	6.59	5.56	6.31	7.00	5.53	5.14	5.11
210	7.45	7.46	7.90	8.17	5.26	6.63	5.58	6.31	7.07	5.59	5.14	5.12
220	7.55	7.40	7.90	8.25	5.25	6.70	5.58	6.28	7.00	5.58	5.13	5.12
230	7.62	7.41	7.91	8.27	5.24	6.71	5.57	6.23	6.92	5.54	5.14	5.10
240	7.51	7.53	7.93	8.36	5.22	6.65	5.54	6.15	6.74	5.45	5.13	5.09
250	7.50	7.52	7.95	8.23	5.19	6.65	5.48	6.02	6.52	5.36	5.10	5.05
260	7.68	7.39	7.88	8.15	5.17	6.60	5.44	5.96	6.49	5.33	5.09	5.03
270	7.78	7.45	7.91	8.31	5.21	6.71	5.51	6.09	6.68	5.43	5.11	5.06
280	7.83	7.71	8.12	8.60	5.30	6.97	5.65	6.41	7.11	5.67	5.19	5.16
290	7.93	7.84	8.25	8.89	5.38	7.15	5.74	6.66	7.46	5.87	5.24	5.22
300	7.93	7.75	8.21	8.88	5.37	7.16	5.71	6.64	7.48	5.86	5.22	5.21
310	7.95	7.72	8.17	8.52	5.32	6.98	5.65	6.49	7.23	5.75	5.19	5.16
320	7.93	7.84	8.21	8.45	5.30	6.93	5.66	6.38	7.07	5.72	5.17	5.14
330	7.83	7.80	8.21	8.65	5.31	7.02	5.67	6.42	7.10	5.76	5.18	5.16
340	7.78	7.76	8.20	8.70	5.32	6.93	5.64	6.39	7.13	5.80	5.19	5.17

E_n (keV)	ΔN(t), % 0.12-1s	ΔN(t), % 1-2 s	ΔN(t), % 2-3 s	ΔN(t), % 3-4 s	ΔN(t), % 4-44 s	ΔN(t), % 0.12-2s	ΔN(t), % 2-12 s	ΔN(t), % 12-22 s	ΔN(t), % 22-32 s	ΔN(t), % 32-152s	ΔN(t), % 0.12-44 s	ΔN(t), % 0.12-152 s
350	7.79	7.75	8.06	8.52	5.28	6.79	5.56	6.20	6.91	5.66	5.17	5.12
360	7.79	7.56	7.87	8.15	5.19	6.72	5.46	5.96	6.46	5.46	5.10	5.06
370	7.64	7.46	7.74	8.03	5.14	6.68	5.39	5.83	6.22	5.37	5.06	5.02
380	7.65	7.62	7.69	8.25	5.15	6.73	5.43	5.92	6.34	5.41	5.08	5.04
390	7.71	7.79	8.00	8.57	5.21	6.88	5.54	6.16	6.62	5.53	5.12	5.09
400	7.82	7.78	8.18	8.75	5.24	7.05	5.59	6.27	6.72	5.59	5.15	5.11
410	8.01	7.90	8.33	8.79	5.26	7.07	5.60	6.26	6.82	5.61	5.16	5.11
420	8.18	7.96	8.49	8.81	5.29	7.11	5.67	6.31	6.96	5.69	5.17	5.14
430	8.33	7.98	8.58	8.88	5.34	7.20	5.73	6.46	7.21	5.72	5.21	5.18
440	8.36	8.11	8.77	9.13	5.34	7.28	5.69	6.44	7.28	5.67	5.22	5.16
450	8.38	7.97	8.55	9.11	5.30	7.21	5.63	6.29	7.01	5.60	5.19	5.12
460	8.23	7.77	8.38	9.03	5.26	7.12	5.61	6.21	6.76	5.55	5.15	5.11
470	8.14	7.76	8.35	8.93	5.26	7.11	5.61	6.15	6.72	5.55	5.15	5.10
480	8.29	7.73	8.45	8.87	5.28	7.04	5.60	6.19	6.77	5.58	5.17	5.11
490	8.29	7.95	8.70	8.69	5.28	7.11	5.62	6.30	6.77	5.60	5.16	5.12
500	8.27	8.23	9.04	8.84	5.32	7.32	5.69	6.40	6.92	5.69	5.21	5.14
510	8.35	8.30	9.15	9.53	5.43	7.55	5.81	6.65	7.43	5.88	5.28	5.21
520	8.58	8.68	9.37	10.28	5.51	7.67	5.92	6.93	7.80	6.06	5.36	5.30
530	8.93	8.56	9.41	10.07	5.47	7.58	5.92	6.78	7.67	6.00	5.32	5.25
540	8.89	8.40	9.04	10.07	5.42	7.55	5.85	6.61	7.59	5.87	5.26	5.22
550	8.84	8.50	9.25	10.11	5.43	7.72	5.87	6.62	7.44	5.84	5.28	5.22
560	8.81	8.63	9.48	10.01	5.48	7.91	5.94	6.75	7.52	5.98	5.32	5.25
570	8.74	8.79	9.32	10.09	5.56	7.89	6.03	7.07	7.91	6.22	5.37	5.33
580	8.90	8.84	9.39	10.38	5.65	8.10	6.15	7.39	8.46	6.42	5.42	5.40
590	9.20	9.01	9.77	11.30	5.72	8.16	6.27	7.70	9.09	6.67	5.49	5.47
600	9.50	9.24	10.39	11.90	5.79	8.17	6.33	8.04	9.47	6.96	5.53	5.55
610	9.79	9.17	10.35	11.62	5.85	8.54	6.40	8.11	9.79	6.98	5.55	5.59
620	10.08	9.37	10.37	11.67	5.88	8.51	6.40	8.10	9.90	6.87	5.59	5.58
630	10.17	9.80	10.33	11.40	5.84	8.51	6.39	8.05	9.60	6.85	5.56	5.56
640	10.11	9.71	10.51	11.22	5.82	8.61	6.45	8.20	9.61	6.89	5.57	5.61
650	10.17	9.64	11.02	11.87	5.84	8.70	6.44	8.25	9.40	6.83	5.58	5.56
660	9.95	9.85	11.08	12.52	5.89	8.90	6.44	8.29	9.31	6.93	5.63	5.60
670	9.87	9.90	11.07	12.24	5.91	8.97	6.47	8.25	9.32	6.92	5.63	5.60
680	10.30	10.25	11.08	11.82	5.86	8.83	6.46	7.97	9.32	6.69	5.60	5.55
690	10.75	10.63	10.52	11.82	5.81	8.84	6.45	7.74	8.97	6.58	5.57	5.49
700	10.69	10.27	10.72	11.84	5.75	8.99	6.44	7.59	8.64	6.52	5.52	5.48
710	10.82	10.43	10.92	11.63	5.76	8.92	6.44	7.71	8.66	6.50	5.55	5.48
720	11.10	10.76	11.14	12.08	5.81	9.00	6.53	7.96	8.93	6.62	5.60	5.53
730	11.08	11.04	11.54	12.25	5.90	9.30	6.73	8.30	9.23	6.86	5.64	5.63
740	11.39	10.99	11.25	12.93	6.06	9.80	6.86	8.60	9.62	7.10	5.75	5.70
750	11.58	11.07	11.50	14.24	6.16	10.28	7.00	8.66	10.11	7.27	5.84	5.76
760	11.52	11.28	12.10	14.41	6.18	10.08	7.05	8.85	10.04	7.29	5.85	5.80
770	11.99	10.95	12.51	14.07	6.18	9.87	7.00	8.92	9.76	7.07	5.85	5.77
780	12.51	11.67	13.09	14.91	6.12	10.33	6.96	8.26	8.94	6.76	5.86	5.62

E_n (keV)	ΔN(t), % 0.12-1s	ΔN(t), % 1-2 s	ΔN(t), % 2-3 s	ΔN(t), % 3-4 s	ΔN(t), % 4-44 s	ΔN(t), % 0.12-2s	ΔN(t), % 2-12 s	ΔN(t), % 12-22 s	ΔN(t), % 22-32 s	ΔN(t), % 32-152s	ΔN(t), % 0.12-44 s	ΔN(t), % 0.12-152 s
790	13.04	12.05	13.38	14.91	5.99	10.18	6.74	7.77	8.41	6.53	5.77	5.53
800	13.22	11.62	13.06	14.84	5.94	9.81	6.64	7.89	8.48	6.54	5.69	5.51
810	13.30	11.86	13.50	14.58	6.10	10.40	6.90	8.52	9.34	6.81	5.85	5.66
820	13.28	12.17	14.37	14.43	6.38	10.72	7.36	9.16	10.92	7.33	6.03	5.91
830	13.24	12.87	14.74	15.24	6.64	10.61	7.67	9.54	11.78	7.79	6.25	6.06
840	12.85	12.88	14.28	15.19	6.70	10.63	7.73	9.77	12.03	7.95	6.22	6.15
850	13.43	12.45	14.59	14.19	6.68	10.57	7.72	10.23	12.29	7.98	6.20	6.17
860	14.54	12.54	14.61	14.83	6.59	10.74	7.53	10.17	11.48	7.66	6.16	6.02
870	14.80	12.69	14.04	15.10	6.48	11.07	7.48	9.23	10.85	7.43	6.09	5.91
880	13.65	12.88	13.74	15.75	6.37	11.27	7.48	8.82	10.51	7.30	6.04	5.88
890	13.77	13.06	14.00	16.79	6.39	11.18	7.46	8.99	10.29	7.26	6.05	5.81
900	14.97	13.30	14.64	16.76	6.57	10.88	7.67	9.34	10.78	7.63	6.16	6.05
910	15.02	13.98	15.39	17.27	6.77	11.47	7.82	9.76	11.39	8.00	6.38	6.11
920	14.78	14.26	16.76	17.83	6.94	11.86	7.94	10.29	11.98	8.23	6.49	6.24
930	15.24	14.49	17.14	17.02	7.03	11.88	8.23	10.57	12.66	8.35	6.57	6.31
940	15.39	14.87	16.10	16.79	7.07	12.24	8.62	10.55	12.62	8.55	6.48	6.41
950	15.04	15.12	16.24	17.72	7.33	12.50	8.78	10.91	13.21	8.82	6.70	6.60
960	15.06	15.67	16.76	18.80	7.38	12.77	8.71	11.03	13.25	8.82	6.84	6.47
970	16.52	15.63	17.71	19.52	7.27	13.15	8.70	10.96	13.61	8.77	6.72	6.65
980	18.33	15.99	19.69	19.74	7.33	14.17	8.96	11.72	13.79	8.76	6.73	6.58
990	18.23	17.04	19.22	19.38	7.69	14.20	8.90	12.21	13.69	8.99	7.07	6.66
1000	17.99	17.57	17.29	19.23	7.93	14.10	9.00	12.22	13.99	9.10	7.20	6.77
1010	17.15	17.16	18.54	21.66	7.70	14.32	9.20	12.17	13.92	9.14	7.14	6.67
1020	16.93	16.73	20.38	20.27	7.51	13.50	9.27	11.15	13.71	8.73	6.92	6.70
1030	17.38	17.38	17.81	19.80	7.40	13.48	8.72	10.85	13.46	8.31	6.83	6.40
1040	17.34	17.52	18.93	19.53	7.19	13.83	8.43	11.16	12.15	8.31	6.78	6.35
1050	17.40	17.22	18.55	20.34	7.49	14.50	8.44	11.31	13.67	8.57	6.83	6.75
1060	16.96	18.17	18.84	20.97	7.26	15.30	8.78	13.45	13.52	9.11	6.95	6.99
1070	17.60	18.90	17.55	20.21	7.98	14.96	8.25	12.49	14.03	9.20	7.24	6.80
1080	18.87	19.91	17.60	20.25	8.67	15.25	8.81	13.79	13.64	9.42	7.41	7.06
1090	18.18	19.61	18.36	22.81	8.07	14.92	8.78	11.98	13.78	9.62	7.33	6.90
1100	17.35	18.70	21.87	21.66	7.61	13.68	9.23	15.31	13.74	8.62	7.16	6.84
1110	17.52	18.88	22.62	20.68	7.65	14.81	8.05	15.84	13.45	7.90	6.98	6.49
1120	17.92	19.83	21.06	20.84	7.41	14.09	7.86	13.53	11.13	8.13	6.87	6.45
1130	17.59	19.38	28.95	19.78	7.00	12.66	7.96	15.69	11.63	8.19	6.73	6.45
1140	19.35	18.26	26.93	20.06	7.07	13.37	7.94	14.53	12.98	8.31	6.65	6.56
1150	18.01	17.39	18.89	20.84	7.15	14.57	7.96	15.19	12.42	7.92	6.71	6.38
1160	17.65	16.67	18.44	21.00	7.20	14.09	8.49	16.49	11.19	8.47	6.81	6.65
1170	22.18	17.73	21.46	22.01	7.91	14.06	8.74	15.20	14.54	9.21	7.09	6.91
1180	19.36	20.74	24.78	24.00	8.24	14.39	9.60	15.06	12.41	8.35	7.08	6.61
1190	17.98	17.82	24.06	25.21	8.91	14.24	9.03	15.09	12.50	8.08	7.31	6.32
1200	22.30	22.36	21.46	29.34	9.55	15.93	9.39	16.11	13.44	8.94	7.56	6.56
1210	25.07	20.94	24.53	35.13	10.09	13.49	9.53	17.98	17.38	8.76	8.00	6.36
1220	25.68	22.25	31.41	31.54	11.06	17.06	11.28	15.67	17.38	9.72	8.33	6.14

E_n (keV)	ΔN(t), % 0.12-1s	ΔN(t), % 1-2 s	ΔN(t), % 2-3 s	ΔN(t), % 3-4 s	ΔN(t), % 4-44 s	ΔN(t), % 0.12-2s	ΔN(t), % 2-12 s	ΔN(t), % 12-22 s	ΔN(t), % 22-32 s	ΔN(t), % 32-152s	ΔN(t), % 0.12-44 s	ΔN(t), % 0.12-152 s
1230	18.34	23.12	27.40	31.83	10.84	20.90	11.25	22.66	20.41	9.59	8.98	6.67
1240	24.74	23.18	43.22	30.36	12.15	16.79	13.47	31.48	21.23	11.14	9.42	6.73
1250	19.94	27.96	37.07	36.40	11.23	16.74	13.58	27.72	17.78	12.72	9.91	6.86
1260	26.71	26.31	28.42	34.23	13.91	18.26	13.87	21.06	15.25	12.82	10.28	7.35
1270	31.05	27.48	34.28	45.00	14.17	20.06	15.53	30.22	24.24	13.30	10.65	7.78
1280	22.06	32.97	27.57	38.20	13.49	17.50	15.03	23.14	26.13	17.58	9.79	7.97
1290	17.63	27.04	35.01	45.76	15.66	32.88	13.74	22.33	39.54	11.37	10.17	8.21
1300	19.51	27.56	50.29	38.41	14.27	16.54	13.72	26.10	20.38	12.50	10.37	8.47
1310	27.70	29.91	27.58	84.64	12.64	26.40	15.44	39.40	34.06	14.19	9.91	8.88
1320	23.42	21.11	46.73	48.31	13.77	33.71	12.80	29.44	22.56	13.72	9.55	8.80
1330	25.92	32.23	29.64	46.50	14.23	17.91	15.92	25.73	36.13	13.75	9.10	8.39
1340	23.86	36.17	30.44	36.46	12.86	20.01	14.66	22.02	44.07	15.49	8.85	8.91
1350	23.82	31.22	29.61	45.11	12.69	18.08	14.24	22.87	16.20	17.63	8.78	8.98
1360	25.75	22.16	25.70	72.68	11.88	24.45	18.71	25.05	28.60	15.98	9.00	8.67
1370	19.63	22.89	30.88	44.69	13.36	24.21	16.76	24.87	23.89	11.99	8.79	8.71
1380	25.19	31.40	33.47	37.81	13.03	16.84	15.77	32.92	26.89	13.06	8.65	8.42
1390	21.60	46.69	36.61	35.67	12.90	14.75	13.75	31.72	17.38	11.86	8.50	8.47
1400	21.68	37.81	43.91	39.64	15.77	13.85	13.43	28.19	18.78	12.95	8.40	8.31
1410	21.62	24.37	47.19	31.22	15.68	15.40	13.67	27.88	29.36	11.75	8.30	8.08
1420	19.38	22.24	61.79	37.14	14.86	24.37	13.77	38.49	22.32	14.61	8.20	8.95
1430	20.03	23.72	45.97	28.70	14.36	20.42	13.31	21.96	16.69	11.03	8.61	8.83
1440	19.79	21.40	39.04	35.44	13.37	19.94	12.98	21.53	18.10	10.47	9.02	9.09
1450	22.28	21.71	38.85	30.46	11.23	19.77	13.38	21.50	23.88	12.16	9.06	8.85
1460	23.28	22.44	39.86	30.73	11.24	20.03	13.32	18.69	21.08	11.19	9.12	9.41
1470	23.19	22.37	39.72	30.63	11.20	19.98	13.29	19.07	21.62	11.46	9.26	8.64
1480	25.01	24.08	43.80	32.92	12.03	22.08	13.83	19.29	21.92	11.61	8.99	8.91
1490	28.00	26.90	51.10	36.61	13.46	25.45	14.66	20.18	23.20	12.23	8.90	9.33
1500	30.57	29.29	58.13	39.69	14.73	22.04	12.96	19.95	22.90	12.09	9.51	10.19
1510	31.59	30.24	61.32	40.88	15.29	18.83	11.33	16.81	18.61	10.04	10.47	11.76
1520	33.36	31.86	67.15	42.92	16.22	20.02	11.94	16.67	18.45	9.96	12.41	12.32
1530	34.37	32.80	70.91	44.06	16.80	20.76	12.31	17.21	19.15	10.29	14.58	14.69
1540	36.83	35.04	80.95	46.47	18.20	22.57	13.23	18.16	20.43	10.89	18.47	16.18
1550	38.63	36.68	89.86	43.18	19.31	23.99	13.92	19.52	22.33	11.83	24.05	12.27
1560	37.37	35.51	83.84	41.53	18.58	22.98	13.42	19.59	22.45	11.89	16.59	11.83
1570	34.94	33.31	73.72	39.33	17.16	21.22	12.53	18.23	20.55	10.95	14.21	15.89
1580	38.06	36.14	87.89	42.10	19.01	23.68	13.76	18.45	20.87	11.11	19.39	16.96
1590	39.58	37.53	96.62	43.37	19.97	24.82	14.32	20.33	23.59	12.46	33.53	13.30
1600	37.76	35.88	86.91	41.80	18.85	23.36	13.60	19.84	22.87	12.10	20.71	15.01

3. Determination of DN group spectra for ^{235}U in the 8-group model (Kalman filtering and Potter algorithm processing)

The relationship between the composite DN spectra in a given time interval and the DN group spectra for cyclic irradiation is given by Eqs (1) and (2).

$$N(E_n)dE = \sum_{i=1}^{N} \left[A\left(\frac{a_i}{\lambda_i}\right)\left(1-e^{-\lambda_i t_{irr}}\right)\left(e^{-\lambda_i t_d}\right)\left(1-e^{-\lambda_i \Delta t_c}\right)T_i \right]_i \chi_i(E_n)dE_n \qquad (1)$$

$$T_i = \left[\frac{M}{1-e^{-\lambda_i T}} - e^{-\lambda_i T}\frac{1-e^{-M\lambda_i T}}{(1-e^{-\lambda_i T})^2} \right],$$

where the T_i term describes the dependence of the sample activation on the number of irradiation cycles; A is the saturation activity; a_i is the relative abundance of the i-th delayed neutron group; $\chi_i(E_n)$ is the energy spectrum of the i-th delayed neutron group normalized to unity; λ_i is the decay constant of the i-th delayed neutron group; t_{irr} is the irradiation time in s; t_d is the delay time in s; Δt_c is the DN counting interval in s; M is the number of cycles; T is the period of one irradiation cycle (irradiation-cooling-counting); N is the number of DN groups; DN energy range is 0 – 1600 keV with energy bins of 10 keV.

For each of the 160 energy bins of the composite DN spectra measured in 6 time intervals in the experiments with long irradiation (t_{irr}=120 s) and in 6 time intervals with short irradiation (t_{irr}=20 s) session, we have 12 linear equations. The system of equations for the energy bin j=1 (0-10 keV) can be written in matrix notation in the following form

$$\mathbf{N_i^j} = \mathbf{A_{ik}} \times \mathbf{x_k^j}, \ (i=1, 2,\ldots,12;\ k=1, 2,\ldots,8)$$

where $\mathbf{N_i^j}$ (m×1) – vector of observables, $\mathbf{x_k^j}$ (n×1) – vector of estimations, $\mathbf{A_{ik}}$ (m×n) – the matrix that shows the connection of the vector of observables $\mathbf{N_i^j}$ with the vector of estimations $\mathbf{x_k^j}$, i – counting time interval being i=1 (0.12-2 s), i=2 (2-12 s), i=3 (12-22 s), i=4 (22-32 s), i=5 (32-152 s), i=6 (0.12-152 s) for long irradiation and i=7 (0.12-1 s), i=8 (1-2 s), i=9 (2-3 s), i=10 (3-4 s), i=11 (4-44 s), i=12 (0.12-44) for short irradiation data; k is DN group number; j - the number of energy bin (j=1 (0-10 keV), j=2 (10-20 keV),…, j=160 (1590-1600 keV)).

For the next energy bin j=2 (10-20 keV), the system of equations is repeated with the same values $\mathbf{A_{ik}}$, the $\mathbf{N_i^j}$ values corresponding to this energy bin and the new vector $\mathbf{x_k^j}$ to be estimated. Altogether the system comprises 1920 equations with 1280 unknowns $\mathbf{x_k^j}$ to be estimated.

The Kalman filter is a well-known tool used in problems of estimating the varying parameters of a system using a dynamic model and a series of measurements with errors (Refs [7, 8]). When it is known that the errors are on average zero and have a normal distribution (Gaussian), the Kalman filter gives the minimum spread and an unbiased estimate of the system parameters. The traditional formulation of the Kalman filter seeks the solution of a system of linear equations representing the mathematical relationship between the observed values and the modeled parameters, i.e. the dynamic model (Ref. [5])

$$\mathbf{z_k} = \mathbf{A_k} \times \mathbf{x_k} + \mathbf{v_k},$$

where the index k, as a rule, refers to the state of the system at time t_k. In our case, the index k can be considered a “k-step” in sequential processing of the measured data $\mathbf{N_i^j}$.

$\mathbf{x_k}$ (n×1) – vector of estimated solution;

$\mathbf{z_k}$ (m×1) – vector of measured data;

$\mathbf{A_k}$ (m×n) – matrix connecting the measured data and estimated solution;

$\mathbf{v_k}$ (m×1) – measurement error with known covariance.

Observation errors $\mathbf{v_k}$ are random errors of variables with zero mean and known covariance **Rk**

$$\mathbf{E}\left[\mathbf{v}_k\right] = \mathbf{0},\ \mathbf{E}\left[\mathbf{v_j v_k^T}\right] = \mathbf{R_k} \cdot \delta_{\mathbf{jk}}$$

where $\delta_{\mathbf{jk}}$ is the Kronecker delta. According to Kalman's algorithm, the estimate at step k is based on the knowledge of the process that preceded step k. A priori estimate is denoted $\mathbf{\hat{x}_k^-}$, where the "^" sign denotes the estimated value and the "–" sign denotes the a priori value. It is assumed that the error covariance matrix $\mathbf{P_k^-}$ associated with the prior estimate $\mathbf{\hat{x}_k^-}$ is known. Using the prior estimate $\mathbf{\hat{x}_k^-}$ and prior covariance $\mathbf{P_k^-}$, as well as the measurement results $\mathbf{z_k}$, an improved (updated) a priori estimate can be obtained using the following expression (Ref. [5])

$$\mathbf{\hat{x}_{k+1} = \hat{x}_k^- + K_k(z_k - A_k \hat{x}_k^-)} \qquad (2)$$

where $\mathbf{\hat{x}_{k+1}}$ is the updated estimate of a priori value $\mathbf{\hat{x}_k^-}$; $\mathbf{A_k}$ - matrix connecting the measured data and the state vector; matrix $\mathbf{K_k}$ - the Kalman correction matrix. The Kalman correction matrix obtained in order to minimize the root-mean-square error estimate is given by Ref. [5]

$$\mathbf{K_k = P_k^- A_k^T (A_k P_k^- A_k^T + R}_k\mathbf{)}^{-1},$$

where **Rk** is the measurement error covariance matrix; superscripts "T" indicate transposed matrix. Using the Kalman correction matrix, one can update the error covariance data

$$\mathbf{\hat{P}_{k+1} = P_k^- - K_k A_k P_k^-}.$$

According to Birman's recommendation (Ref. [5]), the covariance update transformation should be performed using a stabilized covariance update formula, which gives a more stable estimate and error

$$\mathbf{P_{k+1}^- = \hat{P}_{k+1} - \hat{P}_{k+1} A_k^T K_k^T + K_k K_k^T}.$$

As a result of processing the k-th equation, we obtain $\mathbf{\hat{x}_{k+1}}$ and $\mathbf{\hat{P}_{k+1}}$ ($\mathbf{P_{k+1}^-}$), which are an estimate of the state and covariance of errors after processing k observations. This new posteriori data will be used as a priori data in the next step of the estimate (k + 1).

Potter developed the modification of the Kalman algorithm in terms of a square root covariance matrix with the purpose to preserve nonnegativity of computed covariance (Ref. [5]). The introduction of this algorithm improves the numerical accuracy and stability of the estimation process. The Potter algorithm is based on the factorization of a covariance matrix **Pk** in the following form

$$\mathbf{P_k^- = S_k^- S_k^{-T}},\ \mathbf{\hat{P}_k = \hat{S}_k \hat{S}_k^T},$$

where **Sk** is the square root of covariance matrix **Pk**

$$\hat{\mathbf{P}}_{\mathbf{k+1}} = \mathbf{P}_{\mathbf{k}}^{-} - \mathbf{K}_{\mathbf{k}}\mathbf{A}_{\mathbf{k}}\mathbf{P}_{\mathbf{k}}^{-} .$$

Kalman's filter and Potter's algorithm, as discussed in the above text, were implemented in computer codes developed in the LabView language. The relative abundance a_i and half-lives T_i of the DN were taken from the recommended data set (Ref. [2]) (see Table 4).

TABLE 4. The relative abundances and half-lives of the 8-group model for DN emission from thermal neutron-induced fission of ^{235}U.

	Group-1	Group-2	Group-3	Group-4	Group-5	Group-6	Group-7	Group-8
Half-life T_i, s	55.6	24.5	16.3	5.21	2.37	1.04	0.424	0.195
Relative abundance, a_i	0.034 ±0.001	0.153 ±0.006	0.086 ±0.004	0.212 ±0.007	0.298 ±0.009	0.105 ±0.005	0.073 ±0.004	0.039 ±0.002

The coefficients A_{ik} for each measured time interval were normalized to 1

$$\sum_{k=1}^{k=8} A_{ik} = 1$$

so that each composite spectrum has the same normalization as the DN group spectrum. *A priori* DN spectra $\mathbf{x_k}$ were calculated by the summation method on the basis of microscopic DN data, i.e. emission probability P_n, beta-decay half-life $T_{1/2}$ from Ref. [1] and the individual DN precursor spectra from ENDF/B-VII.1 database (Ref. [9]). One iteration of the estimation process was made using an *a priori* state vector from the previous iteration and reset of $\mathbf{P_k}$ to the primary values at the beginning of the next iteration. The obtained solution $\chi_i(E_n)$ of the system equations for the 8-group DN model can be seen in Figs 5 and 6 where the present estimation of the 8-group DN spectra is compared with corresponding data from the JEFF-3.1.1 database (Ref. [9]). The comparison is limited to the JEFF library because JEFF is the only evaluated library that has DN spectra in the 8-group model.

4. Comparison of Kalman and Potter estimation of 8-group DN spectra with JEFF spectra for thermal neutron-induced fission of ^{235}U

The 8-group DN spectra obtained from thermal neutron-induced fission of ^{235}U shown in Figs 5 and 6 are very close to each other. The solutions obtained by applying these methods give similar results for the 8 groups with only a minor difference observed mainly in the DN spectrum of group-6.

The overall shape and peak structure in all eight DN spectra of the present estimation are similar to those in the JEFF database. A good agreement with JEFF data is observed in the first two DN groups. In the remaining DN groups, the main differences are observed in the peak intensities and shape of the spectra in the energy range above 1100 keV.
The numerical results of the estimation of the 8-group DN spectra and their uncertainties are presented in Tables 5-12.

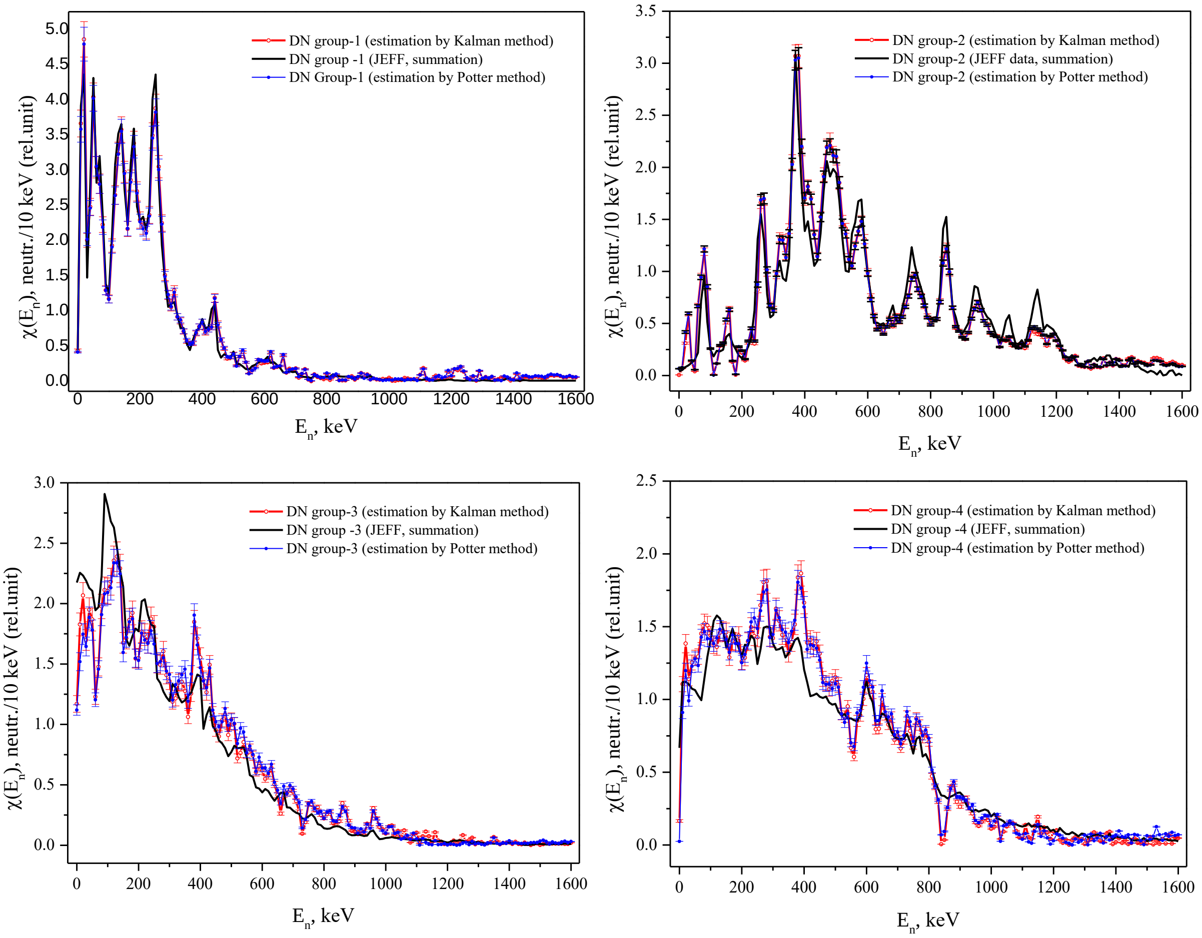

FIG. 5. Group energy spectra of DN from fission of ^{235}U by thermal neutrons. Group-1 - $T_{1/2}$ = 55.6 s, group-2 - $T_{1/2}$ = 24.5 s, group-3 - $T_{1/2}$ = 16.3 s, group-4 - $T_{1/2}$ = 5.21 s. The energy channel width is 10 keV. The solid line is the eight-group spectra from the JEFF library, the line with symbols are the eight-group spectra obtained as a result of the estimation made in this work (Kalman's and Potter's estimation).

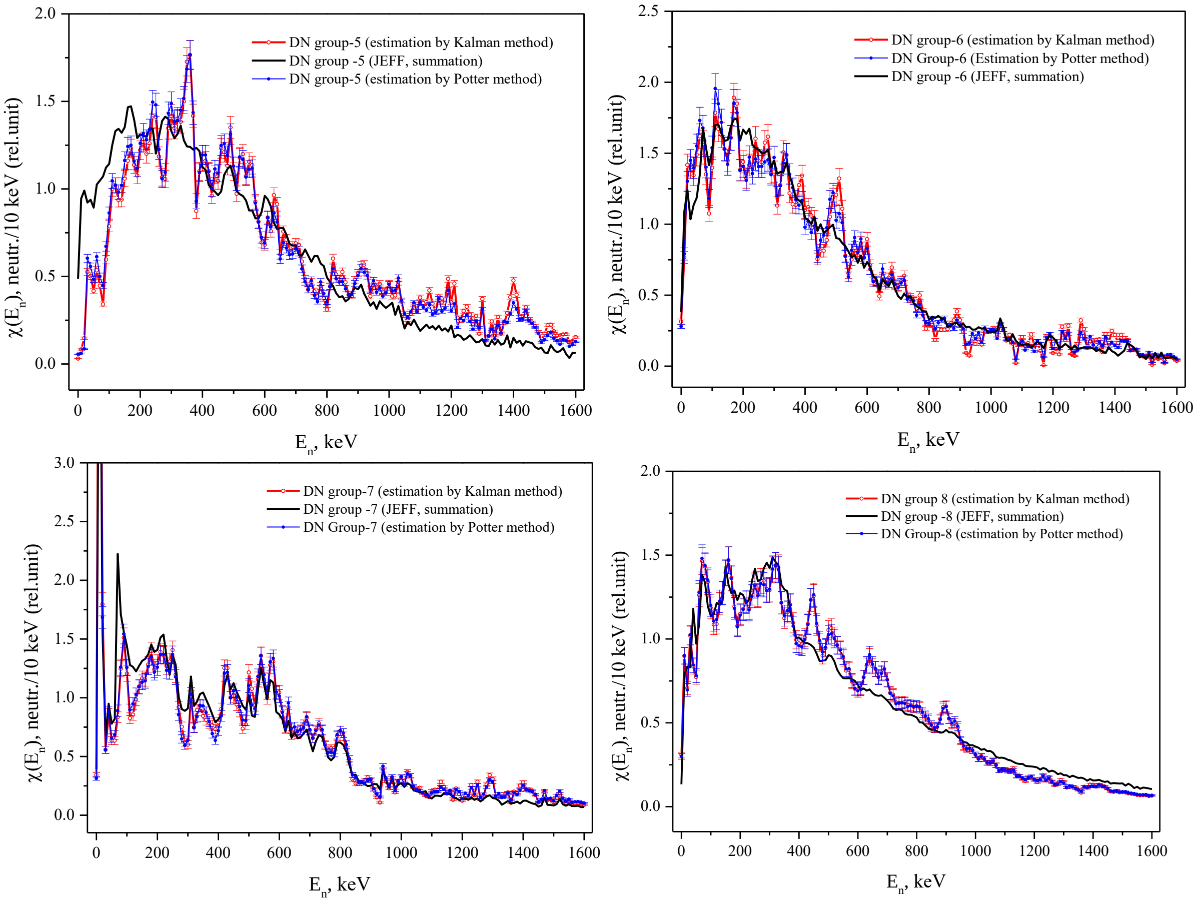

FIG. 6. Group energy spectra of DN from fission of ^{235}U by thermal neutrons. Group-5 - $T_{1/2}$ = 2.37 s, group-6 - $T_{1/2}$ = 1.04 s, group-7 - $T_{1/2}$ = 0.424 s, group-8 - $T_{1/2}$ = 0.195 s. The energy channel width is 10 keV. The solid line is the eight-group spectra from the JEFF library, the line with symbols are the eight-group spectra obtained as a result of the estimation made in this work (Kalman's and Potter's estimation).

TABLE 5. Estimated energy spectrum of the first group of delayed neutrons from fission of ^{235}U.

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$
0	0.421	0.023	540	0.257	0.013	1080	0.019	0.001
10	3.587	0.188	550	0.103	0.005	1090	0.026	0.001
20	4.759	0.247	560	0.145	0.007	1100	0.084	0.004
30	1.957	0.096	570	0.203	0.010	1110	0.177	0.009
40	2.426	0.118	580	0.294	0.015	1120	0.016	0.001
50	3.956	0.196	590	0.242	0.012	1130	0.010	0.000
60	2.976	0.148	600	0.254	0.013	1140	0.024	0.001
70	2.747	0.137	610	0.258	0.013	1150	0.071	0.003
80	2.177	0.109	620	0.392	0.020	1160	0.018	0.001
90	1.263	0.063	630	0.180	0.009	1170	0.024	0.001
100	1.141	0.056	640	0.193	0.010	1180	0.041	0.002
110	1.885	0.093	650	0.206	0.010	1190	0.125	0.006
120	2.591	0.130	660	0.353	0.018	1200	0.054	0.003
130	3.166	0.160	670	0.114	0.006	1210	0.162	0.008
140	3.502	0.178	680	0.168	0.008	1220	0.148	0.007

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$
150	2.912	0.148	690	0.155	0.008	1230	0.196	0.009
160	2.117	0.107	700	0.173	0.009	1240	0.128	0.006
170	2.797	0.141	710	0.043	0.002	1250	0.037	0.002
180	3.311	0.168	720	0.097	0.005	1260	0.020	0.001
190	2.640	0.134	730	0.162	0.008	1270	0.062	0.003
200	2.241	0.113	740	0.020	0.001	1280	0.002	0.000
210	2.150	0.109	750	0.005	0.000	1290	0.136	0.006
220	2.082	0.106	760	0.089	0.005	1300	0.027	0.001
230	2.312	0.118	770	0.055	0.003	1310	0.052	0.002
240	3.420	0.175	780	0.038	0.002	1320	0.029	0.001
250	3.799	0.196	790	0.022	0.001	1330	0.055	0.003
260	2.984	0.155	800	0.097	0.005	1340	0.011	0.001
270	2.200	0.114	810	0.012	0.001	1350	0.020	0.001
280	1.474	0.076	820	0.055	0.003	1360	0.046	0.002
290	1.194	0.061	830	0.080	0.004	1370	0.053	0.003
300	1.026	0.052	840	0.008	0.000	1380	0.044	0.002
310	1.262	0.065	850	0.006	0.000	1390	0.005	0.000
320	0.892	0.046	860	0.006	0.000	1400	0.020	0.001
330	0.836	0.043	870	0.053	0.003	1410	0.094	0.004
340	0.686	0.035	880	0.063	0.003	1420	0.010	0.000
350	0.548	0.028	890	0.017	0.001	1430	0.043	0.002
360	0.523	0.027	900	0.051	0.002	1440	0.056	0.003
370	0.518	0.027	910	0.108	0.005	1450	0.047	0.002
380	0.661	0.035	920	0.044	0.002	1460	0.046	0.002
390	0.753	0.039	930	0.088	0.004	1470	0.060	0.003
400	0.817	0.042	940	0.018	0.001	1480	0.053	0.003
410	0.672	0.035	950	0.033	0.002	1490	0.047	0.002
420	0.716	0.037	960	0.020	0.001	1500	0.033	0.002
430	0.749	0.038	970	0.016	0.001	1510	0.062	0.003
440	1.156	0.059	980	0.026	0.001	1520	0.079	0.004
450	0.794	0.041	990	0.018	0.001	1530	0.071	0.003
460	0.566	0.029	1000	0.042	0.002	1540	0.078	0.004
470	0.446	0.023	1010	0.002	0.000	1550	0.066	0.003
480	0.309	0.016	1020	0.002	0.000	1560	0.049	0.002
490	0.322	0.017	1030	0.010	0.000	1570	0.050	0.002
500	0.379	0.020	1040	0.012	0.001	1580	0.065	0.003
510	0.213	0.011	1050	0.040	0.002	1590	0.051	0.002
520	0.336	0.017	1060	0.032	0.002	1600	0.050	0.002
530	0.402	0.021	1070	0.019	0.001			

TABLE 6. Estimated energy spectrum of the second group of delayed neutrons from fission of ^{235}U.

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$
0	0.005	0.000	540	1.115	0.036	1080	0.266	0.008
10	0.066	0.002	550	1.034	0.032	1090	0.303	0.009
20	0.306	0.010	560	1.228	0.039	1100	0.258	0.008
30	0.580	0.017	570	1.361	0.045	1110	0.308	0.009
40	0.132	0.004	580	1.460	0.050	1120	0.428	0.013
50	0.039	0.001	590	1.289	0.044	1130	0.413	0.012
60	0.663	0.020	600	0.980	0.032	1140	0.394	0.012
70	0.937	0.029	610	0.749	0.024	1150	0.385	0.011
80	1.171	0.036	620	0.572	0.018	1160	0.362	0.011
90	0.832	0.025	630	0.441	0.013	1170	0.281	0.008
100	0.255	0.008	640	0.462	0.014	1180	0.365	0.011
110	0.012	0.000	650	0.401	0.012	1190	0.389	0.012
120	0.113	0.004	660	0.475	0.015	1200	0.330	0.010
130	0.279	0.009	670	0.543	0.017	1210	0.267	0.008
140	0.294	0.009	680	0.464	0.014	1220	0.236	0.007
150	0.502	0.016	690	0.569	0.017	1230	0.156	0.004
160	0.633	0.020	700	0.502	0.015	1240	0.129	0.004
170	0.127	0.004	710	0.561	0.017	1250	0.152	0.004
180	0.007	0.000	720	0.661	0.020	1260	0.186	0.006
190	0.251	0.008	730	0.752	0.023	1270	0.092	0.003
200	0.215	0.007	740	0.922	0.029	1280	0.086	0.002
210	0.141	0.004	750	0.948	0.031	1290	0.081	0.002
220	0.307	0.010	760	0.814	0.026	1300	0.131	0.004
230	0.443	0.014	770	0.751	0.024	1310	0.064	0.002
240	0.301	0.010	780	0.650	0.020	1320	0.103	0.003
250	0.809	0.027	790	0.566	0.017	1330	0.080	0.002
260	1.634	0.057	800	0.488	0.014	1340	0.076	0.002
270	1.664	0.058	810	0.537	0.016	1350	0.162	0.005
280	0.971	0.032	820	0.534	0.016	1360	0.092	0.003
290	0.672	0.022	830	0.706	0.022	1370	0.122	0.004
300	0.633	0.020	840	1.084	0.035	1380	0.095	0.003
310	0.946	0.031	850	1.211	0.040	1390	0.156	0.005
320	1.305	0.044	860	0.971	0.031	1400	0.149	0.004
330	1.289	0.043	870	0.640	0.020	1410	0.097	0.003
340	1.133	0.037	880	0.449	0.013	1420	0.096	0.003
350	1.388	0.046	890	0.426	0.013	1430	0.161	0.005
360	2.018	0.068	900	0.375	0.011	1440	0.173	0.005
370	3.018	0.107	910	0.342	0.010	1450	0.111	0.003
380	3.020	0.109	920	0.400	0.012	1460	0.137	0.004
390	2.152	0.075	930	0.538	0.017	1470	0.125	0.004
400	1.664	0.056	940	0.636	0.020	1480	0.120	0.003
410	1.789	0.061	950	0.693	0.022	1490	0.105	0.003

E_n (keV)	χ(E_n)	Δχ(E_n)	$E_{n,}$ keV	χ(E_n)	Δχ(E_n)	$E_{n,}$ keV	χ(E_n)	Δχ(E_n)
420	1.677	0.057	960	0.617	0.019	1500	0.113	0.003
430	1.334	0.044	970	0.517	0.016	1510	0.165	0.005
440	1.128	0.037	980	0.485	0.015	1520	0.165	0.005
450	1.499	0.050	990	0.399	0.012	1530	0.155	0.005
460	1.899	0.064	1000	0.379	0.011	1540	0.122	0.004
470	2.161	0.074	1010	0.376	0.011	1550	0.106	0.003
480	2.217	0.076	1020	0.269	0.008	1560	0.115	0.003
490	2.095	0.071	1030	0.351	0.011	1570	0.130	0.004
500	2.059	0.071	1040	0.328	0.010	1580	0.113	0.003
510	1.820	0.062	1050	0.361	0.011	1590	0.095	0.003
520	1.464	0.049	1060	0.282	0.008	1600	0.099	0.003
530	1.391	0.046	1070	0.278	0.008			

TABLE 7. Estimated energy spectrum of the third group of delayed neutrons from fission of ^{235}U.

E_n (keV)	χ(E_n)	Δχ(E_n)	$E_{n,}$ keV	χ(E_n)	Δχ(E_n)	$E_{n,}$ keV	χ(E_n)	Δχ(E_n)
0	1.157	0.068	540	0.843	0.043	1080	0.023	0.001
10	1.808	0.094	550	0.747	0.038	1090	0.090	0.005
20	2.045	0.106	560	0.788	0.040	1100	0.103	0.005
30	1.680	0.085	570	0.733	0.038	1110	0.017	0.001
40	1.928	0.098	580	0.598	0.031	1120	0.073	0.004
50	1.848	0.094	590	0.645	0.033	1130	0.112	0.006
60	1.215	0.062	600	0.613	0.032	1140	0.075	0.004
70	1.460	0.074	610	0.543	0.028	1150	0.024	0.001
80	1.955	0.100	620	0.571	0.029	1160	0.106	0.005
90	2.090	0.106	630	0.634	0.032	1170	0.039	0.002
100	2.082	0.106	640	0.498	0.025	1180	0.028	0.001
110	2.157	0.110	650	0.410	0.021	1190	0.009	0.000
120	2.330	0.119	660	0.259	0.013	1200	0.012	0.001
130	2.362	0.121	670	0.413	0.021	1210	0.010	0.001
140	2.266	0.116	680	0.424	0.022	1220	0.038	0.002
150	1.657	0.085	690	0.456	0.023	1230	0.014	0.001
160	1.694	0.087	700	0.436	0.022	1240	0.036	0.002
170	1.843	0.094	710	0.362	0.018	1250	0.083	0.004
180	1.901	0.097	720	0.275	0.014	1260	0.030	0.002
190	1.528	0.078	730	0.094	0.005	1270	0.039	0.002
200	1.532	0.078	740	0.188	0.010	1280	0.062	0.003
210	1.748	0.090	750	0.341	0.018	1290	0.007	0.000
220	1.724	0.089	760	0.335	0.017	1300	0.022	0.001
230	1.658	0.085	770	0.288	0.015	1310	0.025	0.001
240	1.854	0.096	780	0.312	0.016	1320	0.007	0.000
250	1.789	0.092	790	0.250	0.013	1330	0.015	0.001
260	1.488	0.077	800	0.219	0.011	1340	0.026	0.001

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$
270	1.477	0.077	810	0.257	0.013	1350	0.067	0.004
280	1.587	0.082	820	0.273	0.014	1360	0.035	0.002
290	1.393	0.072	830	0.181	0.009	1370	0.007	0.000
300	1.343	0.069	840	0.168	0.009	1380	0.019	0.001
310	1.175	0.061	850	0.198	0.010	1390	0.018	0.001
320	1.202	0.062	860	0.343	0.018	1400	0.024	0.001
330	1.330	0.069	870	0.301	0.015	1410	0.010	0.001
340	1.338	0.069	880	0.201	0.010	1420	0.028	0.002
350	1.264	0.065	890	0.118	0.006	1430	0.011	0.001
360	1.050	0.054	900	0.111	0.006	1440	0.007	0.000
370	1.242	0.065	910	0.091	0.005	1450	0.022	0.001
380	1.828	0.095	920	0.116	0.006	1460	0.011	0.001
390	1.692	0.088	930	0.086	0.004	1470	0.001	0.000
400	1.537	0.080	940	0.176	0.009	1480	0.010	0.001
410	1.356	0.070	950	0.154	0.008	1490	0.017	0.001
420	1.251	0.065	960	0.302	0.015	1500	0.002	0.000
430	1.477	0.076	970	0.221	0.011	1510	0.008	0.000
440	1.080	0.056	980	0.149	0.008	1520	0.016	0.001
450	0.940	0.049	990	0.131	0.007	1530	0.012	0.001
460	0.891	0.046	1000	0.095	0.005	1540	0.014	0.001
470	1.023	0.053	1010	0.152	0.008	1550	0.014	0.001
480	1.070	0.055	1020	0.162	0.008	1560	0.014	0.001
490	0.903	0.047	1030	0.082	0.004	1570	0.014	0.001
500	1.030	0.053	1040	0.118	0.006	1580	0.011	0.001
510	0.994	0.051	1050	0.071	0.004	1590	0.010	0.001
520	0.711	0.037	1060	0.122	0.006	1600	0.021	0.001
530	0.755	0.039	1070	0.062	0.003			

TABLE 8. Estimated energy spectrum of the fourth group of delayed neutrons from fission of ^{235}U.

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$
0	0.158	0.009	540	0.911	0.040	1080	0.093	0.004
10	1.058	0.050	550	0.640	0.027	1090	0.050	0.002
20	1.325	0.061	560	0.579	0.025	1100	0.042	0.002
30	1.093	0.045	570	0.817	0.037	1110	0.131	0.005
40	1.200	0.049	580	0.853	0.039	1120	0.052	0.002
50	1.230	0.051	590	0.961	0.043	1130	0.041	0.002
60	1.240	0.051	600	1.117	0.050	1140	0.126	0.005
70	1.390	0.058	610	1.041	0.046	1150	0.185	0.008
80	1.457	0.062	620	1.007	0.044	1160	0.074	0.003
90	1.444	0.061	630	0.762	0.032	1170	0.115	0.005
100	1.380	0.057	640	0.765	0.032	1180	0.082	0.003
110	1.315	0.055	650	0.957	0.040	1190	0.041	0.002

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$
120	1.304	0.056	660	0.858	0.036	1200	0.088	0.004
130	1.397	0.060	670	0.793	0.033	1210	0.096	0.004
140	1.407	0.061	680	0.841	0.035	1220	0.034	0.001
150	1.400	0.061	690	0.691	0.029	1230	0.014	0.001
160	1.235	0.053	700	0.719	0.030	1240	0.036	0.002
170	1.342	0.058	710	0.635	0.026	1250	0.002	0.000
180	1.337	0.058	720	0.692	0.029	1260	0.031	0.001
190	1.377	0.060	730	0.847	0.036	1270	0.050	0.002
200	1.207	0.052	740	0.750	0.032	1280	0.040	0.002
210	1.232	0.053	750	0.660	0.029	1290	0.039	0.002
220	1.338	0.058	760	0.834	0.037	1300	0.006	0.000
230	1.433	0.063	770	0.789	0.034	1310	0.025	0.001
240	1.374	0.061	780	0.701	0.030	1320	0.042	0.002
250	1.366	0.062	790	0.744	0.031	1330	0.083	0.004
260	1.577	0.073	800	0.677	0.028	1340	0.058	0.002
270	1.729	0.080	810	0.453	0.019	1350	0.026	0.001
280	1.735	0.079	820	0.379	0.016	1360	0.019	0.001
290	1.369	0.061	830	0.284	0.012	1370	0.074	0.003
300	1.360	0.060	840	0.005	0.000	1380	0.087	0.004
310	1.554	0.070	850	0.034	0.001	1390	0.005	0.000
320	1.475	0.067	860	0.237	0.010	1400	0.019	0.001
330	1.382	0.063	870	0.380	0.016	1410	0.044	0.002
340	1.365	0.061	880	0.404	0.017	1420	0.013	0.001
350	1.260	0.056	890	0.285	0.012	1430	0.030	0.001
360	1.334	0.060	900	0.252	0.010	1440	0.006	0.000
370	1.451	0.067	910	0.287	0.012	1450	0.013	0.001
380	1.760	0.083	920	0.310	0.013	1460	0.043	0.002
390	1.787	0.083	930	0.240	0.010	1470	0.013	0.001
400	1.594	0.073	940	0.207	0.009	1480	0.010	0.000
410	1.331	0.061	950	0.147	0.006	1490	0.026	0.001
420	1.349	0.061	960	0.125	0.005	1500	0.009	0.000
430	1.297	0.059	970	0.152	0.006	1510	0.053	0.002
440	1.339	0.060	980	0.176	0.007	1520	0.004	0.000
450	1.259	0.056	990	0.163	0.007	1530	0.027	0.001
460	1.093	0.049	1000	0.107	0.004	1540	0.008	0.000
470	1.064	0.049	1010	0.120	0.005	1550	0.039	0.002
480	1.026	0.047	1020	0.180	0.007	1560	0.009	0.000
490	1.078	0.049	1030	0.040	0.002	1570	0.064	0.003
500	1.104	0.051	1040	0.087	0.004	1580	0.009	0.000
510	1.053	0.048	1050	0.122	0.005	1590	0.048	0.002
520	0.862	0.039	1060	0.148	0.006	1600	0.045	0.002
530	0.844	0.038	1070	0.143	0.006			

TABLE 9. Estimated energy spectrum of the fifth group of delayed neutrons from fission of ^{235}U.

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$
0	0.031	0.001	540	1.062	0.047	1080	0.337	0.013
10	0.082	0.004	550	1.143	0.050	1090	0.297	0.011
20	0.146	0.006	560	1.124	0.050	1100	0.376	0.014
30	0.520	0.020	570	0.917	0.041	1110	0.344	0.013
40	0.497	0.018	580	0.805	0.037	1120	0.350	0.013
50	0.413	0.016	590	0.687	0.031	1130	0.416	0.016
60	0.530	0.020	600	0.674	0.031	1140	0.342	0.013
70	0.442	0.018	610	0.828	0.037	1150	0.299	0.011
80	0.337	0.014	620	0.750	0.033	1160	0.381	0.014
90	0.590	0.024	630	0.954	0.042	1170	0.349	0.013
100	0.778	0.032	640	0.903	0.039	1180	0.364	0.014
110	0.989	0.041	650	0.619	0.026	1190	0.481	0.018
120	1.009	0.043	660	0.749	0.032	1200	0.349	0.013
130	0.927	0.040	670	0.702	0.030	1210	0.454	0.018
140	0.929	0.040	680	0.641	0.027	1220	0.262	0.010
150	1.048	0.045	690	0.663	0.028	1230	0.244	0.009
160	1.149	0.050	700	0.682	0.029	1240	0.299	0.011
170	1.218	0.053	710	0.673	0.028	1250	0.324	0.012
180	1.125	0.049	720	0.579	0.024	1260	0.280	0.011
190	1.065	0.046	730	0.481	0.021	1270	0.227	0.009
200	1.209	0.053	740	0.420	0.018	1280	0.272	0.011
210	1.255	0.056	750	0.463	0.020	1290	0.171	0.006
220	1.188	0.053	760	0.411	0.018	1300	0.367	0.014
230	1.246	0.057	770	0.382	0.016	1310	0.131	0.005
240	1.400	0.064	780	0.441	0.019	1320	0.158	0.005
250	1.396	0.065	790	0.370	0.015	1330	0.240	0.009
260	1.172	0.055	800	0.308	0.012	1340	0.160	0.006
270	1.055	0.049	810	0.439	0.018	1350	0.266	0.010
280	1.045	0.049	820	0.596	0.025	1360	0.170	0.006
290	1.333	0.061	830	0.506	0.021	1370	0.230	0.008
300	1.402	0.064	840	0.479	0.020	1380	0.288	0.011
310	1.333	0.062	850	0.520	0.022	1390	0.378	0.015
320	1.386	0.065	860	0.462	0.020	1400	0.472	0.019
330	1.369	0.064	870	0.391	0.016	1410	0.391	0.015
340	1.484	0.069	880	0.384	0.015	1420	0.265	0.010
350	1.708	0.080	890	0.476	0.019	1430	0.271	0.010
360	1.746	0.082	900	0.514	0.021	1440	0.320	0.012
370	1.402	0.067	910	0.557	0.022	1450	0.253	0.009
380	0.865	0.041	920	0.562	0.023	1460	0.234	0.009
390	1.089	0.052	930	0.514	0.021	1470	0.214	0.008
400	1.142	0.054	940	0.383	0.016	1480	0.183	0.007
410	1.147	0.053	950	0.457	0.019	1490	0.131	0.005

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$
420	1.089	0.051	960	0.436	0.018	1500	0.172	0.006
430	0.951	0.044	970	0.453	0.018	1510	0.219	0.008
440	1.071	0.049	980	0.410	0.017	1520	0.222	0.008
450	1.035	0.047	990	0.414	0.017	1530	0.185	0.007
460	1.219	0.056	1000	0.455	0.018	1540	0.161	0.006
470	1.196	0.055	1010	0.382	0.015	1550	0.134	0.005
480	1.120	0.052	1020	0.388	0.015	1560	0.167	0.006
490	1.337	0.062	1030	0.464	0.018	1570	0.169	0.006
500	1.087	0.051	1040	0.353	0.014	1580	0.125	0.005
510	0.962	0.044	1050	0.274	0.010	1590	0.129	0.005
520	1.166	0.053	1060	0.233	0.009	1600	0.152	0.006
530	1.186	0.054	1070	0.284	0.011			

TABLE 10. Estimated energy spectrum of the sixth group of delayed neutrons from fission of ^{235}U.

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$	E_n, keV	$\chi(E_n)$	$\Delta\chi(E_n)$
0	0.314	0.019	540	0.653	0.035	1080	0.022	0.001
10	0.766	0.042	550	0.751	0.041	1090	0.147	0.008
20	1.417	0.077	560	0.832	0.045	1100	0.205	0.011
30	1.400	0.075	570	0.781	0.042	1110	0.144	0.008
40	1.344	0.072	580	0.866	0.047	1120	0.162	0.009
50	1.490	0.080	590	0.765	0.042	1130	0.223	0.012
60	1.620	0.087	600	0.894	0.049	1140	0.146	0.008
70	1.578	0.085	610	0.710	0.039	1150	0.163	0.009
80	1.351	0.073	620	0.611	0.033	1160	0.109	0.006
90	1.076	0.058	630	0.594	0.032	1170	0.006	0.000
100	1.398	0.076	640	0.492	0.027	1180	0.213	0.011
110	1.785	0.097	650	0.628	0.034	1190	0.191	0.010
120	1.672	0.091	660	0.575	0.031	1200	0.093	0.005
130	1.628	0.088	670	0.622	0.034	1210	0.120	0.006
140	1.528	0.083	680	0.695	0.038	1220	0.083	0.004
150	1.448	0.079	690	0.577	0.031	1230	0.278	0.015
160	1.609	0.087	700	0.564	0.031	1240	0.183	0.010
170	1.891	0.103	710	0.599	0.032	1250	0.285	0.015
180	1.849	0.100	720	0.637	0.035	1260	0.086	0.005
190	1.382	0.075	730	0.495	0.027	1270	0.073	0.004
200	1.440	0.078	740	0.474	0.026	1280	0.159	0.009
210	1.325	0.072	750	0.464	0.025	1290	0.322	0.017
220	1.417	0.077	760	0.408	0.022	1300	0.260	0.014
230	1.406	0.076	770	0.498	0.027	1310	0.127	0.007
240	1.602	0.087	780	0.385	0.021	1320	0.175	0.009
250	1.448	0.079	790	0.265	0.014	1330	0.174	0.009
260	1.436	0.078	800	0.296	0.016	1340	0.184	0.010

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$
270	1.575	0.086	810	0.288	0.016	1350	0.189	0.010
280	1.616	0.088	820	0.186	0.010	1360	0.098	0.005
290	1.359	0.074	830	0.260	0.014	1370	0.226	0.012
300	1.371	0.075	840	0.256	0.014	1380	0.163	0.009
310	1.132	0.062	850	0.257	0.014	1390	0.249	0.013
320	1.275	0.069	860	0.261	0.014	1400	0.220	0.012
330	1.505	0.082	870	0.302	0.016	1410	0.164	0.009
340	1.486	0.081	880	0.322	0.017	1420	0.221	0.012
350	1.218	0.066	890	0.386	0.021	1430	0.198	0.011
360	1.140	0.062	900	0.324	0.018	1440	0.184	0.010
370	1.136	0.062	910	0.244	0.013	1450	0.111	0.006
380	1.275	0.069	920	0.094	0.005	1460	0.118	0.006
390	1.342	0.073	930	0.074	0.004	1470	0.110	0.006
400	1.100	0.060	940	0.174	0.009	1480	0.076	0.004
410	1.120	0.061	950	0.156	0.008	1490	0.077	0.004
420	1.061	0.058	960	0.203	0.011	1500	0.059	0.003
430	1.040	0.057	970	0.152	0.008	1510	0.079	0.004
440	0.755	0.041	980	0.251	0.014	1520	0.010	0.001
450	0.813	0.044	990	0.242	0.013	1530	0.069	0.004
460	0.813	0.044	1000	0.256	0.014	1540	0.051	0.003
470	0.888	0.048	1010	0.265	0.014	1550	0.061	0.003
480	1.052	0.057	1020	0.217	0.012	1560	0.020	0.001
490	1.189	0.065	1030	0.285	0.015	1570	0.065	0.003
500	1.207	0.066	1040	0.255	0.014	1580	0.063	0.003
510	1.321	0.072	1050	0.181	0.010	1590	0.054	0.003
520	1.109	0.060	1060	0.221	0.012	1600	0.037	0.002
530	0.777	0.042	1070	0.159	0.009			

TABLE 11. Estimated energy spectrum of the seventh group of delayed neutrons from fission of ^{235}U.

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$
0	0.343	0.019	540	1.358	0.074	1080	0.169	0.009
10	6.861	0.376	550	1.154	0.063	1090	0.156	0.008
20	1.795	0.098	560	1.000	0.055	1100	0.207	0.011
30	0.557	0.030	570	1.277	0.070	1110	0.217	0.012
40	0.861	0.047	580	1.308	0.072	1120	0.218	0.012
50	0.636	0.035	590	1.038	0.057	1130	0.284	0.015
60	0.636	0.035	600	1.045	0.057	1140	0.243	0.013
70	0.835	0.046	610	0.886	0.048	1150	0.186	0.010
80	1.247	0.068	620	0.746	0.041	1160	0.199	0.011
90	1.512	0.083	630	0.919	0.050	1170	0.131	0.007
100	1.206	0.066	640	0.682	0.037	1180	0.226	0.012
110	0.826	0.045	650	0.705	0.039	1190	0.179	0.010

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$
120	0.855	0.047	660	0.690	0.038	1200	0.123	0.007
130	0.986	0.054	670	0.729	0.040	1210	0.144	0.008
140	1.097	0.060	680	0.769	0.042	1220	0.140	0.008
150	1.164	0.064	690	0.829	0.045	1230	0.257	0.014
160	1.155	0.063	700	0.723	0.040	1240	0.170	0.009
170	1.282	0.070	710	0.657	0.036	1250	0.284	0.015
180	1.397	0.076	720	0.728	0.040	1260	0.132	0.007
190	1.239	0.068	730	0.782	0.043	1270	0.165	0.009
200	1.295	0.071	740	0.722	0.039	1280	0.261	0.014
210	1.389	0.076	750	0.604	0.033	1290	0.341	0.019
220	1.361	0.074	760	0.559	0.031	1300	0.309	0.017
230	1.269	0.069	770	0.568	0.031	1310	0.163	0.009
240	1.307	0.072	780	0.556	0.030	1320	0.161	0.009
250	1.406	0.077	790	0.674	0.037	1330	0.158	0.009
260	1.196	0.065	800	0.718	0.039	1340	0.182	0.010
270	0.919	0.050	810	0.672	0.037	1350	0.194	0.011
280	0.752	0.041	820	0.557	0.030	1360	0.105	0.006
290	0.622	0.034	830	0.452	0.025	1370	0.201	0.011
300	0.601	0.033	840	0.306	0.017	1380	0.189	0.010
310	1.004	0.055	850	0.270	0.015	1390	0.252	0.014
320	0.747	0.041	860	0.266	0.015	1400	0.278	0.015
330	0.896	0.049	870	0.284	0.016	1410	0.220	0.012
340	0.929	0.051	880	0.299	0.016	1420	0.220	0.012
350	0.845	0.046	890	0.322	0.018	1430	0.209	0.011
360	0.812	0.044	900	0.306	0.017	1440	0.172	0.009
370	0.782	0.043	910	0.217	0.012	1450	0.110	0.006
380	0.766	0.042	920	0.151	0.008	1460	0.128	0.007
390	0.732	0.040	930	0.108	0.006	1470	0.199	0.011
400	0.790	0.043	940	0.388	0.021	1480	0.130	0.007
410	0.905	0.050	950	0.293	0.016	1490	0.136	0.007
420	1.253	0.069	960	0.230	0.013	1500	0.111	0.006
430	1.251	0.068	970	0.314	0.017	1510	0.147	0.008
440	1.000	0.055	980	0.194	0.011	1520	0.184	0.010
450	1.017	0.056	990	0.288	0.016	1530	0.125	0.007
460	0.942	0.052	1000	0.325	0.018	1540	0.100	0.005
470	0.886	0.048	1010	0.276	0.015	1550	0.123	0.007
480	0.736	0.040	1020	0.367	0.020	1560	0.097	0.005
490	0.773	0.042	1030	0.334	0.018	1570	0.097	0.005
500	1.216	0.067	1040	0.242	0.013	1580	0.099	0.005
510	1.076	0.059	1050	0.215	0.012	1590	0.097	0.005
520	0.938	0.051	1060	0.233	0.013	1600	0.089	0.005
530	1.156	0.063	1070	0.190	0.010			

TABLE 12. Estimated energy spectrum of the eighth group of delayed neutrons from fission of ^{235}U.

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$
0	0.308	0.017	540	0.937	0.051	1080	0.215	0.012
10	0.899	0.049	550	0.887	0.049	1090	0.222	0.012
20	0.708	0.039	560	0.811	0.044	1100	0.222	0.012
30	1.020	0.056	570	0.816	0.045	1110	0.218	0.012
40	0.836	0.046	580	0.745	0.041	1120	0.215	0.012
50	0.772	0.042	590	0.702	0.038	1130	0.227	0.012
60	1.262	0.069	600	0.698	0.038	1140	0.186	0.010
70	1.465	0.080	610	0.707	0.039	1150	0.183	0.010
80	1.432	0.078	620	0.772	0.042	1160	0.167	0.009
90	1.339	0.073	630	0.840	0.046	1170	0.153	0.008
100	1.185	0.065	640	0.894	0.049	1180	0.174	0.010
110	1.086	0.059	650	0.838	0.046	1190	0.175	0.010
120	1.089	0.060	660	0.821	0.045	1200	0.160	0.009
130	1.210	0.066	670	0.775	0.042	1210	0.147	0.008
140	1.273	0.070	680	0.800	0.044	1220	0.156	0.009
150	1.396	0.076	690	0.819	0.045	1230	0.188	0.010
160	1.470	0.080	700	0.757	0.041	1240	0.155	0.009
170	1.365	0.075	710	0.679	0.037	1250	0.177	0.010
180	1.194	0.065	720	0.668	0.037	1260	0.146	0.008
190	1.078	0.059	730	0.621	0.034	1270	0.128	0.007
200	1.150	0.063	740	0.619	0.034	1280	0.140	0.008
210	1.179	0.065	750	0.621	0.034	1290	0.159	0.009
220	1.218	0.067	760	0.625	0.034	1300	0.147	0.008
230	1.181	0.065	770	0.607	0.033	1310	0.114	0.006
240	1.273	0.070	780	0.608	0.033	1320	0.117	0.006
250	1.322	0.072	790	0.594	0.033	1330	0.120	0.007
260	1.262	0.069	800	0.600	0.033	1340	0.117	0.006
270	1.346	0.074	810	0.589	0.032	1350	0.101	0.006
280	1.348	0.074	820	0.552	0.030	1360	0.083	0.005
290	1.297	0.071	830	0.535	0.029	1370	0.119	0.007
300	1.290	0.071	840	0.516	0.028	1380	0.115	0.006
310	1.413	0.077	850	0.475	0.026	1390	0.132	0.007
320	1.439	0.079	860	0.467	0.026	1400	0.131	0.007
330	1.424	0.078	870	0.475	0.026	1410	0.120	0.007
340	1.216	0.067	880	0.524	0.029	1420	0.131	0.007
350	1.124	0.062	890	0.594	0.033	1430	0.125	0.007
360	1.159	0.063	900	0.598	0.033	1440	0.118	0.006
370	1.206	0.066	910	0.524	0.029	1450	0.107	0.006
380	1.096	0.060	920	0.491	0.027	1460	0.090	0.005
390	0.995	0.055	930	0.499	0.027	1470	0.088	0.005
400	0.973	0.053	940	0.472	0.026	1480	0.093	0.005
410	0.968	0.053	950	0.391	0.021	1490	0.085	0.005

E_n (keV)	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$	$E_{n,}$ keV	$\chi(E_n)$	$\Delta\chi(E_n)$
420	1.009	0.055	960	0.354	0.019	1500	0.086	0.005
430	1.090	0.060	970	0.343	0.019	1510	0.086	0.005
440	1.233	0.068	980	0.345	0.019	1520	0.079	0.004
450	1.256	0.069	990	0.336	0.018	1530	0.077	0.004
460	1.081	0.059	1000	0.309	0.017	1540	0.075	0.004
470	0.980	0.054	1010	0.286	0.016	1550	0.070	0.004
480	0.900	0.049	1020	0.302	0.017	1560	0.068	0.004
490	0.945	0.052	1030	0.285	0.016	1570	0.068	0.004
500	1.053	0.058	1040	0.261	0.014	1580	0.069	0.004
510	1.065	0.058	1050	0.260	0.014	1590	0.063	0.003
520	1.016	0.056	1060	0.275	0.015	1600	0.066	0.004
530	0.964	0.053	1070	0.248	0.014			

5. Consistency of the estimated DN group spectra $\chi_i(E_n)$ with the primary composite experimental data

In order to check the consistency of the estimated DN group spectra $\chi_i(E_n)$ with the primary experimental data $N(E_n)$, we calculated with the help of Eq. (1) the composite spectra in different time intervals $\chi_i(E_n)$ for short and long-time irradiation both for the present and the JEFF group spectra. The obtained results are shown in Figs 7-18. One can see excellent agreement between the composite experimental data and the appropriate data obtained by summation of the group spectra $\chi_i(E_n)$ estimated by both the Kalman filtering and its Potter algorithm. The only difference is observed in the energy range 0-100 keV in the short irradiation data for the time interval 0.12-1 s. The calculated composite spectrum in this energy range is overestimated by 10% but is still in the limits of the experimental uncertainties.

The composite spectra obtained on the basis of the JEFF-3.1.1 8-group spectra reproduce the general shape and the peak structure of the experimental data, but in the time intervals for short irradiation, the spectra values deviate beyond the experimental uncertainties in the energy range 0-600 keV. In the energy range 0-200 keV, the JEFF-3.1.1 data overestimate the experimental data while in the energy range 300-600 keV they underestimate the present experimental data. In the time intervals for long irradiation data, the estimated DN spectra and JEFF spectra are in better agreement. The JEFF data underestimate the experimental composite spectra mainly in the energy range 300-500 keV. In the energy range above 600 keV, the JEFF data overestimate the peak intensities at energies 740, 850, 940, 1050 and 1140 keV.

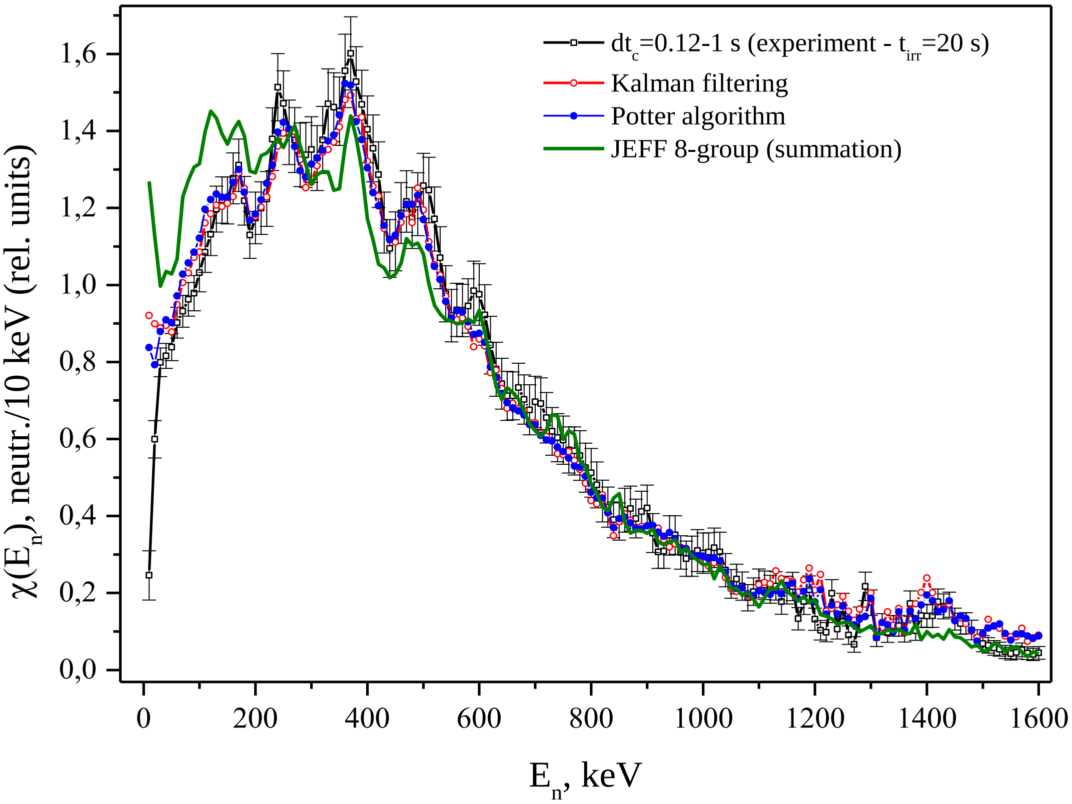

FIG. 7. The DN energy spectrum in the time interval 0.12-1 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, the Potter algorithm and the 8-group spectra taken from the JEFF-3.1.1 file. The irradiation time is 20 s. The time bin is 10 keV.

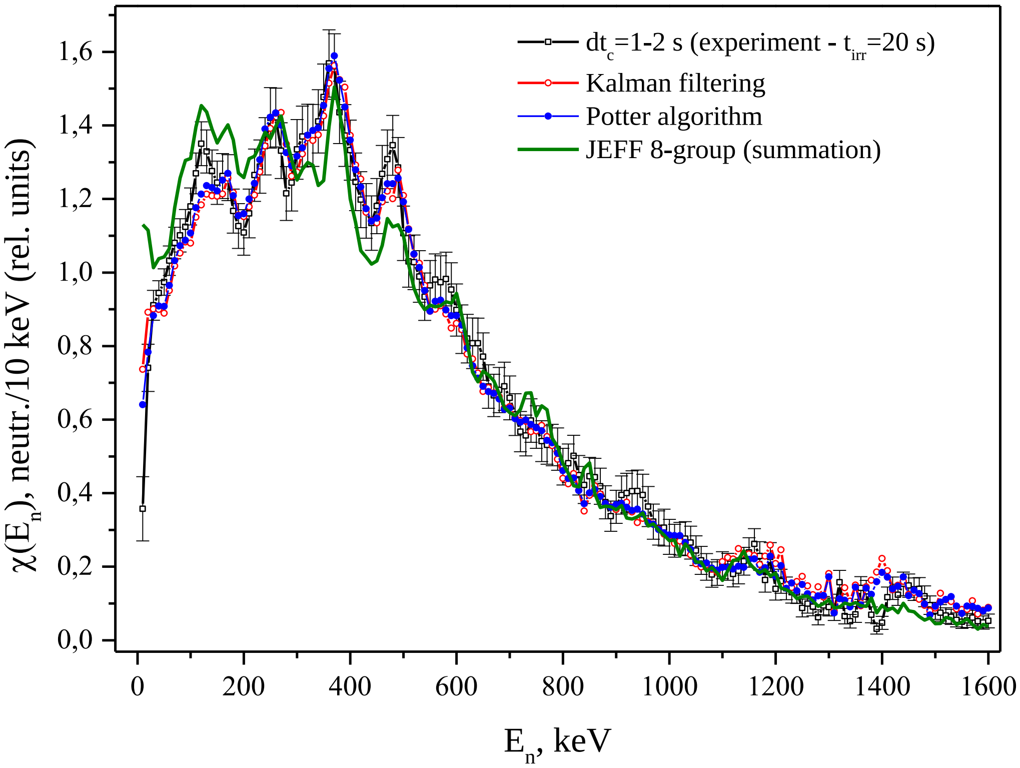

FIG. 8. The DN energy spectrum in the time interval 1-2 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, the Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 20 s. The time bin is 10 keV.

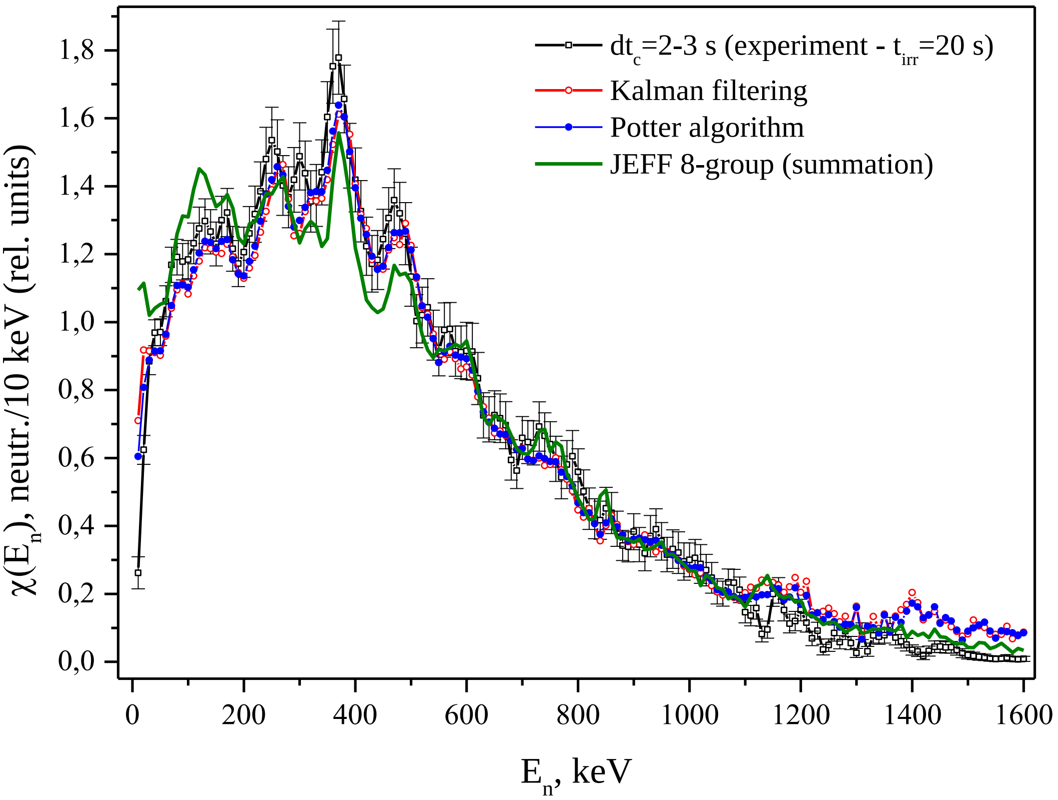

FIG. 9. The DN energy spectrum in the time interval 2-3 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, the Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 20 s. The time bin is 10 keV.

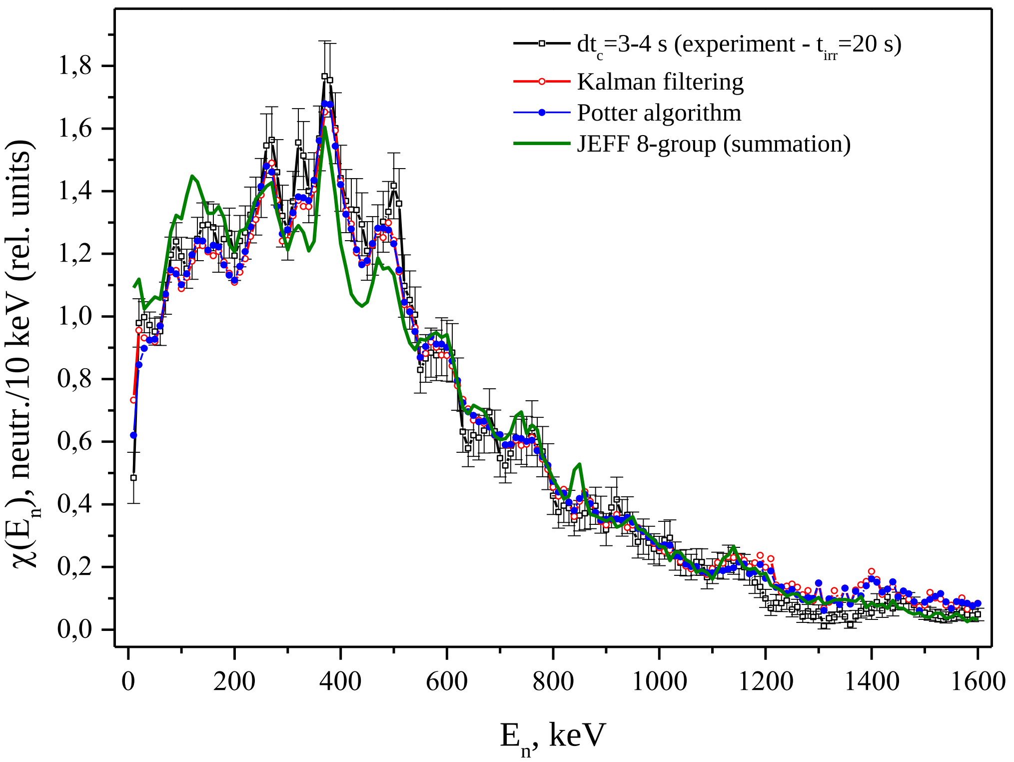

FIG. 10. The DN energy spectrum in the time interval 3-4 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, the Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 20 s. The time bin is 10 keV.

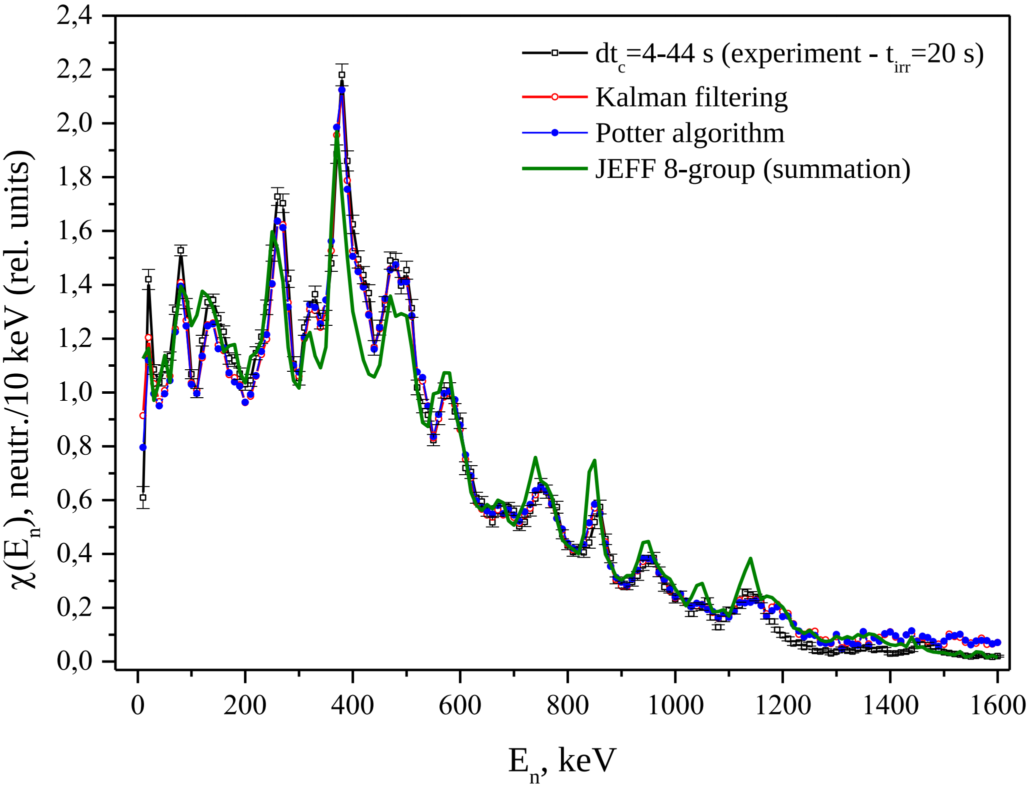

FIG. 11. The DN energy spectrum in the time interval 4-44 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, the Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 20 s. The time bin is 10 keV.

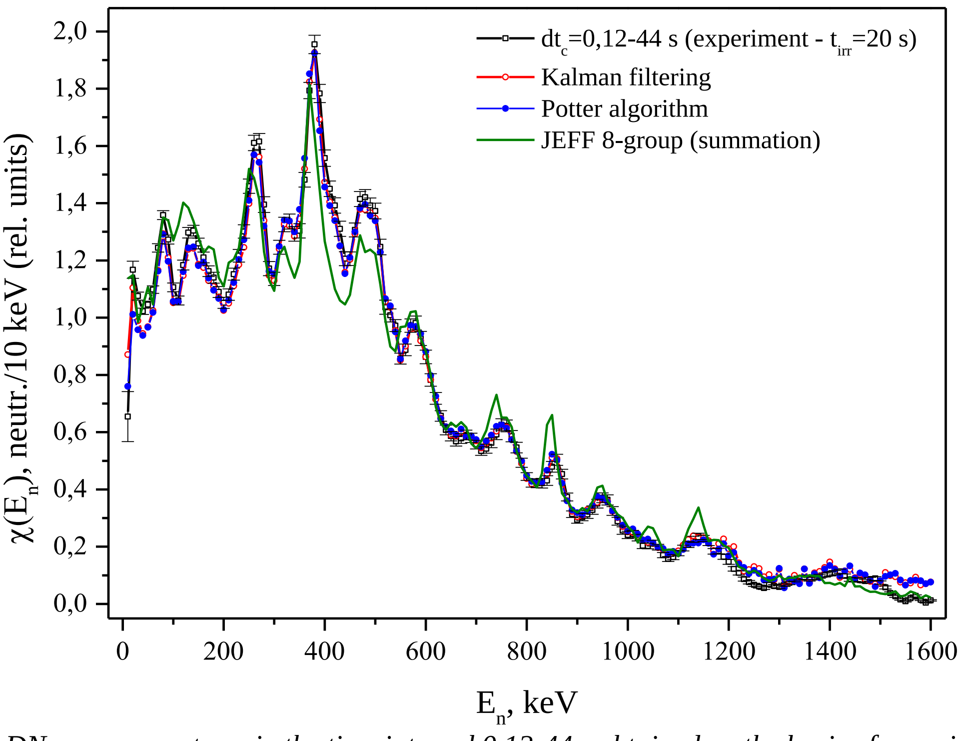

FIG. 12. The DN energy spectrum in the time interval 0.12-44 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, the Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 20 s. The time bin is 10 keV.

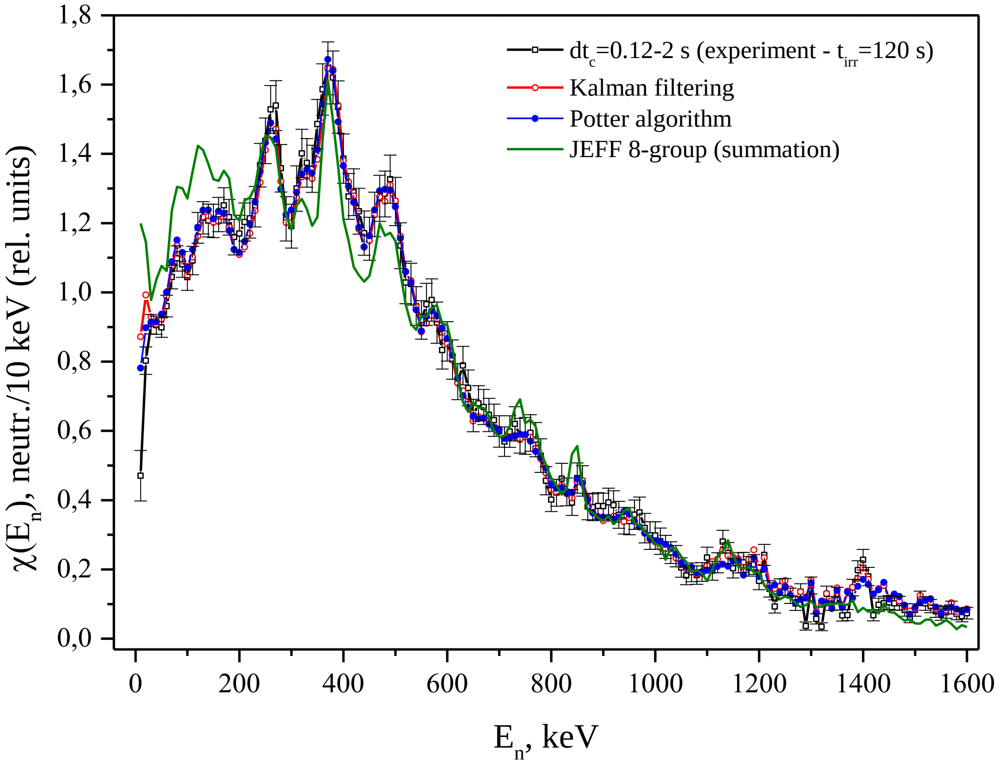

FIG. 13. The DN energy spectrum in the time interval 0.12-2 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, its Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 120 s. The time bin is 10 keV.

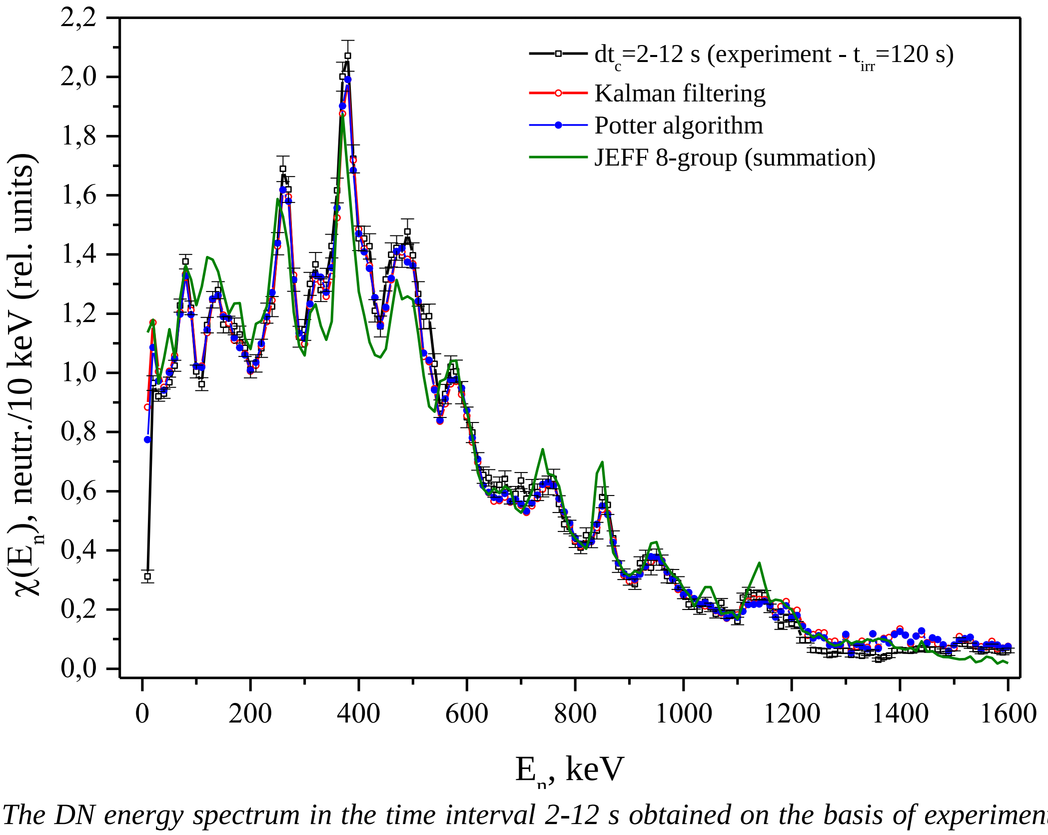

FIG. 14. The DN energy spectrum in the time interval 2-12 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, its Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 120 s. The time bin is 10 keV.

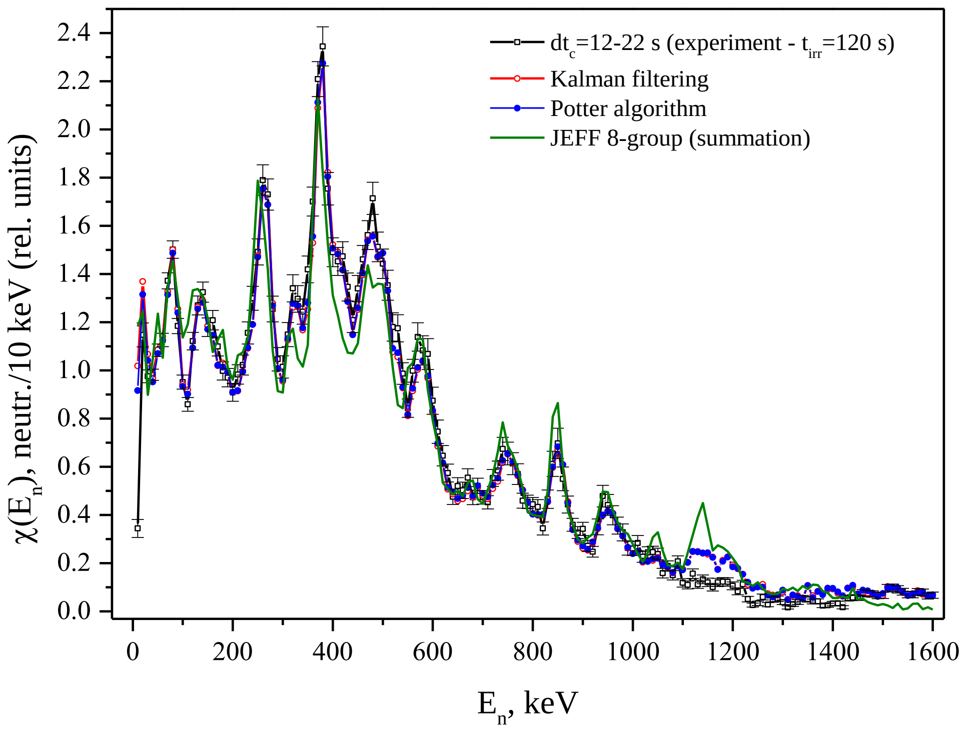

FIG. 15. The DN energy spectrum in the time interval 12-22 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, its Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 120 s. The time bin is 10 keV.

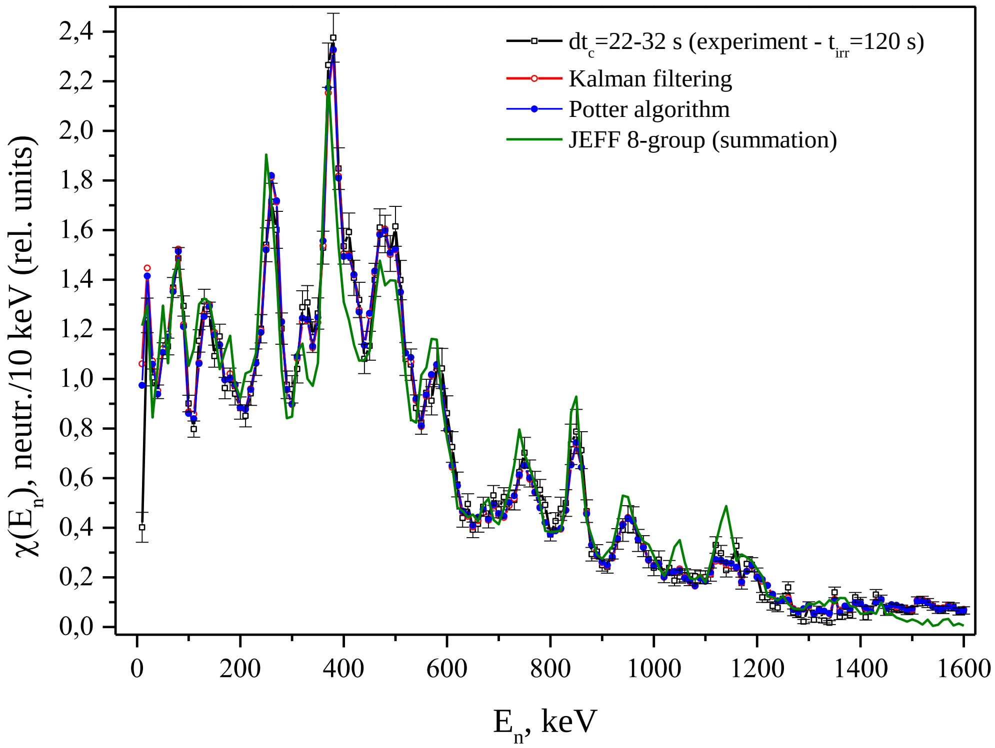

FIG. 16. The DN energy spectrum in the time interval 22-32 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, its Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 120 s. The time bin is 10 keV.

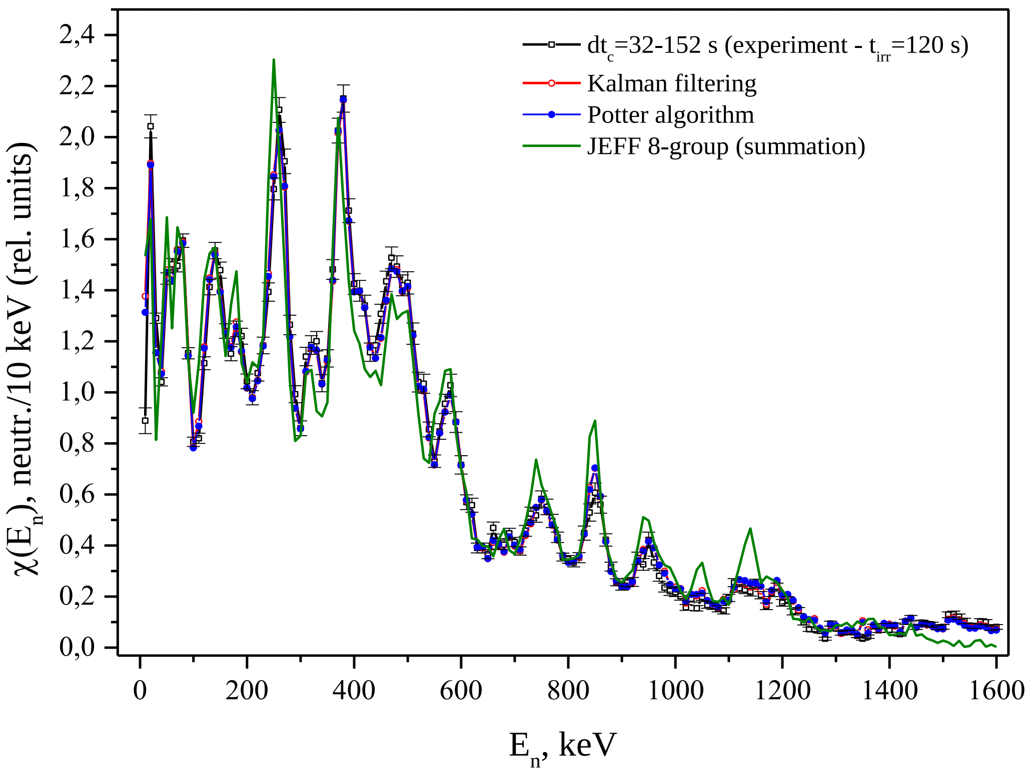

FIG. 27. The DN energy spectrum in the time interval 32-152 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, its Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 120 s. The time bin is 10 keV.

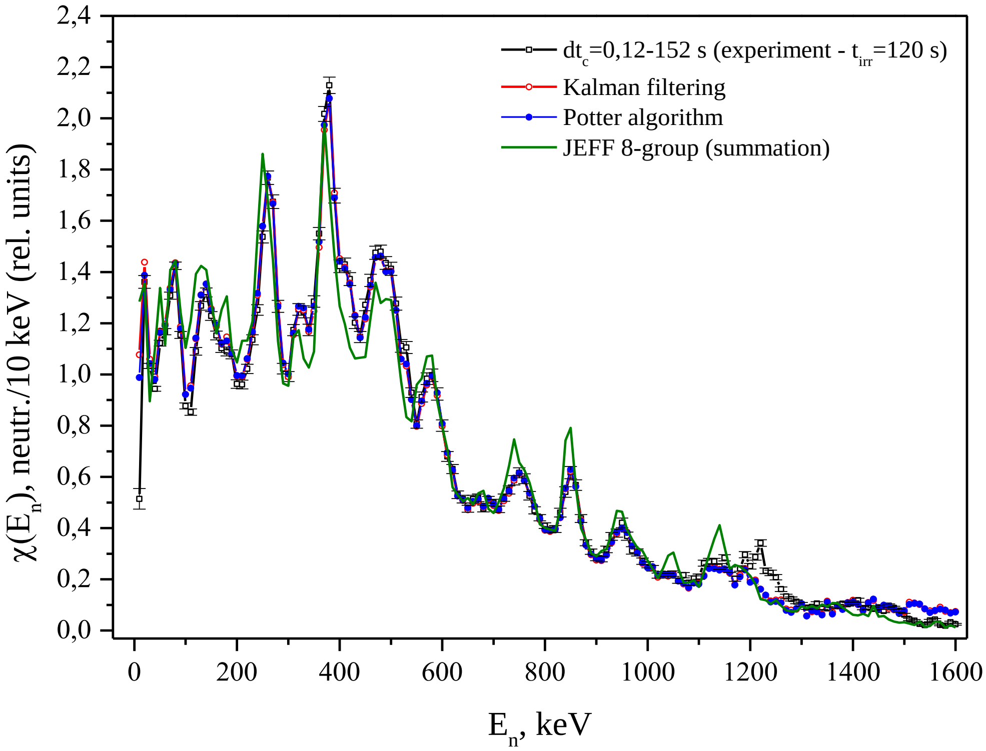

FIG. 18. The DN energy spectrum in the time interval 0.12-152 s obtained on the basis of experimental data and the summation method is compared with the 8-group spectra estimated by the Kalman filtering, its Potter algorithm and the 8-group spectra taken from JEFF-3.1.1 file. The irradiation time is 120 s. The time bin is 10 keV.

6. Presentation of 8-group DN spectral data for ^{235}U in the IAEA Reference database on beta-delayed neutrons

The IAEA delayed neutron spectral database contains high resolution delayed neutron composite energy spectra that have been measured in different time intervals after irradiation of ^{235}U by epi-thermal neutrons. These data have been used as a basis for estimation of the 8-group delayed neutron spectra with the help of the Kalman filtering method. The estimated 8-group spectra are compared with the 8-group spectra from the JEFF library. In order to check the consistency of the estimated delayed neutron 8-group spectra with the primary experimental data, the calculation of the composite spectra in different time intervals with the short and long-time irradiation both for the present and the JEFF 8-group spectra have been done (comparison is made in graphical form).

The database contains the following data:

1. **Composite delayed neutron energy spectra for long (tirr=120 s) and short (tirr=20 s) irradiation time intervals** (*"DN Integral spectra -short and long irradiation (numerical)xlsx" and "DN Integral spectra –experiment (short and long irradiation)".*

   Long irradiation data:
   Integral energy spectra and their uncertainties in time intervals dt_c=0.12-2, 2-12, 12-22, 22-32, 32-152, 0.12-152 s after the end of irradiation. **The data are presented in numerical and graphical form.**

   Short irradiation data:
   Integral energy spectra and their uncertainties in time intervals dt_c=0.12-1, 1-2, 2-3, 3-4, 4-44, 0.12-44 s after the end of irradiation**. The data are presented in numerical and graphical form.**

   In estimation of the uncertainties of the integral spectra, the following sources of errors were considered:

   1) statistical uncertainties - ΔN_c;
   2) neutron background uncertainties – ΔN_b;
   3) uncertainties of the spectrum of recoil nuclei ^3He - ΔN_{He-3} and recoil protons - ΔN_p, as well as the uncertainties of thermal peak ΔN_T;
   4) uncertainties of the efficiency of the neutron spectrometer ΔN_{eff} and the attenuation function of the neutron flux in the lead filter - ΔN_{Pb}.

   In integral spectra data two types of uncertainties are presented. The first one contains resulting uncertainties (ΔN_{res}) calculated on the basis of statistical, background, recoil nuclei and thermal peak uncertainties. The second type of uncertainties is the total uncertainties (ΔN_{tot}) which include efficiency and attenuation function uncertainties.

2. **The 8-group delayed neutron energy spectra for ^{235}U** (*"DN 8-Group spectra (numerical data).xlsx" and "DN 8-Group spectra-graphs").*

   The energy range of delayed neutron spectra: 0-1600 keV.
   The energy bins: 10 keV. Spectra normalized to 100.
   The data are presented in numerical and graph form.
   Comparison of the estimated 8-group delayed neutron spectra with corresponding data from the JEFF library is made in graphical form.

3. **The integral delayed neutron spectra in different time intervals calculated on the basis of the estimated 8-group delayed neutron spectra**. *("DN Integral spectra -experiment and calculations").*

   These data are compared with corresponding primary experimental integral data and data calculated on the basis of the 8-group spectra from the JEFF library.

The obtained 8-group spectra have universal character: they can be used for calculation of DN spectra for any fissioning system just by weighting group spectra data with corresponding group abundances.

7. Conclusion

In the present work, the Kalman filtering method and the Potter algorithm of the square root factorization have been used for the first time in the estimation of the 8-group DN spectra from the composite DN spectra measured at twelve delayed time intervals following thermal neutron-induced fission of ^{235}U. To apply the Kalman filter algorithm, the availability of information about the uncertainties of the initial data is a prerequisite. Given that the integral DN spectra available in the IAEA beta-delayed neutron database lack experimental uncertainties, we estimated these uncertainties as a first step and subsequently used them to determine the 8-group DN spectra and corresponding uncertainties by means of the Kalman filtering method.

The overall shape and peak structure of all eight resulting group spectra are similar to the corresponding group spectra in the JEFF data library. A good agreement with JEFF data is observed in the first two DN groups. In the remaining DN groups, the main differences between the compared spectra are observed in the peak intensities and shape of the spectra in the energy range above 1100 keV.

Both the Kalman estimated and JEFF 8-group DN spectra show good agreement with the experimental DN composite spectra. However, in the shorter time intervals, the composite spectra obtained from the JEFF 8-group data overestimate the low energy part of the neutron spectra in the range 100-200 keV and underestimate the spectra in the energy range 300-500 keV. In the longer time intervals, the compared composite spectra display different peak intensities in the high energy tails.

The 8-group DN spectral data for ^{235}U are available in the IAEA Reference database on beta-delayed neutrons.

The next step in development of the DN group spectra will be the estimation of the spectra in the 6-group model.

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