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AN EVALUATION OF URANIUM-235 NEUTRON CROSS SECTION DATA FOR ENERGIES ABOVE 15 kev

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AN EVALUATION OF URANIUM-235 NEUTRON CROSS SECTION DATA FOR ENERGIES ABOVE 15 kev

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ABSTRACT

The neutron cross section data for uranium-235 in the energy range 15 kev to 15 Mev has been reevaluated at Atomics International. This task was performed in support of the special working group effort directed by the National Neutron Cross Section Center.

The need for reevaluating and updating the fissile/fertile nuclide cross section data sets originally prepared for the ENDF/B library was established by the results of Phase II data testing.

I. INTRODUCTION

Revision of data sets for the major fissile/fertile nuclides has been recommended by the Data Testing Subcommittee of CSEWG. This recommendation was based on results from the ENDF/B Phase-II data testing program, the recent availability of significant new experimental data, and a lack of consistency between fission ratios for data sets evaluated at different laboratories and the experimental values of those ratios.

To minimize the time required to reevaluate these nuclides, a special Task Force consisting of experimentalists and evaluators was convened by the NNCSC. A highlight of this gathering was the frank exchange of opinions and views concerning measured data and data evaluations. Much wasted effort was thereby avoided.

In support of this Task Force effort a reevaluation of neutron cross section data for U-235 in the energy range 15 kev to 15 Mev was completed. The data were checked, found free of mechanical error, and forwarded to the NNCSC for placement on the revised ENDF/B data file.

II. EVALUATION METHODS

The evaluation of uranium-235 cross section data above 15 kev was carried out in accordance with the guidelines set up by the task force on fissile/fertile neutron cross sections. These guidelines included the adoption of Davey's[1,2] evaluated fission cross section data as a standard against which consistent sets of cross sections for the fissile and fertile nuclides would be obtained and re-evaluation of the data for U-235 alpha by using the Schmidt[3] alpha evaluation and incorporating the latest reported measurements. The radiative capture cross section was then obtained from the product of the standard fission cross section and the newly evaluated alpha. The available ENDF/B data files for the total, inelastic, (N,2N) and (N,3N) cross sections would remain unchanged, and the elastic scattering cross section would reflect the changes to the fission and capture cross sections.

For the present evaluation, the energy grid ($E \geq 15$ kev) associated with the original ENDF/B U-235 smooth elastic scattering cross section was chosen as a base for interpolating all other cross sections. The interpolation modes for the several cross section reactions are given in Table 1.

TABLE 1

INTERPOLATION MODES FOR THE SEVERAL U-235 CROSS SECTIONS

Reaction	σ	E
Total	Linear	Logarithmic
Capture	Logarithmic	Logarithmic
Fission	Linear	Logarithmic
Inelastic	Linear	Linear
(N,2N); (N,3N)	Linear	Linear
Alpha	Linear	Logarithmic

Figures 1 through 5 illustrate that the interpolation of the several reactions to the base energy grid does indeed provide a satisfactory representation of the cross section in all cases. The solid line represents the interpolated data and the circles represent the source data.

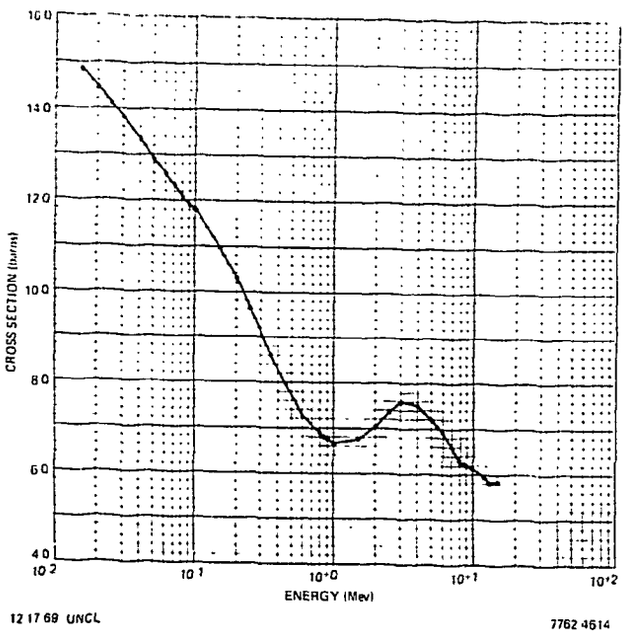

Figure 1. Uranium-235 Total Cross Section, Interpolated and Source Data

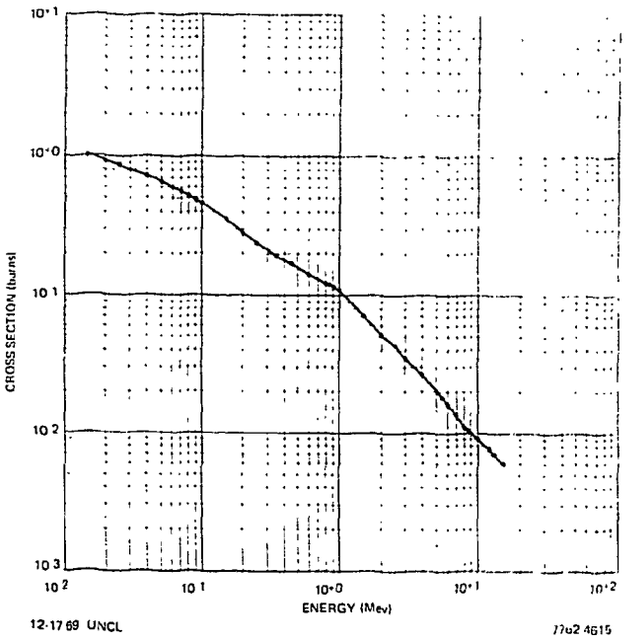

Figure 2. Uranium-235 Capture Cross Section, Interpolated and Source Data

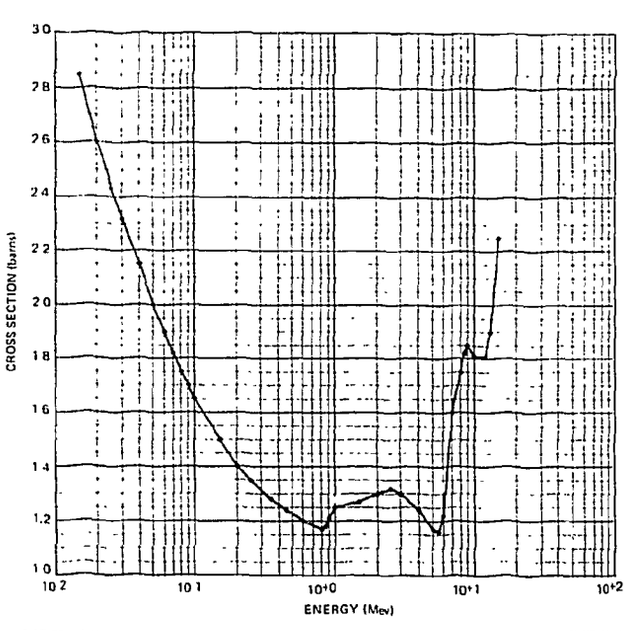

Figure 3. Uranium-235 Fission Cross Section, Interpolated and Source Data

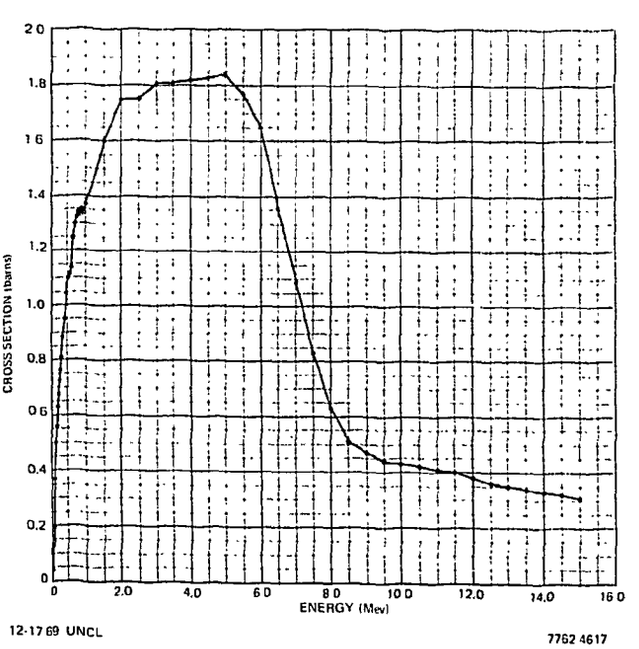

Figure 4. Uranium-235 Inelastic Cross Section, Interpolated and Source Data

For neutron energies between 15 kev and 10 Mev, Davey's evaluated fission cross section data[1, 2] were adopted. These data were similarly interpolated to the base energy grid, and the result is shown in Figure 6.

The data of de Saussure,[4] Weston,[5] Diven,[6] and Hopkins[7] were considered in evaluating alpha between 15 kev and 1 Mev. Figure 7 shows data and the evaluated data curves. The uncertainty on all these data points is between 10 and 15%.

Results of discussions with de Saussure (ORNL) relative to the two sets of ORNL alpha data, namely the lower values of Weston,[5] et al and the higher values of de Saussure,[4] et al provided no basis for preferring one data set over the other. It was decided to use a weighted average of the two sets of data.

The solid line on Figure 7 is the new recommended alpha curve for U-235. The dotted line indicates the Schmidt evaluation[3] where it deviates from the new evaluated curve. The present alpha evaluation is summarized below. The alpha curve over the full energy range is given in Figure 8.

Energy Region	Description
15 to 40 kev	Schmidt evaluation
40 to 60 kev	Smooth joining of the new and the Schmidt evaluations
60 to 200 kev	5 to 7% higher than Schmidt evaluation
200 to 400 kev	Smooth joining of the new and the Schmidt evaluations
400 kev to 10 Mev	Schmidt evaluation
10 to 15 Mev	Smooth continuation of Schmidt evaluation

These alpha values were combined with Davey's fission data evaluation, between 15 kev and 10 Mev, to generate new values of the capture cross section. Above 10 Mev, the U-235 fission cross section was taken from the measured data of Henkel, Nobles and Smith as corrected by Hansen and McGuire.[8] The capture cross section was then obtained by multiplying the fission data with alpha. All partial cross sections except the elastic scattering were summed and subtracted from the original U-235 total cross sections to obtain new values for elastic scattering.

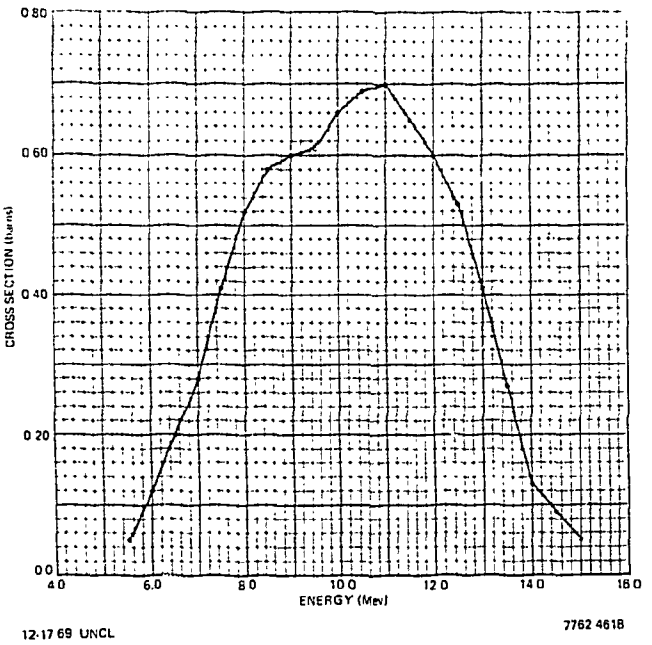

Figure 5. Uranium-235 (N,2N) Cross Section, Interpolated and Source Data

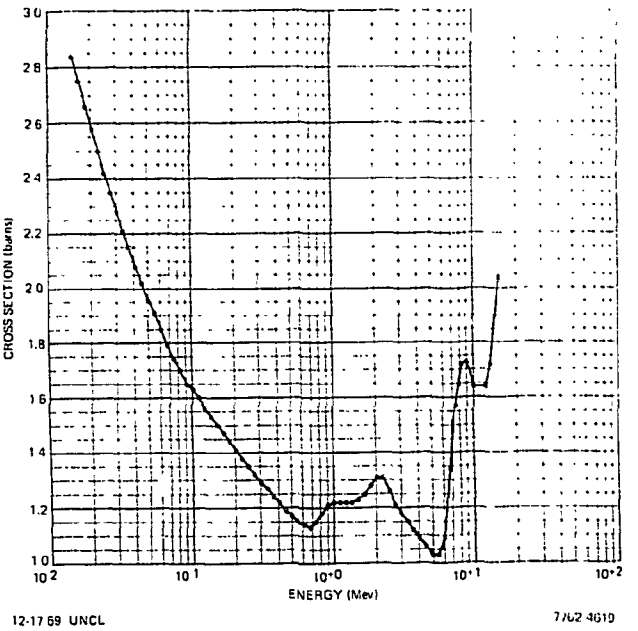

Figure 6. Uranium-235 Fission Cross Section, Davey

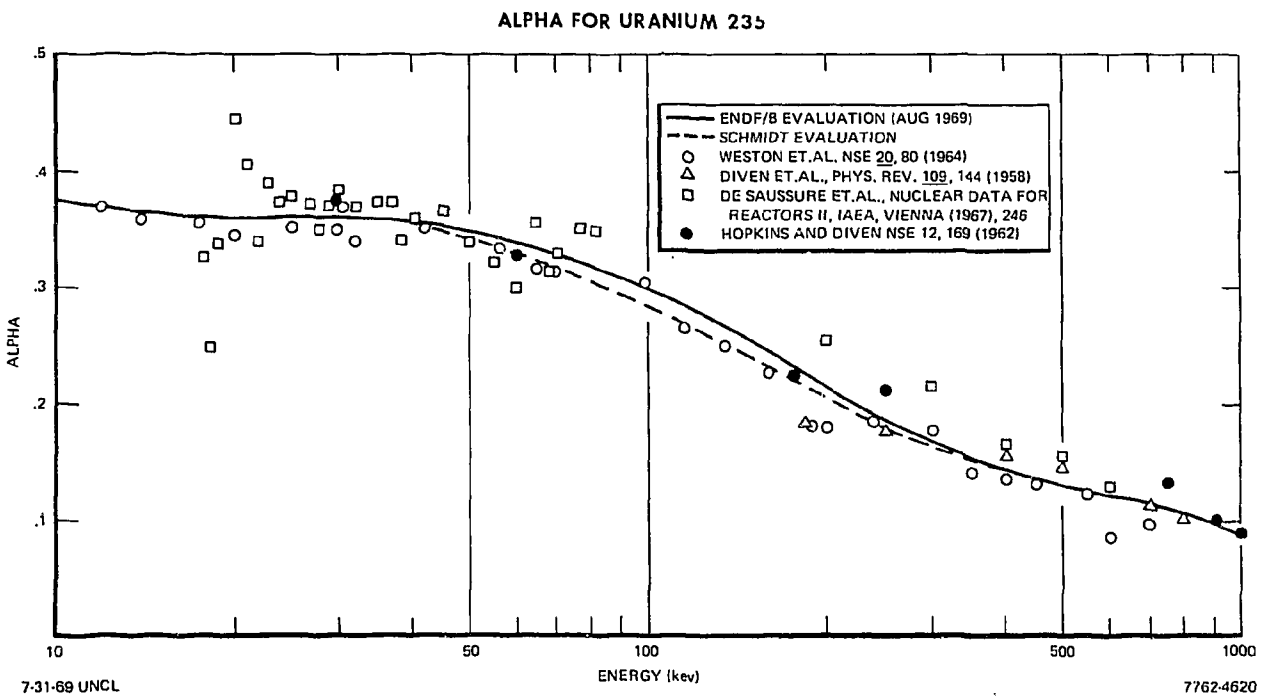

Figure 7. Uranium-235 Alpha, Between 15 kev and 1 Mev

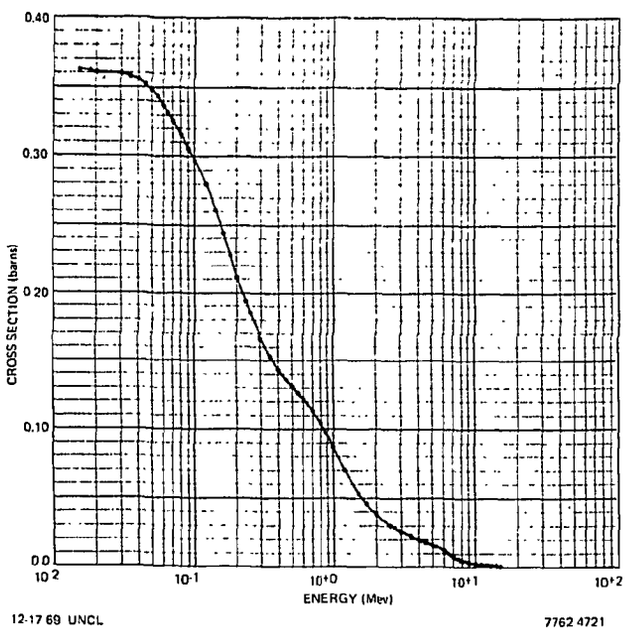

Figure 8. Uranium-235 Alpha
Over Full Energy Range

III. RESULTS

Comparisons of the original and reevaluated cross section data for elastic scattering, capture and fission are shown in Figures 9 through 11. Cross sections for total, elastic scattering, capture and fission reactions are listed in Table 2.

TABLE 2

REEVALUATED ENDFB U-235 CROSS SECTIONS (barns)

ENERGY (EV)	TOTAL	ELASTIC	CAPTURE	FISSION	ALPHA
1.500E 04	14.874	11.003	1.03092	2.840	0.36300
2.000E 04	14.440	10.912	0.93575	2.592	0.36100
2.500E 04	14.100	10.815	0.87026	2.414	0.36045
3.000E 04	13.834	10.724	0.82329	2.287	0.36000
3.500E 04	13.571	10.606	0.78171	2.184	0.35800
4.000E 04	13.344	10.502	0.74601	2.096	0.35600
4.500E 04	13.118	10.363	0.71198	2.023	0.35200
5.000E 04	12.915	10.234	0.68173	1.959	0.34800
5.500E 04	12.748	10.116	0.65766	1.912	0.34400
6.000E 04	12.596	10.024	0.62680	1.860	0.33700
6.500E 04	12.458	9.936	0.60152	1.812	0.33200
7.000E 04	12.330	9.850	0.57738	1.771	0.32600
7.500E 04	12.203	9.754	0.55739	1.737	0.32083
8.000E 04	12.084	9.655	0.54080	1.711	0.31600
8.500E 04	11.993	9.580	0.52346	1.684	0.31085
9.000E 04	11.907	9.484	0.50658	1.655	0.30600
9.500E 04	11.859	9.407	0.49479	1.642	0.30138
1.000E 05	11.814	9.327	0.48468	1.632	0.29700
1.200E 05	11.437	9.006	0.43949	1.570	0.28000
1.400E 05	11.119	8.726	0.39701	1.521	0.26100
1.600E 05	10.824	8.456	0.36134	1.481	0.24400
1.800E 05	10.547	8.194	0.32948	1.445	0.22800
2.000E 05	10.299	7.955	0.29956	1.413	0.21200
2.200E 05	10.016	7.699	0.27666	1.385	0.19972
2.400E 05	9.758	7.451	0.25737	1.359	0.18941
2.600E 05	9.518	7.198	0.24145	1.335	0.18091
2.800E 05	9.293	6.975	0.22731	1.312	0.17319
3.000E 05	9.084	6.768	0.21447	1.292	0.16600
3.200E 05	8.889	6.565	0.20527	1.278	0.16056
3.400E 05	8.705	6.374	0.19658	1.265	0.15544

TABLE 2 (Continued)

ENERGY (EV)	TOTAL	ELASTIC	CAPTURE	FISSION	ALPHA
3.600E 05	8.544	6.211	0.18822	1.247	0.15089
3.800E 05	8.404	6.064	0.18122	1.234	0.14684
4.000E 05	8.271	5.922	0.17502	1.224	0.14300
4.200E 05	8.144	5.775	0.16968	1.211	0.14010
4.400E 05	8.023	5.636	0.16437	1.197	0.13734
4.600E 05	7.911	5.509	0.16001	1.186	0.13496
4.800E 05	7.806	5.394	0.15650	1.177	0.13294
5.000E 05	7.706	5.283	0.15316	1.169	0.13100
5.200E 05	7.609	5.192	0.14974	1.161	0.12894
5.400E 05	7.517	5.105	0.14648	1.154	0.12696
5.600E 05	7.427	5.016	0.14372	1.148	0.12517
5.800E 05	7.341	4.925	0.14144	1.145	0.12356
6.000E 05	7.258	4.837	0.13924	1.141	0.12200
6.200E 05	7.216	4.760	0.13666	1.138	0.12009
6.400E 05	7.176	4.683	0.13418	1.135	0.11823
6.600E 05	7.137	4.617	0.13178	1.132	0.11643
6.800E 05	7.099	4.559	0.12987	1.132	0.11469
7.000E 05	7.062	4.496	0.12861	1.138	0.11300
7.200E 05	7.027	4.448	0.12707	1.144	0.11110
7.400E 05	6.992	4.401	0.12555	1.149	0.10925
7.600E 05	6.958	4.353	0.12431	1.157	0.10746
7.800E 05	6.925	4.305	0.12310	1.165	0.10571
8.000E 05	6.893	4.259	0.12191	1.172	0.10400
8.200E 05	6.856	4.219	0.12044	1.180	0.10210
8.400E 05	6.819	4.181	0.11897	1.187	0.10024
8.600E 05	6.793	4.147	0.11752	1.194	0.09843
8.800E 05	6.777	4.118	0.11607	1.201	0.09665
9.000E 05	6.761	4.089	0.11463	1.208	0.09492
9.200E 05	6.740	4.070	0.11294	1.211	0.09323
9.400E 05	6.719	4.053	0.11113	1.214	0.09157

TABLE 2 (Continued)

ENERGY (EV)	TOTAL	ELASTIC	CAPTURE	FISSION	ALPHA
9.600E 05	6.699	4.028	0.10936	1.216	0.08995
9.800E 05	6.679	3.996	0.10761	1.218	0.08836
1.000E 06	6.660	3.964	0.10590	1.220	0.08680
1.100E 06	6.682	3.951	0.09518	1.220	0.07802
1.200E 06	6.703	3.935	0.08540	1.220	0.07000
1.300E 06	6.722	3.916	0.07800	1.220	0.06394
1.400E 06	6.739	3.890	0.07136	1.223	0.05833
1.500E 06	6.755	3.860	0.06531	1.230	0.05310
1.600E 06	6.817	3.883	0.06116	1.244	0.04918
1.700E 06	6.876	3.900	0.05727	1.259	0.04550
1.800E 06	6.931	3.911	0.05452	1.275	0.04276
1.900E 06	6.983	3.919	0.05186	1.291	0.04016
2.000E 06	7.032	3.926	0.04927	1.307	0.03770
2.100E 06	7.108	4.001	0.04720	1.310	0.03603
2.200E 06	7.180	4.075	0.04511	1.310	0.03444
2.300E 06	7.249	4.162	0.04262	1.295	0.03291
2.400E 06	7.315	4.251	0.04008	1.274	0.03146
2.500E 06	7.378	4.337	0.03769	1.254	0.03006
2.600E 06	7.427	4.395	0.03593	1.234	0.02911
2.700E 06	7.475	4.451	0.03427	1.216	0.02819
2.800E 06	7.520	4.499	0.03284	1.202	0.02731
2.900E 06	7.564	4.543	0.03153	1.191	0.02646
3.000E 06	7.606	4.585	0.03028	1.181	0.02564
3.100E 06	7.596	4.586	0.02921	1.171	0.02494
3.200E 06	7.587	4.587	0.02818	1.162	0.02426
3.300E 06	7.578	4.588	0.02720	1.153	0.02360
3.400E 06	7.569	4.589	0.02626	1.144	0.02296
3.500E 06	7.560	4.590	0.02536	1.135	0.02234
3.600E 06	7.552	4.588	0.02459	1.127	0.02183
3.700E 06	7.543	4.587	0.02385	1.118	0.02132

TABLE 2 (Continued)

ENERGY (EV)	TOTAL	ELASTIC	CAPTURE	FISSION	ALPHA
3.800E 06	7.535	4.586	0.02314	1.110	0.02084
3.900E 06	7.528	4.585	0.02245	1.103	0.02036
4.000E 06	7.520	4.583	0.02179	1.095	0.01990
4.100E 06	7.486	4.555	0.02117	1.088	0.01946
4.200E 06	7.453	4.528	0.02056	1.080	0.01903
4.300E 06	7.420	4.501	0.01997	1.073	0.01861
4.400E 06	7.388	4.474	0.01941	1.066	0.01820
4.500E 06	7.357	4.449	0.01886	1.059	0.01780
4.600E 06	7.326	4.423	0.01837	1.053	0.01745
4.700E 06	7.296	4.398	0.01789	1.046	0.01710
4.800E 06	7.267	4.374	0.01743	1.040	0.01676
4.900E 06	7.239	4.349	0.01699	1.034	0.01643
5.000E 06	7.211	4.324	0.01658	1.030	0.01610
5.100E 06	7.177	4.305	0.01616	1.030	0.01569
5.200E 06	7.144	4.287	0.01575	1.030	0.01529
5.300E 06	7.112	4.269	0.01535	1.030	0.01490
5.400E 06	7.081	4.252	0.01495	1.030	0.01451
5.500E 06	7.050	4.184	0.01457	1.031	0.01413
5.600E 06	7.023	4.157	0.01434	1.042	0.01376
5.700E 06	6.997	4.130	0.01410	1.052	0.01340
5.800E 06	6.971	4.104	0.01386	1.063	0.01304
5.900E 06	6.945	4.079	0.01361	1.073	0.01269
6.000E 06	6.920	4.054	0.01337	1.083	0.01234
6.100E 06	6.885	4.041	0.01299	1.102	0.01178
6.200E 06	6.850	4.007	0.01285	1.144	0.01124
6.300E 06	6.815	3.974	0.01267	1.184	0.01070
6.400E 06	6.781	3.943	0.01245	1.224	0.01017
6.500E 06	6.747	3.912	0.01219	1.263	0.00965
6.600E 06	6.714	3.879	0.01190	1.302	0.00914
6.700E 06	6.682	3.846	0.01157	1.340	0.00863

TABLE 2 (Continued)

ENERGY (EV)	TOTAL	ELASTIC	CAPTURE	FISSION	ALPHA
6.800E 06	6.650	3.819	0.01117	1.374	0.0081
6.900E 06	6.618	3.792	0.01076	1.407	0.0076
7.000E 06	6.587	3.767	0.01031	1.440	0.0071
7.100E 06	6.555	3.728	0.01017	1.472	0.0069
7.200E 06	6.523	3.691	0.01001	1.504	0.0066
7.300E 06	6.492	3.654	0.00983	1.536	0.0064
7.400E 06	6.461	3.618	0.00965	1.567	0.0061
7.500E 06	6.430	3.592	0.00939	1.588	0.0059
7.600E 06	6.400	3.561	0.00913	1.608	0.0056
7.700E 06	6.370	3.530	0.00885	1.628	0.0054
7.800E 06	6.341	3.499	0.00858	1.647	0.0052
7.900E 06	6.311	3.469	0.00829	1.666	0.0049
8.000E 06	6.283	3.440	0.00800	1.685	0.0047
8.200E 06	6.259	3.406	0.00765	1.720	0.0044
8.400E 06	6.237	3.405	0.00716	1.723	0.0041
8.600E 06	6.220	3.403	0.00668	1.725	0.0038
8.800E 06	6.210	3.399	0.00621	1.727	0.0035
9.000E 06	6.200	3.395	0.00574	1.729	0.0033
9.200E 06	6.183	3.391	0.00539	1.725	0.0031
9.400E 06	6.167	3.384	0.00506	1.723	0.0029
9.600E 06	6.150	3.384	0.00469	1.704	0.0027
9.800E 06	6.134	3.384	0.00429	1.672	0.0025
1.000E 07	6.119	3.385	0.00392	1.640	0.0023
1.050E 07	6.071	3.354	0.00343	1.603	0.0021
1.100E 07	6.025	3.310	0.00305	1.602	0.0019
1.150E 07	5.981	3.295	0.00277	1.633	0.0017
1.200E 07	5.939	3.295	0.00249	1.660	0.0015
1.250E 07	5.877	3.251	0.00232	1.723	0.0013
1.300E 07	5.817	3.225	0.00217	1.810	0.0012
1.350E 07	5.825	3.294	0.00206	1.879	0.0011
1.400E 07	5.832	3.386	0.00192	1.924	0.0010
1.450E 07	5.839	3.389	0.00177	1.968	0.0009
1.500E 07	5.846	3.394	0.00161	2.010	0.0008

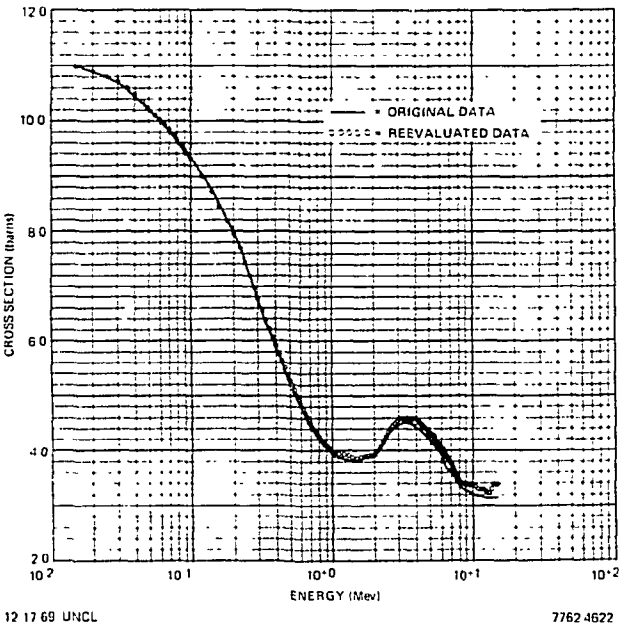

Figure 9. Uranium-235 Elastic Cross Section, Original and Reevaluated Data

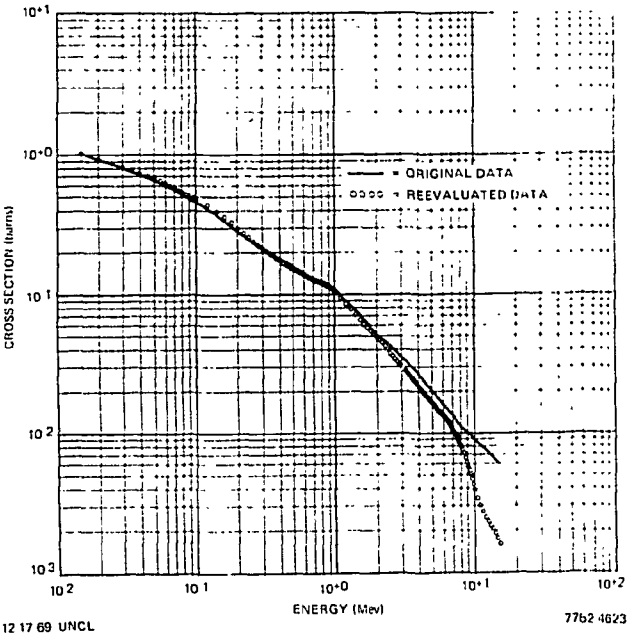

Figure 10. Uranium-235 Capture Cross Section, Original and Reevaluated Data

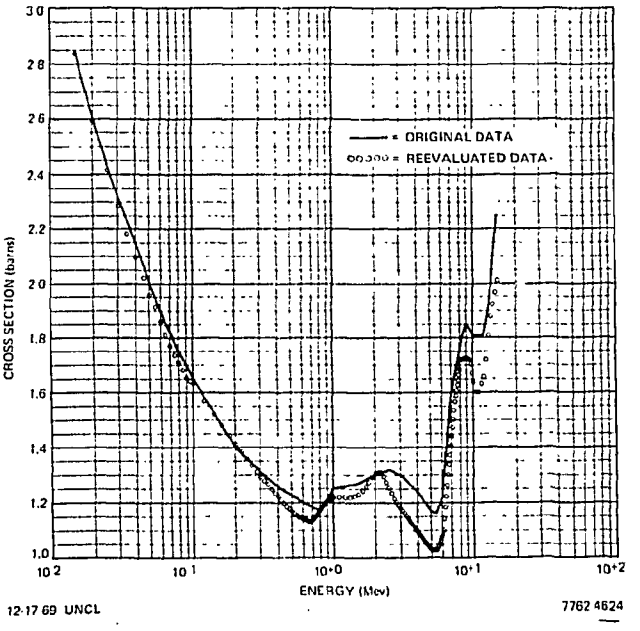

Figure 11. Uranium-235 Fission Cross Section, Original and Reevaluated Data

IV. SUMMARY

In summary, the capture and fission cross sections for U-235 were modified as reported; the total, inelastic (N,2N) and (N,3N) cross sections were not changed; new values of the elastic scattering cross section were obtained which reflect changes in the capture and fission cross sections only.

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