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A 218-Group Neutron Cross-Section Library in the AMPX Master Interface Format for Criticality Safety Studies

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OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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ABSTRACT

A P_3, 218 neutron group cross-section library in the AMPX master interface format has been generated from ENDF/B-IV data for 65 nuclides of primary interest in criticality safety calculations. The library was generated with the AMPX modular code system. Procedures used to generate the cross sections and the organization of the library are described.

LIST OF FIGURES AND TABLES

ACKNOWLEDGMENTS

The authors wish to express appreciation to D. M. Plaster and B. R. Diggs who contributed to the generation of the cross-section library described herein, to N. M. Greene and L. M. Petrie who provided AMPX guidance, to R. W. Roussin, J. B. Wright, and other members of the Radiation Shielding Information Center Staff who packaged the library for distribution, and to Becky Eddlemon who typed this report.

I. The Criticality Safety Master Cross-Section Library

The XLACS module of the AMPX modular code system[1] was used to generate a P_3, 218 neutron group cross-section library from the latest ENDF/B-IV data for the fuel, structural, and neutron-absorbing materials listed in Table 1. Data in the library are in the AMPX master interface format described in Appendix A. The library is a data base for the generation of fine- or broad-group cross sections for shipping cask calculations and other criticality safety neutronics analyses using Monte Carlo codes such as KENO[2] or MORSE[3], or using the one- or two-dimensional discrete ordinates transport codes ANISN[4] or DOT[5], respectively.

The objective in the selection of the energy group boundaries for the library was to fit the important cross-section structure of materials likely to appear in criticality safety problems. Emphasis was placed on the resonance and thermal energy ranges. The 218 energy group structure, which includes 140 epithermal groups above and 78 thermal groups below 3.05 eV, is listed in Table 2. In the epithermal energy range, the energy boundaries were chosen to fit the reaction thresholds and major resonance levels of the following nuclides: Be, B-10, C, N, O, F, Na, Mg, Al, Si, K, Ca, Cr, Mn, Fe, Ni, Cu, Zr, Mo, Ag, Cd, In, Sn, Ba, Gd, Hf, Pb, Th-232, U-233, U-234, U-235, U-236, U-238, Pu-238, Pu-239, Pu-240, and Pu-241. Of the 140 epithermal groups, 51 groups cover the fission-neutron-energy range from 20 MeV to 8.03 keV. This energy range includes most of the cross-section structure for the light and intermediate-mass nuclides. It also includes inelastic scattering and fission thresholds for certain of the heavy nuclides. The 89 groups between 8.03 keV and 3.05 eV were chosen to bracket major resonance levels in the intermediate-mass and heavy nuclides. In the thermal energy range, several of the fuel and neutron absorbing

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nuclides have large resonances which are broad relative to the neutron energy exchange per collision. The 78 closely spaced thermal groups are designed to account for the effects of these resonances in the presence of thermal upscatter. Criteria used in the selection of energy boundaries are listed in Appendix B.

Among the many types of cross-section libraries that can be generated with the AMPX system (libraries such as ANISN-formatted libraries, CCCC- or ISOTXS-formatted libraries, or "working" libraries), the format of an AMPX master interface cross-section library is the most general way to store multigroup neutron cross-section data in the AMPX system. Included in a master cross-section library are one-dimensional multigroup cross-section data, transfer matrices for elastic and inelastic scattering reactions and for neutron producing reactions (e.g., (n,2n)) with arbitrary orders of scatter for fast and thermal data where required, resonance self-shielding parameters for subsequent processing, fission spectrum data, weighting function data, etc. These data are available in a compacted magic word format to remove extraneous zeros and consequently to substantially reduce tape storage requirements. One-dimensional and transfer matrix data in the criticality safety library are identified by MT number[a] in Table 1 and the MT number - reaction relation is identified in Table 3.

Data sets with resolved resonance parameters, resonance nuclei, are identified in Table 1. An unresolved potential scattering cross section of 5×10^4 barns/atom was used to calculate the master cross sections. Resonances were Doppler broadened at 293°K. Resolved resonance cross sections, which will depend on the heterogeneous system to which the cross sections will be applied, must be calculated and added to the master

[a]It is assumed that the reader is familiar with the ENDF nomenclature described in Ref. 6.

cross-section data. As noted above, parameters are included in the master library for the subsequent processing of resolved resonance cross sections by the NITAWL module of the AMPX system. The NITAWL module also combines the master cross-section data with the resolved cross-section data to give a "complete" neutron cross-section data set.

Several weighting spectra were used to prepare the fine group data in the master cross-section library from the ENDF/B point data. For non-resonance materials, a fission-$1/E\sigma_T$-Maxwellian weighting spectrum was used. Materials with resonance parameters were processed with a fission-1/E-Maxwellian weighting function. In addition to being processed with the resonance material weight function, Fe, Ni, and Cr data sets were weighted over a $1/E\Sigma_T$(inconel)-Maxwellian and over a $1/E\Sigma_T$(scainless steel 304)-Maxwellian weight function. The weight functions used for the data sets in the criticality safety library are identified in Table 1. Energy ranges over which the weight functions were used are listed in Table 4. Plots of the fission-$1/E\sigma_T$(oxygen)-Maxwellian, the fission-1/E-Maxwellian, the $1/E\Sigma_T$ inconel-Maxwellian, and the $1/E\Sigma_T$(stainless steel 304)-Maxwellian weight functions are shown in Figs. 1-4, respectively.

The master cross-section library was checked using the AMPX module RADE to prove the following cross-section relationships:

$$\sigma_T = \sigma_a + \sigma_s \tag{1}$$

$$\sigma_{inel} = \sum \sigma_{inel}^{partial} \tag{2}$$

$$\sigma_a = \sigma_c + \sigma_f \tag{3}$$

$$\sigma_c = \sigma_{n\gamma} + \sigma_{n\alpha} + \sigma_{np} + \sigma_{nd} + \ldots \tag{4}$$

$$\sigma_{el}^g = \sum \sigma_0^g \ (g \rightarrow g') \tag{5}$$

$$\sigma_0(g \rightarrow g') > 0 \tag{6}$$

$$\sigma_T, \sigma_a, \sigma_f, \sigma_{np}, \sigma_{n\gamma}, \ldots \text{ etc.} \geq 0 \tag{7}$$

$$-1 \leq \mu(g \to g') \left[= \frac{\sigma_1(g \to g')}{3\sigma_0(g \to g')} \right] \leq 1 \ . \tag{8}$$

II. Availability and Utilization of the Criticality Safety Master Cross-Section Library

The criticality safety master cross-section library, the AMPX modular code system, and the transport codes identified herein may be obtained on request from the Radiation Shielding Information Center at the Oak Ridge National Laboratory.

The flowchart shown in Fig. 1 and the following summary describe how the master cross-section library and modules of the AMPX system can be used to generate either fine- or broad-group cross sections in different formats:

- The MALOCS module can be used to collapse data sets from the master library to any broad group structure which is a subset of the 218 group structure. The multigroup fission-1/E-Maxwellian weighting function used in the generation of the data sets for resonance nuclides in the master library is listed in Table 5. These data can be used as a collapsing function in MALOCS.
- The NITAWL module can be used to prepare ANISN-formatted cross sections from data in the master library.[a]

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[a]ANISN library format is described on page 23 of Ref. 4.

- The LAPHNGAS module can be used to prepare secondary gamma-ray production data in any specified gamma-ray group structure. These data are prepared from data in the ENDF/B libraries. The SMUG module can be used to prepare photon interaction cross sections in any multigroup gamma-ray structure. The CHOX module can be used to combine data from the criticality safety master cross-section library with the LAPHNGAS and SMUG generated data for further processing in the NITAWL module to ultimately generate coupled neutron-gamma multigroup cross sections.
- The COMMAND module can be used to collapse ANISN-formatted data sets to any broad group structure which is a subset of the 218 group structure. The weighting function listed in Table 5 can be used as a collapsing function in COMMAND.
- The ICE module can be used to prepare macroscopic master cross sections from the criticality safety master cross-section library.
- The UPDATE feature of the XLACS module can be used to update the master cross-section library by adding or removing data sets.
- "Working" cross-section libraries produced by the NITAWL module from master data sets can be flux weighted in the XSDRNPM module to produce weighted fine- or broad-group ANISN-formatted libraries, "working" cross-section libraries, or CCCC-formatted libraries. XSDRNPM is the AMPX module with one-dimensional S_n capability for spatial cross-section weighting.

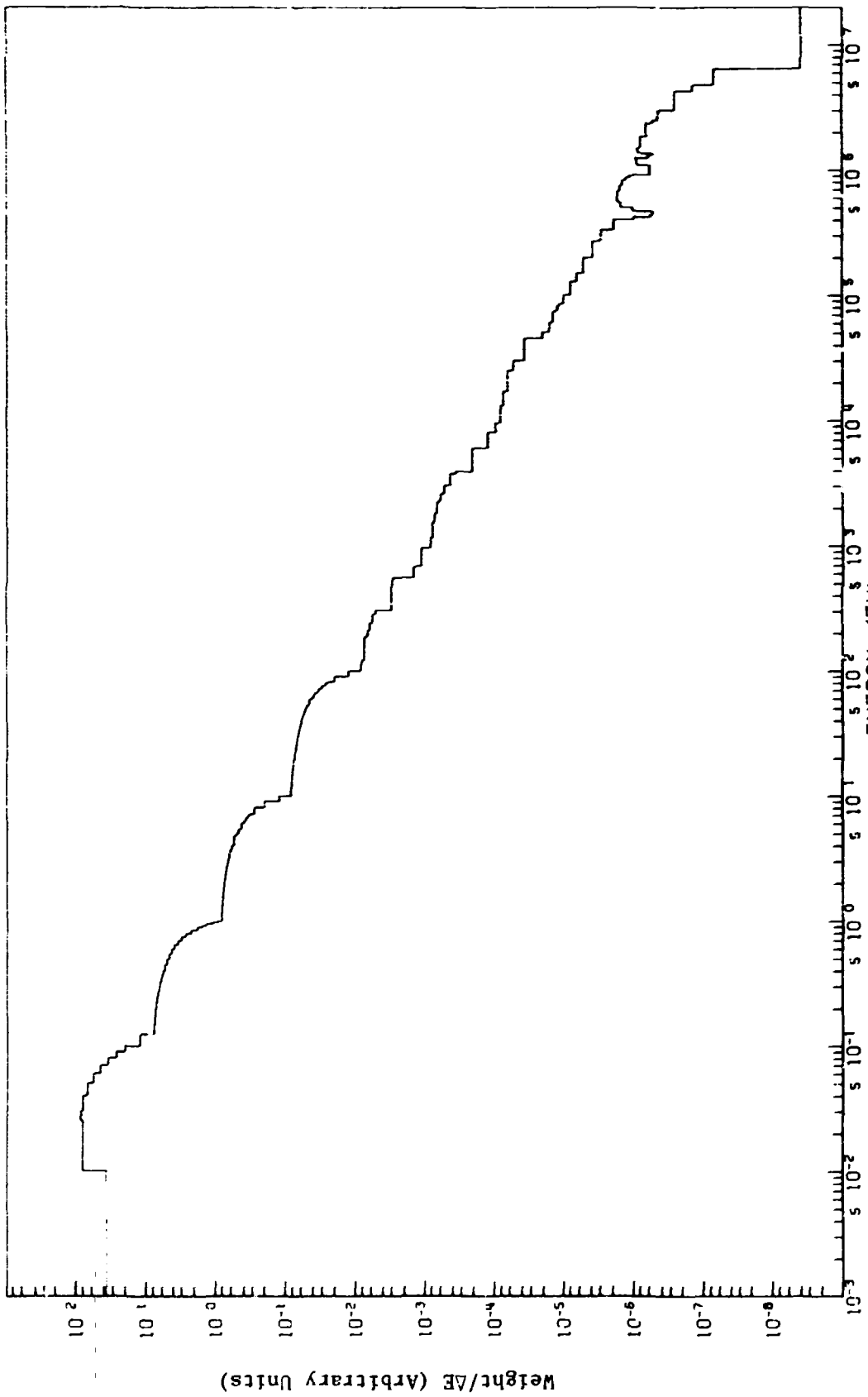

Figure 1. Fission-1/Eσ_T(Oxygen)-Maxwellian Weight Function

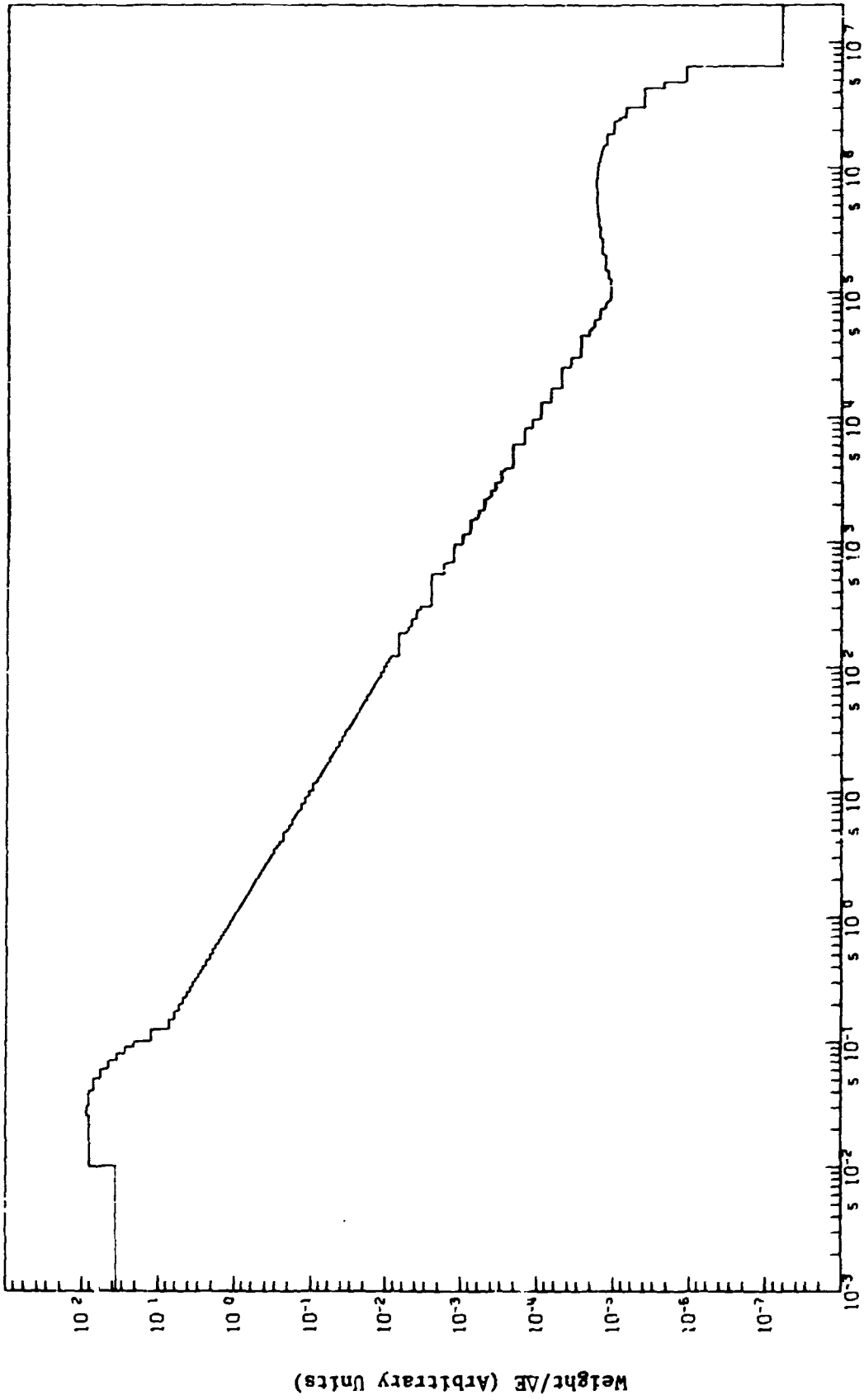

Figure 2. Fission-1/E-Maxwellian Weight Function

Figure 3. $1/E\Sigma_T$(Inconel)-Maxwellian Weight Function

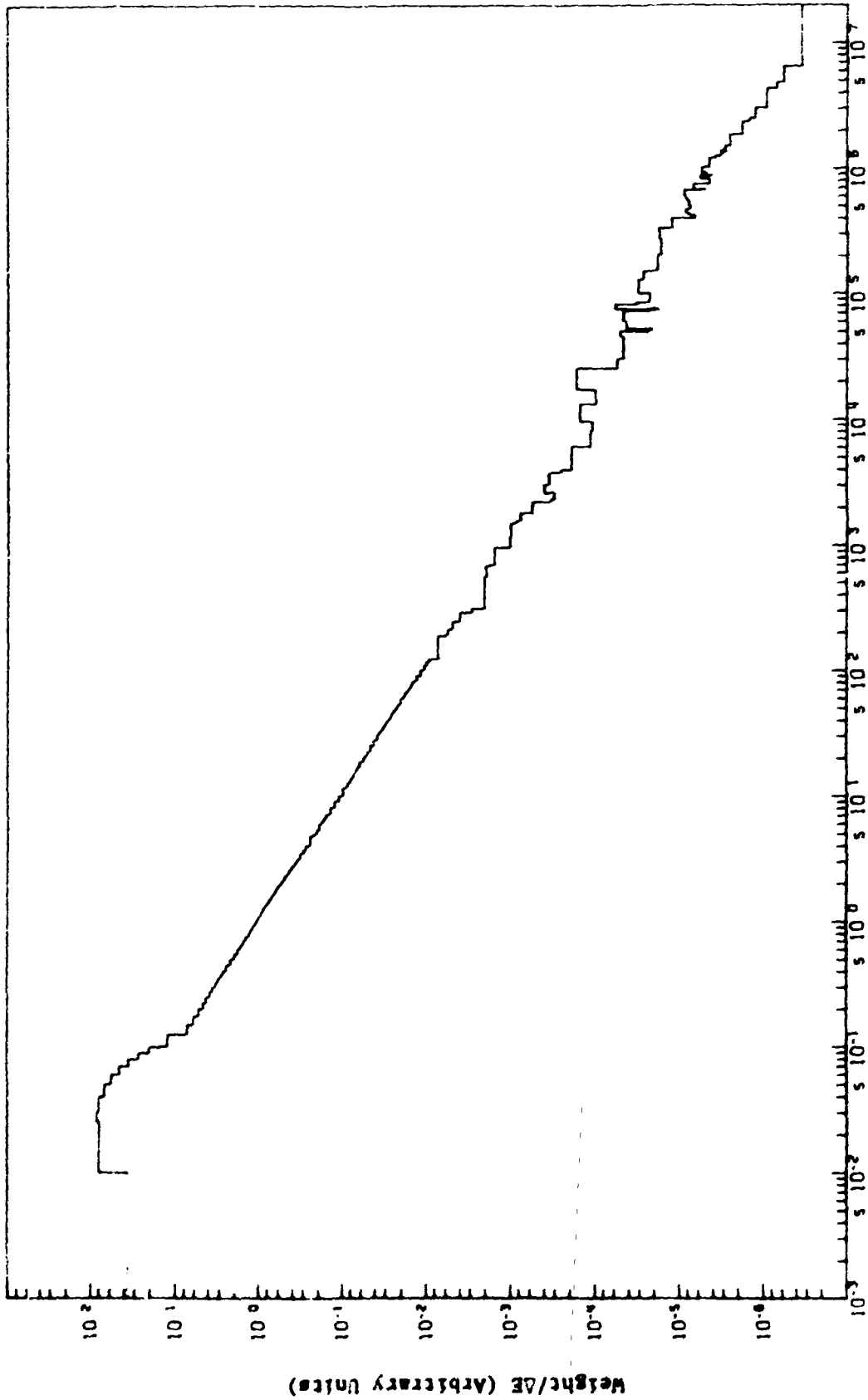

Figure 4. $1/E\Sigma_T$(Stainless Steel 304)-Maxwellian Weight Function

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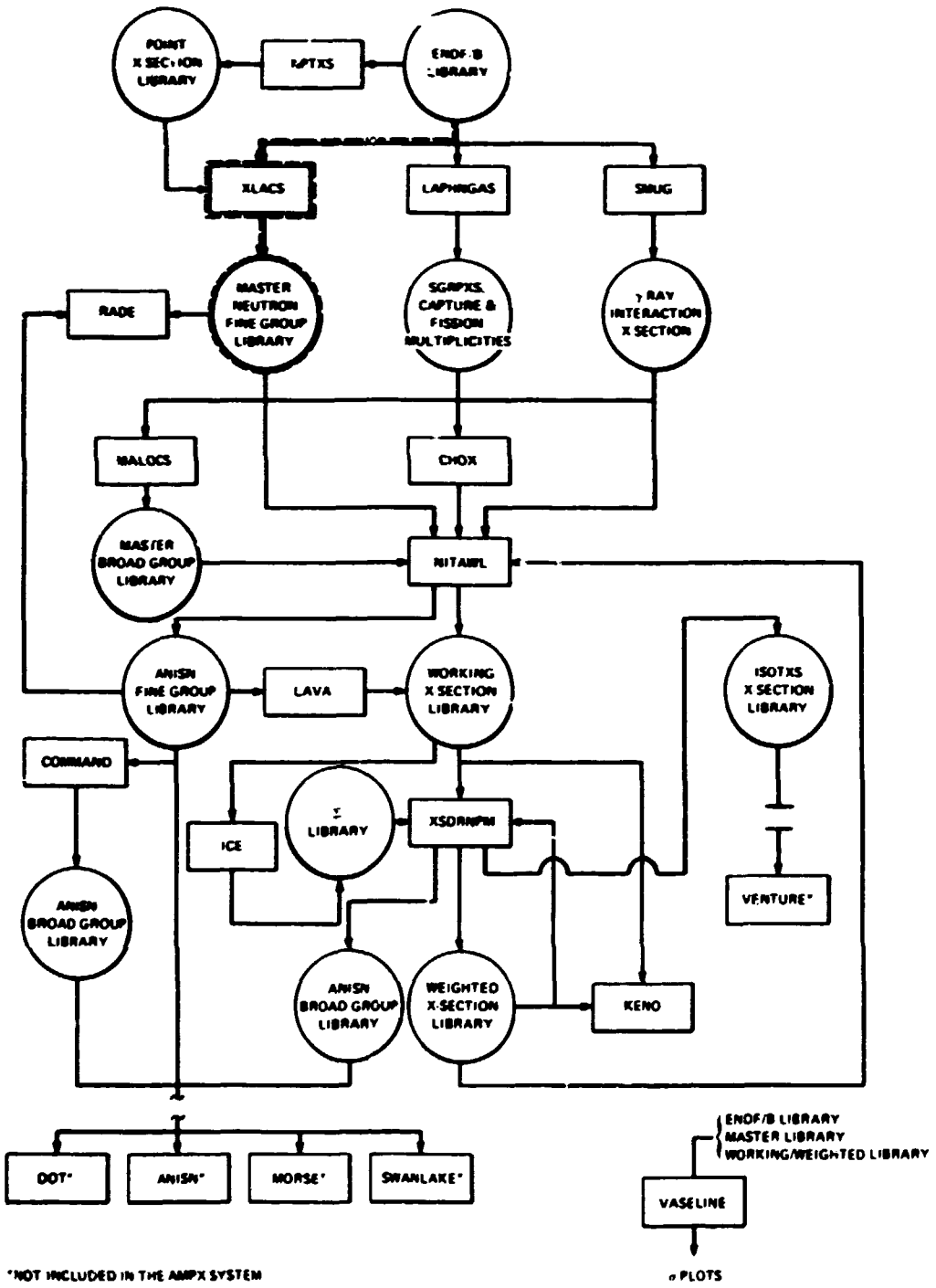
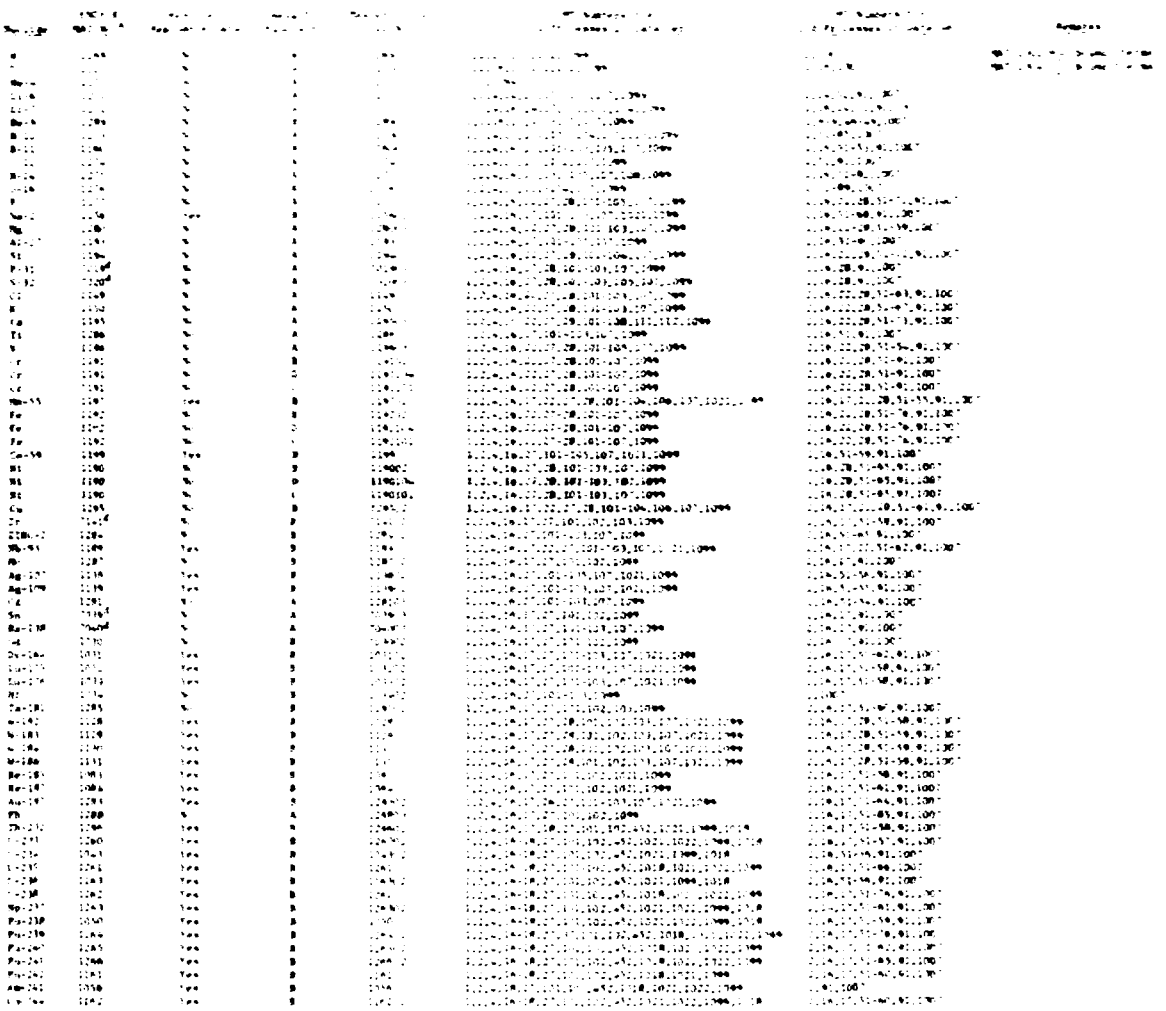


Figure 5. Major Modules of the AMPX System



[a] Neutron data from ENDF/B-VI Library, otherwise noted.
[b] See Table I for energy range of weight function. The [illegible] code is used to identify the weight function.

Code	Weight Function
A	Fission Fis-Maxwellian
B	Fission Fis-Maxwellian
C	14 MeV Fis-Maxwellian
D	14 MeV stainless steel Fis-Maxwellian

[c] See Table II for correspondence between MT numbers and reaction types.
[d] Data from the ENDL library.

Table 2. 218-Group Neutron Structure

Group	Upper Energy (eV)	Lethargy Range	Group	Upper Energy (eV)	Lethargy Range
1	2.0000E 07*	-0.693-0.441	51	9.5000E 03	6.959- 7.127
2	6.4340E 06	0.441-0.734	52	8.0300E 03	7.127- 7.419
3	4.8000E 06	0.734-0.843	53	6.0000E 03	7.419- 7.849
4	4.3040E 06	0.843-1.204	54	3.9000E 03	7.849- 7.891
5	3.0000E 06	1.204-1.395	55	3.7400E 03	7.891- 8.112
6	2.4790E 06	1.395-1.446	56	3.0000E 03	8.112- 8.263
7	2.3540E 06	1.446-1.687	57	2.5800E 03	8.263- 8.382
8	1.8500E 06	1.687-1.897	58	2.2900E 03	8.382- 8.422
9	1.5000E 06	1.897-1.966	59	2.2000E 03	8.422- 8.623
10	1.4000E 06	1.966-1.998	60	1.8000E 03	8.623- 8.772
11	1.3560E 06	1.998-2.027	61	1.5500E 03	8.772- 8.805
12	1.3170E 06	2.027-2.079	62	1.5000E 03	8.805- 9.071
13	1.2500E 06	2.079-2.120	63	1.1500E 03	9.071- 9.262
14	1.2000E 06	2.120-2.207	64	9.5000E 02	9.262- 9.592
15	1.1000E 06	2.207-2.293	65	6.8300E 02	9.592- 9.611
16	1.0100E 06	2.293-2.386	66	6.7000E 02	9.611- 9.808
17	9.2000E 05	2.386-2.408	67	5.5000E 02	9.808-10.398
18	9.0000E 05	2.408-2.436	68	3.0500E 02	10.398-10.466
19	8.7500E 05	2.436-2.452	69	2.8500E 02	10.466-10.637
20	8.6110E 05	2.452-2.501	70	2.4000E 02	10.637-10.771
21	8.2000E 05	2.501-2.590	71	2.1000E 02	10.771-10.783
22	7.5000E 05	2.590-2.690	72	2.0750E 02	10.783-10.858
23	6.7900E 05	2.690-2.703	73	1.9250E 02	10.858-10.892
24	6.7000E 05	2.703-2.813	74	1.8600E 02	10.892-11.314
25	6.0000E 05	2.813-2.859	75	1.2200E 02	11.314-11.339
26	5.7300E 05	2.859-2.900	76	1.1900E 02	11.339-11.373
27	5.5000E 05	2.900-2.997	77	1.1500E 02	11.373-11.436
28	4.9952E 05	2.997-3.058	78	1.0800E 02	11.436-11.513
29	4.7000E 05	3.058-3.124	79	1.0000E 02	11.513-11.618
30	4.4000E 05	3.124-3.170	80	9.0000E 01	11.618-11.711
31	4.2000E 05	3.170-3.219	81	8.2000E 01	11.711-11.736
32	4.0000E 05	3.219-3.411	82	8.0000E 01	11.736-11.787
33	3.3000E 05	3.411-3.612	83	7.6000E 01	11.787-11.841
34	2.7000E 05	3.612-3.912	84	7.2000E 01	11.841-11.906
35	2.0000E 05	3.912-4.200	85	6.7500E 01	11.906-11.944
36	1.5000E 05	4.200-4.356	86	6.5000E 01	11.944-12.007
37	1.2830E 05	4.356-4.605	87	6.1000E 01	12.007-12.041
38	1.0000E 05	4.605-4.768	88	5.9000E 01	12.041-12.140
39	8.5000E 04	4.768-4.804	89	5.3400E 01	12.140-12.167
40	8.2000E 04	4.804-4.893	90	5.2000E 01	12.167-12.194
41	7.5000E 04	4.893-4.920	91	5.0600E 01	12.194-12.222
42	7.3000E 04	4.920-5.116	92	4.9200E 01	12.222-12.241
43	6.0000E 04	5.116-5.259	93	4.8300E 01	12.241-12.268
44	5.2000E 04	5.259-5.298	94	4.7000E 01	12.268-12.307
45	5.0000E 04	5.298-5.404	95	4.5200E 01	12.307-12.334
46	4.5000E 04	5.404-5.809	96	4.4000E 01	12.334-12.371
47	3.0000E 04	5.809-5.991	97	4.2400E 01	12.371-12.405
48	2.5000E 04	5.991-6.377	98	4.1000E 01	12.405-12.439
49	1.7000E 04	6.377-6.645	99	3.9600E 01	12.439-12.452
50	1.3000E 04	6.645-6.959	100	3.9100E 01	12.452-12.481

*Read 2.0000×10^7.

Table 2 (continued)

Group	Upper Energy (eV)	Lethargy Range	Group	Upper Energy (eV)	Lethargy Range
101	3.8000E 01	12.481-12.507	151	2.2100E 00	15.325-15.367
102	3.7000E 01	12.507-12.549	152	2.1200E 00	15.367-15.425
103	3.5500E 01	12.549-12.574	153	2.0000E 00	15.425-15.455
104	3.4600E 01	12.574-12.599	154	1.9400E 00	15.455-15.498
105	3.3750E 01	12.599-12.614	155	1.8600E 00	15.498-15.547
106	3.3250E 01	12.614-12.660	156	1.7700E 00	15.547-15.599
107	3.1750E 01	12.660-12.676	157	1.6800E 00	15.599-15.654
108	3.1250E 01	12.676-12.717	158	1.5900E 00	15.654-15.713
109	3.0000E 01	12.717-12.804	159	1.5000E 00	15.713-15.747
110	2.7500E 01	12.804-12.899	160	1.4500E 00	15.747-15.782
111	2.5000E 01	12.899-13.005	161	1.4000E 00	15.782-15.818
112	2.2500E 01	13.005-13.074	162	1.3500E 00	15.818-15.856
113	2.1000E 01	13.074-13.122	163	1.3000E 00	15.856-15.895
114	2.0000E 01	13.122-13.174	164	1.2500E 00	15.895-15.915
115	1.9000E 01	13.174-13.200	165	1.2250E 00	15.915-15.936
116	1.8500E 01	13.200-13.285	166	1.2000E 00	15.936-15.957
117	1.7000E 01	13.285-13.346	167	1.1750E 00	15.957-15.978
118	1.6000E 01	13.346-13.403	168	1.1500E 00	15.978-15.987
119	1.5100E 01	13.403-13.451	169	1.1400E 00	15.987-15.996
120	1.4400E 01	13.451-13.497	170	1.1300E 00	15.996-16.005
121	1.3750E 01	13.497-13.561	171	1.1200E 00	16.005-16.014
122	1.2900E 01	13.561-13.642	172	1.1100E 00	16.014-16.023
123	1.1900E 01	13.642-13.676	173	1.1000E 00	16.023-16.032
124	1.1500E 01	13.676-13.816	174	1.0900E 00	16.032-16.041
125	1.0000E 01	13.816-13.910	175	1.0800E 00	16.041-16.050
126	9.1000E 00	13.910-14.026	176	1.0700E 00	16.050-16.060
127	8.1000E 00	14.026-14.151	177	1.0600E 00	16.060-16.069
128	7.1500E 00	14.151-14.172	178	1.0500E 00	16.069-16.079
129	7.0000E 00	14.172-14.209	179	1.0400E 00	16.079-16.089
130	6.7500E 00	14.209-14.246	180	1.0300E 00	16.089-16.098
131	6.5000E 00	14.246-14.286	181	1.0200E 00	16.098-16.108
132	6.2500E 00	14.286-14.326	182	1.0100E 00	16.108-16.118
133	6.0000E 00	14.326-14.432	183	1.0000E 00	16.118-16.143
134	5.4000E 00	14.432-14.509	184	9.7500E-01	16.143-16.169
135	5.0000E 00	14.509-14.560	185	9.5000E-01	16.169-16.196
136	4.7500E 00	14.560-14.732	186	9.2500E-01	16.196-16.223
137	4.0000E 00	14.732-14.802	187	9.0000E-01	16.223-16.281
138	3.7300E 00	14.802-14.865	188	8.5000E-01	16.281-16.341
139	3.5000E 00	14.865-14.971	189	8.0000E-01	16.341-16.406
140	3.1500E 00	14.971-15.003	190	7.5000E-01	16.406-16.475
141	3.0500E 00	15.003-15.019	191	7.0000E-01	16.475-16.549
142	3.0000E 00	15.019-15.030	192	6.5000E-01	16.549-16.629
143	2.9700E 00	15.030-15.064	193	6.0000E-01	16.629-16.716
144	2.8700E 00	15.064-15.099	194	5.5000E-01	16.716-16.811
145	2.7700E 00	15.099-15.136	195	5.0000E-01	16.811-16.917
146	2.6700E 00	15.136-15.174	196	4.5000E-01	16.917-17.034
147	2.5700E 00	15.174-15.214	197	4.0000E-01	17.034-17.099
148	2.4700E 00	15.214-15.251	198	3.7500E-01	17.099-17.168
149	2.3800E 00	15.251-15.285	199	3.5000E-01	17.168-17.242
150	2.3000E 00	15.285-15.325	200	3.2500E-01	17.242-17.322

Table 2 (continued)

Group	Upper Energy (eV)	Lethargy Range
201	3.0000E-01	17.322-17.409
202	2.7500E-01	17.409-17.504
203	2.5000E-01	17.504-17.610
204	2.2500E-01	17.610-17.728
205	2.0000E-01	17.728-17.861
206	1.7500E-01	17.861-18.015
207	1.5000E-01	18.015-18.198
208	1.2500E-01	18.198-18.421
209	1.0000E-01	18.421-18.526
210	9.0000E-02	18.526-18.644
211	8.0000E-02	18.644-18.777
212	7.0000E-02	18.777-18.932
213	6.0000E-02	18.932-19.114
214	5.0000E-02	19.114-19.337
215	4.0000E-02	19.337-19.625
216	3.0000E-02	19.625-19.795
217	2.5300E-02	19.795-20.723
218	1.0000E-02**	20.723-27.631

**Bottom energy of group 218 is 1.0000×10^{-5} eV.

Table 3. Definition of Reaction Types

MT Number	Description[a]
1	Total cross section (redundant, equal to the sum of all partial cross sections)
2	Elastic scattering cross section
4	Total inelastic cross section (redundant, equal to the sum of MT=51,52,53,...,90,91)
16	(n,2n) cross section
17	(n,3n) cross section
18	Total fission cross section
22	(n,n')α cross section
23	(n,n')3α cross section
24	(n,2n)α cross section
25	(n,3n)α cross section
26	(n,2n) isomeric state cross section
27	Absorption cross section (sum of MT=18 and 102)
28	(n,n')p cross section
51	(n,n') to the 1st excited state
52	(n,n') to the 2nd excited state
.	
.	
.	
90	(n,n') to the 40th excited state
91	(n,n') to the continuum
101	Parasitic absorption (redundant, sum of MT=102,103, 104,105,106,107,108,109)
102	(n,γ) radiative capture cross section
103	(n,p) cross section
104	(n,d) cross section
105	(n,t) cross section
106	(n,He^3) cross section
107	(n,α) cross section
108	(n,2α) cross section
109	(n,3α) cross section
111	(n,2p) cross section

Table 3 (continued)

MT Number	Description[a]
112	(n,pα) cross section
113	(n,t2α) cross section
1018	Chi for lowest group
1021	"Background" data for capture reaction to be processed in NITAWL module
1022	"Background" data for fission reaction to be processed in NITAWL module
1023	"Background" data for elastic scattering reaction to be processed in NITAWL module
1099	Point-to-fine group weighting function

[a] MT descriptions from Ref. 6.

Table 4. Point-to-Fine Group Weighting Functions

- Non Resonance Materials (fission-$1/E\sigma_T$-Maxwellian)

Energy Range	Weighting
20-1.4 MeV	Fission
1.4×10^6-0.1264 eV	$1/E\sigma_T$
0.1264-1.0×10^{-5} eV	Maxwellian (293°K)

- Resonance Materials (fission-1/E-Maxwellian)

Energy Range	Weighting Spectrum
20-0.1 MeV	Fission
1.0×10^5-0.1264 eV	1/E
0.1264-1.0×10^{-5} eV	Maxwellian (293°)

- Selected Structural Materials (Fe, Ni, Cr)

Energy Range	Weighting Spectrum
2.0×10^7-0.1264 eV	$(1/E\Sigma_T)$ inconel or $(1/E\Sigma_\gamma)$ stainless steel 304
0.1264-1.0×10^{-5} eV	Maxwellian (293°K)

Table 5. 218-Group Fission-1/E-Maxwellian Weight Function

Group	Weight Function	Group	Weight Function	Group	Weight Function
1	8.327300E-01[a]	51	1.681100E-01	101	2.666800E-02
2	1.787000E 00	52	2.914200E-01	102	4.138500E-02
3	1.065100E 00	53	4.307800E-01	103	2.568000E-02
4	5.149199E 00	54	4.189100E-02	104	2.487300E-02
5	3.536099E 00	55	2.204700E-01	105	1.492600E-02
6	1.020399E 00	56	1.508200E-01	106	4.616200E-02
7	4.904799E 00	57	1.192400E-01	107	1.587300E-02
8	4.227500E 00	58	4.009400E-02	108	4.082200E-02
9	1.336599E 00	59	2.006699E-01	109	8.701098E-02
10	6.062400E-01	60	1.495300E-01	110	9.530997E-02
11	5.466100E-01	61	3.279000E-02	111	1.053600E-01
12	9.586599E-01	62	2.657000E-01	112	6.899297E-02
13	7.310500E-01	63	1.910599E-01	113	4.879000E-02
14	1.501800E 00	64	3.299699E-01	114	5.129300E-02
15	1.393000E 00	65	1.921700E-02	115	2.666800E-02
16	1.428900E 00	66	1.973600E-01	116	8.455700E-02
17	3.217500E-01	67	5.896100E-01	117	6.062500E-02
18	4.043199E-01	68	6.782299E-02	118	5.789400E-02
19	2.257700E-01	69	1.718500E-01	119	4.746600E-02
20	6.707000E-01	70	1.335300E-01	120	4.618900E-02
21	1.152499E 00	71	1.197600E-02	121	6.381094E-02
22	1.177600E 00	72	7.503498E-02	122	8.068895E-02
23	1.496600E-01	73	3.434900E-02	123	3.419100E-02
24	1.164200E 00	74	4.217300E-01	124	1.397600E-01
25	4.480700E-01	75	2.489800E-02	125	9.431100E-02
26	3.808200E-01	76	3.419100E-02	126	1.164100E-01
27	8.313000E-01	77	6.280094E-02	127	1.247500E-01
28	4.819700E-01	78	7.696098E-02	128	2.120200E-02
29	4.857399E-01	79	1.053600E-01	129	3.636800E-02
30	3.209100E-01	80	9.309000E-02	130	3.774000E-02
31	3.183800E-01	81	2.469300E-02	131	3.922100E-02
32	1.087700E 00	82	5.129300E-02	132	4.082200E-02
33	8.889000E-01	83	5.406700E-02	133	1.053600E-01
34	9.646000E-01	84	6.453794E-02	134	7.696098E-02
35	6.231400E-01	85	3.774000E-02	135	5.129300E-02
36	2.482800E-01	86	6.351298E-02	136	1.718500E-01
37	2.990400E-01	87	3.333600E-02	137	6.988597E-02
38	1.625200E-01	88	9.972697E-02	138	6.364495E-02
39	3.593200E-02	89	2.656700E-02	139	1.053600E-01
40	8.923095E-02	90	2.729300E-02	140	3.226100E-02
41	2.702900E-02	91	2.805800E-02	141	1.652900E-02
42	1.961100E-01	92	1.846200E-02	142	1.005100E-02
43	1.431000E-01	93	2.728400E-02	143	3.424900E-02
44	3.922100E-02	94	3.905100E-02	144	3.546500E-02
45	1.053600E-01	95	2.690700E-02	145	3.676900E-02
46	4.054599E-01	96	3.704200E-02	146	3.817200E-02
47	1.823200E-01	97	3.357600E-02	147	3.968800E-02
48	3.856600E-01	98	3.474400E-02	148	3.711800E-02
49	2.682599E-01	99	1.270700E-02	149	3.419100E-02
50	3.136600E-01	100	2.853600E-02	150	3.991700E-02

[a]Read 8.327300×10^{-1}.

Table 5 (continued)

Group	Weight Function	Group	Weight Function
151	4.157600E-02	201	8.701098E-02
152	5.826400E-02	202	9.530997E-02
153	3.046400E-02	203	1.053600E-01
154	4.211100E-02	204	1.177800E-01
155	4.959700E-02	205	1.335300E-01
156	5.218600E-02	206	1.541499E-01
157	5.506000E-02	207	1.824700E-01
158	5.826800E-02	208	3.107700E-01
159	3.390200E-02	209	2.059300E-01
160	3.509100E-02	210	2.737000E-01
161	3.636800E-02	211	3.591100E-01
162	3.774000E-02	212	4.618100E-01
163	3.921900E-02	213	5.803500E-01
164	2.020400E-02	214	7.040200E-01
165	2.061800E-02	215	8.121099E-01
166	2.105500E-02	216	4.041300E-01
167	2.150500E-02	217	1.213400E 00
168	8.734699E-03	218	3.591500E-01
169	8.810800E-03		
170	8.887500E-03		
171	8.968897E-03		
172	9.050898E-03		
173	9.132698E-03		
174	9.215098E-03		
175	9.302597E-03		
176	9.390797E-03		
177	9.478997E-03		
178	9.567797E-03		
179	9.662099E-03		
180	9.756397E-03		
181	9.853497E-03		
182	9.948697E-03		
183	2.531800E-02		
184	2.597500E-02		
185	2.666800E-02		
186	2.739900E-02		
187	5.715800E-02		
188	6.062500E-02		
189	6.453794E-02		
190	6.899297E-02		
191	7.410794E-02		
192	8.004296E-02		
193	8.701098E-02		
194	9.530997E-02		
195	1.053600E-01		
196	1.177800E-01		
197	6.453794E-02		
198	6.899297E-02		
199	7.410794E-02		
200	8.004296E-02		

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APPENDIX A

AMPX Master Library Interface*

The AMPX multigroup master cross-section library formats have been designed with a generality paralleling that of the ENDF/B point data libraries. For example:

1. Resonance parameters can be passed.
2. Any number of reaction cross sections is allowed. ENDF/B identifications are retained where possible.
3. Any scattering process can be represented anisotropically to any order.
4. Any process can have a transfer matrix. For example, XLACS produces a transfer matrix for each inelastic level.
5. Temperature dependence is allowed on thermal scattering kernel.

Special arrays designated "magic-word" arrays are used to compact the potentially very lengthy transfer arrays on the interfaces. These formats effectively eliminate zero and impossible elements from the transfer arrays.

Four types of arrays are used in the formats:

1. The aforementioned "magic-word" array,
2. Temperature dependent 1-D arrays,
3. Temperature independent 1-D arrays, and
4. The resonance parameter array.

A.1 Magic-Word Array

The structure of a magic-word array is as follows:

1. Length of magic-word string which follows,
2. Magic word for first non-zero group (note that this is not necessarily the first energy group),

*This material was taken from Section 11 of Ref. 1.

3. String of transfer elements for this group,

4. Magic word for next group,

5. String for next group,

.
.
.
.

etc., until the length specified in the first word is satisfied.

A read statement for this array would contain a list:

L,(X(I),I=1,L)

A magic word is a 9-digit integer consisting of three 3-digit integers (IIIJJJKKK). The number of the group scattered into is KKK. III is the lowest numbered (highest energied) group which scatters to KKK. JJJ is the highest numbered group which scatters to KKK. After the magic word, the transfer string to group KKK is in reverse order:

IIIJJJKKK

σ(JJJ→KKK)

σ(JJJ-1→KKK)

.
.
.
.

σ(KKK→KKK)

σ(KKK-1→KKK)

.
.
.
.

σ(III→KKK)

Note that the within group term does not necessarily fall in the string.

A.2 Temperature Dependent 1-D Arrays

These arrays are structured as follows:

1. ENDF/B Process ID (MT),
2. Temperature in ^{o}K,
3. Average cross section for each energy group,
4. etc.

A.3 Temperature Independent 1-D Arrays

Temperature independent 1-D arrays are structured:

1. ENDF/B process ID for 1st process,
2. Average cross sections for 1st process for all groups,
3. ENDF/B process ID for 2nd process,
4. Average cross sections for 2nd process for all groups,
5. etc.

A.4 Resonance Array Structure

The makeup of this data array is as follows:

1. Mass ratio (A) for the isotope.
2. σ_{po}, potential scattering cross section.
3. Average statistical factor, g, in the unresolved region.
4. Number of resolved resonances.
5. s-factor. This factor is used to determine the region over which the Nordheim Integral Treatment is applied for a resolved resonance.
6. Average energy level spacing, $\langle D \rangle$, for the $\ell = 0$ unresolved sequence passed.
7. $\langle \Gamma_n^o \rangle$, average unresolved neutron width.
8. $\langle \Gamma_\gamma \rangle$, average unresolved gamma width.
9. $\langle \Gamma_f \rangle$, average unresolved fission width.

10. Energy of first resolved resonance.

11. Γ_n, neutron width of first resolved resonance.

12. Γ_γ, gamma width of first resonance.

13. Γ_f, fission width of first resonance.

14. r-factor (used in Nordheim Treatment).

15. Statistical factor, g.

16.
17.
18.
19.
20.
21. } As for 10-15 for second resolved resonance.

.
.
.
.
.

10+(6 x number of resolved resonances) - Energies at which to evaluate the unresolved "averaged" cross sections - low-to-high (eV). These energies will span the unresolved energy range.

.
.
.
.
.

A.5 Master Interface Specification

The format of the master cross-section interface is specified below. Reference is made to the array definitions made immediately prior to this section. The format of gamma-ray data is included below; however, the criticality safety master cross-sectior library contains only neutron data.

Record	Length (Words)	Contents
1	110	IDT - interface identification number NNUC - number of nuclides in this interface NG - number of neutron energy groups IFTG - first thermal neutron group MSN - zero I1 - number of gamma energy groups I2 - zero I3 - zero I4 - zero I5 - zero A(1→100) Hollerith information describing the interface
2	50	ID(1→50) information describing the first nuclide on the interface (See the description of record R1 below for a specification of the ID array.)
NNUC+1	50	As for record 2 for NNUCth nuclide
NNUC+2	2x(NG+1)	Neutron energy group boundaries (high-to-low in eV) followed by corresponding lethargy boundaries
NNUC+3	2x(I1+1)	Gamma energy group boundaries (high-to-low in eV) followed by corresponding lethargy boundaries

NOTE: Records 2 through NNUC+1 constitute a Table of Contents for the interface. Record NNUC+2 or NNUC+3 is omitted when NG=0 or I1=0, respectively.

The following set of records is repeated NNUC times, one nuclide after the other:

Record	Length	Contents
R1	50	ID(1-18) - Hollerith information describing the nuclide
		ID(19) - nuclide identification number
		ID(20) - number of resolved resonances
		ID(21) - number of points at which to evaluate unresolved "averaged" cross sections
		ID(22) - number of one-dimensional neutron arrays (temperature independent)
		ID(23) - number of two-dimensional neutron processes; i.e., a process which requires a neutron-neutron transfer array
		ID(24) - number of temperature dependent one-dimensional neutron arrays
		ID(25) - number of one-dimensional gamma arrays
		ID(26) - number of two-dimensional gamma processes
		ID(27) - number of neutron to gamma production processes
		ID(28) - not used
		ID(29) - mass number (neutron equivalent)
		ID(30) - ZA

Record	Length	Contents
		ID(31) - neutron (XLACS) weighting option
		ID(32) - identifier of neutron weighting
		ID(33) - gamma (SMUG) weighting option
		ID(34) - energy per fission (watt-sec/fission)
		ID(35) - energy released per capture (eV)
		ID(36) - zero
		ID(37) - number of processes with Bondarenko factors
		ID(38) - number of σ_0's
		ID(39) - number of temperatures
		ID(40) - maximum number of groups with Bondarenko factors
		ID(41) - zero
		ID(42) - identifier of gamma production weighting function
		ID(43) - zero
		ID(44) - gamma production (LAPHNGAS) weighting option
		ID(45) - ENDF material number for fast neutron data
		ID(46) - ENDF material number for thermal neutron data
		ID(47) - ENDF material number for gamma data
		ID(48) - ENDF material number for gamma production data

Record	Length	Contents
		ID(49) - standard CITATION identification number
		ID(50) - number of records for this nuclide
R2	ID(38)+ID(39)+2	$(\sigma_0(i), i=1, ID(38))$, $(T(j), j=1, ID(39))$, ELO, EHI where ELO and EHI define the range over where the Bondarenko factors apply
R3	6 * ID(37)	$(MT_i, i=1, ID(37))$, $(NF_i, i=1, ID(37))$, $(NL_i, i=1, ID(37))$, $(NX_i, i=1, ID(37))$, $(NY_i, i=1, ID(37))$, $(NZ_i, i=1, ID(37))$, where MT is the MT number of the process, NF is the first group with Bondarenko factors for the process, NL is the last group with Bondarenko factors, and NX, NY, NZ are zeros, presently

The following two records are repeated ID(37) times:

R4	NL_i-NF_i+1	$(\sigma_{MT}(i), i=NF, NL)$ Infinite dilution values for the cross section of process MT
R5	(NL_i-NF_i+1)* ID(38)*ID(39)	$(((BF(i,j,k), i=1, ID(38)), j=1, ID(39)), k=NF, NL)$

Record	Length	Contents
R6	6xID(20)+9+ID(21)	Resonance data array
R7	ID(22)x(NG+1)	Temperature independent one-dimensional arrays
R8	ID(24)x(NG+2)	Temperature dependent one-dimensional arrays
R9	ID(23)x4	(MTX(I),I=1,ID(23)), (LX(I),I=1,ID(23)), (NLX(I),I=1,ID(23)), (NTX(I),I=1,ID(23)), where MTX = the ENDF/B process identification (MT), LX = the maximum length of a single matrix for the ith process, NLX = the expansion order of the cross sections for the ith process, NTX = the number of temperatures at which the cross section for the process is evaluated

The following arrays are repeated for each two-dimensional neutron process, through ID(23) processes.

R10(a)	T(i)	The temperature (^{o}K) at which the transfer arrays are given for the ifT_i process NOTE: NT = 0 will not require this array
R10(b)	L(i)max	The P_0 array for the MT_i process at T_1, written (X(I),I=1,LX)
R10(b+1)	L(i)max	The P_1 array for the MT_i process at T_1
.	.	.
.	.	.
.	.	.

Record	Length	Contents
R10(b+NL)	L(i)max	The P_{NL_i} array for the MT_i process at T_1
.	.	.
.	.	.
.	.	.
.	.	.
R10( )	Li(i)max	The P_0 array for the MT_i process at T_2
R10( )	Li(i)max	The P_{NL_i} array for the MT_i process at T_{NT_i}

****Repeat this pattern until all neutron processes are exhausted.

Gamma Production Arrays

P1	ID(27)x4	$(MTY_i, i=1, ID(27))$,
		$(LY_i, i=1, ID(27))$,
		$(NLY_i, i=1, ID(27))$,
		$(NNY_i, i=1, ID(27))$,
		where MTY_i, LY_i, and NLY_i have meanings as stated in record R9. NNY_i is a data type identifier. An NNY_i of zero identifies the production arrays for the ith process as fractional yield data. A value of one (1) designates that the arrays are in cross-section units.

The following records are repeated for ID(27) processes.

P2	L(i)max	P_0 neutron to gamma transfer matrix, written L, (X(I),I=1,L)
.	.	.
.	.	.
.	.	.

Record	Length	Contents
P(2+NL_i)	L(i)max	P_{NL_i} neutron to gamma transfer matrix
.	.	.
.	.	.
.	.	.
.	.	.

****Repeat until the two-dimensional gamma processes are exhausted.

Gamma Arrays

G1	ID(25)x(I1+1)	One-dimensional gamma interaction arrays
G2	ID(26)x4	(MTZ_i,i=1,ID(26)),
		(LZ_i,i=1,ID(26)),
		(NLZ_i,i=1,ID(26)),
		(NTZ_i,i=1,ID(26)) [NTZ_i will always have all zeros.]
		These terms are defined as for record R9 except that they apply to gammas.

Repeat the following records for each process:

G3	L(i)	The P_0 array for the MTZ_i gamma process, written (X(I),I=1,LZ)
.	.	.
.	.	.
.	.	.
G(3+NL_i)	I(i)	The P_{NLZ_i} array for the NTZ_i gamma process

****This concludes the data for a nuclide.

APPENDIX B

Criteria Used in the Selection of Group Boundaries

Criteria used in the selection of boundaries for the 218-group energy structure are listed in Table A.1. (The 218-group energy structure is listed in Table 2.) Various versions of BNL-325,[7-14] ENDF-200,[15] and the ENDF/B data[16] were sources of the criteria. Information in Table A.1 can be used to identify cross-section structure by nuclide and thereby aid in the selection of broad-group structures from the 218 group set. Thresholds and resonance regions are identified by reaction type down to approximately 500 eV. Below 500 eV, individual levels are not identified by reaction type since they may exhibit significant scatter, capture and/or fission.

Table B.1. Criteria for Selection of the 140 Epithermal Group Boundaries

Energy (eV)	Criterion
20+6[a]	Upper cutoff
6.434+6	O - inelastic threshold
4.8+6	C - inelastic threshold
4.304+6	N - n,α threshold
3+6	Hansen-Roach boundary
2.479+6	N - inelastic threshold
2.354+6	O - n,α threshold B-10 - upper bound on 1.9 MeV (.4b) n,α level
1.85+6	Be - n,2n threshold
1.5+6	U-238 - fission plateau B-10 - lower bound on 1.9 MeV (.4b) n,α level
1.4+6	Hansen-Roach boundary
1.356+6	Ni - inelastic threshold O - upper bound on 1.312 MeV (6b) n,n' level Mg - inelastic threshold (1.34 MeV)

[a]Read 20×10^6.

Table B.1 (continued)

Energy (eV)	Criterion
1.317+6	Si - inelastic threshold
1.25+6	B-10 - inelastic threshold O - lower bound on 1.312 MeV (6b) n,n' level
1.2+6	Th-232 - fission threshold B-10 - n,t threshold Ca - inelastic threshold (1.187 MeV)
1.1+6	O - upper bound on 1 MeV (8b) n,n' level
1.01+6	K - inelastic threshold Pu-240 - fission plateau
9.20+5	Zr - inelastic threshold
9.00+5	Hansen-Roach boundary O - lower bound on 1 MeV (8b) n,n' level
8.75+5	Al - inelastic threshold Si - upper bound of 805 KeV (7.5b) n,n' level
8.611+5	Fe - inelastic threshold
8.20+5	Be - upper bound of 810 KeV (5.3b) n,n' level
8.00+5	Be - lower bound of 810 KeV (5.3b) n,n' level
7.50+5	Na - upper bound of 710 KeV (8b) n,n' level Si - lower bound of 805 KeV (7.5b) n,n' level
6.79+5	Cu - inelastic threshold
6.70+5	Be - n,α threshold Be - upper bound of 620 KeV (7.5b) n,n' level Na - lower bound of 710 KeV (8b) n,n' level
6.00+5	U-236 - fission threshold Be - lower bound of 620 KeV (7.5b) n,n' level Si - upper bound of 570 KeV (7.8b) n,n' level
5.73+5	Pb - inelastic threshold Cr - inelastic threshold (575.1 KeV) Mg - inelastic threshold (584 KeV)
5.50+5	Si - lower bound of 570 (7.8b) n,n' level
4.9952+5	Fe - n,p threshold O - upper bound on 442 KeV (17b) n,n' level
4.70+5	Na - inelastic threshold Mg-24 - upper bound on 430 KeV (12b) n,n' level
4.40+5	N - upper bound on 432 KeV (6.5b) n,n' level
4.20+5	N - lower bound on 432 KeV (6.5b) n,n' level

Table B.1 (continued)

Energy (eV)	Criterion
4.00+5	Hansen-Roach boundary O - lower bound on 442 KeV (17b) n,n' level Mg-24 - lower bound on 430 KeV (12b) n,n' level
3.30+5	Mg-24 - upper bound on 275 KeV (13b) n,n' level
2.70+5	Si - upper bound on 200 KeV (11b) n,n' level Cd-113 - inelastic threshold
2.00+5	Mo - inelastic threshold Mg-24 - lower bound on 275 KeV (13b) n,n' level
1.50+5	Si - lower bound on 200 KeV (11b) n,n' level Cr-52 - upper bound on 138 KeV (10b) n,n' level
1.283+5	Mn-55 - inelastic threshold F - upper bound of 100 KeV (26b) n,n' level Cr-52 - lower bound on 138 KeV (10b) n,n' level and upper bound of 95 KeV (18b) n,n' level Mg - upper bound on 81 KeV (Mg-25) and 85 KeV (Mg-24,45b) n,n' levels
1.00+5	Hansen-Roach boundary Al - upper bound on 89 KeV (18b) n,n' level
8.5+4	Fe - upper bound on 83.7 KeV (27b) n,n' level Cr-52 - lower bound on 95 KeV (18b) n,n' level
8.2+4	Fe - lower bound on 83.7 KeV (27b) n,n' level Al - lower bound on 89 KeV (18b) n,n' level F - lower bound on 100 KeV (26b) n,n' level
7.5+4	Fe - upper bound on 74 KeV (22b) n,n' level
7.3+4	Fe - lower bound on 74 KeV (22b) n,n' level
6.0+4	Gd - inelastic threshold Mg - lower bound on 81 KeV (Mg-25) and 84 KeV (Mg-24,45b) n,n' levels Na - upper bound on 55 KeV (10b) n,n' level Al - upper bound on 35.04 KeV (34b) n,n' level Cr-52 - upper bound on 51 KeV (25b) n,n' level
5.2+4	F - upper bound on 49.7 KeV (30b) n,n' level
5.0+4	U-238 - fission threshold Th-232 - inelastic threshold (50.2 KeV) Pu-240 - fission threshold Na - lower bound on 55 KeV (10b) n,n' level

Table B.1 (continued)

Energy (eV)	Criterion
4.5+4	F - lower bound on 49.7 KeV (30b) n,n' level Cr-52 - lower bound on 51 KeV (25b) n,n' level U-236 - inelastic threshold (46 KeV) U-238 - inelastic threshold (44.9 KeV) U-234 - inelastic threshold (44.3 KeV) Pu-238 - inelastic threshold (44.3 KeV) Pu-240 - inelastic threshold (43.1 KeV) U-233 - inelastic threshold (40.6 KeV)
3.0+4	Fe - upper bound on 27.9 KeV (90b) n,n' level F - upper bound on 27.3 KeV (32b) n,n' level
2.5+4	Fe - lower bound on 27.9 KeV (90b) n,n' level F - lower bound on 27.3 KeV (32b) n,n' level Mg-25 - upper bound on 20 KeV (8.5b) n,n' level Al - lower bound on 35.04 KeV (34b) n,n' level
1.7+4	Hansen-Roach boundary Ni-58 - upper bound on 15.5 KeV (142b) n,n' level Mg-25 - lower bound on 20 KeV (8.5b) n,n' level
1.3+4	U-235 - inelastic threshold Ni-58 - lower bound on 15.5 KeV (142b) n,n' level Ni-60 - upper bound on 12.5 KeV (52b) n,n' level Cr-53 - upper bound on several levels from 3.3 to 10.5 KeV (10 to 25b)
9.5+3	Ni-60 - lower bound on 12.5 KeV (52b) n,n' level Mn - upper bound on 8.87 KeV (140b) n,n' level
8.03+3	Pu-239 - inelastic threshold Mn - lower bound on 8.87 KeV (140b) level and upper bound on 7.17 KeV (150b) level
6+3	Na - upper bound on 2.8 KeV (380b) n,n' level Ni-62 - upper bound on 4.6 KeV (30b) n,n' level Mn - lower bound on 7.17 KeV (150b) n,n' level
3.9+3	Zr-96 - upper bound on 3.84 KeV (170b) n,n' level Mn - upper bound on 2.375 KeV (600b) n,n' level
3.74+3	Zr-96 - lower bound on 3.84 KeV (170b) n,n' level
3.0+3	Hansen-Roach boundary Zr-92 - upper bound on 2.73 KeV (160b) n,n' level Cu - upper bound on 2.55 KeV (Cu-65,22b) and 2.06 KeV (Cu-63,41b) levels Cr-53 - lower bound on several levels from 3.3 to 10.5 KeV (10 to 25b) Ni-62 - lower bound on 4.6 KeV (30b) n,n' level
2.58+3	Zr-92 - lower bound on 2.73 KeV (160b) n,n' level

Table B.1 (continued)

Energy (eV)	Criterion
2.29+3	Zr-94 - upper bound on 2.26 KeV (50b) n,n' level
2.2+3	Zr-94 - lower bound on 2.26 KeV (50b) n,n' level
1.8+3	Na - lower bound on 2.8 KeV (380b) n,n' level Cu - lower bound on 2.55 KeV (Cu-65,22b) and 2.06 KeV (Cu-63,41b) levels
1.55+3	Zr-91 - upper bound on 1.53 KeV (90b) n,n' level
1.5+3	Zr-91 - lower bound on 1.53 KeV (90b) n,n' level Mn - lower bound on 2.375 KeV (600b) n,n' level
1.15+3	Mn - upper bound on 1.098 KeV (420b) n,n' level
950	Mn - lower bound on 1.098 KeV (420b) n,n' level
683	Zr-91 - upper bound on 679 eV (75b) n,n' level
670	Zr-91 - lower bound on 679 eV (75b) n,n' level Cu-63 - upper bound on 577 eV (23b) level
550	Hansen-Roach boundary Mn - upper bound on 337 eV (2000b) level Cu-63 - lower bound on 577 eV (23b) level
305	Zr - upper bound on 302 eV (Zr-96,55b) and 291.5 eV (Zr-91,400b) levels
285	Zr - lower bound on 302 eV (Zr-96,55b) and 291.5 eV (Zr-91,400b) levels
240	Cu-65 - upper bound on 229 eV (13b) level
210	U-238 - upper bound on 208.6 eV (900b) level Cu-65 - lower bound on 229 eV (13b) level Mn - lower bound on 337 eV (2000b) level
207.5	U-238 - lower bound on 208.6 eV (900b) level
192.5	U-238 - upper bound on 189.6 eV (2800b) level
186	U-238 - lower bound on 189.6 eV (2800b) level
122	Th-232 - upper bound on 120.75 eV (600b) level
119	Th-232 - lower bound on 120.75 eV (600b) level U-238 - upper bound on 116.9 eV (1500b) level
115	U-238 - lower bound on 116.9 eV (1500b) level Th-232 - upper bound on 112.87 eV (450b) level Sn-116 - upper bound on 111.2 eV (62b) level
108	Th-232 - lower bound on 112.87 eV (450b) level Sn-116 - lower bound on 111.2 eV (62b) level U-238 - upper bound on 102.7 eV (3700b) level Ba-135 - upper bound on 104 eV (52b) level

Table B.1 (continued)

Energy (eV)	Criterion
100	Hansen-Roach boundary U-238 - lower bound on 102.7 eV (3700b) level Ba-135 - lower bound on 104 eV (52b) level Sn-112 - upper bound on 94.8 eV (10b) level
90	Sn-112 - lower bound on 94.8 eV (10b) level Ba-135 - upper bound on 82 eV (80b) and 88 eV (55b) levels
82	U-238 - upper bound on 81.1 eV (250b) level
80	U-238 - lower bound on 81.1 eV (250b) level
76	Pu-239 - upper bound on 74.7 eV (1300b) level
72	Pu-239 - lower bound on 74.7 eV (1300b) level Ba-135 - lower bound on 82 eV (80b) and 88 eV (55b) levels Th-232 - upper bound on 69.13 eV (1500b) level
67.5	Th-232 - lower bound on 69.13 eV (1500b) level U-238 - upper bound on 66.2 eV (3300b) level Pu-239 - upper bound on 66 eV (1000b) level
65	U-238 - lower bound on 66.2 eV (3300b) level Pu-239 - lower bound on 66 eV (1000b) level Sn-124 - upper bound on 61.95 eV (8b) level
61	Th-232 - upper bound on 59.46 eV (180b) level Sn-124 - lower bound on 61.95 eV (8b) level
59	Th-232 - lower bound on 59 eV (180b) level
53.4	Pu-239 - upper bound on 52.7 eV (1000b) level
52	Pu-239 - lower bound on 52.7 eV (1000b) level
50.6	Pu-239 - upper bound on 50.1 eV (800b) level
49.2	Pu-239 - lower bound on 50.1 eV (800b) level
48.3	Pu-239 - upper bound on 47.8 eV (200b) level Sn-118 - upper bound on 45.75 eV (12.5b) level
47	Pu-239 - lower bound on 47.8 eV (200b) level
45.2	Pu-239 - upper bound on 44.6 eV (900b) level
44	Pu-239 - lower bound on 44.6 eV (900b) level Sn-118 - lower bound on 45.75 eV (12.5b) level
42.4	Pu-239 - upper bound on 41.7 eV (700b) level Pu-240 - upper bound on 41.6 eV (45b) level
41	Pu-239 - lower bound on 41.7 eV (700b) level Pu-240 - lower bound on 41.6 eV (45b) level Sn-117 - upper bound on 38.8 eV (20b) level

Table B.1 (continued)

Energy (eV)	Criterion
39.6	U-235 upper bound on 39.41 eV (500b) level Pu-240 - upper bound on 38.1 eV (650b) level
39.1	U-235 - lower bound on 39.41 eV (500b) level Pu-239 - upper bound on 38.5 eV (120b) level
38	Pu-239 - lower bound on 38.5 eV (120b) level U-238 - upper bound on 36.7 eV (4800b)
37	Sn-117 - lower bound on 38.8 eV (20b) level Pu-240 - lower bound on 38.1 eV (650b) level
35.5	U-235 - upper bound on 35.16 eV (600b) level
34.6	U-235 - lower bound on 35.16 eV (600b) level U-238 - lower bound on 36.7 eV (4800b) level
33.75	U-235 - upper bound on 33.5 eV (380b) level
33.25	U-235 - lower bound on 33.5 eV (380b) level Pu-239 - upper bound on 32.3 eV (120b) level
32.25	U-235 - upper bound on 32.05 eV (400b) level
31.75	U-235 - lower bound on 32.05 eV (400b) level
31.25	Pu-239 - lower bound on 32.3 eV (120b) level U-235 - upper bound on 30.8 eV (150b) level
30	Hansen-Roach boundary U-235 - lower bound on 30.8 eV (150b) level
27.5	Pu-239 - upper bound on 26.2 eV (300b) level
25	Pu-239 - lower bound on 26.2 eV (300b) level Th-232 - upper bound on 23.45 eV (2100b) level Ba-135 - upper bound on 24.4 eV (40b) level Pu-239 - upper bound on 22.2 eV (1000b) level
22.5	Th-232 - lower bound on 23.45 eV (2100b) level Ba-135 - lower bound on 24.4 eV (40b) level Pu-240 - upper bound on 20.4 eV (2400b) level U-238 - upper bound on 21 eV (5500b) level Th-232 - upper bound on 21.78 eV (1500b) level
21	Pu-239 - lower bound on 22.2 eV (1000b) level Th-232 - lower bound on 21.78 eV (1500b) level
20	U-238 - lower bound on 21 eV (5500b) level U-235 - upper bound on 19.3 eV (1000b) level
19	U-235 - lower bound on 19.3 eV (1000b) level Pu-240 - lower bound on 20.4 eV (2400b) level

Table 8.1 (continued)

Energy (eV)	Criterion
18.5	Pu-239 - upper bound on 17.7 eV (1100b) level Pu-241 - upper bound on 17.83 eV (1500b) level Gd-157 - upper bound on 17.1 eV (990b) level Ag-107 - upper bound on 16.3 eV (600b) level
17	Pu-239 - lower bound on 17.7 eV (1100b) level Pu-241 - lower bound on 17.83 eV (1500b) level
16	Gd-157 - lower bound on 17.1 eV (990b) level Pu-239 - upper bound on levels at 14.3 and 14.68 eV (1700b)
15.1	Pu-241 - upper bound on 14.75 eV (2500b) level
14.4	Pu-241 - lower bound on 14.75 eV (2500b) level
13.75	Pu-241 - upper bound on 13.4 eV (1800b) level Ag-107 - lower bound on 16.3 eV (600b) level Pu-239 - lower bound on levels at 14.3 and 14.68 eV (1700b) U-233 - upper bound on 12.9 eV (500b) level
12.9	Pu-241 - lower bound on 13.4 eV (500b) level U-235 - upper bound on 12.39 eV (900b) level Pu-239 - upper bound on 11.9 eV (1400b) level
11.9	U-233 - lower bound on 12.9 eV (500b) level U-235 - lower bound on 12.39 eV (900b) level U-235 - upper bound on 11.67 eV (550b) level
11.5	Pu-239 - lower bound on 11.9 eV (1400b) level U-235 - lower bound on 11.67 eV (550b) level U-233 - upper bound on 10.45 eV (620b) level Pu-239 - upper bound on 10.95 eV (1600b) level
10	Hansen-Roach boundary U-233 - lower bound on 10.45 eV (620b) level Pu-239 - lower bound on 10.95 eV (1600b) level Hf - upper bound on 5 levels with peak at 7.78 eV (Hf-178,10,000b) In-115 - upper bound on 9.12 eV (1000b) level
9.1	U-235 - upper bound on 8.79 eV (1000b) level Ag-109 - upper bound on 5.19 eV (12,000b) level Pu-241 - upper bound on 8.6 eV (1800b) level
8.1	U-235 - lower bound on 8.79 eV (1000b) level Pu-241 - lower bound on 8.6 eV (1800b) level Pu-239 - upper bound on 7.85 eV (1800b) level U-238 - upper bound on 6.67 eV (8000b) level Gd-155 - upper bound on 7.74 eV (160b) level In-115 - lower bound on 9.12 eV (1000b) level

Table B.1 (continued)

Energy (eV)	Criterion
7.15	Pu-239 - lower bound on 7.85 eV (1800b) level Gd-155 - lower bound on 7.74 eV (160b) level U-235 - upper bound on 7.08 eV (210b) level Pu-241 - upper bound on 6.93 eV (1000b) level
7	U-235 - lower bound on 7.08 eV (210b) level U-233 - upper bound on 6.82 eV (800b) level Gd-155 - upper bound on 6.302 eV (510b) level U-236 - upper bound on 5.49 eV (48000b) level
6.75	Pu-241 - lower bound on 6.93 eV (1000b) level
6.5	U-233 - lower bound on 6.82 eV (800b) level U-235 - upper bound on 6.39 eV (600b) level
6.25	U-235 - lower bound on 6.39 eV (600b) level
6	U-238 - lower bound on 6.67 eV (8000b) level Gd-155 - lower bound on 6.302 (510b) level
5.4	U-234 - upper bound on 5.19 eV (59,000b) level
5	Hf - lower bound on 5 levels with peak at 7.78 eV (Hf-178, 10,000b) U-234 - lower bound on 5.19 eV (59,000b) level U-235 - upper bound on 4.845 eV (210b) level
4.75	U-235 - lower bound on 4.845 eV (210b) level Pu-241 - upper bound on 4.3 eV (2200b) level (couplet) In-115 - upper bound on 3.86 eV (850b) level
4	Pu-241 - lower bound on 4.3 eV (2200b) level (couplet)
3.73	U-235 - upper bound on 3.61 eV (170b) level U-233 - upper bound on 3.66 eV (280b) level U-236 - lower bound on 5.49 eV (48,000b) level
3.5	U-235 - lower bound on 3.61 eV (170b) level U-233 - lower bound on 3.66 eV (280b) level
3.15	In-115 - lower bound on 3.86 eV (850b) level U-235 - upper bound on 3.1 eV (90b) level
3.05	U-235 - lower bound on 3.1 eV (90b) level Ag-109 - lower bound on 5.19 eV (12,000b) level
	Cutoff between ENDF/B hydrogen data for fast and thermal energy ranges.