Summary Documentation for the ENDL92 Continuous-Energy Neutron Data Library (Release 1)

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ENDL92 is a continuous-energy neutron data library for use with MCNP™. The ENDL92 library contains data files for 106 nuclides, which includes 100 data files from the original library, four specially modified data files for Zn, Sn, Pt, and Hg from Los Alamos National Laboratory (LANL), and two data files for average fission products. This document describes the general characteristics of the library and the Quality Assurance process that was followed in the absence of having the original evaluations available to us (the Evaluated Nuclear Data Library (ENDL) from Lawrence Livermore National Laboratory (LLNL)). The ENDL92 library has data for four nuclides previously unavailable to MCNP; ^{20}Ne, Zn, Sb, and Hg. The incident neutron energy range of the data files extends from E_n=1.0x10^{-10} - 30.0 MeV, with the exception of ^{242}Am which only extends to 20 MeV. This library is valuable in that it will allow the user to make comparisons between ENDL and ENDF evaluations and libraries.

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I. Introduction

In early 1995, we received the latest version of Lawrence Livermore National Laboratory's (LLNL) neutron cross-section library ENDL92 and the dosimetry library ENDLDOS92. The dosimetry library ENDLDOS92 is equivalent to the previously released library LLLDOS, and therefore ENDLDOS92 will not be distributed. ENDL92 is a continuous-energy neutron data library for use with MCNP.[1] The original library contained data files for 105 nuclides, plus two data files for average fission products. Five of these data files (Cu, ^{138}Ba, ^{197}Au, Gd, and W) were withdrawn from the ENDL92 library by us at Los Alamos National Laboratory (LANL) because of problems with the elastic and total cross sections in the resonance region. Four other data files (Zn, Sn, Pt, and Hg) were extensively modified by LANL prior to release to correct problems with the elastic and total cross sections in the resonance region. For these four data files, both the LANL-modified and original versions are provided to the user.

The incident neutron energy range for the ENDL92 library extends E_n=1.0x10^{-10} - 30.0 MeV, with the exception of ^{242}Am that only extends to 20 MeV. Often the extension in energy range from 20.0 to 30.0 MeV was accomplished with the addition of fewer than 3 new energies. The Evaluated Nuclear Data Library (ENDL)[2], is the collection of evaluations which serve as the starting point for the MCNP compatible data libraries. While we were unable to obtain any information relating to the original evaluations, we were still able to perform a modified QA process that highlighted several problems. The purpose of this report is to provide a description of the library for MCNP users, and to document the modifications that were made to the original files received from LLNL. This library is valuable in that it will allow the user to make comparisons between ENDL and ENDF evaluations and libraries.

All documentation is stored on the open and secure HPSS under the directory /hpss/nucldata/doc/endl92.

II. Library Description

The data files for the continuous-energy neutron data library ENDL92 were given the ZAID ending of '.42c' for use with MCNP. The library is comprised of 106 data files processed at 300K, including 100 original data files, modified data files for Zn, Sn, Pt, and Hg, and two average fission product files. The four modified data files have been given the ZAID ending of '.42c', while the original four data files from LLNL have been given the ZAID ending of '.40c'. A detailed discussion on the modifications to these four files can be found in the Section VII: Modifications. The two average fission products are designated by the ZAIDs 49120.42c and 49125.42c.[3] Table 1 gives general information for the ENDL92 library similar to that found in Appendix G of the MCNP4A manual.[1] ENDL92 contains a number of data files for previously unavailable nuclides; ^{20}Ne, Zn, Sb, and Hg. A detailed discussion of the data for Zn, Sn, Pt, and Hg can be found in Section VII: Modifications.

As indicated previously, all of the data files in this library extend to 30 MeV, with the exception of ^{242}Am that only extends to 20 MeV. Although, the extended upper energy limit may seem very desirable for certain applications, it is important to examine how the data were extended from 20 to 30 MeV. For many, the extension is the addition of fewer than 3 data points having equivalent cross-section values as those at 20.0 MeV, as illustrated in Figure 1. This is equivalent to how MCNP would automatically extend the library for the user by assuming the last cross-section value for all energies above the upper limit of the data table.

We next describe general comparisons between the data sets on ENDL92 and those found on the previous MCNP library from LLNL, ENDL85. Table 2 categorizes the data files as those that have been somewhat improved, and those that are 'new' evaluations having a much finer treatment of the resonance region, etc.. Figure 2 shows a coplot of the total cross section for Pb from the ENDL85 and ENDL92 data libraries, illustrating some of the improvements in the resonance region for the 'new' evaluations. The remainder are essentially equivalent to that of the previous ENDL85 library. Figures 3 and 4 show the total cross sections for the new available isotopes of ^{20}Ne and Sb.

For every nuclide, the secondary energy distribution information has been greatly expanded. No charged particle production reactions (MT=103, 104, 105, and 107) have been explicitly included as there were in ENDL85 (the only absorption reaction provided explicitly on ENDL92 is radiative capture, MT=102). Cross sections for these reaction channels *are*, however, properly included in the total and total absorption when they exist. Additionally, there are no total charged-particle production data, MT=203,204,205, and 207. Therefore, the user cannot perform tallies using the FM card for these reactions. Table 3 lists the reactions for which cross sections are provided in the ENDL92 library. Each MCNP data file contains 5 standard reactions; the total (MT=1), total elastic (MT=2) and total absorption (MT=101) cross sections, total gamma production (MT=202), and neutron heating information (MT=301). Plots of all reaction cross sections were made and stored on HPSS under /hpss/nucldata/doc/endl92 (one plot per page), and can be viewed using PSCAN or printed using ppages as they are in *cgs* format. A more complete description of the reaction data, including the elastic reaction, is available as a supplement to this document. The first few pages of this supplement are found in Appendix A as an example.

While the LLNL libraries contain data files for more nuclides than the typical ENDF-based library, the amount of experimental data used in the evaluation process, and the quality of their modeling codes used to produce data where experimental data does not exist, are not as great as with ENDF evaluations. For example, Figure 5 is a coplot of the total cross section for ^{74}As and ^{75}As. As can be seen, the data in the ENDL92 library are equivalent for these two As nuclides.

A number of the heavier elements have simplified data for the reaction cross sections (^{231,233}Th, ^{234,237,239,240}U and ^{235,236,238}Np). In particular, the user will note that the elastic cross-section data for a number of these heavier elements is essentially the same. A representative plot of the type of simplified data for the total, elastic, total absorption, and total fission is shown in Figure 6 for ^{234}U. The reader will notice that no structure in the resonance region is provided for these materials. Figure 7 illustrates the simplification of the elastic cross section data by co-plotting the elastic cross section for ^{232}U, ^{236}U and ^{242}Am(metastable).

Table 1: General Information for the ENDL92 Neutron Data Library

ZAID	Atomic Wt. Ratio	Library Name	Source	Temp (°K)	Total File Length	Number of Energies	Maximum Energy	Photon Production	Nubar Data
1001.42c	0.999167	ENDL92	LLNL	300	1968	121	30.0	yes	no
1003.42c	2.99014	ENDL92	LLNL	300	2308	52	30.0	no	no
2003.42c	2.990121	ENDL92	LLNL	300	1477	151	30.0	yes	no
2004.42c	3.968218	ENDL92	LLNL	300	1332	49	30.0	no	no
3006.42c	5.963451	ENDL92	LLNL	300	7805	294	30.0	yes	no
3007.42c	6.955734	ENDL92	LLNL	300	5834	141	30.0	yes	no
4007.42c	6.956651	ENDL92	LLNL	300	1544	127	30.0	yes	no
5010.42c	9.926921	ENDL92	LLNL	300	4733	175	30.0	yes	no
5011.42c	10.91473	ENDL92	LLNL	300	4285	244	30.0	yes	no
6012.42c	11.896913	ENDL92	LLNL	300	6229	191	30.0	yes	no
6013.42c	12.891649	ENDL92	LLNL	300	5993	429	30.0	yes	no
7014.42c	13.88278	ENDL92	LLNL	300	20528	770	30.0	yes	no
7015.42c	14.87125	ENDL92	LLNL	300	22590	352	30.0	yes	no
8016.42c	15.85751	ENDL92	LLNL	300	9551	337	30.0	yes	no
9019.42c	18.835196	ENDL92	LLNL	300	37814	1118	30.0	yes	no
10020.42c	19.820693	ENDL92	LLNL	300	14286	1011	30.0	yes	no
11023.42c	22.792274	ENDL92	LLNL	300	19309	1163	30.0	yes	no
12000.42c	24.096206	ENDL92	LLNL	300	9288	468	30.0	yes	no
13027.42c	26.749754	ENDL92	LLNL	300	32388	1645	30.0	yes	no
14000.42c	27.84423	ENDL92	LLNL	300	16696	855	30.0	yes	no
15031.42c	30.707681	ENDL92	LLNL	300	6805	224	30.0	yes	no
16032.42c	31.697413	ENDL92	LLNL	300	6623	307	30.0	yes	no
17000.42c	35.148439	ENDL92	LLNL	300	12012	807	30.0	yes	no
18000.42c	39.604824	ENDL92	LLNL	300	5580	152	30.0	yes	no
19000.42c	38.762424	ENDL92	LLNL	300	11060	544	30.0	yes	no
20000.42c	39.73569	ENDL92	LLNL	300	13946	1002	30.0	yes	no
22000.42c	47.488512	ENDL92	LLNL	300	8979	608	30.0	yes	no
23051.42c	50.506324	ENDL92	LLNL	300	94082	5988	30.0	yes	no
24000.42c	51.549325	ENDL92	LLNL	300	12573	377	30.0	yes	no

ZAID	Atomic Wt. Ratio	Library Name	Source	Temp (°K)	Total File Length	Number of Energies	Maximum Energy	Photon Production	Nubar Data
25055.42c	54.466096	ENDL92	LLNL	300	10262	460	30.0	yes	no
26000.42c	55.367243	ENDL92	LLNL	300	38653	3385	30.0	yes	no
27059.42c	58.426927	ENDL92	LLNL	300	119231	13098	30.0	yes	no
28000.42c	58.195734	ENDL92	LLNL	300	44833	3116	30.0	yes	no
28058.42c	57.437649	ENDL92	LLNL	300	38930	4914	30.0	yes	no
30000.42c	64.818349	ENDL92	LLNL/XTM	300	271897	33027	30.0	yes	no
30000.40c	64.818349	ENDL92	LLNL	300	271897	33027	30.0	yes	no
31000.42c	69.121066	ENDL92	LLNL	300	6311	219	30.0	yes	no
33074.42c	73.28888	ENDL92	LLNL	300	55752	6851	30.0	yes	no
33075.42c	74.277975	ENDL92	LLNL	300	56915	6840	30.0	yes	no
39088.42c	87.154309	ENDL92	LLNL	300	11682	181	30.0	yes	no
39089.42c	88.142103	ENDL92	LLNL	300	69315	8771	30.0	yes	no
40000.42c	90.436369	ENDL92	LLNL	300	131855	17909	30.0	yes	no
41093.42c	92.108258	ENDL92	LLNL	300	73324	9277	30.0	yes	no
42000.42c	95.115821	ENDL92	LLNL	300	9293	442	30.0	yes	no
47107.42c	105.986718	ENDL92	LLNL	300	27108	2885	30.0	yes	no
47109.42c	107.969199	ENDL92	LLNL	300	33603	3796	30.0	yes	no
48000.42c	111.444335	ENDL92	LLNL	300	211537	29369	30.0	yes	no
49000.42c	113.833632	ENDL92	LLNL	300	65498	7870	30.0	yes	no
50000.42c	117.670386	ENDL92	LLNL	300	248212	34612	30.0	yes	no
50000.40c	117.670386	ENDL92	LLNL/XTM	300	248212	34612	30.0	yes	no
51000.42c	120.704099	ENDL92	LLNL	300	95953	10721	30.0	yes	no
53127.42c	125.814294	ENDL92	LLNL	300	76321	9854	30.0	yes	no
54000.42c	130.172059	ENDL92	LLNL	300	43411	5173	30.0	yes	no
54134.42c	132.75507	ENDL92	LLNL	300	8033	192	30.0	yes	no
63000.42c	150.654578	ENDL92	LLNL	300	37421	4498	30.0	yes	no
67165.42c	163.513486	ENDL92	LLNL	300	103467	13884	30.0	yes	no
72000.42c	176.95667	ENDL92	LLNL	300	108989	14113	30.0	yes	no
73181.42c	179.393568	ENDL92	LLNL	300	47852	4927	30.0	yes	no
75185.42c	183.364126	ENDL92	LLNL	300	23715	2214	30.0	yes	no
75187.42c	185.349709	ENDL92	LLNL	300	20969	1821	30.0	yes	no

ZAID	Atomic Wt. Ratio	Library Name	Source	Temp (°K)	Total File Length	Number of Energies	Maximum Energy	Photon Production	Nubar Data
78000.42c	193.414067	ENDL92	LLNL	300	43559	5400	30.0	yes	no
78000.40c	193.414067	ENDL92	LLNL/XTM	300	43559	5400	30.0	yes	no
80000.42c	198.866819	ENDL92	LLNL	300	29731	2507	30.0	yes	no
80000.40c	198.866819	ENDL92	LLNL/XTM	300	29731	2507	30.0	yes	no
82000.42c	205.420035	ENDL92	LLNL	300	270244	18969	30.0	yes	no
83209.42c	207.185129	ENDL92	LLNL	300	20921	1200	30.0	yes	no
90231.42c	229.051567	ENDL92	LLNL	300	15712	187	30.0	yes	both
90232.42c	230.044718	ENDL92	LLNL	300	109829	13719	30.0	yes	both
90233.42c	231.039623	ENDL92	LLNL	300	16015	206	30.0	yes	both
91233.42c	231.038298	ENDL92	LLNL	300	27720	1982	30.0	yes	both
92233.42c	231.037688	ENDL92	LLNL	300	29521	2163	30.0	yes	both
92234.42c	232.030405	ENDL92	LLNL	300	13677	149	30.0	yes	both
92235.42c	233.024766	ENDL92	LLNL	300	72790	5734	30.0	yes	both
92236.42c	234.0178	ENDL92	LLNL	300	14595	311	30.0	yes	both
92237.42c	235.012345	ENDL92	LLNL	300	13465	210	30.0	yes	both
92238.42c	236.005797	ENDL92	LLNL	300	107739	7477	30.0	yes	both
92239.42c	237.000681	ENDL92	LLNL	300	14336	205	30.0	yes	both
92240.42c	237.994368	ENDL92	LLNL	300	14000	128	30.0	yes	both
93235.42c	233.024897	ENDL92	LLNL	300	17717	660	30.0	yes	both
93236.42c	234.018847	ENDL92	LLNL	300	13464	179	30.0	yes	both
93237.42c	235.011793	ENDL92	LLNL	300	31966	2477	30.0	yes	both
93238.42c	236.005951	ENDL92	LLNL	300	13445	165	30.0	yes	both
94237.42c	235.012025	ENDL92	LLNL	300	17284	279	30.0	yes	both
94238.42c	236.004576	ENDL92	LLNL	300	30572	2177	30.0	yes	both
94239.42c	236.998566	ENDL92	LLNL	300	93878	6827	30.0	yes	both
94240.42c	237.991613	ENDL92	LLNL	300	198041	16626	30.0	yes	both
94241.42c	238.986034	ENDL92	LLNL	300	14108	203	30.0	yes	both
94242.42c	239.979319	ENDL92	LLNL	300	48688	4287	30.0	yes	both
94243.42c	240.973962	ENDL92	LLNL	300	20253	745	30.0	yes	both
95241.42c	238.986012	ENDL92	LLNL	300	32579	2011	30.0	yes	both
95242.42c	239.980114	ENDL92	LLNL	300	21828	1368	20.0	yes	both

ZAID	Atomic Wt. Ratio	Library Name	Source	Temp (°K)	Total File Length	Number of Energies	Maximum Energy	Photon Production	Nubar Data
95243.42c	240.973341	ENDL92	LLNL	300	52074	4867	30.0	yes	both
96242.42c	239.979411	ENDL92	LLNL	300	37766	3141	30.0	yes	both
96243.42c	240.973349	ENDL92	LLNL	300	21543	1099	30.0	yes	both
96244.42c	241.966113	ENDL92	LLNL	300	46590	4198	30.0	yes	both
96245.42c	242.960238	ENDL92	LLNL	300	25678	1564	30.0	yes	both
96246.42c	243.953366	ENDL92	LLNL	300	24550	1376	30.0	yes	both
96247.42c	244.947877	ENDL92	LLNL	300	39971	3256	30.0	yes	both
96248.42c	245.941265	ENDL92	LLNL	300	40345	3355	30.0	yes	both
97249.42c	246.935292	ENDL92	LLNL	300	19573	809	30.0	yes	both
98249.42c	246.935157	ENDL92	LLNL	300	49615	4554	30.0	yes	both
98250.42c	247.928108	ENDL92	LLNL	300	17659	574	30.0	yes	both
98251.42c	248.922668	ENDL92	LLNL	300	17673	545	30.0	yes	both
98252.42c	249.916101	ENDL92	LLNL	300	21027	1210	30.0	yes	both
49125.42c	116.490609	ENDL92	LLNL	300	9142	119	30.0	yes	no
49120.42c	116.490609	ENDL92	LLNL	300	12755	164	30.0	yes	no

Table 2: Improved and New Evaluations in the ENDL92 Library

‘Improved’ Evaluations	‘New’ Evaluations
1001.42c	3006.42c
5010.42c	23051.42c
7014.42c	30000.42c
8016.42c	49000.42c
15031.42c	50000.42c
16032.42c	51000.42c
18000.42c	78000.42c
26000.42c	80000.42c
28000.42c	82000.42c
28058.42c	
39088.42c	
40000.42c	
42000.42c	
48000.42c	
54134.42c	
63000.42c	
72000.42c	
90233.42c	
92235.42c	
92238.42c	
94238.42c	
94239.42c	
94240.42c	
95241.42c	
97249.42c	
98250.42c	
49125.42c	

Table 3: MT Reaction Numbers for the ENDL92 Library

ZAID	MT Reaction Numbers	Plot Filename
1001.42c	102	plot1
1003.42c	16	plot1
2003.42c	102	plot1
2004.42c		plot1
3006.42c	51, 91, 52, 16, 32, 102	plot1
3007.42c	51, 16, 33, 102	plot1
4007.42c		plot1
5010.42c	91, 51, 52, 53, 54, 35, 16, 102	plot1
5011.42c	91, 51, 52, 53, 16, 102	plot1
6012.42c	51, 23, 52, 53, 54, 55, 56, 102	plot1
6013.42c	51, 52, 53, 16, 102	plot1
7014.42c	51- 60, 16, 28, 102	plot1
7015.42c	91, 51, 52, 53, 54, 55, 56, 57, 16, 28, 22, 102	plot1
8016.42c	91, 51, 52, 53, 54, 16, 28, 22, 102	plot1
9019.42c	91, 51- 71, 16, 28, 22, 102	plot1
10020.42c	91, 51, 52, 16, 28, 22, 102	plot1
11023.42c	91, 51, 16, 28, 22, 102	plot1
12000.42c	91, 51, 52, 53, 16, 102	plot1
13027.42c	91, 51- 63, 16, 28, 102	plot1
14000.42c	91, 51, 52, 16, 28, 102	plot1
15031.42c	91, 16, 28, 102	plot1
16032.42c	91, 16, 28, 102	plot1
17000.42c	91, 16, 28, 22, 102	plot1
18000.42c	91, 16, 102	plot1
19000.42c	91, 16, 28, 22, 102	plot1
20000.42c	91, 16, 28, 22, 102	plot2
22000.42c	91, 51, 16, 102	plot2
23051.42c	91, 51-74, 16, 28, 22, 102	plot2
24000.42c	91, 51, 52, 53, 54, 55, 56, 57, 58, 16, 28, 102	plot2
25055.42c	91, 16, 28, 102	plot2
26000.42c	91, 51, 16, 102	plot2
27059.42c	91, 16, 28, 91, 33, 22, 102	plot2
28000.42c	91, 51-62, 16, 28, 22, 102	plot2
28058.42c	91, 16, 28, 102	plot2
30000.42c	91, 16, 17, 28, 22, 23, 102	plot2
30000.40c	91, 16, 17, 28, 22, 23, 102	plot2
31000.42c	91, 16, 102	plot2
33074.42c	91, 16, 17, 102	plot2
33075.42c	91, 16, 17, 102	plot2

ZAID	MT Reaction Numbers	Plot Filename
39088.42c	91, 16, 102	plot2
39089.42c	91, 51, 52, 53, 54, 55, 56, 57, 16, 102	plot2
40000.42c	91, 51, 52, 53, 54, 55, 56, 57, 58, 16, 17, 102	plot2
41093.42c	91, 51-62, 16, 17, 102	plot3
42000.42c	91, 16, 17, 102	plot3
47107.42c	91, 51, 52, 53, 54, 55, 56, 16, 17, 102	plot3
47109.42c	91, 51, 52, 53, 54, 55, 16, 17, 102	plot3
48000.42c	91, 16, 17, 102	plot3
49000.42c	91, 16, 17, 37, 102	plot3
50000.42c	91, 16, 17, 102	plot3
50000.40c	91, 16, 17, 102	plot3
53127.42c	91, 16, 17, 102	plot3
54000.42c	91, 16, 17, 102	plot3
54134.42c	91, 51, 52, 53, 16, 17, 102	plot3
63000.42c	91, 16, 17, 102	plot3
67165.42c		plot3
72000.42c	91, 51, 52, 53, 54, 16, 17, 102	plot3
73181.42c	91, 51-59, 16, 17, 102	plot3
75185.42c	91, 16, 17, 102	plot3
75187.42c	91, 16, 17, 102	plot3
78000.42c	91, 16, 17, 102	plot3
78000.40c	91, 16, 17, 102	plot3
80000.42c	91, 16, 17, 37, 102	plot4
80000.40c	91, 16, 17, 37, 102	plot4
82000.42c	91, 16, 17, 102	plot4
83209.42c	91, 51, 52, 53, 54, 55, 16, 17, 22, 102	plot4
90231.42c	91, 16, 17, 37, 18, 102	plot4
90232.42c	91, 16, 17, 37, 18, 102	plot4
90233.42c	91, 16, 17, 37, 18, 102	plot4
91233.42c	91, 51, 52, 53, 54, 55, 16, 17, 18, 102	plot4
92233.42c	91, 16, 17, 18, 102	plot4
92234.42c	91, 16, 17, 18, 102	plot4
92235.42c	91, 16, 17, 37, 18, 102	plot4
92236.42c	91, 16, 17, 18, 102	plot4
92237.42c	91, 16, 17, 18, 102	plot4
92238.42c	91, 51-72, 16, 17, 37, 18, 102	plot4
92239.42c	91, 16, 17, 37, 18, 102	plot4
92240.42c	91, 16, 17, 37, 18, 102	plot4
93235.42c	91, 16, 17, 18, 102	plot4
93236.42c	91, 16, 17, 18, 102	plot4
93237.42c	91, 16, 17, 18, 102	plot4
93238.42c	91, 16, 17, 18, 102	plot4

ZAID	MT Reaction Numbers	Plot Filename
94237.42c	91, 51, 52, 16, 17, 18, 102	plot5
94238.42c	91, 16, 17, 18, 102	plot5
94239.42c	91, 51, 52, 53, 54, 55, 56, 16, 17, 37, 18, 102	plot5
94240.42c	91, 51, 52, 53, 54, 55, 16, 17, 18, 102	plot5
94241.42c	91, 16, 17, 37, 18, 102	plot5
94242.42c	91, 51, 52, 53, 54, 16, 17, 37, 18, 102	plot5
94243.42c	91, 16, 17, 37, 18, 102	plot5
95241.42c	91, 16, 17, 18, 102, 115	plot5
95242.42c	91, 16, 17, 37, 18, 102	plot5
95243.42c	91, 16, 17, 37, 18, 102	plot5
96242.42c	91, 16, 17, 18, 102	plot5
96243.42c	91, 16, 17, 37, 18, 102	plot5
96244.42c	91, 16, 17, 37, 18, 102	plot5
96245.42c	91, 16, 17, 37, 18, 102	plot5
96246.42c	91, 16, 17, 37, 18, 102	plot5
96247.42c	91, 16, 17, 37, 18, 102	plot5
96248.42c	91, 16, 17, 37, 18, 102	plot5
97249.42c	91, 16, 17, 37, 18, 102	plot5
98249.42c	91, 16, 17, 37, 18, 102	plot5
98250.42c	91, 16, 17, 37, 18, 102	plot5
98251.42c	91, 16, 17, 37, 18, 102	plot5
98252.42c	91, 16, 17, 37, 18, 102	plot5
49125.42c	91, 16, 17, 102	plot5
49120.42c	91, 16, 17, 102	plot5

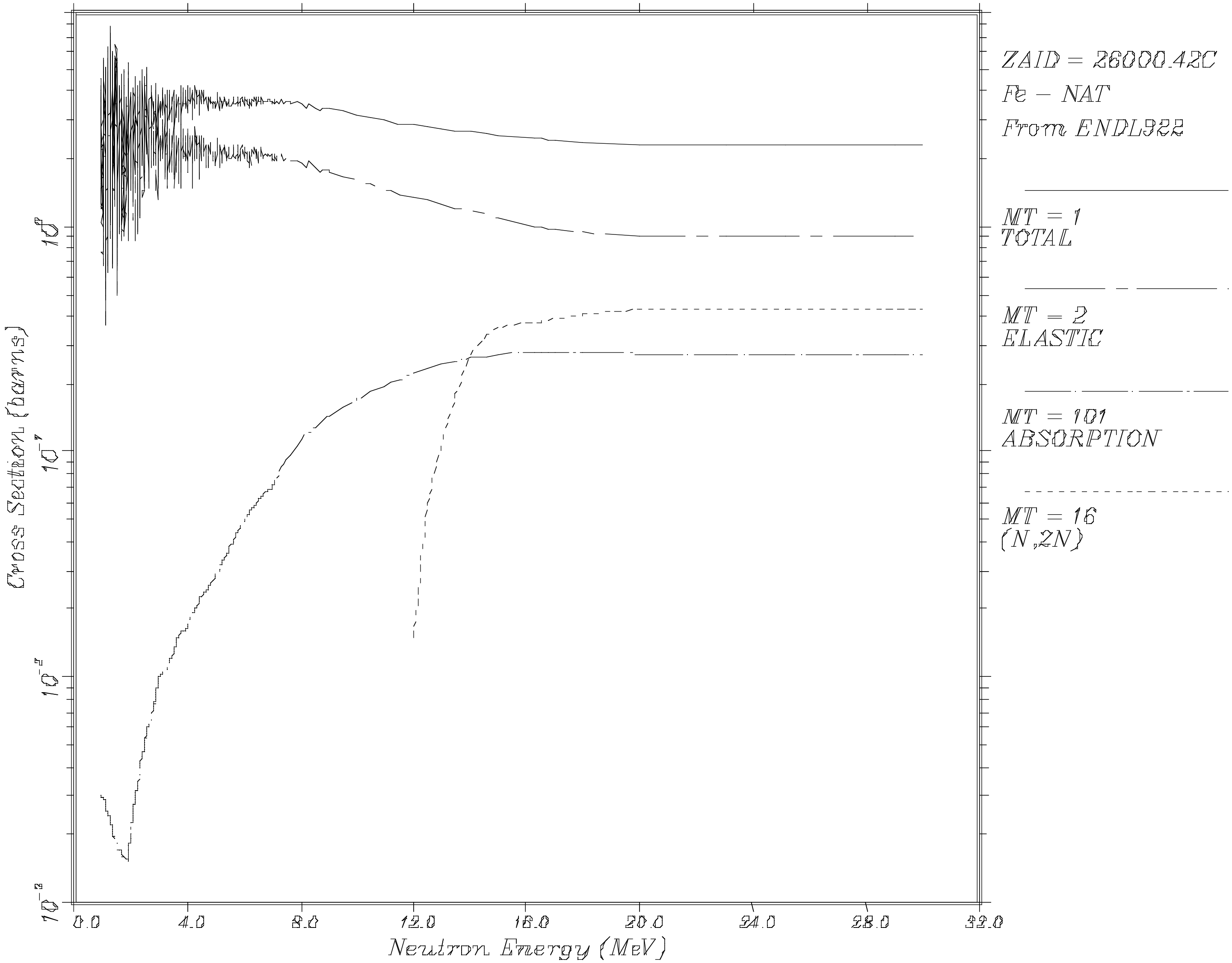

Figure 1: Total, Elastic, Total Absorption, and (n,2n) Cross Sections for Natural Iron

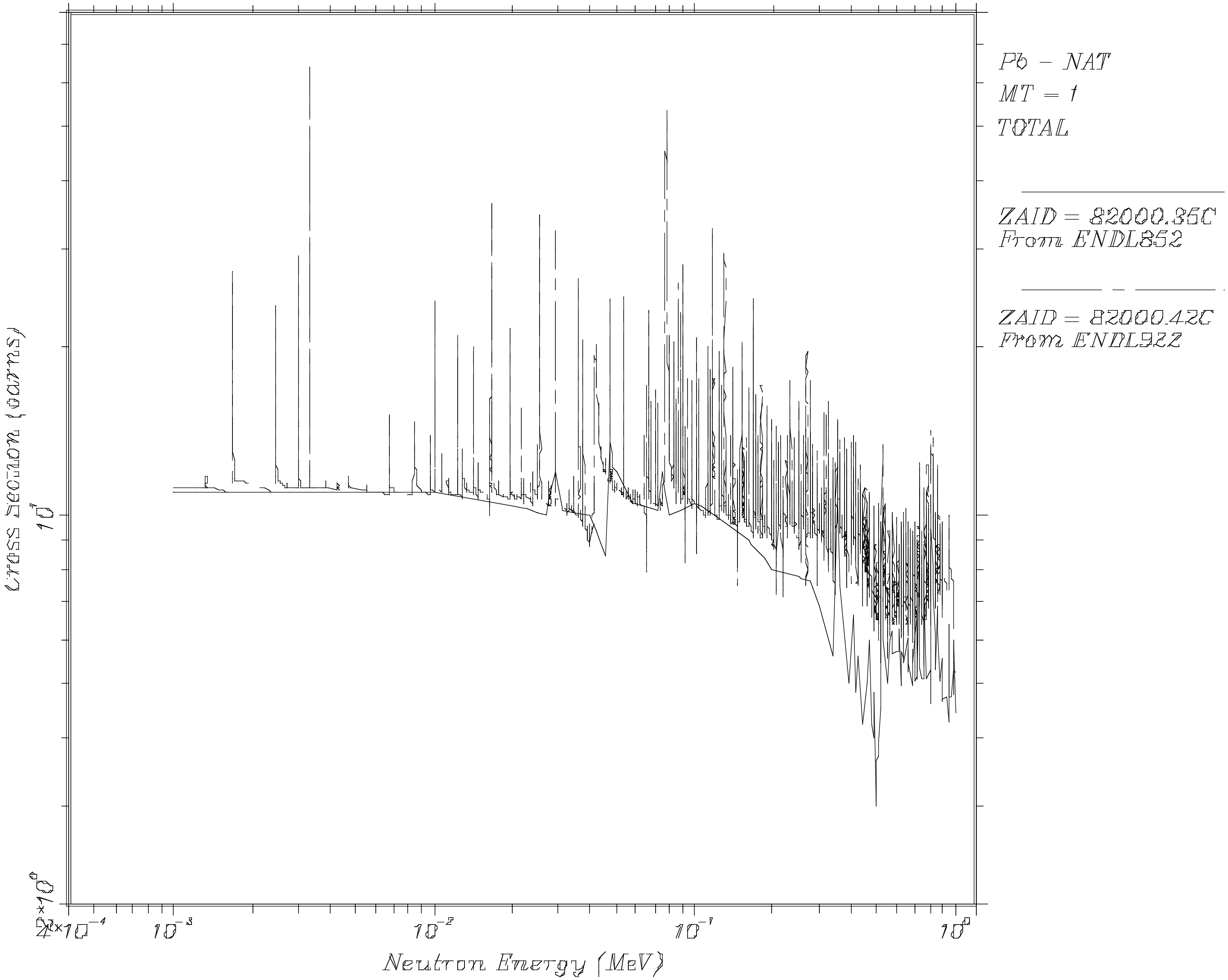

Figure 2: Total Cross Section for Natural Pb from ENDL85 and ENDL92

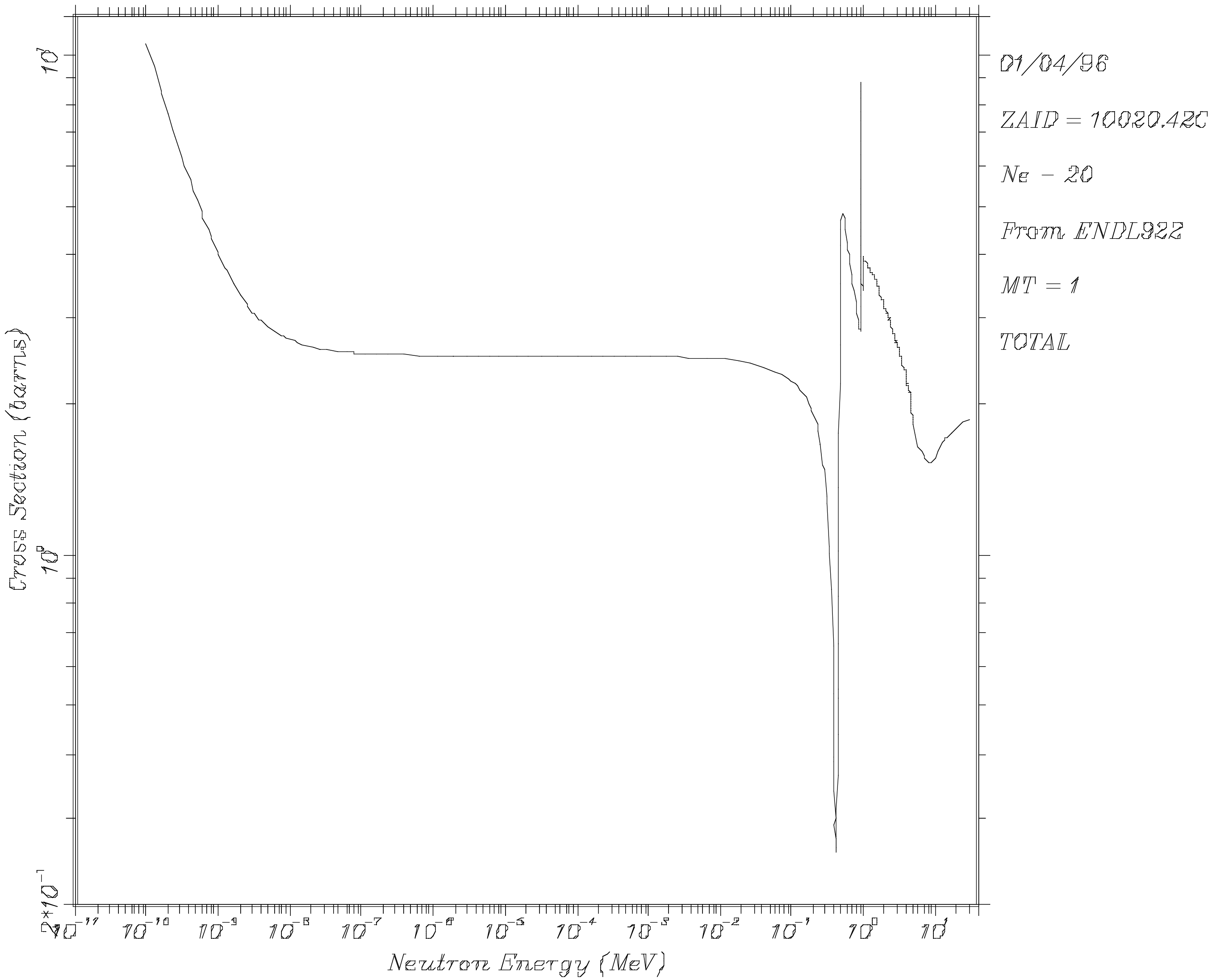

Figure 3: Total Cross Section for ^{20}Ne

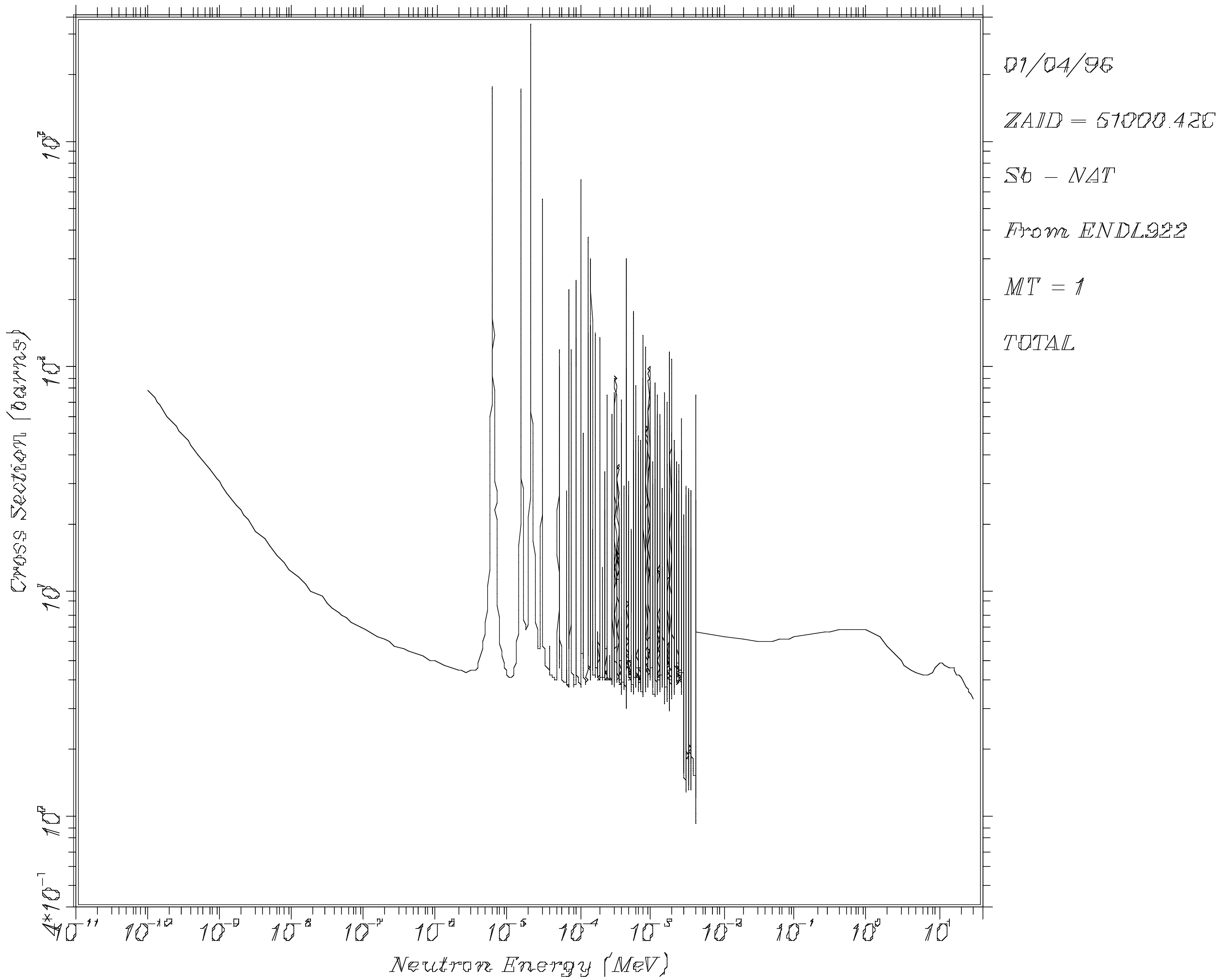

Figure 4: Total Cross Section for Natural Sb

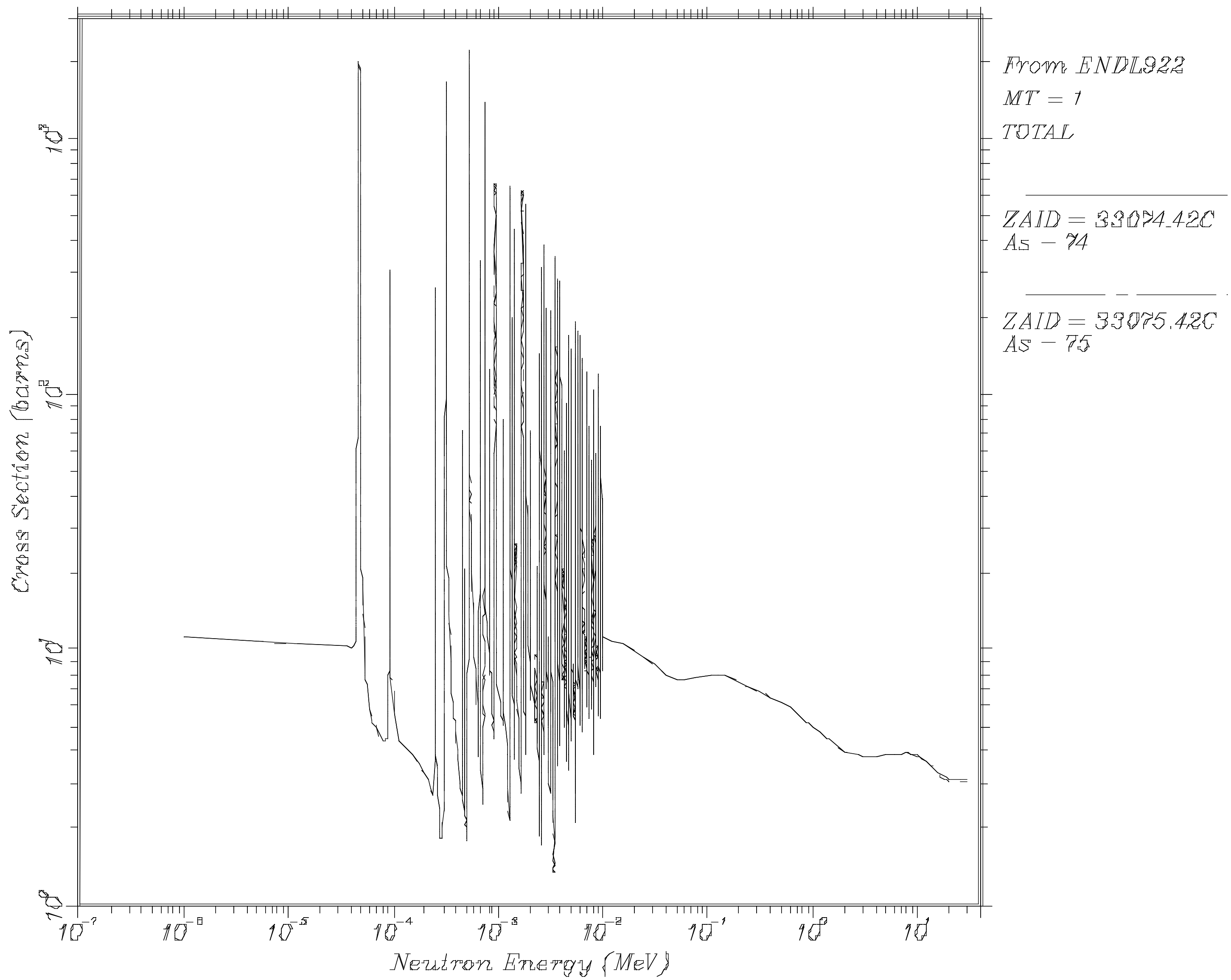

Figure 5: Total Cross Sections for ^{74}As and ^{75}As

III. MCNP Compatibility and Library Availability

All data formats are equivalent to those found in ENDF/B-V evaluations, and as such this library is compatible with all currently supported versions of MCNP. The ENDL92 library resides on both open and secure computing platforms, and can be found in the HPSS directories /hpss/nucldata/mc/type1 and /hpss/nucldata/mc/type2. The ENDL92FP library contains two average-fission products, designated by the ZAIDs 49120.42c and 49125.42c, and are located in the same areas as ENDL92 at LANL. The ENDL92FP library is not publicly available.

IV. Related Libraries

The ENDL92 library is closely related to the ENDL85 library. The ENDL85 library was processed by the Data Team here at LANL from the original ENDL evaluations. As such it contains cross sections for neutron absorption reactions (such as MTs=103-107), which are not available in ENDL92. ENDL85 was processed at 0°K, while ENDL92 is for room temperatures, 300°K. The user should specify the proper library corresponding to the temperature of the problem. If the user does not specify a temperature using the TMP card, MCNP will attempt to Doppler broaden the ENDL85 library to room temperature. MCNP's method for Doppler broadening only affects the total and elastic scattering cross-sections.

V. Benchmark Results

The Data Team has begun the process of assembling a suite of benchmark tests that will be performed for future data libraries. Currently, we have developed a suite of 33 criticality benchmarks, some of which use different specifications for the same benchmark depending on the reference.[6-8] All benchmark results are documented in Appendix B of this report.

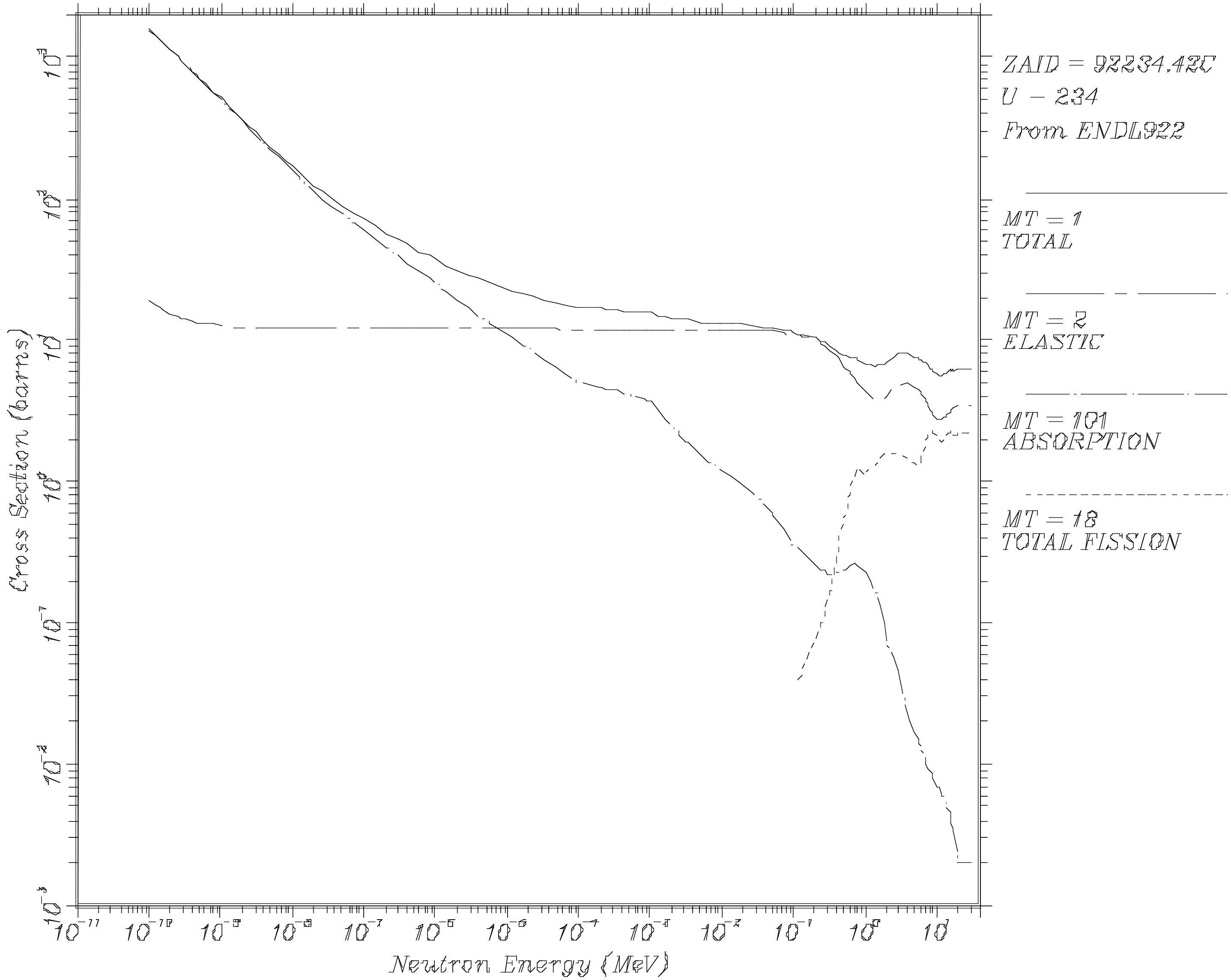

Figure 6: Total, Elastic, Total Apsorption, and Total Fission Cross Sections for ^{234}U

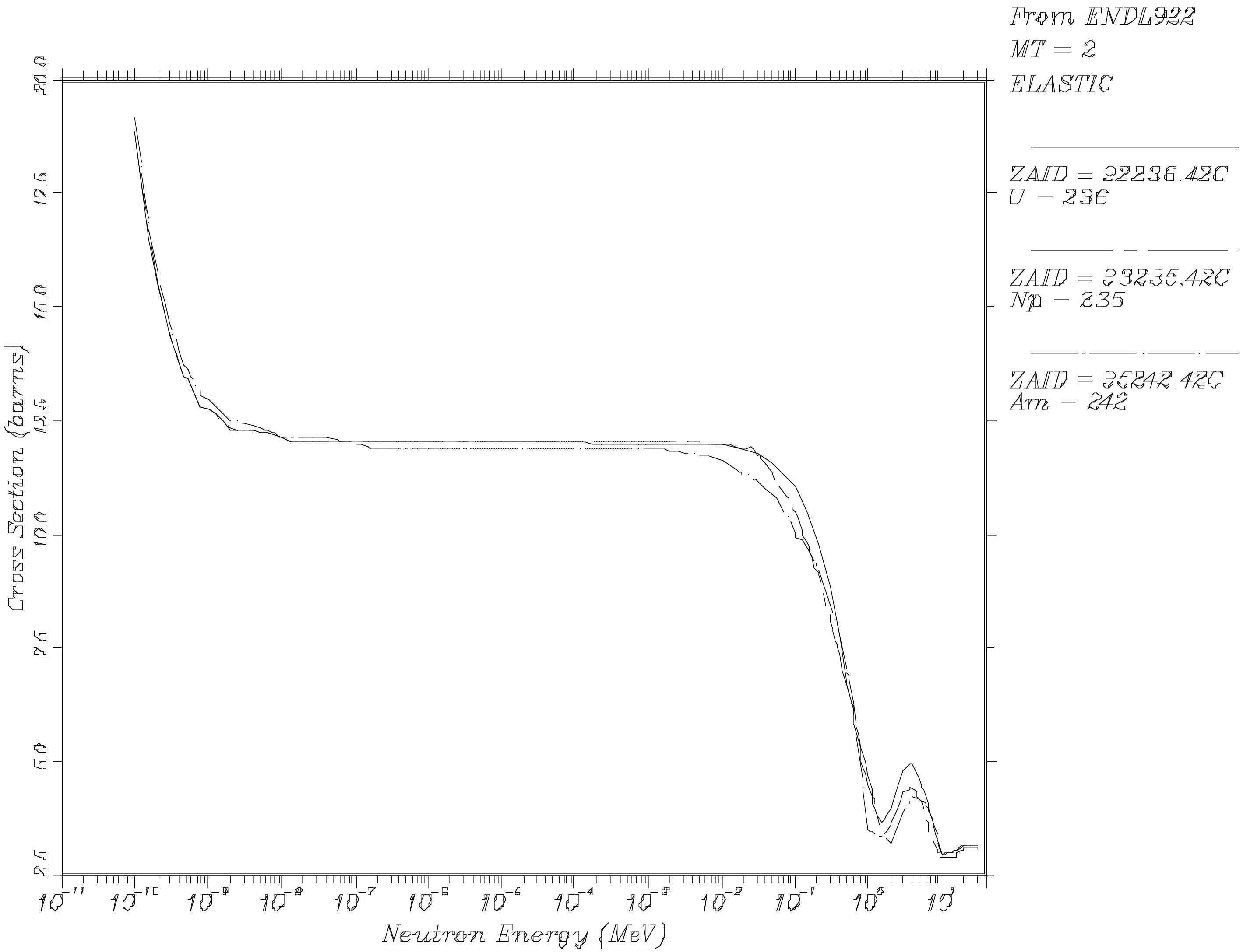

Figure 7: Elastic Cross Sections for ^{236}U, ^{235}Np, and ^{242}Am(ms)

VI. Quality Assurance

The modified QA process that was used for the ENDL92 was as follows:

* The ACER module of NJOY, version 94.10, was used to create 'interpreted' output similar to that from the older FISHP code. This output reformats the information contained in an MCNP type 1 file into something that is easy to read. It can then be archived on microfiche for the final data files that are released. The output from each ZAID was then examined to check for problems with reaction thresholds, energy grids, proper reference frame for secondary distributions, cumulative probabilities for photon distributions, etc. Additionally, secondary energy distributions were checked to ensure that the energy of the secondary neutron did not exceed that of the incident neutron. A couple of special codes[9] were used to verify the reaction thresholds and secondary energy distribution data.
* A simple code was written to compare information for the files on the ENDL85 library with that of the ENDL92 library. This provided us with information about the relative completeness of reaction cross sections and secondary distribution data.[9]
* Comparisons of cross section data for the available reactions were made between many files of the ENDL92 and ENDL85 libraries. Plots of all reaction cross sections were made and examined for each nuclide, and are stored on HPSS under /hpss/nucldata/doc/endl92 as mentioned previously
* A simple MCNP simulation (≥30 minutes) was run on a 32-bit HP-735 workstation for each ZAID (nicknamed the Ho-Ho test). This corresponded to a minimum of more than 200,000 histories to a maximum of over 5,000,000 histories. The problem was for a sphere having a radius of 10cm, and a density of 10 g/cc (or 1 g/cc for very fissionable nuclides). A neutron point source was located at the center of the sphere, ranging in energy from E_n=1x10^{-12} - 30 MeV. Both flux and heating tallies for neutrons and photons were performed. *From these results, it is suggested that in the future we instead use nps=2-5x10^{6} to ensure that the light nuclides, etc. are adequately tested.*

The following section details the modifications that were made to the original LLNL files based on the results of this QA process.

VII. Modifications: Minor and Major

From reviewing the NJOY output and comparison plots with ENDL85, it became clear that the reaction cross-section data remained unchanged for most nuclides. The ENDL92 library included no reaction data for the charged particle production reactions (n,p), (n,d), (n,t), (n,^{3}He), and (n,α) (MT=103, 104, 105, 106 and 107), as well as no corresponding total charged particle production data, MT=203,204,205, 206 and 207. However, the data for secondary neutron energy distributions appears to be a greatly expanded for most all nuclides.

A simple code was written to provide information for comparing the extent of data in the ENDL85 and ENDL92 libraries. It was originally thought that it may not be worthwhile to distribute all of the files. However, upon examining the output from this comparison code, we decided that the increase in secondary neutron energy distribution data was important enough for all nuclides to be distributed, even though the charged particle production reactions had not been included.

Minor Modifications:

Several problems necessitating minor changes in the data files themselves were discovered. First, there were a number of errors in the specification of scattering system, lab or center-of-mass. Table 4 details the TYR values that were changed for the affected

ZAIDs, where the inelastic reactions are given by (n,n*#). All inelastic reactions should be specified in the center-of-mass frame.

Table 4: TYR values modified in the ENDL92 library

ZAID	Reaction	MT#	New TYR Value
3006.42c	(n,n*2)	52	-1
6012.42c	(n,n*2)	52	-1
6012.42c	(n,n*3)	53	-1
6012.42c	(n,n*4)	54	-1
6012.42c	(n,n*5)	55	-1
6012.42c	(n,n*6)	56	-1

Secondly, many inelastic reaction threshold errors were detected. These errors occur when the first energy, E_1, for a given reaction does not meet the following criteria for each individual reaction:

$$E_1 \leq \|Q\|\left(\frac{awr+1}{awr}\right).$$

If the above criteria is not met for reactions which use LAW=3 to specify the secondary energy distributions, MCNP may experience a fatal error. Appendix C details all of the threshold errors detected. Modifications were made only for those reactions which used LAW=3, and are detailed in Table 5. Note that more significant digits than necessary are listed, thereby allowing us to round up to the appropriate value to ensure we met the above criteria.

The third problem encountered concerned ^{7}Be. This was one of the same problems that we encountered when we first examined the ENDL90 library, prompting us to concentrate on the ENDL92 library only. This problem stems from a subtly in MCNP, that is not documented in Appendix F of the manual. If detailed photon production data of any form is included in the data file, then the YP array must exist even if the only entry is a '0', specifying that yields are not given for any reaction. The data file for ^{7}Be was modified to include an additional data entry as the very last word of the data file, with the entry specified as '0' for the YP array. The values for NXS(1) and JXS(22) were changed from 1543 to 1544 indicating the additional data entry, and the value for JXS(20) was changed from 0 to 1544 specifying the location of the YP array. The XSDIR entry was also adjusted accordingly.

Major Modifications:

Upon examining the plots of all reaction cross-section data for each nuclide, nine data files showed major problems with the elastic cross section data as illustrated in Figure 8 for W. It is clear that the elastic scattering cross section is too low for certain neutron energies. This difficulty would be largely mitigated (for most transport applications) if the corresponding total cross section did not also exhibit such drastic behavior. As illustrated in Figure 9, however, this was not the case - there was a corresponding un-physical behabiour in the total cross section for W. Unfortunately, these nine data files were for nuclides which had some of the most detailed treatment of the resonance region: Cu, Zn, Sn, ^{138}Ba, Gd, W, ^{197}Au, Pt, and Hg. Five of these data files (Cu, ^{138}Ba, Gd, W, ^{197}Au) were removed from the library distribution as there existed other data of higher quality for the user. We decided that it was important to try to salvage the data for the remaining four nuclides (Zn, Sn, Pt, and Hg) because other data were either not available, or had limited treatment of the resonance region. We therefore made modifications to the elastic and total cross sections for these elements. LLNL provided no information to us when queried about these problems, so our modifications are based on experimental data where possible.[10-11]

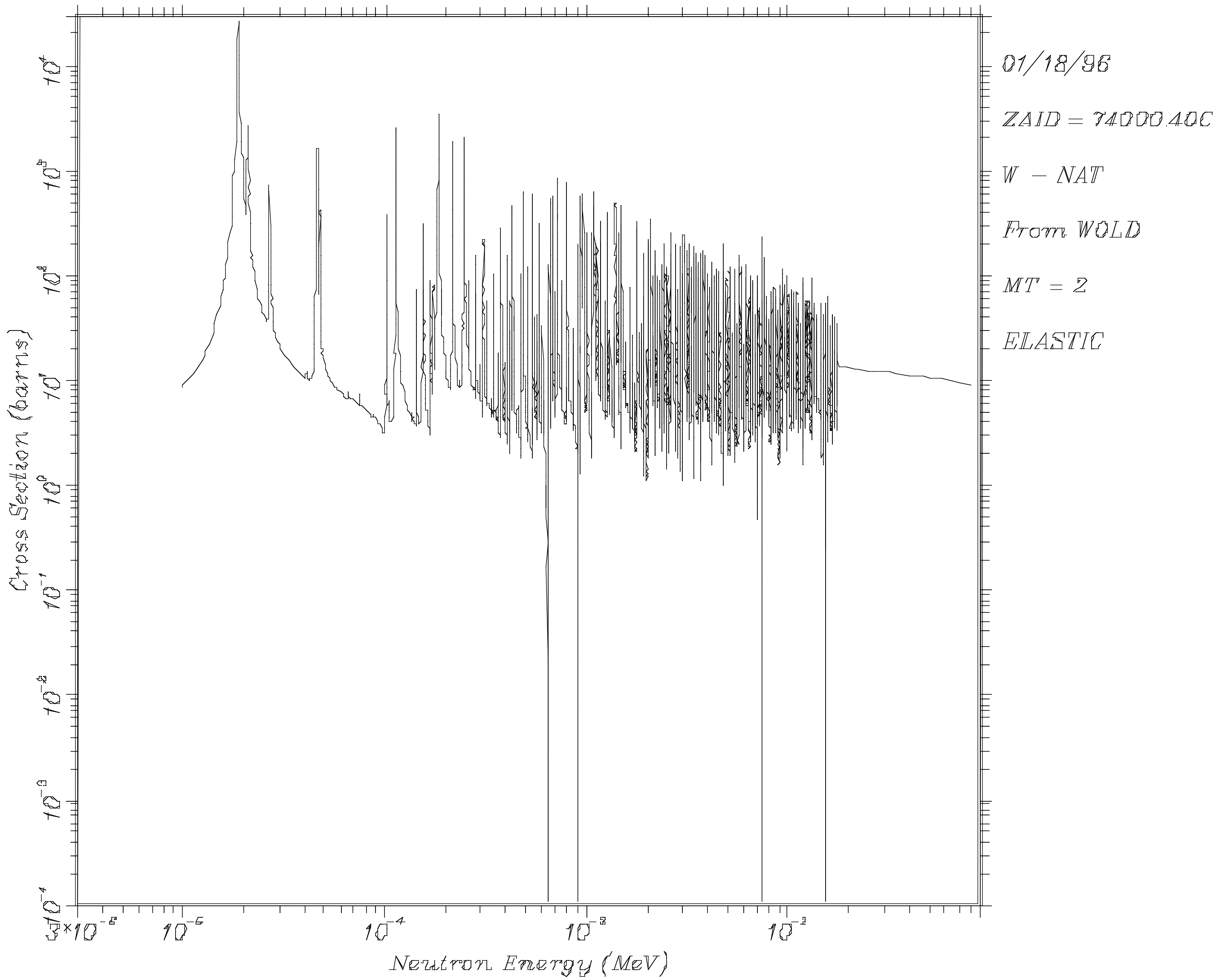

Figure 8: Elastic Cross Section for Natural W

Table 5: Modifications to Reaction Thresholds for the ENDL92 Library

ZAID	Reaction MT	Old Energy (MeV)	New Energy (MeV)
6012.42c	52 (n,n*2)	8.293023937500e+00	8.293023950835e+0
6012.42c	53 (n,n*3)	1.043945366250e+01	1.043945367929e+01
6012.42c	55 (n,n*5)	1.175116071667e+01	1.175116073557e+01
9019.42c	51 (n,n*1)	1.158401303520e-01	1.158401303603e-01
9019.42c	54 (n,n*4)	1.535408273211e+00	1.535408273320e+00
9019.42c	55 (n,n*5)	1.636505114246e+00	1.636505114362e+00
9019.42c	57 (n,n*7)	4.114430811685e+00	4.114430811976e+00
9019.42c	60 (n,n*10)	4.610437188010e+00	4.610437188337e+00
9019.42c	61 (n,n*11)	4.796834488667e+00	4.796834489007e+00
9019.42c	62 (n,n*12)	4.798940672856e+00	4.798940673196e+00
9019.42c	64 (n,n*14)	4.931630276713e+00	4.931630277063e+00
9019.42c	66 (n,n*16)	5.623511782543e+00	5.623511782941e+00
9019.42c	70 (n,n*20)	5.834130201365e+00	5.834130201778e+00
9019.42c	71 (n,n*21)	5.928908489835e+00	5.928908490255e+00
12000.42c	52 (n,n*2)	1.676815496811e+00	1.676815497843e+00
12000.42c	53 (n,n*3)	1.905945564699e+00	1.905945565871e+00
13027.42c	54 (n,n*4)	2.834131778908e+00	2.834131780353e+00
13027.42c	55 (n,n*5)	3.091402892074e+00	3.091402893650e+00
13027.42c	56 (n,n*6)	3.113187946011e+00	3.113187947598e+00
13027.42c	57 (n,n*7)	3.815496589613e+00	3.815496591558e+00
13027.42c	62 (n,n*12)	4.751216525402e+00	4.751216527824e+00
54134.42c	51 (n,n*1)	8.533801706254e-01	8.533801706406e-01
54134.42c	52 (n,n*2)	1.625150195063e-00	1.625150195093e-00
54134.42c	53 (n,n*3)	1.744039050003e-00	1.744039050035e-00
72000.42c	51 (n,n*1)	9.352555238389e-02	9.352555238523e-02
72000.42c	52 (n,n*2)	3.087348879769e-01	3.087348879814e-01
91233.42c	52 (n,n*2)	5.714627951494e-02	5.714627951510e-02
91233.42c	53 (n,n*3)	7.150817401518e-02	7.150817401538e-02
91233.42c	55 (n,n*5)	1.044501418199e-01	1.044501418203e-01
94239.42c	53 (n,n*3)	1.646919873081e-01	1.646919873094e-01

certain neutron energies. This difficulty would be largley mitigated (for most transport applications) if the corresponding total cross section did not also exhibit such drastic behaviour. As illustrated in Figure 9, howver, this was not the case - there was a corresponding un-physical behahiour in the total cross section for W. Unfortunately, these nine data files were for nuclides which had some of the most detailed treatment of the resonance region: Cu, Zn, Sn, ^{138}Ba, Gd, W, ^{197}Au, Pt, and Hg. Five of these data files (Cu, ^{138}Ba, Gd, W, ^{197}Au) were removed from the library distribution as there existed other data of higher quality for the user. We decided that it was important to try to salvage the data for the remaining four nuclides (Zn, Sn, Pt, and Hg) because other data were either not available, or had limited treatment of the resonance region. We therefore made modifications to the elastic and total cross sections for these elements. LLNL provided no information to us when queried about these problems, so our

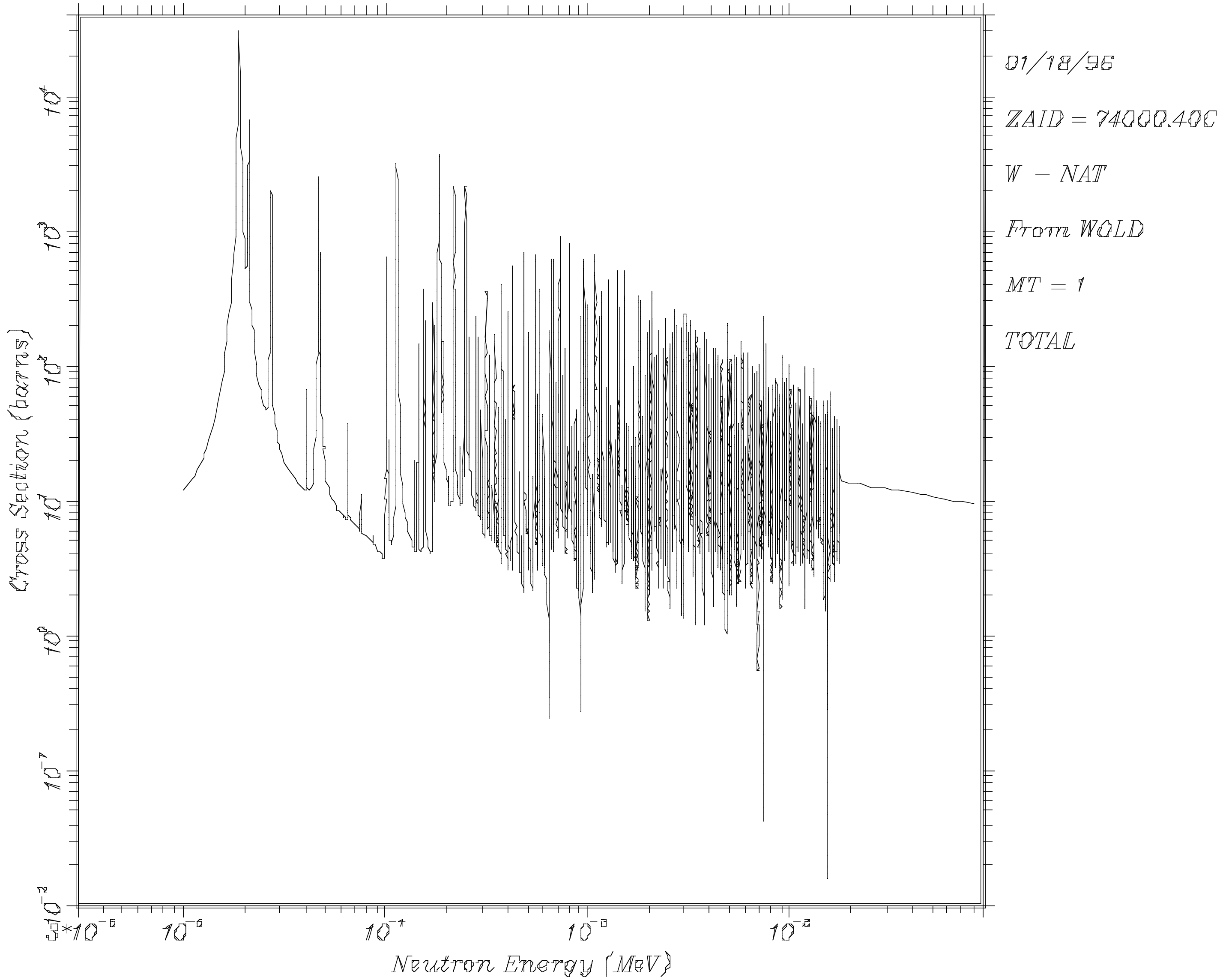

Figure 9: Total Cross Section for Natural W

In general, these type of errors can occur when a single-level Breit-Wigner treatment for the resonances is used. We see similar problems with ENDF evaluations and libraries for a few nuclides, however while the elastic cross section may be affected, the total cross section data appears good. In these cases, no changes are made to the data files. As both elastic and total were affected in the ENDL92 library, we felt the problems with the total cross section would dominate in most calculations and needed to be addressed. We have therefore provided both the original data file, designated by the ZAID ending of '.40c', as well as the X-5-modified data file designated by '.42c' for the user.

For Zn, no ENDF evaluations or library exists. However, experimental data for the total cross section does exist which provided a means for adjusting the elastic and total cross sections in the data file. In this particular case, a minimum value for the total cross section as a function of energy was determined based on experimental data. Table 6 details the three energy regions and the minimum value for the total cross section that was specified. The total cross section was then raised to this minimum value where necessary, and the same correction was applied to the elastic cross section in the data file. Figures 10 and 11 show the total cross section for the original (.40c) and modified (.42c) data files for Zn respectively over the energy region of interest. Figure 12 illustrates the experimental data used in this process. As can be seen, we have established minimum cross section levels below that of the experimental data for the three energy regions such that we provide reasonable data while maintaining as much of the original file as possible.

Table 6: Specifications for Modifying Zn (30000.42c)

Energy Region (MeV)	Minimum Total XS (barns)
4×10^{-4} - 1.2×10^{-2}	1.01
1.2×10^{-2} - 3.0×10^{-2}	0.4
3.0×10^{-2} - 1.5×10^{-1}	1.5

For Sn, Pt, and Hg, there were noticeable energy regions where the total cross section had a sharp drop in the original library. Using the experimental data for these nuclides, shown in Figures 13-15, we determined a constant value to be added to the elastic and total cross sections as a function of energy. The specific energy regions and constant values are detailed in Table 7. Figures 16 and 17, 18 and 19, and 20 and 21 show the total cross section in the region of interest for the original (.40c) and modified (.42c) data files of Sn, Pt, and Hg respectively. Once again, we have made the minimum adjustment for reasonableness, while maintaining as much of the original file as possible.

Table 7: Specifications for Modifying Sn, Pt and Hg

ZAID	Energy Region (MeV)	Background Added (barns)
50000.42c	5.033×10^{-3} - 9.7442×10^{-2}	2.0
78000.42c	9.08×10^{-4} - 1.8×10^{-3}	2.0
80000.42c	9.6×10^{-4} - 4.0×10^{-3}	1.0
80000.42c	4.45×10^{-3} - 4.5×10^{-3}	2.0
80000.42c	4.5×10^{-3} - 1.0×10^{-2}	4.0

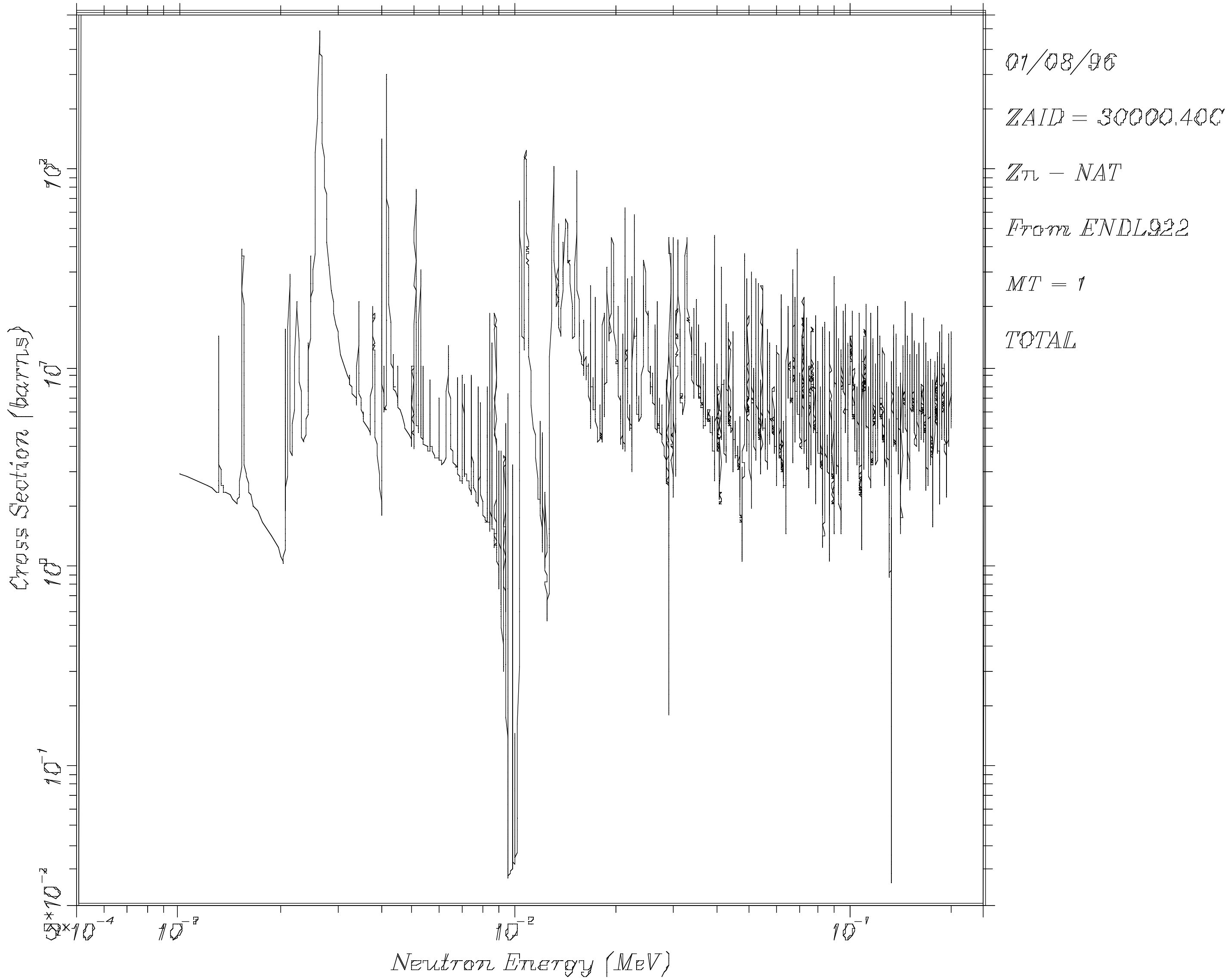

Figure 10: Total Cross Section for Natural Zn from LLNL

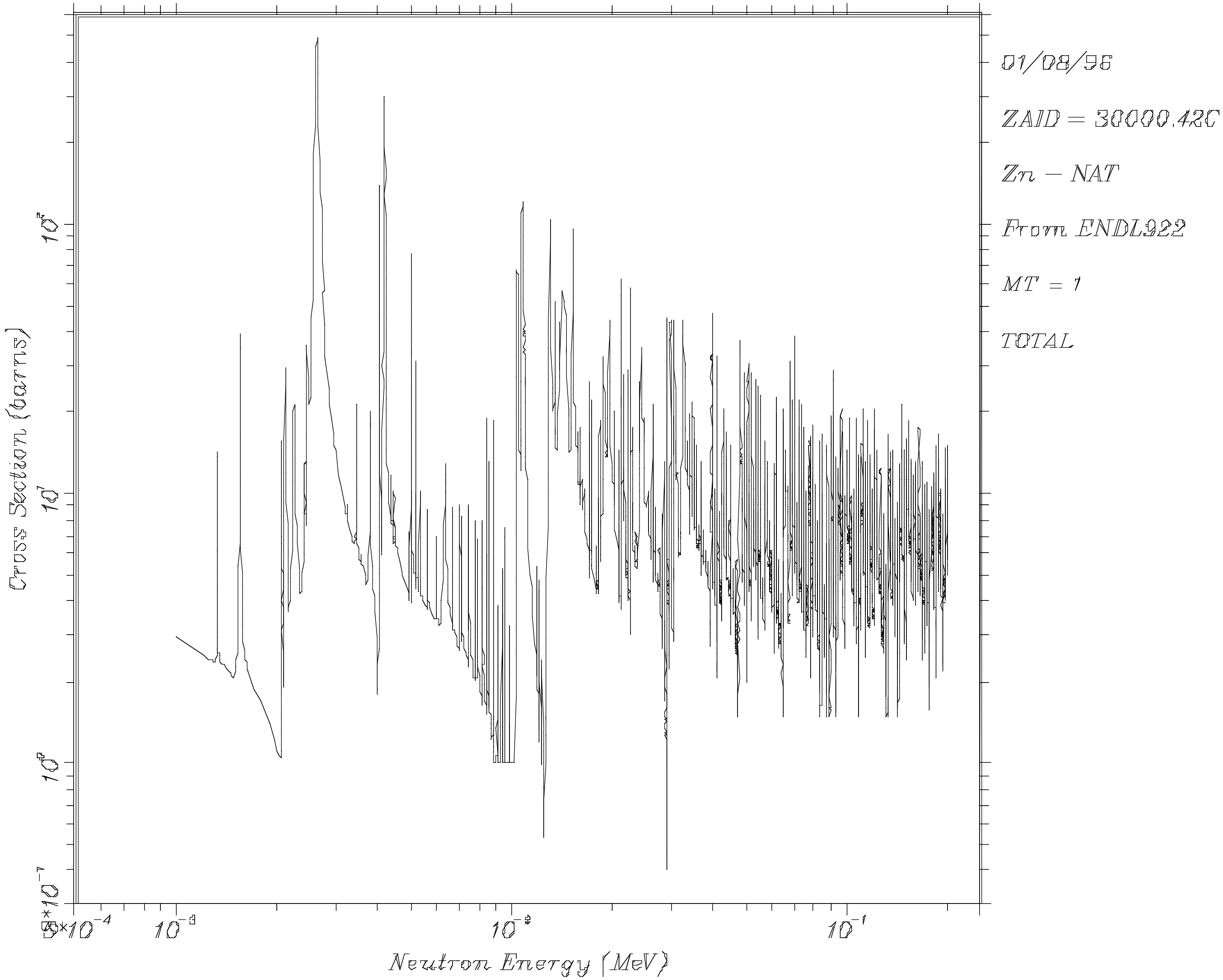

Figure 11: Modified Total Cross Section for Natural Zn (by LANL/XTM)

Figure 12: Cross Sections for Natural Zn from Ref. 4

Figure 13: Cross Sections for Natural Sn from Ref. 4

Figure 14: Cross Sections for Natural Pt from Ref. 4

Figure 15: Cross Sections for Natural Hg from Ref. 4

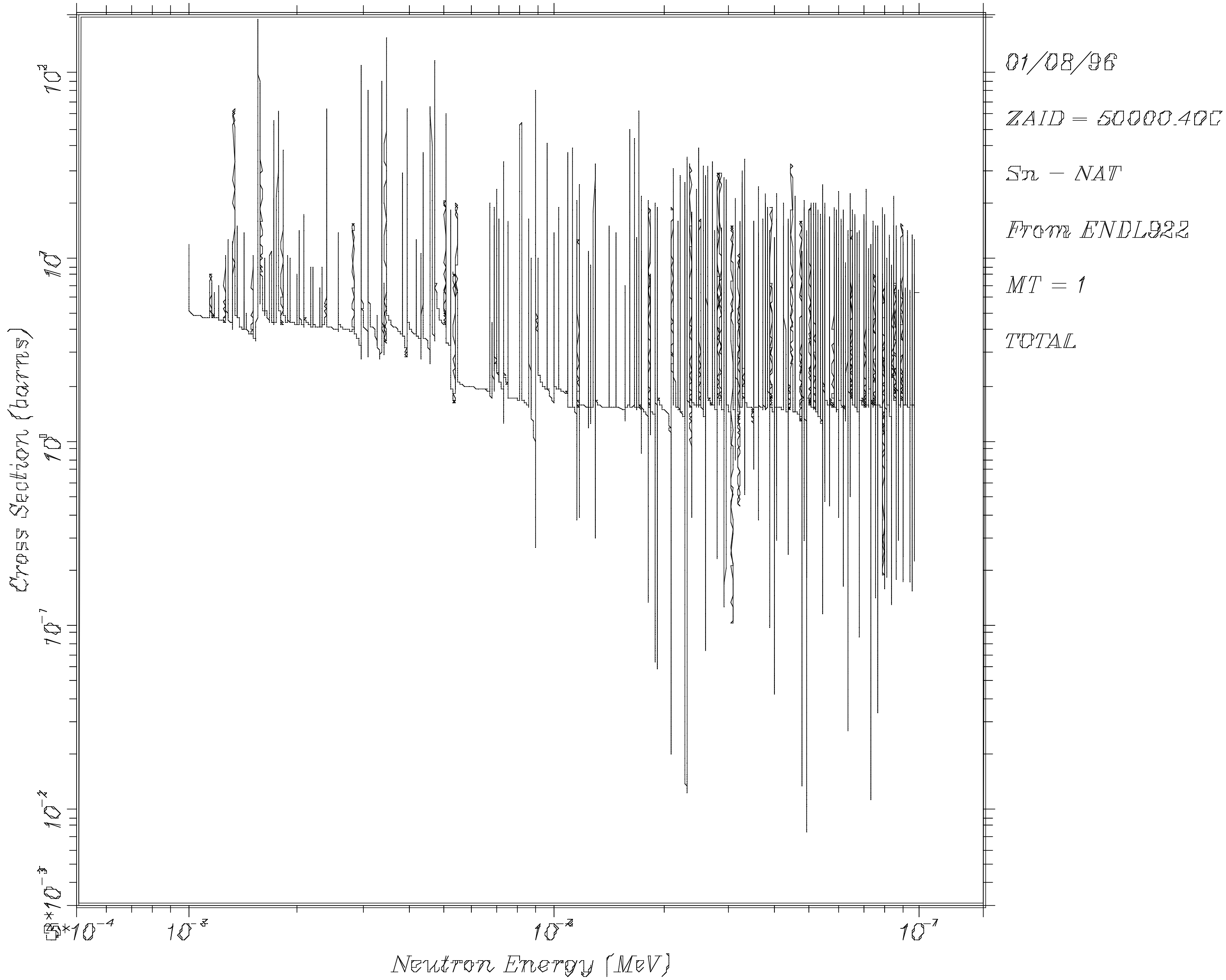

Figure 16: Total Cross Section for Natural Sn from LLNL

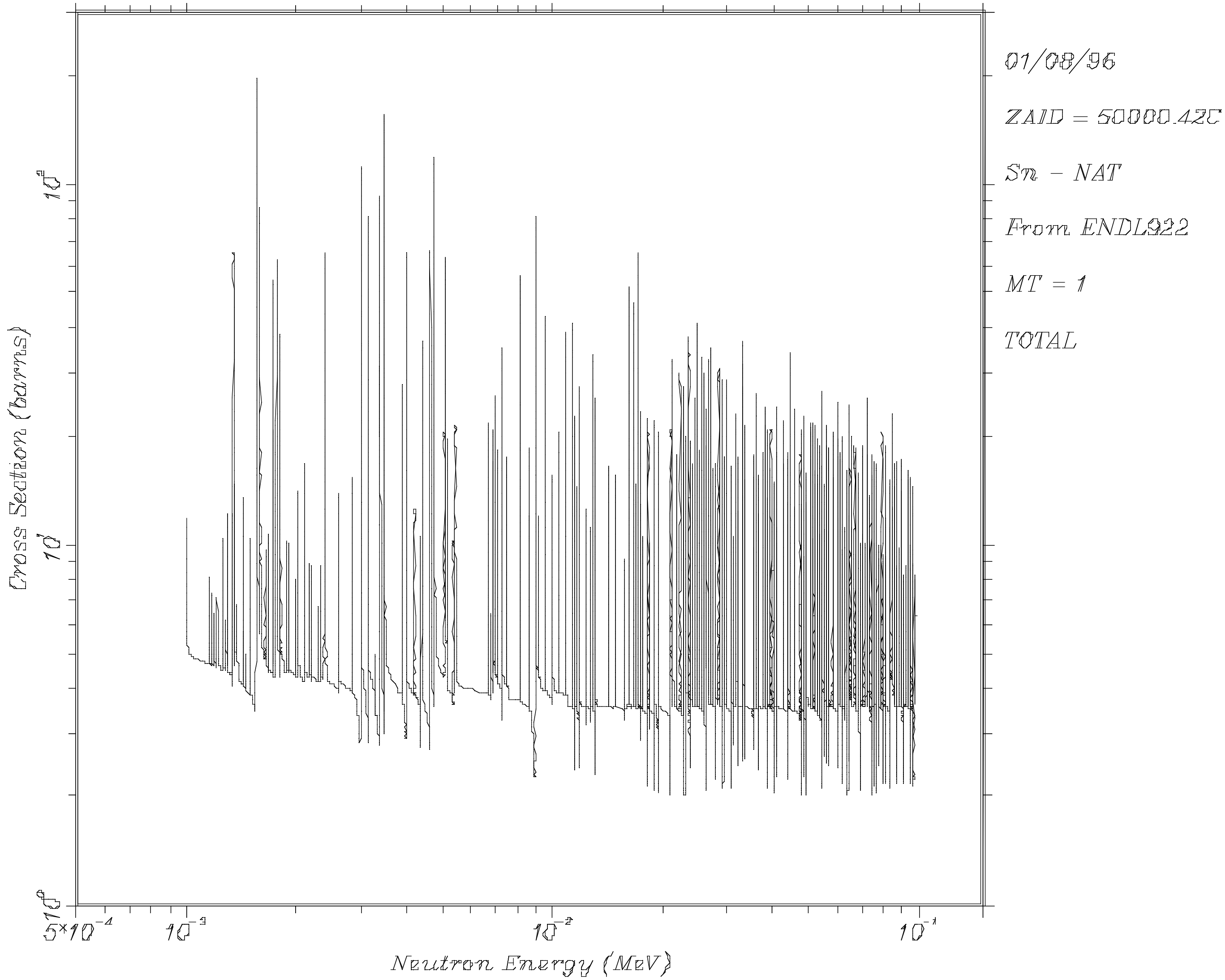

Figure 17: Modified Total Cross Section for Natural Sn (by LANL/XTM)

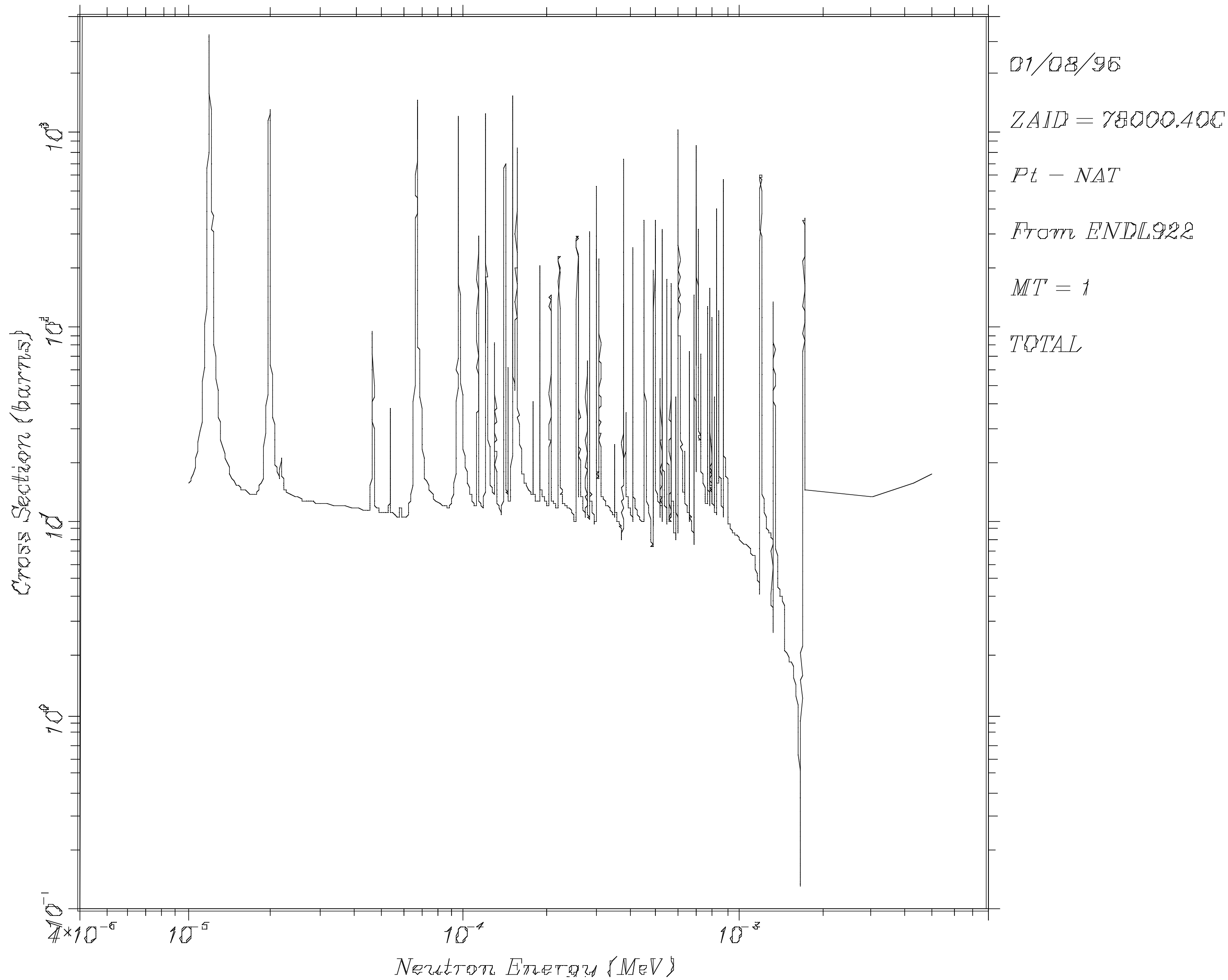

Figure 18: Total Cross Section for Natural Pt from LLNL

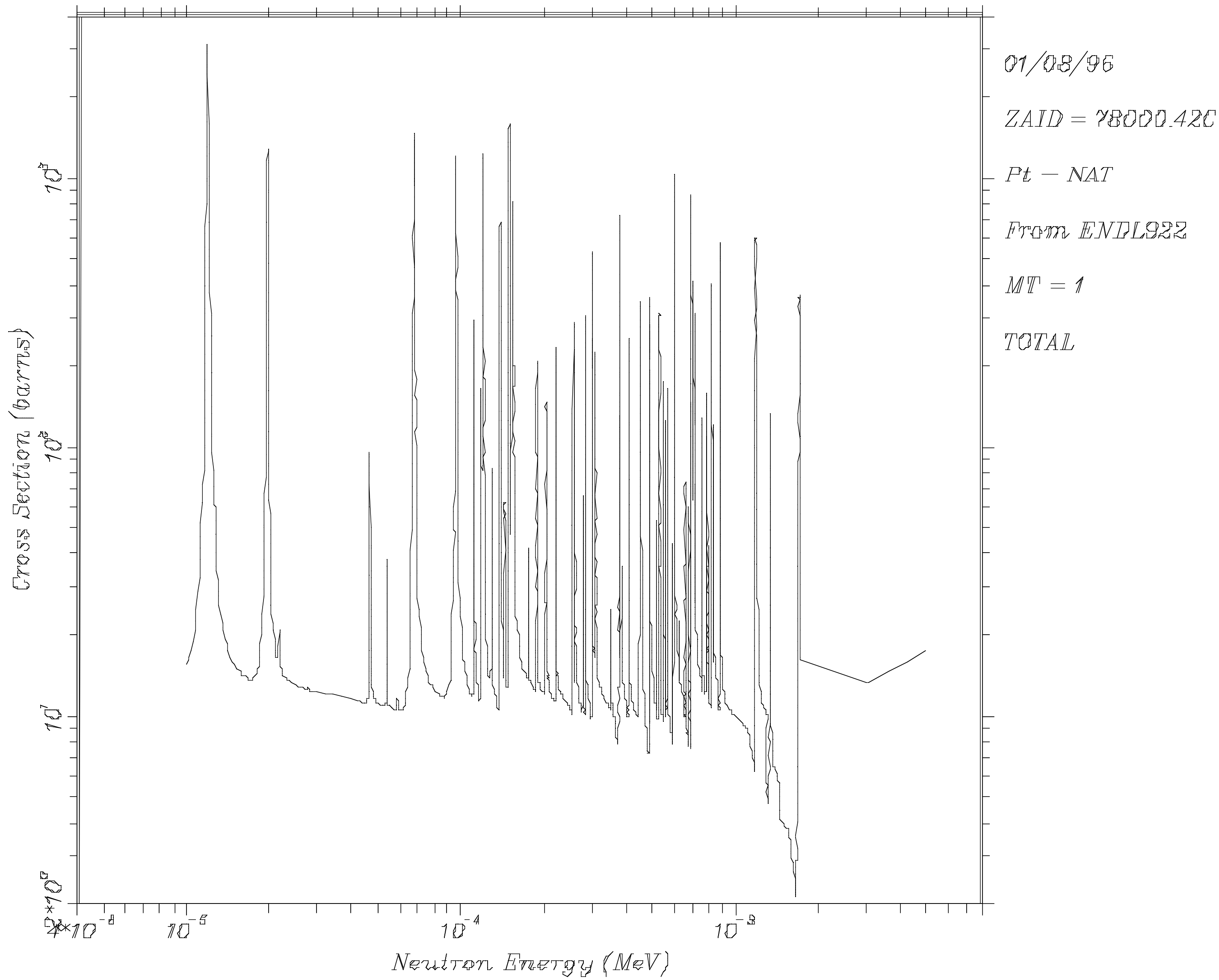

Figure 19: Modified Total Cross Section for Natural Pt (by LANL/XTM)

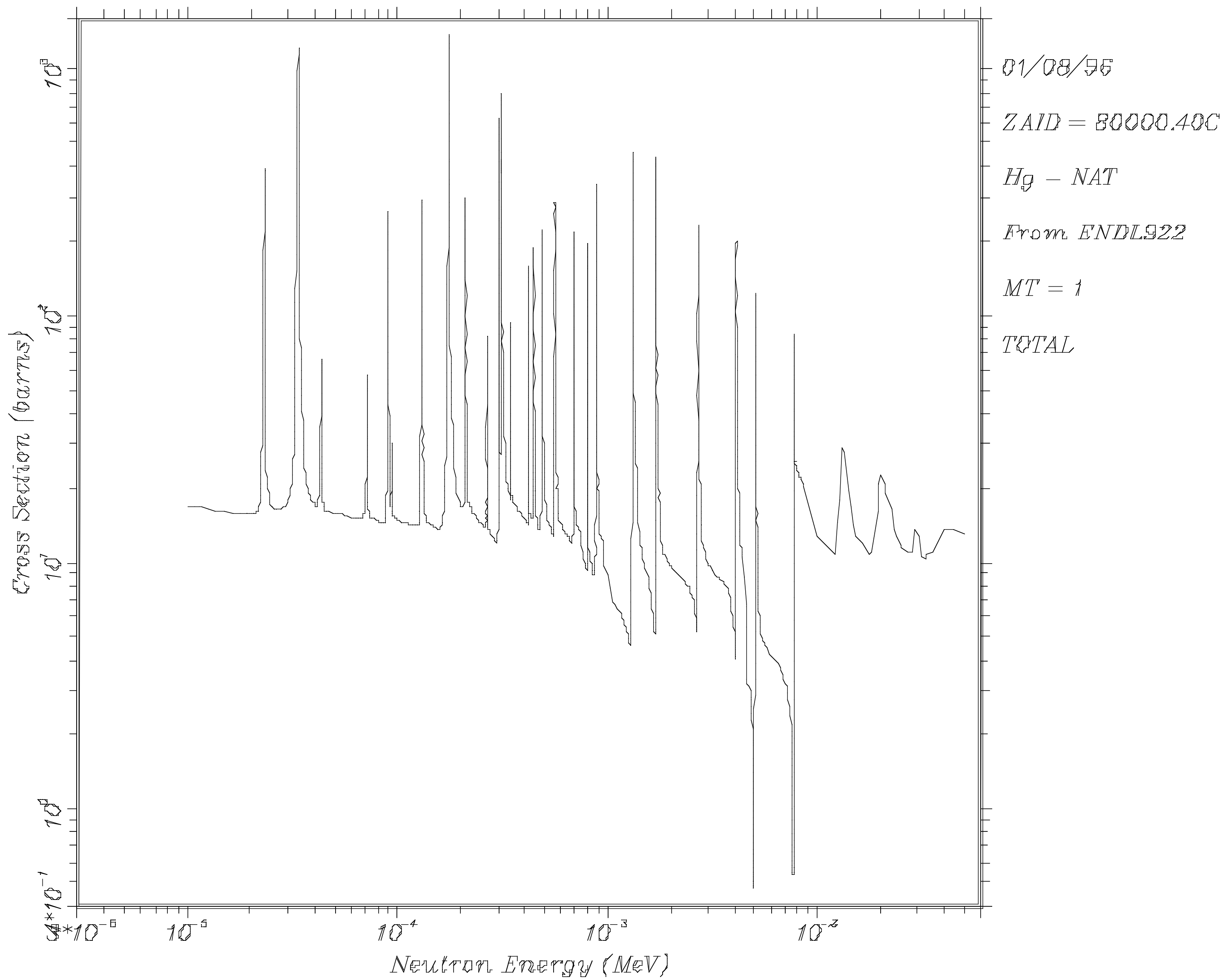

Figure 20: Total Cross Section for Natural Hg from LLNL

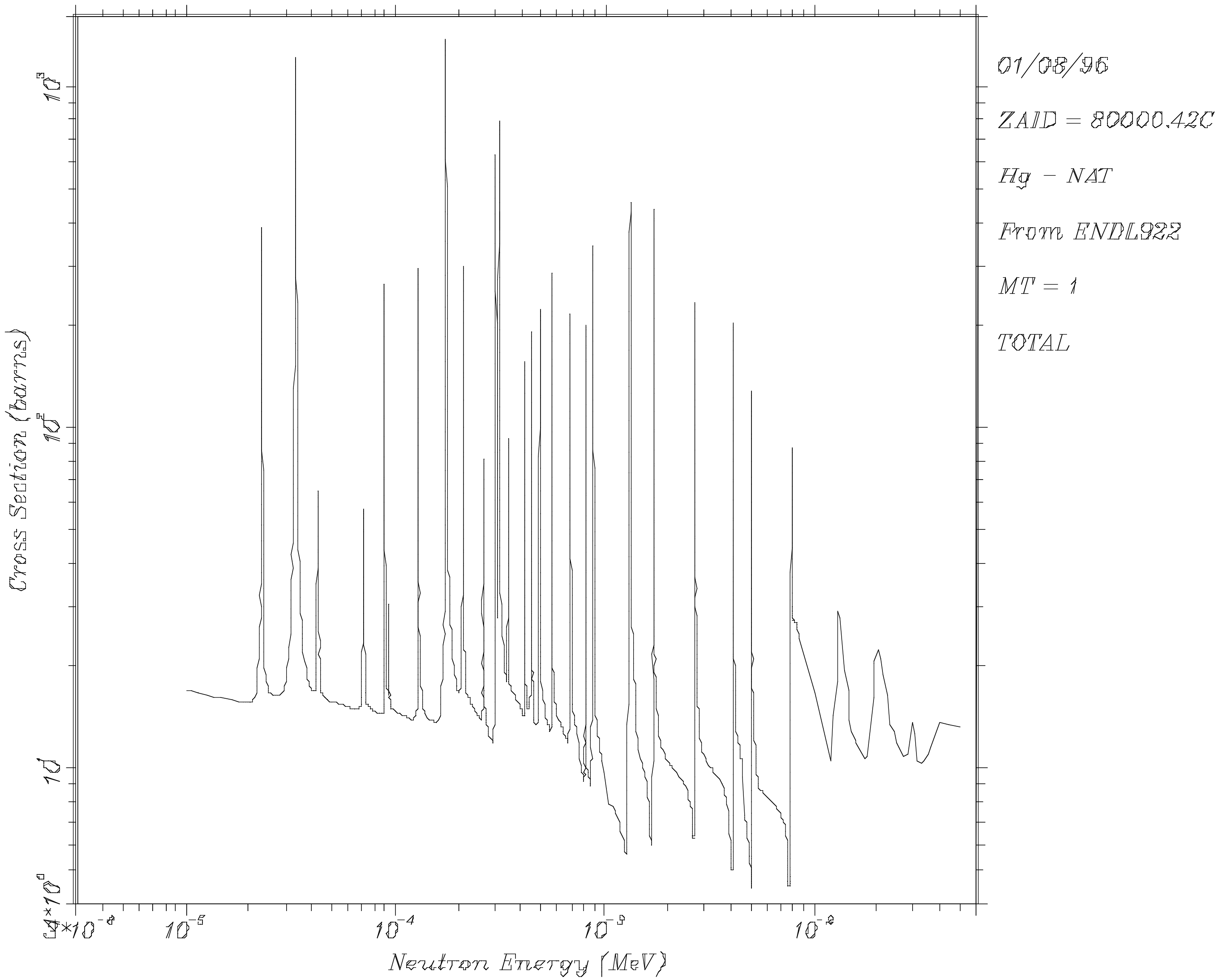

Figure 21: Modified Total Cross Section for Natural Hg (by LANL/XTM)

VIII. Acknowledgements

I would like to acknowledge the contributions of Bob Little in the production of this library. His thoughtful discussions during the QA and modification process, and his tireless editing skills are most appreciated. Additionally, Bob Seamon assisted in the preliminary QA process for ENDL92.

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11 " Experience with ^{158}Ba using NJOY and SAMMY", S. Frankle, Los Alamos National Laboratory internal memorandum, XTM-96-04 (1996).

Appendix A

Example of Expanded Information for Reaction Data
in the ENDL92 Neutron Data Library

Reaction	MT	TYR	LSIG	LAND	LDLW	Emin	Emax	Q-value
==>ag47107 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	9.4500E-01	3.0000E+01	0.0000E+00
(n,n*1)	51	-1	60	667	953	9.4000E-02	8.5000E+00	-9.3000E-02
(n,n*2)	52	-1	130	738	964	1.2100E-01	8.5000E+00	-1.1986E-01
(n,n*3)	53	-1	197	809	975	3.2900E-01	8.5000E+00	-3.2500E-01
(n,n*4)	54	-1	256	880	986	4.2700E-01	8.5000E+00	-4.2300E-01
(n,n*5)	55	-1	309	951	997	7.7000E-01	8.5000E+00	-7.6280E-01
(n,n*6)	56	-1	352	1022	1008	9.3100E-01	8.5000E+00	-9.2200E-01
(n,2n)	16	2	391	0	1019	9.6209E+00	3.0000E+01	-9.5310E+00
(n,3n)	17	3	412	0	1973	1.7650E+01	3.0000E+01	-1.7460E+01
(n,gma)	102	0	418			1.0000E-10	3.0000E+01	7.2690E+00
==>ag47109 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	7.1000E-01	3.0000E+01	0.0000E+00
(n,n*1)	51	-1	62	597	1037	8.8815E-02	5.5000E+00	-8.7999E-02
(n,n*2)	52	-1	122	668	1048	1.3423E-01	5.5000E+00	-1.3299E-01
(n,n*3)	53	-1	178	739	1059	3.1388E-01	5.5000E+00	-3.1099E-01
(n,n*4)	54	-1	228	810	1070	4.1884E-01	5.5000E+00	-4.1499E-01
(n,n*5)	55	-1	271	881	1081	7.0850E-01	5.5000E+00	-7.0199E-01
(n,2n)	16	2	306	0	1092	9.2700E+00	3.0000E+01	-9.1818E+00
(n,3n)	17	3	329	0	2166	1.6620E+01	3.0000E+01	-1.6460E+01
(n,gma)	102	0	335			1.0000E-10	3.0000E+01	6.8057E+00
==>al13027 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	5.2500E+00	3.0000E+01	0.0000E+00
(n,n*1)	51	-1	201	1227	823	8.7500E-01	3.0000E+01	-8.4300E-01
(n,n*2)	52	-1	1126	1893	834	1.0510E+00	3.0000E+01	-1.0130E+00
(n,n*3)	53	-1	1982	2559	845	2.2930E+00	3.0000E+01	-2.2100E+00
(n,n*4)	54	-1	2514	3225	856	2.8341E+00	3.0000E+01	-2.7320E+00
(n,n*5)	55	-1	2944	3541	867	3.0914E+00	3.0000E+01	-2.9800E+00
(n,n*6)	56	-1	3334	3962	878	3.1132E+00	3.0000E+01	-3.0010E+00
(n,n*7)	57	-1	3720	4383	889	3.8155E+00	3.0000E+01	-3.6780E+00
(n,n*8)	58	-1	4025	4489	900	4.1040E+00	3.0000E+01	-3.9560E+00
(n,n*9)	59	-1	4308	4840	911	4.2070E+00	3.0000E+01	-4.0550E+00
(n,n*10)	60	-1	4581	5191	922	4.5740E+00	3.0000E+01	-4.4090E+00
(n,n*11)	61	-1	4825	5507	933	4.6770E+00	3.0000E+01	-4.5080E+00
(n,n*12)	62	-1	5063	5823	944	4.7512E+00	3.0000E+01	-4.5800E+00
(n,n*13)	63	-1	5294	6139	955	4.9910E+00	3.0000E+01	-4.8110E+00
(n,2n)	16	2	5508	0	966	1.3545E+01	3.0000E+01	-1.3057E+01
(n,n*)p	28	1	5541	0	1547	8.5800E+00	3.0000E+01	-8.2710E+00
(n,gma)	102	0	5626			1.0000E-10	3.0000E+01	7.7300E+00
==>am95241 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	5.0000E-02	3.0000E+01	0.0000E+00
(n,2n)	16	2	122	0	1671	5.9500E+00	3.0000E+01	-5.9300E+00
(n,3n)	17	3	158	0	3474	1.2650E+01	3.0000E+01	-1.2600E+01
fission	18	19	172	0	4362	1.0000E-10	3.0000E+01	2.0000E+02

Reaction	MT	TYR	LSIG	LAND	LDLW	Emin	Emax	Q-value
==>am95241 <== continued								
(n,gma)	102	0	2185			1.0000E-10	3.0000E+01	5.4318E+00
(n,pd)	115	0	4198			1.0000E-10	3.0000E+01	5.4800E+00
==>am95242 <==								
elastic	2	1				1.0000E-10	2.0000E+01	
(n,n*c)	91	1	1	0	1	1.0000E-01	2.0000E+01	0.0000E+00
(n,2n)	16	2	49	0	679	5.6000E+00	2.0000E+01	-5.5300E+00
(n,3n)	17	3	74	0	1254	1.1300E+01	2.0000E+01	-1.1250E+01
(n,4n)	37	4	86	0	1960	1.8250E+01	2.0000E+01	-1.8130E+01
fission	18	19	91	0	2334	1.0000E-10	2.0000E+01	1.9200E+02
(n,gma)	102	0	1461	1.0000E-10		2.0000E+01	6.3800E+00	
==>am95243 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	8.0000E-02	3.0000E+01	0.0000E+00
(n,2n)	16	2	82	0	1284	6.4100E+00	3.0000E+01	-6.3738E+00
(n,3n)	17	3	115	0	2664	1.1950E+01	3.0000E+01	-1.1901E+01
(n,4n)	37	4	133	0	3633	1.8500E+01	3.0000E+01	-1.8424E+01
fission	18	19	140	0	4068	1.0000E-10	3.0000E+01	2.0000E+02
(n,gma)	102	0	5009			1.0000E-10	3.0000E+01	5.3600E+00
==>ar18000 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	1.5000E+00	3.0000E+01	0.0000E+00
(n,2n)	16	2	45	0	717	1.0500E+01	3.0000E+01	-9.8700E+00
(n,gma)	102	0	60			1.0000E-10	3.0000E+01	6.1000E+00
==>as33074 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	2.0100E-01	3.0000E+01	0.0000E+00
(n,2n)	16	2	47	0	1396	8.0910E+00	3.0000E+01	-7.9820E+00
(n,3n)	17	3	67	0	2757	1.9025E+01	3.0000E+01	-1.8771E+01
(n,gma)	102	0	74			1.0000E-10	3.0000E+01	1.0246E+01
==>as33075 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	2.0100E-01	3.0000E+01	0.0000E+00
(n,2n)	16	2	44	0	1396	1.0383E+01	3.0000E+01	-1.0246E+01
(n,3n)	17	3	60	0	3470	1.8480E+01	3.0000E+01	-1.8228E+01
(n,gma)	102	0	67			1.0000E-10	3.0000E+01	7.3280E+00
==>b5010 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	5.0000E+00	3.0000E+01	0.0000E+00
(n,n*1)	51	-1	22	562	612	1.0500E+00	3.0000E+01	-7.1700E-01
(n,n*2)	52	-1	72	668	623	2.2500E+00	3.0000E+01	-1.7400E+00

Reaction	MT	TYR	LSIG	LAND	LDLW	Emin	Emax	Q-value
==>b5010 <== continued								
(n,n*3)	53	-1	110	774	634	2.5000E+00	3.0000E+01	-2.1540E+00
(n,n*4)	54	-1	145	880	645	4.0000E+00	3.0000E+01	-3.5900E+00
(n,n*)d2a	35	1	171	0	656	6.7000E+00	3.0000E+01	-6.0200E+00
(n,2n)	16	2	188	0	1507	8.9800E+00	3.0000E+01	-8.1580E+00
(n,gma)	102	0	202			1.0000E-10	3.0000E+01	1.1450E+01
==>b5011 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	7.5000E+00	3.0000E+01	0.0000E+00
(n,n*1)	51	-1	49	562	423	2.3370E+00	3.0000E+01	-2.1400E+00
(n,n*2)	52	-1	167	738	434	4.8690E+00	3.0000E+01	-4.4600E+00
(n,n*3)	53	-1	251	844	445	5.4910E+00	3.0000E+01	-5.0300E+00
(n,2n)	16	2	324	0	456	1.2510E+01	3.0000E+01	-1.1460E+01
(n,gma)	102	0	332			1.0000E-10	3.0000E+01	3.3700E+00
==>be4007 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
==>bi83209 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	3.2767E+00	3.0000E+01	0.0000E+00
(n,n*1)	51	-1	57	1402	1248	9.1000E-01	3.0000E+01	-8.9660E-01
(n,n*2)	52	-1	302	1508	1259	1.6200E+00	3.0000E+01	-1.6085E+00
(n,n*3)	53	-1	414	1614	1270	2.5800E+00	3.0000E+01	-2.5590E+00
(n,n*4)	54	-1	485	1720	1281	3.0200E+00	3.0000E+01	-3.0000E+00
(n,n*5)	55	-1	546	1826	1292	3.1400E+00	3.0000E+01	-3.1210E+00
(n,2n)	16	2	605	0	1303	7.5000E+00	3.0000E+01	-7.4600E+00
(n,3n)	17	3	643	0	2556	1.4430E+01	3.0000E+01	-1.4354E+01
(n,n*)a	22	1	657	0	3550	1.3900E+01	3.0000E+01	3.1440E+00
(n,gma)	102	0	673			1.0000E-10	3.0000E+01	4.6000E+00
==>bk97249 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*c)	91	1	1	0	1	5.0000E-02	3.0000E+01	0.0000E+00
(n,2n)	16	2	89	0	1462	6.2300E+00	3.0000E+01	-6.2000E+00
(n,3n)	17	3	129	0	2712	1.1830E+01	3.0000E+01	-1.1780E+01
(n,4n)	37	4	152	0	3756	1.7900E+01	3.0000E+01	-1.7800E+01
fission	18	19	165	0	4239	1.0000E-10	3.0000E+01	2.0000E+02
(n,gma)	102	0	976			1.0000E-10	3.0000E+01	4.9700E+00
==>c6012 <==								
elastic	2	1				1.0000E-10	3.0000E+01	
(n,n*1)	51	-1	1	632	1	4.8024E+00	3.0000E+01	-4.4300E+00
(n,n*)3a	23	-1	89	0	12	7.9800E+00	3.0000E+01	-7.3600E+00
(n,n*2)	52	-1	141	843	2214	8.2930E+00	3.0000E+01	-7.6500E+00
(n,n*3)	53	-1	189	984	2225	1.0439E+01	3.0000E+01	-9.6300E+00
(n,n*4)	54	-1	225	1125	2236	1.0949E+01	3.0000E+01	-1.0100E+01
(n,n*5)	55	-1	258	1231	2247	1.1751E+01	3.0000E+01	-1.0840E+01

Appendix B

Benchmark Results for the ENDL92 Neutron Data Library

Criticality Benchmark Results

A suite of 33 criticality benchmarks has been developed, consisting of a selection of fast, reflected, thermal, and low-enrichment systems. The results using ENDL92 are detailed in Table B.1, and we have provided the results for the ENDF60 and MCNP4A Recommended data libraries for comparison purposes. The ENDF60 results correspond to using nuclides with the ZAID ending of '.60c', and the Recommended library corresponds to those ZAIDs identified as such in Appendix G of the MCNP4A manual ('.55c' for tungsten nuclides and ^{239}Pu, with all other nuclides specified by '.50c').

The following is a brief description of the criticality benchmarks.[6,8] A more complete discussion of these benchmarks will be released as an LA-Report in the near future.[7]

Fast Systems

Godiva: Bare Sphere(s) of Highly Enriched Uranium (HEU)				
*	1.	CSEWG-F5		[Godiva 1]
	2.	NEANSC: HEU-MET-FAST-001		
		a.	Simple Sphere	[Godiva 2a]
		b.	Concentric Spherical Shells	[Godiva 2b]
Jezebel (4.5% 240Pu): Bare Sphere of Plutonium Metal				
*	1.	CSEWG-F1		[(4.5%) Jezebel 1]
	2.	NEANSC: PU-MET-FAST-001		[(4.5%) Jezebel 2]
Jezebel (20.1% 240Pu): Bare Sphere of Plutonium Metal				
*	1.	CSEWG-F21		[(20.1%) Jezebel 1]
	2.	NEANSC: Pu-MET-FAST-002		[(20.1%) Jezebel 2]
Jezebel-23: Sphere of 233U				
	CSEWG-F19			[233U Jezebel-23]
3x3 Pu Array				
*	3x3x3 array of bare Pu fuel cans			[3x3x3 Pu array]

Reflected Fast Systems

Bigten: CSEWG-F20, U(N) reflected HEU sphere				
	1.	Spherical 1D model		[Bigten 1D]
	2.	Cylindrical 2D model		[Bigten 2D]
Reflected HEU spheres				
	1.	CSEWG-F22 U(N) reflector		[Flattop-25]
	2.	NEANSC: HEU-MET-FAST-003		
		a.	8” Nickel reflector	[HEU-003: Ni]
		b.	1.9” Tungsten Carbide	[HEU-003: 1.9”]
		c.	6.5” Tungsten Carbide	[HEU-003: 6.5”]
Flattop-23:				
	CSEWG-F24, U(N) reflected 233U sphere			[Flattop-23]
U(N) reflected Pu spheres				

1. Flattop-Pu: CSEWG-F23 [Flattop-Pu]
2. NEANSC: PU-MET-FAST-010 [PU-010: U(N)]

Thor: Thorium reflected Pu sphere

1. CSEWG-F25 [Thor]
2. NEANSC: PU-MET-FAST-008 [PU-008: Thor]

Thermal Systems

Water reflected spheres

1. NEANSC: PU-MET-FAST-011, Pu sphere [PU-011: Water]
2. Water reflected sphere of HEU [Water Reflected U sphere]

Uranium Solutions

* 1. 3 Cylinders of Uranyl Fluoride, equilateral triangle [3 Uranium Cyl.]
2. Unreflected spheres of Uranyl Nitrate
   a. ORNL-1:CSEWG-T1 [ORNL1]
   b. ORNL-2:CSEWG-T2, with 1.0286x10-6 atms/cm3 10B [ORNL2]
   c. ORNL-4:CSEWG-T4, with 2.5318x10-6 atms/cm3 10B [ORNL4]

Pu Solutions

1. Unreflected spheres of Plutonium nitrate solution
   a. PNL-1: CSEWG-T13, H/239Pu=700 [PNL1]
   b. PNL-5: CSEWG-T17, H/239Pu=578 [PNL5]
2. NEANSC: PU-SOL-THERM-003, case 2 water reflected sphere of Plutonium nitrate solution [PU-SOL-003]

Low Enriched Systems of Uranium

Homogenized plates of U(N) and HEU

1. Low-1, (10.9% 235U) [Low Enriched U-1]
* 2. Low-2, (12.32% 235U) [Low Enriched U-2]
3. Low-3, (14.11% 235U) [Low Enriched U-3]
* 4. Low-4, (16.01% 235U) [Low Enriched U-4]

* Indicates that these benchmarks have been revised from LA-12212.[8]

Table B.1: Criticality Benchmark Results for the ENDL92, ENDF60 and MCNP4A Recommended Libraries

Benchmark Name	Results using Recommended Library keff	Results using Recommended Library std. dev.	Results using ENDF60 Library keff	Results using ENDF60 Library std. dev.	Results using ENDL92 Library keff	Results using ENDL92 Library std. dev.
Godiva 1	0.9959	0.0007	0.9969	0.0007	1.0004	0.0007
Godiva 2a	0.9966	0.0007	0.9957	0.0007	1.0004	0.0008
Godiva 2b	0.9972	0.0007	0.9970	0.0007	0.9996	0.0007
(4.5%) Jezebel 1	0.9985	0.0009	0.9978	0.0009	1.0014	0.0009
(4.5%) Jezebel 2	0.9976	0.0010	0.9974	0.0009	0.9991	0.0008
(20%) Jezebel 1	1.0003	0.0008	0.9994	0.0009	1.0036	0.0009
(20%) Jezebel 2	0.9990	0.0008	0.9986	0.0007	1.0040	0.0008
Jezebel-23	0.9922	0.0008	0.9921	0.0008	0.9975	0.0008
3x3x3 Pu array	1.0011	0.0002	1.0026	0.0002	-	-
Bigten 1D	1.0035	0.0007	1.0060	0.0007	0.9827	0.0008
Bigten 2D	1.0026	0.0007	1.0054	0.0008	0.9794	0.0007
Flattop-25	1.0045	0.0010	1.0041	0.0009	0.9987	0.0009
HEU-003: Ni	1.0143	0.0008	1.0048	0.0007	1.0051	0.0007
HEU-003: 1.9” Tungsten Carbide	0.9986	0.0008	1.0062	0.0008	-	-
HEU-003: 6.5” Tungsten Carbide	1.0036	0.0007	1.0099	0.0008	-	-
Flattop-23	1.0020	0.0011	1.0036	0.0010	1.0037	0.0010
Flattop-Pu	1.0075	0.0010	1.0036	0.0010	1.0003	0.0011
PU-010: U(N)	0.9987	0.0010	0.9999	0.0009	1.0014	0.0010
Thor	1.0055	0.0009	1.0073	0.0009	1.0021	0.0009
PU-008: Thor	1.0090	0.0010	1.0093	0.0008	1.0017	0.0009
PU-011: Water	1.0009	0.0011	0.9990	0.0010	1.0003	0.0011
Water Reflected U sphere	0.9948	0.0008	0.9977	0.0007	0.9991	0.0008
3 Uranium Cyl.	0.9993	0.0010	0.9953	0.0010	1.0136	0.0011
ORNL1	1.0001	0.0006	0.9965	0.0006	1.0073	0.0006
ORNL2	0.9985	0.0006	0.9955	0.0006	1.0071	0.0006
ORNL4	0.9991	0.0007	0.9947	0.0006	1.0060	0.0007
PNL1	1.0145	0.0009	1.0063	0.0009	1.0263	0.0009
PNL5	1.0076	0.0010	0.9996	0.0009	1.0184	0.0010
PU-SOL-003	1.0046	0.0008	1.0013	0.0008		
Low Enriched U-1	1.0034	0.0006	1.0002	0.0005	0.9853	0.0005
Low Enriched U-2	1.0029	0.0007	1.0023	0.0005	0.9887	0.0006
Low Enriched U-3	1.0017	0.0006	0.9985	0.0006	0.9906	0.0006
Low Enriched U-4	1.0050	0.0006	1.0007	0.0006	0.9931	0.0006

Appendix C

Threshold Problems in the ENDL92 Neutron Data Library

ZAID	MT	Q-value	Original Energy (MeV)		New Energy (MeV)		LAW
3006	mt= 16	q= -3.69800	egiven= 4.3180000000000E+00	should be	4.3181107378932E+00	diff= 2.6E-05	law= 4
6012	mt= 52	q= -7.65000	egiven= 8.2930239375000E+00	should be	8.2930239508350E+00	diff= 1.6E-09	law= 3
6012	mt= 53	q= -9.63000	egiven= 1.0439453662500E+01	should be	1.0439453679286E+01	diff= 1.6E-09	law= 3
6012	mt= 55	q=-10.84000	egiven= 1.1751160716670E+01	should be	1.1751160735562E+01	diff= 1.6E-09	law= 3
7015	mt= 28	q=-10.20700	egiven= 1.0893000000000E+01	should be	1.0893357905354E+01	diff= 3.3E-05	law= 4
7015	mt= 22	q=-10.99100	egiven= 1.1730000000000E+01	should be	1.1730077078255E+01	diff= 6.6E-06	law= 4
8016	mt= 16	q=-15.67000	egiven= 1.6658000000000E+01	should be	1.6658175318824E+01	diff= 1.1E-05	law= 4
9019	mt= 51	q= -0.11000	egiven= 1.1584013035200E-01	should be	1.1584013036020E-01	diff= 7.1E-11	law= 3
9019	mt= 54	q= -1.45800	egiven= 1.5354082732110E+00	should be	1.5354082733198E+00	diff= 7.1E-11	law= 3
9019	mt= 55	q= -1.55400	egiven= 1.6365051142460E+00	should be	1.6365051143614E+00	diff= 7.1E-11	law= 3
9019	mt= 57	q= -3.90700	egiven= 4.1144308116850E+00	should be	4.1144308119756E+00	diff= 7.1E-11	law= 3
9019	mt= 60	q= -4.37800	egiven= 4.6104371880100E+00	should be	4.6104371883361E+00	diff= 7.1E-11	law= 3
9019	mt= 61	q= -4.55500	egiven= 4.7968344886670E+00	should be	4.7968344890066E+00	diff= 7.1E-11	law= 3
9019	mt= 62	q= -4.55700	egiven= 4.7989406728560E+00	should be	4.7989406731950E+00	diff= 7.1E-11	law= 3
9019	mt= 64	q= -4.68300	egiven= 4.9316302767130E+00	should be	4.9316302770621E+00	diff= 7.1E-11	law= 3
9019	mt= 66	q= -5.34000	egiven= 5.6235117825430E+00	should be	5.6235117829408E+00	diff= 7.1E-11	law= 3
9019	mt= 70	q= -5.54000	egiven= 5.8341302013650E+00	should be	5.8341302017775E+00	diff= 7.1E-11	law= 3
9019	mt= 71	q= -5.63000	egiven= 5.9289084898350E+00	should be	5.9289084902541E+00	diff= 7.1E-11	law= 3
10020	mt= 16	q=-16.86600	egiven= 1.7709000000000E+01	should be	1.7716928875191E+01	diff= 4.5E-04	law= 4
10020	mt= 28	q=-12.84400	egiven= 1.3486000000000E+01	should be	1.3492009633165E+01	diff= 4.5E-04	law= 4
12000	mt= 52	q= -1.61000	egiven= 1.6768154968110E+00	should be	1.6768154978423E+00	diff= 6.2E-10	law= 3
12000	mt= 53	q= -1.83000	egiven= 1.9059455646990E+00	should be	1.9059455658704E+00	diff= 6.1E-10	law= 3
12000	mt= 16	q= -7.32400	egiven= 7.6279000000000E+00	should be	7.6279482647186E+00	diff= 6.3E-06	law= 4
13027	mt= 54	q= -2.73200	egiven= 2.8341317789080E+00	should be	2.8341317803521E+00	diff= 5.1E-10	law= 3
13027	mt= 55	q= -2.98000	egiven= 3.0914028920740E+00	should be	3.0914028936490E+00	diff= 5.1E-10	law= 3
13027	mt= 56	q= -3.00100	egiven= 3.1131879460110E+00	should be	3.1131879475976E+00	diff= 5.1E-10	law= 3
13027	mt= 57	q= -3.67800	egiven= 3.8154965896130E+00	should be	3.8154965915574E+00	diff= 5.1E-10	law= 3
13027	mt= 62	q= -4.58000	egiven= 4.7512165254020E+00	should be	4.7512165278230E+00	diff= 5.1E-10	law= 3
13027	mt= 16	q=-13.05700	egiven= 1.3545000000000E+01	should be	1.3545116638381E+01	diff= 8.6E-06	law= 4
13027	mt= 28	q= -8.27100	egiven= 8.5800000000000E+00	should be	8.5801991051581E+00	diff= 2.3E-05	law= 4
14000	mt= 28	q=-11.58600	egiven= 1.2000000000000E+01	should be	1.2002100570926E+01	diff= 1.8E-04	law= 4
16032	mt= 28	q= -8.86500	egiven= 9.1400000000000E+00	should be	9.1446758208627E+00	diff= 5.1E-04	law= 4
17000	mt= 22	q= -6.99900	egiven= 7.1900000000000E+00	should be	7.1981269085947E+00	diff= 1.1E-03	law= 4
19000	mt= 16	q=-13.07500	egiven= 1.3410000000000E+01	should be	1.3412311206337E+01	diff= 1.7E-04	law= 4
20000	mt= 16	q=-10.03000	egiven= 1.0282000000000E+01	should be	1.0282417914474E+01	diff= 4.1E-05	law= 4
23051	mt= 28	q= -8.05700	egiven= 8.2150000000000E+00	should be	8.2165245775558E+00	diff= 1.9E-04	law= 4
27059	mt= 16	q=-10.45400	egiven= 1.0631000000000E+01	should be	1.0632924351096E+01	diff= 1.8E-04	law= 4
29000	mt= 16	q= -9.91000	egiven= 1.0067000000000E+01	should be	1.0067301327630E+01	diff= 3.0E-05	law= 4
30000	mt= 16	q=-11.12400	egiven= 1.1295000000000E+01	should be	1.1295618070679E+01	diff= 5.5E-05	law= 4
30000	mt= 17	q=-19.61000	egiven= 1.9910000000000E+01	should be	1.9912537789107E+01	diff= 1.3E-04	law= 4
30000	mt= 28	q= -8.53290	egiven= 8.6633000000000E+00	should be	8.6645432789734E+00	diff= 1.4E-04	law= 4

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ZAID    MT      Q-value     Original Energy (MeV)                      New Energy (MeV)                  LAW
30000  mt= 22 q= -4.42530 egiven= 4.4930000000000E+00 should be  4.4935723344280E+00 diff= 1.3E-04 law= 4
30000  mt= 23 q=-11.30000 egiven= 1.1473000000000E+01 should be  1.1474333351194E+01 diff= 1.2E-04 law= 4
33074  mt= 17 q=-18.77100 egiven= 1.9025000000000E+01 should be  1.9027123439190E+01 diff= 1.1E-04 law= 4
33075  mt= 16 q=-10.24600 egiven= 1.0383000000000E+01 should be  1.0383941294172E+01 diff= 9.1E-05 law= 4
39088  mt= 16 q= -9.36300 egiven= 9.4700000000000E+00 should be  9.4704301443891E+00 diff= 4.5E-05 law= 4
40000  mt= 16 q= -7.20000 egiven= 7.2700000000000E+00 should be  7.2796139880406E+00 diff= 1.3E-03 law= 4
40000  mt= 17 q=-14.95000 egiven= 1.5110000000000E+01 should be  1.5115309600168E+01 diff= 3.5E-04 law= 4
41093  mt= 16 q= -8.82600 egiven= 8.9218000000000E+00 should be  8.9218220271629E+00 diff= 2.5E-06 law= 4
47107  mt= 16 q= -9.53100 egiven= 9.6209000000000E+00 should be  9.6209263622824E+00 diff= 2.7E-06 law= 4
49000  mt= 16 q= -9.03700 egiven= 9.1160000000000E+00 should be  9.1163877858522E+00 diff= 4.3E-05 law= 4
49000  mt= 37 q=-25.75600 egiven= 2.5982000000000E+01 should be  2.5982260021291E+01 diff= 1.0E-05 law= 4
50000  mt= 17 q=-15.00000 egiven= 1.5127000000000E+01 should be  1.5127474724184E+01 diff= 3.1E-05 law= 4
51000  mt= 16 q= -8.96600 egiven= 9.0396000000000E+00 should be  9.0402808245476E+00 diff= 7.5E-05 law= 4
51000  mt= 17 q=-15.77200 egiven= 1.5902000000000E+01 should be  1.5902666647866E+01 diff= 4.2E-05 law= 4
51000  mt= 37 q=-25.01100 egiven= 2.5218000000000E+01 should be  2.5218209201735E+01 diff= 8.3E-06 law= 4
53127  mt= 17 q=-16.28200 egiven= 1.6411000000000E+01 should be  1.6411412958435E+01 diff= 2.5E-05 law= 4
54000  mt= 16 q= -7.77100 egiven= 7.8300000000000E+00 should be  7.8306979110548E+00 diff= 8.9E-05 law= 4
54000  mt= 17 q=-15.79500 egiven= 1.5914000000000E+01 should be  1.5916339403566E+01 diff= 1.5E-04 law= 4
54134  mt= 51 q= -0.84700 egiven= 8.5338017062540E-01 should be  8.5338017064057E-01 diff= 1.8E-11 law= 3
54134  mt= 52 q= -1.61300 egiven= 1.6251501950630E+00 should be  1.6251501950924E+00 diff= 1.8E-11 law= 3
54134  mt= 53 q= -1.73100 egiven= 1.7440390500030E+00 should be  1.7440390500340E+00 diff= 1.8E-11 law= 3
72000  mt= 51 q= -0.09300 egiven= 9.3525552383890E-02 should be  9.3525552385225E-02 diff= 1.4E-11 law= 3
72000  mt= 52 q= -0.30700 egiven= 3.0873488797690E-01 should be  3.0873488798133E-01 diff= 1.4E-11 law= 3
72000  mt= 16 q= -7.10000 egiven= 7.1400000000000E+00 should be  7.1401228165064E+00 diff= 1.7E-05 law= 4
74000  mt= 16 q= -7.46000 egiven= 7.5009000000000E+00 should be  7.5009281528497E+00 diff= 3.8E-06 law= 4
80000  mt= 16 q= -7.47100 egiven= 7.5000000000000E+00 should be  7.5085678559026E+00 diff= 1.1E-03 law= 4
90232  mt= 17 q=-11.56000 egiven= 1.1610000000000E+01 should be  1.1610251099441E+01 diff= 2.2E-05 law= 4
91233  mt= 52 q= -0.05690 egiven= 5.7146279514940E-02 should be  5.7146279515096E-02 diff= 2.7E-12 law= 3
91233  mt= 53 q= -0.07120 egiven= 7.1508174015180E-02 should be  7.1508174015375E-02 diff= 2.7E-12 law= 3
91233  mt= 55 q= -0.10400 egiven= 1.0445014181990E-01 should be  1.0445014182021E-01 diff= 3.0E-12 law= 3
91233  mt= 16 q= -6.65560 egiven= 6.6844000000000E+00 should be  6.6844073451788E+00 diff= 1.1E-06 law= 4
92235  mt= 16 q= -5.23000 egiven= 5.2524000000000E+00 should be  5.2524439663207E+00 diff= 8.4E-06 law= 4
93235  mt= 16 q= -6.98300 egiven= 7.0120000000000E+00 should be  7.0129667550116E+00 diff= 1.4E-04 law= 4
93235  mt= 17 q=-13.11400 egiven= 1.3170000000000E+01 should be  1.3170277248349E+01 diff= 2.1E-05 law= 4
93236  mt= 17 q=-12.66800 egiven= 1.2722000000000E+01 should be  1.2722132392166E+01 diff= 1.0E-05 law= 4
93238  mt= 17 q=-12.11600 egiven= 1.2167000000000E+01 should be  1.2167337688514E+01 diff= 2.8E-05 law= 4
94237  mt= 17 q=-13.21500 egiven= 1.3250000000000E+01 should be  1.3271231165193E+01 diff= 1.6E-03 law= 4
94239  mt= 53 q= -0.16400 egiven= 1.6469198730810E-01 should be  1.6469198730932E-01 diff= 7.4E-12 law= 3
94243  mt= 16 q= -5.03920 egiven= 5.0600000000000E+00 should be  5.0601118029109E+00 diff= 2.2E-05 law= 4
94243  mt= 17 q=-11.33300 egiven= 1.1380000000000E+01 should be  1.1380029977455E+01 diff= 2.6E-06 law= 4
95241  mt= 16 q= -5.93000 egiven= 5.9500000000000E+00 should be  5.9548131677263E+00 diff= 8.1E-04 law= 4
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ZAID    MT     Q-value     Original Energy (MeV)                    New Energy (MeV)                  LAW
95241  mt= 17 q=-12.60000 egiven= 1.2650000000000E+01 should be  1.2652722750987E+01 diff= 2.2E-04 law= 4
95243  mt= 17 q=-11.90100 egiven= 1.1950000000000E+01 should be  1.1950387205865E+01 diff= 3.2E-05 law= 4
95243  mt= 37 q=-18.42400 egiven= 1.8500000000000E+01 should be  1.8500456590275E+01 diff= 2.5E-05 law= 4
96244  mt= 37 q=-19.47000 egiven= 1.9550000000000E+01 should be  1.9550465812996E+01 diff= 2.4E-05 law= 4
49120  mt= 16 q= -3.67000 egiven= 3.7000000000000E+00 should be  3.7015046854979E+00 diff= 4.1E-04 law= 4
49120  mt= 17 q= -9.70000 egiven= 9.7800000000000E+00 should be  9.7832685148036E+00 diff= 3.3E-04 law= 4
         biggest change= 1.60235E-03
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