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INTERNATIONAL ATOMIC ENERGY AGENCY

NUCLEAR DATA SERVICES

DOCUMENTATION SERIES OF THE IAEA NUCLEAR DATA SECTION

IAEA-NDS-169

Rev. 3, February 1996

FENDL/MC

**Library of continuous energy cross sections in ACE format
for neutron-photon transport calculations with the Monte Carlo
N-particle Transport Code system MCNP 4A**

Version 1.1 of March 1995

generated by R.E. MacFarlane by processing FENDL/E-1.0

Summary documentation by A.B. Pashchenko, H. Wienke and S. Ganesan*)

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Abstract: Selected neutron reaction nuclear data evaluations for elements of interest to the IAEA's program on Fusion Evaluated Nuclear Data Library (FENDL) have been processed into ACE format using the NJOY system by R.E. MacFarlane. This document summarizes the resulting continuous energy cross-section data library FENDL/MC version 1.1. The data are available cost free, upon request from the IAEA Nuclear Data Section, online or on magnetic tape.

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IAEA-NDS-documents are updated whenever there is additional information of relevance to the users of the data library.

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R.E. MacFarlane, "FENDL/MC, Library of cross-sections in continuous-energy ACE format for neutron-photon transport calculations with the Monte Carlo N-particle Transport Code system MCNP 4A, version 1.1 of March 1995" summary documentation by A.B. Pashchenko, H. Wienke and S. Ganesan, report IAEA-NDS-169 Rev. 3 (International Atomic Energy Agency, November 1995). Data received on tape (or: retrieved on-line) from the IAEA Nuclear Data Section.

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FENDL/MC

**Library of continuous energy cross sections in ACE format
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Version 1.1 of March 1995
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Summary

The present data library contains continuous-energy neutron, coupled neutron photon and photon-atom cross-section tables for use in the Monte Carlo N-particle Transport Code system MCNP 4A [1], derived from FENDL/E version 1.1, a library of selected evaluated neutron and photon cross sections for nuclides of importance for neutron-photon transport calculations for fusion reactor design, in the energy range from 10^{-5} eV up to 20 MeV [2]. These have been produced by R.E. MacFarlane using his nuclear data processing system NJOY, version 91, developed at Los Alamos Laboratory, USA [3] (output of the module NJOY/ACER). The discussions related to the development of FENDL/MC data files, problems encountered and updates are presented in the papers of R. E. MacFarlane presented at the IAEA Advisory Group Meetings in 1993 [4] and 1994 [5]. The summary of the Working Groups on processing of FENDL basic libraries is available in the documents INDC(NDS)-297 [6] and 312 [7] respectively.

The library has a total size of 480 Megabytes. It contains the following files:

- 299 datafiles derived from evaluations for 62 isotopes. Evaluations for 55 nuclides are from FENDL/E-1.1. From the evaluations which are not (yet) available in FENDL/E-1.1 those for ^2H , ^3He , ^4He , and ^{138}Ba are from ENDF/B-VI and those for ^{93}Nb , ^{95}Zr , Sn are from BROND-2. Each data file in the data library corresponds to one material. Using Al-27 as an example, the file naming works like this:

AL27 - Type 1 (ASCII) data in ACE format (A C(ompact) E(NDF)). This file contains the continuous-energy neutron and coupled neutron photon cross section tables for use in MCNP 4A. The ACE files are prompt only. Delayed heating and gamma production are not included. The specifications used in the processing are:

- Temperature: 300 kelvin = 2.585 E-8 MeV
- No thinning

- AL27X - Stub card for the MCNP XSDIR file. These cards have to be edited to have the correct route and path, which depends on how the library is installed.
- AL27O - NJOY output file, including an interpreted listing of the ACE file.
- AL27P - PostScript file containing graphs of the ACE cross sections.
- AL27V - VIEWR input that made the PostScript file. These files might be useful for people who want to convert them to use them as input for some other plotting code. There are no VIEWR input files for the nuclides ^2H , $^{14,15}\text{N}$, $^{\text{nat}}\text{Si}$, ^{31}P , $^{\text{nat}}\text{S}$, $^{63,65}\text{Cu}$, $^{\text{nat}}\text{Mo}$, ^{181}Ta and ^{209}Bi .
- The file XSDIR-FENDL which is the index file that is used by MCNP 4A to obtain cross sections. It is a sequential formatted ASCII file with 80-character records (lines) which are obtained by editing the above mentioned "X." files to have the correct "file" and "route" entries. A detailed description of the XSDIR data directory file is given in Appendix F of Ref. [1].
- A file named: AAREADME_TRAPMC.TXT, which also contains the information given in this summary.

The data are available online, through FTP file transfer, from the IAEA Nuclear Data Section under the address IAEAND.IAEA.OR.AT, username: FENDL. A listing of available data files is given in the Appendix of the present document. The format of the ACE data files is described in Appendix F of Ref. [1].

Comments and warnings (from R.E. MacFarlane):

- The new versions of the Monte Carlo files for the isotopes of F, Cr, Mn, Fe, Ni, Cu, and Pb have their energy-angle distributions converted into laboratory angle-energy form (Law 7, like Be) instead of using the Kalbach format in the CM. These files are closer to the intent of the evaluator.
- Up until recently, ACE files have been made with a temperature entry of 2.53-8 MeV. Actually, the data were at 300 K. Recently a conversion has been employed using the Boltzmann constant and now all files are at 2.585-8 MeV.
- Some materials give the warning "no photon-prod mt found in acegam" in MCNP at some particular energy during the run. The cause and consequences of this problem is not clear yet. The materials affected are Zr-90, Zr-92 and Zr-96 from BROND-2, and Bi-209 and Ta-181 from JENDL-3.1.

- H-2 from BROND-2 does not go into ACE format yet because of the discrete lines for direct interactions in the (n,2n) reaction. Therefore the ENDF/B-VI version has been processed by R.E. McFarlane.
- Mo-nat from JENDL-3.1 would not go into ACE format because of the multiple interpolation ranges for secondary energy in MF5/MT91. Mo-nat from ENDF/B-VI could be used temporarily.
- N-14 from BROND-2 causes MCNP to go into some kind of lock-up condition that completely freezes up the terminal. Therefore the ACE files processed from the ENDF/B-VI version are available.

References

1. Judith F. Briesmeister, Ed, "MCNP - A General Monte Carlo N-Particle Transport Code, Version 4A", Los Alamos National Laboratory report LA-12625-M (1993).
2. A.B. Pashchenko, H. Wienke, S. Ganesan and P.K. McLaughlin, "FENDL/E, evaluated nuclear data library of neutron interaction cross sections, photon production cross sections and photon-atom interaction cross sections for fusion applications, version 1.1 of November 1994", IAEA(NDS)-128, Nuclear Data Section, International Atomic Energy Agency, Vienna, Austria (Rev. 2, February 1996).
3. R.E. MacFarlane, "The NJOY Nuclear Data Processing System, Version 91", Los Alamos National Laboratory report LA-12740-M (1994). Code and manual distributed as package PSR-171 by the Radiation Shielding Information Center (RSIC), Oak Ridge National Laboratory, Oak Ridge, USA.
4. R.E. MacFarlane, "Processing of ENDF/B-VI and FENDL for Multigroup and Monte Carlo Applications", paper presented at the IAEA Advisory Group Meeting "Review of Uncertainty Files and Improved Multigroup Cross Section Files for FENDL", Tokai, Japan, 8-12 November 1993 [6].
5. R.E. MacFarlane, "Status of Processing for FENDL-1", report LA-UR-94-3083, Los Alamos National Laboratory, presented at the IAEA Advisory Group Meeting on "Improved Evaluations and Integral Data Testing for FENDL", Garching, Germany, 12-16 September 1994 [7].
6. S. Ganesan, Ed., "Review of Uncertainty Files and Improved Multigroup Cross Section Files for FENDL", summary report of the IAEA Advisory Group Meeting organized by the International Atomic Energy Agency in cooperation with the Japan Atomic Energy Research Institute and held at the Tokai Research Establishment, JAERI, Japan, 8-12 November 1993, INDC(NDS)-297, Nuclear Data Section, International Atomic Energy Agency, Vienna, Austria.

7. S. Ganesan, Ed., "Improved Evaluations and Integral data testing for FENDL", summary report of the IAEA Advisory Group Meeting organized by the International Atomic Energy Agency in cooperation with the Max-Planck Institute für Plasmaphysik, Garching, Germany, 12-16 September 1994, report INDC(NDS)-312, Nuclear Data Section, International Atomic Energy Agency, Vienna, Austria (December 1994).

APPENDIX: Listing of NJOY/ACER output files:

DATA SET: UD6:[FENDL.TRANSPORT.PROCESSED.FENDLMC]

Element	NDS internal name	Number of blocks (1 block = 512 bytes)
1-H-1	H1	142
	H1O	226
	H1P	586
	H1V	254
	H1X	1
1-H-2	H2	110
	H2O	188
	H2P	629
	H2X	1
1-H-3	H3	136
	H3O	261
	H3P	454
	H3V	144
	H3X	1
2-He-3	HE3	116
	HE3O	217
	HE3P	500
	HE3V	175
	HE3X	1
2-He-4	HE4	121
	HE4O	184
	HE4P	391
	HE4V	199
	HE4X	1
3-Li-6	LI6	498
	LI6O	806
	LI6P	1631
	LI6V	812
	LI6X	1
3-Li-7	LI7	585
	LI7O	2004
	LI7P	2734
	LI7V	818
	LI7X	1
4-Be-9	BE9	2581
	BE9O	2188
	BE9P	822
	BE9V	354
	BE9X	1

Element	NDS internal name	Number of blocks (1 block = 512 bytes)
5-B-10	B10	1122
	B10O	1548
	B10P	2321
	B10V	1482
	B10X	1
5-B-11	B11	4340
	B11O	5307
	B11P	3747
	B11V	3087
	B11X	1
6-C	CNAT	900
	CNATO	1377
	CNATP	2291
	CNATV	1522
	CNATX	1
7-N-14	N14	2325
	N14O	3319
	N14P	3894
	N14X	1
7-N-15	N15	1576
	N15O	2625
	N15P	3297
	N15X	1
8-O-16	O16	2335
	O16O	2828
	O16P	3937
	O16V	3314
	O16X	1
9-F-19	F19	3759
	F19O	4982
	F19P	4791
	F19V	2669
	F19X	1
11-Na-23	NA23	1776
	NA23O	3482
	NA23P	4285
	NA23V	2209
	NA23X	1

Element	NDS internal name	Number of blocks (1 block = 512 bytes)
12-Mg	MGNAT	1808
	MGNATO	4306
	MGNATP	5311
	MGNATV	2719
	MGNATX	1
13-Al-27	AL27	1739
	AL27O	2841
	AL27P	3536
	AL27V	2134
	AL27X	1
14-Si	SINAT	4561
	SINATO	7674
	SINATP	4542
	SINATX	1
15-P-31	P31	271
	P31O	391
	P31P	971
	P31X	1
16-S	SNAT	4354
	SNATO	6911
	SNATP	2721
	SNATX	1
17-Cl	CLNAT	967
	CLNATO	1894
	CLNATP	2507
	CLNATV	1408
	CLNATX	1
19-K	KNAT	982
	KNATO	1489
	KNATP	2256
	KNATV	1382
	KNATX	1
20-Ca	CANAT	4326
	CANATO	7192
	CANATP	5243
	CANATV	2627
	CANATX	1
22-Ti	TINAT	2699
	TINATO	5262
	TINATP	4946
	TINATV	2256
	TINATX	1

Element	NDS internal name	Number of blocks (1 block = 512 bytes)
23-V	VNAT	6702
	VNATO	10790
	VNATP	2998
	VNATV	2331
	VNATX	1
24-Cr-50	CR50	7316
	CR50O	10686
	CR50P	2911
	CR50V	2276
	CR50X	1
24-Cr-52	CR52	6868
	CR52O	8091
	CR52P	2484
	CR52V	2765
	CR52X	1
24-Cr-53	CR53	4666
	CR53O	6069
	CR53P	3378
	CR53V	2755
	CR53X	1
24-Cr-54	CR54	4025
	CR54O	5424
	CR54P	2533
	CR54V	2053
	CR54X	1
25-Mn-55	MN55	10418
	MN55O	11922
	MN55P	5235
	MN55V	3352
	MN55X	1
26-Fe-54	FE54	6919
	FE54O	9473
	FE54P	3871
	FE54V	2695
	FE54X	1
26-Fe-56	FE56	11645
	FE56O	15770
	FE56P	6759
	FE56V	4560
	FE56X	1

Element	NDS internal name	Number of blocks (1 block = 512 bytes)
26-Fe-57	FE57	6730
	FE57O	8924
	FE57P	3779
	FE57V	3397
	FE57X	1
26-Fe-58	FE58	4404
	FE58O	5543
	FE58P	3222
	FE58V	2665
	FE58X	1
27-Co- 59	CO59	8707
	CO59O	12576
	CO59P	3216
	CO59V	2267
	CO59X	1
28-Ni-58	NI58	12256
	NI58O	18126
	NI58P	3552
	NI58V	2371
	NI58X	1
28-Ni-60	NI60	7347
	NI60O	8642
	NI60P	3061
	NI60V	1831
	NI60X	1
28-Ni-61	NI61	3815
	NI61O	4436
	NI61P	3070
	NI61V	2491
	NI61X	1
28-Ni-62	NI62	3339
	NI62O	4078
	NI62P	2381
	NI62V	1685
	NI62X	1
28-Ni-64	NI64	2721
	NI64O	3644
	NI64P	2202
	NI64V	1487
	NI64X	1

Element	NDS internal name	Number of blocks (1 block = 512 bytes)
29-Cu-63	CU63	7810
	CU63O	10867
	CU63P	3416
	CU63X	1
29-Cu-65	CU65	6394
	CU65O	8972
	CU65P	3139
	CU65X	1
40-Zr-90	ZR90	1850
	ZR90O	2841
	ZR90P	2329
	ZR90V	1168
	ZR90X	1
40-Zr-91	ZR91	4393
	ZR91O	6931
	ZR91P	2476
	ZR91V	1195
	ZR91X	1
40-Zr-92	ZR92	2329
	ZR92O	3086
	ZR92P	2122
	ZR92V	1195
	ZR92X	1
40-Zr-94	ZR94	1740
	ZR94O	2802
	ZR94P	2054
	ZR94V	863
	ZR94X	1
40-Zr-95	ZR95	246
	ZR95O	402
	ZR95P	820
	ZR95V	273
	ZR95X	1
40-Zr-96	ZR96	1298
	ZR96O	1854
	ZR96P	1560
	ZR96V	666
	ZR96X	1

Element	NDS internal name	Number of blocks (1 block = 512 bytes)
41-Nb-93	NB93	7114
	NB93O	10705
	NB93P	2120
	NB93V	1030
	NB93X	1
42-Mo	MONAT	14777
	MONATO	20291
	MONATP	7608
	MONATX	1
50-Sn	SNNAT	9105
	SNNATO	16234
	SNNATP	3116
	SNNATV	1810
	SNNATX	1
56-Ba-138	BA138	296
	BA138O	408
	BA138P	930
	BA138V	351
	BA138X	1
73-Ta-181	TA181	13216
	TA181O	18703
	TA181P	2892
	TA181X	1
74-W-182	W182	4534
	W182O	6242
	W182P	2044
	W182V	1032
	W182X	1
74-W-183	W183	3580
	W183O	5486
	W183P	2108
	W183V	1053
	W183X	1
74-W-184	W184	3158
	W184O	4124
	W184P	1988
	W184V	979
	W184X	1

Element	NDS internal name	Number of blocks (1 block = 512 bytes)
74-W-186	W186	3286
	W186O	4280
	W186P	2006
	W186V	993
	W186X	1
82-Pb-206	PB206	10284
	PB206O	14340
	PB206P	5708
	PB206V	2918
	PB206X	1
82-Pb-207	PB207	4462
	PB207O	7028
	PB207P	5708
	PB207V	2918
	PB207X	1
82-Pb-208	PB208	4489
	PB208O	5020
	PB208P	2977
	PB208V	1619
	PB208X	1
83-Bi-209	BI209	3069
	BI209O	5261
	BI209P	2651
	BI209X	1

DISTRIBUTION OF THE FENDL LIBRARY

(As recommended at the IAEA Advisory Group Meeting on FENDL, held in Del Mar, California, 5-9 Dec.1995)

The master copy of the FENDL-1 library resides with the Nuclear Data Section of the International Atomic Energy Agency. To facilitate user access to the library the official copy of FENDL-1 was distributed in February 1996 to the major nuclear data centres in Europe (NEA Data Bank, Paris), Japan (JNDC, Tokai-mura), Russia (CJD,Obninsk) and USA (NNDC, Brookhaven and RSIC, Oak Ridge). As agreed between data centers, sharing common FENDL information, the recipients are receiving now the same products from all above centers. The data are available and may be further distributed to the user community according to the customer service options given below. Each FENDL sub-library will be in a single data set, i.e. Activation, Decay, etc. in the 8 mm tape, 6 mm tape, 4 mm tape or standard 9 track magnetic tape (6250 bpi or 1600 bpi) and CD-ROM options. The interested scientists may request FENDL-1 (or parts of it) directly from the IAEA/NDS or from one of these centers.

Table 1. FENDL CUSTOMER SERVICE OPTIONS

MEDIA	FORMAT	By WHOM
Electronic	FTP	IAEA, NEADB, NNDC
4 mm tape	UNIX TAR VAX BACKUP ASCII	CJD, IAEA, NEADB, NNDC, RSIC CJD, IAEA, NEADB, NNDC NEADB
6 mm tape	UNIX TAR VAX BACKUP ASCII	NEADB NEADB NEADB
8 mm tape	UNIX TAR VAX BACKUP ASCII	NEADB, NNDC, RSIC NEADB, NNDC NEADB
9 track	ASCII EBCDIC	CJD, IAEA CJD, IAEA
CD-ROM	UNIX TAR ASCII	RSIC NEADB

Table notes

- 1) NNDC will distribute FENDL unprocessed data
- 2) RSIC will distribute FENDL processed data
- 3) RSIC offers cost free service to ITER customers

FENDL SUMMARY

FENDL is the evaluated nuclear database for fusion applications. Its present version consists of the following sublibraries for which the documentation and the FTP subdirectory for online service are given below. At the ITER neutronics coordination meeting in San Diego, Feb. 1995, the ITER participants agreed to use FENDL in all design calculations.

1. **FENDL/A-1.1** (April 93): neutron activation cross-sections, selected from different available sources, for 636 nuclides, given in four representations:
 - FENDL/A: "point data", i.e. cross-sections as function of energy in ENDF-6 format (see IAEA-NDS-148, Rev. 2, Feb. 1995). FTP subdirectory: ACTIVATION.FENDLA
 - "MCNP": processed into the format for input to the MCNP Monte-Carlo transport code (see IAEA-NDS-168, Rev. 3, Feb. 1996). FTP subdirectory: ACTIVATION.PROCESSED.MCNP
 - "VITJ_E": VITAMIN-J 175 group data, processed for input to the code REAC*2/3 using the VITAMIN-E weighting spectrum (see IAEA-NDS-168, Rev. 3, Feb. 1996). FTP subdirectory: ACTIVATION.PROCESSED.VITJ_E
 - "VITJ-FLAT": VITAMIN-J 175 group data, processed using a flat weighting spectrum (see IAEA-NDS-148, Rev. 2, Feb. 1995). FTP subdirectory: ACTIVATION.PROCESSED.VITJ_FLAT
2. **FENDL/D-1.0** (Jan. 92): nuclear decay data for 2900 nuclides in ENDF-6 format, extracted from ENDF/B-6 and ENSDF (see IAEA-NDS-167, Jan. 1995). FTP subdirectory: DECAY.FENDLD
3. **FENDL/DS-1.0** (Oct. 93): neutron activation data for dosimetry by foil activation. This is identical with file 1 (neutron activation cross-sections) of the International Reactor Dosimetry File IRDF-90 version 2 of Oct. 1993 (see IAEA-NDS-141, Rev. 2, Oct. 1993), given as multigroup data in 640 group extended SAND-2 format, without covariance data. FTP subdirectory: DOSIMETRY.FENDLDS
4. **FENDL/C-1.0** (Nov. 91): data for the fusion reactions D(d,n), D(d,p), T(d,n), T(t,2n), He-3(d,p) extracted from ENDF/B-6 and processed (see IAEA-NDS-166, Jan. 1995). FTP subdirectories: FUSION.FENDLC and FUSION.PROCESSED
5. **FENDL/E-1.1** (Nov. 94): data for coupled neutron-photon transport calculations, including
 - a data library for neutron interaction and photon production for 63 elements or isotopes, selected from ENDF/B-6, JENDL-3, or BROND-2 (see IAEA-NDS-128, Rev. 2, Feb. 1996)
 - a photon-atom interaction data library for 34 elements taken from ENDF/B-6 (see IAEA-NDS-58, Rev. 4, Sept. 1994)

These are available in three representations:

- original ENDF-6 format, as above, with resonance-parameters where applicable. FTP subdirectory: TRANSPORT.FENDLE
- "FENDL/MG" (March 95): VITAMIN-J 175 group data in GENDF and MATXS format processed by NJOY using the VITAMIN-E weighting spectrum (see IAEA-NDS-129, Rev. 3, Feb. 1996). FTP subdirectory: TRANSPORT.PROCESSED.FENDLMG
- "FENDL/MC" (March 95): processed into the ACE format needed for input to the Monte Carlo code MCNP4A (see IAEA-NDS-169, Rev. 3, Feb. 1996). FTP subdirectory: TRANSPORT.PROCESSED.FENDLMC

FENDL BENCHMARKS

The FENDL/BENCHMARKS subdirectory contains compiled fusion benchmark descriptions and data, provided by the international community of benchmark specialists, for validation of the above mentioned FENDL libraries.

INTERNET/FTP online access to FENDL files

The FENDL data files can be electronically transferred to users from the IAEA Nuclear Data Section online system through INTERNET. In the NDS open area 'FENDL', a subdirectory was created for each sublibrary. The subdirectory names are given above. The file transfer via INTERNET (unix system) can be performed by 'ftp' command to the address 'iaeand.iaea.or.at' or '161.5.2.2'. The user should logon to the foreign user name 'FENDL'. No password is required. After having logged on, the user can set the definition to any required subdirectory and transfer files as desired. A grand total of 47 (sub)directories with 810 files with total size of nearly 2 million blocks or about 1 Gigabyte (1 block = 512 bytes) of numerical data is currently available on-line.