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FENDL/E

Evaluated nuclear data library of neutron nuclear interaction cross-sections and photon production cross-sections and photon-atom interaction cross sections for fusion applications

Version 1.1 of November 1994

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Abstract: This document presents the description of a physical tape containing the basic evaluated nuclear data library of neutron nuclear interaction cross-sections and photon production cross-sections and photon-atom interaction cross-sections for fusion applications. It is part of FENDL, the evaluated nuclear data library for fusion applications. The nuclear data are available cost-free for distribution to interested scientists upon request. The data can also be retrieved by the user via online access through international computer networks.

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Note:

The IAEA-NDS-documents should not be considered as publications or reports. When a nuclear data library is sent out by the IAEA Nuclear Data Section, it will be accompanied by an IAEA-NDS-document which should give the data user all necessary information on contents, format and origin of the data library.

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

For citations care should be taken that credit is given to the author of the data library and/or to the data center which issued the data library. The editor of the IAEA-NDS-document is usually not the author of the data library.

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FENDL/E

Evaluated nuclear data library of neutron nuclear interaction cross-sections, photon production cross-sections and photon-atom interaction cross-sections for fusion applications

Version 1.1 of November 1994

Prepared by
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Summary

The library FENDL/E, version 1.1 of November 1994, contains selected evaluated neutron, photon-atom and photon production cross sections, in ENDF format, with resonance parameters where appropriate, for 55 nuclides of importance for coupled neutron-photon transport calculations for fusion reactor design, in the energy range from 10^{-5} eV up to 20 MeV.

The neutron nuclear interaction and photon production cross sections have been selected from the following evaluated nuclear data libraries:

- BROND-2: BROND file version 2 contributed by the Russian Federation, see document IAEA-NDS-90 Rev. 8. [Ref. 1]

- ENDF/B-VI.x: ENDF/B file version VI, revision x contributed by the U.S.A., see document IAEA-NDS-100 Rev. 6. [Ref. 2]. Note that revision x is the revision number of the given material, not of the library.

- JENDL-3.1: JENDL file version 3.1 contributed by Japan, see document IAEA-NDS-110 Rev. 4. [Ref. 3].

BROND-2 and ENDF/B-VI are in ENDF-6 format, see document IAEA-NDS-76 Rev. 4. [Ref. 4], JENDL-3.1 is in ENDF/B-5 format, see document IAEA-NDS-75, Rev.1 [Ref. 5]. The FENDL/E-1.0 Evaluations for photon-atom interaction are all taken from ENDF/B-VI photon-atom interaction Library, see report IAEA-NDS-58 Rev.2 [Ref. 6].

The selection of evaluations for inclusion in FENDL/E-1.0 was established by applying the following criteria [Ref. 7]:

- presence of gamma ray production cross sections and spectra
- correlated energy-angle emission data (MF=6)
- energy spectra for secondary charged particles
- presence of complete covariance data

The data are available from the IAEA Nuclear Data Section in ftp subdirectory "UD6: [FENDL.TRANSPORT.FENDLE]". This subdirectory has a total size of about 36 Megabytes and includes 58 datafiles plus a file named "aareadme_trae.txt" containing the information presented in this summary. The 57 nuclear data files of each of the isotopes/elements (note: there are two evaluations present for ^{14}N and ^{55}Mn) have been identified individually with names such as:

"BI209J3.DAT" for the data of Bi-209 from JENDL-3.1
"ZR096BR.DAT" for the data of Zr-96 from BROND-2.
"CU063.DAT" for the data of Cu-63 from ENDF/B-VI.2, etc.

All the photon-atom interaction cross section files are available in one single file in the subdirectory with the name FENDLEP.dat". A List of FENDL/E-1.1 evaluations for neutron interaction and photon production cross sections is presented in Appendix A and that of FENDL/E-1.1 evaluations for photon-atom interactions in Appendix B.

The data files have been processed into multigroup cross sections, for use in discrete-ordinate transport calculations, and into pointwise files compatible with Monte Carlo codes, by R.E. MacFarlane using his nuclear data processing system NJOY, version 91, developed at Los Alamos National Laboratory, USA [Ref. 8]. They are available in the FENDL sublibraries FENDL/MG-1.0 [Ref. 9] and FENDL/MC-1.0 [Ref. 10] respectively.

References

1. V.N. Manokhin et al.,"BROND-2.2 Russian Evaluated Neutron Reaction Data Library Summary documentation, H.D. Lemmel and P.K. McLaughlin, IAEA-NDS-90 Rev. 8. (January 1994).

2. P.F. Rose (Editor), "ENDF-6 Summary Documentation", 4th Edition of BNL-NCS-17541 (=ENDF-201) (October 1991), U.S. National Nuclear Data Center, Brookhaven National Laboratory, Upton, N.Y., USA. The IAEA documentation is presented in "ENDF-6 The U.S. Evaluated Nuclear data Library for Neutron Reaction Data by the U.S. National Nuclear Data Center including revisions up to June 1993", IAEA-NDS-100, Rev. 6 (June 1995).

3. K. Shibata et al., "Japanese Evaluated Nuclear Data Library, Version 3, JENDL-3, JAERI-1319 (1990), IAEA Nuclear Data Services documentation, IAEA-NDS-110, Rev. 4. (June 1992).

4. P.F. Rose and C.L. Dunford, ENDF-102, "Data Formats and Procedures for the Evaluated Nuclear Data File ENDF-6", U.S. National Nuclear Data Center, Brookhaven National Laboratory, Upton, N.Y., USA, BNL-NCS-44945(October 1991). The IAEA documentation is presented in "ENDF-6 Formats Manual", IAEA-NDS-76, Rev .4 (January 1992).

5. R. Kinsey and B.A. Magurno, "ENDF-5 Formats Manual", (1984), IAEA Nuclear Data Services documentation, IAEA-NDS-75, Rev. 1 (September 1986).

6. "EN6-PHOTO and JEF-2/PHOTO Photo-atomic Interaction Data Library" by the Lawrence Livermore National Laboratory, USA. Summary documentation by H.D. Lemmel, report IAEA-NDS-58, Rev. 4 (International Atomic Energy Agency, Sept. 1994).

7. S. Ganesan (Compiler), "Review of Uncertainty Files and Improved Multigroup Cross Section Files for FENDL", summary report of an IAEA Advisory Group Meeting held in cooperation with the Japan Atomic Energy Research Institute, Tokai Research Establishment, JAERI, Japan, 8-12 November 1993, report INDC(NDS)-297 (January 1994).

8. R.E. MacFarlane, "The NJOY Nuclear Data Processing System, Version 91", Los Alamos National Laboratory report LA-12740-M (1994).

9. R.E. MacFarlane, "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 1996". Summary documentation by A.B. Pashchenko, H. Wienke and S. Ganesan, report IAEA-NDS-169, Rev. 3 (International Atomic Energy Agency, February 1996).

10. R.E. MacFarlane, "FENDL/MG, Library of multigroup cross sections in GENDF and MATXS format for neutron-photon transport calculations, version 1.1 of March 1996". Summary documentation by A.B. Pashchenko, H. Wienke and S. Ganesan, report IAEA-NDS-129, Rev. 3 (International Atomic Energy Agency, February 1996).

11. S. Ganesan (Compiler), "Improved Evaluations and Integral Data Testing for FENDL", Summary report of an IAEA Advisory Group Meeting held at Garching near Munich, Germany, September 1994, report INDC(NDS)-312 (December 1994)

Appendix A

List of FENDL/E-1.1 Evaluations for neutron interaction and photon production

MATERIAL	LIBRARY	MAT Number	Name in Online System	Number of records
H-1	ENDF/B-VI.1	125	H001E6.DAT	2117
H-2	BROND-2.0	102		not present*)
H-3	ENDF/B-VI.0	131	H003E6.DAT	732
Li-6	ENDF/B-VI.1	325	LI006E6.DAT	2621
Li-7	ENDF/B-VI.0	328	LI007E6.DAT	4945
Be-9	ENDF/B-VI.0	425	BE009E6.DAT	13909
B-10	ENDF/B-VI.1	525	B010E6.DAT	4594
B-11	ENDF/B-VI.0	528	B011E6.DAT	8531
C-Nat	ENDF/B-VI.1	600	C000E6.DAT	3518
N-14	BROND-2.0	710	N014BR.DAT	6103
	ENDF/B-VI.1	725	N014E6.DAT	13136
N-15	BROND-2.1	720	N015.BR.DAT	4917
O-16	ENDF/B-VI.0	825	O016E6.DAT	8539
F-19	ENDF/B-VI.0	925	F019E6.DAT	9485
Na-23	JENDL-3.1	3111	NA023J3.DAT	4711
Mg-Nat	JENDL-3.1	3120	MG000J3.DAT	4254
Al-27	JENDL-3.1	3131	AL027J3.DAT	4984
Si-Nat	BROND-2.0	1402	SI000BR.DAT	6780
P-31	ENDF/B-VI.0	1525	P031E6.DAT	848
S-Nat	ENDF/B-VI.0	1600	S000E6.DAT	4594
Cl-Nat	ENDF/B-VI.0	1700	CL000E6.DAT	4269
K-Nat	ENDF/B-VI.0	1900	K000E6.DAT	3727

*) ^{2}H from BROND-2 has not been included because the discrete lines for direct interactions in the (n,2n) reactions don't allow for processing into ACE format. Therefore the ENDF/B-VI version has been processed by R.E. MacFarlane (See p.25 of INDC(NDS)-312 [Ref. 11] and remarks in IAEA-NDS-169 [Ref. 9]). However, FENDL/MG-1.1 contains the BROND-2.0 version processed into GENDF and MATXS format.

MATERIAL	LIBRARY	MAT Number	Name in Online System	Number of records
Ca-Nat	JENDL-3.1	3200	CA000J3.DAT	5260
Ti-Nat	JENDL-3.1	3220	TI000J3.DAT	5243
V-Nat	ENDF/B-VI.0	2300	V000E6.DAT	6542
Cr-50	ENDF/B-VI.1	2425	CR050E6.DAT	6807
Cr-52	ENDF/B-VI.1	2431	CR052E6.DAT	8492
Cr-53	ENDF/B-VI.1	2434	CR052E6.DAT	8520
Cr-54	ENDF/B-VI.1	2437	CR052E6.DAT	5513
Mn-55	ENDF/B-VI.0	2525	MN055E6.DAT	17970
	(JENDL-3.1)	3251	MN055J3.DAT	20463
Fe-54	ENDF/B-VI.1	2625	FE054E6.DAT	7992
Fe-56	ENDF/B-VI.1	2631	FE056E6.DAT	16865
Fe-57	ENDF/B-VI.1	2634	FE057E6.DAT	11156
Fe-58	ENDF/B-VI.1	2637	FE058E6.DAT	7404
Co-59	ENDF/B-VI.2	2725	CO059E6.DAT	7878
Ni-58	ENDF/B-VI.1	2825	NI058E6.DAT	9956
Ni-60	ENDF/B-VI.1	2831	NI060E6.DAT	6716
Ni-61	ENDF/B-VI.0	2834	NI061E6.DAT	6984
Ni-62	ENDF/B-VI.1	2837	NI062E6.DAT	5739
Ni-64	ENDF/B-VI.1	2843	NI064E6.DAT	5100
Cu-63	ENDF/B-VI.2	2925	CU063E6.DAT	9460
Cu-65	ENDF/B-VI.2	2931	CU065E6.DAT	7943
Zr-90	BROND-2.0	4090	ZR090BR.DAT	3764
Zr-91	BROND-2.0	4091	ZR091BR.DAT	4510
Zr-92	BROND-2.0	4092	ZR092BR.DAT	3288
Zr-94	BROND-2.0	4094	ZR094BR.DAT	3033
Zr-96	BROND-2.0	4096	ZR096BR.DAT	2414
Nb-93	BROND-2.0	4193		not present
Mo-Nat	JENDL-3.1	3420	MO000J3.DAT	8918
Sn-Nat	BROND-2.0	5000		not present
Ba-134	ENDF/B-VI.0	5637		not present **)
Ba-135	ENDF/B-VI.0	5640		not present **)

MATERIAL	LIBRARY	MAT Number	Name in Online System	Number of records
Ba-136	ENDF/B-VI.0	5643		not present **)
Ba-137	ENDF/B-VI.0	5646		not present **)
Ba-138	ENDF/B-VI.1	5649		not present **)
Ta-181	JENDL-3.1	3731	TA181J3.DAT	4617
W-182	ENDF/B-VI.0	7431	W182E6.DAT	4595
W-183	ENDF/B-VI.0	7434	W183E6.DAT	4553
W-184	ENDF/B-VI.0	7437	W184E6.DAT	4487
W-186	ENDF/B-VI.0	7443	W186E6.DAT	4693
Pb-206	ENDF/B-VI.0	8231	PB206E6.DAT	8050
Pb-207	ENDF/B-VI.1	8234	PB207E6.DAT	8046
Pb-208	ENDF/B-VI.0	8237	PB208E6.DAT	5520
Bi-209	JENDL-3.1	3831	BI209J3.DAT	4227

**) Except for ^{138}Ba, the Ba isotope evaluations adopted for FENDL/E-1.1 do not include photon production and therefore do not satisfy the selection rules for FENDL/E. Furthermore natural Ba consists for 72% of ^{138}Ba and thus far no transport requirement is known for Ba (See p. 25 of INDC(NDS)-312 [Ref. 11]).

Appendix B

List of FENDL/E-1.0 Evaluations for photon-atom interaction taken from ENDF/B-VI photon-atom interaction library

MATERIAL	MAT No.	No.Records
AL000	1300	1610
B000	500	1277
BA000	5600	2311
BE000	400	883
BI000	8300	2836
C000	600	1198
CA000	2000	1629
CL000	1700	1599
CO000	2700	1904
CR000	2400	1838
CU000	2900	1737
F000	900	1263
FE000	2600	1845
H000	100	833
K000	1900	1635
LI000	300	911
MG000	1200	1309
MN000	2500	1882
MO000	4200	2118
N000	700	1292
NA000	1100	1368
NB000	4100	2184
NI000	2800	1870
O000	800	1207
P000	1500	1576
PB000	8200	2840
S000	1600	1573
SI000	1400	1607
SN000	5000	2327
TA000	7300	2652
TI000	2200	1882
V000	2300	1882
W000	7400	2668
ZR000	4000	2190

Attachment

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	CJD, IAEA, NEADB, NNDC, RSIC
	VAX BACKUP	CJD, IAEA, NEADB, NNDC
	ASCII	NEADB
6 mm tape	UNIX TAR	NEADB
	VAX BACKUP	NEADB
	ASCII	NEADB
8 mm tape	UNIX TAR	NEADB, NNDC, RSIC
	VAX BACKUP	NEADB, NNDC
	ASCII	NEADB
9 track	ASCII	CJD, IAEA
	EBCDIC	CJD, IAEA
CD-ROM	UNIX TAR	RSIC
	ASCII	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 MATXSR 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.

(96/2/29; app. to 7, 128, 129, 148, 166, 167, 168, 169)