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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

FENDL-2 AND ASSOCIATED BENCHMARK CALCULATIONS

Summary Report of the Advisory Group Meeting
organized by the International Atomic Energy Agency
and held in Vienna, Austria, 18-22 November, 1991

Prepared by A.B. Pashchenko and D.W. Muir

March 1992

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

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Abstract

The present Report contains the Summary of the IAEA Advisory Group Meeting on "The FENDL-2 and Associated Benchmark Calculations" convened on 18-22 November 1991, at the IAEA Headquarters in Vienna, Austria, by the IAEA Nuclear Data Section. The Advisory Group Meeting Conclusions and Recommendations and the Report on the Strategy for the Future Development of the FENDL and on Future Work towards establishing FENDL-2 are also included in this Summary Report.

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Summary of the Meeting

1. Introduction

The IAEA Nuclear Data Section, in co-operation with several national nuclear data centres and research groups, is creating an internationally available Fusion Evaluated Nucear Data Library (FENDL), which will serve as a comprehensive source of processed and tested nuclear data tailored to the requirements of the Engineering Development Activities (EDA) of the International Thermonuclear Experimental Reactor (ITER) Project and other fusion-reactor development projects. This programme is supported by several IAEA Coordinated Research Programmes.

FENDL will be composed of "sublibraries" containing different data types, describing the transport of both the plasma-source neutrons and secondary gamma rays through reactor components, as well as the resulting radiation effects, such as nuclear heating, tritium breeding, activation and material damage. Also included will be cross sections for fusion and other important charged-particle nuclear reactions of the plasma constituents, as well as data for fusion-relevant neutron dosimetry.

With the welcomed international release of ENDF/B-VI, JENDL-3 and BROND in early 1990, the FENDL project has turned from its earlier emphasis on the review and selection of candidate neutron-interaction evaluations to (a) processing and testing of cross sections for neutron and gamma-ray transport and (b) assembling, processing and testing of large special-application files needed to supplement the available files, especially in the field of activation and decay data.

For the multigroup cross section library, ENDF/B-VI files were selected by a series of IAEA advisory groups as major source of basic evaluated data, supplemented by JENDL-3 and BROND files. Pointwise cross section data have been reconstructed from resolved resonance parameters and linearized with thinning tolerances of 0.1%. Self-shielded cross sections are being calculated for 300, 900 and 1500 Kelvin and dilution factors of 10^0, 10^1, 10^2, 10^3, 10^4 and 10^{10} barns. Thermal scattering-law data are being included for Be in Be metal, C in graphite and H in water. Following a request from ITER for neutron and gamma shielding calculations, the following specific elements were added: Na, Mg, P, S, Cl, K, Ca and Ta.

For the second version of FENDL, FENDL-2, extensive benchmark-testing of FENDL-1 data and intercomparisons with newly available data files are planned with the aim to improve the physical reliability of FENDL-1 data for neutron-gamma transport and activation studies. Also, in order to allow the users to carry out realistic activation calculations, the activation cross section sublibrary are planned to be extended by several thousand additional reactions in early 1992, so as to contain all targets with half lives greater than 10 days and all reactions energetically possible below 20 MeV.

2. Organization of Advisory Group Meeting and Meeting Proceedings

Following the recommendation of the 18th INDC Meeting, the IAEA Nuclear Data Section convened an Advisory Group Meeting on "FENDL-2 and Associated Benchmark Calculations" at the IAEA Headquarters in Vienna on 18-22 November, 1991.

The scope of the AGM was considered at the IAEA Consultants' Meeting on "First results of FENDL-1 Testing and Start of FENDL-2", Vienna, 25-28 June 1990.

The objectives of the Advisory Group Meeting were the following:

(i) - to review present evaluation activities and future plans in the area of application to fusion research,

(ii) - to discuss multigroup processing issues and benchmark testing of FENDL-1,

(iii) - to discuss the results of the International Comparison Study of Fusion Activation Calculations,

(iv) - to identify the sources of activation cross-section and decay data for inclusion in the FENDL-2 activation library,

(v) - to discuss the comparison of new charged-particle evaluations for fusion application and approve charged-particle nuclear data for incorporation into FENDL-2,

(vi) - to discuss opportunities for future co-operation with regional and national fusion-relevant nuclear data programmes.

The Agenda of the meeting is listed in Appendix A.

The Advisory Group Meeting was opened by Dr. J.J. Schmidt, Head of the Nuclear Data Section and chaired by Prof. A.V. Ignatyuk.

The programme consisted of four general sessions for presentations of reports by participants of their programmes on:

I. Evaluated Nuclear Data Files for Fusion
(Chairman: F.M. Mann)

II. Charged Particle Nuclear Data (CPND)
(Chairman: H. Maekawa)

III. Activation Data
(Chairman: J. Kopecky)

IV. Neutron Data Processing, Integral Experiments and Benchmark Calculations
(Chairman: A. Santamarina)

The meeting participants performed an in-depth analysis of all the above items.

The 27 papers presented indicated significant progress which had currently been achieved in the development of the first version of the Fusion Evaluated Nuclear Data Library (FENDL-1) for fusion reactor technology. Four Working Groups summarised the status of the nuclear data for:

(i) General Purpose File for FENDL-2
(Chairman: D. Larson)

(ii) Activation Cross Sections for Incorporation into FENDL-2
(Chairman: R. Forrest)

(iii) Neutron Data Processing, Integral Experiments and Benchmark Calculations
(Chairman: S. Ganesan)

(iv) Charged Particle Nuclear Data
(Chairman: R. White)

The future work plans towards establishing FENDL-2 have also been discussed during the session of the Working Group on Strategy for the Future Development of the FENDL Library.

A draft of the meeting conclusions and recommendations prepared by the chairmen of the Working Groups was discussed at the summary session on the final day and adopted with minor modification. These conclusions and recommendations are given in Appendix B.

3. Meeting Attendance

The Meeting was attended by 27 leading experts from the major national programmes on fusion research (US, EC, The Russian Federation, Japan) and corresponding ITER home teams, of which 14 were paid by the Agency. (See Appendix C: List of participants.) In addition 10 staff members of the IAEA Nuclear Data Section also attended the meeting.

4. Results of the Meeting

Considering the progress in the development of the Fusion Evaluated Nuclear Data Library and in view of the urgent need for one consistent evaluated nuclear data library such as FENDL for the Engineering Design Activity phase of ITER and other fusion reactor projects, the Advisory Group recommended to the Agency to issue FENDL-1 by July 1992 and to make it available to ITER and other fusion reactor projects.

The main conclusion of the Meeting was that, despite the significant progress in the development of the nuclear data base, FENDL-1 is still not adequate to fulfil all demands of fusion reactor design activities.

The Advisory Group strongly recommended that, after the completion of FENDL-1, the FENDL-related activities be continued and an improved version of FENDL-1, i.e., FENDL-2, be established.

The Advisory Group emphasized that the improvements in the FENDL files and the reduction of the data uncertainties resulting from these efforts will lead to significant cost savings, for example for the ITER project, by reducing the engineering safety margins related to the uncertainties in the basic nuclear data.

5. Strategy for the Future Development of the FENDL Library

The meeting participants performed a Report on the Strategy for the Future Development of the FENDL Library and on future work towards establishing FENDL-2.

Complete text of these recommendations are given in Appendix D.

IAEA Advisory Group Meeting on

FENDL-2 and Associated Benchmark Calculations

November 18-22, 1991
IAEA Headquarters, Vienna
Meeeting Room V, C-07

Agenda

Monday, November 18

09:30 - 09:45 1) Opening of the Meeting (J.J. Schmidt)

09:45 - 10:00 2) Election of Chairman
Adoption of agenda
Announcements, etc.

GENERAL SESSION

I. Introduction **Chairman: A.V. Ignatyuk**

10:00 - 10:30 1) FENDL project: status and future plans
(D.W. Muir/J.J. Schmidt, IAEA/NDS)

II. Evaluated Nuclear Data Files for Fusion

Chairman: F.M. Mann

10:30 - 11:15 2) The European Fusion File EFF-2
(J. Kopecky, ECN Petten, Netherlands)

11:15 - 11:30 **Coffee Break**

11:30 - 12:15 3) JENDL Fusion File
(Y. Nakajima, JAERI, Japan)

12:15 - 14:00 **Lunch**

14:00 - 14:45 4) Analysis of the BROND files recommended for FENDL-2
(A. Ignatyuk, FEI, Obninsk, USSR)

14:45 - 15:30 5) Potential improvements to ENDF/B-VI for structural materials
(D. Larson, ORNL, USA)

15:30 - 15:45 **Coffee Break**

15:45 - 16:30 6) Presentation of secondary particle energy-angular distributions for FENDL-2
(V. Pronyaev, FEI, Obninsk, USSR)

16:30 - 16:40 7) Intercomparison of particle emission data for Cr, Fe, Ni and Pb for various libraries
(Zhou Delin, IAE Beijing)

16:40 - 17:00 **Coffee Break**

III. Charged Particle Nuclear Data (CPND)

Chairman: H. Maekawa

17:00 - 17:30 8) Comparison of LLNL and Soviet thermonuclear constants and presentation of new type of thermonuclear data library
(R. White, LLNL, USA)

17:30 - 18:00 9) Arzamas Charged Particle Nuclear Data Library for Fusion
(B. Guzhovsky, Arzamas, USSR)

18:00 - 18:30 Discussion on CPND files to be incorporated in FENDL-2

Tuesday, November 19

IV. Activation Data

Chairman: J.Kopecky

09:00 - 09:40 10) European Activation File - EAF-2
(J. Kopecky, ECN Petten, Netherlands)

09:40 - 10:20 11) Revision of ADL data for FENDL-2
(A. Ignatyuk, FEI, Obninsk, USSR)

10:20 - 11:00 12) ANL Radioactivity code and associated data libraries
(Y. Gohar, ANL, USA)

11:00 - 11:15 **Coffee Break**

11:15 - 11:45 13) The European Activation System (EASY)
(R. Forrest, Harwell, UK)

11:45 - 12:15 14) Systematic Calculations of Fusion Activation Cross Sections using the EXIFON Computer Code
(D. Seeliger, TUD, Dresden)

12:15 - 12:45 15) Report on the International Activation Calculation Benchmark Comparison Study-II
(E. Cheng, TSI Research, USA)

12:45 - 14:00 **Lunch**

V. Neutron Data Processing, Integral Experiments and Benchmark Calculations

Chairman: A. Santamarina

14:00 - 14:30 16) Multigroup processing of FENDL data for neutron and gamma-ray transport
(S. Ganesan, IAEA/NDS)

14:30 - 15:00 17) Cross-section libraries based on JENDL3
(H. Maekawa, JAERI, Japan)

15:00 - 15:30 18) Nuclear responses for FENDL-2
(Y. Gohar, ANL, USA)

15:30 - 15:45 **Coffee Break**

15:45 - 16:15 19) FENDL-2 Verification
(Y. Gohar, ANL, USA)

16:15 - 16:45 20) Analysis of the NET coil shielding parameters. Validation of the European Calculational Tools
(A. Santamarina, Cadarache, France)

16:45 - 17:10 21) Beryllium benchmark analysis (ENDF/B-VI data)
(U. Fischer, KFK, Germany)

17:10 - 17:30 22) ^{56}Fe Benchmark analysis (EFF-2 + ENDF/B-VI data)
(U. Fischer, KFK, Germany)

17:30 - 18:00 23) Calculation of BE-slab benchmark experiments with ENDF/B-VI and ENDF/B-IV neutron data
(D.Markovsky, IAE, Moscow, USSR)

18:00 **Reception hosted by the Agency**
NDS Library, Room A2340

Wednesday, November 20

V. Neutron Data Processing, Integral Experiments and Benchmark Calculations (continued)

09:00 - 09:30 24) Bulk shield experiments at FNS/JAERI for the ITER/EDA R&D program
(H. Maekawa, JAERI, Japan)

09:30 - 10:00 25) Integral benchmark experiment on Li-Be-C sphere system
(K. Sumita, Osaka University, Japan)

10:00 - 10:30 26) Observation on the adequacy of some transport and activation cross-sections as revealed from the integral experiments of US/JAERI collaboration program on Fusion Neutronics
(M. Youssef, Univ. of California, USA)

10:30 - 11:00 27) Calculation results of IAEA benchmark problems, based on TFE on Be slabs at FNS/JAERI
(K. Ilieva, INRNE Sofia, Bulgaria)

11:00 - 11:15 **Coffee Break**

11:15 - 11:25 28) A report of international workshop on Fusion Neutronics at Karlsruhe on 7th June 1991
(H. Maekawa, JAERI, Japan)

11:25 - 12:30 29) Discussion

12:30 - 14:00 **Lunch**

VI. Formation of the Working Groups (all)

14:00 - 14:30	Working Group I	Room V/C-07
	Working Group II	Room C0743
	Working Group III	Room A2340 (NDS Library)
	Working Group IV	Room C0451

Working Group I: **Review of General Purpose File for FENDL-2**
14:30 - 18:00 Chairman: D. Larson

Working Group II: **Review of Activation Cross-Sections for Incorporation into FENDL-2**
14:30 - 18:00 Chairman: R. Forrest

1. Presentation of FENDL-1 Activation Subfile.

2. New measurement results of activation cross-sections for radionuclides, reported on the last CRP and comparison with FENDL-1 evaluated data.

3. Selection of evaluations for the FENDL-2 activation cross section library for the 256 major activation reactions.

Working Group III: Review of Neutron Data Processing, Integral Experiments and Benchmark Calculations
Chairman: S. Ganesan

Working Group IV: Review of Charged Particle Data
Chairman: R. White

Thursday, November 21

Working Group I - cont'd

Preparation of WG report

Working Group II - cont'd

1. Selection of the sources for other reactions for inclusion in the FENDL-2 activation library.

2. Selection of the sources of decay data for inclusion in the FENDL-2 activation library.

3. Discussion of the results of the second activation bechmark calculation.

4. Discussion of the importance of charged particle and photon-induced reactions for the activation problem.

5. Discussion of integral experimental testing of activation data.

6. Preparation of WG report

Working Group III - cont'd

Preparation of WG report

Working Group IV - cont'd

Preparation of WG report

Friday, November 22

09:00 - 13:00	1. Report of WG I (review) 2. Report of WG II (reveiw) 3. Report of WG III (review) 4. Report of WG IV (review) 5. Drafting of Meeting Conclusions
13:00 - 14:00	**Lunch**
14:00 - 17:00	6. Discussion/Correction of Draft Meeting Conclusions 7. Summary Adoption of schedule of work 8. Date and place of future FENDL meeting

Appendix B

Conclusions and Recommendations of the IAEA Advisory Group Meeting on "FENDL-2 and Associated Benchmark Calculations", IAEA Headquarters, Vienna, Austria, 18-22 November 1991

Report of Working Group I: Review of General Purpose File for FENDL-2

Attendees: D.C. Larson (Chairman)
V.G. Pronyaev
A.V. Ignatyuk
Y. Nakajima
Y. Kanda
H. Vonach
D. Zhou
Z.D. Su
J. Kopecky

I. Agenda

The adopted Agenda is given in Appendix I. The topics below follow the agenda.

II. Review of Tables 1 and 2 from the last meeting (Appendix II, p. 3-6, Report INDC(NDS)-241, Nov. 1990)

The Working Group identified evaluations previously chosen for inclusion in the FENDL-1 file of general purpose evaluations (FENDL/E-1) that have known deficiencies and, further, whether or not the data have been corrected in modified files released since the original selection. At this meeting the Working Group also determined the materials for which there are new evaluations available that are candidates for inclusion in FENDL/E-2. The actual selection of evaluations for FENDL-2 will be made at the next FENDL meeting.

a) Review of corrections/updates to evaluations in Tables 1 and 2, with consideration of the "comments" section.

^{1}H	AWR corrected for ENDF/B-VI Mod 1
^{10}B	Uncertainty files to be added
^{19}F	Retain ENDF/B-VI choice
Cr isotopes	Resonance region under review
^{60}Ni	Missing resonances added for ENDF/B-VI Mod 1
Pb	Natural material evaluation from EFF-2 available for comparison

JENDL files currently in FENDL/E-1 for ^{27}Al, Ca, Ti, Mo and ^{209}Bi will be updated for consideration in FENDL/E-2.

b) Discussions with representatives of CENDL, JENDL, EFF, BROND and ENDF/B showed that, for several materials, new evaluations will become available for consideration for FENDL/E-2. These materials are given in Appendix II, along with the sources of the new evaluations. Prior to the next FENDL meeting, the NDS is requested to provide Phase 1 review kits and plots comparing the candidate evaluations with the present FENDL/E-1 evaluations, and experimental data. At the next FENDL meeting, information from these review kits and plots will be used to identify the best available evaluation for each material.

c) The fusion user community was requested to provide a list of any new materials needed in the FENDL/E-2 Library. E. Cheng provided a list, which was compared against FENDL/E-1 contents. Only three of the requested materials (^{3}He, ^{4}He and ^{40}Ar) are new. ^{40}Ar is needed only for activation purposes, so this request was given to the Activation Working Group for consideration. (A general purpose file is not needed.) The ^{3}He file was chosen from the Chinese Nuclear Data Library (CENDL), while the ^{4}He file was selected from ENDF/B-VI, both without review, for inclusion in FENDL/E-1.1.

In addition to this list, W. Dänner and Y. Gohar provided a list of prioritized user needs for information identified as deficient in FENDL/E-1. This list is given in Appendix III, and includes a potential need for a rhenium evaluation.

III. Selection of Basic Requirements for FENDL-2 Evaluations

The working group decided to retain the selection requirements chosen for FENDL/E-1, i.e., checking for the presence of gamma-ray production data, emission data in File-6 format, presence of charged particle spectra, and presence of covariance data, in addition to the usual evaluated data information. To help insure the quality of the files being reviewed, the Working Group also requested the NDS to provide CHECKR, FIZCON and PSYCHE checking code output as part of the review kit for the next FENDL meeting.

IV. Progress in Measurement and Evaluation of Outgoing Particle Spectra

At this FENDL meeting, encouraging progress was shown in the measurement, evaluation and plotting capability for outgoing particle spectra. Appendix IV lists (n,xn) and (n,x+charged particles) measurement facilities identified at the Working Group. Some of these are new facilities, indicating renewed attempts by the nuclear data community to address stated important needs by evaluators and users for particle emission data.

Evaluation of particle emission spectra is also improving. The JENDL Fusion File, scheduled for completion in 1993, will contain DDX particle emission spectra in File-6 format. The BROND library is also being updated to include File-6 data. Both of these libraries are using the formalism based on the Kalbach-Mann systematics to incorporate the angular information. The other libraries (EFF, ENDF/B, CENDL) continue to use File 6 in their updates.

Zhou Delin, CNDC, presented very nice results from their new program, comparing DDX data from the various evaluated libraries for both neutron and charged particle emission spectra. This analysis/plotting package will be prepared for general distribution through the NDS in early 1992.

V. Uncertainty File Improvements in Content and Coverage for FENDL-2

The primary need identified at this meeting was for a format appropriate to store uncertainties for File-6 data.

Much work has been done to improve and extend uncertainty files for EFF-2. They included uncertainty files for elastic scattering Legendre coefficients, as well as the more usual uncertainty files for cross sections.

Most evaluations chosen from ENDF/B-VI and EFF-2 for FENDL contain at least partial uncertainty information.

VI. Discussion of Generation of Elastic Scattering Angular Distributions in the Resonance Region from Reich-Moore (R-M) Parameters

ENDF/B-VI structural materials often use R-M resonance parameters. This formalism allows direct generation of the angular distributions from the resonance parameters via the Blatt-Biedenharn formalism. This task is left to be performed by the processing codes, to reduce the size of the evaluations. However, no processing codes yet have this capability, so the best available angular distribution data are the ones given in MF/MT = 4/2, even though they may not be fully consistent with angular distributions obtained directly from the resonance parameters. Recent resonance region analyses for ^{56}Fe and ^{58}Ni at ORNL incorporate differential scattering, transmission and capture data in a simultaneous analysis to obtain R-M resonance parameters. The resonance region differential data have not been fully corrected for multiple scattering effects, so are not appropriate for direct incorporation in the files.

VII. Proposed Areas for Improvements of Evaluations

Two sources provide direct information for improvements of FENDL evaluated data files:

a) Evaluation comparison provides direct detailed information on differences between evaluated data files, which may point out physics difficulties not apparent from data testing activities. One clear example is the shape of the (n,α) cross sections for the structural materials, first discovered at an earlier FENDL meeting. Differences observed through this technique often lead to specific improvements in the individual libraries.

b) Benchmarking and Data Testing provide useful information regarding discrepancies observed by the user community. Such information is particularly useful regarding normalization problems with evaluated cross sections.

The Working Group issued the following recommendations for improvements of evaluations:

1) Evaluators should review the anisotropy of gamma ray data with large cross sections to aid in determining if gamma ray angular distributions should be included in evaluated data files.

2) Recommendations of previous IAEA meetings on reference parameter libraries, and level densities should be adopted.

3) Measurements to less than 3% uncertainty of nonelastic cross sections as a function of neutron energy are encouraged.

4) Measurements of capture gamma-ray spectra for structural materials in the resonance region are encouraged.

5) Measurements of charged-particle and neutron emission cross sections for materials of importance to fusion energy are encouraged.

6) Processing code developers are encouraged to add the capability to generate angular distributions from R-M resonance parameters, to be passed directly to group anisotropy in processing codes.

7) Measurements of the $^{63}Cu(n,p)$ cross section near threshold are encouraged to help resolve copper kerma questions.

VIII. Action Items

1) The JAERI Nuclear Data Center to provide the new JENDL evaluations for ^{6}Li, ^{7}Li, ^{9}Be, ^{14}N, ^{27}Al, isotopes of Ti, ^{nat}Ti, ^{nat}Cr, ^{56}Fe, ^{59}Co, ^{58}Ni, ^{nat}Cu, ^{93}Nb, ^{nat}Mo, ^{nat}Pb, ^{209}Bi and ^{nat}Ca to the NDS at least 6 months prior to the next FENDL meeting for plotting and analyses.

2) The Chinese Nuclear Data Centre to provide the new CENDL evaluations and/or for D, T, and ^{56}Fe to the NDS at least 6 months prior to the next FENDL meeting.

3) EFF team to provide their new evaluations for ^{7}Li, ^{9}Be, ^{27}Al, ^{28}Si, ^{52}Cr, ^{56}Fe, ^{58}Ni, and ^{60}Ni to the NDS at least 6 months prior to the next FENDL meeting.

4) The U.S. Nuclear Data Center to provide the new ENDF/B-VI evaluations for ^{14}N, ^{15}N, ^{28}Si, ^{29}Si and ^{30}Si to the NDS at least 6 months prior to the next FENDL meeting.

5) The Chinese Nuclear Data Centre to provide the CENDL evaluation for ^{3}He to the NDS as soon as possible for incorporation in FENDL/E-1.

6) The U.S. National Nuclear Data Center to provide the ENDF/B-VI evaluation for ^{4}He to the NDS as soon as possible for incorporation in FENDL/E-1.

7) NDS to provide review kits (CHECKR, PSYCHE, FIZCON) and plots of the new evaluations vs FENDL/E-1 evaluations, and experimental data where possible, for review and selection of FENDL/E-2 evaluations, at the next FENDL meeting.

IX. Recommendations regarding General Purpose Evaluations

The FENDL General Purpose File is the nuclear data base for fusion neutronics calculations. Its quality determines the accuracy of all predictions concerning tritium breeding, nuclear heating, radiation damage to materials, shielding, and many other important properties of fusion reactor design.

The FENDL/E-1 File represents fairly well the present status of knowledge of neutron cross sections of the materials covered. This knowledge, however, is still not good enough to fulfil all demands of the fusion reactor designers and makes it necessary to include undesirably large safety margins in fusion reactor design which substantially increase the cost of such devices.

Therefore it is necessary to continuously improve the quality of the FENDL general purpose files, concentrating both on already recognized weak points, and especially for those types of data which have been or will be identified as especially important by sensitivity studies within the user community.

With the reduction in national nuclear data programmes, this evaluation programme should be implemented with international co-operation. There are many laboratories with an approximately equal level of understanding of the problems and which can contribute evaluation work of adequate quality. The role of the Nuclear Data Section of the IAEA as a co-ordinator of this activity has been, and continues to be essential to facilitate comparison of evaluated data files, reduce duplication of work, and provide a unique opportunity to promote discussion between evaluators and users of the data.

This Working Group appreciated the attendance and participation of active members from the user community familiar with the particular needs of the ITER project.

APPENDIX I - Agenda of Working Group I

I. Adoption of agenda.

II. Review of Tables 1 and 2 from the last meeting (Appendix II, p. 3-6, Report INDC(NDS)-241, Nov. 1990, and identification of new candidate evaluations for FENDL-2.

III. Selection of Basic Requirements for FENDL/E-2 Evaluations.

IV. Progress in Measurement and Evaluation of Outgoing Particle Spectra.

V. Uncertainty File Improvements in Content and Coverage for FENDL/E-2.

VI. Discussion of Generation of Elastic Scattering Angular Distributions in the Resonance Region from Reich-Moore Parameters.

VII. Proposed Areas of Improvements for Evaluations.

VIII. Action Items.

IX. Recommendations Regarding General Purpose Evaluations.

APPENDIX II

TABLE I: Additional files proposed to be considered for inclusion in FENDL/E-2

Nuclide or Element	Library	γ-ray Data	File-6 Data	Chg.Part. Spectra	Covariance Data	Comments
^{1}H	CENDL-2	?	Y	Y	N	
^{2}H	CENDL-2	N	N	N	N	
^{3}He	CENDL-2	N	Y	N	Y	New eval. added for FENDL/E-2.
^{4}He	ENDF/B-VI	?	?	?	?	New eval. added for FENDL/E-2.
^{6}Li	JENDL Fusion File	Y	N	Y	N	
^{7}Li	JENDL Fusion File	Y	N*	Y	N	
^{7}Li	EFF-2	Y	Y	Y	N	
^{9}Be	EFF-2	Y	Y	Y	N	
^{9}Be	JENDL Fusion File	Y	N*	Y	N	Possibly completed.
^{14}N	ENDF/B-VI	Y	Y	Y	Y	
^{14}N	JENDL Fusion File	Y	N*	Y	N	
^{15}N	ENDF/B-VI	Y	Y	Y	Y	
^{27}Al	EFF-2	Y	Y	Y	N	
^{27}Al	JENDL Fusion File	Y	Y	Y	N	
^{28}Si	EFF-2	Y	Y	Y	N	
^{28}Si	ENDF/B-VI	Y	Y	Y	Y	

Table I is continued on following page.
+ For explanations see end of Table I.

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TABLE I (Contd.): Additional files proposed to be considered for inclusion in FENDL/E-2

Nuclide or Element	Library	γ-ray Data	File-6 Data	Chg.Part. Spectra	Covariance Data	Comments
^{29}Si	ENDF/B-VI	Y	Y	Y	Y	
^{30}Si	ENDF/B-VI	Y	Y	Y	Y	
^{nat}Ca	JENDL Fusion File	Y	Y	Y	N	
$^{isotopes}Ti$	JENDL Fusion File	Y	Y	Y	N	
^{nat}Ti	JENDL Fusion File	Y	Y	Y	N	
^{52}Cr	EFF-2	Y	Y	Y	Y	
^{nat}Cr	JENDL Fusion File	Y	Y	Y	N	
^{56}Fe	EFF-2	Y	Y	Y	Y	
^{56}Fe	CENDL-2	Y	Y	Y	Y	
^{56}Fe	JENDL Fusion File	Y	Y	Y	N	
^{59}Co	JENDL Fusion File	Y	Y	Y	N	
^{58}Ni	EFF-2	Y	Y	Y	Y	
^{58}Ni	JENDL Fusion File	Y	Y	Y	N	
^{60}Ni	EFF-2	Y	Y	Y	Y	
^{nat}Cu	JENDL Fusion File	Y	Y	Y	N	
^{93}Nb	JENDL Fusion File	Y	Y	Y	N	
^{nat}Mo	JENDL Fusion File	Y	Y	Y	N	

Table I is continued on following page.
+ For explanations see end of Table I.

TABLE I (Contd.): Additional files proposed to be considered for inclusion in FENDL/E-2

Nuclide or Element	Library	γ-ray Data	File-6 Data	Chg.Part. Spectra	Covariance Data	Comments
^{nat}Pb	JENDL Fusion File	Y	Y	Y	N	
^{209}Bi	JENDL Fusion File	Y	Y	Y	N	

+ Table Explanation:

Y = Yes, data present
N = No, data not present
* = Indicates excitation energy bins (pseudo levels used en lieu of File-6)

APPENDIX III

PRIORITIZED USER NEEDS FOR INFORMATION IDENTIFIED AS DEFICIENT IN FENDL/E-1

Data Types

	A	B	B	C
Priority	γ-ray Data	File-6 Data	Charged Particle Data	Covariance Data
I		Mo, W	C, ^{16}O, Mo, W, Pb	^{16}O, Mo, W
I'	Re	Re	Re	Re
II		Al, Sn(?)	^{6}Li, ^{7}Li ^{10}B, Al	^{9}Be, ^{6}Li ^{27}Al, Si, Zr, Sn
III	Ba			

Priorities:

I Basic materials for ITER, completion desirable

I' Depends on choice of ITER divertor concept

II Needed in ITER only if driver blanket remains option

III Necessary only if Ba is used in biological shield

The different data types listed above are ranked in priority as follows: Priority (A) > Priority (B) > Priority (C).

APPENDIX IV

Particle Emission Measurement Facilities identified at meeting

Facility	Site	Main Researcher	Type	Incident Energy
JAPAN				
Dynamitron	Tohoku U.	Baba	(n,xn)	2-7 and 18 MeV
Cyclotron	Tohoku U.	Nakamura	(n,xn)	10-40 MeV
Tandem VDG	JAERI	Chiba	(n,xc.p.)	8-12 MeV
Cyclotron	JAERI	Nakamura	(n,xn)	10-40 MeV
FNS	JAERI	Konno	(n,xn)	14 MeV
OKTAVIAN	Osaka U.	Takahashi	(n,xn)	14 MeV
Tandem accelerator	Kyushu U.	Watanabe	(p,xc.p.)	up to 18 MeV
CHINA				
Tandem H113 10 MeV	IAE	TANG Hongqing		(n,xn)
Van de Graaff	Beijing U.	WEN Chenglin	(n,xn)	7 MeV
	U. Science & Technology	XIAO Zhengxi	(n,xc.p.)	14 MeV
USA				
ORELA	ORNL	Dickens	(n,xn)	1-20 MeV
FNG	ANL	Guenther	(n,xn)	6-10 MeV
WNR	LANL	Haight	(n,xc.p.)	5-20 MeV
Tandem accelerator	Ohio U.	Rapaport	(n,xn)	10 MeV
EUROPE				
Neutron Generator	IRK Vienna	Vonach	(n,xn)	14 MeV
Cyclotron	PTB Braunschweig	Mannhart	(n,xn)	6-14 MeV
Neutron Generator	IPPE Obninsk	Simakov	(n,xn)	14 MeV
Van de Graaff	IPPE Obninsk	Kornilov	(n,xn)	1-3 MeV
Van de Graaff	Geel	Liskien	(n,n'γ)	8 MeV

Report of Working Group II - Activation Data and Codes

by R.A. Forrest (Chairman)

Present: R.A. Forrest (Chairman)
F.M. Mann
A.B. Pashchenko
A.V. Ignatyuk
E.T. Cheng
Y. Kanda
J. Kopecky
D. Seeliger
ZHOU Delin
WANG DaHai

(1) Version 1 of the FENDL pointwise activation sublibrary (FENDL/PA-1), consisting of "256 reactions" most important for activation, was reviewed in detail using, as an additional source of data, the results of the Research Co-ordination Meeting on Activation Cross Sections for the Generation of Long-lived Radionuclides held at the IAEA on 11-12 November 1991 and new evaluations. The sources of data were agreed (see Table 1) and this new sublibrary, FENDL/PA-1(Revised), will be compiled by A. Pashchenko.

(2) It was agreed that the FENDL activation library should be as complete as possible, to enable realistic activation calculations to be performed by users. In order to achieve this in reasonable time, all reactions from the European Activation File version 1 (EAF-1) will be supplied by J. Kopecky to the IAEA/NDS in both pointwise and processed (175 Vitamin-J multigroup) forms. Together with FENDL/PA-1(Revised), these will form the basis of Version 1.1 of the FENDL/PA and FENDL/GA (groupwise activation) sublibraries. The actions are:

- NDS will process FENDL/PA-1(Revised) into 175 groups;
- ECN Petten will supply to NDS EAF-1 in pointwise and 175-group format;
- NDS will compile and distribute FENDL/GA-1.1 in 175-group format;
- ECN Petten will supply to NDS the format that the EAF-1 library uses for its pointwise form, and the processing code to convert from pointwise to group format.

All data must arrive at NDS prior to March 1992 and NDS will process and distribute them by June 1992.

(3) Participants who wish to contribute reaction cross section data to replace the data in FENDL/PA-1.1 must supply evidence that their data are superior to the data in that sublibrary. This evidence should consist either of general arguments that an improved calculational procedure has been used or of plots showing the new evaluated data and the original recommended data together with all supporting experimental data. This information will be reviewed by the Working Group at the next FENDL meeting and will form the basis for the production of FENDL/PA-2. Participants should send information on improved cross section data and data in FENDL pointwise activation format to the NDS at least 6 months prior to the next meeting to enable timely distribution to the members of the Working Group.

(4) In order to use activation cross section data in inventory codes it is necessary to have a source of decay data. The decay data sublibrary (FENDL/D-1.1) will be based on the data library used by the REAC code and data system. F. Mann will supply to NDS by March 1992 his data library (which is, in turn, based on ENDF/B-VI and ENSDF) in ENDF/B-VI format for distribution by NDS in June 1992. Approximately 2900 nuclides are included.

Any participant wishing to have data considered for inclusion in FENDL/D-2 should supply information to NDS in a similar manner to that described in Section (3), with the data in ENDF-6 format.

(5) The importance of sequential charged particle data ((z,n) cross section data and associated libraries prepared at present by KfK Karlsruhe and the Institute of Experimental Physics at Arzamas) was discussed. Due to the lack of manpower, it was agreed not to include any data libraries to cover this effect in FENDL-1.1, but to consider sequential charged particle data at the next meeting and to decide then how to include such libraries.

(6) The question of photon induced reactions contributing to activation was discussed. It was agreed to ask the Charged Particle Working Group to discuss this matter before the next meeting and to advise this Working Group at the next meeting whether the compilation of such data should be pursued.

(7) It is likely that an uncertainty file for the reaction cross sections will be included within the European Activation File over the next year. The Working Group will review the importance of such a file for FENDL, and it requests feedback from users of activation data about the level of complexity desirable in such an uncertainty file.

(8) Details of the calculation benchmark organized by E. Cheng were discussed. It was agreed that the authors of the draft report presented at this meeting should add conclusions and recommendations from this study and send them to NDS for distribution of the full report by June 1992.

It was agreed that the two phases of the calculational benchmark have successfully identified problems with codes and libraries. While a further phase of the calculational benchmark might be necessary in the future, the Working Group did not recommend that this be organized at this meeting. As a conclusion of the present work, an agreement was reached on the criteria that an inventory code used for fusion activation calculations should satisfy. Necessary, but not sufficient, criteria that an inventory code should satisfy are:

a) reproduce the reference values given in the benchmark report to within 1% for all nuclides in both the ^{50}Cr and Fe irradiations (this implies that multistep reactions can be treated accurately);

b) reproduce the reference values of H and He isotopes given in the benchmark report to within 1% in both the ^{50}Cr and Fe irradiations (this implies that, e.g., in (n,t) reactions the triton is included in the inventory);

c) the inventory code (or a companion code forming part of the calculational system) should be able to read cross section data in the 175-group format and decay data in ENDF-6 format, the format in which FENDL will be distributed.

At the next meeting consideration should be given to choosing additional criteria and a reference code or codes which can be recommended to accompany the FENDL libraries.

(9) It was agreed that it would be valuable to test the codes and libraries against recently performed experimental data (see the paper entitled "Observation on the Adequacy of Some Transport and Activation Cross-sections as Revealed from the Integral Experiments of U.S./JAERI collaboration program on Fusion Neutronics", presented at this meeting by M. Youssef) by means of an experimental benchmark.

The following actions were agreed:

- E. Cheng to coordinate the effort to obtain well documented experimental results for about three materials (possibly Ni, Zr and W) from the JAERI/USDOE collaborative program on fusion blanket neutronics. The documentation of experimental data is in preparation for publication as a joint report of the collaborative activity. It includes sufficient information for benchmark calculations (the neutron spectrum, irradiation time, cooling time, material density, etc.), for more than 20 materials.
- These documented data to be forwarded to the Nuclear Data Section.
- A. Pashchenko to distribute details of the documented experiment and the specifications for the inventory calculations to all participants in the previous calculational benchmark and to other interested parties to enable them to test the predictive power of their code/library.
- All participants to send results to E. Cheng at least three months prior to the next meeting, so the results can be compiled.
- The results to be discussed at the next FENDL meeting.

(10) FENDL/PA-1.1 will contain no cross section data for actinides. At the next meeting the Working Group will review any existing data libraries containing cross section data for actinides that would be suitable for use in calculations of actinide impurities in materials. The Working Group will choose suitable cross section data to be included in FENDL.

(11) The questions of auxiliary data libraries containing information on biological hazards of radionuclides and regulations for waste disposal were discussed. These will not be provided for Version 1.1; however, A. Pashchenko, E. Cheng and Y. Gohar will make enquiries (e.g., at IAEA and with ITER teams) with respect to the information required by users. This question should be reconsidered at the next meeting.

(12) A collection of documented neutron spectra (in 175 groups) for various fusion applications would be valuable, since these could be distributed to users of inventory codes upon request. It was agreed that this collection would be started by the set of reference spectra to be chosen by E. Cheng as a result of the IEA Workshop on Low Activation Materials. E. Cheng will send the spectra and supporting documentation to NDS by June 1992. Additional candidates for inclusion in the collection will be reviewed by the Working Group at future meetings.

(13) Consideration was given to the strategy for future work in the area of nuclear data for activation. It was agreed that this is an area of vital importance to:

- designers of fusion devices who require activation data for choice of existing materials;
- planners who must consider the management of waste (including decommissioning) arising from the operation of fusion reactors;
- the fusion community who have to convince funding bodies and the public that fusion power is (or can be) an environmentally benign and safe technology.

It must be stressed that data libraries and inventory codes require more than just "polishing up". Construction of quality assured libraries with suitable documentation is a major task and requires continued funding. The inadequacy of many existing codes and libraries to reproduce the benchmarks and experiments that have recently been studied is a concrete example of how difficult it is to accurately calculate activation and should be used to convince funding agencies that this area requires continued effort and support.

(14) The Working Group acknowledged the efforts of A. Pashchenko of the IAEA/NDS in preparing comprehensive documentation to aid in the choice of data for the FENDL activation file.

Table 1

New Data Sources Replacing Current Data in FENDL/PA-1

Reaction	Data Source
Tb-159(n,2n)g,m	ADL-91
Bi-209(n,2n)	no change
Ag-109(n,2n)g,m1,m2	no change
Hf-179(n,2n)g,m1,m2	ADL-91
Hf-180(n,2n)g,m1,m2	no change
Eu-153(n,2n)g,m1,m2	ADL-91
Eu-151(n,2n)g,m	no change
Cu-63(n,p)	ENDF/B-VI
Mo-94(n,p)g,m	ADL-91
W-182(n,nα)	no change
Dy-158(n,p)	no change
Mo-98(n,γ)	no change
Ho-165(n,γ)g,m	ADL-91
Zr-93(n,α)	ADL-90 (not ADL-91)

General Remarks

(1) evaluated (n,γ) data from REAC-ECN-5 which are the results of renormalization at 14.5 MeV to branching ratio $BR = \sigma^m/(\sigma^m+\sigma^g) = 0.5$ will be replaced by EAF-2

(2) all BOSPOR-86 data will be replaced by ADL-91 data

(3) all ADL-90 data will be replaced by ADL-91 data (except for Zr-93(n,α))

Report of Working Group III - Neutron and Gamma-ray Data Processing, Integral Experiments and Benchmark Calculations

Members:		
	L.Petrizzi	ENEA-Frascati
	A. Santamarina	CEA-Cadarache
	D. Markovskij	IAE-Moscow
	D. Chuvilin	IAE-Moscow
	Y. Gohar	ANL-U.S.A.
	K. Ilieva	INRNE-Sofia
	E.T. Cheng	TSI Research, U.S.A.
	H. Maekawa	JAERI
	U. Fischer	KFK
	S. Ganesan	IAEA (Chairman)
	G.C. Panini	ENEA, Bologna
	K. Sumita	Osaka University
	M. Youssef	UCLA, U.S.A.
	D. Larson	ORNL, U.S.A.
	D.W. Muir	IAEA

The Working Group reviewed the status of neutron and gamma-ray data processing, integral experiments and benchmark calculations for FENDL.

1. Data Processing

There is an urgent need to make available multigroup, self-shielded neutron-gamma coupled cross sections for the FENDL materials given in the Appendix, for which evaluations have been selected at an earlier meeting. With the limited manpower available at the IAEA, evaluated files for most of the materials of interest to FENDL have been successfully processed, and including up to the generation of Group ENDF or "GENDF" files. In the first stage, the production of multigroup coupled neutron-gamma data files in the VITAMIN-J structure (175 neutron groups + 42 gamma groups) has been limited to ENDF/B-VI materials. GENDF tapes have been generated for the following isotopes:

^{1}H, ^{2}H, ^{3}H, ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{14}N, ^{15}N,

^{16}O, ^{23}Na, Mg, ^{27}Al, Si, P, S, Cl, K, Ti, ^{51}V, $^{50-54}$Cr, ^{55}Mn,

$^{56-58}$Fe, ^{59}Co, ^{58,60,62,64}Ni, ^{63,65}Cu, $^{90,91,94-96}$Zr, ^{93}Nb,Sr,

$^{134-137}$Ba, $^{182-186}$W, $^{206-208}$Pb and ^{209}Bi.

Data for the underlined elements and isotopes will be taken from ENDF/B-VI. The remaining, non-ENDF/B, FENDL-1 materials (see the Appendix) are expected to be processed into GENDF form by March 1992.

The Working Group recognized that the multigrouping task is a time-consuming process, involving many materials, evaluations that do not always conform to selected (ENDF-6) formats, a large number of energy groups, compatibility problems between the available versions of GROUPR, MATXSR and TRANSX, and machine-precision concerns.

Discussions took place on the way to formulate sharing of work between the NDS and other interested parties that may become involved in the next stages of this large processing task: production of application dependent libraries from GENDF tapes, processing of JENDL-3, EFF-2, BROND, CENDL, the dosimetry library (IRDF-90), etc. These discussions centered around methods to expedite the processing tasks, so as to make FENDL available soon as a comprehensive and complete library for fusion design calculations. At a later stage the multigroup library will be supplemented with companion libraries of input data for continuous energy Monte Carlo codes (e.g., MCNP). The Working Group noted that there is also a need to resolve a compatibility problem between the MCNP code and the output of the ACER module of NJOY. The Working Group also recognized the need to generate multigroup covariance matrices for sensitivity studies at a later stage of FENDL development.

The NDS has the goal of producing FENDL/M-1, a multigroup library in MATXS format, with a tentative target completion date of July 1992. However, progress toward this goal is currently hampered by compatibility problems between the GROUPR and MATXSR modules of NJOY and between MATXSR and the TRAMIX (TRANSX) post-processing program. If the NDS is able to obtain consulting assistance from the NJOY and TRANSX author R.E. MacFarlane in the next few months, it is felt that the target completion data can realistically be met. Without such assistance a long delay in the availability of the MATXS library remains a definite possibility.

In the meantime, FENDL participants are encouraged to obtain from the NDS the GENDF files needed for the analysis of specific clean integral experiments, and to post-process them locally (using, for example, the DTFR module of NJOY to produce ANISN-formatted, infinite-dilution data for neutron transport).

The Working Group recommended that a high priority list of isotopes/elements be established so that the initial processing efforts can be limited to a smaller number of isotopes. Analysis of selected benchmarks will be performed with the multigroup library to validate the FENDL-1 data for these isotopes.

The Working Group recommended that NDS prepare in time before the next FENDL Meeting a representative list of integral benchmarks and their specifications. The list of high priority isotopes to be processed for near-term analysis of benchmarks includes ^{1}H, ^{6,7}Li, Be, C, N, O, Si, Ca, Cr, Mn, Fe, Ni, Cu, W and Pb.

Displacement and damage-energy production cross sections, prompt kerma factors and dosimetry reaction cross sections (IRDF-90) will be part of the FENDL multigroup library. However, at a later stage, kerma factors including decay energies are anticipated to be processed for FENDL materials for use in fusion design analysis by shared efforts of interested participants.

2. Integral Experiments and Benchmark Calculations

The Working Group strongly recommended that the Agency co-ordinate the efforts of compilation of specifications of experimental fusion benchmarks for nuclear data validation purposes. Individual experimental teams should provide details of benchmark specifications to NDS in the format mentioned in BNL-19302, ENDF (202) (Ref. 1). The specifications should be complete to enable a team in the future to perform analysis of the experiments for data testing and validation. The experimental data should include an estimate of realistic uncertainties for the measured quantities. The Agency will distribute these specifications to interested parties.

The following clean experimental benchmarks could already be identified at the meeting for inclusion in the proposed compilation.

1. K. Sugiyama et.al., Nuclear data testing on integral experiments of lithium spheres JAERI-M-86-029, p. 141-148;

2. 14 MeV integral experiment at OKTAVIAN to check differential data of secondary neutrons, JAERI-M 86-029, p. 149-159 (Fe only).

3. V.A. Zagryadskii et al., Calculated Neutron Transport Verifications by Integral 14 MeV Neutron Source Experiments with Multiplying Assemblies, Fusion Eng. Design, 9(1989), 357-358.

4. TOF on Fe Slabs

   Oyama Y., Maekawa H., Measurements and Analyses of Angular Neutron Flux Spectra on Liquid Oxygen, Nitrogen and Iron Slabs, Int'l. Conf. on Nuclear Data for Science and Technology, 13-17 May, 1991, Jülich, Germany.

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* (spherical geometry)

5. Integral Be experiments* done in Idaho.

6. Integral Be experiments* done in China.

7. Kurchatov IAE experiment performed with a combined Be sphere (Experiment has not yet been completed).

   The Working Group encouraged experiments planned in 1992 in U.S.S.R. and China with measurements of leakage spectra and neutron multiplication on a combined (U.S.A. + P.R. of China + U.S.S.R.) Be sphere with total thickness up to 20 cm and a follow up on the compilation of specifications of these experiments for benchmarking purposes.

8. KfK transmission experiment.

9. Integral Experiments on Fe and Pb Assemblies

a) Konno C., et al., Measurements and Analyses of Low Energy Neutron Spectrum in a Large Cylindrical Iron Assembly Bombarded by D-T Neutrons, ISFNT-2, KfK, Karlsruhe.

b) Elfruth T., et.al., Pb TOF and multiplication experiment, TU Dresden and Kurchatov IAE, published in Atomkernenergie, 49, 121 (1987), subject of a previous IAEA benchmark task.

c) Oishi K., et. al., Measurement and Analysis of Neutron Spectra in a Large Cylindrical Iron Assembly Irradiated by 14 MeV Neutrons, Proc. 7th Int'l Conf. on Radiation Shielding, Sep. 12-16, 1988, Bournemouth, England.

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* (spherical geometry)

10. In addition to the compilations of specifications of the above mentioned clean benchmarks, the Working Group encouraged compilation of engineering benchmarks which will be useful at a later stage of integral data testing. The following were identified:

a) Oyama Y., et. al.: "Phase-IIA and -IIB Experiments of JAERI/USDOE Collaborative Program on Fusion Blanket Neutronics", JAERI-M 89-215 (Part I and II) (1989)
b) Nakagawa M., et. al.: "JAERI/USDOE Collaborative Program on Fusion Blanket Neutronics --Analysis of Phase-IIA and -IIB Experiments--", JAERI-M 89-154 (1989)
c) Youssef M. Z., et. al.: "U.S./JAERI Collaborative Program on Fusion Neutronics --Phase-IIA and -IIB Fusion Integral Experiments, The US Analysis--", UCLA-ENG-90-14/FNT-31 (Dec. 1989).

Elements to be used for the analysis of ITER/EDA shielding experiments.

^{1}H, ^{6}Li, ^{7}Li, Be, B, C, N, O, Si, (P), (S), Cr, Mn, Fe, Ni, Cu, Mo, W

( ) --- low priority.

Reference

1. Cross Section Evaluation Working Group Benchmark Specifications, Vol. II, BNL 19302, ENDF-202, December 1983, National Nuclear Data Center, Brookhaven National Laboratory, Upton, Long Island, New York 11973, U.S.A.

APPENDIX

TABLE I: Results of Review of FENDL-1 General Purpose Evaluations Identified at Previous Meetings +

Nuclide or Element	Library	γ-Ray Data	MF6 Data	Chg.Part. Spectra	Covariance Data	Act./Dos Consistency	Comments
H	V6	Y	NA	Y	Y	-	Correct AWR for nuclear rather than atomic mass. Consider use of MF=30 for covariances.
D	BROND	Y	Y	Y	N	-	Several improvements have been made to the file since last meeting.
T	V6	Y	N	N	N	-	
Li-6	V6	Y	N*	NC	NC	-	
Li-7	V6	Y	N*	NC	Y	-	(EFF2/ENDF/B-VI, Revision 1) will be considered for FENDL-2 after testing.
Be-9	V6	Y	Y	Y	N	-	Neutron emission spectra appear to be underestimated at back angles.
B-10	V6	Y	N*	NC	NC	-	
B-11	V6	Y	Y	Y	N	-	
C	V6	Y	N*	NC	Y	-	
N-14	BROND	Y	Y	Y	N	-	
N-15	BROND	Y	Y	Y	N	-	
O-16	V6	Y	N*	NC	N	-	
F-19	V6	Y	Y	Y	Y	N?	New BROND analysis using Pade approximates should be compared. (n,2n) cross sections might not be consistent with activation file. file.

Table I is continued on following page.
+ For explanations see end of Table I.

#5731N,p.39-42/mw

TABLE I (Contd.): Results of Review of FENDL-1 General Purpose Evaluations Identified at Previous Meetings +

Nuclide or Element	Library	γ-Ray Data	MF6 Data	Chg.Part. Spectra	Covariance Data	Act./Dos Consistency	Comments
Al-27	JENDL-3	Y	N	N	N	N	
Si	BROND	Y	NC	Y	N	-	Use EFF-2 if completed in time. ENDF/B-VI isotopic evaluations will be available for consideration for FENDL-2.
Ti	JENDL-3	Y	N	NC	N	N	^{47}Ti(n,p) not consistent with activation file.
V-51	V6	Y	N	N	Y	Y	
Cr-50 52-54	V6	Y	Y	Y	Y	Y	Questions raised regarding resonance region for even Cr isotopes that should be checked.
Mn-55	V6/ JENDL-3	Y	Y	Y	Y	Y	Collaborative evaluation but only ENDF/B-VI contains MF=6 data.
Fe-54 56-58	V6	Y	Y	Y	Y	Y	14 MeV neutron emission spectrum at 30° higher than Takahashi data in pre equilibrium region. Should be checked.
Co-59	V6	Y	N	N	Y	Y	
Ni-58, 60-62,64	V6	Y	Y	Y	Y	Y	Check first few resonances in Ni isotopes for completeness.
Cu-63,65	V6	Y	Y	Y	Y	Y	
Zr-90-92, 94,96	BROND	Y	Y	Y	N	N	Cheng recommended that isotopic evaluations be used. ^{90}Zr(n,2n) not consistent with activation file.

Table I is continued on following page.
+ For explanations see end of Table I.

TABLE I (Contd.): Results of Review of FENDL-1 General Purpose Evaluations Identified at Previous Meetings +

Nuclide or Element	Library	γ-Ray Data	MF6 Data	Chg.Part. Spectra	Covariance Data	Act./Dos Consistency	Comments
Nb-93	BROND	Y	Y	N	N	NC	^{93}Nb(n,n')^{93m}Nb and (n,2n)^{92m}Nb should be added from activation/dosimetry files.
Mo	JENDL-3	Y	N	N	N	N	Isotopic evaluations do not include γ-ray data. Recommend addition of γ-ray data before FENDL-2.
Sn	BROND	Y	N	Y	N	N	MF=3 is a combination of full evaluation of major isotopes. MF=4,5 based on calculations for two isotopes.
Ba-134--138	V6	N	N	N	N	-	Fission product evaluations of limited scope.
W-182--186	V6	Y	N	N	N	N	Some improvement in 14-MeV-neutron emission spectra possibly needed. Use of isotopic evaluations recommended by Cheng.
Pb-206--208	V6	Y	Y	N	Y	N	^{206}Pb(n,alpha) not consistent with activation file. ^{204}Pb evaluation is encouraged.
Bi-209	JENDL-3	Y	N	N	N	N	^{209}Bi(n,2n) and (n,γ) not consistent with activation file.

+ Table Explanation

Y = Yes, data present
N = No, data not present
* = Indicates excitation energy bins (pseudo levels used in lieu of MF=6)
NC = not complete but some data present
NA = not applicable
V6 = ENDF/B-VI

TABLE II: Additional Evaluations Recommended for FENDL-I+

Nuclide or Element	Library	γ-Ray Data	MF6 Data	Chg.Part. Spectra	Covariance Data	Act./Dos Consistency	Comments
Na-23	JENDL-3	Y	N	N	N	N	
Mg	JENDL-3	Y	N	N	N	N	
P-31	V6	Y	N	N	N	Y	JENDL-3 only includes files thru MF=5 - no γ-ray data.
S	V6	Y	N	N	N	N	JENDL-3 has no γ-ray data.
Cl	V6	Y	N	N	N	-	JENDL-3 has no γ-ray data.
K	V6	Y	N	N	N	-	JENDL-3 has no γ-ray data.
Ca	JENDL-3	Y	N	N	N	-	
Ta-181	JENDL-3	Y	N	N	N	N	Should be compared with BROND update.

+ Same symbols used as in Table I.

REPORT OF WORKING GROUP IV ON REVIEW OF CHARGED-PARTICLE DATA FOR FENDL

B. Guzhovskij, U.S.S.R. and R.M. White, U.S.A.

The Working Group on the charged-particle sublibrary to be included in FENDL (FENDL/C) makes the following recommendations in order of priority:

(1.1) To adopt the ENDF/B-VI integrated charged-particle cross section evaluations for the following reactions; $^{2}H(d,n)^{3}He$, $^{2}H(d,p)^{3}H$, $^{3}H(t,2n)^{4}He$, $^{3}H(d,n)^{4}He$, and $^{3}He(d,p)^{4}He$. These evaluations have been intercompared with evaluations carried out at Arzamas, U.S.S.R., and the Working Group concluded that these integrated cross sections have now been established to accuracies of $\pm$3%, $\pm$3%, $\pm$8%, $\pm$2% and $\pm$8% respectively over the energy range important to fusion applications. We believe that these uncertainties represent the lower limit of what can be accomplished with the experimental database.

(1.2) To adopt the Livermore thermonuclear applications file TDF and the utility routines in TDFLIB, which access the necessary processed information from TDF for application programs that require quantities such as Maxwellian-averaged reaction rates, etc., calculated from reaction cross sections. The current file TDF containing the five reactions listed in Recommendation (1.1) has been created from the reaction cross section information contained in the ENDF/B-VI charged-particle file.

(1.3) To include in FENDL/C and in the TDF file evaluations from Arzamas, U.S.S.R. for the reactions involving $t+^{3}He$ and $^{3}He+^{3}He$. FENDL and TDF will then contain all of the energy-producing reactions of importance for near-term fusion reactor designs. The expanded applications file TDF will be created at LLNL and checked at both Arzamas and LLNL to insure its validity.

(2.1) To expand FENDL/C to include angular-distribution data for the reactions listed above and integrated cross sections and angular distributions of the reactions between the isotopes of hydrogen and lithium, beryllium and boron.

(2.2) To expand FENDL/C to include charged-particle (diagnostic) reactions which produce high-energy gamma-rays.

The Working Group recommended that further developments be made in processed files of charged-particle reactions needed for plasma research and 14 MeV neutron sources. The working group recognized that it may be necessary to introduce some changes into the ENDF format which would permit more a compact presentation of charged-particle cross section data. We agree with Recommendation (6) of Working Group II at this meeting concerning photonuclear reactions.

Finally, the Working Group recommended that continued checks and further development of co-ordinated efforts be considered at a Consultants' Meeting on "Charged-particle and Photonuclear Data Libraries", which should be organized adjacent to the BNL-92 Symposium on Nuclear Data Evaluation Methodology in the U.S.A. in October 1992.

Appendix C

IAEA Advisory Group Meeting on
"FENDL-2 and Associated Benchmark Calculations"

18-22 November 1991, IAEA Headquarters, Vienna, Austria

Scientific Secretary: A.B. Pashchenko, RIPC

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Appendix D

Strategy

for the Future Development

of the FENDL Library

Report of the Working Group on the Strategy for the Future Development of the FENDL Library

Members: Y. Gohar, Chairman
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Considering the progress which had currently been achieved in the development of the first version of the Fusion Evaluated Nuclear Data Library (FENDL-1) and in view of the urgent need for one consistent evaluated nuclear data library such as FENDL for the Engineering Design Activity (EDA) phase of ITER and other fusion reactor projects, the Working Group recommended to the Agency to issue FENDL-1 by July 1992 and to make it available to the ITER and other fusion reactor projects. FENDL-1 should contain the following sublibraries:

(i) coupled 175 group neutron-42 group gamma cross section sets for the following materials:

^{1}H, ^{2}H, ^{3}H, ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{14}N,

^{15}N, ^{16}O, ^{19}F, ^{27}Al, Si, ^{23}Na, Mg, P, S, Cl, Ti, K, Ca,

^{51}V, $^{50,52-54}Cr$, ^{55}Mn, $^{54,56-58}Fe$, ^{59}Co, $^{58,60-62,64}Ni$,

$^{63,65}Cu$, $^{90-92,94-96}Zr$, ^{93}Nb,Mo,Sn, ^{181}Ta, $^{134-138}Ba$,

$^{182-186}W$, $^{206-208}Pb$ and ^{209}Bi;

(ii) FENDL activation library in both pointwise (FENDL/PA-1) and multigroup (FENDL/GA-1) forms;

(iii) the decay data sublibrary (FENDL/D-1);

(iv) charged particle nuclear reaction cross sections for p, d, t, He-3 and He-4 (FENDL/C-1);

(v) fusion-relevant neutron dosimetry cross sections, selected from IRDF(90) and processed into 175 groups (FENDL/GN-1).

The Working Group noted its appreciation of the efforts of the IAEA Nuclear Data Section in the processing of FENDL-1, the compilation of specifications of fusion benchmark experiments for nuclear data validation purposes, and the co-ordination of the FENDL activity. It also acknowledged the significant contributions in terms of evaluated data files and their intercomparison and benchmark testing rendered by the following research groups in Member States:

- IRK Vienna/Austria
- Academy of Sciences/Bulgaria
- Chinese Nuclear Data Centre, Beijing/China
- Cadarache/France
- KFK Karlsruhe/Germany
- MPI Munich/Germany
- TU Dresden/Germany
- ENEA Bologna/Italy
- JAERI/Japan
- Osaka University/Japan
- Tohoku University/Japan
- ECN Petten/Netherlands
- ARZAMAS/USSR
- FEI Obninsk/USSR
- Kurchatov Institute/USSR
- Harwell Laboratory/UK
- Argonne National Laboratory/USA
- Westinghouse Hanford Corporation/USA
- Lawrence Livermore National Laboratory/USA
- Los Alamos National Laboratory/USA
- Oak Ridge National Laboratory/USA
- TSI Research/USA
- University of California/USA

The Working Group recommended that the Agency send letters of appreciation to the Universities and national laboratories contributing to the FENDL effort.

A careful review by the four technical Working Groups at this meeting of the data files currently being assembled for FENDL-1 revealed the following shortcomings and needs:

(i) The FENDL-1 file of general purpose evaluations, FENDL/E-1, which is the nuclear data base for fusion neutron and gamma transport calculations is still not adequate to fulfil the target accuracies of fusion reactor design activities with the subsequent introduction of undesirable safety margins during the process of fusion reactor design. These safety factors substantially increase the cost of such devices. Many of the adopted evaluations, while the best available, need significant upgrading, and new experimental data are needed to reduce uncertainties to acceptable levels.

(ii) The existing inventory codes and nuclear activation data libraries have been shown to be still inadequate to correctly reproduce activation benchmarks and experiments. A continued major effort is required in this area, specifically the FENDL activation library should be as complete as possible, to enable realistic calculations to be performed by users. In order to achieve this goal, all neutron induced reactions on stable and unstable targets (with half-lives exceeding 0.5 day) should be included in the FENDL pointwise activation sublibrary (FENDL/PA-1), until now consisting only of the "256 reactions" most important for activation. The activation cross section data for certain actinides is needed for calculations of actinide impurities in materials. Currently, there is an increased concern for the low activation fusion reactor due to the sequential charged-particle and photon induced activation reactions. It is likely that an uncertainty file for the reaction cross-sections will be required within the FENDL activation library. Furthermore, in order to use activation cross-section data in inventory codes, the decay data library should be established. Consideration should be given to choosing a reference inventory code or codes which can be recommended for fusion activation calculations to accompany the FENDL libraries. A collection of well documented neutron spectra for various fusion applications would be valuable for validation of data libraries and inventory codes, since these could be distributed to users of inventory codes upon request. For more details and specific needs of activation data and codes as well as for the strategy for future work planned in the area of nuclear data for activation refer to Working Group II Report.

(iii) There are still difficulties in the generation of some multigroup data for neutron and gamma transport calculations, and there is an urgent need to make these data available in processed multigroup form for fusion materials as identified by Working Group 3 (see Appendix to the report of Working Group 3).

(iv) A compendium of the specifications of existing experimental fusion benchmarks urgently needs to be established for validation of FENDL-1 and the preparation of data improvements for FENDL-2.

(v) The cross-section data base is still rather poor for a large number of nuclear reactions of light charged nuclei that occur among the components of various fusion fuels in high temperature plasmas. Currently, there is an increased need to expand FENDL charged-particle sublibrary (FENDL/C) to include the integrated cross sections and angular distributions of the reactions that are important for the investigation of fusion fuel candidates:

^{1}H, ^{2}H, ^{3}H, ^{3}He, ^{4}He, ^{6}Li, ^{7}Li, ^{7}Be, ^{9}Be, ^{10}B, ^{11}B.

To fulfil all demands of fusion reactor designers, it is necessary to include within FENDL charged-particle diagnostic reactions that produce high-energy gamma-rays. There is an urgent need to make further developments in the processed files of charged-particle reactions needed for plasma research and 14 MeV neutron sources. Furthermore, some changes should be introduced into the ENDF format to permit more compact presentation of charged-particle cross-section data.

The Working Group emphasized that additional data processing and methods-development efforts are required from FENDL participants to complement the processing effort within the IAEA Nuclear Data Section to produce the FENDL-1 multigroup cross section data libraries. Also, the participants have to perform an assessment of the processed libraries through calculational benchmark problems, coordinated by the Nuclear Data Section of the IAEA.

The Working Group strongly recommended that, after the completion of FENDL-1, the FENDL-related activities be continued and an improved version of FENDL-1, i.e., FENDL-2, be established.

The future work towards establishing FENDL-2 should be focussed on the following tasks:

(1) New evaluations of elemental and isotopic evaluated general purpose nuclear data files based on new experimental measurements and improved nuclear data modelling calculations and detailed intercomparisons of, and selections from, all released evaluated nuclear data libraries for neutron-gamma transport and activation studies.

(2) Expansion of the current nuclear activation data sublibrary of FENDL with many more activation reactions including sequential reactions and with nuclear decay data, so as to allow realistic activation calculations to be carried out; more experimental efforts as well as improved model calculations are required and are strongly encouraged to enhance the reliability of the activation data file.

(3) Expansion of the current charged-particle sublibrary of FENDL with integrated cross-section and angular distribution data of the reaction, between the isotopes of hydrogen and lithium, beryllium and boron as well as charged-particle diagnostic reactions which produce high-energy gamma rays.

(4) Continuation of the nuclear data processing and verification activities including further development of the NJOY code system, the TRANSX post-processor and the KAOS code for nuclear responses, with the goal of providing improved libraries for fusion studies.

(5) Adopting recent fusion-related integral experiments for nuclear data testing to identify deficiencies and verify the reliability of FENDL-1 general purpose files, nuclear activation cross sections and nuclear decay data.

(6) Nuclear data files (evaluations and processed libraries) should continue to be made available by the IAEA Nuclear Data Section to support the ITER EDA and other fusion reactor design activities.

These recommendations are based on the current needs of ITER EDA and other fusion reactor projects. The Working Group emphasized that improvements in the FENDL files and the reduction of data uncertainties resulting from these efforts will lead to significant cost savings, for example for the ITER project, by reducing the engineering safety margins related to the uncertainties in the basic nuclear data.

In view of the enormous volume of work involved in the above-mentioned tasks, the Working Group strongly recommended continuous and appropriate work sharing among the FENDL participants, under the co-ordination of the IAEA Nuclear Data Section, and enhanced funding of contributions to FENDL by the relevant national support agencies.