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Extension and Improvement of the FENDL Library for Fusion Applications (FENDL-2)

Report on an IAEA Advisory Group Meeting

IAEA Headquarters, Vienna, Austria
3-7 March 1997

Prepared by

M. Herman and A.B. Pashchenko

September 1997

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

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Abstract

The present report contains the summary of the IAEA Advisory Meeting on Extension and Improvement of the Fusion Evaluated Nuclear Data Library (FENDL), organized by IAEA Nuclear Data Section and held in IAEA headquarters in Vienna from 3 to 7 March 1997. The FENDL library is a comprehensive collection of high-quality nuclear data, selected from the various existing national data libraries, covering the necessary input for physics and engineering studies of the material development, design, operation and safety of ITER and other fusion devices. The library has undergone an intensive testing and validation against integral benchmarks. The main scope of the Meeting was to discuss recent developments within FENDL project, review new evaluations to be included in the library, and decide on the release of the second version of the library (FENDL-2.0). During the meeting it was demonstrated that the FENDL-2.0 library shows a net improvement over the preceding FENDL-1. The release of the Library was authorized with the exception of the general purpose file FENDL/E-2.0 and its processed form, which is scheduled at the end of 1997.

September 1997

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I. INTRODUCTION

The IAEA Nuclear Data Section (NDS), in co-operation with several national nuclear data centers and research groups, has created the international Fusion Evaluated Nuclear Data Library (FENDL). The goal of the effort was to provide a comprehensive and high quality data library in support of design of the International Thermonuclear Experimental Reactor (ITER) project and other fusion-related developments. Within the scope of this activity, the IAEA/NDS served as a coordinator for the assembling, processing and testing of the FENDL library and organized a series of international meetings. The FENDL project started in 1987 and its first stage was completed in 1995 with the official release of the FENDL-1 library early in 1996, after approval by the Advisory Group Meeting (AGM) held at Del Mar in 1995 [INDC(NDS)-352]. At the same meeting, actions and schedules for the second stage of the project, the improvement of the FENDL-1 library, were agreed. This stage took into account feedback suggested by the benchmark experiments and calculations [INDC(NDS)-351, INDC(GER)-041], as well as additional and updated evaluations from various research activities in several countries.

FENDL is a collection of selected nuclear data from the various national libraries designed to cover all nuclear data needs in design, operation and safety of the ITER machine as well as in other fusion-related projects. In addition to the pointwise data the library contains also processed sublibraries ready to use in the transport calculations and results of the benchmark experiments. Version 2.0 of the FENDL library is composed of the following sublibraries:

- | | |
|----------------|---|
| - FENDL/E-2.0 | general purpose basic evaluations (pointwise) |
| - FENDL/A-2.0 | activation library |
| - FENDL/D-2.0 | decay data library |
| - FENDL/C-2.0 | charged particle library |
| - FENDL/DS-2.0 | dosimetry library |
| - FENDL/MG-2.0 | processed multigroup library |
| - FENDL/MC-2.0 | processed Monte Carlo library |

II. OBJECTIVES

The present meeting was organized to review the results of the benchmark validation and quality assurance studies regarding new evaluations and decide on replacements for some evaluations contained in the FENDL-1. The main goal of the meeting was to authorize the release of FENDL-2.0. In addition, activities regarding improvements of the FENDL-2 library following the release of Version 2.0 were to be discussed.

III. ORGANIZATION AND ATTENDANCE

The Meeting was held in the Headquarters of IAEA in Vienna from 3 to 7 March 1997. It was attended by 22 participants from 11 countries, a representative of the ITER Joint Teams and several staff members of the NDS.

IV. PROCEEDINGS AND RESULTS

The meeting was opened by D.W. Muir, Head of the Nuclear Data Section (NDS). He thanked A.B. Pashchenko for his contribution to the FENDL project. A.B. Pashchenko, who left the Nuclear Data Section on March 15, had been involved in the project since January 1990. D.W. Muir announced also that M. Herman, a new NDS staff member, will take over Pashchenko's responsibilities with regard to the FENDL project. A short historical review of the project was given by J.J. Schmidt, former Head of NDS who retired in 1992 after 30 years of service with NDS. Schmidt, who was an initiator of the FENDL, recalled that the idea came about during the Gaussig meeting in 1986. The project turned out to be an incentive for intensive experimental activities, especially in the 14 MeV energy range, as well as developments in nuclear theory. D.C. Larson, who has participated in all FENDL meetings, was elected as the meeting Chairman. The Agenda of the meeting was discussed and adopted (see Attachment 1). All sessions were carried out in plenary and only Working Groups were held in parallel.

A minute of silence was dedicated to the memory of Dr. Yasuyuki Kikuchi, JAERI, who passed away in September 1996. He was a world leader in the field of nuclear data for many years. His outstanding contribution to the FENDL project will long be remembered by all FENDL participants.

D.W. Muir announced that the FENDL-1 documentation is currently available.

SESSION 1. "Neutronics analysis of ITER, priorities for ITER and role of FENDL"

H. Iida reported on the recent calculations of ITER Garching Joint Work Site Nuclear Analysis Group using FENDL/MG-1.0 and FENDL/MC-1.0.

E.T. Cheng described application of the FENDL to ITER activation analysis performed at T.S.I. Research Corp. He pointed out that the FENDL-based results are becoming the basis for the safety design and the assessment of health and environmental effects of ITER, due to their completeness, credibility and unique validation process.

M.E. Sawan reviewed the application of the ACE formatted FENDL/MC-1.0 sublibrary to 3D neutronics and shielding analyses performed for divertor region of ITER. He stressed that adding gas production and damage data to the processed library was very helpful in calculating design relevant parameters.

SESSION 2. "General purpose library. Basic evaluations for FENDL/E-2.0. Processed libraries and benchmark calculations."

The recommendations of the Karlsruhe meeting (June 1996) regarding data testing and evaluation selection were presented by the reviewers appointed at the Karlsruhe meeting (see Attachment I - Agenda). A. Ignatyuk raised the question of whether the Si evaluation might be accepted without demonstrating prescribed tests. D.C. Larson answered that the Si evaluation was analysed by the American Society for Testing and Materials, which adopted the file, and promised the full documentation to be available June 1997.

The results of the FZ Karlsruhe benchmark tests for Fe, Be, Al, Si, and Mo candidate evaluations were presented by U. Fischer. He concluded that the results for FENDL-2 candidates are as good as, or better than, FENDL-1. No improvement was observed only for the Mo data, while the elemental JENDL-FF evaluation turned to be in agreement with OKTAVIAN experiment. Strong disagreement between benchmark calculations and experimental data for ^{56}Fe at 14 MeV turned out to be due to the omission of total (level-summed) (n,p) and (n, α) data from the first version of the EFF-3 evaluation. Y. Oyama presented integral test of FENDL-2 candidates against Fast Neutron Source (FNS) Slab Insytem, FNS Slab Leakage, and OKTAVIAN Gamma-ray Sphere experiments.

U. Fischer suggested that the number of ultra-high resolution data in the ^{56}Fe file should be reduced without losing information. G. Reffo took the responsibility for providing the thinned file.

In the following, actions resulting from the Karlsruhe meeting were reviewed.

A. Blokhin presented improvements in the BROND-2 deuterium and tin evaluations. H. Vonach further discussed the problems related to the EFF-3 evaluation for ^{56}Fe . G. Reffo presented the new Bologna-97 file for ^{27}Al . S. Chiba described actions undertaken at JAERI to improve JENDL-FF for deuterium, ^{12}C , ^{14}N , ^{16}O , ^{93}Nb , Mo, Zr, and W.

The Section 2. was continued on the second day of the meeting and concentrated on new results of benchmark testing of FENDL-2.0 materials and on the interfacing to ITER design.

S. Ganesan presented the current status of IAEA compilation of fusion benchmarks, available online from the IAEA-NDS. He noticed that this compilation is a result of truly international effort and was used to validate the working libraries for use in ITER and other fusion applications. He also suggested that the compilation should be updated continuously. In particular, benchmarks which had been submitted to U. Fischer should be included.

G. Reffo presented the verification report on the new Bologna-97 evaluation for ^{27}Al . The checking codes revealed no serious errors or inconsistencies in the data. The energy balance is practically always within 1%.

U. Fischer reported on the integral data test of the revised EFF-3 evaluation of ^{56}Fe , which was a replacement candidate for FENDL-2.0. The TUD iron slab experiment, measurements at two locations in bulk shield mock-up of ITER, and IPPE iron shell experiment were analysed, with acceptable results.

The results of the JAERI integral tests for revised FENDL-2 candidate evaluations were presented by Y. Oyama. With respect to FENDL-1, large improvement was observed in the case of Si evaluation. Low energy part was improved in the Nb and Mo evaluations and small improvement was noticed at high energy neutron penetration in the Fe case. No significant difference was observed for C, Ni, and generally for gamma-rays.

Total leakage multiplication experiments on a beryllium sphere were presented by D.V. Markovskij. The results for FENDL-1 and JENDL-FF data show good agreement with the measurements, practically within experimental uncertainty, both for 3-D and 1-D calculations.

Benchmarking of BROND deuterium file using neutron leakage spectra of spherical heavy water assemblies was reported by A.I. Blokhin. Ganesan proposed to submit these data to the FENDL benchmark compilation.

Quality assurance checks of FENDL-1.x and FENDL-2.0 multigroup data, performed by J.E. White using the AMPX-77 system, showed that the FENDL-2.0 multigroup files appear to be in very good shape.

M.E. Sawan, analysing calculational benchmark results with the new multigroup processed library, stressed that the large differences are obtained when using different processing codes (NJOY/TRANSX against MINX/AMPX/KAOS). Differences in nuclear responses calculated with FENDL and ENDF/B-V using the same processing codes are in general smaller than differences between the results using different processing codes. The KAOS library based on ENDF/B-V gives higher power densities compared to the FENDL library processed with NJOY (up to 50% in magnet). These indicate a need for the investigation of the processing methods. Differences due to the diverse group structures are very small.

SESSION 3. "Activation data. Basic Evaluations for FENDL/A-2.0 and FENDL/D-2.0 libraries. Processed data and Benchmark validation. Interfacing to ITER Design."

Y. Ikeda reviewed the recommendations and results of actions resulting from the Del Mar meeting in December 1995.

J. Kopecky and J.-Ch. Sublet reported on the assembling of FENDL/A-2.0 in Culham. The file contains 13006 reactions on 739 targets and is actually available from the NDS-IAEA. Most of the cross sections were taken from ADL-3 and JEF-2.2. More than 3300 reactions were renormalized. The uncertainty file is not included in the FENDL/A-2.0 library, but it was created for the EAF-4.1 library. D.C. Larson raised a question about extending FENDL/A-2.0 to higher energies. R. Forrest replied that it would require a considerable effort and should be very well planned.

Preliminary results of the FENDL/A-2.0 testing were presented by Y. Ikeda. He described the experimental assembly and concluded that, although some problems were encountered, FENDL/A-2.0 gives better results than FENDL/A-1 and JENDL/A-3.2.

Validation of the FENDL/A-2.0 library, by means of the appropriate module of the code SYMPAL-96, was reported by J.-Ch. Sublet. The cross sections were compared against experimental (15%) and systematics' results at three incident energies: 0.0253 eV, 30 keV, and 14.5 MeV. The FENDL/A-2.0 turned out to be a considerable step forward.

R. Forrest reported on the current status of the FENDL/D-2.0 decay data library and testing of the FENDL/A-2.0. For the consistency reasons it was accepted to adopt

EAF_DEC-4.1 as FENDL/D-2.0. Comparison of FENDL/D-2.0 with FENDL/D-1 revealed many differences regarding decay energies as well as half-lives. In the latter cases FENDL/D-2.0 appears to be more correct when judged against the most recent compilation (R.B. Firestone, Table of Isotopes, Eighth Edition, John Wiley and Sons, 1996). The benchmark calculations with code FISPACT were performed using FENDL/A-2.0 and EAF-4.1 libraries. The overall agreement was very good (within 10%) with the exception of water for which a factor-of-2 difference was observed. This difference, however, was traced to the change in the $^{17}\text{O}(n,\alpha)^{14}\text{C}$ cross section in FENDL/A-2.0. Therefore, evidence of the correct processing and assembling of the FENDL/A-2.0 activation library was provided.

F. Mann informed participants that all materials present in the FENDL/D-2.0 decay library were processed into MCNP and REAC compatible formats. For some isotopes with an extensive number of photon transitions, the minor photon lines were grouped into a 21 group structure. The files are available from NDS-IAEA.

A. Igant'yuk discussed consistency of FENDL/A-2.0 and FENDL/D-2.0 libraries and their future developments. He noticed that decay half-lives essentially agree with the recent Nuclear Wallet Cards, presented different cross section systematics developed at Obninsk, and stressed the need for the inclusion of uncertainties into the file.

M. Herman presented some of the results of the recent LANL update of the ECNAF Neutron Activation Library, stressing the importance of a correct modeling for the isomeric cross section predictions.

J. Csikai presented the results of the extensive international cooperation to provide experimental validation of the FENDL/A-2.0 library. Activation cross sections for different reactions were measured for neutron incident energies around 3 and 14 MeV, between 8 and 12 MeV, and for Be(d,n), Pu-Be, as well as for Am-Be neutrons. In addition, neutron leakage spectra from slabs of different materials were measured using Be(d,n), D₂ gas cell, and Pu-Be neutrons.

A. Filatenkov presented the results of the systematic measurements of activation cross sections on 70 isotopes in the energy range from 13.4 to 14.9 MeV performed at Khlopin Radium Institute (St. Petersburg, Russia).

E. Cheng discussed the potential impact of the FENDL/A-2.0 library on low-activation fusion materials. FENDL/A-2.0 results show general reduction in the induced long-lived activity. The SiC has been proved to be a very low-activity fusion material. E. Cheng stressed that the validation of the library is essential to minimize the risks.

Application of the FENDL/A-2.0 library to the decay heat calculation for the ITER divertor was presented by J.-Ch. Sublet.

J. Sanz discussed the effects of using recent evaluations FENDL/A-2.0 and EAF-4.1 on predictions of the long-term activation of the important IFE materials. He pointed out that large differences were observed between some results obtained using new data bases and a former one (EAF-3.1). Uncertainty analysis showed that some cross sections need further improvement for the assessment of the long-lived activity hazard.

SESSION 4. "Status of the Incident Charged-Particle (FENDL/C-2.0) and Dosimetry (FENDL/DS-2.0) Libraries"

H. Wienke showed the results of the analysis of consistency between pointwise FENDL/DS-2.0 and 640 multigroup IRDF-90 libraries.

D.W. Muir presented the improved Los Alamos/U. of Vienna evaluation for T(d,n) reaction, which has been submitted to NDS-IAEA by G. Hale and is included in the FENDL/C-2.0 library.

SESSION 5. "Post FENDL-2.0 activity for maintenance and improvement of FENDL-2"

E.T. Cheng described the design of the proposed Near-term Volumetric Neutron Source (ST-VNS) based on the spherical tokamak configuration. ST-VNS appears to be an attractive possibility for nuclear technology testing, with highly favorable design and performance parameters. Cheng noted that FENDL libraries are being used to assess the feasibility of the ST-VNS and stressed that nuclear data validation process is very important for the project.

Y. Oyama discussed the high energy nuclear data needs for the International Fusion Material Test Facility (IFMIF) based on two 40-MeV deuteron accelerators with 125-mA current and Li jet flow target. As neutron energies will extend up to 55 MeV, the nuclear data up to this energy are needed. Currently, the JENDL High Energy File is being prepared at JAERI to cover most urgent IFMIF needs. In the Phase I, the library containing 57 isotopes (21 elements) up to a neutron energy of 50 MeV will be created. Its release is foreseen in 1997.

D. Markovskij presented a proposal for the comprehensive benchmark experiments on Vanadium spheres, which was recommended by the Consultants' Meeting at Karlsruhe in 1995. This material is of particular interest as it is supposed to be a constituent of the structure alloys used in the fusion devices, due to its low long-lived activation. However, the quality of the Vanadium data can not actually be verified due to the scarcity of integral measurements. D. Markovskij proposal was unanimously supported by FENDL meeting participants. Y. Ikeda noted that last year a circular slab test experiment on vanadium was performed at Japan.

In the discussion regarding future activities, the problem of consistency between the general purpose and the activation sublibraries of FENDL-2.0 was addressed. It was realized that requirement of the high quality of the activation data imposes some degree of inconsistency. D.C. Larson proposed to substitute certain reaction cross sections in the general purpose library FENDL/E with the high precision results from FENDL/A-2.0 in the future release of the library. D.W. Muir suggested a systematic intercomparison of FENDL/A-2.0 and FENDL/E-2.0. He also mentioned that one or two consultants' meetings, with limited number of participants, are foreseen to maintain FENDL-2 library and eventually decide on its updates. The FENDL/A meeting should be held in spring 1998, while the FENDL/E consultants' meeting was provisionally scheduled for early 1999. It was also decided that once FENDL-2.0 is fully available the FENDL-1 library will be removed from the on-line retrieval system and only a back-up copy will be kept at NDS-IAEA.

A "User Contact Committee" was formed in order to get in touch with the FENDL-2 users all over the world and collect their feedback for further library development and updates.

Following participants agreed to monitor the use of FENDL-2 over the indicated geographical regions:

- U. Fisher Europe
- Y. Ikeda Japan
- D. Markowskij Russia
- M. Sawan USA
- J. White USA.

The members of the "User Contact Committee" will report their observations to NDS-IAEA at the end of 1998.

After formal presentation of the papers three Working Groups (WGs) were formed:

- WG I: Approval of General Purpose (FENDL/E-2.0), Charged-Particle (FENDL/C-2.0) and Dosimetry (FENDL/DS-2.0) Libraries. Chairman: U. Fischer, Scientific Secretary: Y. Oyama
- WG II: Approval of Activation (FENDL/A-2.0) and Decay (FENDL/D-2.0) Data Libraries. Chairman: F. Mann, Scientific Secretary: R.A. Forrest
- WG III: Recommendations for post-FENDL-2.0 AGM activity. Chairman: E. Cheng, Scientific Secretary: S. Ganesan

It was decided that WG III would be held during the plenary session, as being of interest to all participants of the meeting.

The summary reports of the Working Groups are presented in Attachment 3.

The meeting authorized the release of the FENDL-2.0 library, with the exception of the general purpose file FENDL/E-2.0 and its processed form. Some minor deficiencies discovered in the FENDL/E-2.0 evaluations should be corrected by the authors before September 1, 1997. Then all entries should be reprocessed with the NJOY version 94.61 or higher, and the results should be submitted to NDS by October 1, 1997. Quality assurance checks will be performed by John White by November 30, 1997. The FENDL/E-2.0 pointwise, multigroup, and MC libraries should be released by the end of 1997.

Attachment 1

**IAEA Advisory Group Meeting on
EXTENSION AND IMPROVEMENT OF THE FENDL LIBRARY FOR FUSION
APPLICATIONS (FENDL-2)**

March 3-7, 1997
IAEA Headquarters, Vienna
Meeting Room VI, C-07

AGENDA

(Version 3 March 1997, 2:00 p.m.)

Monday, March 3

09:30 Opening of the meeting

- Welcome address (D.W. Muir)
- History of FENDL project (J.J. Schmidt)
- Election of Chairman
- Discussion of agenda and adoption
- Administrative announcements

10:00 Session 1: Neutronics analysis of ITER. Priorities for ITER and role of FENDL.

Discussion leader: E. Cheng

- (1) H. Iida, "Recent Activity of ITER Garching JWS Nuclear Analysis Group"
- (2) E. Cheng, "Application of FENDL to ITER Activation Analysis"
- (3) M. Sawan, "Application of FENDL to 3D Neutronics"

**11:00 Session 2: General purpose library. Basic evaluations for FENDL/E-2.
Processed libraries and Benchmark calculations**

**(i) Review of recommendations of FENDL-2 data-testing and evaluation-selection meeting in
Karlsruhe in June 1996**

- Organization of the meeting (A.B. Pashchenko)
- Recommendations on selection and/or on modifications of evaluations (each the Karlsruhe reviewer makes a 5-10 minute presentation on the recommendations for those materials for which he was responsible)

Discussion leaders: H.K. Vonach/A.I. Blokhin

- (1) H.K. Vonach, "Recommendations for ^{28,29,30}Si, Oxygen, Carbon, Nitrogen"
- (2) S. Chiba, "Recommendations for Deuterium and ⁵⁶Fe"
- (3) C.L. Dunford, "Summary of Review of Tungsten, Niobium, Molybdenum, Tin, and Gallium Evaluations for FENDL-2"
- (4) A.I. Blokhin, "Recommendations for Beryllium, Zirconium, Vanadium, Aluminum, Gadolinium"

Discussion

11:50 Coffee break

12:00 **Session 2:** General purpose library: Basic evaluations for FENDL/E-2.
Processed libraries and Benchmark calculations (contd.)

- (i) Review of recommendations of FENDL-2 data-testing and evaluation-selection meeting in Karlsruhe in June 1996 (contd.)
 - The benchmark testing results reported at the Karlsruhe meeting (brief reviews and main conclusions and recommendations)

Discussion leaders: U. Fischer/Y. Oyama

- (1) EU-results
 - U. Fischer, Y. Wu: "FZK benchmark results for Fe, Be, Al, Si and Mo FENDL-2 candidate evaluations"

12:30 Lunch break

14:00 **Session 2:** General purpose library. Basic evaluations for FENDL/E-2.
Processed libraries and Benchmark calculations (contd.)

- (i) Review of recommendations of FENDL-2 data-testing and evaluation-selection meeting in Karlsruhe in June 1996 (contd.)
- (2) JEARI-results
 - Y. Oyama, "Integral Test for FENDL-2 Candidates"

Discussion

- (ii) Review of actions resulted from the Karlsruhe meeting

Discussion leaders: C.L. Dunford/S. Chiba

- (1) Resolving of discovered problems for deuterium and tin evaluations from the BROND library (A. Blokhin)
- (2) Resolving of discovered problems and modification of selected Aluminium and ^{56}Fe evaluations from the EFF-3 project (G. Reffo/H. Vonach)
 - F. Fabbri, M. Herman, S. Masetti, R. Orsi, G. Reffo, A. Trkov, "The Bologna-97 Fusion File for ^{27}Al "
- (3) Selected evaluations for Silicon isotopes from the ENDF/B-VI project (D. Larson/J. White)

16:00 Coffee break

Session 2: General purpose library. Basic evaluations for FENDL/E-2.
Processed libraries and Benchmark calculations (contd.)

- (ii) Review of actions resulted from the Karlsruhe meeting (contd.)

16:15 (4) Resolving of discovered problems and modification of selected evaluations from the JENDL-FF project (S. Chiba)

Discussion

17:30 Reception hosted by the Nuclear Data Section, NDS Library, Room A-2340

Tuesday, March 4

9:00 **Session 2:** General purpose library. Basic evaluations for FENDL/E-2.
Processed libraries and Benchmark calculations (contd.)

(iii) New results of benchmark testing of FENDL-2 materials and Interfacing to ITER Design

Discussion leaders: U. Fischer/Y. Oyama/M. Sawan

- S. Ganesan and U. von Möllendorff, "The current status of IAEA compilation of fusion benchmarks for nuclear data validation studies"

(1) EU-results

- F. Fabbri, M. Herman, S. Masetti, R. Orsi, G. Reffo, A. Trkov, "Verification Report on the Bologna-97 Evaluated Nuclear Data File for ^{27}Al "

- U. Fischer, Y. Wu, "Integral data test for the revised EFF-3 ^{56}Fe data"

(2) JEARI-results

- Y. Oyama, "Integral Test for Revised Files of FENDL-2 Candidates"

10:45 Coffee break

Session 2: General purpose library. Basic evaluations for FENDL/E-2.
Processed libraries and Benchmark calculations (contd.)

(iii) New results of benchmark testing of FENDL-2 materials and Interfacing to ITER Design

(3) Russian-results

- D.V. Markovskij, "Total neutron leakage multiplication experiments and analysis on a combined beryllium sphere with a 14-MeV source"

- A.I. Blokhin, "Benchmarking of BROND deuterium file using neutron leakage spectra of spherical heavy water assemblies"

(4) US-results

- J. White, "Quality Assurance (QA) checks of FENDL-1.x and Multigroup Data Using the AMPX-77 System"

- M. Sawan, "Calculational Benchmark results based on the new multi-group processed libraries and impact on design relevant parameters for the ITER"

Discussion

12:30 Lunch break

14:00 **Session 3:** Activation data. Basic Evaluations for FENDL/A-2 and FENDL/D-2 libraries.
Processed data and Benchmark validation. Interfacing to ITER Design.

Discussion leaders: F. Mann/J. Ikeda/J. Kopecky

(1) Y. Ikeda, "Review of recommendations of FENDL/A-2 data-selection at the meeting in Del Mar in December 1995. Results of actions"

(2) J. Kopecky and J.-Ch. Sublet, "Assembling of FENDL/A-2 in Culham"

(3) J.-Ch. Sublet and J. Kopecky, "The FENDL/A-2.0 libraries - Validation of FENDL/A-2.0"

(4) Y. Ikeda, "Preliminary Results of FENDL/A-2 Testing "

(5) J.-Ch. Sublet, J. Kopecky and A. Simpson, "The FENDL/A-2.0 libraries - Processing of FENDL/A-2.0"

- (6) F. Mann, "Processing of FENDL/A-2 and Status of Working libraries"
- (7) R. Forrest, "FENDL/D-2 and testing of FENDL/A-2"
- (8) A. Ignatyuk, "Consistency of FENDL/A-2 and FENDL/D-2 and a future development of the libraries"
- (9) M. Herman, "LANL update of the ECNAF Neutron Activation Library "

16:00 Coffee break

- 16:15 (10) New measurement results for validation of FENDL/A-2 selected evaluations
- J. Csikai, "Some new experimental results for validation of FENDL/A-2.0 evaluations"
 - A. Filatenkov, "Results of Activation Cross Sections Measurement carried out at KRI in comparison with some evaluations selected for FENDL/A-2.0"

Wednesday, March 5

09:00 **Session 3:** Activation data. Basic Evaluations for FENDL/A-2 and FENDL/D-2 libraries. Processed data and Benchmark validation. Interfacing to ITER Design (contd.)

- (11) Activation data and interfacing to ITER Design
- E. Cheng, "Potential Impact on Low Activation Fusion Materials using FENDL libraries"
 - J.-Ch. Sublet, "The FENDL/A-2.0 Libraries - ITER Divertor Results"
 - J. Sanz, "Long-term Activation of Elements Important in IFE Materials: Effect of Recent Cross Sections Developments and Uncertainty Analysis"

Discussion

10:30 Coffee break

- 10:45 (12) Discussion on future low level maintenance and improvement of FENDL-2 activation data libraries

11:45 **Session 4:** Status of the Incident Charged-Particle (FENDL/C-2) and Dosimetry (FENDL/DS-2) Libraries.

Discussion leader: S. Ganesan

- (1) H. Wienke, "About consistency of pointwise FENDL/DS and 640 multigroup IRDF-90 libraries"
- (2) D.W. Muir, G. Hale, "The improved Los Alamos/U. of Vienna evaluation for T(d,n) reaction for FENDL/C-2"

Discussion

12:30 Lunch break

14:00 **Session 5:** Post FENDL activity for maintenance and improvement of FENDL-2.

Discussion leader: E.T. Cheng

Proposed topics:

- (1) Low-level nuclear data development for near-term devices
 - (1) E. Cheng, "A Near-term Plasma Based Volumetric Neutron Source"
 - (2) Y. Oyama, "High Energy Nuclear Data Needs for Fusion Materials Test Facility (IFMIF)"

- (ii) International cooperation on evaluation and data testing
 - (1) D. Markovskij, "On ISTC Proposal for Vanadium Data Benchmarking "
- (iii) Interface between data users and data developers
- (iv) others

16:00 Coffee break

16:15 **Session 6:** Organization of the Working Groups

(1) Formation of Working Groups, Election of Chairmen and Scientific Secretaries

Proposed Working Groups:

- (1) WG I: for approval of General Purpose (FENDL/E-2.0), Charged-Particle (FENDL/C-2.0) and Dosimetry (FENDL/DS-2.0) libraries
 - Adoption of the final list of evaluations
 - Actions and Schedule for assembling of General Purpose Library
 - Processing of FENDL/E-2 and Assembling of Monte Carlo and Multigroup Working Libraries
- (2) WG II: for approval of Activation (FENDL/A-2.0) and Decay (FENDL/D-2.0) Data Libraries
- (3) WG III: Recommendations for post-FENDL-2 AGM activity

17:00-18:00 Meeting of Working Groups I, II, III, discussions, recommendations

Thursday, March 6, 1997

09:00 Meetings of Working Groups I, II, III, discussions, recommendations for Working Group IV (contd.)

12:30 Lunch break

14:00-15:00 Meeting of Working Groups I, II, III, discussions, recommendations for Working Group IV (contd.)

15:00-18:00 Meeting of Working Group IV, discussions, recommendations

Friday, March 7, 1997

09:00 **Session 7:** Working Group Reports and Final Consideration

- (1) Working Group Reports, Discussion and Adoption

12:30 Lunch break

13:00-15:30 **Session 7:** Working Group Reports and Final Consideration (contd.)

- (2) Conclusions and Recommendations
- (3) Closing

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**IAEA Advisory Group Meeting
on Extension and Improvement of the FENDL Library
for Fusion Applications (FENDL-2)**

IAEA Headquarters, Vienna
3-7 March 1997

Scientific Secretary: A.B. Pashchenko

LIST OF PARTICIPANTS

Date: 97/03/03

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IAEA Nuclear Data Section

**Summary Report of Working Group I on
"Approval of General Purpose (FENDL/E-2.0), Charged Particle (FENDL/C-2.0) and
Dosimetry (FENDL/C-2.0) Libraries"**

Members: A. Blokhin
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S. Ganesan
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G. Reffo
H. Vonach
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I. Adoption of Final List of Evaluations

The preliminary selection of evaluations for the FENDL/E-2 library was made at the IAEA Consultants' Meeting on "Selection of Basic Evaluations for the FENDL-2 Library", held at Karlsruhe, June 24-28, 1996. For the final adoption of the pre-selected evaluations several actions were requested to be completed by the contributing parties for the current FENDL-2 meeting. Based on the review report of the Karlsruhe CM, INDC(NDS)-356, the WG went through the list of proposed new FENDL/E-2 evaluations and discussed their status and the actions undertaken after the Karlsruhe meeting. There follows the list of proposed FENDL-2 evaluations including for each evaluation the recommendation made by the Karlsruhe meeting, the status of the requested actions, comments on specific problems and the final adoption by the WG.

^{28,29,30}Si

Recommended evaluation: ENDF/B-VI

FENDL-1: BROND-2

Requested actions: completed

Comments: none

FENDL-2: ENDF/B-VI adopted

¹⁶O

Recommended evaluation: JENDL-FF

FENDL-1: ENDF-B/VI

Requested actions: completed

Comments: α -production is contained in MT=55-79 (with LR=22) and MT=107. No MT=22 is on the file. The α -production cross-section is correctly reconstructed by NJOY-94.61 and later versions.

FENDL-2: JENDL-FF adopted

¹²C

Recommended evaluation: JENDL-FF

FENDL-1: ENDF-B-VI

Requested actions: completed

Comments: Evaluation includes contributions from ¹³C (small resonance in elastic and total cross-section). The scattering cross-section in the low energy range has been adopted from ENDF/B-VI. IAEA-NDS-175 has to be corrected (delete line ^{nat}C from ENDF/B-VI).

FENDL-2: JENDL-FF adopted

¹⁴N

Recommended evaluation: JENDL-FF

FENDL-1: BROND-2/ENDF/B-VI

Requested actions: completed

Comments: Possible update of low energy resonance region required in future file.

FENDL-2: JENDL-FF adopted

D

Recommended evaluation: BROND-2 and JENDL-FF

FENDL-1: BROND-2/ENDF/B-VI

Requested actions: completed

Comments: BROND-2 evaluation with file data from JENDL-FF.

FENDL-2: BROND-2/JENDL-FF in this combination adopted

⁵⁶Fe

Recommended evaluation: EFF-3

FENDL-1: ENDF/B-VI

Requested actions: completed

Comments: Full EFF-3 file with high resolution data. Additionally, a file with reduced number of data points will be made available to IAEA/NDS by ENEA Bologna.

FENDL-2: EFF-3 adopted

^{nat}W

Recommended evaluation: JENDL-FF

FENDL-1: ENDF/B-VI

Requested actions: completed

Comments: Isotopic evaluations replaced by elemental evaluation. Further update is required to come back to isotopic evaluations in FENDL-2 needed for special applications (isotopic tailoring). Existing isotopic evaluations do not contain γ -production data.

FENDL-2: JENDL-FF adopted

²⁷Al

Recommended evaluation: EFF-3

FENDL-1: JENDL-3.1

Requested actions: completed

Comments: INDC-NDS-175 needs to be updated. Change EFF2.4 to EFF-3.

FENDL-2: EFF-3 adopted

⁹³Nb

Recommended evaluation: JENDL-FF

FENDL-1: BROND-2

Requested actions: completed

Comments: none

FENDL-2: JENDL-FF adopted

^{nat}Mo

Recommended evaluation: JENDL-FF

FENDL-1: JENDL-3.1

Requested actions: completed

Comments: Isotopic evaluations replaced by elemental evaluation. Further update is required to come back to isotopic evaluations in FENDL-2 needed for special applications (isotopic tailoring). Existing isotopic evaluations do not contain γ -production data.

FENDL-2: JENDL-FF adopted

^{nat}Sn

Recommended evaluation: BROND-2

FENDL-1: BROND-2

Requested actions: completed

Comments:

- i) The submitted multigroup data library contained an unphysical high value of the (n,2n) scattering matrix. When the processing was repeated at IAEA/NDS this error did not show up. The WG recommends to reprocess that file at the IAEA/NDS using the current NJOY version.
- ii) Isotopic evaluations replaced by elemental evaluation. Further update is required to come back to isotopic evaluations in FENDL-2 needed for special applications (isotopic tailoring). Existing isotopic evaluations do not contain γ -production data.

FENDL-2: BROND-2 adopted

^{nat}Ga

Recommended evaluation: JENDL-3.2

FENDL-1: not included

Requested actions: none

Comments: Added upon request of E. Cheng as Ga may be used as a coolant in fusion reactors. The selected JENDL-3 evaluation does not satisfy the criteria set up for FENDL evaluations (e. g. no γ -production data) but is the only available data file.

FENDL-2: JENDL-3.2 adopted

⁹Be

Recommended evaluation: JENDL-FF

FENDL-1: ENDF/B-VI

Requested actions: none

Comments: A patch file to MCNP4A may be needed to successfully run MCNP with the ACE data file.

FENDL-2: JENDL-FF adopted

^{nat}Zr

Recommended evaluation: JENDL-FF

FENDL-1: BROND-2

Requested actions: completed

Comments: Isotopic evaluations replaced by elemental evaluation. Further update is required to come back to isotopic evaluations in FENDL-2 needed for special applications (isotopic tailoring). Existing isotopic evaluations do not contain γ -production data.

FENDL-2: JENDL-FF adopted

⁵¹V

Recommended evaluation: JENDL-FF

FENDL-1: ENDF/B-VI

Requested actions: none

Comments: New integral experiments available for V. Data tests confirm the selected JENDL-FF.

FENDL-2: JENDL-FF adopted

Gd

Comments: Excluded from the list of proposed evaluations. There seems to be no obvious need for Gd data in fusion related applications.

II. Further required actions with regard to updates of FENDL/E-2.0

Full isotopic evaluations should be introduced for the elements Zr, Mo, W, Sn that currently contain only elemental evaluations. Evaluations for those isotopes and any other possible and/or needed updates to the current FENDL/E-2.0 library should be submitted to IAEA/NDS by October 1, 1998 in both basic and processed form for final distribution. They will be benchmarked and reviewed for inclusion in FENDL/E-2.1. A Consultants' Meeting on that should be planned for early 1999. JAERI offered to explore the possibility to update their evaluations by adding γ -production data to the currently existing isotopic evaluations of Zr, Mo, W. For Mo there is currently available a full isotopic EFF-2 evaluation that may be submitted as candidate for FENDL/E-2.1.

The draft documents IAEA-NDS-175, -176 on the FENDL/E-2.0 basic and derived (FENDL/MG-2.0 FENDL/MC-2.0) libraries need to be revised by IAEA/NDS before being released. Consistency between the files and the document contents should be ensured.

The following evaluations contained currently in the processed libraries should also be included in the basic libraries to ensure consistency: ^3He , ^4He , Ti-isotopes, ^{197}Au . The evaluations originate from ENDF/B-VI. They have not been reviewed for FENDL but are in current use for fusion applications. They are recommended for further interim use until a final decision will be made.

III. Processing of new FENDL/E-2 evaluations

WG I recommends to reprocess the selected FENDL-2 evaluations according to the attached specifications (see Attachment 5). It was agreed that

- each party processes their selected evaluations
- NJOY version 94.61 or higher must be used for the processing
- both gas production, dpa cross-section and kerma data have to be included
- multigroup and MC libraries have to be processed and submitted to IAEA/NDS by October 1, 1997 including, if possible, the associated NJOY input decks
- QA checks will be performed by John White and results submitted to the Agency by November 30, 1997

After confirming the QA results, the derived files will be distributed by IAEA/NDS as FENDL/MG-2.0 and FENDL/MC-2.0 libraries. The currently available derived data files were provided by the various parties for the purpose of benchmarking. They do not necessarily comply with the proper processing specifications.

IV. Charged Particle Data Library FENDL/C-2.0

The LANL/U. of Vienna library of charged particle cross-section data is approved for inclusion in FENDL/C-2.0. IAEA/NDS will distribute the entire charged particle data library FENDL/C-2.0 including the reactions taken over from the previous version, FENDL/C-1.0.

V. Dosimetry Cross-Section Data Library FENDL/DS-2.0

The current version of the FENDL-2 dosimetry library produced by H. Wienke of IAEA/NDS is approved as FENDL/DS-2.0. It is available for distribution at IAEA/NDS.

VI. Distribution of FENDL-2 libraries

The distribution policy for the entire set of FENDL-2 libraries will be the same as for FENDL-1 (see Del Mar meeting summary report, INDC(NDS)-352).

**Summary Report of Working Group II on
“Approval of Activation (FENDL/A-2.0) and Decay (FENDL/D-2.0) Data Libraries”**

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M. Herman
A. Ignatyuk
Y. Ikeda
A. Pashchenko
R.A. Forrest (Scientific Secretary)
F. Mann (Chairman)

The actions described in the previous Activation Working Group (IAEA AGM on completion of FENDL-1 and start of FENDL-2 (INDC(NDS)-352)) were reviewed; it was noted that all actions dealing with the production of files for FENDL/A-2.0 and FENDL/D-2.0 were completed on time. The draft documentation (IAEA-NDS-173) has been completed, all comments and corrections should be sent to Herman by 31 March 1997 to allow the final version to be completed.

The actions on data testing were reviewed:

- Comparison of FENDL-2 calculations with the JAERI/DOE experiments will be completed by Ikeda by 30 April 1997 and communicated to Herman.
- Calculation of the Sawan activation benchmark by Forrest have been reported at the present meeting.
- Muir will assist in the implementation of the library validation suite at UKAEA Culham, testing will be completed by 30 April 1997 and communicated to Herman.
- Validation plots comparing the library data to experiments and systematics have been reported at the present meeting by Sublet.
- A comparison between FENDL/D-1.0 and FENDL/D-2.0 has been reported at the present meeting by Forrest.
- A report covering the data testing will be produced by Herman by 31 May 1997.

It was noted that the following work has been reported using the FENDL/A-2.0 library:

- R.A. Forrest, 'FENDL/D-2.0 and testing FENDL/A-2.0', this meeting.
- J.-Ch. Sublet, 'Three-dimensional neutronic, activation and residual decay heat analysis for the ITER design', UKAEA FUS 340, 1996.
- E. Cheng, 'Application of FENDL to ITER Activation Analysis', this meeting.
- E. Cheng, 'Potential Impact on Low Activation Fusion Materials using FENDL Libraries', this meeting.
- E. Cheng, A.B. Pashchenko, and J. Kopecky, 'Overview on Recent Nuclear Data Development for Fusion Reactor Technology', Fusion Technology, Vol. 30, p. 1182 (1996).
- Y. Ikeda, Private communication.
- J. Sanz, 'Long-term radioactivity of elements important to IFE: effect of recent cross section developments and uncertainty analysis', DENIM-465, 1996.

Given the encouraging results of the preliminary data testing the Working Group approves the FENDL/A-2.0 and FENDL/D-2.0 libraries and encourages the IAEA NDS to make them available to as wide a range of users as possible.

The recommendation made at the previous FENDL AGM to maintain and develop the FENDL-2 activation library was endorsed. "The Working Group strongly recommends the IAEA NDS that following the completion of FENDL/A-2.0 a mechanism is found to maintain and develop the activation library. Without this the library will become obsolete and of limited use to ITER. A new Safety and Environmental file (perhaps of similar status to the IAEA safeguards library) could be a vehicle for continued maintenance of the FENDL activation library." The selection panel should remain in existence and should advise on any candidate evaluations that are put forward as replacements for existing cross section data.

The Working Group recommends that an attempt be made to produce FENDL/A-2.1 which should correct possible errors and make improvements to a small number of reactions which are of significant impact in user calculations on fusion relevant applications. The improvements may arise because of improved measurements, calculations or evaluations.

To be considered, a new evaluation should consist of:

- Pointwise data,
- Plots of new data compared to existing data and available experimental data,
- Written justification for change.

The new evaluation must be communicated to Herman (NDS) at least 1 month prior to the date of the Review meeting (see below). These evaluations will be distributed to the Selection Panel in good time to allow consideration prior to the Review Meeting.

The Working Group recommends that the IAEA organize a Consultants' meeting in October 1998 at which members of the Selection Panel will select and approve candidate evaluations.

The Working Group recommends that only FENDL/A-2.0 and FENDL/D-2.0 versions remain on the ftp region. FENDL/A-1 and FENDL/D-1 files should be archived. Users are strongly recommended to use FENDL/A-2.0 and FENDL/D-2.0 rather than FENDL/A-1 and FENDL/D-1 libraries wherever possible.

The Working Group recommends that new experimental measurements be undertaken to help in the validation of FENDL/A-2.0 and in the preparation of FENDL/A-2.1. To aid the fulfilment of this recommendation a list of reactions of the highest priority for future measurement will be prepared. Kopecky will produce the list and send to Herman at NDS by 30 April 1997. This will be distributed to Working Group members, and comments should be sent to NDS by 31 May 1997. NDS will decide on the most appropriate place to publish the reviewed request list.

It is acknowledged that, because of the choice to adopt the best data sources for the individual activation reactions on a particular target nuclide, there are many cases of inconsistency between the general purpose and activation libraries. To help to improve this consistency a small number of reactions (e.g. for W and Cu targets) should be determined by Fischer/Cheng

and generators of new FENDL/E evaluations consider if any future evaluations for these materials should use data from the activation library to replace existing data for minor reactions. More generally, any future evaluations should take note of the selections made by the FENDL/A effort for the 400 most important reactions (see INDC(NDS)-352).

In line with recommendations made at previous FENDL meetings, the Working Group recommends that there should be no activation uncertainty file for either FENDL/A-2.0 or -2.1. However the Working Group realize the long-term importance of such an uncertainty file and recommend that the Selection Panel should consider what information should be contained in such a file and in what format it is represented. The possible Consultants' Meeting should address these issues. As an example of a possible approach to an uncertainty file, the one generated at UKAEA Culham during the processing of FENDL/A-2.0 will be made available to the NDS by Forrest by 31 March 1997. As an interim measure users are encourage to make use of this file to gain experience. This file will be termed 'EAF_UN-4.1(rev)' and stored in an appropriate area by NDS.

The Working Group considered the possibility of data at energies above 20 MeV in future FENDL activation libraries. It was decided that such data should not be explicitly requested but that any candidate evaluations containing such data would not be automatically rejected. It is recommended that the NDS store any such data in case there is a need for such data in the future.

The Working Group acknowledges the outstanding contribution of A.B. Pashchenko during much of the development of both FENDL-1 and FENDL-2 libraries. Especially in the area of activation libraries, his skill and hard work have enabled the IAEA NDS to produce a unique set of libraries to benefit the scientific communities in both the developed and developing countries.

**Summary Report of Working Group III on
"Recommendations for post-FENDL-2 AGM activity"**

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The working group noted that the post-FENDL-2 activity is essential in order to consolidate the progress achieved in creating FENDL-2 for fusion applications.

The WG recommends, based on discussions and recommendations of WGs I to III the following activities:

1. The WG recommends updating of isotopic evaluations for W, Zr, Sn, and Mo. The presently available FENDL-2 evaluations are for natural elements in these cases. The WG also recommends the selection of evaluations for ^3He , ^4He , ^{197}Au and Ti isotopes for inclusion in FENDL/E-2.1. The updating and selection processes will follow all rules of FENDL (INDC(NDS)-297, 1994) for qualification including processing and integral testing.

Action on NDS: A consultants meeting by 1999 to approve these evaluations is recommended.

2. The WG recommends that activities be carried out to improve FENDL/A-2.0. This should be done by correcting possible errors and making improvements to a small number of reactions in FENDL/A-2.0.

Actions on NDS: A consultants meeting in October 1998 to produce the improved activation library FENDL/A-2.1 should be held.

3. The WG noted that there is a need to update the IAEA compilation of fusion neutronic benchmarks as many experiments were directly submitted to enable FENDL-1 data testing, to Dr. U. Fischer. There are discrepancies in Be spherical shell transmission experiments performed at Obninsk, Russia and OKTAVIAN, Osaka, Japan. There are on-going and proposed experimental programmes on vanadium spherical shell transmission experiments. The benchmark programmes of several non-ITER applications should be taken into account.

Action: A consultants meeting on updating benchmark experimental data for 14-MeV neutronics is recommended by 1999. This meeting can be possibly held in combination with that recommended in Recommendation 1.

4. The WG noted that there is a need to co-ordinate measurements and evaluations of ^{28}Si (n,n'p) reaction in relation to the use of SiC in fusion systems. It is recommended to modify the scope of an existing proposal of an appropriate CRP to include these data.
5. The WG recommends that a standing committee be established to assist the promotion of FENDL libraries to be used in fusion energy development and other activities. The following AGM participants have agreed to be members of this committee: E.T. Cheng, U. Fischer, S. Ganesan, Y. Ikeda, D. Markovskij, M. Sawan and J. White.

Neutron interaction and photon production cross sections available in FENDL/E-2.0

Neutron interaction cross sections for the isotopes and elements shown have been adopted from the following sources:

ENDF/B-VI: ^1H , ^3H , ^3He , ^4He , ^6Li , ^7Li , ^{10}B , ^{11}B , ^{19}F , $^{28-30}\text{Si}$, ^{31}P , S, Cl, K, $^{50,52-54}\text{Cr}$, ^{55}Mn , $^{54,57,58}\text{Fe}$, ^{59}Co , $^{58,60-62,64}\text{Ni}$, $^{63,65}\text{Cu}$, ^{197}Au , $^{206-208}\text{Pb}$

JENDL-3: ^{23}Na , Mg, Ca, Ti, ^{55}Mn , Ga, ^{181}Ta , ^{209}Bi

BROND-2: ^2H , ^{15}N , Sn

JENDL-FF: ^9Be , ^{12}C , ^{14}N , ^{16}O , ^{51}V , Zr, ^{93}Nb , Mo, W

EFF-3: ^{27}Al , ^{56}Fe

Photon-atomic interaction cross sections for the elements:

ENDF/B-VI: H, He, Li, Be, B, C, N, O, F, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Ga, Zr, Nb, Mo, Sn, Ba, Ta, W, Au, Pb, Bi.

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Attachment 5

Specification for processing FENDL/E-2.0 evaluations

It was agreed at the Meeting, that all FENDL/E-2.0 evaluations, including those carried over from FENDL/E-1.0, should be reprocessed using NJOY94 version 61 or later according to the following (uniform) specifications:

for producing the multigroup GENDF and MATXS files (sublibrary FENDL/MG-2.0):

- Neutron groups: 175, in Vitamin-J structure,
- Gamma groups: 42, in Vitamin-J structure,
- Vitamin-E neutron weight function (IWT=11 in NJOY),
- Gamma weight function: 1/E with roll-offs (IWT=3 in NJOY),
- Legendre order for neutron and photon scattering: P6 correction to P5, for P5 discrete coordinate transport calculations,
- Temperature: 300 Kelvin,
- Dilution factors: see Table 1,
- Reconstruction, linearization and thinning tolerances used in RECONR: 0.2%,
- Up to 7 digits of accuracy for resonance reconstruction,
- To be processed: all evaluated reactions energy balance, heating, kinematic heating, damage, gas production, MT=251 ($\bar{\mu}$), MT=252 ($\bar{\chi}$), MT=253 (γ), and MT=259 ($\overline{1/v}$);

for producing the pointwise data in ACE format (sublibrary FENDL/MC-2.0):

- Temperature: 300 Kelvin = $2.5 \cdot 10^{-2}$ eV,
- No thinning,
- Detailed photons,
- To be processed: all evaluated reactions energy balance, heating, kinematic heating, damage, gas production.

Table 1: σ_0 values in FENDL/MG-2.0 (in barns)

10^{10}

Materials: ^1H , ^2H , ^3H , ^3He , ^4He , ^6Li , ^7Li , ^9Be , ^{10}B , ^{11}B , C, ^{14}N , ^{15}N , ^{16}O , ^{19}F , ^{23}Na , Mg, ^{27}Al , $^{28-30}\text{Si}$, ^{31}P

10^{10} , 10^3 , 10^2 , 10^1 , 1

Materials: ^{51}V , Zr, Sn, $^{206-208}\text{Pb}$

10^{10} , 10^4 , 10^3 , 10^2 , 10^1

Materials: ^{93}Nb , Mo, ^{181}Ta , W, ^{209}Bi .

10^{10} , 10^5 , 10^4 , 10^3 , 10^2 , 10^1

Materials: $^{54,57-58}\text{Fe}$, ^{59}Co

10^{10} , 10^5 , 10^4 , 10^3 , 10^2 , 10^1 , 3, 1, $3 \cdot 10^{-1}$, 10^{-1}

Material: ^{56}Fe

10^{10} , 10^5 , 10^4 , 10^3 , 10^2 , 10^1 , 1

Material: ^{55}Mn

10^{10} , 10^3 , $3 \cdot 10^2$, 10^2 , $3 \cdot 10^1$, 10^1

Materials: S, Cl, K,

10^{10} , 10^4 , 10^3 , $3 \cdot 10^2$, 10^2 , $3 \cdot 10^1$, 10^1

Materials: $^{63,65}\text{Cu}$

10^{10} , 10^3 , $3 \cdot 10^2$, 10^2 , $3 \cdot 10^1$, 10^1 , 3, 1

Materials: Ca, $^{50,52-54}\text{Cr}$, $^{58,60-62,64}\text{Ni}$, ^{197}Au

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