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Overview on FENDL-1 Benchmark Validation Task

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IAEA Advisory Group Meeting on "Completion of FENDL-1 and Start of FENDL-2", Del Mar, California, USA, December 5-9, 1995

IAEA ADVISORY GROUP MEETING ON „ IMPROVED EVALUATIONS AND INTEGRAL DATA TESTING OF FENDL"
Garching, Germany, September 6 - 12, 1994

Working Group II on Experimental and Calculational Benchmarks agreed to organise a FENDL data testing task with expected contributions from many countries, including Bulgaria, China, India, France, Germany, Japan, Russia, and the United States.

Initial tests during the final processing of FENDL/E-1.0 are expected to attest the completeness of FENDL/MG-1.0 and FENDL/MC-1.0.

Results of an initial data testing phase that can be obtained by December 31, 1994, will be collected, evaluated and documented in a joint report.

This report should be made available by February 28, 1995, at the time the processed FENDL libraries are to be released for use in design calculations.

This will give some confidence in using the FENDL data for fusion applications (e. g. ITER).

Organisation of FENDL benchmark task: U. Fischer, KfK

FENDL BENCHMARK TASK: TABLE OF EVENTS

October 14, 1994:

First e-mail circular to potential benchmark participants; Request for communicating intended contributions to task organiser.

Responses from Y. Oyama (JAERI), D. Markovskiy (KIAE), P. Batistoni (ENEA), C. Ichihara (Kyoto University), H. Hunter (ORNL), M. Youssef (UCLA)

December 16, 1994:

Second e-mail circular; Communicating to all participants the announced benchmark contributions; Request for including numerical C/E data; Deadline for submission of results set to January 20, 1995.

January 1995

Contributions were submitted to KfK by:

Japan: Comprehensive report + diskette on FNS and OKTAVIAN experiments, edited by Y. Oyama, JAERI

USA: Comprehensive report on SS-316 assemblies edited by M. Youssef, UCLA

Russian Federation: Numerical results for ENDF/B-VI, BROND and JENDL-3 data on diskette, provided by V. Sinitsa, IPPE Obninsk

France: Report on Fe data by L. Benmansour, A. Santamarina, CEA

Germany: Numerical C/E data and graphs by U. Fischer et al., KfK

February 21, 1995:

Third e-mail circular; Communicating to all participants the received benchmark contributions; Ultimate deadline for submission of contributions set to February 28, 1995.

March 31, 1995:

Fourth e-mail circular; Distribution of draft summary report in electronic format. Data tables and text documents made available in various formats (WORD & WordPerfect for IBM/DOS & Mac, ASCII) on ftp-server.

April - June, 1995:

Responses for revisions/corrections to draft report obtained by Y. Oyama (JAERI), M. Youssef (UCLA). New benchmark contributions obtained by L. Petrizzi, V. Rado (ENEA Frascati), K. Seidel (TU Dresden).

October 17-19, 1995:

***FENDL benchmark meeting at FZK Karlsruhe:* „IAEA Consultants' Meeting on Benchmark Validation of FENDL-1"**

- Discussion of benchmark analyses, experiment by experiment, material by material
- New/additional benchmark contributions by ENEA, JAERI, TUD, IPPE, KIAE
- Agreement on evaluation of benchmark analyses and recommendations to data improvements in FENDL-2
- Preparation of final benchmark report

December 1995:

Presentation of to IAEA Advisory Group Meeting on FENDL, December, 5-9, 1995, Del Mar.

Type of integral experiment	Material configuration	Material	Experiment	Benchmark analysis
TOF-measurements of angular leakage spectra	Cylindrical slabs	Li_2O, Be, C, O, N, Fe, Pb	FNS/JAERI	FNS/JAERI
In-system measurements of neutron spectra & reaction rates	Cylindrical slabs	Li_2O, Be, C, Fe, Cu, W	FNS/JAERI	FNS/JAERI, Hitachi Ltd., KIAE Moscow
TOF-measurements of neutron leakage spectra	Spherical shells	Be, Be-Li, Li, Li_2O, LiF, C, CF_2, Al, Si, Ti, Cr, Mn, Co, Ni, Cu, Zr, Nb, Mo, W	Universities of Osaka & Kyoto	Universities of Osaka & Kyoto, FZK Karlsruhe, IPPE Obninsk, KIAE Moscow
TOF-measurements of gamma ray leakage spectra	Spherical shells	LiF, CF_2, Al, Si, Ti, Cr, Mn, Co, Cu, Nb, Mo, W, Pb	Universities of Osaka & Kyoto	FNS/JAERI
Bulk shield experiment	Cylindrical block	SS-316	FNS/JAERI	FNS/JAERI, UCLA
Bulk shield and streaming experiment	Rectangular block, with and without duct	SS-316	ORNL	RSIC/ORNL
Bulk shield and nuclear heating experiment	Rectangular block	SS-316, SS-316 and perspex	ENEA Frascati	ENEA Frascati
TOF-measurements of neutron leakage spectra	Spherical shells	Be, Al, Fe, Pb-17Li	IPPE Obninsk	IPPE Obninsk, KIAE Moscow, FZK Karlsruhe
TOF-measurements of neutron leakage spectra	Spherical shells	Be	FZK Karlsruhe	FZK Karlsruhe, Hitachi Ltd.
Neutron and photon leakage spectra measurements	Rectangular slab, with and without straight gap	Fe	TUD Dresden	TUD Dresden, FZK Karlsruhe
Multiplication experiment	Spherical shells	Be	KIAE Moscow	KIAE Moscow
Mock-up shield experiment	Rectangular slab, with and without straight gap	Fe	MePhI-KIAE Moscow	KIAE Moscow

Table I: Integral experiments and analyses contributed to the FENDL-1 benchmark validation task

Integral Data Tests of the FENDL-1 Nuclear Data Library for Fusion Applications

Summary Report of the International Working Group on „Experimental and Calculational Benchmarks on Fusion Neutronics for FENDL Validation"

Edited by U. Fischer
Forschungszentrum Karlsruhe

Contributors:

Y. Oyama, F. Maekawa, C. Konno, M. Wada - JAERI, C. Ichihara - Kyoto University, A. Takahashi - Osaka University, K. Ueki - Ship Research Institute, K. Kosako - Sumitomo Atomic Industries, K. Hayashi - Hitachi Engineering Company

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U. Fischer, F. Kappler, E. Stein, H. Tsige-Tamirat, E. Wiegner - FZK Karlsruhe, P. Batistoni, L. Petrizzi, V. Rado - ENEA Frascati, L. Benmansour, A. Santamarina - CEA Cadarache, K. Seidel - TUD Dresden

A. Blokhin, S. P. Simakov, V. Sinitsa - IPPE Obninsk, D. Markovskij - RRC-KI Moscow

October 1995

FENDL BENCHMARK TASK : MAIN RESULTS

Comprehensive data test analyses have been performed for the FENDL-1 data file in an international effort. Benchmark calculations have been performed with the working libraries FENDL/MG-1.0 for discrete ordinates calculations and FENDL/MC-1.0 for Monte Carlo calculations with the MCNP-code. A variety of available integral fusion benchmark experiments has been analysed for that purpose. The obtained results allow to qualify the FENDL-1 working libraries for fusion applications.

(1) Multiplying and breeding materials

- The neutron multiplication power can be well predicted for both neutron multiplier candidates, **beryllium** and **lead.** In addition, the neutron spectra in lead assemblies can be calculated very satisfactorily. This does not hold for beryllium: there is a need for a revision of the secondary energy-angle distributions and, possibly, the (n,2n) cross-section which should be accomplished in FENDL-2.

- The data quality of the breeding material **lithium** look rather satisfactory. The measured angular neutron spectra for **Li_2O.** e. g. can be well reproduced.

- For the breeding material constituent **aluminium, silicon and zirconium** there is a clear need for an improvement of the neutron emission cross-section data: the measured leakage spectra cannot be reproduced satisfactorily with FENDL-1 data. In addition, obvious deficiencies are detected in the secondary energy distributions of the (n,xn)-reactions. Thus there is a strong need for an updating of the **Al, Si** and **Zr** evaluations for FENDL-2.

(2) Structural and/or shielding materials

- For the most important structural material **iron** there is an underestimation of the measured neutron spectra below ≅ 1.5 MeV which especially affects the calculations of the shielding efficiency. As shown by Hogenbirk for the TUD iron slab experiment, this discrepancy may be resolved with the inclusion of the fine resonance structure in the total and partial iron cross-section data above 0.8 MeV, as it is accounted for e. g. in the current EFF-3 iron evaluation. This task can be accomplished within the FENDL-2 development.

- No evidence for urgent data improvements can be deduced from the available benchmark results for **manganese,** whereas the results for **copper** suggest a revision of the emission cross-section data both in the high (5-10 MeV) and low energy (E< 0.1 MeV) range. This holds also for **chromium** below 1 MeV. Again this should be accounted for in FENDL-2. For **nickel** the is a need for better experimental integral data.

- The results from the available benchmark experiments for the shielding material **tungsten** indicate the need for a data revision for FENDL-2.

- With regard to required data revisions for FENDL-2, there is one unique trend that can be deduced from the analysis of the **SS-316** bulk shield experiments: there is an increasing trend of underestimating the high energy tail (E > 10 MeV) of the neutron spectrum at deep locations both by Monte Carlo calculations with FENDL/MC-1.0 data and discrete ordinates calculations with FENDL/MG-1.0 multigroup data. This may lead to underestimations in calculating radiation damages to the superconducting coils in fusion devices like ITER. In addition, there are indications that low energy spectra (E<0.1 MeV) are likewise underestimated in the **SS-316** experiments. For the fast energy range (1 to 10 MeV) there is a trend of underestimating the neutron spectrum at deep locations. In any case sensitivity and uncertainty analyses are required to assign observed discrepancies to individual materials and their cross-section data.

- No integral experimental data are available for the low-activation structural material **vanadium.** In view of its increasing importance for future fusion reactors with enhanced safety features, integral benchmark experiments are required to check the nuclear performance of vanadium for such applications.

(3) Other materials

- For most of these materials the results from the available benchmark experiments indicate the need for further improvements of their cross-section data for FENDL-2. Especially this holds for **titanium, cobalt, fluorine, oxygen, nitrogen,** and **graphite.** For **niobium** and **molybdenum** the deviations between measured and calculated neutron spectra are less serious.

(4) Gamma-ray spectra and heating rates

- There is an overall good agreement between the OKTAVIAN experiments and the FENDL-1 calculations for the materials **LiF, CF_2, Al, Ti, Cu, Mo, W, and Pb** for the gamma heating rates. The agreement for **Si, Cr, Mn, Co and Nb** is not satisfactory. This holds likewise for the gamma-ray spectra. In addition, a serious underestimation of the high energy gamma spectrum (E>5 MeV) is observed for lead.
- The measured gamma heating rates for **iron** and **copper** can be reproduced satisfactorily. This is also holds for **SS-316,** although there is a trend for underestimating the measured gamma heating rates in the analysed steel assemblies.

General conclusion on the data quality

- With regard to the data quality, it can be stated that fusion nuclear data have reached a high confidence level with the available FENDL-1 data library.

- With few exceptions this holds for the materials of highest importance for fusion reactor applications.

- As a result of the performed benchmark analyses, some existing deficiencies and discrepancies have been identified that should be removed in the forthcoming FENDL-2 data file.

(5) Monte Carlo vs. Discrete ordinates calculations

- The performed benchmark analyses allow a direct comparison of the quality of the two different computational approaches and working data libraries used:

  ⇒The Monte Carlo technique with FENDL/MC-1.0 data (MCNP-code) and the discrete ordinates procedure with FENDL/MG-1.0 multigroup data (e. g. ONEDANT/TWODANT -code).

- In general, the two approaches give the same results, as has been shown both for analyses of spherical shell and slab experiments. There are, however, two exceptions to this rule encountered in the course of the benchmark analyses:

  ⇒Transport problems involving neutron thermalisation cannot be properly accounted for in discrete ordinates calculations with multigroup data in the VITAMIN-J group structure. This is due to missing upsacttering capabilities while splitting the thermal energy range into two groups.

  ⇒Deep penetration problems can be better described by Monte Carlo calculations with continuously represented cross-section data than by discrete ordinates calculations with multigroup data. Problems arise by the applied group structure, the spatially varying weighting function, the resonance shielding and deficiencies introduced by the discrete ordinate technique itself in describing the strongly forward peaked neutron transport in a deep penetration problem.

Conclusion:

The Monte Carlo technique with continuously represented cross-section data allows to handle the encountered fusion neutronics problems with confidence while discrete ordinates calculations do not. Consequently, care has to be taken in applying the FENDL/MG-1.0 library to fusion neutronics problems where it may not be appropriate.

Neutron multiplication and breeding materials

Element	Data quality	Comments
Be	further improvements needed	SED/SAD to be improved; neutron multiplication well predicted; discrepant integral experiments need to be clarified
Pb	satisfactory	
Li	satisfactory	
Al, Si, Zr	further improvements needed	SED to be improved; γ-production to be improved for Si

Structural and/or shielding materials

Element	Data quality	Comments
Fe	further improvements needed	fluctuation factors to be included in partial neutron cross-sections; need for including anisotropic γ-emission data indicated
Cr	further improvements needed	need for additional integral experiments; γ-production to be improved
Cu	further improvements needed	SED in 5-10 MeV range and below 1 MeV to be improved
Mn	satisfactory	need for additional integral experiments
Ni	unclear	urgent need for new integral experiment
W	further improvements needed	improvements for SED and γ-production needed
SS-316	further improvements needed	disagreement for high and intermediate energy range of neutron spectrum
V	unclear	urgent need for integral experiment; currently no data available

Other materials

Element	Data quality	Comments
C	further improvements needed	SED needs improvement
N	further improvements needed	SED/SAD needs improvement
O	further improvements needed	SED/SAD needs improvement
F	further improvements needed	large discrepancies observed in integral data tests; SED possibly to be improved although differential data in agreement with experimental data
Ti	further improvements needed	SED needs improvement
Co	further improvements needed	SED needs improvement; need for more integral experiments
Nb	further improvements needed	SED needs improvement; γ-production to be improved
Mo	satisfactory	minor discrepancy in neutron spectrum