



International Atomic Energy Agency

INDC(NDS)-351  
Distr. G+FE**INDC****INTERNATIONAL NUCLEAR DATA COMMITTEE**

**IAEA Consultants' Meeting on  
BENCHMARK VALIDATION OF FENDL-1  
Karlsruhe, Germany  
17 to 19 October 1995**

**hosted by the  
Forschungszentrum Karlsruhe, Germany**

**SUMMARY REPORT**

Prepared by

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January 1996

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Printed by the IAEA in Austria  
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**Abstract**

The present report contains the Summary of the IAEA Consultants' Meeting on "Benchmark Validation of FENDL-1", held at Karlsruhe, Germany, from 17 to 19 October 1995. This meeting was organized by the IAEA Nuclear Data Section (NDS) with the co-operation and assistance of local organizers of the Forschungszentrum Karlsruhe, Germany.

Summarized are the conclusions and the main results of extensive benchmarking of FENDL-1 by comparing experimental data from numerous number of fusion integral experiments, to analytical predictions based on discrete ordinates as well as Monte Carlo calculations.

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## **1. Introduction**

The IAEA Nuclear Data Section, in co-operation with several national nuclear data centres and research groups, has created the first version of an internationally available Fusion Evaluated Nuclear Data Library (FENDL-1). The FENDL library has been selected to serve as a comprehensive source of processed and tested nuclear data tailored to the requirements of the Engineering Design Activity (EDA) of the ITER project and other fusion-related development projects.

The benchmark validation of the FENDL-1 as required by the customer, i.e. the ITER team, is considered to be a task of high priority in the coming months. The well tested and validated nuclear data libraries in processed form of the FENDL-2 are expected to be ready by end of 1996 for use by the ITER team in the final phase of ITER EDA after extensive benchmarking and integral validation studies in the 1995-1996 period.

The IAEA Advisory Group Meeting on Improved Evaluations and Integral Data Testing for FENDL held at Garching, Germany, 12-16 September 1994, recommended to organize the international FENDL benchmark task with the objective of integral data testing that could provide confidence in using the FENDL-1 working libraries for fusion applications at the time they are released.

Several laboratories and institutions from the European Union, Japan, the Russian Federation and the United States have contributed to this benchmark task by analyzing a variety of existing integral 14 MeV neutron benchmark experiments. The majority of them are included in the compilation of fusion neutronics benchmark experiments which is freely available from the IAEA Nuclear Data Section online. The contributions were submitted to the task organizer U. Fischer, Forschungszentrum Karlsruhe, for analysis and inclusion in the joint report on the international FENDL-1 benchmark validation.

## **2. Objectives of the Meeting**

Following recommendations from the Garching Meeting, U. Fischer prepared and distributed a draft report on FENDL benchmarking at the end of March this year. Meanwhile, he received comments from several contributors as well as additional benchmark results to be included in the report.

The benchmark report relies on many experimental data that have been provided by various laboratories for a series of materials. Many benchmark analyses have been contributed using different computational tools and data. The main objective of the benchmark task, however, was to validate the FENDL-1 data file for fusion applications through data tests against available benchmark experiments and give guidance to the development of FENDL-2 data file. It was still a huge task to finalize the FENDL data improvements. For this reason U. Fischer proposed to organize a meeting with all benchmark contributors included. The idea was to go through the benchmark analyses, experiment by experiment, material by material. In this way a discussion and evaluation can take place right at the meeting, thereby facilitating

enormously the preparation of the final report that has to be commonly agreed and presented at the IAEA Advisory Group Meeting on FENDL, 5-9 December 1995 in Del Mar, California.

The purpose of this meeting was to discuss in detail the contributed benchmark analyses and to prepare the final report. The meeting agenda is given as *Attachment 1*.

### **3. Organization of the Meeting**

The meeting was organized by the IAEA Nuclear Data Section with the co-operation and assistance of the local organizers from the Forschungszentrum Karlsruhe, FZK, and held in Karlsruhe from 17 to 19 October 1995.

The meeting was attended by sixteen FENDL benchmark task participants and contributors from 5 member countries. The complete list of participants and their affiliations are given as *Attachment 2*.

### **4. Meeting Proceedings and Results**

The meeting was opened by U. Fischer, the FENDL Benchmark Task Organizer. After the welcome speech by A.B. Pashchenko on behalf of the IAEA, U. Fischer was elected as chairman of the meeting.

The full 3 days of the meeting were devoted to FENDL-1 benchmark analysis. After the general overview on FENDL benchmark validation task presented by U. Fischer and information concerning the IAEA collection of Fusion Neutronics Benchmark Experiments reported by U. von Möllendorff, the meeting attendees presented and discussed step by step the results of the benchmark analysis.

The results of the following contributors from Japan, the USA, the European Union and the Russian Federation have been considered at the meeting:

Y. Oyama, C. Konno, F. Maekawa, 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 Ltd.

M. Youssef - UCLA, H. Hunter, C. Slater - ORNL.

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

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

On the first day, Tuesday 17 October 1995, the meeting participants went through the analysis, experiment by experiment, for the breeding and multiplying materials (Beryllium, Lead, Lithium) and breeding material constitutions (Aluminum, Silicon, Zirconium). The major item of the second day was analysis for the structural and/or shielding materials (Iron, Chromium, Copper, Manganese, Tungsten, Steel SS-316). The first part of the last day, Thursday, 19 October 1995, was devoted to analysis of benchmarks for other materials of lower priority (Graphite, Oxygen, Cobalt, Niobium, Titanium) and discussion on gamma-ray spectra and heating rates analysis. In addition, supplementary contributions to fusion benchmark experiments and analysis have been reported by S. Simakov (new results of the IPPE experiment on spherical iron shells) and K. Hayashi (benchmark analysis with JENDL-FF data).

The results for the three categories of materials are summarized in the draft of the summary report of the International Working Group on "Experimental and Calculational Benchmarks on Fusion Neutronics for FENDL Validation" prepared by U. Fischer [1]. The procedure for the preparation of the final report was agreed as follows. U. Fischer will integrate all submitted proposals and prepare a hardcopy draft of the report including tables and figures provided by participants. This report will be presented at the Del Mar Advisory Group Meeting on "Completion of FENDL-1 and Start of FENDL-2", 5-9 December 1995. The report will be distributed as hardcopy on that occasion. Afterwards it will be issued as an INDC(NDS)-report.

## 5. Conclusions

FENDL-1 data went through extensive benchmarking by comparing experimental data from numerous number of fusion integral experiments to analytical predictions based on discrete ordinates as well as Monte Carlo calculations. Neutrons and gamma leakage spectra, in-system spectra, reaction rates of different threshold energies and gamma-ray heating were among the experimental items used in benchmarking multigroup data (FENDL/MG-1.0) and continuous data (FENDL/MC-1.0).

The general conclusion can be stated that the data quality with the available FENDL data has reached a high confidence level for fusion applications. With few exceptions this holds especially for the materials being most important for fusion reactor applications. As a result of the performed benchmark analyses, some existing deficiencies and discrepancies have been identified that can be removed in the forthcoming FENDL-2 data file.

The selected experiments were mostly on assemblies made of single material. These single material set-ups (e.g. iron sphere, beryllium cylindrical slab, etc.) are most useful in judging the quality of FENDL data of the particular material under consideration and thus guidance can be made to data evaluators on any existing deficiencies and discrepancies that may be removed in the forthcoming FENDL-2 data file. However, some of the selected benchmarks were made out of composite materials. Examples are the bulk shielding experiments on SS316 devoted to the validation of ITER shielding blanket. While the results of the single material benchmarks give guidance to improving the existing data bases, the

results from benchmarking composite materials can also give guidance to blanket/shield designers of fusion reactors (e.g. ITER) to reasonable estimates of design margins/safety factors to be implemented in the design process. These design margins are based on the observed discrepancies between calculations and measurements. Recent effort has been made to develop methodologies to estimate these design margins using statistical models and propagation of errors [2,3]. The economical impact of using these safety factors/design margins in design process rather than improving first a particular evaluation through new cross-section measurements should be studied through cost/benefit analysis. This will require an extensive cross-section sensitivity/uncertainty analyses along with reasonable estimates of new experiments to improve data and the economical penalty involved when safety factors are used directly by designers [4].

## **6. Acknowledgments**

The participants hope very much that the recommendations of this meeting will be acted upon by the Agency for the mutual benefit of its Member States.

The participants wish to thank the Agency for focussing the much needed attention on the benchmark validation of FENDL-1 discussed here and wish to thank Dr. U. Fischer of Forschungszentrum Karlsruhe for the efficient organization of the meeting and for the warm hospitality extended to the participants.

## **References**

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- [3] M.Z. Youssef, A. Kumar, M.A. Abdou, Y. Oyama, C. Konno, F. Maekawa, Y. Ikeda, K. Kosako, M. Nakagawa, T. Mori, and H. Maekawa, "Fusion Integral Experiments and Analysis and the Determination of Design Safety Factors, Part II: Application to the Prediction Uncertainty of Tritium Production Rate from the USDOE/JAERI Collaborative Program on Fusion Blanket Neutronics", Fusion Technology, 28, No., 2 (1995) 388-432.
- [4] M.Z. Youssef and Y. Oyama, "Required Design Margins in Fusion Reactors to Compensate for Nuclear Data Uncertainties - A Global Approach to Define Safety Factors Based on Integral Experiments", Proc. International Conference on Nuclear Data for Science and Technology Gatlinburg, Tennessee, May 9-13, 1994, Vol. 2, p. 874.



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**Scientific Secretary: Anatoly B. PASHCHENKO**

**A G E N D A**

**Tuesday, October 17**

- 08:00        *Pick-up at hotels*
- 08:30        Opening of the meeting  
             Welcome & administrative announcements (**U. Fischer**)  
             Welcome address by IAEA representative (**A.B. Pashchenko**)  
             Discussion of agenda & adoption
- 08:45        **The FENDL benchmark validation task** (U. Fischer)  
             - Overview -
- 09:30        **The Collection of Fusion Benchmark Experiments** (U. v. Moellendorff)  
             - Overview and status -
- 10:30        *Coffee break*
- 10:45        **Discussion on FENDL-1 benchmark analyses**  
             *Part I: Breeding and multiplying materials*
- (1) **Beryllium**  
             Spherical shell experiments: OKTAVIAN, IPPE Obninsk,  
             KI Moscow and KANT  
             (Contributors: Ch. Ichihara, A. Blokhin, S. Simakov, D. Markovskij,  
             U. Fischer, U. v. Moellendorff)
- FNS slab experiment: TOF and in-system measurements  
             (Contributors: Y. Oyama, D. Markovskiy)
- 12:30        *Lunch break*

13:30 **Discussion on FENDL-1 benchmark analyses**

*Part I (continued)*

(2) **Lead**

Spherical shell experiments: OKTAVIAN, IPPE Obninsk,  
KI Moscow and TUD

(Contributors: Ch. Ichihara, A. Blokhin, S. Simakov, D. Markovskij,  
U. Fischer, K. Seidel)

FNS slab experiment: TOF measurements

(Contributor: Y. Oyama)

15:30 *Coffee break*

15:45 **Discussion on FENDL-1 benchmark analyses**

*Part I (continued)*

(3) **Lithium**

Spherical shell experiments: OKTAVIAN, IPPE Obninsk  
(BeLi/ PbLi assemblies)

(Contributors: Ch. Ichihara, A. Blokhin, S. Simakov, U. Fischer)

FNS slab experiment on Li(2)O: TOF and in-system measurements

(Contributor: Y. Oyama)

(4) **Aluminum, Silicon, Zirconium**

Spherical shell experiments: OKTAVIAN, IPPE Obninsk

(Contributors: Ch. Ichihara, A. Blokhin, S. Simakov, U. Fischer)

17.30 *Departure to hotels*

**Wednesday, October 18**

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08:00 *Pick-up at hotels*

08:30 **Discussion on FENDL-1 benchmark analyses**

*Part II: Structural and/or shielding materials*

(1) **Iron**

Spherical shell experiments: OKTAVIAN, IPPE Obninsk

(Contributors: Ch. Ichihara, A. Blokhin, S. Simakov, U. Fischer)

Slab experiments: FNS TOF & in-system measurements,  
TUD TOF measurements

(Contributors: Y. Oyama, K. Seidel, D. Markovskiy, U. Fischer)

10:30 *Coffee break*

10:45 **Discussion on FENDL-1 benchmark analyses**  
*Part II (continued)*

(2) **Chromium**

Spherical shell experiment: OKTAVIAN  
(Contributor: Ch. Ichihara)

(3) **Copper**

Spherical shell experiment: OKTAVIAN  
(Contributors: Ch. Ichihara, U. Fischer)

Slab experiment: FNS in-system measurements  
(Contributor: Y. Oyama)

(4) **Manganese**

Spherical shell experiment: OKTAVIAN  
(Contributor: Ch. Ichihara)

(5) **Tungsten**

Spherical shell experiment: OKTAVIAN  
(Contributor: Ch. Ichihara)

Slab experiment: FNS in-system measurements  
(Contributor: Y. Oyama)

12:30 *Lunch break*

13:30 **Discussion on FENDL-1 benchmark analyses**  
*Part II (continued)*

(6) **SS-316**

(i) FNG bulk shield experiment  
(Contributors: P. Batistoni, V. Rado, D. Markovskiy)

(ii) ORNL bulk shield experiment

15:30 *Coffee break*

15:45 **Discussion on FENDL-1 benchmark analyses**  
*Part II, SS-316 (continued)*

(iii) FNS bulk shield experiment  
(Contributors: M. Youssef, Y. Oyama)

- 17:30      *Departure to hotels*
- 20:00      *Dinner at Gastdozentenhaus, Karlsruhe*

**Thursday, October 19**

- 08:00      *Pick-up at hotels*
- 08:30      **Discussion on FENDL-1 benchmark analyses**  
*Part III: Other materials*
- (1) **Graphite**  
Slab experiments: FNS TOF & in-system measurements  
(Contributor: Y. Oyama)
  - (2) **Oxygen**  
Slab experiment: FNS TOF measurements on liquid O(2)  
(Contributor: Y. Oyama)
  - (3) **Cobalt, niobium, manganese, titanium**  
Spherical shell experiments at OKTAVIAN  
(Contributor: Ch. Ichihara)
- 10:30      *Coffee break*
- 10:45      **Discussion on FENDL-1 benchmark analyses**  
*Part IV: Gamma-ray spectra and heating rates*
- (1) **OKTAVIAN spherical shell experiments:** Gamma leakage spectra of LiF, CF(2), Al, Si, Ti, Cr, Mn, Co, Cu, Nb, Mo, W and Pb  
(Contributor: Y. Oyama)
  - (2) **FNS slab experiments:** In-system measurements of heating rate and gamma ray spectra of Fe, Cu, W  
(Contributor: Y. Oyama)
  - (3) **TUD iron slab experiment:** TOF measurement of gamma ray spectrum  
(Contributor: K. Seidel)
  - (4) **SS-316 bulk shield experiments:** heating rate measurements
    - (i) FNG measurements  
(Contributors: P. Batistoni, V. Rado)
    - (ii) FNS measurements

(Contributors: M. Youssef, Y. Oyama)

- 12:30      *Lunch break*
- 13:30      **Summary discussion & adoption of recommendations**
- 15:30      *Coffee break*
- 15:45      **Supplementary contributions to fusion benchmark experiments & analyses**
- (i)    S. Simakov: New results of IPPE experiment on spherical iron shells
  - (ii)   K. Hayashi: Benchmark analyses with JENDL-FF data
  - (iii) Others
- 17:30      *Departure to hotels*

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