International Atomic Energy Agency

INDC(NDS)-264
Distrib.: G

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

Summary Report
of the IAEA Advisory Group Meeting on

"NUCLEAR DATA FOR NEUTRON MULTIPLICATION IN FUSION-REACTOR FIRST-WALL AND BLANKET MATERIALS"

hosted by the China Southwest Institute of
Nuclear Physics and Chemistry (SWINPC)
at Chengdu, China, 19-21 November 1990

Prepared
by

D.W. Muir and A.B. Pashchenko

IAEA Nuclear Data Section
Vienna, Austria

September 1992

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

Reproduced by the IAEA in Austria
September 1992

INDC(NDS)-264
Distrib.: G

Summary Report
of the IAEA Advisory Group Meeting on

"NUCLEAR DATA FOR NEUTRON MULTIPLICATION IN FUSION-REACTOR FIRST-WALL AND BLANKET MATERIALS"

hosted by the China Southwest Institute of
Nuclear Physics and Chemistry (SWINPC)
at Chengdu, China, 19-21 November 1990

Prepared
by

D.W. Muir and A.B. Pashchenko

IAEA Nuclear Data Section
Vienna, Austria

September 1992

Abstract

The present Report contains the Summary of the IAEA Advisory Group Meeting on Nuclear Data for Neutron Multiplication in Fusion-Reactor First-Wall and Blanket Materials, which was hosted by the Southwest Institute of Nuclear Physics and Chemistry (SWINPC) at Chengdu, China and held from 19-21 November 1990. This AGM was organized by the IAEA Nuclear Data Section (NDS), with the cooperation and assistance of local organizers at the SWINPC. The papers which the participants prepared for and presented at the meeting will be published as an INDC report.

Table of Contents

Appendices

1. Introduction

This report summarizes the IAEA Advisory Group Meeting on Nuclear Data for Neutron Multiplication in Fusion-Reactor First-Wall and Blanket Materials, which was hosted by the Southwest Institute of Nuclear Physics and Chemistry (SWINPC) at Chengdu, China and held from 19-21 November 1990. This AGM was organized by the IAEA Nuclear Data Section (NDS), with the cooperation and assistance of local organizers at the SWINPC.

This meeting was convened in response to a recommendation of the Second IAEA Specialists' Meeting on the Fusion Evaluated Nuclear Data Library (FENDL), held in Vienna from 8 to 11 May 1989. The basic objective of the recommended meeting was to assess the status of nuclear data important to the calculation of neutron multiplication and net tritium breeding in fusion reactors. Therefore special emphasis was placed on the discussion of past and future integral experiments using 14-MeV neutron sources and on the potential value of such experiments in testing and improving the relevant nuclear data.

2. Meeting Attendance

The meeting was attended by 30 scientists from 6 countries. A list of these participants is given below as Appendix 1. Dr. Edward T. Cheng of TSI Research, San Diego/California, was selected as meeting Chairman. The meeting agenda is given in Appendix 2.

3. Conclusions and Recommendations

A major overall conclusion of the meeting was that integral measurements and theoretical predictions are now approaching consistency, at least within the stated uncertainties in the measurements and in the basic data that underly the predictions. In this sense, the previously worrisome "discrepancies" between predictions and measurments of beryllium multiplication have been resolved. Even so, unexplained differences of 5 to 10% still exist between the two most recent measurements of thick-sphere neutron multiplication in beryllium (namely, those in the United States and in China). In addition there are 3-5% differences between the latest predictions, on the one hand, and the best measurements of multiplication in lead, possibly attributable to deficiencies in the microscopic data. Also, participants noted the lack of covariance data in many of the important data evaluations, and solicited help from data evaluators to improve this situation.

Participants strongly recommended the processing and international distribution of the Fusion Evaluated Nuclear Data Library (FENDL), to serve as a unique reference data file. Another important recommendation was that the IAEA Nuclear Data Section collect and distribute a series of documents describing, in a consistent format, high-quality experimental fusion-relevant benchmark experiments. These documents should be produced by the responsible experimental groups and then reviewed for completeness and consistency by the Nuclear Data Section.

The detailed conclusions and recommendations of the four working groups that were formed during the Advisory Group Meeting are presented in Appendix 3. The minutes of a sub-group that met to discuss the U.S.A./China/Japan combined beryllium-sphere exchange programme are given in Appendix 4.

LIST OF PARTICIPANTS IN THE IAEA ADVISORY GROUP MEETING

19-21 NOVEMBER 1990

GUO Yongheng
Foreign Affairs Office
China National Nuclear Corporation
P.O. Box 2101
Beijing 100822
Tel: 8013717
Telex: 222315 facnc cn

HUANG Jinhua, WANG Qingming and YOU Chenglun
Southwest Institute of Physics
P.O. Box 432
Chengdu 610041
Fax: 0833-32721
Tel: (028) 581122-321

LIU Cheng-an, LIU Lanyan and SUN Weili
Institute of Applied Physics and
Computational Mathematics
P.O. Box 8009
Beijing 100088
Tel: (01) 2014411
Telex: 222499 iapcm cn
Fax: 011-861-2010108

ZHANG Kun
Institute of Nuclear Science and
Technology
Sichuan University
P.O. Box 390-1
Chengdu 610064
Tel: 583875-2696

ZHOU Delin, LI Ze and XIA Haihong
Institute of Atomic energy of China
P.O. Box 275-46
Beijing 102431
Tel: 868221-2864

JIANG Wenmian, YANG Jianguo and YANG Shili
Southwest Institute of Nuclear Physics and
Chemistry
P.O. Box 525-51
Chengdu 610003
Tel: 600088 caep cn

SHEN Ji-An, CHEN Yuan and CHEN Gang
Southwest Institute of Nuclear Physics and
Chemistry
P.O. Box 525-74
Chengdu 610003
Telex 600088 caep cn

D. SEELIGER
Sektion Physik
Technische Universität Dresden
Mommsenstrasse 13
D-O-8027 Dresden
Germany
Tel: (003751) 463/3378
Fax: (003751) 47-02-94

U. FISCHER
Kernforschungszentrum Karlsruhe
Postfach 3604
D-7500 Karlsruhe 1
Germany
Tel: 07247-82/2437
Fax: 07247-82-5070

H. MAEKAWA
Head, Fusion Reactor Physics Laboratory
Division of Reactor Engineering
JAERI
Tokai-mura, Naka-gun
Ibaraki-ken 319-11
Japan
Tel: 0081-292-82-6015
Fax: 0081-292-82-5709

K. SUMITA
Osaka University
Faculty of Engineering
Department of Nuclear Engineering
2-1 Yamadaoka
Suita-shi
Osaka 565
Japan
Fax: 06-875-5696

M. BABA
Nuclear Engineering Department
Tohoku University
Aoba, Aramaki
Sendai-shi, 980
Japan

H. GRUPPELAAR
Department of Physics
Netherlands Energy Reserch Foundation (ECN)
NL-1755 ZG Petten
Netherlands
Tel: 0031 2246-4083
Fax: 0031 2246-4480

E.T. CHENG
TSI Research
225 Stevens Ave. Suite 110
Solana Beach, CA 92075
USA
Tel: 619-793-3567
Fax: 619-793-0569

J.W. DAVIDSON
Los Alamos Group A-4
Mail Stop F611
Los Alamos, NM 87545
USA
Tel: 505-667-2423
Fax: 505-665-5283

J.R. SMITH
Idaho National Engineering Laboratory
EG & G Idaho, Inc.
P.O. Box 1625
Idaho Falls, Idaho 83415-7113
USA
Tel: 208-526-4160
Fax: 208-526-4715

M.Z. YOUSSEF
6288 Boelter Hall
School of Engineering
University of California
Los Angeles, CA 90024
USA
Tel: 213-825-7879
Fax: 213-825-2599

D.V. MARKOVSKIJ and D.Yu. CHUVILIN
Institut Atomnoi Energii I.V. Kurchatova
Ploschad I.V. Kurchatova
SU-Moscow D-182, 123182
USSR
Fax: 959430073

B.V. ZHURAVLEV
Fiziko-Energeticheskij Institut
Ploschad Bondarenko
SU-249 020 Obninsk, Kaluga Region
USSR
Telex: 412509+ura

NUCLEAR DATA FOR NEUTRON MULTIPLICATION IN FUSION-REACTOR FIRST-WALL AND BLANKET MATERIALS

Advisory Group Meeting
organized by the
International Atomic Energy Agency (IAEA)
in cooperation with the
Southwest Institute of Nuclear Physics and Chemistry (SWINPC)
Chengdu, China, 19-21 November 1990

Monday, 19 November 1990

9:00 Welcome from the Chinese Government
9:10 Welcome from Local Organizer
9:20 Welcome from Scientific Secretary
9:30 Selection of Chairman of Meeting and Working Group Leaders

10:00 Session I. Data Needs for Neutron Multiplication and Net Tritium Breeding

(I-1) E.T.CHENG, "Nuclear Data Needs and Status for Fusion Power Reacters"
(I-2) D.V.MARKOVSKIJ, "The Status of ITER Neutronics Analysis"
(I-3) Workshop I. Discussions of priorities, data accuracies, sensitivities, etc.

13:30 Session II. Differential Data and Evaluations

(II-1) H.GRUPPELAAR, "Double-Differential Cross-Section Data for Li-7, Be and Pb"
(II-2) D.SEELIGER, "Status of BROND and Related Data Evaluation Activities"
(II-3) E.T.CHENG, "Status of ENDF/B-6 Evaluations for Li-7, Be and Pb"
(II-4) M.BABA, "Differential Neutron Emission Data of Neutron Multiplier and Structural Materials for Fusion Reactors"
(II-5) ZHANG Kun, "The Be Secondary Neutron Spectra Induced by 14.7-MeV Neutrons"
(II-6) B.V. ZHURAVLEV, "Differential Neutron Emission Cross Sections and Neutron Leakage Spectrum from Beryllium at 14 MeV"
(II-7) Workshop II. Discussions of evaluation methods, measurement of microscopic data, uncertainties, etc.

Tuesday, 20 November 1990

8:30 Session Ⅲ. Integral Experiments and Analysis

(Ⅲ-1) JIANG Wenmian, "Integral Experiments on Beryllium Using Pure Water and Polyethylene Moderators"

(Ⅲ-2) LIU Lian-yan, "Analysis of the SWINPC Beryllum Integral Experiment"

(Ⅲ-3) J.Wiley DAVIDSON, "Analysis of EG & G/Idaho Integral Experiment or Beryllium"

(Ⅲ-4) J.Richard SMITH, "Beryllium Integral Experiment at EG & G/Idaho Using a Manganese Bath Detector"

(Ⅲ-5) M.Z. YOUSSEF, "Impact of differences in Various Beryllium Evalvations on Integral Tritium Breeding and Other Reaction Rates"

(Ⅲ-6) K.SUMITA, "Nentronic Integral Experiments for Evaluation of Tritium Breeding in a Fusion Blanket; Li, Pb, Be and C Sphere Systems with OCTAVIAN"

(Ⅲ-7) U.FISCHER, "Benchmark Analysis of 14-MeV Neutron Tnansport in Beryllium"

(Ⅲ-8) H.MAEKAWA, "Outline of IAEA Benchmark Problem based on the Time-of-Flight Experiment with Beryllium Slabs at JAERI"

(Ⅲ-9) H.MAEKAWA, "JAERI Analyses of the IAEA Benchmark Problem and an Integral Experiment on a Beryllium Assembly"

(Ⅲ-10) D.Y. CHUVILIN, "Measured and Calculated Neutron Leakage from Beryllium Shells with a Cf-252 Source"

(Ⅲ-11) Workshop Ⅲ. Discussions of integral-experiment methods, accuracies, future work, etc.

Wednesday, 21 November 1990

8:30 Session IV. Discussions of benchmark problems, past and future, for FENDL data testing. Suggested topics and speakers include the following:

- LLNL Pulsed Sphere Experiments (Muir/Cheng)
- Osaka Experiments (Sumita/Takahashi)
- FNS Experiments (Maekawa)
- Kurchatov Experiments (Markowskij/Chuvilin)
- Dresden Experiments (Seeliger)
- Chinese Experiments (Zhang/Cai, CNDC)
- KFK Experiments (Fischer)
- Others

13:00 Session V. Workshop reports and overall recommendations to IAEA

17:30 Meeting adjourns

WORKING GROUP REPORTS

WG-I. Working Group Report on

DATA NEEDS FOR NEUTRON MULTIPLICATION AND NET TRITIUM BREEDING

Chairman: J.W. Davidson

The objectives established for this Working Group were 1) the identification of the critical needs for nuclear data which affect neutron multiplication in fusion reactor first wall and blanket design, 2) the prioritization of these needs, and 3) the determination of the accuracy requirements for this data. The first and second objectives were organized through the selection of various material groupings; these were subsequently prioritized according to their importance to current and future design analyses. The material groupings were, in order of priority, 1) neutron multiplying materials, 2) materials with significant impact on neutron multiplication, and 3) fissioning materials, the latter group was included to address the needs of hybrid reactor design analyses. Another grouping inluding materials with a variety of indirect affects on multiplication was considered to be too broad for the focus of this meeting.

Neutron Multiplying Materials

It is recommended that the materials to be included in this group are ^{9}Be, Pb, and ^{7}Li. The highest priority should be given to data for ^{9}Be with Pb and ^{7}Li data equally sharing a second priority. Double-differential cross-section data for ^{9}Be is the most important data need in this group. The next order of priority is assigned to double-differential cross-section data for ^{7}Li and (n,2n) cross-section data for Pb. The double-differential cross-section data for Pb is given a lower priority due to the high (n,2n) threshold which allows only small contributions from secondary (n,2n). Other data needs include elastic, (n,γ), (n,t) and (n,α) cross-section data for ^{9}Be.

Materials with Significant Impact on Neutron Multiplication

It is recommended that two materials be included in this group; Zr as a breeder compound component and Fe as a first wall structure component. No priority within this group is assigned to these materials. In both cases, the double-differential cross-section data is the critical data need with respect to neutron multiplication. Other data needs include the Fe inelastic cross section.

Fissioning Materials

It is recommended that two obvious materials, ^{238}U and ^{232}Th, be included in this group. The critical nuclear data needs with respect to neutron multiplication for theses materials are the double-differential neutron emission cross sections and (n,2n), (n,3n) and (n,f) cross-section data.

Data Accuracy Requirements

The final objective of the working group was the determination of accuracy requirements for the above data. It is recommended that accuracy requirements for all specified data be based on appropriate sensitivity and uncertainty analyses. It is recognized that the recommendation for uncertainty analyses generates another nuclear data need, i.e., covariance nuclear data.

WG-II. Working Group Report on

DIFFERENTIAL DATA AND EVALUATION

Chairman: H. Gruppelaar
Co-Chairman: K. Sumita

1. Introduction

Three papers were presented on the status of nuclear data evaluations, in particular on ENDF/B-IV, -V, -VI, JENDL-3, EFF-1, EFF-2 and BROND. One paper (by ZHANG Benai) was contributed on the status of CENDL-1 for Be-9. Three other papers and the paper of Seeliger were presented on recently performed or ongoing differential data measurements and related integral experiments. During the workshop following the presentations there was a discussion on the status of nuclear data evaluations, differential data and further requirements for Li-7, Be-9 and Pb. In this report integral data are not mentioned as they are the subject of another workshop.

2. Li-7

Energy-Angle Integrated Data

All recent evaluations (except for ENDF/B-IV) agree very well with respect to the most important cross-section, i.e., the tritium production cross section. The accuracy in the 14 to 15 MeV range is about 2 to 3%.

However the relative partition of this cross section into its five components is less well known. Evaluations show different cross sections for the reactions proceeding through the various levels in Li-7. More work is required (both from evaluators and experimentalists) to improve this situation. The subdivision is important as it largely defines the double differential cross sections (DDX). In particular the cross section for exciting the 4.63 MeV level in Li-7 is different in various evaluations and there is no consensus as yet on its value as a function of energy.

Other quite important cross sections are the total neutron emission cross section and the total cross section.

DDX Data

The evaluations of ENDF/B-VI, EFF-1 (= ENDF/B-V.2) and JENDL-3 describe DDX data by means of a pseudo-level representation, whereas the EFF-2 evaluation uses more rigourous modelling based on physical experiments or assumptions. From the first group of evaluations JENDL-3 is probably most advanced, as fits have been made to many recent (Japanese) DDX experimental data. From the standpoint of physics, the description of EFF-2 by Beynon and Field has to be preferred. Intercomparisons of EFF-2 with recent data show quite good results, but further testing and benchmarking is necessary.

The new experiments presented at this meeting should be used for this prupose and for further adjustments. Key quantitites are: energy-angle integrated cross sections for separate components of the t-production process, center-of-mass angular distributions of these components, including t-distributions and more data at low outgoing energies. Additional experimental data for this purpose may be required, also data at lower incident energies.

At energies above 14 MeV further work is needed on evaluations, and perhaps also additional measurements are required. However, this energy range is not important for fusion reactor design.

Covariances

The presently adopted ENDF/B-VI evaluation contains recently re-evaluated covariance data, both for energy-angle integrated data and for distributions. This was relatively easy in ENDF/B-VI, because of the adoption of the pseudo-level description. In EFF-2, which contains virtually the same energy-angle integrated cross-sections as ENDF/B-VI, covariances are not given as yet. They could easily be included for the energy-angle integrated cross-sections, but not for DDX. Work to improve this situation is recommended, e.g., by adopting the new MF30 format. Procedures and processing tools need also to be developed.

3. Be-9

Energy-Angle Integrated Cross-Sections

For the most important cross-section, i.e., the (n,2n) cross-section, recent evaluations (ENDF/B-VI, EFF-2, JENDL-3, CENDL-1) are lower than before (ENDF/B-IV, ENDF/B-V, EFF-1) at 14 MeV. This change is not very well documented. Therefore it is recommended to perform a re-evaluation of the cross section in the 14 to 15 MeV range, together with an uncertainty analysis, and to document this. It may very well be that the present uncertainty is close to about 3 to 5%, but this has to be established. The recent measurements at Osaka and Tohoku support the ENDF/B-VI value. Any changes in the 14 MeV value may affect the rest of the energy range.

As in the case of Li-7, the relative partition of this cross-section into different components is less well known. Evaluations show different cross-sections for the scattering proceeding through the varous levels in Be-9. More work is required (both from evaluators and experimentalists) to improve this situation. The subdivision is important as it largely defines the double differential cross sections. It is also not very well established how much inelastic scattering without break-up (n,n'γ) is present.

The absorption cross section is important as it affects the total multiplication in a Be blanket component. Two of its constituents, namely the (n,t) and (n,α)He-6(ground state) cross sections, contribute to t-production in Be.

Finally, the total cross section needs to be known with small uncertainty.

DDX Data

The evaluations of ENDF/B-IV and -V are obsolete and should not be used. The EFF-1 evaluation (from Los Alamos, Young and Stewart) adopts a pseudo-level respresentation and thus takes into account energy-angle correlations in an empirical way. The EFF-1 evaluation fits the data of Drake, et al., rather well, but the format is not strictly ENDF-5. The JENDL-3 evaluation adopts the ENDF-5 format, and therefore does not have full energy-angle correlations included. Nevertheless a rather very good fit with recent Japanese data was obtained.

The ENDF/B-VI and EFF-2 evaluations include a rigourous modelling based on physical experiments or assumptions. From the first group of evaluations JENDL-3 is probably most advanced, as fits have been made to many recent (Japanese) DDX experimental data. From the standpoint of physics, the description of ENDF/B-VI or EFF-2 has to be preferred. The two evaluations use the same energy-angle integrated data and, with respect to DDX, are of comparable quality, although different computational models were used (Monte Carlo vs. analytical). Intercomparisons of EFF-2 and ENDF/B-VI with recent data show quite good results, but further testing and benchmarking is necessary.

It was pointed out at this meeting by Zhuravlev that there is a backward-angle discrepancy between ENDF/B-VI or EFF-2 evaluations and measurements at 14 MeV. There is no doubt about the experimental data, as various data sources agree in this respect. A possible explanation could be that the various components of the (n,2n) reaction need to be re-distributed and that there should be room for a new process: direct three-body break-up.

The new experimental data presented at this meeting by Baba, Zhuravlev and ZHANG Kun (forthcoming) should be used for this purpose and for further adjustments. Key quantities are: energy-angle integrated cross sections for the separate processes, center-of-mass angular distributions for particles emitted in each process, including alpha particles. Additional experimental data for this purpose may be required, also at lower incident energies. In the case of Be-9, low incident energies are more important than for Li-7, due to its use in combination with Li-6 enriched breeder material.

Curiously, the data evaluations of JENDL-3 and EFF-1 (Young and Stewart) perhaps yield "better" results in applications than those of ENDF/B-VI or EFF-2, in spite of the better physical modelling of the last two evaluations. This has to be investigated. Still, the main route for further improvements should go via the physically more advanced modelling of Perkins, et al., or Beynon and Field, respectively.

With respect to experimental data there is a discrepancy at forward angles (30^{o}) between Drake's data and data from Obninsk, reported at this meeting by Zhuravlev. Furthermore, it was reported by Baba, that at low emission energies improvements had been made, indicating that Drake's data are poor at low emission energies. The new data should be accounted for in the evaluations.

Covariances

The EFF-1 evaluation (Young and Stewart) contains evaluated covariance data, both for energy-angle integrated data and for distributions. This was relatively easy, because of the adoption of the pseudo-level description. However, these covariance data are no longer valid, as more accurate data have been included in the newer evaluations.

In ENDF/B-VI and EFF-2, which contains the same energy-angle integrated cross-sections, covariances are not given. It is highly recommended to include covariance data not only for energy-angle integrated data, but also for energy-angle distributions. Work to improve this situation is recommended, e.g., by adopting the new MF30 format. Procedures and processing tools need also to be developed.

Processing

The Be-9 evaluations of ENDF/B-VI and EFF-2 utilize the MF6 format of ENDF-VI with laboratory tabulated angle-energy (LAW = 7) or energy-angle (LAW = 1) distributions, respectively. In order to use these data fully in transport and Monte Carlo calculations, additional tools are required in processing and blanket calculations.

4. Pb

4.1 Energy-Angle Integrated Data

Also in lead the important cross section is the (n,2n) cross-section. In order to judge the evaluation the CRP recommended value of 2193 ± 70 mb (3.2%) could be used. All recent evaluations (ENDF/B-VI, EFF-1,2, BROND, JENDL-3) agree within 4% with this value, but slight updates are recommended to meet the above mentioned value. ZHOU Delin communicated a recent evaluation of the Pb(n,2n) cross section that gives a result of 2252 ± 40 mb.

The shape of the excitation function is a more serious problem. There are large differences at energies other than 14 to 15 MeV. If the shape of Fréhaut's measured data cannot be trusted, new (n,2n) measurements at energies below 14 MeV should be recommended.

Furthermore, there is a tendency to use isotopic rather than elemental evaluations (e.g., in ENDF/B-VI). Thus, isotopic data may become more relevant and this creates new data needs. The highest priority is still to get the natural data in a good shape.

The inelastic scattering cross-section is relatively small at 14 MeV, but should be known rather well, in particular the excitation of direct-collective states. From recent (n,n'γ) measurements, performed at Obninsk, it follows that there is still significant inelastic scattering below the (n,2n) threshold.

A problem in Pb is that many discrete levels contribute, and that there are not sufficient MT-numbers to store this information. Lumping of levels is necessary. This problem is relaxed for isotopic evaluations.

4.2 DDX

The angle-integrated emission spectrum at 14 MeV is well established from the CRP on this subject (see also results of Pavlik and Vonach). ENDF/B-VI, JENDL-3, BROND, and EFF-1,2 are in resonably good agreement with this recommendation. More detailed measurements are now available (e.g., from Dresden), with better resolution at high emission energies, showing structure effects quite clearly. Thus further fine-adjustment of the above-mentioned evaluations is possible.

The most serious problem is that no data are available at lower energies. Therefore it is highly recommended to perform such measurements for energies in the range of 5 to 12 MeV.

With respect to energy-angle correlated data, there are only four evaluations that can deal these data properly, all in ENDF-VI format. These are: EFF-1, EFF-2, BROND and ENDF/B-VI (isotopic only). Three different methods are used with reasonably good results with respect to the data, although improvements are possible. Suggestions for improvements were made at this meeting by Seeliger and by Zhuravlev.

New measurements from Osaka and Tohoku universities were reported by Sumita and by Baba. The last-mentioned data emphasize the low-emission energy range and are in excellent agreement with the JENDL-3 data (since there is isotropy at low E').

Covariances

Although ENDF/B-VI contains covariance data for the isotopic evaluations there are no covariances given for MF6. Special attention must be paid to guarantee that the isotopic evaluations give satisfactory covariance data for the natural element. In any case MF6 uncertainty data are required in the future; see also the remarks for Be-9.

Nuclear Modelling

Natural lead, or rather its isotopes, are very interesting from the point of view of theoretical modelling. The work on nuclear models for such different items as energy-dependent level-density parameters, direct-collective effects, MSD/MSC pre-equilibrium models, CC models, etc., have been very useful in understanding the physics and have therefore improved the evaluations considerably. Further theoretical work and modelling is continuing and should be encouraged. This is of prime importance to predict DDX data at energies other than 14 MeV.

As an example of the power of present day modelling, Seeliger reported on absolute SMD/SMC calculations, with excellent agreement with emission spectra.

5. Recommendation for a CRP

At the meeting it was acknowledged that three Co-ordinated Research Programmes (CRPs) of the Agency had been very important to achieve the present day status of the lead evaluations. These are the CRPs on "Measurements and Analysis of Neutron Emission Spectra in (p,n) and (α,n) Reactions", "Double Differential Neutron Emission Measurement and Analysis" and "Methods of Calculation of Fast Neutron Nuclear Data for Structural Materials".

A similar activity is suggested on the physics aspects of the modelling of light materials. A CRP with the title "Evaluation Methods and Theoretical Modelling of DDX for Light Materials" is recommended. This CRP should concentrate on Li-7 and Be-9 and possibly also on other light materials. Such an activity seems justified in view of the high-priority needs listed above. The physics issues for light materials are quite different from those of heavier materials and also for this reason some special attention is required.

WG-III. Working Group Report on

INTEGRAL EXPERIMENTS AND ANALYSES

Chairman: D. Seeliger
Co-chairman: D.V. Markovskij

1. Status of Integral Experiments and Analyses as Presented in Session III of this AGM

New experimental results on the 14 MeV neutron multiplication in Be shells having thickness up to 14.58 cm with a total absorption method with both water and polyethylene moderators were presented by CHEN Yuan from the SWINPC Chengdu. The corresponding uncertainties were estimated being ± 3.7% and ± 2.8%, respectively.

The analysis of these experiments using the ANISN code with both ENDF/B-IV and ENDF/B-VI evaluated data libraries were presented by LIU Liang-yan. The calculated leakage multiplication using the code ANISN for both cases was found higher than the corresponding experimental data by 3-15%, though the calculations using ENDF/B-VI library are closer to the experiment than the calculations using ENDF/B-IV. As one of the additional sources of uncertainty, the quality of the oxygen nuclear data was pointed out.

J.R. Smith from Idaho NEL presented measurements of the multiplication of 14 MeV neutrons in beryllium for four thicknesses of spherical shells using a manganese bath. For the 4.6-cm, 12.1-cm, 15.6-cm and 19.9-cm thicknesses the net multiplication values are 1.313, 1.755, 1.897 and 1.956, respectively. Excellent agreement was observed between experimental values and calculations using the MCNP code and the Young-Stewart LANL beryllium evaluation, as shown in the presentation by J.W. Davidson from LANL. The accuracy of these experiments are estimated to about 2.5-3.0%, being limited also mainly by the high-energy parasitic absorptions of neutrons via processes such as $^{16}O(n,\alpha)^{13}C$.

M.Z. Youssef from the University of California at Los Angeles presented both experimental and calculational results for a slab geometry of Be in which a Li_2O breeding zone follows the multiplier. He found that C/E values for T_6 are lower than unity just behind the Be layer for 3-5 cm but they return to values of 1.05-1.15 thereafter for all beryllium evaluations used (ENDF/B-V, ENDF/B-VI, LANL). The closer values to unity are obtained by using the ENDF/B-VI evaluation. The calculated values for T_7 in the Li_2O are always larger with the ENDF/B-VI evaluation for Be. The integrated neutron spectra obtained from calculations using the three libraries mentioned above in comparison with experiments using a NE-213 proton recoil spectrometer are underestimated above 10 MeV and overestimated in the 1-10 MeV energy ranges. It was stressed that uncertainties in the secondary energy distributions have large impact on uncertainties of local reaction rates and, therefore, these uncertainties (covariance data) should be included in the analysis of integral experiments that use beryllium as a multiplier. Youseff showed, for example, that these uncertainties could lead to about a 10% uncertainty in local T_6 behind Be slabs.

A series of integral measurements to evaluate the neutron multipliers Pb and Be, carried out at the Osaka University, were presented by K. Sumita. These investigations are carried out at the OKTAVIAN intense neutron generator using a large natural lithium sphere with and without a graphite reflector. The preliminary measurement results of tritium breeding and time dependent reaction rates for Li are compared with the calculated values to investigate the evaluated libaries (JENDL-3, JENDL-3T, ENDF/B-IV, EFF-1). Discrepancies at the lower energy end of the spectrum probably require a revision of the (n,2n) cross section for Be in JENDL-3.

H. Maekawa presented analyses of the IAEA benchmark problem based on a TOF experiment on Be slabs, an integral experiment on Be assembly and a TOF experiment on Pb slabs, using JENDL-3 for comparison. The status of JENDL-3 is fairly good for fusion neutronics calculations comparing to JENDL-3T, ENDF/B-IV and LANL evaluations. The neutron data for Pb in JENDL-3 are also considerably improved, compared to JENDL-3T.

From the energy-integrated angular flux comparison it can be concluded that some minor changes are required for both the ^{9}Be(n,2n) and Pb(n,2n) cross sections in JENDL-3, including secondary neutron energy and angular distributions. For both elements, some minor changes are also recommended for the total cross section and both elastic and inelastic cross sections around 14 MeV to improve the agreements. For this purpose sensitivity and uncertainty analyses are recommended. The present analysis indicates, that there are some problems in the DDX of the LANL evaluation, which might have also an influence on the analysis of the INEL beryllium-sphere experiment, presented at this meeting.

U. Fischer from KFK presented a corresponding analysis of 14 MeV neutron transport in beryllium. He showed that for analyzing the Be benchmark experiments the S_n/P_L-approximation is sufficient to reproduce the results of rigourous S_n calculations. For 1D experiments (sphere) a P_1 or P_3 approximation is sufficient, whereas for 2D experiments (slab) additionally P_5 is needed. Good agreement is observed between calculations using the EFF-1 data (LANL evaluation) and experiment on one- and two-dimensional geometry for both neutron multiplication factor and the neutron spectrum.

D.Yu. Chuvilin presented new results on the multiplication of ^{252}Cf spontaneous fission neutrons in Be shells using the total absorption method in the Kurchatov Institute. A summary of the status of neutron multiplication in Pb spheres as obtained by the co-ordinated effort in many laboratories during the last years was presented by Markovskij from the Kurchatov Institute. The recent Kurchatov measurement of neutron multiplication in a 22.5 cm thick lead sphere (IAEA benchmark) using the total absorption method yields a multiplication factor of 1.856 ± 0.077. As a result of recent work done in many laboratories, good agreement is now achieved between calculations and experimental neutron leakage for lead within the limit of uncertainties. However, the experimental values still tend to give somewhat higher (less than 5% higher) neutron multiplication than predicted by the calculations using different codes and libraries.

2. Conclusions and Recommendations

2.1 Experimental Methods

For the experimental determination of the total neutron multiplication in spherical assemblies three methods are available providing similar accuracy:

- polyethylene sphere absorption: ± 2.8%
- boron tank : ± 3%
- manganese bath : ± 2.5-3.0%

The accuracy for the methods using a water moderator could be further increased (uncertainty below ± 2%) if the oxygen (n,α) cross section data, particularly at 14 MeV, were improved to an accuracy better than 5%.

The adequate use of these methods for highly accurate neutron multiplication measurements requires a comprehensive analysis of all geometrical and impurity effects on neutron transport, preferably using the Monte Carlo technique. Some concern was expressed about problems that might occur in the polyethylene absorption method as a result of the inhomogeneous array inside the detector. It was recommended also to present calculations of the spatial distributions of neutron spectra inside the boron tank.

For reasons other than the effect on total neutron multiplication, experimental information on the secondary energy distribution of leakage neutrons is also needed. This could be measured using the following methods with the corresponding typical uncertainties (depending on the energy range considered):

- time-of-flight spectroscopy (TOF): ± (5-7)%, 0.1-15 MeV
- proton recoil spectroscopy (PRS) : ± 10%, 0.01-5 MeV
- activation technique : ± (10-20)%, 0-15 MeV

In the energy range 5-15 MeV typical for fusion neutronics a clear preference should be given to TOF spectroscopy, whereas in the lower energy range above 10 keV and up to a few MeV, very useful additional information can be obtained by PRS.

Having in mind the different advantages/disadvantages but also different costs (for TOF they are rather high), both integral and spectral methods should be properly used further in parallel for neutron multiplication measurements in different laboratories.

2.2 Data Libraries

Now there are several recent evaluated nuclear data libraries available, such as: ENDF/B-VI, JENDL-3, EFF-1 and BROND. Therefore, it is recommended to use these libraries for further neutron multiplication calculations instead of the older libraries (ENDF/B-IV, ENDL-75, etc.).

The comparative performances of ENDF/B-VI, JENDL-3 and LANL evaluations for Be should be studied further (for instance, with codes based on multigroup data).

The IAEA Nuclear Data Section is strongly encouraged to provide the international fusion neutronics community with a unique reference data file for fusion transport calculations as soon as possible (FENDL library).

2.3 Codes

At present fusion neutronics transport calculations are carried out using many different codes, having their advantages for specific problems (such codes as MORSE, MCNP, DOT, ANISN, BRAND, BLANK, ANTRA and others). Therefore, it is impossible to give a general preference to one of these codes for use in neutron transport calculations. The WG, however, recommended that further reference calculations for the comparison between different laboratories should be carried out using widely available codes, for example ANISN and MCNP.

Therefore, it would be highly appreciated, if the developers of the MCNP code could provide for the use of the ENDF/B-VI data for beryllium.

On the one hand, WG participants stressed the urgent need for making sensitivity/uncertainty analyses for neutron multiplication problems in Be and Pb. On the other hand, in many of the participating countries, no sensitivity analysis codes are available at present. Therefore, the WG encourages the IAEA/NDS to explore the possibilities for a broader distribution of the perturbation-theory-based sensitivity/uncertainty codes, such as SENSIBL and FORSS, by the code developers. Also, it would be helpful if the MCNP version for sensitivity studies could be further developed and made available to the fusion neutronics community.

Sensitivity calculations and uncertainty analyses should include partial cross sections (elastic scattering, nonelastic channels), the angular and energy distributions of secondary particles (DDX). However there is presently no covariance data for DDX. The WG recommends the generation of such data.

2.4 Experiments

As mentioned above, there now exist several recent measurements of neutron multiplication in Be. Now more work should be directed towards a consistent analysis of all these measurements using a unique data base (preferably ENDF/B-VI, EFF-1 and JENDL-3).

The inconsistency between the Idaho and Chengdu experiments should be explored further, including a detailed uncertainty analysis of both experiments.

More measurements are needed both for neutron leakage distributions and for neutron multiplication in thick Be shells. In this context the importance of the planned SWINPC-OSA-LLNL-Kurchatov-TUD collaboration was stressed by the WG participants. Similar experiments are going on in KFK and ANL. Some concern was expressed over problems in the analysis caused by slow neutron absorption in Be shells with these large sizes.

Although neutron multiplication in Pb is now in good shape, further analyses are encouraged to establish the reasons for the remaining small (less than 5%) differences between experiments and calculations. Following this, it should be decided whether further measurements with a thick lead shell are needed or not.

From the point of view of accurate neutron transport calculation any improvements of the oxygen (n,α) cross section are strongly encouraged.

The WG participants stressed the importance of the beginning of new type of mockup experiments, including Be as a multiplier, for the final validation of the blanket transport calculations.

WG-IV. Working Group Report on

BENCHMARK EXPERIMENTS AND DATA TESTING OF FENDL

Chairman: D.W. Muir
Co-Chairman: H. Maekawa

FENDL Processing Issues

IAEA Nuclear Data Section plans to produce multigroup (both 175-group and approximately 50-group) and MCNP libraries. It will be distributed in BCD (card-image) form as single-isotope (or material) NJOY group output (GENDF) and NJOY continuous-energy output (ACE). It will be left to users to perform small calculations to assemble final working libraries on their local computers. The Working Group endorsed the plan to include self-shielding factors in the library.

IAEA-Organized Neutronics Data Testing for Fusion

The participants recommended that the IAEA organize a data testing activity within the FENDL programme. This should include the compilation and publication of complete specifications of fusion-relevant benchmark experiments. These specifications should include a complete description of the experiment, the measured results and the measurement uncertainties. In addition, it is recommended that such a benchmark specification include a simple-geometry approximation to the actual, usually 3-dimensional, geometry of the experiment, together with the measured results "corrected" to equivalent values expected for direct measurements on the simple-geometry model. The analysis of the documented benchmarks should be organized as a sub-group of the FENDL activity, similar to the benchmarking of activation codes recently organized by E. Cheng for the IAEA.

Requirements for Processed Covariances

In support of the recommendation of WG-III concerning the wider distribution of a complete sensitivity and uncertainty analysis system, WG-IV recommended that such a system be complemented with a processed multigroup (175) covariance library processed into a compatible format. It was further suggested that a covariance collapsing code be supplied as part of such a sensitivity/uncertainty analysis package. This work should follow the completion of the processed multigroup and MCNP-input data libraries mentioned above.

Specific Benchmark Experiments

The Working Group recommended that, after completion of efforts to understand certain existing discrepancies, the Nuclear Data Section should include, among the FENDL benchmarks, Be total-multiplication experiments such as those reported at this meeting. In addition, the JAERI Be slab leakage experiment should be analyzed with Monte Carlo codes (BLANK, MCNP), using both EFF-1 and ENDF/B-VI data. Following the analysis of pure Be experiments, measurements involving mixtures of Be and Li were suggested as a means of reducing sensitivity to thermal neutrons. It was further suggested that additional integral measurements on structural materials be carried out and analyzed with FENDL.

MEMORANDUM

Information Exchange Meeting Regarding the Availability of US/PRC Combined Beryllium Sphere After the Osaka OCTAVIAN EXPERIMENTS

Minshan Hotel, Chengdu, China, November 20, 1990

Attendees:	U.S.A.:	E.T.Cheng (TSI Research)
	U.S.S.R:	D.V.Markovskij (Kurchatov),
		D.Y.Chuvilin (Kurchatov),
		B.V.Zhuravlev (Fiziko-Energeticheskij)
	P. R.C.:	Yang Jiangguo (SWSINP),
		Jiang Wenmian (SWINPC),
		Chen Yuan (SWINPC),
		Chen Gang (SWINPC),
		Zhang Shukui (SWINPC)
	JAPAN:	K.Sumita (Osaka University)
	Germany:	D.Seeliger (Technical University-Dresden)

Attendees representing interested parties participated at an information meeting, under the coordination of Dr. E.T. Cheng, at Minshan Hotel, Chengdu, China, on November 20, 1990, to discuss interests and required procedures regarding the U.S./P.R.C. combined berylluim sphere presently located at OKTAVIAN facility, Osaka University, Japan. This memorandum summaries the results of this meeting.

I. Status and Interest

Dr. Cheng reviewed the status of present U.S./P. R. C. combined beryllium sphere. He pointed out that the successful joint beryllium experiment project is primarily based on the following bilateral exchange agreements: U. S. /P. R. C. exchange on fusion reactor technology; U. S.DOE/Japanese University exchange on fusion neutronics; and SWINPC/Osaka University exchange on beryllium integal experiment. Any laboratory which is interested in obtaining the beryllium sphere is advised to establish bialteral relationship with concerned parties.

Professor Sumita talked about the status of beryllium integral experiment at OKTAVIAN, Osaka University. He emphasized that OKTAVIAN group would like to perform more experiments with the U.S./P.R.C. beryllium sphere until July 1991. Due to the tax law in Japan, however, he has to send the P.R.C. and U.S. beryllium shells, in july 1991, back to P.R.C. and U.S., respectively, if not otherwise instructed by P.R.C. and U.S. Professor Sumita also kindly offered to pay for the cost of transporting the beryllium shell.

Dr. Markovskij expressed Kurchatov's interest in obtaining the P.R.C./U.S. combined beryllium sphere for a period of experimental time at Kurvchatov. The integral experiment will be performed using the total absorption method (Chuvilin, Kurchatov), and perhaps time-of-flight method (Zhuravlev, Obninsk). The Kurchatov Institute will also fabricate an additional outer shell of 5 cm thick to increase the total beryllium sphere thickness to 19.48 cm, if the additional shell is combined with the present P.R.C./U.S. beryllium sphere.

Dr. Cheng mentioned that the U.S. welcomes Kurchatov's proposal. He also agreed to coordinate the proposed exchange.

Professor Jiang amd professor Yang personally expressed interest in the beryllium exchange proposed by Dr. Markovskij.

They experssed interest in having the proposed U. S./P.R.C/U.S.S.R. beryllium sphere at SWINPC to perform integral experiments with polyethylene and water moderators.

Professor Seeliger also expressed interest in obtaining the proposed U.S./P.R.C./U.S.S.R. beryllium sphere at TUD to perform integral time-of-flight experiments.

II. Recommendations

The following recommendations were made to promote the proposed beryllium exchange.

1. Kurchatov Institute (Dr. Markovskij) sends a letter to SWINPC (Protessor Fu Yibei, director, or his deputies) expressing interest in obtaining the combined U.S./P.R.C. beryllium sphere and indicating the fabrication of an additional 5 cm shell to increase the available total thickness. Copies of this letter should also be sent to professor Sumita and Dr.Cheng.

2. SWINPC (Professor FU or his deputies) will respond to Kurchatov's request and proposes an agreement on the exchange between Kurchatov and SWINPC.

3. Kurchatov and SWINPC should discuss with each other on the exchange and notify Professor Sumita and Dr. Cheng when the agreement is finalized.

4. Kurchatov will send a letter to Dr. Ralph Moir of LLNL (U.S.A.), with a copy to Dr. Cheng, regarding the loan of beryllium shells from LLNL(U.S.A.).

5. SWINPC and LLNL will then instruct Osaka University to send the combined beryllium sphere to Kurchatov Institute in Moscow. (Note that the whole procedure should be completed by July 1991).