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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

CHARGED-PARTICLE AND PHOTONUCLEAR DATA EVALUATIONS FOR FENDL

Summary Report of the IAEA Specialists' Meeting organized by the International Atomic Energy Agency in cooperation with the Institute of Physics, Bratislava, and held at the Smolenice Castle, Slovakia
18 - 21 April 1994

Prepared by
A.B. Pashchenko
IAEA Nuclear Data Section

November 1994

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

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ABSTRACT

The present report contains the Summary of the IAEA Specialists' Meeting on "Charged-Particle and Photonuclear Data Evaluations for FENDL", held at the Smolenice Castle, Slovakia, from 18 to 21 April 1994. The meeting was organized by the IAEA Nuclear Data Section (NDS) with the co-operation and assistance of local organizers from the Institute of Physics, Bratislava.

The purpose of the Meeting was to review the present status and availability of evaluated charged-particle and photonuclear data libraries for incorporation into the IAEA Fusion Evaluated Nuclear Data Library (FENDL), to review the theoretical models and their parametrization for the computation of nuclear data, to review the remaining gaps in the required data, and to identify further measurements and calculations needed to fill these gaps.

The conclusions and recommendations are presented on the basis of discussions held by meeting participants.

IAEA Specialists' Meeting on

"Charged-Particle and Photonuclear Data Evaluations for FENDL"

Smolenice Castle, Slovakia

(1) Introduction

In October 1992, the IAEA sponsored a Consultants' Meeting on Charged-Particle and Photonuclear Data Libraries for FENDL at the (U.S.) National Nuclear Data Center (NNDC) at Brookhaven National Laboratory.

At this meeting the participants noted that new experimental, evaluational and theoretical efforts have been started or are planned in several countries in the area of Evaluation of Charged-particle and Photonuclear Data for Fission and Fusion Application, and the co-ordination of these efforts by the Agency appears to be very timely and desirable. So the Consultants' Meeting recommended that continued checks and further development of co-ordinated efforts be considered at the IAEA Specialists' Meeting on "Evaluation of Charged-particle and Photonuclear Data for the IAEA FENDL Project", which should be organized in Moscow, Russia, or Smolenice, Slovakia, in the fall of 1993 or beginning of 1994.

(2) Scientific Background

Worldwide, there exist several evaluated nuclear data libraries for neutron-induced reactions. These libraries, in processed form, have served as the physical underpinning for thermal and fast fission reactor design and shielding, structural material design for potential fusion reactors, medical shielding and therapy applications, and other applications for which neutron-induced reaction cross sections are required. On the other hand, evaluations of charged-particle-induced reactions have been extremely limited. Because of the importance to fusion energy applications, the evaluation of charged-particle-induced reactions has largely been limited to reactions between isotopes of hydrogen and helium, i.e. the energy-producing fusion gas reactions.

Since there is increasing interest in the use of beams of heavier ions, e.g., ^{6,7}Li, as a means of more effectively heating fusion plasmas, evaluations of the interactions of isotopes of hydrogen and helium with the isotopes of lithium need to be carried out. Another important example of the need for charged-particle data is in the use of proton beams with energies up to 300 MeV for radiation oncology purposes. There is also increasing interest in the medical physics community in the possible use of other light charged particles, e.g., deuterons and alpha-particles, for cancer therapy. For these medical applications, interactions of the isotopes of hydrogen and helium with the main biological materials, i.e., carbon, nitrogen, and oxygen, must be

evaluated. When compared to the availability of well-documented, evaluated neutron-induced data, the status of evaluated charged-particle-induced data is in an early stage of development. In fact, the only reasonably complete library of this type is the Evaluated Charged-Particle Library (ECPL) at Livermore. But with the exception of the fusion gas reactions discussed above, this library has not been updated for many years.

Considerable progress has been achieved in the understanding of the role of sequential (charged-particle,n) reactions for inventory calculations. The sequential reaction is defined as a reaction which is caused by charged particles emitted from the primary neutron reaction with the materials. This reaction process has been overlooked in the radioactivity calculation so far. Recently, Cierjacks and Hino (KfK Karlsruhe, Germany) investigated the contribution of the sequential reaction to the induced radioactivities in D-T fusion reactor component and showed that these reactions can not be neglected for the long-lived radioactivity estimation.

(3) Objectives of the Meeting

The purpose of the meeting was to review the present status and availability of evaluated charged-particle and photonuclear data libraries for incorporation into the IAEA Fusion Evaluated Nuclear Data Library (FENDL), to review the theoretical models and their parametrization for the computation of nuclear data, to review the remaining gaps in the required data and, to identify further measurements and calculations needed to fill these gaps.

(4) Organization of the Meeting

The meeting was organized by the IAEA Nuclear Data Section with co-operation and assistance of local organizers from the Institute of Physics, Bratislava, and held from 18 to 21 April 1994 at the Smolenice Castle, the conference facility of the Slovak Academy of Sciences.

The meeting had full and excellent support from the local organizers.

(5) Meeting Proceedings

The meeting was opened by Dr. Ch.L. Dunford, Head of the Nuclear Data Section, and Dr. S. Hlavac on behalf of the Slovak Academy of Sciences.

The participants elected Dr. P. Obložinský, IAEA/NDS staff member, as Chairman of the meeting.

The meeting was subdivided into two parts. As shown in Attachment 3, presentations were given by 13 participants on a wide range of topics during the first half of the meeting. During the latter half of the meeting, the participants formed two working groups to address charged-particle and photonuclear matters separately. These groups were chaired by Dr. G. Hale of the Los Alamos National Laboratory, USA, and Dr. V. Varlamov, Centre on Photonuclear Data, Moscow, Russia, respectively. A summary of the presentations is given below as part of working group reports. The Meeting Agenda and a list of documents distributed at the meeting are given in Attachments 2 and 4, respectively.

(6) Meeting Attendance

The meeting was attended by 19 experts from 6 Member States including three staff members (Ch.L. Dunford, P. Obložinský and A.B. Pashchenko) from the Agency. The complete List of Participants and their affiliations are presented in Attachment 1.

(7) Results of the Meeting

The two Working Groups focussed the discussion on the following topics:

- Thermonuclear and associated charged-particle reactions;
- Charged-particle activation and medical-isotope production reactions;
- Photonuclear reaction cross section data.

The detailed reports of both Working Groups as well as the complete set of recommendations are presented below under item (10).

(8) Future Meetings

It was recommended that the IAEA/NDS should convene a Consultants' Meeting in early 1996 to review the final status of evaluations in the FENDL charged-particle and photonuclear data files.

(9) Acknowledgements

The meeting participants hope that the recommendation of this meeting may be pursued by the Agency to the mutual benefit of its Member States.

The participants wish to thank the Agency for focussing much needed attention on the important problems discussed here and wish to thank the staff of the Institute of Physics, Bratislava, for the efficient organization of the meeting and for the warm hospitality extended to its participants.

(10) Reports of Working Groups

Report of the Charged–Particle Data Evaluation Working Group

Participants: E. Běták, M. Blann, A.Blokhin, M. Drosg, B. Guzhovskij, S. Hlaváč, V. McLane, P. Obložinský, S. Sudár, H. Takahashi, T. Tárkányi, V. Varlamov
Chairman: G. Hale
Scientific Secretary: A. Pashchenko
Observers: V. Polhorský, and all other participants of the Meeting

Contributed Papers:

Drosg (Vienna) summarized the status of recent differential cross section measurements he has made for the T(d,n)^{4}He reaction at energies in the E_d=4-7 MeV range. He also presented new ^{6}Li(n,t) integrated cross sections that are on the order of 10% higher than ENDF/B-VI in the region of the shoulder at E_n=2 MeV.

Hale (Los Alamos) presented the results of an R-matrix analysis of the ^{5}He system at energies below E_d=10 MeV that accounts well for data from all reactions in the ^{5}He system, especially Drosg's differential cross section measurements in the E_d=4–10 MeV range.

Drosg then followed with a discussion of his d+t cross section evaluation up to 20 MeV energy range done in 1978, which recently was adopted by LLNL as the (ENDF/B-VI) integrated cross section evaluation at energies above ≈3 MeV, and which matches reasonably well to Hale's R-matrix results in the E_d=7–10 MeV region. It was agreed to extend Drosg's evaluation to 30 MeV.

Tárkányi (Debrecen) presented measurements along with some calculations and evaluated curves for many reactions involving p, d, ^{3}He, and ^{4}He on isotopes and natural elements of Be, B, C, Kr, Ar, Xe, Zn, Cu, Ti, Cd, Fe, Te of interest in the production of medical isotopes, and in the activation of structural materials. He and his colleague, Sudár, in the following talk, made the point that evaluations are just beginning for this important list of reactions, and that so far, model calculations have been useful only to identify problem areas in the data, but with more work could be used to help provide the evaluations themselves.

Guzhovskij (Arzamas) discussed diagnostic reactions in hot plasma, mainly afforded by the observation of energetic photon lines in the spectra of protons, deuterons, and α's on isotopes of Li. Many of these cross sections have been evaluated recently at Arzamas.

Běták (Bratislava) described a spin-dependent calculation of pre-equilibrium reactions (PEGAS code) that includes the competition of γ-transitions at each step. He found that the spin dependence was not negligible in some cases, leading to large differences with the spin-independent description of nucleon-emission processes.

Takahashi (Brookhaven) discussed the possibility of measuring fusion cross sections at very low energies by using muonic atoms of hydrogen (and helium) isotopes as either the beam or target, thereby enhancing the cross sections by factors large enough to be measurable.

Hlaváč (Bratislava) reported a new measurement of the production of α-particles from the interaction of 14.7 MeV neutrons with ^{16}O, by detecting γ-rays from the de-excitation of excited states of the $^{13}C^*$ residual nucleus. These measurements appear to lie below the ENDF/B-VI evaluation, and to agree with the JENDL-3 value.

Working-group discussion and recommendations:

A. Thermonuclear and associated charged-particle reactions:

The working group recognized that these were of primary concern in the FENDL file. However, the problem here is that the four major thermonuclear reactions T(d,n)^{4}He, D(d,n)^{3}He, D(d,p)T, and ^{3}He(d,p)^{4}He, have been evaluated more or less independently, except to the extent that Drosg's work has been used as noted earlier, at Arzamas, Livermore, and Los Alamos. These evaluations for the integrated d+t cross section do not appear to be in serious disagreement anywhere in the energy range that is important for applications. Therefore, we recommend the following:

- Evaluators of the d+t cross section from Arzamas, Livermore, Los Alamos, and Vienna meet at the Gatlinburg, Tenn. (USA) Nuclear Data Conference in May, and make a definite decision how to combine the 3 evaluations of the integrated cross section (some sort of statistical average might be appropriate) to get the FENDL evaluation. Legendre coefficients for the reaction angular distribution, plus possibly other

relevant information, would be taken from the Los Alamos/Vienna combined evaluation, which will extend to 30 MeV for the T(d,n)^{4}He reaction. The evaluated FENDL file, including, at a minimum, integrated cross sections, Maxwellian $< \sigma v >$, and Legendre coefficients for the T(d,n)^{4}He reaction, will be constructed and made available to IAEA within 2 months after the Gatlinburg conference.

- Evaluations completed recently at Arzamas for the reactions of ^{1,2,3}H on ^{6,7}Li, useful for plasma diagnostics, should be included in the FENDL sub-library. This work should be completed by the end of 1995.

- The IAEA should convene a Consultants' Meeting in early 1996 to review the final status of evaluations in the FENDL charged-particle file.

B. Charged-particle activation and medical-isotope production reactions

Work in this area is still in the initial phases. Many of the reactions still need to be measured, and it is not known if there is a complete compilation of the existing measurements. Therefore, we recommend that:

- The available compilations of such data be reviewed as to their completeness and currency. The IAEA should support the creation of an on-line computer data and reference display system, possibly starting from the existing NUCLEX system, for use by FENDL users and evaluators of charged-particle data.

Further it is our recommendation that:

- The IAEA support, in any way feasible, the effort to measure, compile, and evaluate (including the improvement of intermediate-energy model calculations) the cross sections for reactions associated with charged-particle activation, medical- isotope production, and beam monitoring. It is essential to start the evaluations with the most important reactions for medical isotope-production and for treatment planning in radiation oncology, and in beam-monitoring, so that a recommended set of cross-section values can be made available to users.

Report of the Photonuclear Reaction Data Working Group

Participants: E. Běták, M. Blann, A.Blokhin, M. Drosg, B. Guzhovskij, G. Hale, S. Hlaváč, P. Obložinský, A. Pashchenko, S. Sudár, H. Takahashi, T. Tárkányi
Chairman: V.Varlamov
Scientific Secretary: V.McLane
Observers: V. Polhorský, and all other participants of the Meeting

Contributed Papers:
1. **M.Blann** (USA LLNL) - oral
"Calculation of (γ,n to 11n) and (γ,p) Reactions and Comparison with Experimental Data".
2. **A.Blokhin** (Russia, Obninsk, CJD) - oral
"BOFOD: Present Status of the Evaluated Photonuclear Data File of CJD".
3. **A.Blokhin** (Russia, Obninsk, CJD) - oral
"Description of the Structure of Photonuclear Cross Sections in the Framework of One-Phonon Microscopic Model".
4. **V.Varlamov et al.** (Russia, Moscow, CDFE) - oral
"The Experimental Data and Evaluation Method for EPNDL-1".
5. **Zhuang Youxiang et al.** (China, Beijing, CNDC) - poster
"The Calculation of Photonuclear Data".

Introduction

Photonuclear reactions play an important role in a number of applications. Many laboratories use gamma rays for performing activation analysis of minerals, ores, coals, and other bulk materials for industrial applications using different sources of gamma radiation.

Other areas, where accurate photonuclear data are needed, are reactor in-core dosimetry (to take into account contributions from the photofission events in the monitor foils), radiation damage estimates in reactor structural materials (both for displacement and transmutation calculations), safeguards (for taking into account gamma-induced neutron production on light nuclei), and radiation oncology.

Because of high energy gamma-quanta production in processes of thermonuclear - plasma heating, photonuclear reactions are important for thermonuclear reactors. These reactions, but primarily neutron production reactions, have implications for not only plasma diagnostics, but for structural integrity of reactors and personnel safety.

Summary of contributed papers

1. Specialists working in the fields mentioned above are using "raw" photonuclear reaction cross section data from different (and often discrepant) experimental measurements because of the absence of recommended or evaluated data sets.
2. There are several different methods for photonuclear reaction cross section evaluation. They can be divided into two parts:

- model free treatment,taking into account systematical discrepancies between the results of different measurements by using the special method of recalculating the data obtained with individual apparatus functions to the unique presentation for the desired apparatus function of the needed quality (MSU INP CDFE);

- theoretical treatments of photonuclear reaction cross section data using various models (IPPE CJD, Japanese and Chinese working groups).

There is a need to create evaluated data files containing data for the most widely used photo-induced reactions.

Recommendations

1. Coordinate the efforts of various centers and groups in developing a list of photonuclear reactions of highest priority for evaluation.
2. Concentrate on evaluating, first, photoneutron reaction cross sections important for incorporation into the FENDL library.
3. Coordinate the efforts of different centers and groups in developing, a joint method for the evaluation of photonuclear reaction cross sections, taking into account both apparatus functions recalculation and theoretical models.
4. Concentrate efforts on the development of the Evaluated Photonuclear

Data Library (EPNDL-1) for FENDL project.

5. Identify certain experiments to serve as benchmark or standards for photonuclear evaluation. These experiments should include total monoenergetic gamma absorption measurements, and measurements of cross sections where the source is a gamma ray line emitted by an excited nucleus.

6. Organize a coordinated research program with the purpose of development of the evaluated photonuclear data library for the most widely used reactions, development of methodology of photonuclear reaction cross section evaluations, the role of theoretical model calculations (first of all, in cases when either no experimental data exist, or the data are inadequate).

7. It is recommended that IAEA NDS endorse collaboration between nuclear data centers and groups by using new possible sources of funding, such as the International Science Foundation (Soros) and European Foundations (Mitterand, et.al.).

Attachment 1

Charged Particle and Photonuclear Data Evaluations for FENDL

Smolenice, Slovakia, 18 - 21 April 1994

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AGENCY PARTICIPATION

Charles L. Dunford (first day only)

Pavel Obložinský

Anatoly Pashchenko (Scientific Secretary)

Attachment 2

IAEA Specialists' Meeting
on

Charged Particle and Photonuclear Data Evaluations for FENDL

Smolenice, Slovakia, 18 - 21 April 1994

Organized in co-operation with the Institute of Physics,
Slovak Academy of Sciences, Bratislava

AGENDA

Monday, 18 April

14:00 - 17:30 **Opening Session**

Opening Remarks by S. Hlaváč, Institute of Physics of the Slovak Academy of Sciences and Charles L. Dunford, Head of the IAEA Nuclear Data Section

- Election of Chairman
- Adoption of Agenda and Time Schedule
- Announcement of Organizational Matters

Session 2: Charged Particle Induced Reactions

- Presentations of Participants
- Discussions

Cocktail Party in the Red Salon of the Smolenice Castle

Welcome toast by Prof. J. Lánik, Director of IPSAS, Bratislava

Tuesday, 19 April

09:00 - 12:00 **Session 2 (continued)**

- Presentations of Participants
- Discussions

12:00 - 13:00 ***Lunch Break***

13:00 - 17:30 **Session 3: Photonuclear Reaction Data**

- Presentations of Participants
- Discussions
- Formation of Working Groups to draft the conclusions and recommendations of the meeting

Session 4: Conclusions and Recommendations

Wednesday, 20 April

09:00 - 12:00 - Drafting of meeting Conclusions and Recommendations

12:00 - 13:00 ***Lunch Break***

13:00 - 17:30 **Session 4 (continued)**

- Completion of Working Group Reports

Thursday, 21 April

09:00 - 12:00 **Session 5: Final Considerations**

- Discussion of Conclusions and Recommendations
- Corrections and Adoption of Final Reports
- Adoption of the Schedule of Work and Future Meetings
- Closing of the Meeting

Attachment 3

List of Presentations

(1) ***M. Drosg***, Institute of Experimental Physics, Vienna, Austria and Los Alamos. "Recent Charged-Particle Cross Section Measurements with Fast Neutrons in Few Nucleon Systems".

(2) ***G. Hale***, Los Alamos National Laboratory, USA. "R-Matrix Theory for d+t Reaction Analysis".

(3) ***M. Drosg***, Institute of Experimental Physics, Vienna, Austria and Los Alamos. "Extension of an R-Matrix Analysis of the Differential (and Total) Cross Sections of $^{3}H(d,n)^{4}He$ by an Evaluation up to 20 MeV".

(4) ***S. Sudar***, Institute of Experimental Physics, Debrecen. "Measurement and Calculation of Proton Induced Reactions on Iron".

(5) ***T. Tárkányi***, ATOMKI, Debrecen. "ATOMKI Program on Measurements, Compilation and Evaluation of Integral Data of Charged Particle Induced Reactions".

(6) ***B. Guzhovskij***†, Institute of Experimental Physics, Arzamas, Russia. "Nuclear Data for Hot Plasma Diagnostics in Tokamak".

(7) ***E. Betak***, Institute of Physics, Bratislava. "Spin-Dependent Fully Pre-equilibrium Calculations of Nucleon Emission".

(8) ***V. Varlamov***, Centre on Photonuclear Data, Moscow. "The Experimental Data and the Evaluation Methods for EPNDL-1".

(9) ***A. Blokhin***, CJD, Obninsk, Russia. "BOFOD: Present Status of the Evaluated Photonuclear Data File of CJD".

(10) ***A. Blokhin***, CJD, Obninsk, Russia. "Description of the Structure of Photonuclear Cross Sections in the Framework of one Phonon Microscopic Model".

(11) ***H. Takahashi***, Brookhaven National Laboratory, USA. "Possibility to Measure the Low Energy Fusion Cross-Section Using Muonic Atom".

(12) ***M. Blann***, Lawrence Livermore National Laboratory, USA. "Calculations of (γ, n to 11 n) and (γ,p) Reactions and Comparison with Experimental Data".

(13) ***S. Hlavac***, Institute of Physics, Bratislava. "Cross Sections at the $^{16}O(n,\alpha\gamma)$ Reaction at 14.7 MeV".

Attachment 4

IAEA Specialists' Meeting
on

Charged Particle and Photonuclear Data Evaluations for FENDL

Smolenice, Slovakia, 18 - 21 April 1994

LIST OF DOCUMENTS DISTRIBUTED AT THE MEETING

SPM/SMOL/P-1	Tentative Agenda and List of Presentations
SPM/SMOL/P-2	List of Participants
SPM/SMOL/P-3	Report INDC(NDS)-268, 1993. Summary Report of Consultants' Meeting on "Charged-Particle and Photonuclear Data Libraries for FENDL", BNL, USA, 8-9 October 1992.
SPM/SMOL/P-4	INDC(CCP)-326, 1991. S.N. Abramovich et al. Nuclear Physics Constants for Thermonuclear Fusion. A Reference Handbook.
SPM/SMOL/P-5	Russian original to SPM/SMOL/P-4.
SPM/SMOL/P-6	INDC(NDS)-297, 1994. Summary Report of Advisory Group Meeting on "Review of Uncertainty Files and Improved Multigroup Cross Section Files for FENDL", JAERI, Japan, 8-12 November 1993.
SPM/SMOL/P-7	INDC(NDS)-260. Summary Report of the Advisory Group Meeting on "FENDL-2 and Associated Benchmark Calculations", Vienna, Austria, 18-22 November 1991.
SPM/SMOL/P-8	INDC(NDS)-264. Summary Report of the Advisory Group Meeting on "Nuclear Data for Neutron Multiplication in Fusion-Reactor First-Wall and Blanket Materials", Chengdu, China, 19-21 November 1990.

SPM/SMOL/P-9 INDC(NDS)-241. Summary Report of Consultants' Meeting on "1st Results of FENDL-1Testing and Start of FENDL-2", Vienna, Austria, 25-28 June 1990.

SPM/SMOL/P-10 INDC/P(93)-16. Proposal for a new CRP on Evaluation of Cross-Sections of Monitor Reactions for Neutrons with Energies above 20 MeV.

SPM/SMOL/P-11 INDC/P(93)-17. Proposal for a CRP on Charged-Particle Light-Elements Reaction Data.

SPM/SMOL/P-12 INDC/P(93)-20. Proposed CRP on Charged-Particle Activation Data.

SPM/SMOL/P-13 Recommendations of the 19th Meeting of the International Nuclear Data Committee.

SPM/SMOL/P-14 Zhang Jingshang et.al. The Calculation of Photonuclear Data.

SPM/SMOL/P-15 Recommendation of the 19th Meeting of the International Nuclear Data Committee, Vienna, Austria, 8-12 March 1991