X199743316





International Atomic Energy Agency

 $\frac{\text{INDC(NDS)-353}}{\text{Distr.: G} + \text{FE}}$

INTERNATIONAL NUCLEAR DATA COMMITTEE

IMPROVEMENT OF MEASUREMENTS, THEORETICAL COMPUTATIONS AND EVALUATIONS OF NEUTRON INDUCED HELIUM PRODUCTION CROSS SECTIONS

Summary Report on the Third and Final Research Co-ordination Meeting organized by the International Atomic Energy Agency in co-operation with the Tohoku University and held in Sendai, Japan, from 25 to 29 September 1995

> Prepared by A.B. Pashchenko IAEA Nuclear Data Section Vienna, Austria

R

September 1996

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

Reproduced by the IAEA in Austria September 1996

INDC(NDS)-353 Distr.: G + FE

IMPROVEMENT OF MEASUREMENTS, THEORETICAL COMPUTATIONS AND EVALUATIONS OF NEUTRON INDUCED HELIUM PRODUCTION CROSS SECTIONS

Summary Report on the Third and Final Research Co-ordination Meeting organized by the International Atomic Energy Agency in co-operation with the Tohoku University and held in Sendai, Japan, from 25 to 29 September 1995

ABSTRACT

The present report contains the Summary of the Third and Final IAEA Research Co-ordination Meeting (RCM) on "Improvement of Measurements, Theoretical Computations and Evaluations of Neutron Induced Helium Production Cross Sections" which was hosted by the Tohoku University and held in Sendai, Japan, from 25 to 29 September 1995. This RCM was organized by the IAEA Nuclear Data Section (NDS), with the co-operation and assistance of local organizers from Tohoku University. Summarized are the proceedings and results of the meeting. The List of Participants and meeting Agenda are included.

Prepared by A.B. Pashchenko IAEA Nuclear Data Section Vienna, Austria

September 1996



Contents

1.	Introduction	7
2.	Objectives of the Meeting	,
3.	Organization of the Meeting	,
4.	Meeting Proceedings and Results	3
5.	Acknowledgements)

Attachments

Attachment 1:	Meeting Agenda	11
Attachment 2:	List of Participants	15
Attachment 3:	Conclusions and Recommendations	19
Attachment 4:	Chairing Remarks	27



1. Introduction

At the 1986 Gaussig Advisory Group Meeting on Nuclear Data for Fusion Reactor Technology it was recommended to create an international evaluated nuclear data library for this purpose. In the process of selecting evaluated nuclear data files for this library it turned out that even the most recent evaluations (ENDF/B-VI, JENDL-3, EFF-2, BROND-2) showed large discrepancies up to a factor of two for the (n,α) cross sections in the neutron energy region "threshold - 14 MeV" and that only very few and discrepant experimental data existed for neutron energies below 14 MeV.

In order to improve this situation a Coordinated Research Program (CRP) was initiated by the IAEA Nuclear Data Section with the following objectives:

- Improvement of the experimental data base for $(n,x\alpha)$ cross sections between threshold and 14 MeV, especially for the structural materials Cr, Fe and Ni and their main isotopes;
- Improvement of the theoretical models and their parametrizations for the computation of $(n,x\alpha)$ data, especially investigation of the causes of the existing discrepancies;
- Improvement of the existing $(n,x\alpha)$ data evaluations especially for the structural materials.

For this purpose the IAEA succeeded in obtaining the participation of ten laboratories from seven countries (Institute of Atomic Energy, Beijing, China; Center of Applied Studies for Nuclear Development, Havana, Cuba; Kossuth University Debrecen, Hungary; Japan Atomic Energy Research Institute and Tohoku University, Japan; Institute of Physics and Power Engineering and Institute of Nuclear Power Engineering, Obninsk, Russia; Oak Ridge National Laboratory and Los Alamos National Laboratory, U.S.A. and Institut für Radiumforschung und Kernphysik, University of Vienna, Austria). In addition scientists from Tohoku University, Kyushu University and Data Engineering Incorporation, Japan, Institute for Reference Materials and Measurements, Geel, Belgium, the Slovak Academy of Science, Bratislava, and the Institute of Atomic Physics, Bucharest, Romania, joined the program on a more informal basis.

The major activities of the CRP were performed by individual participants at their home institutes. Periodically the IAEA convened CRP meetings, bringing together all participants to review the status of the activities of the CRP. Between meetings, participants informed the IAEA of all relevant work on the subject and sent copies of all papers, progress reports, etc., to the IAEA, which were distributed to all participants. At least once a year, each participant submitted a progress report to the IAEA. A first Research Coordination Meeting (RCM) of this CRP was held at Debrecen, Hungary, in November 1992 and the second meeting was organized in Beijing, China, in November 1994. The third and final CRP meeting was hosted by Tohoku University and held in Sendai, Japan, from 25 to 29 September 1995. This report documents the summary of the third and final RCM of this program.

2. Objectives of the Meeting

A number of important results have already been reported at the first and second CRP meetings and the participants agreed on a detailed plan for their future work. The intermediate results of the CRP were reported at the International Conference on Nuclear Data for Science and Technology in Gatlinburg, 9-13 May 1994.

The purpose of this meeting was to discuss and evaluate the results from the research carried out by participating institutes and to prepare the joint status report of the CRP members to the IAEA, summarizing the results of the programme. The meeting agenda is given below as <u>Attachment 1</u>.

3. Organization of the Meeting

The third and final Research Co-ordination Meeting of the CRP was organized by the IAEA Nuclear Data Section with cooperation and assistance of local organizers from the Tohoku University.

The meeting was attended by ten chief scientific investigators involved and representives of the CRP teams and by ten observers and/or local participants. The CRP members were: H.K. Vonach (Austria), Zhang Jingshang (China), R. Capote Noy (Cuba), G.J. Csikai (Hungary), S. Chiba and M. Baba (Japan), N.V. Kornilov and A. Zelenetskij (Russia), Chia-Yao Fu and R.C. Haight (U.S.A.).

Y. Ikeda, Y. Kikuchi, Y. Takao, N. Yamamuro (all from Japan) and E. Wattecamps (Belgium) participated as observers and N. Hirakawa, S. Iwasaki, S. Matsuyama, T. Sanami and Y. Nauchi (all from Tohoku University) contributed as local organizers and participants.

The complete list of participants and their affiliations are given in <u>Attachment 2</u>.

4. Meeting Proceedings and Results

The meeting was opened by H. Oikawa, the Director of the Faculty of Engineering, Tohoku University, Sendai. After the welcome by A.B. Pashchenko on behalf of the Agency, H.K. Vonach was selected to be the chairman, and G.J. Csikai - as a co-chairman of the meeting.

The first day and first half of the second day of the meeting were devoted to presentations of progress reports by CRP members and observers on Measurements (Session 1) and on Theoretical Calculations and Evaluations (Session 2).

A considerable part of the experimental and theoretical work proposed in the recommendations of the second CRP meeting in Beijing, November 1994, has been successfully completed and reported at the meeting. It was agreed at the meeting that the proceedings of the RCM-3 should be published as an IAEA(NDS) - report within several months after the meeting. The texts of presentations and final results will be reproduced directly from the author's manuscripts.

After presentation of the results, the meeting chairman H.K. Vonach has formed two working groups on "Theoretical Computations and Evaluations" and "Experimental Investigations of (n,α) Cross Sections, Energy and Angular Distributions" for drafting of conclusions and recommendations of the meeting.

The full text of the CRP meeting conclusions and recommendations on the future work after the final CRP meeting are given below in <u>Attachment 3</u> as working group reports.

In addition to the recommendations given by the two working groups the CRP members made two general recommendations:

- The CRP meeting was hosted by Tohoku University. This allowed the CRP members to visit the accelerator laboratories of the university and to get thoroughly acquainted with the experimental facilities for the study of neutron induced reactions and the experimental program in fast neutron physics. The CRP members have been very impressed with the existing possibilities for nuclear data measurements and the high quality of the experimental work. The CRP members, therefore, strongly recommend that the fast neutron physics program of Tohoku University be supported at least at the present level. Its contribution is essential for the international nuclear data program as only very few laboratories still can do this work.
- The CRP members propose that the IAEA Consultants' meeting (CM) on "Improvement of measurements, theoretical computations and evaluations of neutron induced helium-production cross sections" should be held in 1997 in conjunction with the next International Nuclear Data Conference in Italy for the following reasons:
- The CRP on "Improvement of measurements, theoretical computations and evaluations of neutron induced helium production cross sections" has been very successful towards the goal of providing an improved data base of neutron induced He-production data for fusion reactor technology and other applications. It has provided He-production cross sections for iron with very much reduced uncertainties, which now satisfy the needs for all applications.
- For a number of other important materials like Ni, experiments of similar quality have been performed within the CRP, however final data analysis had not been completed by the time at the last CRP meeting. Thus in order to make full benefit of the large work started within CRP it appears necessary to have a Consultants' meeting at a time where all experiments started within the CRP will have been finally analyzed.
- It can be expected that this will take no longer than 1.5 years thus it appears to be timely to have this meeting in 1997 in conjunction with the next International Nuclear Data Conference in Italy. This would allow the presence of observers which could make important contributions without exceeding the budget for the CM. The results of the CRP should be reported at the conference (action on H.K. Vonach and A.B. Pashchenko).

The major item of the next three days was the preparation of the Joint Status Report summarizing the results of the CRP to the IAEA (Session 3). For this purpose on Tuesday afternoon, H.K. Vonach organized working groups for discussion and drafting of different chapters of the status report:

- Executive Summary (H.K. Vonach, G.J. Csikai, A.B. Pashchenko);
- Status of the He-production cross sections for the structural materials Cr, Fe and Ni (H.K. Vonach, G.J. Csikai, M. Baba, S. Chiba, N.V. Kornilov, R.C. Haight, S. Iwasaki, E. Wattecamps, Y. Takao);
- Summary of performed activation measurements (G.J. Csikai);
- Progress in theoretical computations of He-production cross sections (C.Y. Fu, R. Capote Noy, A.B. Pashchenko, N. Yamamuro, A.V. Zelenetskij, J. Zhang);
- Progress in experimental technique for investigation of (n,α) cross sections (H.K. Vonach,
 M. Baba, N.V. Kornilov);

The draft of the Status Report was discussed and adopted on Friday at the joint Session of the meeting.

The report gives a short summary of the work of each CRP member and those observers who contributed significantly to the work of the CRP. In addition, it summarizes the progress achieved by the CRP as whole in four sections: on measurement of α -production cross sections of structural materials, on theoretical computations of (n,α) cross sections, on measurements of activation cross sections and on improvement of experimental methods for (n,α) investigations. Details about these topics are given in publications which are also listed in this status report.

It was agreed that the status report should be revised after final analysis of all experiments started within the CRP and published as INDC(NDS)-document. This will be final report of the CRP to the IAEA.

5. Acknowledgements

The CRP members wish to thank the Agency for focusing much needed attention on the program for the improvement of measurements, theoretical computations and evaluations of neutron induced helium production cross sections. The final RCM had full and efficient support of the local organizers. The participants expressed their gratitude and appreciation to Messrs. Mamoru Baba (Chief Local Organizer), Naohiro Hirakawa, Shin Iwasaki, Shigeo Matsuyama, Toshiya Sanami, and Yasushi Nauchi, all of the Tohoku University in Sendai, for their interest, special arrangements and personal contributions to the meeting.

The closing remarks of G.J. Csikai, Co-Chairman of the RCM-3 are given in Attachment 4.

Attachment 1

Third and final Research Co-ordination Meeting on

"Improvement of Measurements, Theoretical Computations and Evaluations of Neutron Induced Helium Production Cross Sections"

Sendai, Japan 25-29 September 1995

AGENDA

Monday, 25 September

09:30 - 10:00 **Opening Session**

Opening remarks by Hiroshi Oikawa, Director of the Faculty of Engineering, Tohoku University and Anatoly B. Pashchenko, IAEA Nuclear Data Section

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

10:00 - 12:30 Session 1

- Progress Reports by the CRP Participants on Measurements
 - G.J. Csikai, Debrecen, Hungary: "Measured, Estimated and Calculated Helium Production Cross Sections"
 - (2) S. Chiba, Tokai, Japan: "Summary of JAERI's Contribution to the IAEA RCM on 'Improvement of Measurements, Theoretical Computations and Evaluations of Neutron Induced Helium Production Cross Sections'"
 - R.C. Haight, Los Alamos, NM, U.S.A.:
 "An Update on Measurements of Helium Production Reactions with a Spallation Neutron Source"
 - (4) M. Baba, Sendai, Japan:
 "Differential (n,α) Cross Section Measurement of Structural Elements"

Coffee break

- (5) S. Iwasaki, Sendai, Japan:
 "Activation Cross Section Measurements at the Tohoku University"
- (6) E. Wattecamps, Geel, Belgium:
 "Measured and Calculated Differential and Total Yield Cross Section Data of 58-Ni(n,xα) and 63-Cu(n,xp) in the Neutron Energy Range from 2.0 to 15.6 MeV"
- (7) E. Wattecamps, Geel, Belgium:
 "Ongoing and Planned Neutron Activation Cross Section Measurements of 50-Cr, 52-Cr, 53-Cr, 54-Cr, 54-Fe and 58-Ni at IRMM Geel and FZ Juelich in the Energy Range from 5 to 20 MeV"
- (8) Y. Takao, Kyushu University, Japan:
 "Helium Atoms Measurement System and Helium Production Cross Section Measurement".

Discussion

- 12:30 14:00 Lunch
- 14:00 17:30 Session 2
 - Progress Reports on Theoretical Calculations and Evaluations
 - (9) Chia-Yao Fu, Oak Ridge, TN, U.S.A.:
 "Effects of Shape Differences in the Level Densities of Three Formalisms on Calculated Cross Sections"
 - (10) Zhang Jingshang, Beijing, China:"The UNF Programme Set and Its Theoretical Fundamental"
 - (11) N. Yamamuro, Yokohama, Japan:"The (n,xα) Reaction Cross Section Data up to 50 MeV"

Coffee break

- (12) N. Kornilov, Obninsk, Russia:"Investigation of α-emission for Nuclear Induced Reactions"
- (13) R. Capote Noy, Habana, Cuba and A.V. Zelenetskij, Obninsk, Russia: "Nuclear Level Densities and Optical Model Parameters in Helium Production Cross Section Calculations on 54-Fe, 56-Fe, 52-Cr and 58-Ni"

Discussion

Tuesday, 26 September

09:00 -	12:30	Session	3
---------	-------	---------	---

- Preparation of the Final Report Summarizing the Results of the CRP
- General discussion (contents, chapters, sections)
- Formation of the Working Groups to draft the Summary Report
- 12:30 14:00 Lunch
- 14:00 15:00 Session 3 (continued)
 - Working Groups discussions and drafting of different chapters of the final report
- 15:00 17:00 Technical tour: Fast Neutron Laboratory

Wednesday, 27 September

- 09:00 12:30 Session 3 (continued)
 - Working Groups Sessions on drafting of the final report
- 12:30 14:00 Lunch
- 14:00 17:30 Technical tour: Cyclotron-Radioisotope Center

Thursday, 28 September

- 09:00 12:30 Session 3 (continued)
 - Completion of the Final Report
 - General discussion and corrections

Friday, 29 September

- 09:00 16:00 Session 4
 - Final Consideration, Correction and Adoption of the Final Report
 - Discussion on Future Activities
 - Closing of the RCM



Attachment_2

334-F4-RC-498.3

INTERNATIONAL ATOMIC ENERGY AGENCY

Third Research Co-ordination Meeting on "Improvement of Measurements, Theoretical Computations and Evaluations of Neutron Induced Helium Production Cross Sections" Sendai, Japan 25 to 29 September 1995

Scientific Secretary: Anatoly B. PASHCHENKO

LIST OF PARTICIPANTS

AUSTRIA

Herbert K. VONACH (6876/CF) Institut für Radiumforschung und Kernphysik der Universität Wien Boltzmanngasse 3 A-1090 Vienna Fax: +43-1-31367-3502 Tel.: +43-1-3177205 E-mail: vonach@pap.univie.ac.at

BELGIUM

E. WATTECAMPS
Institute for Reference Materials and Measurements
Retieseweg
B-2440 Geel
Fax: +32-14-584-273
Tel.: +32-14-571-381
E-mail: eric@garfield.irrm.jrc.be

<u>CHINA</u>

ZHANG Jingshang (7048/RB) Chinese Nuclear Data Center Institute of Atomic Energy P.O. Box 275 (41) Beijing 102413 Fax: +86-10-935-7008 Tel.: +86-10-935-7275 E-mail: ciaednp@bepc2.ihep.ac.cn

<u>CUBA</u>

Roberto CAPOTE NOY (7049/RB) Centro de Estudios Aplicados al Desarrollo Nuclear Calle 30 #502 e/5ta y 7ma. C. Habana Fax: +537-33-1188 Tel.: +537-22-1518 E-mail: ceaden@ceniai.cu

HUNGARY

Gyula J. CSIKAI (6971/RB) Institute of Experimental Physics Kossuth Lajos University Bem tér 18/a, P.O. Box 105 H-4001 Debrecen Fax: +36-52-315-087 Tel.: +36-52-415-222 E-mail: h470csi@ella.hu

<u>JAPAN</u>

Satoshi CHIBA (7050/CF) Nuclear Data Center Department of Reactor Engineering, JAERI 2-4 Shirakata-shirane Tokai-mura, Naka-gun Ibaraki-ken, 319-11 Fax: +81-292-82-6122 Tel.: +81-292-82-5483 E-mail: chiba@cracker.tokai.jaeri.go.jp Yujiro IKEDA Fusion Neutronics Laboratory Japan Atomic Energy Research Institute Tokai-mura, Naka-gun Ibaraki-ken 319-11 FAX: +81-29-282-5709 Tel.: +81-29-282-6074 E-mail: ikeda@fnshp.tokai.jaeri.go.jp

Yasuyuki KIKUCHI Nuclear Data Center Department of Reactor Engineering, JAERI 2-4 Shirakata-Shirane Tokai-mura, Naka-gun Ibaraki-ken, 319-11 Fax: +81-29-282-6122 Tel.: +81-29-282-5480 E-mail: kikuchi@cracker.tokai.jaeri.go.jp

Yoshiyuki TAKAO Department of Energy Conversion Kyushu University 6-1 Kasuga-kouen, Kasuga-shi Fukuoka-ken 816 Fax: +81-92-575-1352 E-mail: takao@ence.kyushu-u.ac.jp

Nobuhiro YAMAMURO Data Engineering Incorporation 60 Kita-Hassaku-cho, Midori-ku Yokohama 226 E-mail: j90224@sinet.ad.jp

RUSSIA

Nikolai KORNILOV (6877/CF) Institute of Physics and Power Engineering Bondarenko Sq. 1 249020 Obninsk, Kaluga Region Fax: +7-095-883-3112, 095-230-2326 Tel.: +7-08439-98813, 08439-97557 E-mail: poa@cjd.obninsk.su

Andrey V. ZELENETSKIJ (7128/CF) Institute of Atomic Energetics 249020 Obninsk, Kaluga Region Fax: +7-095-255-2225 Tel.: +7-095-3-69-31 E-mail: iate@storm.iasnet.com

UNITED STATES OF AMERICA

Chia-Yao FU (7051/CF) Oak Ridge National Laboratory P.O. Box 2008 Oak Ridge, TN 37831-6364 Fax: +1-615-574-9619 Tel.: +1-615-574-6116 E-mail: cyf@ornl.gov

Robert C. HAIGHT (7909/CF) Mail Stop H803, Group P-23 Los Alamos National Laboratory Los Alamos, NM 87545 Fax: +1-505-665-4121 Tel.: +1-505-667-2829 E-mail: haight@lanl.gov

<u>I.A.E.A.</u>

Anatoly B. PASHCHENKO (Scientific Secretary of the Meeting) IAEA Nuclear Data Section Wagramerstrasse 5, P.O. Box 100 A-1400 Vienna, Austria Fax: +43-1-20607 Tel.: +43-1-2060-21708 E-mail: pashchenko@iaeand.iaea.or.at

LOCAL ORGANIZERS

Mamoru BABA (Chief Local Organizer) Department of Nuclear Engineering Faculty of Engineering Tohoku University Aoba-ku, Sendai 980-77 Fax: +81-22-217-7900 Tel.: +81-22-217-7909 E-mail: baba@fermi.nucle.tohoku.ac.jp

Naohiro HIRAKAWA

Department of Nuclear Engineering Faculty of Engineering Tohoku University Aoba-ku, Sendai 980-77 Fax: +81-22-217-7900 Tel.: +81-22-217-7908 Shin IWASAKI Department of Nuclear Engineering Faculty of Engineering Tohoku University Aoba-ku, Sendai 980-77 Fax: +81-22-217-7900 Tel.: +81-22-217-7907 E-mail: iwa@minel.nucle.tohoku.ac.jp

Shigeo MATSUYAMA Department of Nuclear Engineering Faculty of Engineering Tohoku University Aoba-ku, Sendai 980-77 Fax: +81-22-217-7900 Tel.: +81-22-217-7910 E-mail: shige@rpl.nucle.tohoku.ac.jp

LOCAL PARTICIPANTS

Toshiya SANAMI Department of Nuclear Engineering Tohoku University Aoba-ku, Sendai 980-77 Fax: +81-22-217-7900 Tel.: +81-22-217-7910 E-mail: toshi@rpl.nucle.tohoku.ac.jp

Yasushi NAUCHI Department of Nuclear Engineering Tohoku University Aoba-ku, Sendai 980-77 Fax: +81-22-217-7900 Tel.: +81-22-217-7910 E-mail: nauchi@rpl.nucle.tohoku.ac.jp



Attachment 3

CONCLUSIONS AND RECOMMENDATIONS

3rd Research Co-ordination Meeting of the Agency's CRP on "Improvement of Measurements, Theoretical Computations and Evaluations of Neutron Induced Helium Production Cross Sections"

Chairman: H.K. Vonach

I. Report of the Working Group on Theoretical Computations and Evaluations

Working Group Chairman: C.Y. Fu

Working Group Members A.B. Pashchenko R. Capote Noy N. Yamamuro A.V. Zelenetskij Zhang Jingshang

(1) **Progress Summary**

The working group on computations and evaluations concluded that the most serious problem in accurately predicting the (n,α) cross section was in the level densities used for the calculations. Small changes in the level densities used for competing channels, particularly (n,n'), can result in substantially larger changes in the calculated (n,α) cross sections. For this reason, a large part of the research program is related to nuclear level densities.

The Gilbert-Cameron (GC), Generalized Superfluid Model (GSM) and Back-Shifted Fermi Gas (BSFG) formulas for nuclear level densities, equally popular among evaluators, differ in excitation energy dependence (shape). By forcing agreement of these three level densities at two selected energies, the shape effects on calculated (n,α) cross sections and α -emission spectra can be examined. Fu has shown for ⁵⁸Ni using the TNG code that this shape difference in level-density formulas can change both the calculated (n,α) cross sections and α -emission spectra by up to 60% below incident neutron energies of 20 MeV. It is concluded that, in addition to the well known problems in level density parameters, the level density formulas themselves are also problematic in nuclear model calculations.

Capote performed combinatorial calculations (CC) of the total level densities (with vibrational enhancement added for RCM-3 to improve the CC accuracy) to impose constraints on the level densities of residual nuclei not having experimental neutron resonance information. This lack of level density information is true for ⁵⁸Ni and ⁵⁸Co, the two major residual nuclei in the ⁵⁸Ni cross-section calculations. To use the CC results in cross-section calculations, Capote derived BSFG parameters by fitting the discrete levels and the CC result near the neutron binding energy. To study

the BSFG and GSM differences, Zelenetskij did the same fitting of CC using GSM. The differences in the calculated cross sections using BSFG and GSM reflect the shape differences between BSFG and GSM. This result of BSFG and GSM differences is consistent with that shown above by Fu. The CC-GSM combination appears to be a useful tool for cross-section calculations since a rather good description of (n,2n), (n,p) and (n,α) cross sections was achieved without level-density adjustments.

The above approach by Capote and Zelenetskij has also been applied for ⁵⁶Fe. In this case, the uncertainties in the level densities are smaller because two of the residual nuclei have neutron resonance information. This smaller uncertainty allows optical model problems in the alpha particle channel to be addressed. Zelenetskij and Capote found that the agreement of their calculations with experimental data obtained in this CRP can be improved by increasing the diffuseness in the optical model parameters for alpha particles.

Yamamuro calculated (n,α) and α -production cross sections for Cr, Fe, and Ni, as well as their major isotopes up to 50 MeV. He is able to obtain very good agreement with experimental data. This success is attributed to the use of Ignatyuk type of shell corrections in the GC formalism and the freedom to adjust the diffuseness parameter in the optical model for α particles. The level density parameter α is also allowed to be adjusted. He hopes that systematics for the diffuseness parameters can be established.

Zhang has improved his UNF code in several major areas. First, the master equation formulation of the pre-equilibrium model used in his code now conserves angular momentum and parity. This conservation is then utilized to improve the Iwamoto-Harada pickup model in such a way that angular distributions in complex particle emissions can be obtained in a natural manner. Validity of this model has been established by comparisons with experimental double differential (n,α) cross sections for V, Fe, Nb, and Bi.

(2) Concluding Remarks

Yamamuro has used the GSM shell correction in the GC formalism in order to achieve good agreement with experimental data up to 50 MeV. Let us call this level density approach GCY. During the Sendai meeting, GCY has been compared with GC, BSFG, and GSM for their shape differences for ⁵⁸Ni up to 20 MeV. The spread of the level densities is a factor of 2 at around 20 MeV, where GCY yields the highest level density, GC next, GSM the third, and BSFG the lowest. To determine which of the 4 formalisms is the most suitable for cross section calculations up to 50 MeV remains an interesting and challenging task.

II. Report of the Working Group on Experimental Investigations of (n, α) Cross Sections, Energy and Angular Distributions

Working Group Chairman: H. Vonach

Working Group Members M. Baba S. Chiba J. Csikai R.C. Haight S. Iwasaki N.V. Kornilov A.B. Pashchenko Y. Takao E. Wattecamps

(1) **Results Reported at the Meeting**

A considerable part of the experimental work proposed in the recommendations of the second CRP-meeting (Beijing, November 1994) has been successfully completed and reported at the meeting. In detail the following results have been achieved.

a) α -emission from structural materials

The α -emission measurements from Los Alamos have been analyzed and total α -emission cross sections from threshold to 30 MeV for both ⁵⁸Ni and ⁶⁰Ni were presented by Haight. In addition double differential α -emission measurements for ⁵⁸Ni for neutron energies in the range 4.5-11 MeV were performed by Baba and the results also presented at the meeting. In these measurements an α -energy resolution of about 150 keV was obtained allowing resolution of several discrete levels (α_0 , α_1 , α_2). The results of Haight and Baba agree within uncertainties both with each other and earlier measurements of Paulsen and Baba for ^{nat}Ni and He-accumulation measurements of Haight for ⁵⁸Ni, ⁶⁰Ni and ^{nat}Ni. There is some disagreement on absolute α -emission cross sections with the result of Goverdovski around En=5 MeV (see report of second RCM, p. 10).

As the result of the described experiments, there exists now an adequate experimental data base for the neutron induced α -production in nickel and its main isotopes ⁵⁸Ni and ⁶⁰Ni.

b) α -emission from other elements

Helium production cross-sections for Al and ^{nat}Si were determined by He accumulation measurement by Takao for several energies around 14 MeV. The results are in good agreement with previous data from Kneff (He-accumulation) and Grimes (α -emission measurements). For all elements the (n, α) activation cross sections at 14 MeV based on an improved systematics of Csikai are in good agreement with the direct measurement.

c) Activation measurements

New measurements of activation cross sections were reported by Csikai, Iwasaki and Chiba.

Csikai reported new results on the reactions ${}^{45}Sc(n,\alpha){}^{42}K$, ${}^{63}Cu(n,\alpha){}^{60}Co$, ${}^{65}Cu(n,\alpha){}^{62}Co$ and ${}^{208}Pb(n,\alpha){}^{205}Hg$ at En=14 MeV and ${}^{90}Zr(n,\alpha){}^{87m}Sr$ (En=6.8 MeV and 13 MeV), ${}^{51}V(n,\alpha){}^{48}Sc$ (En=9.9-13.86 MeV) and ${}^{89}Y(n,\alpha){}^{86}Rb$ (En=11.8 MeV and 13.82 MeV). Iwasaki reported new measurements on the reactions ${}^{59}Co(n,\alpha){}^{56}Mn$ and ${}^{93}Nb(n,\alpha){}^{90m}Y$ for neutron energies 12.0-20.0 MeV and Chiba presented Ikeda's new results for the reactions ${}^{17}O(n,\alpha){}^{14}C$, ${}^{18}O(n,n'\alpha){}^{14}C$, ${}^{19}F(n,\alpha){}^{16}N$, ${}^{23}Na(n,\alpha){}^{20}F$, ${}^{35}Cl(n,\alpha){}^{32}P$, ${}^{37}Cl(n,\alpha){}^{34}P$, ${}^{55}Mn(n,\alpha){}^{52}V$ and ${}^{89}Y(n,\alpha){}^{86m}Rb$ for neutron energies 13.4-14.9 MeV. For those cases, which have been measured before there is in general good agreement with previous results.

(2) Recommendations on the Future Work after the Final CRP-meeting

Although a large part of the work plan of the CRP has been fulfilled successfully, some further work is required for three reasons:

- 1) A number of experiments started within the CRP has not been completely analyzed.
- 2) For one of the important structural materials, chromium, no measurement for the main isotope ⁵²Cr has been performed because of technical difficulties in obtaining suitable targets.
- 3) New request for He-production in materials have developed since the start of the CRP such as the need for He-production in silicon for the semi-conductor industry.

In detail, the following tasks should be addressed:

- a) The analysis of the He-production measurements on ⁵⁶Fe, ⁵⁸Ni and ⁶⁰Ni at Los Alamos and those of the ⁵⁸Ni measurements at Tohoku University should be completed as soon as possible in order to allow a detailed comparison of the energy and angular distributions of the emitted α -particles from the different experiments. For this purpose, it would be very desirable if the results of the Geel experiments could also be transformed to the CM system. Furthermore an effort should be made to find the reason for the discrepancy between the ⁵⁸Ni(n, α) cross sections of Goverdovski and the rest of the experiments.
- b) As soon as the final α -production cross-sections from the Los Alamos and Tohoku experiments on ^{58,60}Ni become available a new evaluation of the α -emission cross sections for ⁵⁸Ni and ⁶⁰Ni should be performed at IRK. For this purpose all data on ⁵⁸Ni, ⁶⁰Ni and ^{nat}Ni should be jointly evaluated by the least squares method.
- c) All participants are requested to investigate the possibilities to provide a suitable ⁵²Cr (thickness 2-3mg/cm²) target to Baba in order to enable at least one measurement of the (n,α) excitation function for this important isotope from threshold to 14 MeV. In the absence of such target, it is strongly recommended to perform a new α -emission measurement for natural Cr.

d) Cross section measurements for n, α reactions leading to long lived radioactive nuclei, started in a Jülich-Debrecen-Cologne collaborations, have so far not been completed because of technical problems. These measurements, which include the reactions ${}^{13}C(n,\alpha) {}^{10}$ Be, ${}^{17}O(n,\alpha){}^{14}C$, ${}^{18}O(n,n'\alpha){}^{14}C$ and ${}^{39}K(n,\alpha){}^{36}Cl$ should be completed because of their importance for radioactive waste estimates.

e) (n, α) measurements for light elements.

For medical purposes, it is recommended that double differential α -emission measurements for carbon and oxygen be performed up to quite high energies. This request could be fulfilled by the analysis of the (n, α) measurements already performed at WNR and the planned (n, α) measurements at Tohoku University in the 40-70 MeV range.

f) Integral test for activation cross sections.

Spectrum averaged (n,α) cross sections for thick target Be+d and Li+d neutrons are required at different incident deuteron energies for testing and validation of the differential data especially for structural materials (V, Fe, Zn, Nb, Zr and Mo isotopes) from threshold to 20 MeV. Measurements started in a Debrecen-Jülich collaboration and at Tohoku University are therefore strongly encouraged.

g) (p, α) experiments

According to RCM-2 recommendations, (p,α) reactions were investigated at IPPE Obninsk concerning the reaction mechanism. The ⁵⁴Cr (p,α) reaction cross sections and energy and angular distributions were measured near 7 MeV. The angular distributions for the α_0 and α_1 channels indicate different mechanisms for these channels. However, additional investigations are needed to make final conclusion and determine the contribution of the direct reaction mechanism for some other nuclei.

h) For the estimation of radiation damage of integrated circuit more information on the double-differential α -emission cross section for ^{nat}Si is needed up to high neutron energies (several hundred MeV). Analysis of the WNR experiments and further measurements extended to higher neutron energies are strongly encouraged.

III. General Recommendations

In addition to the recommendations given by the two working groups the CRP members wish to express two general recommendations:

- 1) The CRP meeting was hosted by Tohoku University. This allowed the CRP members to visit the accelerator laboratories of the university and to get thoroughly acquainted with the experimental facilities for the study of neutron induced reactions and the experimental program in fast neutron physics. The CRP members have been very impressed with the existing possibilities for nuclear data measurements and the high quality of the experimental work. The CRP members, therefore, strongly recommend that the fast neutron physics program of Tohoku University be supported at least at the present level. Its contribution is essential for the international nuclear data program as only very few laboratories still can do this work.
- 2) The CRP members propose that the IAEA Consultants' meeting (CM) on "Improvement of measurements, theoretical computations and evaluations of neutron induced helium- production cross sections" should be held in 1997 in conjunction with the next International Nuclear Data Conference in Italy.

The meeting participants pointed out that the CRP on "Improvement of measurements, theoretical computations and evaluations of neutron induced helium production cross sections" has been very successful towards the goal of providing an improved data base of neutron induced He-production data for fusion reactor technology and other applications. It has provided He-production cross sections for iron with very much reduced uncertainties, which now satisfy the needs for all applications.

For a number of other important materials like Ni, experiments of similar quality have been performed within the CRP, however final data analysis had not been completed by the time at the last CRP meeting. Thus in order to make full benefit of the large work started within the CRP it appears necessary to have a Consultants' Meeting at a time where all experiments started within the CRP will have been finally analyzed. It can be expected that this will take no longer than 1.5 years thus it appears to be timely to have this meeting in 1997 in conjunction with the next International Nuclear Data Conference in Italy. This would allow the presence of observers which could make important contributions without exceeding the budget for the Consultants' Meeting. The results of the CRP should be reported at the Conference (action on H.K. Vonach and A.B. Pashchenko).

This Consultants' Meeting should have the following objectives:

- It should produce recommended He-production cross sections for Cr and Ni and their main isotopes similarly to Fe data already obtained within the CRP. For this purpose a proposal for each material will have to be worked out by members which is discussed and possibly modified and adopted by the Consultants' Meeting.
- There should be a detailed comparison of the α-energy spectra and angular distributions obtained in different experiments for the same material especially for the isotopes ⁵⁶Fe (and ^{nat}Fe) and ⁵⁸Ni for which several high quality measurements exist. This comparison should be

done for some incident neutron energies between threshold and 14 MeV. It can be expected that this will result in high-quality recommended double-differential α -production data, which will provide a unique benchmark for nuclear reaction calculations. Comparisons of these data with theoretical predictions should also be discussed.

- It can be expected that the α -production measurements performed at WNR, Los Alamos, will provide cross sections up to 50 MeV for a number of materials. This gives the possibility to test theoretical computations to considerably higher energies. The results of such comparison should be discussed at the Consultants' Meeting.
- A number of integral tests of activation cross sections for (n,α) reactions have been started within the CRP, but could not be completed by the time of this meeting. These results should also be reported and discussed at the Consultants' Meeting.
- The Joint Status Report 1995 should be revised at the meeting and published as the final report of the CRP to the IAEA.

The CRP members are aware of the fact that the success of the proposed Consultants' Meeting requires considerable preparatory work from the Consultants' Meeting members and they are willing to fulfill this task if the Consultants' Meeting is accepted (see plan for future work given in the two working group reports).

Attachment 4

Chairing Remarks of G.J. Csikai, Co-Chairman of RCM-3

Acknowledgements

The members and the observers of the RCM-3 are very grateful to Prof. M. Baba and his coworkers for the unforgettable hospitality and for the excellent working conditions during the whole meeting held in Sendai between 25-29 September 1995 at the Department of Nuclear Engineering, Tohoku University. Thanks are due to Prof. H. Oikawa, Director of the Faculty of Engineering, Tohoku University for hosting this meeting and making all the necessary facilities available.

Visits at the Dynamitron, Fast Neutron Laboratory and the Cyclotron-Radioisotope Center were appreciated very much by the participants who enjoyed the successful use of these multipurpose machines in research, education and applications. We are convinced that this model must be followed by other universities, too, to ensure the specialization in many fields of nuclear oriented research and applications for the students as well as in the education of the rising nuclear generation.

The participants of the Final Meeting of this RCM-3 are deeply indebted to the IAEA, personally to Dr. A.B. Pashchenko for the invitation to attend this meeting and for his efforts in the organization and coordination of the He-production CRP and the related RCMs. This programme could provide for the participating members and their institutions the most direct way in exchanging information and thus can improve the experimental and theoretical methods used for the determination of nuclear data with an emphasis on the differential and integral He-production cross sections. This CRP has initiated many other investigations related to the applications of nuclear data in science and technology.

On behalf of the participants I wish the scientists at Tohoku further successes in their work and the Agency also in the organization of such Co-ordinated Research Programmes under the supervision of the IAEA, Nuclear Data Section.

We are willing to fulfill the tasks of the new CRPs on our special fields with a great enthusiasm similarly to the previous programmes.

Sendai, 29 September 1995

Julius Csikai Co-Chairman of RCM-3

Nuclear Data Section International Atomic Energy Agency P.O. Box 100 A-1400 Vienna Austria e-mail, INTERNET: SERVICES@IAEAND.IAEA.OR.AT e-mail, BITNET: RNDS@IAEA1 fax: (43-1) 20607 cable: INATOM VIENNA telex: 1-12645 atom a telephone: (43-1) 2060-21710

online: TELNET or FTP: IAEAND.IAEA.OR.AT username: IAEANDS for interactive Nuclear Data Information System username: NDSOPEN for FTP file transfer

R