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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

CO-ORDINATED RESEARCH PROGRAMME ON MEASUREMENT AND ANALYSIS OF 14 MEV NEUTRON NUCLEAR DATA NEEDED FOR FISSION AND FUSION REACTOR TECHNOLOGY

Summary Report
of the Second Research Co-ordination Meeting
organized by the
International Atomic Energy Agency
and held at Chiang Mai University, Chiang Mai, Thailand
4-8 February 1985

Prepared by
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International Atomic Energy Agency

July 1985

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

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I. Summary of the Meeting

Introduction

The second Research Co-ordination Meeting (RCM) of the participants in the IAEA Co-ordinated Research Programme (CRP) on Measurement and Analysis of 14 MeV Neutron Nuclear Data needed for Fission and Fusion Reactor Technology was convened by the IAEA Nuclear Data Section at Chiang Mai, Thailand. The Chiang Mai University was the host, who also organized the International Symposium on Fast Neutrons in Science and Technology concurrently with the meeting. The Symposium was co-sponsored by IAEA and the International Seminar in Physics of Uppsala University, Sweden. The second RCM was run by the Scientific Secretary M.K. Mehta with the assistance of the local organizing committee and the local secretary T. Vilaithong.

Objectives

The objectives of this co-ordinated research programme are the measurement and analysis of scattering and reaction cross sections and of secondary particle energy and angular distributions for 14 MeV neutrons available from neutron generators via the $^{3}H(d,n)^{4}He$ reaction. The measurements are to be made on elements and their isotopes which are the constituents of fission and fusion reactor structural, coolant, absorber, shielding, reprocessing and neutron flux/fluence monitoring materials.

The principal objectives of this second Research Co-ordination Meeting (RCM) were to review the status and progress of the measurement programme of each participating laboratory, to review and discuss the experimental and analysis techniques used, to intercompare the results of measurements already made and to discuss and decide on the programme for the next year for each of the laboratories.

Organization of the meeting

The Agenda for the meeting was arranged through previous correspondance with the CRP participants as shown in Appendix I.

To take advantage of the availability of a number of well-known experts in the field of fast neutron research, the Chiang Mai University organized concurrently with this meeting an International Symposium on Fast Neutrons in Science and Technology. The combined programme of the RCM and the Symposium spanned four and a half days with a visit to the Chiang Mai University Fast Neutron Research Facility arranged for Friday (8 February) afternoon.

Following the pattern of the First RCM held in Gaussig, GDR, in November 1983 this RCM was organized with sessions in three different categories consisting of

- reports from the participating laboratories
- five invited talks
- working group discussions.

Three working groups (WG A, B, C) dealt with types of data measured with different experimental techniques e.g. activation and other off-line methods, charged particle emission cross sections measured through detection or accumulation of the emitted species, and double differential cross sections for neutron emission spectra. A fourth working group (WG D) discussed the status of current theoretical models for calculating reaction cross sections. The working groups discussed and intercompared the results reported by the participants and the plan of measurement for the next year. WG A also discussed the results reported by the participants on activity measurements of the nickel foils irradiated at the Lawrence Livermore Laboratory's intense neutron source and distributed to the participants under the intercomparison exercise recommended by the working group at the first RCM in Gaussig in November 1983. The intercomparison indicated that as far as the activity measurement was concerned the results from all laboratories were consistent with each other (within the indicated errors) and even displayed the flux difference between the front and the back of the foil stack effectively. A separate report will be published in the INDC(NDS) series describing this exercise and the results in detail.

The invited talks were by scientists from five laboratories in Sweden, Japan, FRG, P.R. China and USA which are especially active in fast neutron research either as producer or user of 14 MeV neutron nuclear data. The topics of these talks were directly related to the programme of the CRP. Four of these laboratories are not directly participating in the CRP but have strong programmes in fast neutron physics overlapping with the objectives of the CRP. Scientists from these laboratories were invited by the host Chiang Mai University to take part in the concurrently organized International Symposium on Fast Neutrons in Science and Technology.

The part of the programme related to the Symposium consisted of five plenary invited review talks, three of them being general reviews of the use of neutrons in technological research, in industrial research and in basic research respectively. The other two plenary talks dealt with instruments and methods for fast neutron research and evaluation of fast neutron cross sections through reaction model calculations. In addition there were eleven short contributed papers presented by participating scientists from the region as well as from USA, Sweden and P.R. China.

Meeting attendance

Currently there are nine research contracts and six research agreements under this CRP. Thirteen chief scientific investigators or their nominees (in two cases) participated in the meeting. Two research contract holders could not participate due to unavoidable local circumstances. In adddition to the CRP participants, a number of scientists from countries in the region as well as from USA and Europe attended the concurrently organized symposium. These, plus several scientists from institutions and universities in Thailand added up to a participation of 45 at the meeting. The CRP participants at the second RCM are listed in Appendix II while Appendix III lists all the participants who attended the Symposium.

Conclusions and Recommendations

Each working group has prepared a report which includes specific technical recommendations. These reports were discussed in the last session and approved by all participants and are reproduced in full under III in this document. As a second stage of the intercomparison exercise on activation measurements the Working Group A has recommended activation measurements on natural Mo foils, one batch to be irradiated at the Lawrence Livermore Laboratory and distributed for measurements of long-lived activities, and each participant laboratory to irradiate one of the unirradiated Mo foils from the same batch to measure short-lived activities. This exercise will involve complex gamma spectra and will intercompare the spectral analysis codes as well as other techniques of reducing measured activities to cross sections. The Working Group C has recommended measurement of neutron emission spectra from 14 MeV neutron bombardment of Pb and C, for intercomparison between participant laboratories whose programme includes neutron spectra measurement. Following general recommendations were agreed to by all participants:

1. The work of this CRP should be terminated during 1986 and a third and final RCM should be held in May/June 1986.

2. Each participating laboratory should prepare a final report of all the work done under the CRP and send it to the respective Working Group chairman. The report should include final numerical results of measurements and/or calculations with associated errors, complete description of experimental/theoretical techniques, methods of data analysis, corrections and uncertainties.

3. These reports should be discussed by respective Working Groups at the third RCM and a terminal report summarising and including the final results should be prepared to be published by IAEA/NDS.

Next Meeting

The participants of the RCM agreed to have the third and final meeting of the CRP in May or June 1986 and agreed to hold it at a suitable place in Yugoslavia at the invitation of the Ruder Boskovic Institute, Zagreb.

II. Meeting Programme

The scientific programme of the meeting was distributed over 14 sessions comprizing the three categories mentioned earlier. Some were joint sessions which included parts of the Symposium programme. In addition there were sessions fully devoted to the Symposium programme consisting of review talks and contributed papers. The break up of the RCM programme sessions is given below.

Session I		Adoption of agenda and formulation of working groups Chairman - M.K. Mehta
Session II		Reports by 3 participating laboratories: Austria, Bangladesh and Czechoslovakia Chairman - K. Gul
Session III		Reports by 4 participating laboratories: Federal Republic of Germany, German Democratic Republic, Hungary, Morocco Chairman - A.M. Ghose
Session IV		Invited lectures (joint session)
	I-1	Neutron spectrometer for the JET project G. Grosshocs (Chalmers University of Technology, Sweden)
	I-2	The Osaka OCTAVIAN fast neutron research facility A. Takahashi (University of Osaka, Japan) Chairman - B. Goel
Session V		Reports by 4 participating laboratories: Pakistan, Poland, Thailand, Yugoslavia Chairman - L. Hansen
Session VI		Reports by 4 participating laboratories: Vietnam, Malaysia, Romania, USA Chairman - D. Miljanic

Session VII Working Group A: Activation and other off-line methods
Chairman - J. Csikai

Session VIII Invited lectures (joint session)
I-3 Evaluator's and user's view of 14 MeV neutron data
B. Goel (Institute of Neutronenphysik and Reaktortechnik, FRG)
Chairman - A. Marcinkowski

Session IX Invited lectures (joint session)
I-4 The 14 MeV neutron work at LLNL
L.F. Hansen (Lawrence Livermore National Laboratory, USA)
Chairman - I. Garlea (replaced)

Session X Working Group B: Charged particle emission cross section measurement
Chairman - H. Vonach

Session XI Invited lecture (joint session)
I-5 14 MeV neutron work of the People's Republic of China
Wen Shen Lin (Normal University of Beijing, P.R. China)

Session XII Working Group C: Double differential neutron emission cross section measurements
Chairman - D. Seeliger

Session XIII Working Group D: Nuclear reaction model calculations
Chairman - A. Marcinkowski

Session XIV Working Group reports, conclusions & recommendations
Chairman - M.K. Mehta

III. Working Group Reports

(1) Report of Working Group A on Activation and other Off-Line Methods

J. Csikai (Chairman), S.M. Qaim, H. Vonach, I. Ribansky, M. Berrada, H.D. Luc, T. Vilaithong, A.M. Ghose, A. Marcinkowski and M.K. Mehta

1. A guide-line on measurements of 14 MeV neutron induced cross sections by the activation method was prepared in 1984 by J. Csikai, with inputs from some of the members of the Working Group, and distributed by the IAEA to all the participating laboratories.

2. An exercise on the intercomparison of activity measurements was worked out. Ni foils were prepared in IRK, Vienna and irradiated in LLNL, Livermore and distributed among the participating laboratories doing activation measurements. At the Working Group meeting results were available from eight laboratories. Except for one or two cases the results from various laboratories appeared to be consistent. A detailed evaluation will be carried out by the IAEA later and the participating laboratories will be informed.

3. It was felt that this exercise was relatively simple. It is suggested that the exercise should now be carried out on natural molybdenum. Two sets of foils should be prepared, one of them should be irradiated with 14 MeV neutrons to determine the activity of ^{95}Zr in a complex gamma ray spectrum.

The unirradiated foils should be used for cross section measurements in each laboratory, selecting one or more suitable reactions. The earlier exercise intercompared activity measurement instrumentation and methodology. The gamma spectrum to be analysed consisted of simple fully resolved peaks. The proposed new exercise will involve analysis of a complex gamma spectrum and irradiation instrumentation and methodology.

4. Each participating laboratory should calibrate the detectors using the IAEA supplied gamma calibration sources. Any participant laboratory which has not obtained such a set should request it from NDS-IAEA.

5. The Working Group noted that results of cross section measurements were presented at the meeting or sent to the IAEA by the following laboratories: IRK, Vienna, Austria (H. Vonach); Atomic Energy Research Establishment, Dhaka, Bangladesh (N.I. Molla); Slovak Academy of Sciences, Bratislava, Czechoslovakia (I. Ribansky); KFA Jülich, FR Germany (S.M. Qaim); Kossuth University, Debrecen, Hungary (J. Csikai); University Sains, Penang, Malaysia (A.M. Ghose); Mohammed V. University, Rabat, Morocco (M. Berrada); Institute of Nuclear Studies, Warsaw, Poland (A. Marcinkowski); Chiang Mai University, Thailand (J. Csikai, T. Vilaithong); National Science Research Center, Hanoi, Vienam (H.D. Luc).

As some of these results are not final measurements it is suggested that final reports of each working group prepared for the next and final RCM should contain all numerical values for measurements carried out under this CRP.

Some additional results of fast neutron cross section measurements were presented by scientists from laboratories not participating in the CRP (e.g. China, Japan).

6. It appears that the discrepancies in the data are decreasing because of the improved methods of measurements, e.g. experience gained during the IAEA training courses, study tours, experts' missions, fellowships, improvements in the measuring and irradiating techniques, use of separated isotopes and radiochemical separations. For soft and low intensity gammas the discrepancies are higher. Therefore, extra care is needed in absorption corrections and choice of reference nuclear data. Some discrepancies are possibly caused by uncertainty in the physico-chemical composition of the target material used. A number of new data were presented. It was not possible to evaluate all those measurements during the Working Group meeting.

7. Most of the data presented, deal with the nuclei outlined in the CRP programme and are relevant to the WRENDA list. It is therefore recommended to the IAEA NDS to initiate an evaluation of all the reported data in the knowledge of the details of the measuring conditions by the next CRP meeting. It is proposed that J. Csikai coordinates this work, involving Z. Bödy currently on fellowship assignment at the IAEA/NDS.

8. The proposals for work during the last phase of the CRP are in agreement with the requirements of the IAEA and should meet some timely fusion reactor design needs.

9. In view of the fact that many of the laboratories in developing countries received the necessary equipment only recently, the Working Group strongly felt that a new CRP programme should be defined. This recommendation is underlined by the fact that cross sections on many important nuclei are still unknown; see e.g. the compilation of Qaim (Handbook of Spectroscopy Vol. III, CRC Press 1981); Csikai (in Nuclear Theory and Applications - 1980, IAEA-SMR-68/I; Bychkov et al. Report INDC(CCP)-146;LJ, 1980).

(2) Report of Working Group B on Charged Particle Emission Cross Section Measurements

H. Vonach (Chairman), D. Miljanic, S.M. Qaim and M.K. Mehta

Since the last meeting the following progress was made:

1. The Vienna group completed the analysis of the ^{56}Fe(n,alpha), ^{60}Ni(n,alpha) and ^{93}Nb(n,p) experiments. The results for ^{56}Fe(n,alpha) and ^{60}Ni(n,alpha) were published in Phys. Rev., the Nb(n,p) results have been accepted for publication in Nucl. Science and Eng.

New measurements of double differential charged particle emission cross-sections have been performed by means of the Vienna multi-telescope system for the reactions ^{55}Mn(n,alpha), ^{59}Co(n,alpha), Ag(n,p) and In(n,p). The ^{55}Mn and ^{59}Co(n,alpha) data have been analyzed and the total He-production cross section was found to be in good agreement with recent activation data. The analysis of the (n,p) experiments has not yet been completed.

2. The Warsaw group has completed the analysis of the ^{58}Ni(n,p) data presented at the last CRP meeting and the results of this work have been accepted for publication.

3. The Zagreb group reported new measurements of coincident alpha spectra from the ^{7}Li(n,alpha) reaction, measurements of the angular distribution of deuterons and tritons from the ^{27}Al(n,d) and ^{27}Al(n,t) reactions and measurements of continuous alpha-particle spectra from the multi-particle break-up reaction from ^{9}Be+n.

4. The Jülich group presented measurements of total tritium emission production cross sections induced by Be(d,n) break-up neutrons for a larger number of isotopes. This work is already published in Nuclear Physics A. Some new measurements were reported for the ^{7}Li(n,n't)alpha reaction in the energy range of 8-10 MeV.

Until the next CRP meeting the following work is planned:

1. The Vienna group intends to complete the analysis of the measured (n,p) reaction on Ag and In and to measure the double differential charged particle emission cross sections for the reactions ^{50}Cr(n,alpha), ^{181}Ta(n,p) and Au(n,p).

2. The Warsaw group will investigate with their multi-telescope system the ^{60}Ni(n,p) reaction, supplementing very well the (n,alpha) measurements on this important isotope performed at the IRK Vienna.

3. At the Institut Ruder Boskovic, Zagreb, the analysis of the experiments reported at this meeting will be completed. In addition it is planned to start coincidence measurements of (n,n'alpha) reactions on selected nuclei by coincident alpha-particle and neutron detection.

4. The Kernforschungsanlage Jülich will investigate total tritium production in the reactions ^{9}Be(n,t), ^{10}B(n,t) and ^{14}N(n,t).

The possibility of measurement of the backward part of neutron elastic scattering angular distributions for light nuclei by the detection of their recoils was discussed. This could be done for all stable hydrogen and helium isotopes as well as for ^{6}Li and ^{9}Be. In the case of ^{7}Li the sum of the cross sections for neutron scattering to the ground and first excited states could be measured. Some of these measurements were done at 14 MeV. However, they should be extended to other nuclei and energies to complement existing data from neutron detection measurements and to improve their accuracy.

Finally it was stressed that even with the classical telescope method very useful work in the field of charged particle emission from neutron induced reactions can be performed. It is therefore recommended that scientists from developing countries should be encouraged to start such work, which is also a good starting point to get familiar with more advanced experimental techniques.

(3) Report of Working Group C on Double Differential Neutron Emission Cross Section Measurements

D. Seeliger (Chairman), K. Gul, L.f. Hansen, H.D. Luc, D. Miljanic, I. Ribansky, T. Vilaithong, H. Vonach and M.K. Mehta

Further substantial contributions to the WG discussions came from the following scientists who are not CRP participants but who were present as participants to the International Symposium on Fast Neutrons: N. Chirapatpimol (Thailand), B. Goel (FRG), T.K. Jandeel (Irak), W. Shen Lin (P.R. China), A. Takahashi (Japan) and several other scientists from Thailand.

During the meeting in Chiang Mai a voluminous amount of new results in the areas of TOF-Spectroscopy as well as DDCS (double differential cross section) measurements have been presented in more than 10 lectures, invited and contributed talks and laboratory reports by G. Grosshoeg, K. Gul, L. Hansen, T. Jandeel, R. Madey, D. Seeliger, A. Takahashi, T. Vilaithong and others.

The remarkable progress achieved at the Chiang Mai University in the development of the TOF-Spectroscopy using the associated particle method is acknowledged.

New measurements also by the associated particle method were presented by PINSTECH, Pakistan.

Impressive results using neutron spectroscopy are obtained in different Chinese laboratories and also in Baghdad.

This leads to the conclusion, that besides the well-established activation techniques for cross section determination, in a growing number of developing laboratories the more sophisticated methods of neutron TOF-Spectroscopy have been introduced in the laboratory practice.

A major contribution to the DDCS neutron data is still coming from the traditional laboratories working in this field in Livermore, Dresden and Osaka. New experiments are in preparation at Vienna.

The WG C came to the following recommendations:

1. Noting the increasing number of laboratories involved in neutron TOF-measurements for DDCS data determination, the establishment of a few well-known reference data for intercomparisons is highly recommended.

Following the recommendations of the IAEA Advisory Group Meeting on Standard Reference Data (Geel, October 1984) as well as the discussions at the present Symposium at Chiang Mai, the following cross sections are recommended for this purpose:

a) ^{12}C differential elastic and inelastic scattering cross sections (the latter for the first excited 2^+ level only) as reference data for isolated neutron groups.

b) Pb (natural) double-differential neutron emission cross sections as reference data for continuous spectra. (As alternative candidates for reference data, ^{56}Fe and ^{93}Nb were also considered, but based on the recent measurements at Osaka and Dresden as well as considering the practical importance of lead as a multiplier material the latter one was selected as the first candidate).

In order to establish consistency between the measurements undertaken by the CRP participant laboratories an intercomparison exercise based on the above mentioned reference data is strongly recommended. The exercise would consist of measurement of neutron emission spectra from 14 MeV neutron bombardment of ^{12}C and natural Pb targets. The measurement of spectra should be done at 90^o. Those laboratories which have appropriate facilities should also measure the spectra at a number of angles including suitably selected forward and backward angles.

2. The following institutes agreed to participante in the intercomparison for carbon and lead data: IRK (Vienna), LLL (Livermore), TU (Dresden), Normal University (Beijing), PINSTECH (Rawalpindi), University (Chiang Mai). Institutes in Bratislava, Zagreb and Baghdad agreed to participate in the intercomparisons as and when their facilities became operational. It was realised that a few laboratories not represented at Chiang Mai may be interested in such an exercise. Their participation would be most welcome.

3. The compilation of all measured data for this exercise by different groups will be carried out at the

- Lawrence Livermore Lab. for ^{12}C
- Technical University Dresden for Pb.

These laboratories should present a summary on the intercomparisons including the recommendation of a set of reference data at the 3rd CRP-Meeting in 1986.

4. It was strongly recommended to IAEA/NDS to make available a californium spontaneous fission neutron source included in a fission chamber for measurements and intercomparisons of the efficiency functions of neutron detectors used in TOF spectrometers in the laboratories of CRP participants. It was suggested that Dr. Klein at PTB, Braunschweig, FRG, may be approached for this purpose.

5. The light response functions for the calculation of the efficiency should be compiled at the Chiang Mai University where this activity has been started already.

6. For the purpose of reporting data for the final reports (general recommendation # 2 on p. 3) the Technical University Dresden will prepare a recommendation concerning the informations which should be given uniquely in all DDCS neutron emission data reports and distribute it well before the 3rd CRP-Meeting.

7. At the 3rd CRP-Meeting in 1986, after the results of all DDCS measurements are discussed and summarized for the final CRP-report (general recommendation # 3 on p.3), further steps for the improvement of the experimental and theoretical neutron emission DDCS data base should be taken and recommended to the IAEA to be considered by the planned 1986 Advisory Group Meeting on Nuclear Data for Fusion Reactor Technology.

(4) Report of Working Group D on Reaction Model Calculations

A. Marcinkowski (Chairman), H.D. Luc, B. Berrada, S. Wiboolsake, W. Shen Lin, H. Vonach, D. Seeliger, C.Y. Fu, K. Gul, I. Ribansky, A. Takahashi and M.K. Mehta

1. Present status of model calculations of cross sections for 14 MeV neutrons:

- The working group states an unsatisfactory situation in the description of the preequilibrium component of the neutron spectra by the existing theoretical models in contrast to the compound nucleus model calculations, which in the light of the recent International Nuclear Models and Codes Comparison (carried out by NEA, see Appendix IV) yield satisfactorily consistent data.

- The double differential cross sections including proton and alpha emission spectra have not been intercompared.

2. Recommendations:

Concluding that any improvements of the concistency of the preequilibrium calculations are beyond the activities of the CRP the working group recommends to the NDS to initiate an action aimed at:

- the extension of the intercomparisons conducted by NEA to the calculations of (n,p) and (n,alpha) reaction double-differential cross sections at different projectile energies (e.g. for ^{56}Fe).

- the better definition of the preequilibrium calculations by assuming a physically consistent set of constants, e.g. the mean free path of nucleons in the nucleus, the number of neutrons or protons in the initial exciton configuration etc.

Co-ordinated Research Programme on Measurement and Analysis of 14 MeV Neutron Nuclear Data needed for Fission and Fusion Reactor Technology
Second Research Co-ordination Meeting, Chiang Mai, 4-8 February 1985

Adopted Agenda

1. Opening statements, announcements and adoption of agenda

2. Reports by CRP participants

3. Invited lectures

4. Working group meetings - discussions and preparation of reports

5. Working group reports: presentation, discussions, conclusions and recommendations

6. Next meeting

Co-ordinated Research Programme on Measurement and Analysis of 14 MeV Neutron Nuclear Data needed for Fission and Fusion Reactor Technology
Second Research Co-ordination Meeting, Chiang Mai, 4-8 February 1985

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Drs. Hansen and Seeliger participated in place of Drs. Haight and Seidel respectively. Drs. Garlea and Molla could not attend due to unavoidable circumstances.

Co-ordinated Research Programme on Measurement and Analysis of 14 MeV Neutron Nuclear Data needed for Fission and Fusion Reactor Technology Second Research Co-ordination Meeting, Chiang Mai, 4-8 February 1985

List of Participants at the International Symposium on Fast Neutrons in Science and Technology and the second Research Co-ordination Meeting

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International Nuclear Model and Code Comparison on Pre-equilibrium Effects

H. Gruppelaar and P. Nagel

Final results have been analysed of an international effort to compare statistical nuclear models and codes that calculate reaction cross sections, emission spectra and angular distributions, taking into account pre-compound or preequilibrium effects. These models are widely used in nuclear data evaluations and in predictions of neutron-induced reaction cross sections at energies of 5 to 50 MeV, i.e. in an energy-range that is of interest for technological applications. The participants were asked to calculate cross sections of neutron-induced reactions on 93 Nb at incident energies of 10, 14.6, 20 and 25.7 MeV. This nucleus was chosen because it is well-studied, both experimentally and theoretically, and because pronounced precompound effects were observed in neutron emission spectra at 14.6 and 25.7 MeV. At lower incident energies (below 5 to 10 MeV) precompound effects become of minor importance and the usual Hauser-Feshbach models with a correction for width fluctuation effects could be used.

The full report will be published by the NEA Data Bank later this year.

The contributions received are as follows:

CLASS A, Modified HF codes, unified models

STAPRE, GNASH, EMPIRE, PERINNI, HAUSER-V, TNG

CLASS B, Exciton-model codes (spin-independent)

PRANG, PEQGM, PREM, PREANG1, PRECO-D2, AMAPRE

CLASS C, Hybrid model

ALICE HYBRID + evaporation model, ALICE GDH + evaporation model, ALICE, GDH + evaporation model, SECDIST + evaporation model, EMPIRE.

The analysis showed that:

- There are no serious problems in the optical-model calculations (σ_t, σ_{el}, σ_r).
- There is quite good agreement in the calculation of σ_{nnx} (maximum standard deviation is at 25.7 MeV: ±4%). The PREM results show the largest deviation, at least at 25.7 MeV (-8.7%). The ALICE results are inconsistent with σ_r. Note that the equilibrium results are in excellent agreement, except for the HAUSER-V results at low energy.
- With respect to the σ_{npx} data, there is not much agreement; the standard deviation is 40% to 50%. However, the equilibrium calculation is also quite uncertain: ±50% at low energies up to 30% at 25.7 MeV.

- For the calculation of $\sigma_{n\alpha x}$, the situation is still worse: the standard deviations range from 30% to 60%; for the equilibrium results they vary from 30% to 80%. Extremely low cross sections are calculated by PREANG1.

- For the calculations of $\sigma_{nn'\gamma}$, $\sigma_{n2n\gamma}$ and $\sigma_{n3n\gamma}$, we find quite acceptable results, with a standard deviation of less than 10% for high values of these cross sections (>500 mb), except at E=10 MeV. In general the codes of Class A are superior, although reasonably good results can also be obtained with codes of class B as follows from the tables. We note that the differences between the PERINNI results and the other codes at 10 MeV is partly due to the renormalisation to the back-shifted Fermi-gas formula, rather than using the Gilbert-Cameron level density.

- The standard deviation of the calculated total neutron-production cross sections is less than 5%. However, the pre-equilibrium contribution in this quantity is rather small (at most 23% at 25.7 MeV). The hybrid model codes also give good results.

- With respect to the total photon-production data, we notice reasonably good agreement between the class A codes that calculate these quantities; STAPRE, GNASH, TNG and EMPIRE. The results of PEQGM are much higher. Again, the pre-equilibrium effect is not large in this lumped quantity.

- Some codes also calculate cross sections for the population of isometric states.

The calculation of σ_{nnx} is generally satisfactory, although in some codes there is no consistency with the total reaction cross section (the codes should automatically check and eventually correct this discrepancy). The calculation of the much weaker σ_{npx} and $\sigma_{n\alpha x}$ cross sections is unreliable. In particular the treatment of the α-emission needs more care. The calculation of multi-particle emission cross sections is difficult near thresholds: the energy grid is not always fine enough and perhaps no appropriate corrections are made if only part of a "bin" can be further emitted.

In codes of classes B and C, where the level density is described by a continuum over the whole energy range, it is important to utilise a realistic expression at low energies, otherwise the (n,2n) and (n,3n) cross sections cannot be calculated with high accuracy. Again it is necessary to check the consistency of the multi-particle emission with the first-emission cross sections. Some results of 10 MeV need to be better understood, mainly because the (n,2n) threshold is relatively low. Probably the γ-ray competition is important as well (it is neglected in most codes of classes B and C). We feel that most codes of classes B and C need further development in the following directions:

(1) Refinement of multi-particle emission treatment with respect to enery mesh and integration;

(2) More realistic description of the level density at low energies, in agreement with experimental level schemes (or introduction of discrete-level excitation).

(3) Introduction of γ-ray competition.

Our impression is that the neglect of angular-momentum conservation is not the prime reason for some differences between the results of classes A and B+C. This follows for example from a comparison of PERINNI and PRANG results.

International Nuclear Model Computer Exercise: Spherical Optical Model

In addition to the Coupled Channel, Spherical Optical and Statistical Model Comparison Exercise, the Charged Particle Optical Model Exercise has also now been completed (NEANDC-198U/INDC(NEA)5).

This latter exercise was organised in order to identify possible reasons for some important discrepancies that were found in the charged particle emission cross sections of the spherical optical model exercise.

The comparison covered calculations for protons and alpha-particles scattered at 5, 10, 15 and 20 MeV from Carbon-12, Cobalt-59 and Lead-208. The reaction cross-sections agreed reasonably well for practical purposes. It could be verified that the Coulomb functions used in the codes were essentially correct. A closer examination showed significant differences in detail. One code was found eventually to give erroneous results. Another iteration of the exercise was run in which the participants were asked to use the same mathematical parameters that control the integration of the radial wave equation and to use the same values of the wave number and Coulomb parameter. This exercise concentrated on neutron and proton as incident particles and Carbon-12 as target. Agreement could then be improved considerably.

One code was run on two different computers using the same word length both in single and double precision. On the average the agreement was of 0.1 percent for the differential cross section and about 0.7 percent for the polarisation. This can be considered as an estimation of the best agreement that can be obtained in this kind of exercises.

The results for the different codes in the last iteration agreed on the average to 1 percent in the differential cross-section and 2-3 percent in the polarisation.

The published results can be considered as a standard to check spherical optical model calculations.

Bibliographic note: ^{235}U and ^{239}Pu Sample Masses

A report in the ANL Nuclear Data and Measurements series received at the Data Bank may be of particular interest to evaluators:

^{235}U and ^{239}Pu Sample-mass determinations and inter-comparisons,
W. Poenitz and J. Meadows, ANL/NDM-84, Nov. 1983.

Abstract

In order to estimate the uncertainties on the fission cross-sections which come from the determination of the fissile sample masses, fifteen samples of ^{235}U obtained from seven laboratories and four samples of ^{239}Pu were studied. The masses were determined from absolute alpha counting and the relative 2π alpha and fission ratio measurements, and intercompared.

The results indicate that ^{235}U sample masses are well enough known ($\pm$0.3 percent) for the required high accuracy fission cross-section measurements. The comparison for the ^{239}Pu sample indicates problems in the order of 1-3 percent which are more likely to be related to counting efficiencies than to sample masses.

The absolute alpha decay rates and absolute masses of the ^{235}U samples can be used to determine the halflife of ^{234}U. This one was found equal to $(2.457\pm0.005)\ 10^5$ yrs.