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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

MEASUREMENT AND ANALYSIS OF 14 MeV NEUTRON NUCLEAR DATA NEEDED FOR FISSION AND FUSION REACTOR TECHNOLOGY

Summary Report
of the First Research Co-ordination Meeting
organized by the
International Atomic Energy Agency
and held at Technical University of Dresden, Gaussig, GDR
21-25 November 1983

Prepared by
M.K. Mehta
Nuclear Data Section
International Atomic Energy Agency

September 1984

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I. Summary of the Meeting

Introduction

The first meeting 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 Gaussig, GDR, the Technical University of Dresden were the host, who also organized the XIII International Symposium on Nuclear Physics - Fast Neutron Reactions, concurrently with the meeting. The Research Co-ordination Meeting was run by the Scientific Secretary M.K. Mehta with the assistance of the local organizing committee consisting of D. Seeliger (chairman), K. Seidel, D. Hermsdorf, H. Morten and U. Kayser. The chairmanship of the various sessions were shared by all the participants to the CRP.

Objectives

The principal objectives of the first research coordination meeting 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 future measurements to be undertaken by each laboratory.

Organization of the Meeting

The Agenda for the meeting was arranged through previous cooerespondence with the CRP participants and is given in Appendix 1. The programme of the meeting based on the Adopted Agenda was spread over four and a half days of sessions with a short visit to the neutron generator laboratory of the Physics Section of the Technical University Dresden in Pirna being paid on Friday (25 November 1983) morning.

The meeting was organized with sessions in three different categories consisting of

- eight invited review talks,
- reports from the participating laboratories on the status of their programmes and
- working group discussions.

Three working groups dealt with three areas of importance in the measurements under this programme, namely experimental techniques, nuclear data measurements, and comparison with theoretical models.

The invited talks dealt with specific areas of interest to the participants and reviewed the "state of the art" in each area. The progress reports from the laboratories reviewed the current and projected programme of each laboratory and the working groups discussed technical details and specific problems associated with the programme of each laboratory. The working group A was subdivided into two subgroups: WG A(A) on measurement techniques which dealt with standard and new detectors, spectrometers, data acquisition, beam monitors, calibration etc., and WG A(B) on neutron generators which dealt with radiological protection, targets, ion sources, etc. in relation to regular operation of 14 MeV neutron generators. Working Group B was subdivided into three subgroups, according to techniques or types of nuclear data measured under this programme. Activation and other off-line methods were covered under WG B(A), neutron and gamma spectroscopy were covered under WG B(B), and WG B(C) dealt with charged particle spectroscopy. The discussions under these subgroups also included corrections to be applied to measurements and accuracy estimations.

Meeting Attendance

At the time of the meeting there were seven research contracts and six research agreements under this CRP. Eleven principal scientific officers participated in the meeting; one was replaced by another scientist working in the programme. One principal scientific officer could not participate due to unavoidable local circumstances. In addition to the above one consultant was invited by the Agency for consultation on specific technical matters. The participants to the first RCM of the CRP are listed in Appendix 2.

Scientists from a number of developing laboratories who are participants in the Interregional Project TC/INT/1/018 on Nuclear Data Measurement Techniques and Instrumentation were invited by the host institution at no cost to the Agency. In addition one participant each from Japan and USSR plus the participants from the local laboratories added up to a total participation of 51 at the meeting. The list of all participants is given in Appendix 3.

Conclusions and Recommendations

Each working group prepared a report which included specific technical recommendations. In addition, WG B(A) & WG B(B) developed guidelines for standardising the methodology of measurement to be followed by the participating laboratories so that intercomparison of final results can be carried out and a "recommended" set of data could be produced at the end of this CRP which can be included in the EXFOR data files of the Agency.

A major intercomparison exercise was recommended by WG B(A) on activation techniques. A large number of the same target samples should be activated at the intense neutron source of the Lawrence Livermore National Laboratory in the USA and then be distributed to all participants who would measure the activities at their own laboratories. The results will be intercompared and discussed at the next research co-ordination meeting. This exercise will help especially the new laboratories in the developing countries to test their equipment and measurement reliability capability, and at the same time will go a long way to remove the discrepancies in the existing data by standardizing the activation measurement technique.

Next Meeting

Participants of the CRP decided to have their next meeting in February 1985. A informal invitation was extended both by the participants from Chiang Mai, Thailand and Zagreb, Yugoslavia. It was agreed to have the meeting in Chiang Mai, Thailand.

II. Meeting Programme

The scientific programme of the meeting was arranged in sessions as follows:

Session 1 - Review Lectures

L1 - Present 14 MeV data needs for fission and fusion reactor technology,
J.J. Schmidt, IAEA

L2 - Measurement of (n,gamma), (n,p) and (n,2n) cross sections by activation techniques
J. Csikai, Debrecen

L3 - Measurements of (n,d), (n,t), (n,He-3) and (n,He-4) cross sections by activation techniques and other off-line methods
S.M. Qaim, Juelich

L4 - Measurements of cross sections and spectra for neutron emitting channels by fast neutron spectroscopy
D. Seeliger, Dresden

L5 - Measurements of cross sections and spectra by charged particle spectroscopy
H. Vonach, Vienna

L6 - Measurements of cross sections and spectra by gamma-ray spectroscopy
P. Oblozinsky, Bratislava

L7 - Theoretical models and computer codes for 14 MeV neutron nuclear data calculations
D. Hermsdorf, Dresden

L8 - Recent progress in pre-equilibrium models
I. Ribansky, Bratislava

Session II - Progress Reports from CRP Participants

Following scientists from laboratories participating in the CRP presented progress reports at the meeting. Dr. I. Molla was unable to attend due to unavoidable circumstances. Dr. Ngoc attended the meeting and presented the report on behalf of Dr. H.D. Luc from Viet Nam.

1. H. Vonach, Vienna, Austria
2. P. Oblozinsky, I. Ribansky, Bratislava, Czechoslovakia
3. K. Seidel, Dresden, German Democratic Republic
4. S.M. Qaim, Juelich, Germany, Federal Republic of
5. J. Csikai, Debrecen, Hungary
6. M. Berrada, Rabat, Morocco
7. K. Gul, Rawalpindi, Pakistan
8. A. Marcinkowski, Warsaw, Poland
9. T. Vilaithong, Chiang Mai, Thailand

10. R.C. Haight, Livermore, USA
11. P.N. Ngoc, Vietnam
12. D. Miljanic, Zagreb, Yugoslavia

Session III - Working Group A

- Experimental Techniques -

This WG was subdivided into two subgroups each with a specific scope in connection with the experimental techniques used for 14 MeV measurements.

WGA(A) - Measurement Techniques
(Standard and new detectors and spectrometers, data acquisition, beam monitors, efficiency checks A.5.0)
Chairman: K. Seidel, Dresden

WGA(B) - Neutron Generators
(Experience in the use of N.G., radiological protection, targets, ion sources, tritium monitoring, dosimetry control of staff and laboratories)
Chairman: M. Berrada, Rabat

Session IV - Working Group B

- Nuclear Data Measurements -

This WG was subdivided into three subgroups correpsonding to the different measurement techniques and data routing methods used. It included the discussion of corrections, accuracy estimations, comparison of measured data for nuclei, recommendations (guidelines) for the different types of measurements as well as for the next candidates to be measured.

WGB(A) - Activation analysis and other off-line methods
Chairman: J. Csikai, Debrecen

WGB(B) - Neutron and gamma ray spectroscopy
Chairman: D. Seeliger, Dresden

WGB(C) - Charged Particle Spectroscopy
Chairman: H. Vonach, Vienna

Session V - Working Group C

- Comparison with Theoretical Models -

Session VI - Concluding Session

Working Group Sessions consisted of prepared short contributions of participants as well as free discussions. The reports of the Working Groups were discussed and final recommendations formulated during the concluding session on the last day. These reports constitute the major products of this meeting and are reproduced below.

III. Working Group Reports

(1) Report of Working Group WG A(A) on Techniques and Measurements

Chairman: K. Seidel

Three topics were discussed in this group: neutron monitors, neutron time-of-flight detectors and data acquisition/reduction.

1. Neutron monitors

The type of monitor is determined, first of all, by the goals of the measurement. For the group of experiments where the fluence must be monitored, I. Garlea [1] showed the use of fission radiators on solid state track detectors. Their handling is simple during the measurement but the track counting is time consuming. In the same way, activation foils can be used. In difference to track detectors the irradiation time as well as the counting time regime must be taken into account. In absolute monitoring, the same problems arise connected with the sample preparation, as discussed in working group B(A).

A group of experiments requires real time monitoring. A relatively simple-to-handle device is a fission chamber with ^{238}U. It has also the advantage to be sensitive for (fast) neutrons only. Absolute monitoring is possible by registration of the associated α-particles. Advantages of these methods are achievable uncertainties in the order of 1 % and sensitivity only for 14 MeV neutrons which are produced in the tritium target. The method was discussed in the contribution of H.W. Ortlepp [2].

2. Neutron time-of-flight detectors

Generally, liquid organic scintillators coupled with fast photomultipliers are used and a neutron gamma discrimination is realized. One of the most important problems is the determination of the efficiency of these detectors. Problems arising in Monte-Carlo-Calculations, for example from uncertainties of light yield data (or electron/proton light yield ratios) are avoided if the energy dependence of the efficiency is experimentally determined with the fission neutron spectrum of ^{252}Cf. In the contribution of H. Märten [3], a two dimensional method was discussed and the importance of an improved evaluation of this standard spectrum was emphasized.

The normalization of the efficiency is possible with the elastic scattering from H (standard) or for example C.

3. Data acquisition/reduction

S. Unholzer [4] showed a time-of-flight spectrometer which is directed to precise determination of angular distributions how microcomputer based measuring algorithm improves data uncertainties and long-time stability.

The data reduction of spectra containing both continuous parts and more or less resolved peaks by a modular programme organized as dialogue via graphic display was discussed by T. Elfrik [5].

References [1] through [5]: Contributed presentations at the Working Groups to be published.

(2) Report of Working Group WG A(B) on Neutron Generators

Chairman: M. Berrada

The WG on Neutron Generators discussed questions connected with the utilization of such accelerators, i.e.

- vacuum system,
- ion source,
- cooling water circuit,
- tritium targets,
- pneumatic transfer systems,
- analysing/deflecting magnet, and
- beam pulsing.

It also discussed questions related to the safety of neutron generator installations, viz.

- neutron and gamma ray shielding,
- monitoring of neutrons and gamma rays for the radiological protection of in-house personnel and the environment,
- release of tritium and its monitoring, and
- measures of precaution against accidents due to the high voltage.

The conclusions and recommendations from these discussions are summarized as follows.

1. In order to coordinate some mutual assistance between the different laboratories participating in this CRP (and more generally in the Interregioal Project TC/INT/1/018) in the areas of

   - equipment maintenance,
   - supply of needed spare parts, and
   - improvement of existing or acquisition of additional equipment

   the WG recommends to include information on problems and needed assistance in the Interlaboratory Report recommended by the WG B(A) on Activation Analysis and circulated by the IAEA Nuclear Data Section among the participants.

2. In order to avoid the difficulties arising from the hardness and mineral and other impurities of town water, the WG recommends the installation of a closed circuit of distilled or demineralized water including a refrigerating system designed to cool the different parts of the accelerator (generator, target, diaphragma) and of the peripheric instruments such as deflecting magnet and diffusion pumps.

3. In order to define more accurately the neutron energy for the correct determination of nuclear data, to increase the life time of the tritium targets, and to allow the mounting of two different experiments, the installation of an analysing/deflecting magnet for the separation of monoatomic and diatomic beam ions and other beam impurities is strongly recommended.

4. In order to ensure the safe utilization of the neutron generator, the WG recalls some important aspects treated in detail in the IAEA brochure entitled "Radiological safety aspects of the operation of neutron generators", IAEA Safety Series no. 42 (1976) and recommends that each participating laboratory ensures

(i) the utilization of correctly calibrated personnel neutron and gamma ray monitors;

(ii) the control of the tritium content of the air of the accelerator room and its periodic measurement in the urine of the most strongly exposed laboratory personnel; and

(iii) the adoption of security measures against accident risks connected with the high voltage and neutron and gamma irradiations.

(3) Working Group Recommendations of WG B(A) on Activation and other off-line methods

Chairman: J. Csikai

1. A preliminary guide-line on the measurements of 14 MeV neutron induced reaction cross sections by the activation method has been worked out. This will be circulated to the CRP participants in December 1983. Comments if any should be sent to Prof. Csikai by 31 January 1984 for preparing the final version of this guide-line.

2. Two exercises have been proposed for intercomparison purposes. In the first one Ni foils can be irradiated in LLNL and distributed through the IAEA to all the participating laboratories, who should measure the cross sections for $^{58}Ni(n,p)^{58}Co$ and $^{60}Ni(n,p)^{60}Co$ reactions. The Ni foils of 0.1 mm thickness should be ordered from Goodfellow and cut in 10 mm ∅ pieces. In the second exercise the IAEA will distribute unirradiated Ni foils to determine the cross sections for the above reactions.

3. It is recommended that each laboratory determines the neutron energy by the $^{90}Zr(n,2n)^{89}Zr$ to $^{93}Nb(n,2n)^{92m}Nb$ ratio method. The $^{90}Zr(n,2n)$ cross section curve suggested by Csikai (Antwerp Conference 1982) should be taken as the reference data.

4. The recommended flux monitor reactions are: $^{27}Al(n,\alpha)^{24}Na$, $^{56}Fe(n,p)^{56}Mn$, $^{238}U(n,f)$.

5. It is recommended that every new laboratory should first repeat a few well known cross sections like $^{27}Al(n,p)^{27}Mg$, $^{65}Cu(n,2n)^{64}Cu$, $^{58}Ni(n,p)^{58}Co$, $^{59}Co(n,2n)^{58}Co$ and $^{59}Co(n,\alpha)^{56}Mn$.

   As a second step some less known cross sections should be measured like $^{46}Ti(n,2n)$, $^{50}Cr(n,2n)$, $^{54,56}Fe(n,2n)$, $^{94}Mo(n,2n)$, $^{29,30}Si(n,p)$, $^{54}Cr(n,p)$, $^{63}Cu(n,p)$ and $^{48}Ti(n,\alpha)$, $^{54}Cr(n,\alpha)^{63}Cu(n,\alpha)$, etc.

   In the third step unknown cross sections are recommended to be measured like $^{50}V(n,2n)$, $^{60,64}Ni(n,2n)$, $^{164}Dy(n,p)$, $^{112,120}Sn(n,\alpha)$, $^{96}Ru(n,np)$, $^{112}Sn(n,np)^{115}In(n,n\alpha)$, etc.

   The meeting drew attention to the practical importance of the (n,t) reactions but taking into account the experimental difficulties it was recommended that this and other low yield reactions like $(n,^{3}He)$, (n,2p) and (n,γ) should be attempted only after having enough experience. Use of radiochemical method is recommended.

6. Use of the activation method for unfolding neutron spectra should be encouraged.

7. When deciding upon the measurements recent compilations like those of Qaim [Handbook of Spectroscopy Vol. III, CRC Press, 1981, p. 141-162] and Csikai [in Nuclear Theory and Applications - 1980, IAEA-SMR-68/I (1981) p.215-254] should be taken into account.

8. It is recommended to circulate among the participants the Interlaboratory Reports and Annual Reports of the laboratories involved in the CRP project.

(4) Report of Working Group WG B(B) on Neutron Spectrometry

Chairman: D. Seeliger

1. In the working group participated the following people:

Dr. Takahashi	Osaka University, Japan
Dr. Vilaithong	Chiang Mai University, Thailand
Dr. Kiss	Eotvös University, Hungary
Dr. Gul	Pakistan Institute of Nuclear Science and Technology, Pakistan
Dr. Seidel	Technical University Dresden, GDR
Dr. Vonach	IRK, Vienna
Dr. Seeliger	Technical University Dresden, GDR

These groups are equipped with TOF spectrometers (or will be equipped in the next future).

At the meeting had been presented also reports from USSR laboratories not directly represented on the CRP.

The Bratislava group presented equipment for measurements of n-γ coincidences. Some other groups (Alexandria University and ZFK/TUD collaboration) reported possibilities for neutron spectra measurements by spectra unfolding methods.

2. At the meeting were reported the following new results on double-differential cross section (DDCS) measurements:

- high resolution measurements of DDCS for many nuclei by the OSAKA University;
- from the TUD were presented first experimental results with an improved TOF spectrometer;
- Dr. Vilaithong gave a report on important methodical parts of a high resolution spectrometer at Chiang Mai University;
- Dr. Kiss reported on a kinematical complete TOF experiment;
- Dr. Gul showed new DDCS measurements for Fe and discussed the physical nature of structures observed.

3. Based on the review given by Dr. Seeliger the WG discussed the present status of DDCS data and concluded the following:

- A satisfactory situation (at least two independent experiments which agree in the essential features of the spectra) can be stated for the following elements: Be, Al, Si, Ti, Cr, Fe, Ni, Cu, Zn, Zr, Nb, Mo, Sn, Ta, W, P, Bi. Even in this cases data do not agree in all details. The accuracy really achieved in these cases has to be checked in comparison with the WRENDA requests.

- Only one or incomplete data measurements are available for the following elements: Li, O, F, Na, Mg, P, S, Ca, V, Mn, Co, Ga, Se, Br, Ag, Cd, In, Sb, I, Ba, Au, Hg. Among these elements are a few which are required by WRENDA list with priority 1 or 2 like O, ^{6}Li, ^{7}Li, Ca and V.

- No data are available for the following elements: B, N, Ne, Cl, Ar, K, Sc, Ge, As, Kr, Rb, Sr, Y, Tc, Rn, Rh, Pd, Te, Xe, Cs, Rare Earth elements, Re, Os, Ir, Pt, Tl. Among these elements are also some nuclei required by WRENDA list, like ^{10}B, ^{11}B.

Recommendations:

1. The WG recommended to take as a standard for check of the methods and interlab comparisons the neutron spectra for C, Fe and Nb.

For the further work in the frame of the CRP are recommended the following directions for investigations.

2. Filling out data gaps for labs which have TOF spectrometers with moderate resolution ($2\tau \simeq 2\ \mu s$, $L \simeq 2$ m) it is recommended to make measurements in the exit energy range 2 ... 10 MeV for the following elements: Li, Na, V, Mn, Co, Ag, Cd, Ba, B, N, K, Y, Te, Tl.

3. It is recommended to measure spectra in the low energy range with a low detector threshold ($E_B \simeq 0.3 \dots 0.5$ MeV) for important elements which had not been included in the previous IRK programme.

It should be checked for 1-2 important cases if it is necessary to measure also the angular distribution in the low energy region.

4. In the high energy range spectra should be measured with very high resolution ($2\tau \simeq 1.5\ \mu s$, $L = 10 \dots 20$ m). Candidates are practically all important elements for which low-lying isolated states are not investigated at 14 MeV so far. Also measurements with individual isotopes in some cases would be very useful.

- For improvement of shielding calculation measurements concentration on the investigation of angular distributions in the foreward and backward directions would be useful.

- The use of C, Fe and Nb as standards for interlaboratory comparisons requires a careful reevaluation of the 14 MeV DDCS for these elements including the newest data available. An accuracy of at least 5 % should be reached in these cases.

- The discussions also have shown that further investigations of the neutron emission from very light elements are of high importance.

5. There have been discussed also the following directions for further physical investigations in connection with the DDCS measurements:

- investigations of the reaction mechanisms by comparisons with existing models.

- detailed investigations of the physical structures observed in the spectra.

- systematic investigations of shell effects and the influence of collective excitations for individual isotopes.

- desirable investigations could be connected with measurements of n-n-correlation or n-ch.p.-correlations.

6. The WG recommended the NDS to convene a small specialists meeting for intercomparisons of DDCS and compilation of these data in 1985.

7. Information on the results of this work should be distributed also to laboratories which are connected with 14 MeV DDCS measurements but not included in the CRP.

8. A proposal of guidelines for the DDCS measurements will be prepared by Dr. Seeliger and distributed to the CRP participants through the NDS.

(5) Report of Working Group WG B(B') on In-beam gamma ray measurements

Chairman: P. Oblozinsky

Recommendations:

One goal of these measurements is to obtain production cross sections, spectra and angular distributions of gamma rays from (n,xγ) reactions at 14 MeV as required for calculations of shielding as well as nuclear heating of fission and fusion reactors. Physical aspects of such a research concentrate on understanding of reaction mechanisms and γ decay processes.

The measurements can be performed with Ge(Li), NaI(Tl) and also with organic scintillators. We suggest, however, to start with a Ge(Li) detector where single parameter data acquisition is completely adequate.

Technical prerequisites are the following. Modest neutron generator (10^9 - 10^{10} n/4 π s) is sufficient. Indispensable is massive collimator of incident neutrons or shadow bar and shielding of the gamma spectrometer. Usual materials are paraffin, polyethylene and lead. Typical distance between tritium target and spectrometer is about 1 - 1.5 m. Though a few strong lines can be observed even without time-of-flight suppression of background events, this technique is strongly recommended. One should work either with fast pulsing D+T machine (several ns resolution is enough), or, more simple, to adopt the associated alpha particle method. Timing resolution between alpha particle detector and gamma spectrometer should be about 10 ns or even less. Thin plastic scintillator, about ∅ 10 mm x 0.1 mm protected by 1-3 μm thick Al foil from scattered deuterons, should be used as alpha particle detector. Fast phototube is needed.

Required electronics comprises fast NIM modules (2 constant fraction timing units, time analyzer and 2-3 delay lines), standard linear electronics (amplifier, if possible also μs delay amplifier) and a multichannel analyzer. Good oscilloscope is needed.

Efficiency calibration of the Ge(Li) spectrometer should be done in conditions of a real experiment (e.g. CFT threshold included). Typical weight of a sample is 100 g. We suggest to measure at 55 or 125 ^{o}, another choice would be 90 ^{o}.

Experimental procedures should be checked by measuring one well known reaction, e.g. ^{56}Fe(n,n'γ) with strong 847 KeV γ line. For specific nucleus one should consult WRENDA 84 list, reasonable choice would nevertheless be an easily available element from the region of A = 40 - 65 where several important structural materials occur.

For continuum spectra measurements one should use large well shielded NaI(Tl). Two-parametric data acquisiton (TOF x pulse height) is extremely useful and unfolding of raw spectrum is necessary. Of special interest is intermediate spectral energy region $E_\gamma \approx 4 - 14$ MeV for many elements.

Physically important and new measurements can be done using $\gamma-\gamma$ and $n-\gamma$ coincidence techniques. For example, information about γ decay of unbound states can be extracted.

References can be found in the review paper by P.O. at this meeting.

(6) Report of Working Group WG B(C) on study of (n, charged particle) reactions at E_n = 14 MeV

Chairman: H. Vonach

1) Importance of measurements of energy and angular distributions of charged particles from nuclear reactions induced by 14 MeV neutrons

Data of this kind are needed in both basic and applied physics for a variety of problems as for example:

A) Basic Physics:

1) Information on precompound processes in medium and heavy nuclei. Especially combination of (n,p) double-differential cross section measurements with the corresponding largely already existing (n,n') data will allow stringent tests of existing models of precompound reactions.

2) Measurement of nuclear level densities. This can be achieved especially from the study of α-spectra from (n,α) reactions in the mass range A $\sim$ 40-65 whereby it is especially important to measure reliably the emission cross-sections to the region of resolved levels.

3) Study of few nucleon problems e.g. the deuteron break up reaction

B) Applications:

1) Determination of kerma factors of light elements (C, O, N) for neutron dosimetry and nuclear medicine

2) Measurement of total hydrogen and Helium production cross-sections in structural materials for fusion reactors.

3) Measurements for testing of nuclear models used for calculation of cross-sections needed both for fast reactor and fusion reactor design (see also A1)

2) Present knowledge of charged particle production cross-sections, energy and angular distributions

a) total hydrogen and Helium production cross-sections:

Total hydrogen and helium production cross-sections for most of the materials important for fusion reactor design have been measured by means of the Livermore quadrupole spectrometer. In addition many helium production cross-sections have been determined independently by study of helium accumulation and the results were consistent in most cases.

b) angle-integrated energy-distributions for charged particles

A relatively large number of measurements of proton, deuteron and α-particle energy distributions exist for light elements up to $A < 32$, in the region of structural materials ($A \approx 45-65$; see a) and in the Nb-Mo region A = 90-100; good measurements exist further for CsJ, otherwise there exist large gaps the accuracy of the dE/dx values is typically of the order of 15-20% in the peaks of the spectra and considerably worse at high and lower energies.

c) angular distribution of charged particles

Some good information even concerning the angular distribution of particles populating resolved final levels exists for light nuclei; in addition a few detailed ang lar distributions for medium nuclei have been measured by means of the Vienna multi-telescope system but otherwise the information on the angular distribution of the emitted particles is still very scarce(e.g. most of the Livermore measurements were done at

4 angles only). Triton angular and energy distributions have been observed for some light nuclei, ^{3}He-particles (from the $^{40}Ca(n,{}^3He_0)$reaction) have been observed in just one experiment.

Thus the existing data by far do not meet the requirements described in section 1. Much more and better measurements of double-differential cross-sections as function of both energy and angle are needed for a meaningful comparison with precompound reaction models and also more accurate α-energy distributions are needed in order to exploit the possibilities of measuring nuclear level densities. For most of the materials needed for fusion technology there is now one measurement of the α- and proton spectrum available.

For the important nuclei howver existence of at least two independent mutually consistent measurements would be highly desirable. This is as yet only the case for very few reactions (e.g. $^{56}Fe(n,\alpha)$, $^{60}Ni(n,\alpha)$ and $^{93}Nb(n,\alpha)$) where such measurements have been done by both the Livermore and Vienna group.

3) Present activity in the field

Experimental facilities for study of energy and angular distributions in (n,charged particle) reactions at E_n = 14 MeV have existed for some time at the Lawrence Livermote National Laboratory, USA, the Institute für Radiumforschung und Kernphysik, Vienna and the Physics Department of the university of Tübingen, Germany; recently new multi-telescope systems have been put into operation at the Institute for Nuclear Research, Warsaw, Poland and Kyushi University, Japan. However, mainly due to the limited manpower assigned to this work and the very lengthy and difficult measurements which are needed an output of only a few reactions per year can be expected which will not satisfy the data needs in near future.

4) Recommendations

Considering the data needs and the present level of activity in the field it can be strongly recommended that new research groups start experimental work in the field of (n,charged particle) reactions at E_n = 14 MeV. The design and construction of a new experimental setup (e.g. a charged particle telescope system or a quadrupole spectrometer) will certainly need several years; however, even at that time many important measurements will not have been done. For laboratories equipped with high intensity neutron generators (total source strength $> \sim 2.10^{11}$) it might be the best to use some type of quadrupole spectrometer, for those laboratories restricted to lower neutron source strength multi-telescope systems might be preferable, however, even conventional single telescope systems and neutron generators of quite modest strength (10^9 - 10^{10} neutrons in 4π) can produce important and new data in the discussed field.

(7) Report of Working Group WG (C) on comparison with theoretical models

Chairman: A. Marcinkowski

Recommendations:

1. Measurements of spectra of reaction products

   - make DWBA calculations for isolated collective states and fit the continuous part with one of the master-equation approaches. Take care about consistent parametrization of both the preequilibrium and the compound contributions.

   - test your calculations on all reaction channels for ^{93}Nb, if possible not only at 14 MeV.

   - for describing the angular distributions apply the generalized exciton model with phenomenological parameters of Ackermans et al.

2. Measurements of activation cross sections

   - calculate compound contribution according to the angular momentum dependent H-F formalism. Add preequilibrium component obtained from an angular momentum dependent exciton model version - STAPRE [1] or hybrid model EMPIRE [2] formulation.

   - compare your code calculations with the results of the intercomparison of codes [3] for ^{59}Co.

   - test your activation cross section calculations against the measured cross sections for ^{93}Nb.

3. General

   - participants of the CRP are encouraged to use the measured data for extension of the existing parameterisations of the models (codes).

   For the TUD

   - work out an applicable calculational scheme for the DWBA calculations to single levels as well as to the continuum of levels.

   For the INS

   - work out an applicable version of the MGC and MSD calculations including double differential cross sections.

References:

1. NEA Data Bank, Saclay, France
2. Contact Herman M., INS, 00-681 Warsaw, Hoza 69, Poland.
3. Prince A., Reffo G. and Sartori E., NEANDC-152"A", 1983.

Co-ordinated Research Programme (CRP) on Measurement and Analysis of 14 MeV Neutron Nuclear Data needed for Fission and Fusion Reactor Technology

First Research Co-ordination Meeting
Gaussig, 21-25 November 1983

Adopted Agenda

1. Opening Statements and Announcements
    1.1. Opening of meeting (10.00 hrs.)
    1.2. Adoption of Agenda
    1.3. Announcements

2. Presentation of Review Lectures

3. Reports by CRP participants on this work

4. Working Groups Meetings: Prepared presentations and discussions

5. Writing of Working Group Reports

6. Working Group Reports presentation, discussions and conclusions

7. Next Meeting

Co-ordinated Research Programme (CRP) on Measurement and Analysis of 14 MeV Neutron Nuclear Data needed for Fission and Fusion Reactor Technology

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List of CRP Participants who attended the meeting

M. Berrada	Department of Nuclear Physics Faculty of Science Mohammed-5 University B.P. 1014 Rabat, Morocco
J. Csikai	Institute of Experimental Physics of Kossuth Lajos University P.O. Box 105 H-4001 Debrecen Hungary
K. Gul	Neutron Physics Group Pakistan Institute of Nuclear Science and Technology P.O. Nilore Rawalpindi, Pakistan
R.C. Haight	E. Division, L-313 Physics Department Lawrence Livermore National Laboratory P.O. Box 808 Livermore, California 94550 U.S.A.
A. Marcinkowski	Department P-I Institute of Nuclear Studies (IPJ) Ul Hoza 69 PL-00-681 Warsaw Poland
M.K. Mehta (Scientific Secretary)	IAEA
D. Miljanic	Nuclear Physics Department Institut Ruder Boskovic P.O. Box 1016 YU-41001 Zagreb Yugoslavia

P.N. Ngoc	Nuclear Physics Laboratory National Science Research Centre Institute of Physics of the Academy of Science Hanoi, Viet Nam
P. Oblozinsky/I. Ribansky	Department of Nuclear Physics Institute of Physics of the Slovak Academy of Sciences Dubravska Cesta CS-842 28 Bratislava Czechoslovakia
S.M. Qaim	Institut f. Chemie 1 (Nuklearchemie) Kernforschungsanlage Juelich G.m.b.H. Postfach 1913 D-5170 Juelich 1 FRG
K. Seidel	Sektion Physik Technische Universität Dresden Mommsenstrasse 13 DDR-8027 Dresden
T. Vilaithong	Nuclear Physics Laboratory Department of Physics Chiang Mai University Chiang Mai, Thailand
H.K. Vonach	Institut für Radiumforschung und Kernphysik Boltzmanngasse 3 A-1090 Wien Austria

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List of Participants at the XIII International Symposium on Nuclear Physics - Fast Neutron Reactions and at the Research Co-ordination Meeting

A.I. Abramov	Institute of Physics and Power Engineering 249020 Obninsk, U.S.S.R.
S.M. Al-jabori	IAEC, Nuclear Research Inst. Physics Dept. P.O. Box 765, Tuwaitha, Baghdad, Iraq
F.I. Asfour	Atomic Energy Establishment, N.R.C., Experimental Nuclear Physics Dept., Cairo, Egypt
M. Berrada	Department of Nuclear Physics, Faculty of Science, Mohammed-5 University, B.P. 1014, Rabat, Morocco
J. Csikai	Institute of Experimental Physics of Kossuth Lajos University, P.O. Box 105, H-4001 Debrecen, Hungary
M. Fawzy	University, Faculty of Science, Physics Dept., Alexandria, Egypt
I. Garlea	Inst. of Nuclear Power Reactors, P.O.B. MG-6, Bucharest, Romania
K. Gul	Neutron Physics Group, Pakistan Institute of Nuclear Science and Technology, P.O. Nilore, Rawalpindi, Pakistan
F.I. Habbani	Dept. of Physics, Faculty of Science, University of Khartoum, Khartoum, Sudan
R.C. Haight	E. Division, L-313, Physics Department, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94550, U.S.A.
M. Herman	P.R.L., Institute for Nuclear Studies, Hoza 69, 00-681 Warsaw, Poland

N. Janeva	Institute for Nuclear Research and Nuclear Energy, Bul. Lenin 72, 1184 Sofia, Bulgaria
A. Kiss	Eötvös University, Dept. of Atomic Physics, Puskin u. 5-7, H-1088 Budapest, Hungary
St. Kliczewski	Institute of Nuclear Physics, ul. Radzikowskiego 152, 31-342 Krakow, Poland
L. Loska	Institute of Nuclear Technique, Krakow, Poland
D. Marcinkowski	Institute for Nuclear Studies, Ul Hoza 69, PL-00-681 Warsaw, Poland
M.K. Mehta	Nuclear Data Section, International Atomic Energy Agency, P.O. Box 100, A-1400 Vienna, Austria
D. Miljanic	Institut Ruder Boskovic, P.O. Box 1016, YU-41001 Zagreb, Yugoslavia
N.K. Mumba	National Council for Scientific Research, P.O. Box CH 158, Lusaka, Zambia
P.N. Ngoc	Institute of Physics, Nghia Do, Hanoi, Viet Nam
P. Oblozinsky	Institute of Physics of the Slovak Academy of Sciences, Dubravska Cesta, CS-842 28 Bratislava, Czechoslovakia
G. Paic	Institut Ruder Boskovic, P.O. Box 1016, YU-41001 Zagreb, Yugoslavia
T.S. Panteleev	Inst. for Nuclear Research and Nucl. Energy, Lenin Bld. 72, 1184 Sofia, Bulgaria
R.X. Pitrus	IAEC, Nuclear Research Inst. Physics Dept., P.O. Box 765, Tuwaitha, Baghdad, Iraq
S.M. Qaim	Institut f. Chemie 1, (Nuklearchemie), Kernforschungsanlage Juelich G.m.b.H., Postfach 1913, D-5170 Juelich 1, FRG
I. Ribansky	Institute of Physics of the Slovak Academy of Sciences, Dubravska Cesta, CS-842 28 Bratislava, Czechoslovakia
J. Rondio	P.R.L., Institute for Nuclear Studies, Hoza 69, 00-681 Warsaw, Poland
J.J. Schmidt	Nuclear Data Section, International Atomic Energy Agency, P.O. Box 100, A-1400 Vienna, Austria
A. Takahashi	Dept. Nuclear Energy, Faculty of Eng., Osaka University, Suita - Shi, Yamadaoka 21, Osaka 565, Japan

A. Trzcinski	P.R.L., Institute for Nuclear Studies, Hoza 69, 00-681 Warsaw, Poland
T. Vilaithong	Nuclear Physics Laboratory, Department of Physics, Chiang Mai University, Chiang Mai, Thailand
H.K. Vonach	Institut für Radiumforschung und Kernphysik, Boltzmanngasse 3, A-1090 Wien, Austria
D. Albert H. Kumpf W. Hansen	Zentralinstitut für Kernforschung Rossendorf PF 19 8051 Dresden, GDR
D. Seeliger K. Seidel D. Hermsdorf H. Märten S. Unholzer A. Meister T. Streidl P. Mädler S. Mittag W. Pilz G. Pausch J. Pöthig H.G. Ortlepp W. Wagner T. Elfruth H. Kalka	Sektion Physik Technische Universität Dresden Mommsenstrasse 13 DDR-8027 Dresden