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MEASUREMENT, CALCULATION AND EVALUATION OF PHOTON PRODUCTION CROSS-SECTIONS

SUMMARY REPORT

Specialists' Meeting organized by the
International Atomic Energy Agency

and

Co-sponsored by the Czechoslovak Atomic Energy Commission

Smolenice, Czechoslovakia
5 - 7 February, 1990

Prepared by

N.P. Kocherov
IAEA Nuclear Data Section

March 1990

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

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Abstract

The IAEA Specialists' Meeting on Measurement, Calculation and Evaluation of Photon Production Cross-Sections was held in Smolenice, Czechoslovakia, 5-7 February 1990. The meeting was hosted by the Institute of Physics of the Electro-Physical Research Centre, Slovak Academy of Sciences, Bratislava.

This report contains the conclusions and recommendations of this meeting.

The papers which the participants have presented at the meeting will be published as an INDC Report.

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Contents

Introduction

The need for more accurate and more complete data on photon production in neutron and proton interactions with nuclei was explicitly expressed at several IAEA meetings. In particular the Advisory Group Meeting on Nuclear Theory for Fast Neutron Nuclear Data Evaluation organized by the Nuclear Data Section in Beijing, 12-16 October 1987 has recommended to convene a Specialists' Meeting on Measurements, Calculation and Evaluation of Photon Production Cross-Sections. This topic was considered to be of growing importance for a number of applications such as fusion technology, nuclear borehole logging, shielding, mineral analysis, etc.

It was proposed to discuss the following items:

1. Nuclear data needs, required accuracies and gaps in existing data.

2. Experimental techniques of measuring gamma-production in neutron interactions (coincidences, timing, correlations, special devices etc.).

3. Theoretical models and code comparison for the calculation of photon production cross-sections and spectra. Some related quantities like gamma-ray strength functions, semi-direct and precompound gamma-ray emission were also included.

The ideas of the participants on these topics were formulated in detail in their conclusions and recommendations which are contained in this report.

IAEA Specialists' Meeting on the
MEASUREMENT, CALCULATION AND EVALUATION OF
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Smolenice, Czechoslovakia
5 - 7 February 1990

AGENDA

Monday, 5 February 1990

10:00 Transportation to Smolenice
Registration and settlement

12:00 Lunch

14:00 Opening Session

Opening remarks
Adoption of agenda
Election of chairman

15:00 SESSION: **EXPERIMENTAL MEASUREMENT AND TECHNIQUES**
Chairman: P. Oblozinsky

1. S. Wender:
"Gamma-ray production cross-section measurements using a white neutron source from 1 to 200 MeV"

2. S. Hlavac and P. Oblozinsky:
"Measurements of γ-ray production from 52-Cr(n,xγ) reactions at 14.6 MeV"

3. A.A. Filatenkov and S.V. Chuvaev:
"Prompt γ-rays from U^{235}, U^{238} and Th^{232} Fission Fragments"

4. S. Unholzer:
"In-beam measurement of gamma emission spectra from neutron induced reactions"

5. Discussions

Tuesday, 6 February 1990

09:00 SESSION: **CALCULATION OF PHOTON CROSS-SECTIONS**
Chairman: J. Kopecky

1. E. Betak and P. Oblozinsky:
"Preequilibrium γ emission in nuclear reactions" (Review)

2. H. Kalka:
"Global description of gamma emission spectra within statistical multistep theory"

3. M.B. Chadwick and P. Oblozinsky:
"Gamma ray emission from multistep compound reaction"

4. P. Oblozinsky:
"Preequilibrium emission of hard photons in proton-nucleus reactions"

12:30 Lunch

14:00 SESSION (continued)

5. E. Betak and F. Cvelbar:
"Neutron-gamma competition in nucleon-induced reactions"

6. P. Oblozinsky, G. Maino and A. Mengoni:
"Analysis of γ-ray production from 52-Cr(n,xγ) reactions at 14.6 MeV"

7. J. Kopecky:
"Present status of gamma-ray strength functions and their impact on statistical model calculations"

8. M. Uhl, J. Kopecky:
"Calculation of capture cross-sections and gamma-ray spectra as a tool for testing strength function models"

9. F. Becvar, R.E. Chrien and J. Kopecky:
"Two-step cascade transitions following neutron capture: a new source of information on photon strength functions"

10. Discussions

Wednesday, 7 February 1990

09:00 SESSION: **EVALUATION**
Chairman: S. Wender

1. A.A. Nosov, A.A. Rimski-Korsakov, R.M. Yakovlev, M.N. Zubkov:
"High energy gammas in nuclear collisions: Necessary data"

2. A.I. Blokhin:
"Evaluation of gamma production cross sections"

3. S. Hlavac and P. Oblozinsky:
"Evaluation of discrete γ-ray production cross sections in (n,xγ) reactions on Al for nuclear geophysics"

4. Discussions (continued)

5. Drafting of conclusions and recommendations of the participants

CONCLUSIONS AND RECOMMENDATIONS

Session Chairman: S. Wender

The following conclusions were drawn by the participants regarding the topics of measurement, calculation and evaluation of photon production cross sections.

1. Measurements

The participants discussed several experimental techniques and experimental facilities where gamma-ray measurements may be performed.

1.1 The Los Alamos continuous energy "white" neutron source is capable of discrete gamma-ray measurements of cross sections and angular distributions from below 1 MeV to over 200 MeV incident neutron energy. The gamma-ray energies from below 1 MeV to 6 MeV are covered with high resolution Ge detectors. The gamma-ray energies from 2 MeV to over 30 MeV are covered using BGO detectors. Continuum measurements are possible with this source with somewhat greater errors due to uncertainties in background subtractions.

Hard photons (above 30 MeV) following high energy neutron induced reactions may be measured using a gamma-ray telescope which is not sensitive to neutrons.

1.2 The technique of in-beam gamma-ray measurements with a pulsed 14 MeV neutron source together with n-TOF spectroscopy has been demonstrated by S. Unholzer and can be used for:

- small sample differential cross section measurements
- benchmark experiments (leakage spectra)
- extended integral experiments (such as model of fusion reactor blanket). Neutron spectra are measured simultaneously with gamma-rays.

In cases of small samples good angular and time resolution is achievable, allowing (n,γ) and (γ,γ) correlation experiments as well as the investigation of time dependent deexcitation processes.

1.3 The method of in-beam gamma-ray measurements at 14 MeV using continuous beams with the associated-particle technique is well developed. This method is able to provide data on continuum and discrete gamma-ray spectra as well as gamma multiplicities. This was demonstrated by the measurement of gamma-ray production from $^{52}Cr(n,x\gamma)$.

The opinion of the participants is that the majority of the gamma-ray data should be obtained by calculation. It is important to have complete and precise gamma-ray production data for several nuclei from the entire mass region to verify codes. When particular elements are important such as structural materials (Fe, Ni, Cr), complete measurements should be made.

2. Calculations

2.1 The participants stated that there are two approaches to calculating the continuum gamma ray spectra following fast neutron capture:

(i) in the exciton model the giant dipole resonance (GDR) part of the spectrum is described by emission from exciton states with n=1. The physical foundation of this concept is still unclear but the model has proved very useful for evaluations;

(ii) in the statistical multistep approach the spectra are calculated as the sum of multistep compound and direct processes. The latter mechanism would dominate the production of high energy photons. Therefore theoretical descriptions of multistep direct processes should be pursued.

Within the exciton model, also multiple γ-cascades and different correlational quantities can be obtained (Betak, Cvelbar).

The exciton model generally describes the observed photon spectra in the GDR region (Betak, Oblozinsky).

The multistep compound theory of Feshbach-Kerman and Koonin has been developed (Oblozinsky and Chadwick) to include gamma-ray emission. The theory has been used to calculate the primary gamma-ray spectrum for 14 MeV neutron-induced reactions on ^{59}Co, ^{93}Nb and ^{181}Ta

and is able to account for between 20 and 50% of the data in the GDR region.

Within a statistical multistep model (Kalka) emissions of nucleons and gammas are calculated for A>27 and incident energies below 30 MeV. The high-energy part of γ-spectra is modelled by a direct two-step process. For the description of the low-energy part γ-multiplicities $\bar{M} > 1$ are needed.

2.2 The participants have discussed the experimental results for two-step gamma-ray cascades following thermal neutron capture. They recommended to continue this effort to enlarge the information on photon strength functions for E_1 and M_1 radiations at gamma-ray energies below 3 MeV. It is of particular importance to extend the above measurements for a broader class of nuclei, especially including nuclei from the deformed rare earth region. For these nuclei rich and reliable data on photon strength functions at energies $E \gtrsim 6$ MeV already exist. The deformed region seems crucial for understanding the role of valence transitions and their contributions to the photon strength function.

2.3 The importance of the absolute values and the energy dependence of gamma-ray strength functions for the statistical model calculations has been demonstrated by Uhl and Kopecky. It is recommended to re evaluate the experimental data on E_1 and M_1 gamma-ray strength functions (compilation of C. McCullagh, 1981) and to include recent data from Dubna (F. Becvar). This new data base could be used to derive the systematic behaviour of gamma-ray strength functions.

2.4 Statistical model calculations of capture cross sections and gamma-ray spectra depend on the low energy behaviour of the strength functions for E_1 and M_1 radiation. Of particular interest are the microscopic theories for the E_1 strength function which predicts a non-zero limit as the gamma ray energy approaches zero. By analysing total s- and p-wave radiation widths, capture cross sections and gamma-ray spectra for selected spherical nuclei strong evidence for this non-zero limit was found. These investigations should be extended to a broader mass range, in particular to deformed target nuclei. One can hope to find recommended strength functions which are supported by theory and based on independent experimental data. Model calculations employing these recommended strength functions promise an improved predictive power.

2.5 In addition to strength functions the following ingredients are needed to perform reliable model calculations:

(i) Good knowledge of the level densities. Separate activities (also by the IAEA) are devoted to this problem.

(ii) Decay schemes and branching ratios should be known with good precision. This knowledge is important for the calculation of discrete gamma-ray production cross-sections.

2.6 There is substantial interest in hard photon production cross sections. Experimental possibilities for relevant measurements have opened up at Los Alamos (Talk by Wender). Hard photons cover a spectral energy range from about 30 MeV up to several hundred MeV. It seems that the dominant radiative mechanism in this spectral energy range is related to neutron-proton interactions and can be viewed as a bremsstrahlung process or inverse quasideuteron photoabsorption (talks by Oblozinsky and Betak). It is proposed that experimental measurements and theoretical studies be performed. It was recommended to convene a follow-up meeting on this topic in 1992.

3. Data needs and evaluations

3.1 The participants stated that until recently not enough attention has been paid to evaluations of gamma-ray production cross sections based on theoretical models. There is a growing need for high quality gamma-ray production data in several application areas. Such data are needed for nuclear geophysical applications, especially nuclear well logging and mineral analysis. These data are vital for fusion reactor design because the major heat transfer mechanism is the interaction of 14 MeV neutrons with reactor structural materials.

3.2 The participants also stressed the fact that there is a need for gamma production data for incident particle energies up to about 1 GeV for space applications, accelerator shielding and accelerator-breeder target development (A.A. Rimsky-Korsakov's talk). Production cross-sections and (if possible) angular distributions of gamma-rays above 70 MeV induced by GeV protons should be systematically measured.

3.3 The participants felt that a concentrated effort is needed to address the above problems. To speed up the necessary developments they suggested to set up a Co-ordinated Research Programme on Measurement, Calculation and Evaluation of Photon Production Cross Sections under the auspices of the IAEA.

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