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# Summary Report of the 1st Research Co-ordination Meeting on "MEASUREMENT, CALCULATION AND EVALUATION OF PHOTON PRODUCTION DATA"

Bologna, Italy, 14-17 November 1994

Prepared by

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Vienna, Austria

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## Abstract

The present report contains the summary of the 1st Research Co-ordination Meeting on "Measurement, Calculation and Evaluation of Photon Production Data", held in Bologna, Italy, from 14 to 17 November 1994. The meeting was organized in co-operation with the Applied Physics Department, ENEA Bologna. Summarized are conclusions and recommendations of the meeting, together with a list of actions and deadlines. Attached are a detailed agenda of the meeting, abstracts of presentations, and a list of participants.

March 1995

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# PREFACE

The 1$^{st}$ Research Coordination Meeting (RCM) on "Measurement, Calculation and Evaluation of Photon Production Data" was held in Bologna, Italy, from 14 to 17 November 1994. The RCM was hosted by the Applied Physics Department, ENEA Bologna, Italy.

The purpose of the RCM was to review current status of work related to measurement, calculation and evaluation of photon production data and to work out a detailed working programme of the respective Co–ordinated Research Programme (CRP). The scientific background, scope and expected product of the CRP can be found in the attached Information Sheet (**Appendix 1**).

The Research Coordination Meeting was opened by E. Menapace (ENEA Bologna) and by P. Obložinský (IAEA Vienna). F.S. Dietrich of the Livermore National Laboratory, Livermore, USA was elected as chairman of the RCM.

The agenda of the RCM included scientific and technical presentations of participants, discussion of the scope of the CRP, and discussion of future tasks and actions. The RCM was attended by all nine CRP participants (7 chief scientific investigators and 2 representatives of chief scientific investigators), and by ten observers. The agenda, the list of participants and abstracts of their presentations are attached (**Appendix 2**).

Conclusions and recommendations of the Research Coordination Meeting including a detailed list of actions and deadlines are given below.

The participants recommended that the 2$^{nd}$ RCM be held in the spring of 1996. Vienna was proposed as the venue of the meeting.

The RCM was preceeded by the NEA Specialists' Meeting on "Measurement, Calculation and Evaluation of Photon Production Data" from 9 to 11 November 1994, which reviewed the subject of photon production data in broad terms. This served as an introduction to the subsequent RCM, which was concerned with the open problems to be solved in the future. The Summary of the NEA Specialists' Meeting, prepared by its chairman, Prof. C. Coceva, can be found in the **Appendix 3** of the present report.

The RCM had full and efficient support of its local organizers. The participants expressed their gratitude and appreciation to Prof. C. Coceva of ENEA Bologna for his excellent work as a local organizer of the RCM.

# 1 Introduction

Photons ($\gamma$ rays) are emitted in very nearly all nuclear reactions and are of substantial interest for many applications. They represent an important part of the energy released in nuclear power generation facilities. In a fusion reactor, for example, photons from (n,x$\gamma$) reactions constitute the major part of the energy released. Energy output calculations require precise knowledge of $\gamma$ production cross sections, $\gamma$ ray spectra, and generally also their angular distributions. These $\gamma$ rays must be tracked in transport calculations to establish heating of various reactor components. $\gamma$ rays are also important in transport of energy through materials, including biological shielding.

Further, $\gamma$ rays yield important information about the nucleus from which they originate and thus about the isotopic composition of an emitting material. This feature can be used as a very efficient tool to identify production of stable, long-lived, and also short-lived nuclei. This is important for example in assessment of environmentally critical activation problems in nuclear energy as well as non-energy producing facilities, such as nuclear waste transmutation.

Practical interest extends, in addition, to fields as diverse as medical applications, geophysics, material sciences, astrophysics, accelerator-driven transmutation technologies, biology, and archaeology.

The data, needed for applications are always ultimately based on measured quantities, are either used directly in the evaluation process, or used to validate nuclear models which are then employed to calculate data in regions where measurements are absent or unreliable. Models also provide a framework in which to interpret new measured data. Nuclear models are based on a wide variety of physical approaches, including phenomenological and semiclassical treatments, as well as fully quantum–mechanical ones. Continuing improvement of the models together with experimental validation is essential. Nuclear reaction models are becoming increasingly valuable because of the severe and continuing reduction in experimental facilities. Finally, it should be noted that in some cases nuclear models are unavailable or insufficiently accurate to predict the needed data, and in these cases specific measurements must be made.

**The objectives of the CRP, its scientific scope and product** are explained in **Appendix 1**. The product of the CRP will include a report that recommends the most fruitful approaches to be taken in estimating $\gamma$–production data throughout the range of applications addressed by the CRP. This work will include a file of $\gamma$ strength functions for use in calculations to improve the existing data libraries. As the first step in reaching this end product, the RCM assessed the present state of the art of $\gamma$ production. This led to the identification of a number of topics that need to be pursued further in order to reach the objectives of the CRP. This assessment, together with the assignments accepted by the participants to be carried out as part of the CRP, are indicated in the following sections.

# 2 Technical and Scientific Presentations

The papers presented at the RCM addressed a wide variety of problems in photon production and were subdivided into three categories as follows:

- **Measurements**

Talk 1: "Discrete Photon Production Cross Sections in Light Nuclei", S.P. Simakov (Obninsk)

Talk 2: "Production of Discrete Gamma-Lines in Light Nuclei at 14 MeV", S. Hlaváč (Bratislava)

Talk 3: "Precision Measurement of $^{56}Fe$ Cross Section for $E_\gamma = 846$ keV Transition and for $E_n$ Between Threshold and 4 MeV", J.K. Dickens (Oak Ridge)

Talk 4: "$^{208}Pb(n,pxn\gamma)$ Reactions for Neutron Energies up to 200 MeV", A. Pavlik and H. Vonach (Vienna) and R.O. Nelson, R.C. Haight, S.A. Wender, P.G. Young and M.B. Chadwick (Los Alamos)

"Gamma–Ray Production Experiments at the WNR White Neutron Source", R.O. Nelson and S.A. Wender (Los Alamos)

- **Calculations**

Talk 5: "Overview of Reaction Mechanisms for Calculating the High-Energy Component of Fast-Nucleon Induced Gamma Spectra", F.S. Dietrich (Livermore)

Talk 6: "Average Angular Distribution of 14 MeV Neutron Capture Gamma-Rays", F. Cvelbar and A. Likar (Ljubljana)

Talk 7: "Consistent Generation of Imaginary Interaction in DSD Model", A. Likar and T. Vidmar (Ljubljana)

Talk 8: "Production of Continuum and Discrete Gamma Rays in $(n, x\gamma)$ Reactions", E. Běták (Bratislava)

Talk 9: "Effect of Collective Excitations on the Formation of Preequilibrium $\gamma$ Ray Spectra for the Radiative Neutron Capture Reaction in the Energy Region 10 - 20 MeV", A. Dityuk, Yu. Shubin and G. Tertychny (Obninsk)

- **Compilations, Evaluations and Benchmarks**

Talk 10: "Present Status of Experimental Gamma-Ray Strength Functions", J. Kopecky (Petten) and M. Uhl (Vienna)

Talk 11: "Evaluated Gamma-Ray Production Data of JENDL-3.2", K. Shibata, S. Igarasi and T. Asami (Tokai-mura)

Talk 12: "An Integral Test of Neutron-Induced Photon Production Data for Iron", H. Freiesleben, K. Seidel and S. Unholzer (Dresden)

Talk 13: "Benchmark Test of Gamma-Ray Production Data in JENDL-3.2 and FENDL-1", F. Maekawa and Y. Oyama (Tokai-mura), presented by K. Shibata

# 3 Summary of Presentations

At the meeting, new experimental results and proposed measurements were presented in three incident neutron energy regions:

1-4 MeV. A high-accuracy measurement of the production cross section of the 846-keV $\gamma$ following neutron excitation of $^{56}Fe$ was proposed in a talk (No. 3), motivated by the need for improved reactor pressure vessel surveillance dosimetry.

14 MeV. There were 3 presentations on experiments at energies near 14 MeV:

- There was a presentation (No. 1) on discrete photon production cross sections in light nuclei, in which the goal was to find nuclei and/or transitions for which the measurements are scarce or controversial.
- A second concerned the production of discrete gamma lines in light nuclei induced by 14.7 MeV neutrons at the Bratislava facility (presentation No. 2), in which cross sections were determined that are otherwise difficult to obtain.
- The third, an integral test of neutron-induced photon production data for iron (talk No. 12), described measurements at the Dresden 14 MeV neutron generator and a comparison with Monte Carlo transport calculations using the European Fusion File EFF-1.

10-200 MeV. Measurements were reported (talk No. 4) on the study of discrete gamma lines from the $^{208}Pb(n,pxn\gamma)$ reaction. These measurements were carried out at the Los Alamos WNR facility (with calibrations at Bratislava), and were motivated by the need to test nuclear model calculations as a function of increasing neutron energy. This presentation was complemented by a short overview on the current activities at this facility.

Further presented at the meeting were results on improving the quality of nuclear models and their parameters, and on compilation, evaluation and benchmarking activities:

Modelling of high energy photon emission. A number of new developments were reported on the modelling of high–energy gammas (i.e., gammas above approximately 10 MeV). Gamma production in the high energy region is largely due to direct reaction mechanisms, which are complementary to the Hauser–Feshbach statistical model used for calculations at lower energies. An understanding of gamma production in this energy range is important in achieving a complete picture of the physics underlying gamma emissions. Inclusion of the high–energy region is expected to be important for future evaluations in which the prediction of gamma spectra over a broad range of incident–particle and gamma energies is required. Presentations on this subject included the following:

- There have been recent significant improvements in the Direct Semidirect model (DSD). These developments consisted of: extension of the model to transitions to unbound states (talk No. 5); an examination of the origin of both real (talk No. 9) and imaginary parts (talk No. 7) of the coupling form-factor; an analogy of the coherence in the semidirect term to that of Dicke superradiance (talk No. 7); and a phenomenological separation of the DSD and multistep parts of the capture cross section (talk No. 9). Importance of angular distributions in interpreting cross sections for high–energy $\gamma$ production was discussed in talk No. 6.
- Developments in the preequilibrium exciton model were also discussed; the effects of including spin in this model were demonstrated in talk No. 8.

$\gamma$ Ray Strength Functions. An update of the Kopecky-Uhl parametrization of the gamma-ray strength functions was presented (talk No. 10).

Evaluations. Results of recent measurements of capture cross sections in the keV neutron-energy region were reported at NEA Meeting, together with a re-investigation of the models adopted in low-energy calculations (Direct Radiative Capture Model, Valence Model). These experimental results have been incorporated into some of the evaluated data files such as JENDL 3.2 (talk No.11). Further given in this talk was an interesting overview of photon production data in JENDL-3.2.

Benchmarking. Benchmarking of photon production data in the evaluated files JENDL-3 and FENDL-1 with an important assessment of the quality of these files was reported in the talk No.13.

# 4 Status of Activities

Based on the presentations described above (as well as those of the preceding NEA Specialists' Meeting), the participants were able to draw a number of general conclusions about the current status of gamma production, which are briefly described here. These conclusions underlie the recommendations for further work noted in the next section as well as the specific actions to be taken by the participants.

It was chosen to assess separately the status of the measurements, and of the modeling and evaluation activities.

*(a) Status of measurements*

It is recognized that a considerable base of differential photon production data exists. Integral measurements are available for benchmarking purposes, including those reported in this meeting. Existing measurements span the incident neutron energy range from sub-thermal to greater than 20 MeV, with a concentration of results in the

14 MeV region. These experimental data provide a substantial basis for present-day evaluations. The status of the current data base is, however, not always satisfactory, mainly due to discrepant and older measurements in the 14 MeV region. Experiments are still required for needed improvements in evaluations, either directly or as guidance to model calculations. Thus, the RCM reports with concern the lessening of support and the loss of experimental facilities (worldwide) for future experimental efforts.

*(b) Status of calculations and evaluations*

For light nuclei in the low energy range, there is a body of information on capture cross sections and gamma-ray spectra that has not yet been included in the evaluated files.

As a guidance for statistical calculation of photon production data ($A > 40$, $E_n < 10MeV$), a standard Hauser-Feshbach model employing the general formulation of the gamma-ray strength function model as proposed by M. Uhl is recommended [*see Report INDC(NDS)-331, IAEA Vienna, 1994: "Summary Report of the* $1^{st}$ *RCM on Development of Reference Input Parameter Library for Nuclear Model Calculations of Nuclear Data", Cervia, Italy, 19–23 September 1994*]. This recommendation includes the Giant Resonance Model approach with enhanced Generalized Lorentzian for E1 radiation. The absolute normalization of the parameters of the model can be based either on available experimental information, preferably $< \Gamma_\gamma > / < D_0 >$ or on the updated systematics of E1 and M1 strength functions presented at this meeting.

The semiclassical preequilibrium exciton model and the quantum–mechanical DSD model are useful tools for estimating the high–energy part of the gamma spectrum. The exciton model is easily adapted to rapid numerical computation and is applicable globally, i.e., to all cases in which an initial excitation energy and exciton configuration may be described. It is particularly useful in cases for which quantum mechanical models such as DSD are inappropriate. The DSD model based on complex coupling to the Giant Dipole and Giant Quadrupole Resonances reproduces reasonably experimental cross sections, angular distributions and analyzing powers of gamma rays, with some exceptions in heavy nuclei.

The quantity and accuracy of evaluated gamma–ray production data are much less well developed than for evaluated data for other reactions. For some elements no evaluated gamma-production data are available at all. Improvements in evaluated data files are required, particularly for fusion applications.

# 5 Future Directions

To test and validate improvements made in the various reaction models and parametrizations, appropriate experiments must be performed. Such experiments will require a wide variety of projectiles and energies. Since the evaluation of gamma production data in the existing libraries is presently incomplete, further work in this area is very important. Owing to the decline in experimental programs in the nuclear data field, it is important that future measurements be well focussed on well–defined needs in

(a) nuclear model code development,

(b) evaluated data files, for certain energy regions and reactions not presently amenable to nuclear model prediction, and

(c) integral tests and benchmarks.

In the area of nuclear models, we have identified specific problems that should receive attention in the near future: *1)* Direct Radiative Capture of p-wave neutrons, *2)* treatment of fragmentation of the Giant Resonances particularly in the light nuclei using microscopic models such RPA or other more extended treatments.

For the purpose of understanding the gamma strength functions, the general behavior of M1 collective excitations in the whole mass and energy range should be understood. Both experimental and theoretical efforts will be necessary to clarify this question.

Additional measurements of the production of discrete gamma lines by 14 MeV neutrons should be made. We note and encourage the continuance of an experimental program in this area.

The future inclusion of discrete levels and of higher multipolarity gamma transitions would widen the area of applicability of the preequilibrium exciton model.

Additional effort should be made in the direct-semidirect model in two areas: *1)* obtaining a fundamental understanding of the basic approaches, approximations, and parameters of the model and *2)* including the model as part of a multistep nuclear reaction theory.

# 6 Recommendations and Action Plan

The RCM finished the first session of its work with the framing of four general recommendations and the establishment of an action plan based on the above conclusions and the objectives of the CRP. This action plan consists of a series of tasks and projects that were derived from statements prepared by the participants in response to the findings of this meeting. In most cases, the deadline for completing these action items is the time of the next meeting in spring 1996. Progress on these action items will be critical for the drafting of the report of the CRP, which will be initiated at the next meeting. The action plan includes a number of items relevant to the objectives of the CRP, although not covered directly by the CRP participants.

### A. General Recommendations

1. The RCM strongly emphasizes the need to maintain and support the ongoing research at IRMM (Geel, Belgium) and LANSCE (Los Alamos, U.S.A.). Contributions from these two unique facilities with extensive international participation were highly appreciated at this meeting as well as at the NEA Specialists' Meeting immediately preceding it.

2. Nuclear Data Centers provide a critical service in acquiring experimental, calculated and evaluated data, preparing the data in a standard format, and making data available to all users. The RCM expresses concern at the decline in support for these activities over the past several years. The RCM welcomes the creation of a new data center at ENEA (Italy), and urges cooperation with this center and support of its activities.

3. It is recommended that the present CRP activity be strengthened by addition of one or two participants, particularly representing evaluation activities. In this regard, it was noted that an interesting activity is under way at ENEA (Bologna) conducted by A. Mengoni on photon production from neutron interactions with light nuclei. Also noted was the unique experience in photon evaluations acquired over a long period by C.Y. Fu at Oak Ridge. Of interest also is the photon evaluation work at CNDC in Beijing.

4. The participants discussed the venue and date for the next CRP meeting. It was recommended that the meeting should be held in Vienna in the spring of 1996. In making a final decision on the site and time, particular attention should be paid to the benefits of a possible association with another meeting relevant to nuclear data activities.

### B. Action Plan Directed Toward Fulfillment of CRP Objectives

- **Measurements**

1. Because of its substantial importance in the dominant methods of energy production, continuing high–resolution and high–precision measurements on structural materials, in particular iron, are recommended, including high–precision cross sections for the 846 keV $\gamma$ ray in $^{56}Fe$ as presented by J.K. Dickens for improved reactor pressure vessel surveillance. These measurements should be completed in three years. They are closely related to the high-resolution measurements on $^{56}Fe$ reported by Märten (Geel) at the NEA Specialists' Meeting which showed a substantial improvement in numbers of resonances and fluctuations in the production of the 846 keV photon in $^{56}Fe$.
   ** Action Dickens, deadline next CRP Meeting*

2. Gamma ray production measurements provide very useful information on production of stable or long–lived nuclei of importance for activation. For example, discrete $\gamma$ ray production in reactions like $^{28}Si(n,n'p\gamma)$ and $^{39}K(n,\alpha\gamma)$ at 14 MeV should provide critical clues for assessment of required cross sections needed for waste management (*see Report INDC(NDS)-301, IAEA, July 1994: "IAEA Specialists' Meeting on Activation Cross Sections" held at JAERI, Japan, 1993*). We recommend that these measurements be carried out in Bratislava.
   ** Action Hlaváč, deadline next CRP Meeting*

3. It was recommended that photon production cross section measurements at 14 MeV planned by the Obninsk group (Na and F) should be carried out as a joint effort using the Bratislava 14 MeV facility.
   ** Action Simakov and Hlaváč, deadline next CRP Meeting*

4. To study the applicability of nuclear reaction models originally developed for lower energies in an extended incident neutron energy range, $\gamma$ ray production cross sections for transitions in several residual nuclei formed in $^{27}Al(n,x\gamma)$ reactions were measured at the white neutron source WNR in Los Alamos in the neutron energy range of 3 to 200 MeV. The analysis of these $\gamma$ ray production cross section data will be completed. An experiment performed in Bratislava in collaboration with the Slovak Academy of Sciences at a neutron energy of 14.7 MeV will complement the white source measurement. The result of the 14 MeV experiment will also permit a more precise normalization of the white source measurement.
   ** Action Vonach/Pavlik, deadline next CRP Meeting*
   ** Action Hlaváč, deadline next CRP Meeting*

5. The measurement and analysis of neutron and photon flux spectra from integral assemblies is of fundamental interest for fusion reaction design, especially for shield blanket developments. The analysis of neutron induced photon flux spectra from integral assemblies needs also precise knowledge of the complex neutron emission spectra. It is recommended as a basic concept for such investigations to perform a simultaneous measurement of neutron and photon flux spectra and to compare measured spectra with MCNP cal-

culations. The Dresden group will continue these tests of nuclear data files for iron. To this end, MCNP calculations will be performed with available pointwise data files like FENDL-1 and EFF-2 that include more realistic angular distributions. These investigations will be extended to integral assemblies of different material compositions with stainless steel. In addition, the RCM recommends experiments involving simultaneous measurements of neutrons and photons, and photon production experiments which complement reaction studies recommended (and under way) for other IAEA CRP projects.
** Action Unholzer, deadline next CRP Meeting*

- **Models and Calculations**

1. The inclusion of discrete levels in the spin–dependent version of the preequilibrium exciton model should be generalized to include higher than E1 transitions and enable the calculation of both continuum–discrete and discrete–discrete $\gamma$ transitions (and therefore population of discrete states and isomeric cross sections). Particularly, the following will be performed:
   - Test and validate the extended code PEGAS and calculate discrete gamma ray production for cases measured by CRP participants such as $^{56}Fe + n$ and $^{27}Al + n$. These results should be compared with those obtained by using the well established codes STAPRE or GNASH.
   - Continue to study spin effects in gamma ray spectra by comparing results from the codes PEGAS and PEQAG.

   ** Action Běták, deadline next CRP Meeting*

2. Further studies on the DSD model should be pursued, particularly:
   - Study further the DSD model extended to transitions to unbound states and recalculate photon production spectra from capture of 14 MeV neutrons using this extended model.
   - Perform further DSD calculations of angular distribution of fast neutron capture and establish its effect on integrated photon production.
   - Analyse particle multipole vibration interaction in the DSD model.

   ** Action Cvelbar/Likar, deadline next CRP Meeting*
   ** Action Dietrich (first sub–item), deadline next CRP Meeting*

3. A representative DSD code and its documentation should be prepared for the purposes of the NEA Working Party Subgroup 12 "Nuclear Model Validation".
   ** Action Cvelbar, deadline end of 1995*

4. Modelling of gamma spectra at Livermore will proceed as follows:
   - Calculations will be made for gamma spectra relevant to applications in neutron radiotherapy and to the generation of a library of photoneutron

cross sections that will be used in an extension of the LLNL's transport codes to include this process. The GNASH/FKK code will be used to calculate the gamma spectra recently measured at the Los Alamos WNR facility from bombardment of oxygen by 10–100 MeV neutrons. This comparison is important for verifying the accuracy of GNASH/FKK prediction for neutron reactions on light nuclei relevant to radiation oncology.

- Photoneutron cross sections needed for transport calculations using GNASH with an exciton model high–energy tail have been calculated. This appears satisfactory for heavy nuclei, but improvements are needed for light nuclei. This problem will be pursued by using the direct–semidirect model to calculate the inverse (capture) reaction. Initial calculations will be made on $^{12}C$, and the results will be compared with measured photoneutron spectra.
- In comparing the recently–developed extension of the direct–semidirect model to unbound states together with Hauser–Feshbach calculations to a wider variety of experimental data, an assessment will be made of the need for additional multistep contributions. If these are required, the extended DSD model will be combined with existing codes for multistep reactions to yield a multistep–direct model for gamma production based on the FKK formalism.

* *Action Dietrich/Chadwick, deadline next CRP Meeting*

- **Compilations and Evaluations**

1. One of the goals of the CRP is to assess the status of experimental and evaluated photon production data. At 14 MeV incident neutron energy, most important for fusion technology, the following tasks are considered of importance:
   - Extend the review of differential measurements and compilation of experimental data of photon production at 14 MeV to all nuclei important for applications.
   - Compare these data with those from evaluated libraries FENDL-1, BROND-2 and ENDF/B-VI and assess the present status of experimental and evaluated photon production data.

   * *Action Simakov, deadline next CRP Meeting*

2. The work on implementation of the revised gamma–ray strength function modelling in the statistical Hauser–Feshbach model calculations will continue. The recommendation of M. Uhl (see *Report INDC(NDS)-331, IAEA, Vienna 1994*), applied and tested in the mass region A = 100 – 200, will be extended towards lower masses. Kopecky will summarize this approach in a document and provide it with practical examples of evaluated cross sections.

This document will be completed during the spring of 1996 and handed over to NDS prior the next CRP Meeting.
** Action Kopecky, deadline before next CRP Meeting*

3. The work on photon production at JAERI will proceed as follows:
   - It is necessary to improve evaluated data on capture cross section and spectra for light nuclei. This will be accomplished by model calculation in collaboration with A. Mengoni, ENEA Bologna.
   - Revision will be made of gamma-ray production data of structural materials for JENDL Fusion File.
   - For applications such as accelerator-driven transmutation, there is interest in gamma spectra produced by neutrons and protons in the extremely high energy range (up to about 2 GeV). Studies of how this should be done will be undertaken.

   ** Action Shibata, deadline next CRP Meeting*

- **Other Research Relevant to CRP Objectives**

1. It was noted that by measuring photon production from the $^{16}O(n,\alpha\gamma)$ at 14 MeV, useful information on He production was obtained. It is recommended to extend this study to a broader range of incident energies.
   ** Assumed action Vienna - Los Alamos collaboration*
2. From the work presented at the NEA Specialists' Meeting, it was evident that gamma emission from neutron capture in light nuclei and in the mass region of structural materials is dominated by non-statistical effects. In view of the practical importance of these nuclei it is recommended to pursue further investigations of such phenomena, involving discrete gamma transitions from neutron capture in single resonances. The aim is to understand the theoretical framework in which such photon data can be calculated.
   ** Assumed action Mengoni*
3. Extend calculations of photon production based on the preequilibrium nuclear reaction concept and perform microscopic calculations of related level densities and damping widths. Calculate photon production from neutron capture of 14 MeV neutrons, cover a broad range of nuclei of practical interest, produce a file of these data and made it available to the present CRP.
   ** Action Shubin, deadline end of 1995*
4. A set of capture cross-section calculations for light nuclei (C, O, N isotopes) in the low energy range (from thermal up to 1 MeV) will be performed using the Direct Radiative Capture model, including the contribution of p-wave neutrons. Particular care will be devoted to the calculation of the properties of the low-lying levels when important nuclear structure effects are expected to influence the result of the calculation. A first report on the results of the calculation and their inclusion in the evaluated files will be provided.
   ** Assumed action Mengoni*

# International Atomic Energy Agency

## Co–ordinated Research Programme on

# "Measurement, Calculation and Evaluation of Photon Production Data"

*Information Sheet*

## 1. Scientific Background

Photons ($\gamma$ rays) emitted in nuclear reactions are of substantial practical interest for two reasons.

First, they represent an important part of energy released in nuclear power generation facilities. In a fusion reactor, for example, photons from $(n, x\gamma)$ reactions constitute the major part of energy released. Energy output calculations require precise knowledge of $\gamma$ production cross sections, $\gamma$ ray spectra and whenever possible also their angular distributions. These $\gamma$ rays must be tracked in photon transport calculations to establish heating of various reactor components. Another major concern refers to biological shielding and, more generally, to transport of radiation through material.

Second, $\gamma$ rays yield important information about the nucleus from which they originate and thus about the isotope composition of an emitting material. This aspect can be used as a very efficient tool to identify production of stable, long–lived and also short–lived nuclei. This is important for example in assessment of environmentally critical material activation of nuclear energy as well as non–energy facilities, for nuclear waste transmutation and nuclear geophysical applications.

A considerable progress has been achieved in recent years in understanding the physics of photon emission in nuclear reactions, in developing sophisticated techniques for their measurements, and in assessment of importance of photon production for a number of applications [1]. In view of this it has become now possible to improve evaluation procedures and methods and thereby increase accuracy and quality of photon production data in the evaluated nuclear data files.

Such efforts are currently under way in several leading data centers in the Member States aiming to develop procedures and methods so that new and better quality data are produced. The essential objective of the proposed CRP is to coordinate this effort, facilitate information exchange and avoid duplication in order to develop internationally recommended procedures for evaluation of photon production data.

These procedures should reflect the current status of understanding and theoretical modelling of photon emission primarily in $(n, x\gamma)$ reactions, the substantial new amount of measured photon data in continuum as well as in discrete spectral energy range, and the growing variety of applications.

Theoretical procedures should account for substantial new developments in modelling preequilibrium and multistep mechanisms of $\gamma$ ray emission that proved crucial for description of high energy portion of $\gamma$ ray spectra [2]. Such $\gamma$ rays have been completely omitted in earlier calculations, although high energy photons are of top concern for biological shielding. Another important theoretical development that should be taken into account refers to substantial improvements of $\gamma$ ray strength functions, that constitute a key quantity in calculations of photon production cross sections and photon spectra [3].

Current experimental approaches of in-beam $\gamma$ ray spectrometry reflect almost revolutionary developments in nuclear physics instrumentation. New photon production data are available that were measured with high resolution $\gamma$ ray detectors and sophisticated multidetector scintillation systems with excellent time resolution and fully computerized data acquisition. Evaluation procedures for photon production should be thus tested and validated against such modern experimental data.

### References


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2) P. Obložinský and M.B. Chadwick: "Calculations of Photoproduction Reactions", review paper at the International Conference on Nuclear Data for Science and Technology, Jülich (Germany), 13–17 May 1991. In: Proceedings, ed. S.M. Qaim, Springer Verlag, Berlin 1992, pp. 842–847.

3) J. Kopecky and M. Uhl: "Status of Statistical Model Capture Calculations", review paper at the Symposium on Nuclear Data Evaluation Methodology, Brookhaven (USA), 12–16 October 1992. In: Proceedings, ed. C.L. Dunford, American Institute of Physics, New York 1993, in press.


## 2. General Information on the CRP

Where it is deemed desirable that several institutes co-operate in furthering research in a given field, Co-ordinated Research Programme (CRP) represents an effective means to bring together researchers to collaborate in a well defined research topic. The role of the International Atomic Energy Agency (IAEA) is to define, co-ordinate and support the programme.

The duration of a CRP is generally 3 years, but an extension is possible, if recommended and approved by the IAEA. Research Co-ordination Meetings (RCMs) are generally convened at the beginning, in the middle and at the end of a CRP, with the purpose to define details of the programme, review the progress and formulate final report.

In accordance with the proposal from the IAEA Nuclear Data Section and with endorsement by the International Nuclear Data Committee (INDC), an advisory body

**for the nuclear data programme of the IAEA, the proposed CRP on Measurement, Calculation and Evaluation of Photon Production Data was recommended to start in 1994.**

## 3. Scientific Scope and Proposed Programme Goals

The CRP should bring together experimenters, theorists and evaluators aimed to recommend improved evaluation procedures for photon production from $(n, x\gamma)$ reactions. The goal of the CRP is to examine the current status of measurements, calculations and evaluations of photon production with the emphasis on neutron-induced reactions, work out procedures and methods to be recommended for future evaluation procedures of photon production data, and improve selected photon production cross sections in internationally recognized general purpose nuclear data libraries.

The CRP should address the following questions:

- Measurements: in-beam $\gamma$ spectroscopy, high resolution measurements, measurements of bulk $\gamma$ ray emission and $\gamma$ ray angular distributions, benchmark experiments.
- Calculations: statistical, preequilibrium and multistep $\gamma$ emission, $\gamma$ ray strength functions.
- Evaluations: continuum spectra, discrete $\gamma$ ray production, angular distributions, improved evaluation of photon production for structural and shielding materials.

Expected output of the CRP is a document of recommended procedures and methods for evaluation of photon production data together with a file of recommended $\gamma$ ray strength functions to facilitate the implementation of these procedures, and improved files of photon production cross sections for structural and shielding materials.

## 4. Participation

Due to budgetary limitations only a selected number of laboratories can participate in this CRP. Selection of participants will be based on the relevance of the current and projected work described in the proposals received from potential participants. As soon as the proposals have been evaluated all potential participants will be notified and only at that time a decision be made concerning actual participation in the CRP.

## 5. Activities

The major activities will be performed by individual participants at their home institutes. Periodically (approximately every 18 months) the IAEA will convene CRP meetings, bringing together all participants to review the status of the activities of the CRP. Between meetings participants are encouraged to inform the IAEA of all relevant work on the subject and to send copies of all papers, progress reports, etc. to the IAEA which will be distributed to all participants. At least once a year each participant must submit a progress report to the IAEA.

6. **Research Agreements/Contracts**

In order to participate in this CRP each participant must enter into a research agreement or contract with the IAEA. Participants from Developed Countries (as defined by the IAEA) must enter into a research agreement. Under a research agreement a participant does not receive from the IAEA any direct financial support for research. The only financial support received from the IAEA under a research agreement is transportation and per diem of the principal investigator or his representative to attend periodic CRP meetings. Participants from Developing Countries (as defined by the IAEA) can enter into a research contract. Under a research contract in addition to financial support to attend CRP meetings participants can also receive a small amount of financial support for research (up to US$ 5,000 per contract year). Research agreements and contracts are reviewed (based on annual reports) and, subject to approval by the Director General, renewed each year.

7. **Duration of the CRP**

The CRP will run for three years (1994–1997).

8. **Additional Information**

Additional information on the CRP may be obtained from:

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Nuclear Data Section, IAEA
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International Atomic Energy Agency

1st Research Co-ordination Meeting on

**"Measurement, Calculation and Evaluation of Photon Production Data"**

Bologna, Italy
14-17 November 1994

# AGENDA

# ABSTRACTS

# LIST OF PARTICIPANTS

INTERNATIONAL ATOMIC ENERGY AGENCY
AGENCE INTERNATIONALE DE L'ENERGIE ATOMIQUE
МЕЖДУНАРОДНОЕ АГЕНТСТВО ПО АТОМНОЙ ЭНЕРГИИ
ORGANISMO INTERNACIONAL DE ENERGIA ATOMICA

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COMPOSER DIRECTEMENT LE NUMERO DE POSTE: 1712

First Research Co-ordination Meeting on
**"Measurement, Calculation and Evaluation of Photon Production Data"**

Bologna, Italy
14-17 November 1994

# AGENDA

## 1. Timetable

**Monday, 14 November**
============

| | |
|---|---|
| 09:30 - 10:00 | Opening of the Meeting<br>- Host **(E. Menapace)**<br>- IAEA **(P. Obložinský)**<br>- Election of the Chairman<br>- Adoption of the Agenda |
| 10:00 - 13:00 | Presentations: Photon Production Studies<br>- Talk #1 **(S.P. Simakov)**<br>- Talk #2 **(S. Hlaváč)**<br>- Talk #3 **(J.K. Dickens)** |
| 13:00 - 14:30 | Lunch break |
| 14:30 - 17:30 | Presentations: Photon Production Studies (continued)<br>- Talk #4 **(A. Pavlik)**<br>- Talk #5 **(F.S. Dietrich)**<br>- Talk #6 **(F. Cvelbar)** |

**Tuesday, 15 November**
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| | |
|---|---|
| 09:30 - 13:00 | Presentations: Photon Production Studies (continued)<br>- Talk # 7 **(A. Likar)**<br>- Talk # 8 **(E. Běták)**<br>- Talk # 9 **(Yu. Shubin)**<br>- Talk #10 **(J. Kopecky)** |

| | |
|---|---|
| 13:00 - 14:30 | Lunch break |
| 14:30 - 17:00 | Presentations: Photon Production Studies (continued)<br>- Talk #11 (**K. Shibata**)<br>- Talk #12 (**S. Unholzer**)<br>- Talk #13 (**K. Shibata**) |
| 19:00 - open | Dinner in a typical Bologna pub with pizza, spaghetti and wine. |

**Wednesday, 16 November**
==============

| | |
|---|---|
| 09:30 - 13:00 | Discussions: Scope of the CRP<br>- General discussion<br>- Scope and product of the CRP |
| 13:00 - 14:30 | Lunch break |
| 14:30 - 17:30 | Discussions: Future tasks and recommendations<br>- Detailed list of future tasks<br>- Actions and deadlines<br>- Drafting of recommendations |

**Thursday, 17 November**
============

| | |
|---|---|
| 09:30 - 13:00 | Discussions: Recommendations<br>- Drafting of recommendations |
| 13:00 - 14:30 | Lunch break |
| 14:30 - open | Summary of the Meeting<br>- Adoption of the final report<br>- Conclusions and Summary<br>- Closing of the Meeting |

## 2. Technical and Scientific Presentations on Photon Production Studies

* Measurements

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Talk #1: "Discrete Photon Production Cross Sections in Light Nuclei", S.P. Simakov (Obninsk)

Talk #2: "Production of Discrete Gamma-Lines in Light Nuclei at 14 MeV", S. Hlaváč (Bratislava)

Talk #3: "Precision Measurement of the 56-Fe Cross Section for the $E_\gamma$ = 846 keV Transition and for $E_n$ between Threshold and 4 MeV", J.K. Dickens (Oak Ridge)

Talk #4: "208-Pb (n,pxnγ) Reactions for Neutron Energies up to 200 MeV", A. Pavlik and H. Vonach (Vienna) and R.O. Nelson, R.C. Haight, S.A. Wender, P.G. Young and M.B. Chadwick (Los Alamos)

* Calculations

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Talk #5: "Overview of Reaction Mechanisms for Calculating the High-Energy Component of Fast-Nucleon Induced Gamma Spectra", F.S. Dietrich (Livermore)

Talk #6: "Average Angular Distribution of 14 MeV Neutron Capture Gamma-Rays", F. Cvelbar and A. Likar (Ljubljana)

Talk #7: "Consistent Generation of Imaginary Interaction in DSD Model", A. Likar and T. Vidmar (Ljubljana)

Talk #8: "Production of Continuum and Discrete Gamma Rays in (n,xγ) Reactions", E. Běták (Bratislava)

Talk #9: "The Effect of Collective Excitations on the Formation of Preequilibrium Gamma Ray Spectra for the Radiative Neutron Capture Reaction in Energy Region 10 - 20 MeV", A. Dityuk, Yu. Shubin and G. Tertychny (Obninsk)

* Compilations, Evaluations and Benchmarks

-------------------------------------------------------

Talk #10: "Present Status of Experimental Gamma-Ray Strength Functions", J. Kopecky (Petten) and M. Uhl (Vienna)

Talk#11: "Evaluated Gamma-Ray Production Data of JENDL-3.2", K. Shibata, S. Igarasi and T. Asami (Tokai-mura)

Talk#12: "An Integral Test of Neutron-Induced Photon Production Data for Iron", H. Freiesleben, K. Seidel and S. Unholzer (Dresden)

Talk#13: "Benchmark Test of Gamma-Ray Production Data in JENDL-3.2 and FENDL-1", F. Maekawa and Y. Oyama (Tokai-mura)

# ABSTRACTS

# Discrete Photon Production Cross Sections in Light Nuclei

*S.P. Simakov*

*FEI Obninsk, Russia*

**Abstract**

The aim of the paper is to examine the status of the experimental data on discrete gamma-ray production cross sections via $(n, x\gamma)$ reaction for light nuclei ($Z < 20$) at 14 MeV incident neutron energy. From this point of view, the available experimental cross section for most prominent gamma transitions were summarized in the report. This experimental base was analyzed to estimate the actual uncertainty of experimental results, and to find out the nucleus and/or transitions for which the measurements are too scarce and controversial.

The ENDF/B6 library was checked as well to search whether the discrete photon production cross section are presented there and how they agree with known experimental data.

The attempt was made to obtain the qualitative requirements arose from fusion reactor technology, geology, medicine and other needs.

As a final goal, the conclusions about for what nuclei the further experiments and evaluations are of primary importance were made.

# Production of discrete $\gamma$ lines in light nuclei at 14 MeV

*S. Hlaváč*

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## Abstract

Measurement of prompt discrete $\gamma$ line production in interaction of 14.7 MeV neutrons with light nuclei using associated $\alpha$ particle method is described. Measured $\gamma$ production cross sections can be used for cross section determination, which are difficult to obtain using classical methods. This is demonstrated on reaction $^{16}O(n,\alpha\gamma)^{13}C$, where the product nucleus $^{13}C$ is stable. Other examples, which are currently under study are also discussed. Importance of theoretical calculations for reliable determination of the reaction cross section using this method is stressed.

# Precision Measurement of the $^{56}$Fe Cross Section for the $E_\gamma$ = 846-keV Transition and for $E_n$ Between Threshold and 4 MeV

*J.K. Dickens*

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*Oak Ridge, TN 37830-6356, U.S.A.*

**Abstract**

An experimental system is described which is designed to provide accurate cross-section measurements of the production of the 846-keV gamma-ray due to inelastic neutron scattering by $^{56}$Fe. Six aspects of the measurement are considered: (a) precision determination of the incident neutron flux; (b) gamma-ray detection resolution; (c) incident neutron-energy determination; (d) interacting neutron-energy resolution; (e) counting rates; and (f) multiple-scattering and attenuation corrections. For precision determination of the incident neutron flux, a simultaneous measurement of the 478-keV gamma ray from the $^{10}B(n,\alpha_1)^7Li$ reaction is proposed, since this reaction cross section has been recently determined[1] to a precision of $\approx 2\%$ for incident neutrons up to 4 MeV. A large-volume intrinsic Ge detector is proposed for gamma-ray detection; the Oak Ridge Electron Linear Accelerator will provide a pulsed neutron beam. Measurements under actual operating conditions will be necessary to optimize counting rates and incident neutron-energy resolution. Multiple-scattering and attenuation corrections will be determined using a modification of the documented Monte-Carlo code SCINFUL;[2] needed cross sections will be taken from evaluation, or in the case of the cross section for the $^{10}B(n,\alpha\gamma)^7Li$ monitor reaction, from recent experimental results.[1]

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* Research sponsored by the Office of Energy Research, Division of Nuclear Physics, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

1. R.A. Schrack, et.al., *Nucl. Sci. Eng.* 114 (1993) 352.

2. J.K. Dickens, *SCINFUL: A Monte Carlo Based Computer Program to Determine a Scintillator Full Energy Response to Neutron Detection for $E_n$ Between 0.1 and 80 MeV: User's Manual and FORTRAN Program Listing*, ORNL-6462 (March 1988); see also J.K. Dickens, "Scintillation Detection Efficiencies for Neutrons in the Energy Region Above 20 MeV," in *Neutron Cross Section Standards for the Energy Region Above 20 MeV, Proceedings of a Specialists' Meeting*, NEANDC-305 'U', (OECD, Paris, 1991) p. 142.

# $^{208}Pb(n,pxn\gamma)$ Reactions for Neutron Energies up to 200 MeV

*A. Pavlik and H. Vonach*

*Institut für Radiumforschung und Kernphysik, Universität Wien*
*A-1090 Wien, Austria*

*R.O. Nelson, R.C. Haight, S.A. Wender, P.G. Young, and M.B. Chadwick*

*Los Alamos National Laboratory, Los Alamos, NM 87545, U.S.A.*

**Abstract**

The prompt gamma-radiation from the interaction of fast neutrons with enriched samples of 208Pb was measured using the white neutron beam of the WNR facility at Los Alamos National Laboratory. The samples were positioned at about 40 m distance from the neutron production target. The spectra of the emitted gamma-rays were measured with a high-resolution HPGe detector. The incident neutron energy was determined by the time-of- flight method and the neutron fluence was measured with a 238U fission chamber. In addition to the primary purpose of this experiment, the study of $(n, xn\gamma)$ reactions leading to various lead isotopes, gamma transitions in the residual nuclei 207,205,203,201Tl were analyzed. From these data gamma- production cross sections in the neutron energy range from the effective thresholds to 200 MeV were derived. The lines for the analysis had to be chosen carefully as the $(n,pnx\gamma)$ cross sections are rather small and the interference with unresolved lead lines (even weak ones) would cause significant errors. The effect due to isomers with half-lives exceeding a few nanoseconds was taken into account and corrected for, if necessary. The measured cross sections were compared to the results of nuclear model calculations based on the exciton model for preequilibrium particle emission and the Hauser- Feshbach theory for compound nucleus decay.

# Overview of Reaction Mechanisms for Calculating the High-Energy Component of Fast-Nucleon Induced Gamma Spectra

*Frank S. Dietrich*

*N-Division, Physics and Space Technology Directorate*
*Mail Stop L-289, Lawrence Livermore National Laboratory*
*P. O. Box 808, Livermore, CA 94550, USA*

**Abstract**

This presentation will review the status of reaction mechanisms for production of gamma rays in reactions induced by nucleons above a few ( 5-10) MeV in which direct reactions involving the coherent interaction of the projectile with the nucleus may be important. The region of gamma energies considered lies above the region where transitions between bound states are dominant (8-10 MeV), and below the onset of significant contributions from nucleon-nucleon bremsstrahlung. These reaction mechanisms include equilibrium statistical emission, preequilibrium emission, multistep compound and direct reactions, the direct-semidirect model, and the pure-resonance model. Particular attention will be given to the form factors used in the latter two models, and to recent developments in the extension of the direct-semidirect model to unbound final states.

# Average Angular Distribution of 14 MeV Neutron capture $\gamma$-rays

*F. Cvelbar and A.Likar*

*"J. Stefan" Institute and Faculty of Natural Sciences and Technology, University of Ljubljana, Slovenia*

**Abstract**

Angular distribution of 14 MeV neutron capture $\gamma$-rays, averaged over the prompt $\gamma$-ray spectrum, is calculated in the frame of the direct -semi-direct model, extended to cover, besides dipole, also the isovector and isoscalar quadrupole giant resonance contributions. Results indicate that angular distribution of 14 MeV neutron capture $\gamma$-rays is somewhat anisotropic ($a_2$ typical value is about -0.3) but forward-backward symmetric ($a_1$ being typically less than + 0.1). In the calculation of energy integrated cross-section by the multiplication of the $90^0$ value by $4\pi$ , one therefore obtains the result, which is about 10 to 20 per cent too high.

# Consistent generation of imaginary interaction in DSD model

*A. Likar and T. Vidmar*

*Institute J. Stefan and Department of Physics*
*University of Ljubljana, Slovenia*

**Abstract**

The direct-semidirect (DSD) model for nucleon radiative capture reproduces rather well the cross sections and angular distributions for nuclei in the whole mass region but only if the complex coupling between nucleon and giant multipole resonance motion is introduced. The imaginary part of the coupling is strongly mass dependent, being negligible for nuclei with low mass numbers, and surprisingly high for lead. The imaginary isospin part of the optical potential introduces imaginary coupling but with too low strength to reproduce the experimental data. In this contribution we show that part of the Hilbert space, if unproperly eliminated from the formalism, leads to inconsistent formulation of the model. The need for imaginary coupling when the model is confronted with experiment, reflects this inconsistency. The generation of the imaginary part suggested here results from the use of different potentials generating the initial and final wave functions.

# PRE-EQUILIBRIUM EMISSION: SPIN-DEPENDENT CALCULATIONS

E. Běták

*Institute of Physics, Slovak Academy of Sciences, 84228 Bratislava, Slovakia*

## Abstract

We present calculations of angle-integrated spectra and other quantities within the pre-equilibrium model with a full account of angular-momentum couplings both in the equilibration process and in the particle and gamma emissions. This enables us a detailed comparison of spin-dependent calculations to the more simple case of the spin-independent description. The study is done not only for the first ejectile, but a full pre-equilibrium treatment of subsequent (cascade) emissions is employed. Whereas neutron spectra for modest-energy nucleon-induced reactions are practically not influenced, proton and $\gamma$ spectra appear to be more sensitive to the presence of the spin coupling. This effect increases with increasing spin of the target and with the excitation energy of the composite system.

# THE EFFECT OF COLLECTIVE EXCITATIONS ON THE FORMATION OF PREEQUILIBRIUM GAMMA RAY SPECTRA FOR THE RADIATIVE NEUTRON CAPTURE REACTION IN ENERGY REGION 10-20 MEV

*A. Dityuk, Yu. Shubin, G. Tertychny*

*Institute of Physics and Power Engineering*
*249020 Obninsk, Russia*

**Abstract**

It is well known that in medium and heavy mass nuclei collision dumping is the most essential mechanism leading to spreading effects of Giant Multipole Resonances (MGR) due to a mixing of 1p1h doorway states with more complicated nuclear excitations, such as 2p2h, 3p3h etc. The total widths and intermediate structures of MGR can be explained satisfactorily, as it follows from recent publications, in frame of (1p1h + 2p2h + continuum) approach [1], when we take into account mixing 1p1h configurations with the strongest collective excitations.

The main goal of this contribution is to investigate a doorway and collective states influence on the formation of high-energy (preequilibrium) part of primary gamma ray spectra observed in fast neutron radiative capture. To calculate a reaction cross sections we explore the main conceptions of the quanta-mechanical multistep-compound approach [2] which is more consistent, in comparing with the alternative approaches, for correlation between statistical and collective aspects of excited nuclear states in continuum.

Results obtained for Ca, Ni and Zr nuclei enable to conclude that our model is adequate to reproduce not only absolute values of gamma emission cross sections, as in ref. [2], but it claims also to explain the structure peculiarities of preequilibrium gamma ray spectra observed on high-resolution experiments.

## References

1. S. Kamerdzhiev, J. Speth, G. Tertychny, V. Tselyaev, Nucl. Phys. **A555**, 90 (1993); S. Kamerdzhiev, G. Tertychny, J. Speth, Nucl. Phys. **A569**, 313c (1994)

2. A. Horing, H.A. Weidenmüller, Phys. Rev. **C46**, 2476 (1992); M. Herman, A. Horing, G. Reffo, Phys. Rev. **C46**, 2493 (1992)

# PRESENT STATUS OF EXPERIMENTAL GAMMA-RAY STRENGTH FUNCTIONS

*J. Kopecky*

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*M. Uhl*

*Institut für Radiumforschung und Kernphysik*
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**Abstract**

Earlier compilations of photon–strength functions, based on experimental data from resonance– or thermal–neutron capture and photonuclear reactions, have been reviewed and updated with recent data. The assigned f(E1) and f(M1) uncertainties are discussed, especially in view of uncertainties of important quantities such as the s–wave spacing $D_0$ and the absolute E1, M1 calibration. Possible corrections due to strong non–statistical contributions are discussed. Derived systematics of f(E1) and f(M1) values as a function of atomic mass A are discussed in view of their use in statistical model calculations.

# Evaluated Gamma-Ray Production Data of JENDL-3.2

*K. Shibata, S. Igarasi* and T. Asami***

*Nuclear Data Center*
*Japan Atomic Energy Research Institute*
*Tokai-mura, Ibaraki-ken 319-11, Japan*

**Abstract**

The second revision of JENDL-3 contains gamma-ray production data for 66 nuclides. Evaluated quantities are emitted gamma-ray spectra, production cross sections and photon multiplicities. Except for light nuclides, the statistical model was mainly applied to calculate these quantities. The evaluated data are presented by comparing with measurements and with other evaluated data files.

* Nuclear Energy Data Center, Japan
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# An Integral Test of Neutron-Induced Photon Production Data for Iron

*H. Freiesleben, K. Seidel, S. Unholzer*

*Institut für Kern- und Teilchenphysik*
*Technische Universität Dresden*
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**Abstract**

An iron slab of dimension 1m x 1m x 0.3m is irradiated with 14 MeV neutrons. The neutrons and photons penetrating and leaking the assembly are measured. The spectral photon fluence normalized to one source neutron is compared with Monte Carlo transport calculations (code MCNP) based on the data of the European Fusion File EFF1. Discrepancies are discussed.

# Benchmark Test of Gamma-Ray Production Data in JENDL-3.2 and FENDL-1

*Fujio MAEKAWA and Yukio OYAMA*

*Department of Reactor Engineering*
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*Tokai-mura, Naka-gun, Ibaraki-ken 319-11, Japan*

**Abstract**

Gamma-ray production data in JENDL-3.2 and FENDL-1 were tested through analyses of two sets of benchmark experiments conducted at the principal D-T neutron source facilities in Japan: FNS and OKTAVIAN. Gamma-ray spectra and gamma-ray heating rates were measured in experimental assemblies made of Fe, Cu and W in the FNS experiments. On the other hand, leakage gamma-ray spetra from spherical piles made of LiF, $CF_2$, Al, Si, Ti, Mn, Co, Cu, Nb, Mo, W and Pb were measured in the OKTAVIAN experiments. These experiments were analyzed by using the MCNP-4 transport calculation code with cross section libraries based on JENDL-3.2 and FENDL-1. Through comparisons between the experiments and the calculations, validity of the gamma-ray production data contained in the two nuclear data files was confirmed for the most nuclei. However discrepancies between them were still observed in some cases, and improvement of the data was recommended for more accurate data libraries.

# PHOTON PRODUCTION IN THE $(n, n'\gamma)$ REACTION

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**Abstract**

Neutron inelastic scattering is the most important gamma-photon producing reaction beside neutron capture. For neutron energies of a few hundred keV to several MeV the $(n, n'\gamma)$ reaction is the dominating process, until (n,p), (n,2n) and higher multiplicity reactions become possible. For this reason it is extremely important to study the gamma-radiation from inelastic scattering in the constituents of nuclear reactors.

The technique of $(n, n'\gamma)$ reaction spectroscopy with neutrons of a few MeV energy will be surveyed. It will be shown how to obtain gamma-ray production cross sections and gamma-ray angular distributions. Inferred cross sections of nuclear levels will be compared with Hauser-Feshbach type statistical reaction model calculations for a variety of nuclei studied in a cooperation between Kentucky and Budapest. Works with reactor fast neutrons will also be mentioned.

334-F4-RC-571 21 March 1995

INTERNATIONAL ATOMIC ENERGY AGENCY

**First Research Co-ordination Meeting on "Measurement, Calculation and Evaluation of Photon Production Data"**

**Bologna, Italy**
**14 to 17 November 1994**

**Scientific Secretary: Pavel OBLOŽINSKÝ**

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# SUMMARY REPORT OF THE NEA SPECIALISTS' MEETING ON MEASUREMENT, CALCULATION AND EVALUATION OF PHOTON PRODUCTION DATA

Bologna, November 9-11, 1994

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This meeting was organised to fulfil an action placed by the NEA Nuclear Data Committee during its meeting at Harwell, in 1990.

It was organised and sponsored by ENEA, and it took place in Bologna, November 9-11, 1994, with the participation of 37 invited specialists.

Thirty-one talks were presented in the following sessions:

- Direct-semidirect models
- Photon production measurements from inelastic and break-up reactions
- Gamma cascades
- Photon induced reactions
- Collective excitations and radiative decay strengths
- Non-statistical gamma emission
- Pre-equilibrium models and calculations
- Experimental methods and measurements
- Photon production libraries
- Applications

The response of the scientific community does witness a high interest in the subject of the meeting, but it is also the result of a close co-operation between the two Agencies NEA and IAEA. The participation of non-OECD countries was favoured by the fact that IAEA decided to hold in Bologna on November 14-17 the first meeting of its Co-ordinated Research Program on the same subject, with ENEA acting as host and local organiser.

In this way the NEA Specialists' Meeting could provide a fully worldwide review on the subject of photon production data for application purposes.

The title of the meeting indicates three types of activity: measurement, calculation and evaluation. As a matter of fact, evaluation or compilation work as such was reported in just a few talks: for JENDL-3.2 by Shibata (JAERI), for ENDF/B-VI by Fu (Oak Ridge), and the review of radiative strengths presented by Kopecky (ECN, Petten). Of course, many experimental and calculated results were compared, when possible, with existing evaluated libraries. Summing up, I got the impression that more effort is wanted to produce and improve evaluated data libraries specifically concerning photon production data. On the other hand, new evaluations must be based on more extended and detailed experimental measurements, which in turn is the activity most affected by the well known general lack of funding.

As it is natural for an application oriented meeting, most of the talks dealt with neutron induced reactions. Among the exceptions, I found fully relevant the review of Kapitonov (Moscow University) on gamma-induced gamma-emission reactions, and the new interesting technique to realise a tuneable source of monochromatic gamma rays, developed at the University of Gent. Moreover Camera (Milan University) showed how heavy-ion reactions can supply unique information on the structures governing photon emission rates. I should also like to point out that the theory of magnetic dipole gamma strength, reviewed by Lo Iudice (Naples University), was largely based on results of electron scattering experiments.

Coming back to the mainstream of neutron induced reactions, incident energies covered a wide range: from cold neutrons, with their applications in analytical science, up to 200 MeV, in a variety of inelastic and break-up reactions, in which all major time-of-flight accelerators, say Geel, Oak Ridge and Los Alamos, brought in their contributions.

In this wide range, a peak of interest in the energy region around 14 MeV was apparent, especially for what concerns theoretical models and calculations. Here, gamma production is calculated in the framework of pre-equilibrium and direct-semidirect models. Important progress was reported in the application of these models which, together with the multistep compound, were thoroughly discussed and compared.

On the other hand, experimental works presented at the meeting show that 14 MeV neutron sources are mostly used for integral data measurements and validations. This is the case of the ENEA facility in Frascati, and of the japanese activity at Oktavian and FNS facilities.

A considerable time was devoted to investigations, both theoretical and experimental, on the gamma cascade following neutron capture at low energies, which is normally interpreted by means of statistical models.

Here, Becvar (Prague University) presented a method to calculate various measurable characteristics of gamma cascades according to a completely statistical model, so that one has a tool to check any deviation of experimental quantities from a statistical behaviour.

Indeed, several results were discussed concerning non-statistical gamma emission. Such a behaviour is expected where single-particle components have a sizeable amplitude, and therefore it is understandable that it is found in light nuclei, where Kitazawa (Tokyo Institute of Technology) and his group used measured radiative transitions from isolated neutron resonances to deduce impressive information on the involved mechanisms. The same can be said for the very interesting phenomenon of neutron nuclear halo and its consequences, studied by Mengoni (ENEA, Bologna).

Less expected are some non-statistical effects in the gamma cascades in heavy nuclei, observed at JINR Dubna by Popov, and by Sukhovoj. Explanation of these experimental findings represent a real challenge.

Finally, I am pleased to point out that this meeting supplies a quite complete review of the experimental methods currently used or in progress to measure the neutron capture cross-section and the characteristics of gamma ray production. This review is provided by the papers of Corvi, Kaeppeler, Georgiev, Khitrov and Igashira, which represent the long experience of important laboratories such as Geel, Karlsruhe, Dubna and the Tokyo Institute of Technology.