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Summary Report of the 2nd Research Co-ordination Meeting on MEASUREMENT, CALCULATION AND EVALUATION OF PHOTON PRODUCTION DATA

Agency's Headquarters in Vienna, Austria, 21-24 May 1996

Prepared by

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Vienna, Austria

December 1996

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

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Abstract

The present report contains the summary of the Second Research Co-ordination Meeting on "Measurement, Calculation and Evaluation of Photon Production Data", held in Vienna, Austria, from 21 to 24 May 1996. Summarized are conclusions and recommendations of the meeting together with a detailed list of actions and deadlines, including procedures to prepare the final document of the project. Attached is the agenda of the meeting, list of participants and extended abstracts of their presentations.

December 1996

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1 Summary of the Meeting

Objectives and Participation

The Second Research Co-ordination Meeting (RCM) on "Measurement, Calculation and Evaluation of Photon Production Data" was held in the IAEA Headquarters, Vienna, Austria, from 21 to 24 May 1996. The meeting was convened as a part of the IAEA Co-ordinated Research Programme (CRP) aimed at addressing open problems in photon production, focusing on neutron induced reactions in the energy range up to about 30 MeV.

The purpose of the meeting was to review the status of work performed under the CRP, to provide a forum for the discussion of related problems and to coordinate future activities. An effort was made to work out procedures towards finalizing the product of the CRP, including the final report. F.S. Dietrich of the Lawrence Livermore National Laboratory, Livermore, U.S.A. acted as a chairman of the meeting. The detailed Agenda is attached (Appendix 1) along with extended abstracts of scientific and technical presentations (Appendix 2).

The meeting was attended by the chief scientific investigators of all 10 laboratories participating in the project and by 3 cost-free observers. The participating laboratories were represented by E. Běták (Bratislava, Slovakia), F. Cvelbar (Ljubljana, Slovenia), F.S. Dietrich (Livermore, U.S.A.), J.K. Dickens (Oak Ridge, U.S.A.), J. Kopecky (Petten, The Netherlands), A. Mengoni (Bologna, Italy), S.P. Simakov (Obninsk, Russia), K. Shibata (Tokai-mura, Japan), H.K. Vonach (Vienna, Austria) and S. Unholzer (Dresden, Germany). Furthermore, A. Pavlik (Vienna, Austria), S. Hlaváč (Bratislava, Slovakia) and A. Likar (Ljubljana, Slovenia) attended as observers. (For details see Appendix 3).

Major Conclusions and Recommendations

It was anticipated that the CRP should be completed by the end of 1997. To this end, the Final Product of the CRP was discussed. It should include status of experimental data, status of theoretical calculations, recommendations for evaluation of photon production data together with a file of recommended gamma-ray strength functions. Individual tasks were specified (see Chapter 3 of the present report for details) with the aim of having a preliminary draft of the Final Report ready by September 1997. The draft will be reviewed at the last meeting.

The draft of the "Atlas of Neutron Capture Cross Sections", prepared by J. Kopecky and coworkers as a specific outcome of the present CRP, was discussed. The Atlas is of high practical value, since it contains data for neutrons in the 0-20 MeV energy range on all 739 target nuclides with half-lives above 0.5 day, totalling to 972 reactions. It was recommended that the Agency publish the Atlas and disseminate it to the user community. It was further recommended that the IAEA Nuclear Data Section explores the possibility of making the Atlas available on its WWW server.

The CRP noted with strong interest the development of an advanced facility (GEANIE) for gamma measurements at the Los Alamos LANSCE accelerator. This facility is potentially of great importance for further measurements in the subject area covered by this CRP.

It was recommended that the CRP highlights should be presented by the scientific secretary, Pavel Obložinský, at the 9^{th} International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, Budapest, 8-12 October 1996, and also at the Conference on Nuclear Data for Science and Technology, Trieste, 19-24 May 1997. Presentations will be prepared together with the CRP chairman F.S. Dietrich.

It was decided to prepare recommendations for codes for photon production for the NEA-sponsored Working Party on International Cooperation, Subgroup 12 "Nuclear Model Validation". Considered should be codes that are frozen and well documented.

It was agreed to publish extended (1-2 pages) abstracts of papers delivered at the present meeting as an Appendix to the Summary Report. Publishing of full papers in the form of Proceedings is not foreseen except of few cases that should be published on individual basis.

It was recommended to hold the 3^{rd} Research Co-ordination Meeting in Bled, Slovenia, 29 September - 3 October 1997. Prof. F. Cvelbar kindly offered his services to host this meeting.

2 Summary of Presentations

Altogether 16 papers were presented. Out of them, 6 were devoted to measurements, 5 to calculations including theoretical developments, and 5 to evaluations including compilation and benchmarking. Extended abstracts of all presentations may be found in Appendix 2.

a. Measurements

The research program agreed upon at the first meeting of this CRP was successfully carried out and most of the tasks summarized. New experimental results were presented in three incident neutron energy regions. In addition, one presentation reported on production of discrete γ-lines by high-energy protons.

1-4 MeV and 14 MeV Incident Neutron Energy Range

High-accuracy measurements of the production cross sections of the 846-keV γ following neutron excitation are underway at the University of Kentucky (talk No. 1 by J.K. Dickens) motivated by the need for improved reactor pressure vessel surveillance dosimetry. Additional measurements are planned at the Oak Ridge ORELA facility and proposed to be done at the Los Alamos GEANIE facility.

There was a presentation (talk No. 2 by S. Simakov) on measurement of discrete γ-ray production cross sections by 14 MeV neutrons in ^{23}Na, ^{31}P and ^{51}V nuclei. The new measurements, performed with a high resolution HPGe detector, increased the accuracy of the experimental data base available from previous experiments, made mainly with NaI detectors.

There was a presentation (talk No. 3 by S. Hlaváč) aimed at measurement of γ-ray production cross-sections from the Si(n,xγ) reaction, and in particular the 843 keV and 1014 keV γ-rays from the $^{28}Si(n,n'p)^{27}Al$ branch. The detection of γ-yields from this reaction is only one possible way to estimation Al accumulation in silicon containing compounds, an important problem relevant to fusion reactor technology.

To improve the existing experimental data base of discrete gamma-ray production cross sections in $^{27}Al(n,x\gamma)$ reactions and to permit a better normalization of gamma-ray production cross sections measured at the Los Alamos white neutron source, a measurement was performed at the Bratislava facility at E_n = 14.6 MeV (talk No. 4 by A. Pavlik). Gamma-ray production cross sections for prominent transitions in ^{27}Al, ^{26}Mg and ^{27}Mg were measured relative to the 846-keV transition in ^{56}Fe.

Intermediate Incident Nucleon Energies

The final results of a measurement of discrete gamma-ray production cross sections for $^{27}Al(n,x\gamma)$ reactions for an incident neutron energy range 3 to 400 MeV were presented (talk No. 4 by A. Pavlik). The experiment was carried out at the Los Alamos WNR facility and the results were normalized to the cross sections measured at 14.6 MeV in Bratislava (see above). The main motivation for this experiment was to provide experimental data to allow tests of nuclear model calculations in a wide range of incident neutron energies.

High-resolution measurements of the γ-spectra from the interaction of 800 MeV protons with Al and ^{56}Fe were also reported (talk No. 5 by H.K. Vonach). It was shown that useful information on the mass and charge distribution of the spallation products formed in these reactions can be obtained from the intensities of the discrete γ-lines observed in these measurements in spite of the very complex nature of these γ-spectra. Especially it was shown that production cross sections for stable even-even nuclei, which are hard to determine by other methods, can be derived from the observed strong 2_1^+ ground-state transitions in these nuclides.

A report (talk No. 6 by F.S. Dietrich) was given on a new facility for γ-production measurements at WNR, Los Alamos. This facility GEANIE (formerly used at LBL Berkeley under the name of HERA) consists of 21 high-resolution Ge γ-ray detectors with BGO Compton suppression and will become operational within this year. It will allow measurements of γ-production cross-sections, both for discrete γ-lines and continuous γ-spectra, over a wide range of incident neutron energies (1 - 500 MeV) and will be especially useful for the study of the angular distributions and excitation functions of photon production.

b. Calculations

The results of recent investigations of the neutron capture process in light nuclei were reported (talk No. 7 by A. Mengoni). New experimental values of capture cross sections provided the basis for the development of a model (the Direct Radiative Capture, DRC) which, combined with the compound nucleus component, has been employed in the calculation of the capture cross section for $^{12}C(n,\gamma)$ and $^{16}O(n,\gamma)$ in the incident neutron energy range up to 1 MeV. The analysis showed the importance of capture due to incident p-wave neutrons which may dominate the capture mechanism the keV region. It has been reported that fundamental information on the capture channel can be obtained by experiments performed in inverse kinematics (Coulomb dissociation experiments).

The master-equation fully pre-equilibrium code DEGAS has been improved to be able to calculate discrete gamma transitions of higher multipolarities (talk No. 8 by E. Běták). Its results for the discrete gamma production in neutron induced reactions on several elements $27 \leq A \leq 56$ at incident energies above 10 MeV have been compared to those obtained by GNASH. Results are rather sensitive to the level density input parameters and not so much to the exciton numbers ascribed to individual discrete levels. The code DEGAS is strictly based on the pre-equilibrium master equation approach to describe a whole course of a reaction and does not employ different approaches which are usually used for specific tasks and/or stages of the reaction. It is therefore not surprising that the agreement with the data is somewhat worse than obtained with the much more complex code GNASH.

The pre-equilibrium exciton model has been used to calculate the excitation functions of integrated capture cross sections at neutron energies above 10 MeV (talk No. 9 by F. Cvelbar). The results agree well with the experimental data and also with the DSD calculations. Because in the exciton model there is no interference between different exciton contributions which in some way appear in the DSD model, the input experimental energy has been reduced pheomenologically by 1.5 MeV. Furthermore, the DSD model was used to calculate the excitation functions for the radiative transitions to the isolated states as well as the ones for the integrated cross sections, covering all transitions to the bound states. The calculations were compared with experimental data which are usually available at 14 MeV. Agreement is reasonably good. Also calculated were the excitation functions for the Legendre polynomial coefficients, averaged over bound states, which have not yet been measured but are of interest for the correction of relevant integrated experimental data.

The DSD model has been improved by eliminating the need of an imaginary coupling strength, previously introduced into the model as a free parameter (talk No. 10 by A. Likar). In this way, only the real part of the coupling remained. Its strength (V_1 = 135 MeV), is equal to the value obtained from other studies. The consistent version of the DSD model has been tested on neutron and proton capture to individual states in ^{40}Ca, ^{89}Y and ^{208}Pb. The analysis of interference between dipole and quadrupole amplitudes has been performed leading to an asymmetry of angular distributions of gamma rays. The model showed that the experimental data could be reproduced using reasonable assumptions for the fractions of isoscalar and isovector quadrupole sum rules exhausted by these resonances.

The extended DSD model that treats capture to unstable final states, introduced at the first Meeting of this CRP, was applied to capture of 34 MeV protons on Cu, Ag and Au, as well as to 14 MeV neutron capture on Co and Y (talk No. 11 by F.S. Dietrich). As was the case with the initial applications to 19.6 MeV proton capture on Y, the spectral shapes and angular distributions of the 34 MeV proton capture spectra are reasonably well reproduced by a combination of DSD and Hauser-Feshbach mechanisms, without requiring additional processes. Applying this same model to 14 MeV neutron capture spectra shows good agreement with the measurements of Budnar et al. but poor agreement with the measurements of Rigaud et al. on the same nuclei. The disagreement between these two data sets makes it difficult to reach firm conclusions on the suitability of DSD to reproduce the entire high energy portion of 14 MeV neutron capture spectra. It was pointed out that a new, carefully performed experiment would have a strong impact on settling this question. Capture of polarized neutrons on ^{89}Y was suggested as a suitable candidate.

Preliminary calculation of photon production data in the high energy region has been done in the framework of the Quantum Molecular Dynamics (QMD) approach (talk No. 14 by K. Shibata). The quasi-deuteron model was used to describe photon absorption. The n-p bremsstrahlung mechanism was taken into account to describe photon emission of the N-N interaction.

c. Evaluations

The recently produced library of neutron capture cross sections up to E_n = 20 MeV was presented by J. Kopecky (talk No. 12). This data base has been assembled and evaluated for the European Activation File EAF-4.1 and covers all targets with $T_{1/2}$ > 0.5d up to ^{248}Cm. The content of the library and data in graphical form have been presented. It was proposed to publish this library as "Atlas of Neutron Capture Cross Sections".

The neutron capture cross sections of ^{12}C and ^{16}O up to 1 MeV were improved by taking account of the direct radiative capture calculations of A. Mengoni. The results have been incorporated into the JENDL Fusion File (talk No. 14 by K. Shibata).

There was a presentation on the status of experimental and evaluated data for discrete photon production cross-sections at 14 MeV incident neutron energy for practically important nuclei (talk No. 13 by S. Simakov). This review and compilation of existing measurements outlined the picture of availability, accuracy, and insufficiencies of experimental data. The comparison of the compiled experimental data base with FENDL-1, ENDF/B-6 and BROND-2 evaluations has indicated the status of evaluated data. The principal conclusion is that for many nuclei the discrepancies with the experimental database are so large that it is not possible to test the existing nucleon data libraries with the accuracy needed for applications. This applies especially to fusion technology and neutron therapy. Therefore, more evaluation work is needed on the experimental database.

Photon production evaluations for Fe and Ni were updated for the JENDL Fusion File by using statistical-model calculations (talk No. 14 by K. Shibata). The reliability of the revised data was examined by benchmark tests. The results show that the calculations using the JENDL fusion file are in good agreement with integral measurements.

The status of the experimental γ-ray strength functions, as reviewed in detail during the 1st RCM in Bologna, Italy (see INDC(NDS)-330, IAEA, Vienna 1995) was presented (talk No. 15 by J. Kopecky). It was noted that no new experimental data have been measured since and thus the present compilation has been chosen as a recommended data set to be included in the final report. Further, a summary report on the revised gamma-ray strength function modelling (see M. Uhl in INDC(NDS)-331, IAEA, Vienna 1994 and the pending action of J. Kopecky within this CRP) will be included.

Benchmark tests of photon production data in the JENDL Fusion File and FENDL-1 have been done by analyzing two integral experiments performed in Japan (talk No. 14 of K. Shibata). Evaluated photon production cross sections agree with these integral measurements within $\pm$ 20%.

Benchmarking of photon production data for 3 standard iron benchmarks shows reasonable agreement for EFF-2 data and a slight underestimation for FENDL-1 (talk No. 16, by S. Unholzer). The gamma producing neutron flux spectra are comparably well described both by EFF-2 and FENDL-1 data files. The SS-316 stainless steel benchmark experiments which are more sensitive to the small emission angle of flux spectra are reasonably described by all EFF and FENDL-1 data files.

3 Conclusions and Recommendations

a. Final Product of the CRP

The Final Product and deliverables of the CRP were discussed in detail. It was anticipated that the Final Product should be viewed as a composition of the Final Report of the CRP, specific data files and other documented scientific and technical results achieved in the coarse of the CRP. Each participant formulated, in writing, his view of his own contribution to the Final Product. These contributions were discussed and summarized in the following outline:

1. Experimental Photon Data (Measurements)
    1.1. Status
        1.1.1. Capture
            - Low energy neutrons
            - Neutrons above 10 MeV
        1.1.2. Inelastic and Non-elastic
            - 14 MeV neutrons
            - Threshold to 13 MeV neutrons
            - Neutrons above 14 MeV
        1.1.3. Verification experiments (testing, benchmarks)
    1.2. Recommendations for additional experiments
        - WRENDA (priority 1)
        - 14 MeV capture spectra
        - High precision measurements
        - Fill in neutron energy gaps for reactions having impacts on model parameters
        - Verification experiments (testing, benchmarks)

2. Theoretical Photon Data (Calculations)
    2.1. Status of computer codes being used/developed for prediction and evaluation
    2.2. Frozen and documented versions of computer codes available for (general) distribution, especially to evaluators
    2.3. Recommendations on input parameters

3. Evaluations and Compilations
    3.1. Specific compilations
        - Discrete γ at 14 MeV
        - Gamma-ray strength functions
        - Atlas of capture cross sections
    3.2. Status of evaluations
    3.3. Recommendations
        - Guidelines for quality of measurements
        - Guidelines for evaluations

b. Final Report of the CRP

The final Report of the CRP was discussed in detail. The Report will represent a summary of the work performed and results achieved. The body of the Report should largely reflect the outline as agreed above. The following procedure was adopted:

1. The coordinators will contact the participants concerning the details of the length and the scope of their contributions. The guidelines on the format will also be provided.
   * *Action Dietrich, Dickens, Obložinský, deadline 1 March 1997*

2. The contributions by individual CRP participants will be prepared well before the last CRP meeting. Most of the contributions are specified in more detail below, under assignments for the future work, tasks No. 9-17.
   * *Action all CRP participants, deadline 30 June 1997*

3. Assembly of individual chapters will be coordinated by senior CRP participants as indicated below.
   * *Action coordinators Dietrich, Dickens and Obložinský, deadline 31 July 1997*

4. Using the above input the preliminary draft of the Report will be put together by the Scientific Secretary P. Obložinský and distributed to participants well before the last CRP meeting.
   * *Action Obložinský, deadline 15 September 1997*

5. The structure of the Report is as follows. Given in brackets are coordinators and contributors:
   A. General part *(coordinator P. Obložinský)*
      - Overview of topics covered
      - Credits to participants
      - Specific accomplishments and CRP publication list
        (input all CRP participants)
   B. Specific results *(coordinator J.K. Dickens)*
      - Measurements
        (input Dickens, Hlaváč, Pavlik, Simakov, Unholzer, Vonach)
      - Calculations
        (input Běták, Cvelbar, Dietrich, Mengoni, Likar)
      - Evaluations and Compilations
        (input Dietrich, Kopecky, Mengoni, Shibata, Simakov, Vonach)
   C. Recommended evaluation procedures *(coordinator Dietrich)*
      - Physics of γ emission
      - Codes
        (input Běták, Cvelbar, Dickens)
      - Input parameters including strength functions
        (input Běták, Mengoni, Kopecky)

c. Assignments for Future Work

Assignments for future technical work are grouped into 3 categories. Experimental tasks specify 3 measurements of discrete gamma ray production (No. 1-3). Theoretical tasks focus on neutron capture calculations (No. 4-7), and an additional task deals with (n,xγ) cross sections (No. 8). Evaluation and compilation tasks include capture data (No. 9-11) and (n,xγ) production data (No. 12-13), gamma-ray strength functions (No. 14-15), codes (No. 16) and benchmarking (No. 17).

Measurements

1. High-precision measurements at specific, essentially monoenergetic neutron energies of the cross sections for the 846-keV γ-ray in ^{56}Fe currently underway at the University of Kentucky will be completed and a report prepared for publication. Measurements planned at ORELA will be completed and will be reported in an ORNL report. These will be combined with proposed measurements at the GEANIE facility at LANL (if the facility becomes available) to provide "white-source" measurements for comparison with evaluations of comparable resolution.
   * *Action J.K. Dickens, deadline next Research Co-ordination Meeting (RCM)*

2. Perform measurements of discrete gamma ray production in interactions of 14.6 MeV neutrons with natural Mo.
   * *Action S. Hlaváč, deadline next RCM*

3. Perform measurements of discrete gamma ray production for Mn(n,xγ) reactions at 14 MeV as a joint effort using the Bratislava 14 MeV facility.
   * *Action S.P. Simakov, S. Hlaváč, deadline next RCM*

Calculations

4. Study of the direct-semidirect (DSD) model of neutron capture will focus on

   a) Determine sensitivity of capture calculations to potentials and form factors
      * *Action A. Likar, contributions from F.S. Dietrich and F. Cvelbar, deadline next RCM*

   b) Compare imaginary part of the form factor in the "traditional" formulation of the DSD with imaginary coupling generated by consistent requirements.
      * *Action A. Likar, deadline next RCM*

   c) Apply microscopic folding model for real form factors in DSD.
      * *Action F.S. Dietrich, deadline next RCM*

5. Apply effective (dressed) photon operators to direct neutron capture calculations in the low energy region (below 1 MeV).
   * *Action A. Likar, A. Mengoni, deadline next RCM*

6. Calculate neutron capture cross sections in the neutron energy range from thermal to 1 MeV on ^{7}Li and ^{13}C using the direct radiative capture (DRC) model, including the contribution from p-wave neutrons.
   * *Action A. Mengoni, deadline next RCM*

7. Determine the position and width of the peak of neutron capture excitation functions in preequilibrium models and compare them with standard GDR values.
   * *Action F. Cvelbar, E. Běták, deadline next RCM*

8. Show the influence of level densities recommended by the CRP on the Reference Input Parameter Library for photoproduction calculations.
   * *Action E. Běták, deadline next RCM*

Evaluations, Compilations and Benchmarks

9. Perform critical inspection of the existing neutron capture cross sections for light nuclei (up to A = 20) in order to provide a reliable procedure for evaluation (models to be used, experimental information to be collected) of (n,γ) cross sections in this mass region.
   * *Action A. Mengoni, input from J. Kopecky and K. Shibata, deadline 30 June 1997*

10. Examine critically the experimental data for capture gamma-ray spectra in the neutron energy range above 10 MeV.
    * *Action F.S. Dietrich, deadline 30 June 1997*

11. The content of the neutron capture cross section library, extracted from the European Activation File EAF-4.1 and made available to this CRP, will be documented in a report. The possibility of inclusion of this library, as a database supplement to the final CRP report, will be investigated.
    * *Action J. Kopecky, deadline 30 June 1997*

12. Finalize the evaluation of practically important experimental data for discrete γ lines for 14 MeV incident neutrons and compare these results with existing evaluations. The goal is to obtain values, as accurate as possible, for the evaluated cross sections and their uncertainties.
    * *Action S.P. Simakov, input from S. Hlaváč, A. Pavlik and H.K. Vonach, deadline 30 June 1997*

13. The above compilation and evaluation at 14 MeV should be complemented with the

a) Review of differential measurements and compilations of experimental photon data, important for applications, for neutron energies between threshold and 13 MeV (capture data will not be included).
   * *Action J.K. Dickens, deadline 30 June 1997*

b) Report on the status of γ-production measurements for neutron energies above 14 MeV (discrete and continuum photons should be included, capture data will not be included).
   * *Action H.K. Vonach, deadline 30 June 1997*

14. Complete the work on implementation of the revised γ-ray strength function modelling. This task was initiated at the previous RCM, see report INDC(NDS)-330, IAEA, Vienna 1995, p. 16. This work will produce a document in which the recommended models for E1, M1 and E2 radiation will be summarized with practical advice for inputs and the mass region of their applicability.
   * *Action J. Kopecky, deadline end of 1996*

15. The work on updating the γ-ray strength function experimental data base will be completed. The status of the data has not been changed since the previous RCM (no new measurements). This compilation will be summarized in a document, which shall contain the recommended experimental values with their uncertainties, comments on applied corrections, and derived systematics of f(E1) and f(M1) as a function of atomic mass. This information will be also made available in an electronic format and recommended to the CRP on Reference Input Parameter Library.
   * *Action J. Kopecky, deadline end of 1996*

16. One of the goals of the present CRP is to provide methods for evaluation of photon production data. In view of this, it is considered important to provide a list of existing general codes available in code documentation centres, and an indication of the existence and availability of specialized codes.

a) A tabulation will be made of general codes important for photon production, currently available at the Radiation Shielding Information Center at ORNL, Oak Ridge, and at NEA Data Bank, Paris. This should be supplemented by comments and assessment of the codes.
   * *Action J.K. Dickens, deadline 30 June 1997*

b) A similar overview will be developed for specialized codes, limited to DSD and preequilibrium approaches. Neutrons up to about 100 MeV and photons below and above the GDR region would be considered.
   * *Action F. Cvelbar, DSD codes, deadline 30 June 1997*
   * *Action E. Běták, preequilibrium codes, deadline 30 June 1997*

17. Four kinds of integral experiments were proposed as standard fusion benchmarks for photon production: slab experiment, mock-up experiment of the ITER design, sphere experiment, and cylinder experiment. Most of them have already been done at several laboratories (TUD Dresden, Oktavian Osaka, FNS JAERI and ENEA Frascati). Full information on experiments including numerical results and data analyses will be provided, particularly:

a) Slab experiments on Fe and SS-316 (TUD Dresden).
* *Action S. Unholzer, deadline 30 June 1997*

b) Mock-up experiments of ITER design (TUD Dresden together with ENEA Frascati).
* *Action S. Unholzer, deadline 30 June 1997*

c) Sphere experiments (Oktavian, Osaka University) providing leakage γ ray spectra from 13 spherical samples of LiF, CF2, Al, Si, Ti, Cr, Mn, Co, Cu, Nb, Mo, W and Pb.
* *Action K. Shibata, deadline 30 June 1997*

d) Cylinder experiments at FNS, JAERI providing γ-ray spectra and γ-ray heating rates in cylindrical assemblies made of Fe, Cu, W and SS-316.
* *Action K. Shibata, deadline 30 June 1997*

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Appendix 1

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

IAEA Headquarters, Vienna (Meeting Room C-0453)
21-24 May 1996

AGENDA

Tuesday, 21 May

08:45-09:00	Registration (C building, ground floor)		
09:00-09:30	Opening of the Meeting, Adoption of the Agenda, Announcements		
09:30-12:00	Reports from participants (measurements)		
	1.	**J.K. Dickens**:	Precision Measurements of ^{56}Fe Cross Sections for the 846-keV Gamma Transition
	2.	**S.P. Simakov**:	Cross Sections for Gamma-Rays Produced by 14 MeV Neutrons in Na, P and V Nuclei
	3.	**S. Hlaváč**:	Discrete Gamma Production in ^{28}Si + n Reactions near 14 MeV
	4.	**A. Pavlik**:	Discrete Gamma Production in Al + n Reactions up to 400 MeV
	5.	**H.K. Vonach**:	Study of ^{27}Al and ^{56}Fe(p,xγ) Reactions at E_p = 800 MeV (20')
	6.	**F.S. Dietrich**:	Plans for Gamma Measurements at LANSCE/WNR Using the HERA Array (10')
12:00 - 14:00	Lunch break		
14:00 - 17:30	Reports from participants (calculations)		
	7.	**A. Mengoni**:	Photon Production and Absorption in Light Nuclei
	8.	**E. Běták**:	Pre-equilibrium Calculations of Gamma Transitions Including Discrete States
	9.	**F. Cvelbar**:	Model Calculations of 14 MeV Neutron Capture Data Relevant for Technology
	10.	**A. Likar**:	Some New Tests of a Consistent Version of the DSD Model

	11. **F.S. Dietrich**: Application of Extended DSD Model to 34 MeV Proton Capture and to 14 MeV Neutron Capture
17:45	Welcome Drink (in front of the Nuclear Data Section Library, A-2340)

Wednesday, 22 May

08:30 - 12:00	Reports from participants (compilations, evaluations, benchmarks) 12. **J. Kopecky**: Atlas of Neutron Capture Cross Sections 13. **S.P. Simakov**: Status of Experimental and Evaluated Data for Discrete Gamma-Ray Production at 14 MeV Neutron Incident Energy 14. **K. Shibata**: JAERI Activities on Photon Production Data 15. **J. Kopecky**: Remark on the Recommended Set of Gamma-Ray Strength Functions 16. **S. Unholzer**: Test of Photon Production Data in Integral Experiments with 14 MeV Neutrons
12:00 - 14:00	Lunch break
14:00 - 17:00	Discussions and clarification of the refined scope of the CRP Initial discussions and suggestions for the Final Product and Final Report of the CRP
18:30 - open	Dinner in a typical Viennese pub

Thursday, 23 May

08:30 - 12:00	Preparation of the Summary Report of the present Meeting
12:00 - 14:00	Lunch break
14:00 - 17:30	Preparation of the Summary Report of the present Meeting

Friday, 24 May

08:30 - 12:00	Identification of the Final Product, including scope and contents of the Final Report
12:00 - 14:00	Lunch break
14:00 - 17:00	Adoption of the Summary Report, including assignments and responsibilities for the Final Product and Final Report Adjournment

<u>Note</u>: **Reports (including discussion) should be confined to 30' unless indicated otherwise.**

Appendix 2

EXTENDED ABSTRACTS OF PRESENTED PAPERS

Precision Measurements of ^{56}Fe Cross Sections for the 846-keV Gamma Transition and for E_n Between Threshold and 4 MeV

J. K. Dickens

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INTRODUCTION

At the first meeting of this CRP an experiment to measure with high precision the cross sections of the production of the 846-keV gamma ray due to inelastic neutron interactions with iron was proposed[1] and discussed. The main justification for the proposed improved precision was the need for improving calculations of radiation transport through thick iron components of nuclear reactors.[2,3] Present evaluated data for the subject reaction in the ENDF/B-VI files[2] have evaluated uncertainties ≈ 10%; consequently, the results of computation of deep penetration of radiation in iron can have quite large uncertainties -- > 100%, for example, for an attenuation of ~ 3 orders of magnitude -- which can be a serious problem when one considers the magnitude of the radiation field inside a pressure vessel.

For the proposed experiment[1] the sample material (iron) was alloyed with boron, the boron being highly enriched in the ^{10}B isotope. Recent measurements[4] of the $^{10}B(n,\alpha\gamma)^7Li$ photon production yields for E_n between 1 and 4 MeV have yielded cross sections with conservatively assigned uncertainties between 2 and 4%. This ^{10}B thus serves as an accurate monitor of the neutron flux impinging the iron-boron sample during the actual irradiation provided one can determine the ratio of ^{10}B:^{56}Fe atoms in the sample with an uncertainty of < 2%.

PROGRESS SINCE THE FIRST CRP MEETING

A Monte-Carlo-based computer program was written using the documented code SCINFUL[5] as a basis. The program (titled BFe) was applied to the FeB-alloy and it was determined that a disk thickness of ≈ 3 mm was a satisfactory compromise between overall counting rate versus the magnitudes of the multiple-scattering and attenuation corrections. A portion of the 1.27-cm diam rod was sliced into a series of ~ 3-mm thick disks -- a cost-effective method. Disk diameter will be tailored to the experimental facility.

Several studies of the composition of the "boron" powder were made to determine its components; details are given in a recent report.[6] The powder was chemically B_4C and included 23% by weight of water. The water was driven out when the material was heated into a melt, and the condition of the solid sample as taken from the mold indicates that the B_4C was mostly, if not all, dissociated, thus freeing both B and C atoms to alloy with the Fe. A knowledge of the carbon in the sample is necessary to include scattering from carbon explicitly in the BFe program, since, as presently written, absence of carbon is assumed.

When full-time operation of the ORELA ended at the close of FY1994, it was recognized that high-accuracy measurements could not be obtained concurrent with high resolution in neutron energy.[7] What can be done is to obtain high-accuracy measurements for incident-neutron energy groups and to obtain the distribution of neutron energy impinging on the sample within a given neutron energy group. The experimental data can then be compared with a predicted group cross section obtained by folding the experimental neutron energy distribution with cross section values in the current evaluation for iron.

PRESENT AND FUTURE PLANS

Present plans include experiments at the ORELA and at the neutron-scattering facility at the University of Kentucky. An experiment may also be performed at LANL using the multi-detector array GEANIE, but this latter experiment is not certain.

ACKNOWLEDGEMENTS

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Cross Sections for γ-rays produced by 14.7MeV Neutrons in ^{23}Na, ^{31}P and ^{51}V

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Abstract

The results of γ-ray production cross-sections measurements for ^{23}Na, ^{31}P and ^{51}V$(n, x\gamma)$ reactions are reported. The experiment were performed at the neutron generator facilities of the Institute of Physics (Bratislava) by time and space correlated neutron and associated α-particle technique.

The beam of neutrons with energy 14.6±0.2MeV, incident on the sample, was electronically and mechanically collimated. The sample was located behind the shielding at the distance of 270cm from the neutron source. The γ-rays were registered by a 244cm^3 HPGe detector at an angle of 125° relative to the neutron beam. The detector was housed in a tungsten shield to decrease further the background. The $Na_4P_2O_7$ powder sample (shaped as a cylinder ⌀4.4cm×7.0cm) and metallic vanadium sample (hollow cylinder ⌀3cm×⌀2cm×5cm) were used in measurements. The metallic chromium sample was used for absolute normalization of the experimental data relative to the production cross section of 1434 keV γ-ray from ^{52}Cr$(n, x\gamma)$ reaction.

The experimental data were corrected for attenuation of gamma and neutron fluxes and for in-sample scattering. The γ-rays production cross sections for assigned transtions are presented in Table.

There are several measurements of abovementioned cross sections described in the literature – five mesurements for natrium, one for phosphorus and two for vanadium. Approximatly the half of experiments have been done by NaI(Tl) detector with moderated resolution of dozens keV. Comparison of present results with previous data shows that in the case of Na and P the discrepancies in experimental data are are larger than uncertainties reported. In the case of V the data are in reasonable agreement.

Comparison with FENDL-1, ENDF/B6 and BROND-2 libraries (see Table) has shown that in the discrete photon production cross sections are not presented for Na. The evaluated sdata for phosphorus are smaller than experimental data up to factor of 2. The differences between our experimental data and evaluation in the case of vanadium can be expressed by a factor of 10 and more.

E(keV)	Reaction	Transition			σ(mb)	ENDF
627	^{23}Na(n,n')^{23}Na	2704(9/2$^+$)	→	2076 (7/2$^+$)	25±5	-
656	^{23}Na(n,α)^{20}F	656(3$^+$)	→	0(2$^+$)	44±6	-
823	^{23}Na(n,α)^{20}F	823(4$^+$)	→	0(2$^+$)	13±2	-
1275	^{23}Na(n,d)^{22}Ne	1275(2$^+$)	→	0(0$^+$)	194±14	-
1636	^{23}Na(n,n')^{23}Na	2076(7/2$^+$)	→	440(5/2$^+$)	141±11	-
1266	^{31}P(n,n')^{31}P	1266(3/2$^+$)	→	0(1/2$^+$)	190±15	150
2149	^{31}P(n,n')^{31}P	3415(7/2$^+$)	→	1266(3/2$^+$)	49±9	-
2234	^{31}P(n,n')^{31}P	2234(5/2$^+$)	→	0(1/2$^+$)	387±30	150
815	^{51}V(n,2n)^{50}V	1725(?)	→	910(4$^+$)	18.0±4.7	-
836	^{51}V(n,2n)^{50}V	836(5$^+$)	→	0(6$^+$)	34.4±3.1	-
910 913	^{51}V(n,2n)^{50}V	910(4$^+$) 1301(2$^+$)	→ →	0(6$^+$) 388(2$^+$)	81±6	-
929	^{51}V(n,n')^{51}V	929(3/2$^-$)	→	0(7/2$^-$)	50.0±4.0	0.92
946	^{51}V(n,2n)^{50}V	1301(2$^+$)	→	355(3$^+$)	20.5±2.8	-
1090	^{51}V(n,n')^{51}V	?2700(3/2$^+$)	→	1609(1/2$^+$)	59.0±5.0	0.86
1121	^{51}V(n,d)^{50}Ti	2675(4$^+$)	→	1554(2$^+$)	13.8±2.2	-
1174	^{51}V(n,2n)^{50}V	2874(3/2$^+$)	→	0(1/2$^+$)	21.1±2.8	-
1494	^{51}V(n,n')^{51}V	1813(9/2$^-$)	→	319(5/2$^-$)	12.9±2.3	0.14
1554	^{51}V(n,d)^{50}Ti	1554(2$^+$)	→	0(0$^+$)	32.4±3.2	-
1609	^{51}V(n,n')^{51}V	1609(11/2$^-$)	→	0(7/2$^-$)	214±15	2.6
1777	^{51}V(n,n')^{51}V	3386(?)	→	1609(11/2$^-$)	47.6±3.4	0.69
1813	^{51}V(n,n')^{51}V	1813(9/2$^-$)	→	0(7/2$^-$)	72.0±6.0	0.72
2004	^{51}V(n,n')^{51}V	3615(?)	→	1609(11/2$^-$)	12.7±2.9	-
2334	^{51}V(n,n')^{51}V	?3204(?)	→	928(3/2$^-$)	14.6±3.2	-

Table 1: Experimental data for production of discrete γ rays in interaction of 14.6 MeV neutrons with Na, P and V. Data available in ENDF/B-VI evaluation are also shown.

Discrete photon production in ^{28}Si(n,xγ) reactions near 14 MeV

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The primary aim of the experiment was to determine production of discrete γ rays in the ^{28}Si(n,n'pγ)^{27} Al reaction, i.e. production cross section of 843.6 keV and 1014.4 keV γ rays. Cross section measurement of ^{28}Si(n,n'p)^{27}Al reaction was given recently a highest priority by the IAEA Consultants Meeting because of its importance for waste disposal assessment of the long lived radionuclide ^{26}Al, which may be produced from ^{28}Si by sequential reactions.

We measured discrete γ ray production in interaction of 14.6 MeV neutrons with ^{28}Si using associated α particle technique and a large HPGe detector with efficiency of 65 %. We used Si samples of semiconductor purity with diameter of 100 mm and thickness of 5 mm and 10 mm to assess absorption and multiple scattering. In the experiment it was necessary to reduce background from 846.8 keV γ line from iron which was used for supporting structure near the target and the HPGe detector. We reduced this background by removing all iron parts from the target area.

The γ ray production measurements were performed relative to the cross section of 1778.9 keV $2^+ \longrightarrow 0^+$ transition in the ^{28}Si(n,n'γ) reaction, with the cross section of 390$\pm$37 mb taken from the literature. The experimental data are given in a table below together with the theoretical calculations. We were not able to resolve experimentally γ rays of energy 1013.6 keV from (n,p) channel and 1014.4 keV from (n,n'p) channel, therefore experimental value given for 1014.4 keV is a sum of both transitions.

To understand obtained experimental data, we calculated discrete γ ray production using well known statistical/pre- equilibrium code GNASH as well as preequilibrium code DEGAS, developed in our lab. Both codes can calculate sequential particle emission with spin conservation and γ ray emission at every stage of nuclear reaction. However, DEGAS can't calculate emission of composite particles like ^{4}He.

Cross sections calculated by GNASH are in good accord with experimental data measured in (n,n'γ), (n,pγ) reactions. The experimental data in the (n,$\alpha\gamma$) channel are greater approximately by a factor of 2. So far we have no explanation for this difference. There is also a good agreement in (n,n'pγ) channel, keeping in mind that experimental value given for 1014.4 keV γ ray is a sum of two transitions, mentioned above.

Reaction	E_γ(keV)	Experiment (mb)	GNASH (mb)	DEGAS (mb)
(n,n'γ)	1778.9	390±37	350	443.0
	2838.8	95±12	98	85.0
(n,pγ)	941.7	17± 3	16	5.4
	983.0	22±3	23	13.0
	1013.6		14	8.1
	1589.2	24±4	14	6.3
(n,$\alpha\gamma$)	389.7	25±4	13	
	585.1	72±11	36	
	974.7	41±6	14	
(n,n'pγ)	843.6	10±2	6	4.4
	1014.4	22±4	6	22.0

Table 1: Cross sections for discrete γ ray production in ^{28}Si + n reactions at 14.6 MeV. (Preliminary data.)

Discrete gamma production in Al + n reactions up to 400 MeV

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The prompt γ-radiation from the interaction of fast neutrons with Al was measured by high-resolution Ge-detector γ-ray spectroscopy. Measurements were performed at the pulsed white neutron beam of the WNR facility at the Los Alamos National Laboratory (neutron energy range 3 to 400 MeV) and at the neutron generator of the Institute of Physics of the Slovak Academy of Sciences (neutron energy 14.6 MeV).

In the white source measurement Al samples (2 mm and 6 mm thick plates) were positioned at distances of 20.06 m and 41.48 m from the neutron production target. The neutron fluence was determined with a ^{238}U fission chamber. The prompt gamma radiation was detected with a high-purity Ge detector positioned at a γ-ray emission angle of 125°. At this angle the angle-integrated γ-ray production cross section is approximately given by 4π times the measured cross section. The incident neutron energy was determined by the time of flight method and excitation functions for prominent transitions in various nuclei (see Table I) were derived. A more detailed description of the experimental set-up is given in Refs. 1 and 2.

To complement the white source measurement and to permit a better normalization of the white source results, γ-ray production cross sections for prominent transitions in ^{26}Mg, ^{26}Al and ^{27}Al were measured at 14.6 MeV neutron energy. Neutrons were produced via the T(d,n)^{4}He reaction, and the experimental setup is based on the time and space correlated associated alpha particle method. Gamma-rays were detected by a high-purity Ge detector at an emission angle of 125°. Cross sections were determined relative to the well known cross section of the 846.8 keV transition in ^{56}Fe. A measurement with a combined Fe and Al sample (2 mm and 4 mm thick, respectively) was performed to determine discrete photon yields of strong γ transitions in the Al + n interaction relative to the yield of the reference line in Fe. In a second experiment with a pure Al sample (5 mm thick) relative photon yields in Al(n,xγ) reactions were measured. A detailed paper on this 14 MeV experiment is to published [3]. The results of this work improve the existing experimental data base in the 14 MeV range considerably.

The measured γ-ray production cross sections were compared with previous measurements (mostly in the 14 MeV range) and with the results of nuclear model calculations performed with the code GNASH [4] up to 200 MeV incident neutron energy. In general there is good agreement between the measured and the calculated cross sections within about 20 %. Only for one transition analyzed (the 440.0 keV transition in ^{23}Na) the measured and the calculated γ-ray production cross sections disagree (see Fig. 1). All reactions with neutron, proton, alpha particle and deuteron emission in the exit channels are included in the calculation and the discrepancy is not yet understood.

Table I. Nuclear reactions and γ transitions investigated in the white source experiment.

Reaction	Residual nucleus	γ Transition investigated	Energy (keV)
^{27}Al(n,n'γ)	^{27}Al	$9/2^+ \rightarrow 7/2^+$	793.0
		$3/2^+ \rightarrow$ gs	1014.5
		$5/2^+ \rightarrow 3/2^+$	1719.5
		$7/2^+ \rightarrow$ gs	2211.1
		$9/2^+ \rightarrow$ gs	3004.2[a]
^{27}Al(n,2nγ)	^{26}Al	$3^+ \rightarrow$ gs	416.9
		$1^+ \rightarrow 0^+$	829.6
^{27}Al(n,pγ)	^{27}Mg	$5/2^+ \rightarrow 3/2^+$	955.3
		$3/2^+ \rightarrow$ gs	984.6
		$5/2^+ \rightarrow$ gs	1698.3
^{27}Al(n,pnγ) ^{27}Al(n,dγ)	^{26}Mg	$3_1^+ \rightarrow 2_1^+$	1002.5
		$2_2^+ \rightarrow 2_1^+$	1129.7
		$2_1^+ \rightarrow$ gs	1808.7
^{27}Al(n,p2nγ) ^{27}Al(n,dnγ)	^{25}Mg	$3/2^+ \rightarrow 1/2^+$	389.7
		$3/2^+ \rightarrow$ gs	974.8
^{27}Al(n,p3nγ) ^{27}Al(n,d2nγ)	^{24}Mg	$2^+ \rightarrow$ gs	1368.6
^{27}Al(n,2p3nγ) ^{27}Al(n,αnγ)	^{23}Na	$5/2^+ \rightarrow$ gs	440.0
^{27}Al(n,3p3nγ) ^{27}Al(n,αpnγ)	^{22}Ne	$2^+ \rightarrow$ gs	1274.6
^{27}Al(n,3p4nγ) ^{27}Al(n,αp2nγ)	^{21}Ne	$5/2^+ \rightarrow$ gs	350.5
^{27}Al(n,3p5nγ) ^{27}Al(n,αp3nγ)	^{20}Ne	$2^+ \rightarrow$ gs	1633.8
^{27}Al(n,4p6nγ) ^{27}Al(n,α2p4nγ) ^{27}Al(n,2α2nγ)	^{18}F	$3^+ \rightarrow$ gs	937.1

[a] This line was not resolved from the 2981.8 keV ($3/2^+ \rightarrow$ gs) transition.

Table II. Nuclear reactions and γ transitions investigated in the 14 MeV experiment.

Reaction	Residual nucleus	γ Transition investigated	Energy (keV)
^{27}Al(n,n'γ)	^{27}Al	$1/2^+ \rightarrow$ gs	843.7
		$3/2^+ \rightarrow$ gs	1014.5
		$7/2^+ \rightarrow$ gs	2211.1
		$9/2^+ \rightarrow$ gs	3004.2[a]
^{27}Al(n,n'γ)	^{27}Mg	$3/2^+ \rightarrow$ gs	984.6
		$5/2^+ \rightarrow$ gs	1698.3
^{27}Al(n,pnγ) ^{27}Al(n,dγ)	^{26}Mg	$2_1^+ \rightarrow$ gs	1808.7

[a] This line was not resolved from the 2981.8 keV ($3/2^+ \rightarrow$ gs) transition.

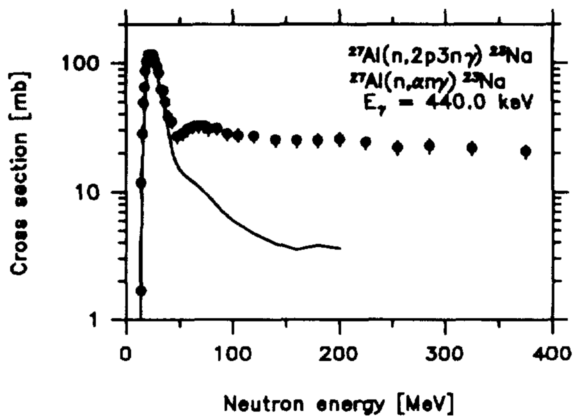

Fig 1. The γ-ray production cross section for the 440.0 keV transition in ^{23}Na. The symbols represent the experimental data and the solid line the GNASH calculation results.

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Study of ^{27}Al and ^{56}Fe(p,xγ) reactions at E_p = 800 MeV

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Spallation of ^{27}Al and ^{56}Fe by 800 MeV protons was investigated at the WNR-facility of the Los Alamos National Laboratory. Production cross sections for a considerable number of residual nuclei were determined for both targets by use of three different methods.

The mass and charge distributions of the reaction products from spallation reactions induced by protons in the energy range from several hundred MeV to several GeV had been investigated in a number of experiments (see, e.g., Ref. 1). Cross sections for the formation of radioactive residual nuclei with half-lives exceeding some hours have been investigated by conventional γ-ray spectroscopy and accelerator mass spectrometry (AMS), the production of stable isotopes of noble gases has been measured by gas production measurements and mass analysis. Much less information, however, exists about the production of stable isotopes from elements other than noble gases, and for short-lived residual nuclei. Only one experiment has been reported, in which the full mass and charge distribution of the spallation products has been measured by detection of the recoiling nuclei in so-called inverse kinematics at E = 600 MeV [2]. Although the results of this experiment are in reasonable overall agreement with the above mentioned activation, AMS and gas production measurements, there are a number of discrepancies exceeding experimental errors [1].

The present experiment was performed using in-beam γ-ray spectroscopy. This method, which so far has not been used in the study of spallation reactions, allows the determination of cross sections for formation of stable and very short-lived isotopes, both of which cannot be measured by conventional activation techniques. Two nuclei, ^{27}Al and ^{56}Fe, have been selected for this study because they have been studied before in a number of papers [1,2]. These nuclei are well suited for the goal of obtaining a rather complete mass and charge distribution of the residual nuclei by combining our results with the existing data base. In addition, checks of the results obtained by very different methods become possible for a number of residual nuclei.

Thin foils of ^{27}Al and ^{56}Fe (6.82 ± 0.27 mg/cm^2 and 12.13 ± 0.24 mg/cm^2) were irradiated with the 800 MeV proton beam of the WNR facility of the Los Alamos National Laboratory [3]. The γ-radiation from the proton-induced reactions was observed with a high-purity Ge-detector. The foils were irradiated in a scattering chamber located in the beam line from the accelerator to the neutron producing target of WNR.

The γ-radiation from the targets was measured with a high-purity Ge-detector at a distance of about 30 m from the targets at an angle of 150° relative to the proton beam. The WNR beam consisted of 40 macro-pulses per second separated by either 16.66 or 33.33 ms. Each macro-pulse had a length of 600 μs. Within each macro-pulse the beam consisted of narrow micro-pulses of a width of about 1 ns at intervals of 1.8 μs. Accordingly the prompt γ-radiation originating from the so-called γ-cascade deexciting the final residual nucleus was observed by its time correlation to the micro-pulses. The γ-radiation from the decay of the short-lived residual nuclei formed in spallation reactions was measured between the macro-pulses by setting a time window of 15 ms after the end of each macro-pulse. After the experiment the irradiated Al and Fe foils were transferred to the Institut für Radiumforschung und Kernphysik in Vienna and the γ-radiation from all long-lived activities produced in the samples was measured with a calibrated high-purity Ge-detector. From the measured short- and long-lived activities production cross sections for the respective nuclei were derived. In the prompt γ-ray spectrum it was possible to observe the transitions from the first excited 2^+ state to the ground state for all even-even nuclei strongly populated in the spallation reactions and to deduce the production cross sections of these mostly stable nuclei from these data. In this way production cross sections for 36 nuclides from the proton interactions with ^{56}Fe and for 12 nuclides in case of ^{27}Al could be measured; in addition meaningful upper limits were obtained for a number of further nuclides in both cases.

The present data as well as the results of all previous measurements were compared with the predictions of the semi-empirical systematics of Tsao and Silberberg [4] and with calculations according to the quantum molecular dynamics model (QDM) followed by statistical decay (SDM) [5,6].

The quality of the theoretical description by the QMD model is approximately as good as that of the semi-empirical systematics, although the QMD model does not contain any parameters fitted to the existing data on nuclide production cross sections. However, there are still deviations up to a factor of two between the experimental data and both calculations even for nuclides in the peaks of the mass distribution. Especially the QMD-model seems to underestimate the production of nuclides with masses very close to the target nucleus e.g. ^{55}Fe or ^{55}Mn from ^{56}Fe, which may be caused by some direct reaction mechanisms not included in the QMD-model. Unfortunately the overall spread even of the more recent data is still so large that it is difficult to draw general conclusions on possible systematic dependencies of the observed discrepancies on Z and A.

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The GEANIE Project at the Los Alamos LANSCE/WNR Facility

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Information supplied by
J. A. Becker, Lawrence Livermore National Laboratory

This contribution to the CRP meeting is intended to call to the attention of the community a new experimental capability for making high-resolution gamma-ray measurements. The HERA multidetector array, formerly at the LBL 88" cyclotron, has been moved to the Los Alamos Neutron Science Center (LANSCE), and has been renamed GEANIE.

The GEANIE array consists of 21 high-resolution germanium gamma detectors with BGO Compton suppression. The germanium detectors are 25% efficient relative to a standard NaI detector, with a peak-to-total ratio of 0.5. The original HERA array will be supplemented by 10 large 50 mm diameter x 17 mm planar detectors to enhance the low energy capability. The facility also includes a 40-element BGO inner ball for making multiplicity and sum-energy measurements. The original facility is being upgraded by constructing a new VME-based data acquisition system.

GEANIE will be used with the two neutron spallation sources at LANSCE. These are the high-energy WNR facility that provides neutrons up to 600-800 MeV, and the Manuel Lujan Neutron Scattering Center (MLNSC) low energy source, which provides intense beams of neutrons below 100 keV. As is usually the case with spallation sources, neutron energies are determined by time of flight.

The array is initially being sited at the high energy facility, and will be used for experiments of interest to the Science Based Stockpile Stewardship (SBSS) program. These include inference of the ^{239}Pu(n,2n) reaction by measurements of gamma rays produced in that reaction, cross sections for other (n,xγ) reactions intended to test and improve the reliability of Hauser-Feshbach and other nuclear reaction modeling codes, and measurements of gamma rays produced in fission. Measurements of gammas produced in (n,xn) reactions on lutetium isotopes will aid the development of a new radiochemical diagnostic of the neutron spectrum in the interior of large assemblies bombarded by high energy protons, such as the spallation targets that will be used in the Accelerator Production of Tritium (APT) project. In addition to these applied measurements, the facility will be eventually used for basic science experiments, including the spectroscopy of parity-violating neutron resonances (at MLNSC).

Proposed experiments are evaluated by a Program Advisory Committee established by the LANSCE management. Information on LANSCE, its facilities, programs, and operations may be found on the World Wide Web at the URL http://www.lansce.lanl.gov. Interested scientists may learn more about GEANIE and its future program by contacting John Becker (E-mail jabecker@llnl.gov); information on the characteristics of the spallation sources is available from LANSCE, John Becker, or Frank Dietrich (dietrich2@llnl.gov).

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XA9743836

Photon production and absorption in light nuclei

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At energies up to several hundred of keV, a neutron can be captured by a light nucleus without forming a compound state. This is due to the very low level density of light nuclei which may posses "windows" as wide as a few MeV among resonance states. In this situation the capture process is due to a direct transition of the incident neutron into one of the low-lying states of the residual nucleus. The model describing such a capture mechanism is called the direct radiative capture model (DRC). The essential ingredients for the calculation of the (n,γ) reaction cross section are the matrix elements [1, 2] $Q^{(EM)}_{c\to b} = < \Psi_b|\hat{T}^{EM}|\Psi_c >$. Here, Ψ_c and Ψ_b are the wave functions describing the initial scattering state and the final bound state respectively and $\hat{T}^{EM}$ is the electromagnetic multi-pole operator.

In describing the DRC process of some light nuclei, we have recently[2] shown that the matrix elements $Q^{(E1)}_{c\to b}$ are very much sensitive to nature of the final capturing state wave function, Ψ_b, and very little sensitive to the treatment of the incident neutron scattering channel state, Ψ_c. This situation holds in the case in which the major contribution to the capture strength is due to incident p-wave neutrons captured into bound s and/or d single-particle orbits, with emission of E1 radiation.

A further characteristic of the DRC mechanism is that the capture process is taking place outside the nuclear radius. In other words, the matrix elements $Q^{(E1)}_{c\to b}$ have appreciable contribution only from the external region. The insensitiveness of the capture process to the detail of the initial state scattering wave function can then be easily understood considering that the neutron-nucleus collision of p wave neutrons is peripheral.

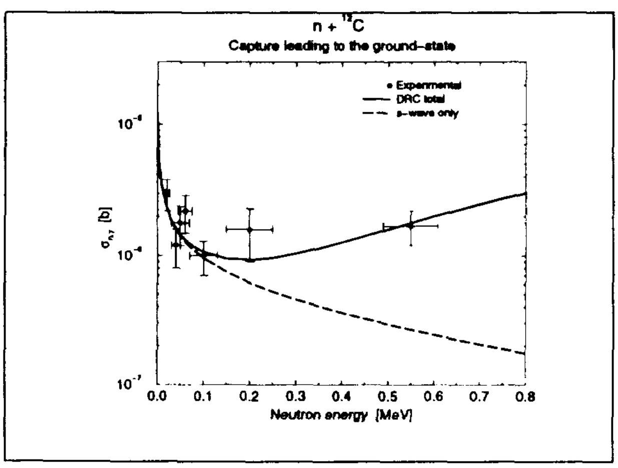

Figure 1: Neutron capture cross section of ^{12}C leading to the ^{13}C ground state. The experimental values are from [3]

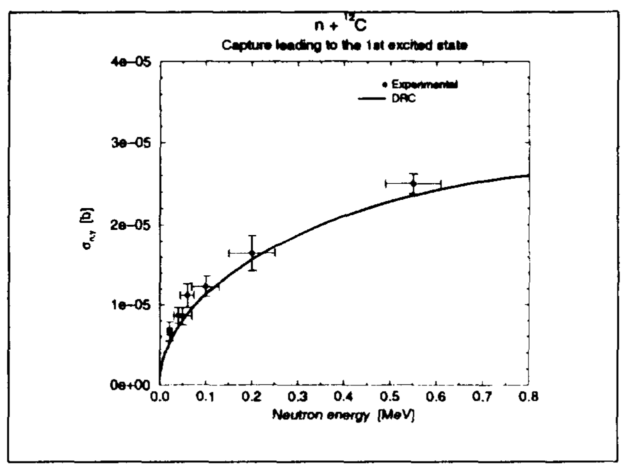

Figure 2: Neutron capture cross section of ^{12}C leading to the first excited state in ^{13}C. The experimental values are from [3]

We have calculated several neutron capture cross sections of light nuclei using the DRC model in the neutron energy range which goes from thermal up to ≈ 1 MeV. The details of the calculation technique and the parameters used in these calculations can be found in the references [5-8]. The result for two of the four γ-ray emitting transitions in the ^{12}C(n,γ) reaction are shown in Figs. 1 and 2 respectively. The

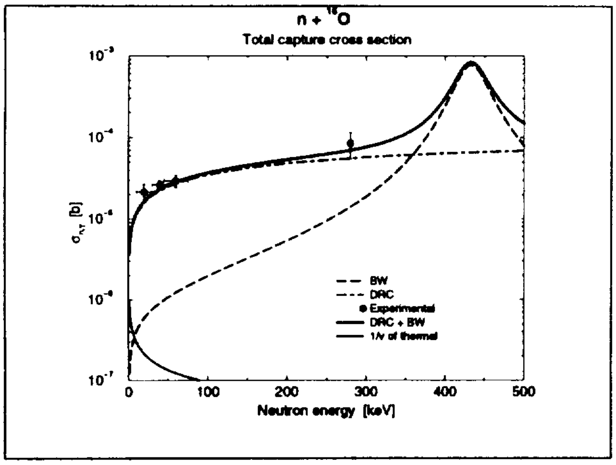

Figure 3: Neutron capture cross section for ^{16}O. The calculation includes the contribution from the resonance state at E_n = 434 keV. The experimental values are from [4].

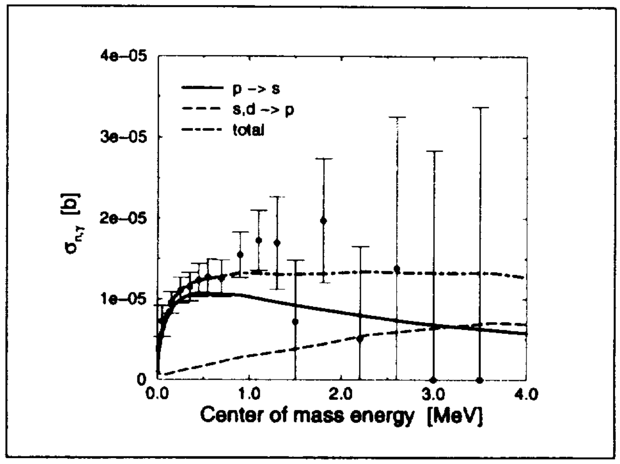

Figure 4: Neutron capture cross section of ^{10}Be. The experimental values are obtained from the measurement of the Coulomb dissociation cross section [9].

total $^{16}O(n,\gamma)$ cross section is shown in Fig. 3. The comparison has been made with recent experimental results from direct measurements. In Fig. 4, we have compared the $^{10}Be(n,\gamma)^{11}Be$ DRC cross section calculation with that derived from the experiment in the inverse kinematics [9] (Coulomb dissociation of ^{11}Be).

These calculations enabled us to assess quantitatively the DRC model in terms of reliability and sensitivity to the few parameters involved. We have planned to make the calculations of the following reactions: $^{7}Li(n,\gamma)$,$^{13}C(n,\gamma)$, $^{14}C(n,\gamma)$ and $^{18}O(n,\gamma)$. For most of these reactions, the DRC process is supposed to be the dominant reaction mechanism. The results of these calculations are expected to be included in the upgrades of several nuclear data files. In particular, in the frame of a collaboration with the JAERI/NDC the results of this investigation are planned to be included into the special purpose files associated to the JENDL-3.2 data library.

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PRE-EQUILIBRIUM CALCULATIONS OF GAMMA TRANSITIONS INCLUDING DISCRETE STATES

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We calculated γ emission within the pre-equilibrium (exciton) model of nuclear reactions with full account for both the spin couplings as well as for couplings of different nuclei and cascades of γ's using the computer code DEGAS (updated and enlarged version of PEGAS [1]). In this report, we concentrate ourselves on discrete states, mainly on the γ transitions between two discrete levels. Where applicable, we have compared the results with those obtained by GNASH [2] as well as to the experimental data. The code DEGAS is heavily based on the set of master equations, that allows one to follow the time evolution of the reaction system up to its complete decay. This description is used consistently for all stages of a nuclear reaction, even if more specific approaches for the extreme cases (especially for compound nucleus) would yield results of better quality.

The set of the Pauli master equations used with explicite treatment of spin variables and all possible couplings and cascades is in its ususal form (see e.g. [3]). The γ emission mechanism is that of single-particle radiative transition. As DEGAS does not follow parities of levels, it is sufficient to consider the electric transitions only. The gamma emission rate of Eλ transition is [4]

$$\lambda_\gamma([E,J,n] \xrightarrow{\epsilon_\gamma \lambda} [U,S,m]) = \frac{\epsilon_\gamma^{2\lambda}\sigma_{GDR}(\epsilon_\gamma)}{3\pi^2\hbar^3c^2} \cdot \frac{b_{mS}^{nJ}\omega(m,E-\epsilon_\gamma,S)}{\omega(n,E,J)} \quad . \tag{1}$$

The corresponding spin coupling terms are

$$x_{nS}^{nJ} = \frac{(2\lambda+1)(2J+1)}{R_n(S)} \sum_{j_1j_2j_3} (2j_1+1)(2j_2+1)R_1(j_1)R_1(j_2)R_{n-1}(j_3) \begin{pmatrix} j_2 & \lambda & j_1 \\ \frac{1}{2} & 0 & -\frac{1}{2} \end{pmatrix}^2 \begin{Bmatrix} j_2 & j_3 & S \\ J & \lambda & j_1 \end{Bmatrix}^2 \tag{2}$$

$$x_{nS}^{n+2,J} = \frac{2J+1}{2S+1} \sum_{j_1j_2} (2j_1+1)(2j_2+1)R_1(j_1)R_1(j_2) \begin{pmatrix} j_2 & j_1 & \lambda \\ \frac{1}{2} & -\frac{1}{2} & 0 \end{pmatrix}^2 \Delta(S\lambda J) \quad . \tag{3}$$

For the notation of spins as well as for other details, see the paper from the preceding meeting [3].

An important additional physical characteristic has to be ascribed to the individual levels to enable their incorporation into the exciton model, namely, one has to specify the corresponding exciton number for each level separately. There is no guidance in this procedure, and we have *ad hoc* used $n = 0$ (or $n = 1$, according to the particle-hole relation) for the ground state, and $n = 2$ (or 3) for all other low-lying discrete states. This procedure is very vulnerable, obviously; however, the results of the level production and of γ transitions showed not to be very sensitive to these details.

More dependence of the results could be reported when using various level density parameters. Rather often, one takes $g = A/13$ and no pairing corrections. This has been compared with taking usual level density parameters, where we employed a's from tables by Iljinov et al. supplemented by pairing from subsequent paper of Mashnik [5].

Fig. 1 brings an example of the excitation curves of the 1316 keV transition obtained in the ^{56}Fe+n reaction, together with calculations both using GNASH and DEGAS codes. Generally, the GNASH agreement is better than that using our code. This is not surprising, however, as GNASH uses much more (and larger) specific input information.

Similarly, Table I illustrates the comparison of discrete γ lines observed in ^{27}Al+n at 14.6 MeV. Again, the overall agreement is somewhat better using the GNASH code. The calculations using DEGAS with mechanically applied level density parameters of [5] differ significantly from the experimental data.

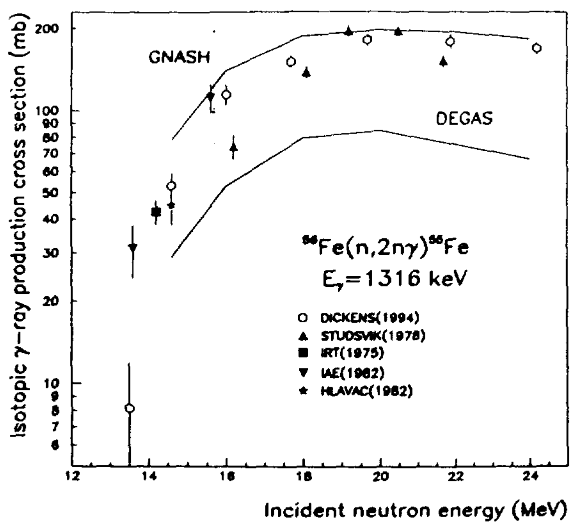

Fig. 1. ^{56}Fe(n,2nγ)^{55}Fe cross section for the 1316 keV γ line. The data are taken from the Bologna paper by Dickens and Larson [6] (and the data quoted therein) plus the measurement by Hlaváč [7].

Table I. Gamma cross sections in ^{27}Al + n at 14.6 MeV

Reaction	Energy	Transition	Experiment	GNASH	DEGAS
$(n, n'\gamma)$	844	844→g.s.	36 ± 6	31	27
	1014	1014→g.s.	72 ± 6	55	62
	1720	2735→1014	(54, 60)	16	14
	2211	2211→g.s.	176 ± 13	98	24
	≈ 3000	≈ 3000 →g.s.	137 ± 12	85	20
$(n, p\gamma)$	985	985→g.s.	32 ± 3	17	32
	1698	1698→g.s.	28 ± 3	23	27

Energies are in keV, cross sections in mb. GNASH and DEGAS are the two calculations. Experimental data are from [8] (with the exception of the 1720 keV line).

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XA9743838

Pre-equilibrium model calculation of 14 MeV neutron capture integrated cross sections relevant also for technology.

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In the past PEEQ analyses [1] of the σ_{int} excitation functions there remained an open question why the calculated broad peak appears systematicaly at about 1,5 MeV higher energy than the experimental one. From the present study it follows that this displacement comes from the expression for the probability of the γ-ray emission [2]

$$W_\gamma = \frac{\epsilon^2}{\pi^2 c^2 \hbar^3} \Sigma_k \sigma_\gamma(k \to n), \epsilon) \frac{\omega_k(E-\epsilon)}{\omega_n(E)}$$

by the multiplication of the γ-ray absorption cross section σ_γ, having the shape of GDR, with the square of the γ - ray energy ϵ^2, and with the ratio of the level densities $\frac{\omega_k(E-\epsilon)}{\omega_n(E)}$. (Here E means the excitation energy of the nucleus while k and n are pre and after emission exciton number, respectively). In the DSD model [3] this displacement is removed by the interference between the direct and semi-direct term (Fig.1). As there is no interference in the PEEQ model, we introduced into its calculations the GDR energy shifted by 2 MeV. Thus an improved agreement between the experimental and calculated data for (n,γ) and also (p,γ) integrated cross section excitation functions has been obtained (Fig. 2).

To establish the predictive power of the PEEQ model based on the shifted GDR energies, we analysed the possibility to reproduce the experimental 14.1 MeV neutron radiative capture integrated cross sections σ_{int} for series of evaluated nuclei [4] using in the calculation only one free parameter i.e the constant K = 135 MeV^3 in the Kalbach's [5] expression for the nuclear cascade transition matrix element $M^2 = KA^{-3}C(e)$, where A means the mass number and $C(e)$ is the function defined by Kalbach and is dependent on the excitation energy per exciton $e = \frac{E}{n}$. Reproduction is relatively good (Fig.3) if in the M^2 the $A^{-2}(\frac{A}{6000} + \frac{1}{40})$ dependence, instead of the A^{-3} one is used in the calculation. Exciton level densities were calculated (taking into account the pairing of Gilbert and Cameron) using the (equidistant) single particle level density g extracted from the physically sound Rohr's experimental doorway state level density [6] (localy averaged for the present purpose), which is similarly to σ_{int} smoothly A dependent, without shell effects. Values are about 4 times lower than the values obtained from the (usualy used) approximative expression $g = A/13$ (valid for the Fermi system), which, on the average, agree with the density of all nuclear states near to the Fermi energy for nuclei far from the clossed shells. For clossed shell nuclei experimental level density is several times lower than the $A/13$ value. In the calculation the maximal number of excitons $n = 7$ has been taken. Allowing $n > 7$, the shape of the excitation function for some nuclei loses the expected shape of the GDR.

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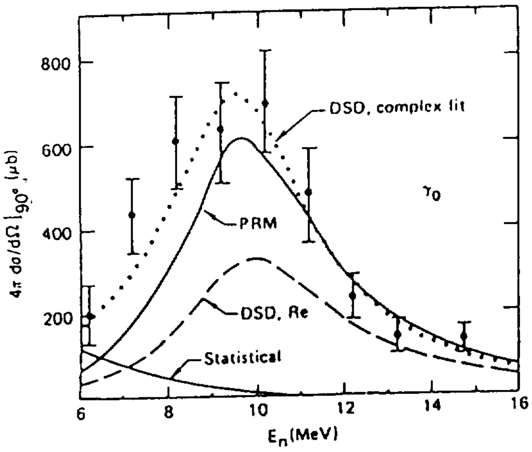

Fig.1. Displacement of the peak energy in the $^{208}Pb(n, \gamma_0)$ excitation function due to the interference of the direct and the semi-direct term in the DSD calculations (DSD complex fit) (taken from [2], where PRM means the Pure resonance model and Re stays for the real particle - vibration coupling in DSD calculation)

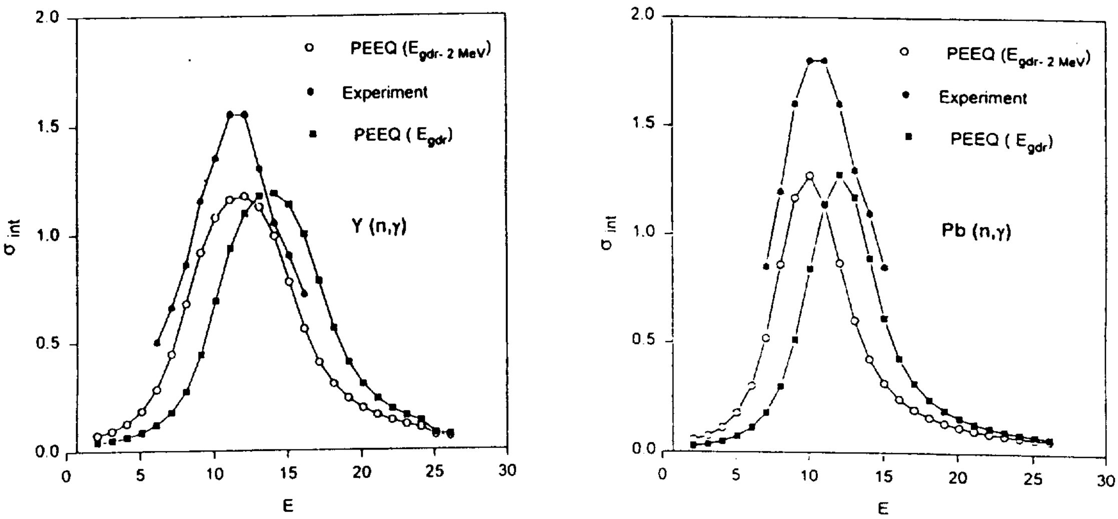

Fig.2. Comparison of the PEEQ σ_{int} (n, γ) excitation function using in the calculation the original GDR energy value and the value reduced for 2 MeV for Ytrium and Lead.

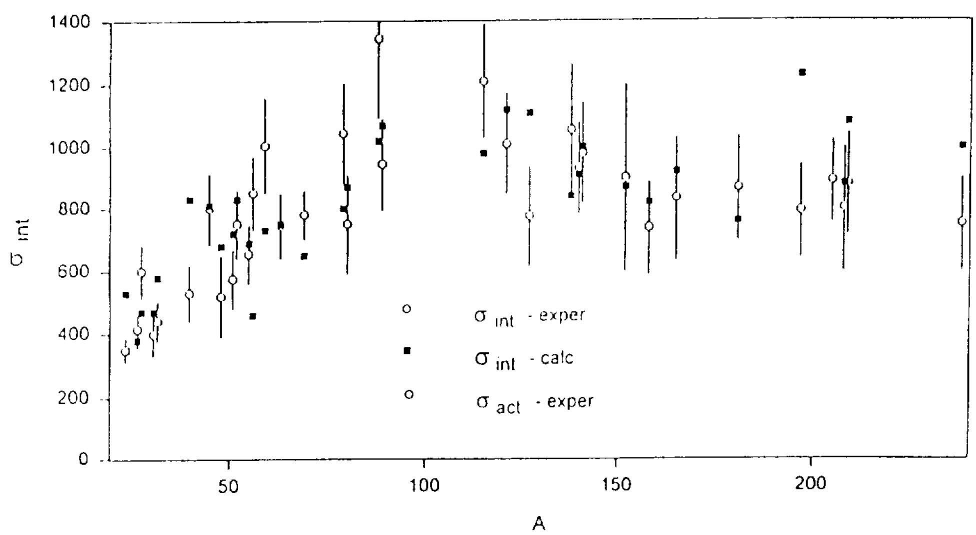

Fig.3. Comparison of the 14.1 MeV neutron experimental and PEEQ calculated values of the integrated radiative capture cross sections. To get the experimental points more equidistant, the activation cross sections (not much different from the integrated one) for Ti48, Ga69, Ba138 and Sm152 are included in the analysis.

Some new tests of the consistent DSD model

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We report here calculations of fore-aft asymmetry of gamma rays from radiative capture of MeV neutrons in ^{208}Pb and ^{89}Y and compare them with existing experimental data. The interference of dipole and quadrupole amplitudes arising from excitation of dipole and isoscalar and isovector quadrupole resonances in the target nucleus has been investigated using the consistent version of the DSD capture model [1]. It has been shown that this model can account well for the observed asymmetries of angular distributions of gamma rays from neutron capture in ^{40}Ca [2]. Radiative capture of neutrons is especially suitable for the study of quadrupole resonances since the direct quadrupole amplitude in which the neutron is captured to the final single particle state is weak. The whole quadrupole amplitude is therefore assigned to the excitation of quadrupole resonances in the studied nucleus.

The asymmetry coefficient A_1 of angular distributions of emitted γ-rays is defined as the ratio:

$$A_1 = \frac{Y(55^\circ) - Y(125^\circ)}{Y(55^\circ) + Y(125^\circ)} \tag{0.1}$$

where $Y(\theta)$ is the γ-ray intensity at the angle θ with respect to the neutron beam.

We analyze the data from experiments reported by Drake et al. [3], Bergqvist et. al. [4], Zorro et. al. [5] and Håkansson et. al. [6]. This work presents, what we believe, better assignments of basic parameters of quadrupole resonances and on the other hand provides further test of the consistent DSD model.

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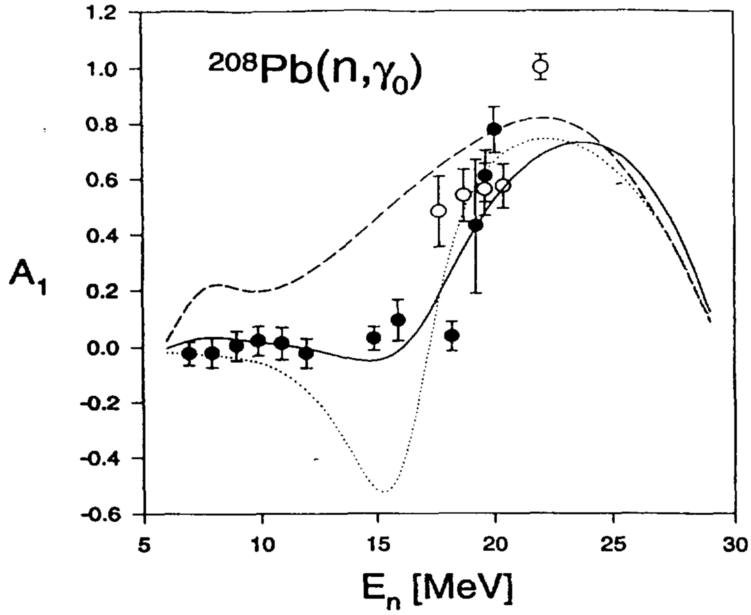

Figure 1: The asymmetry coefficient A_1 as a function of neutron energy for the reaction $^{208}Pb(n,\gamma_0)^{209}Pb$. Excitation of giant dipole resonance and isoscalar quadrupole resonance with 20% of the energy weighted sum rule and isovector one with 50% of the isovector sum rule have been supposed to obtain the solid line. The dashed line is obtained if dipole and the isoscalar quadrupole resonance only are excited, later with 100% of isoscalar sum rule. The dotted line follows if dipole and only isovector quadrupole resonance (100% of the sum rule) are excited.

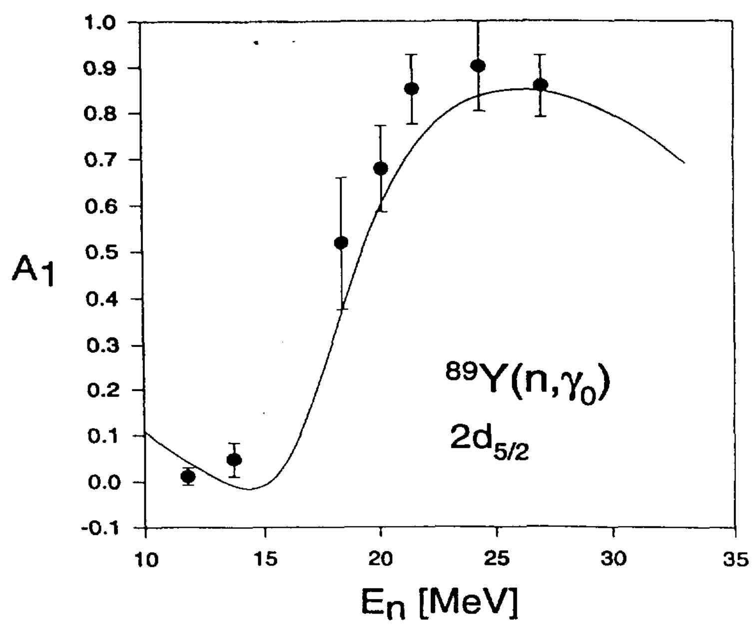

Figure 2: The asymmetry of gamma rays observed in neutron capture to the ground state doublet in ^{90}Y. The solid line indicates the results obtained with consistent DSD model. The deduced strengths of quadrupole resonances are 35% of the sum rule for ISQ and 100% for IVQ.

Extended DSD Calculations for 34-MeV Proton and 14-MeV Neutron Capture

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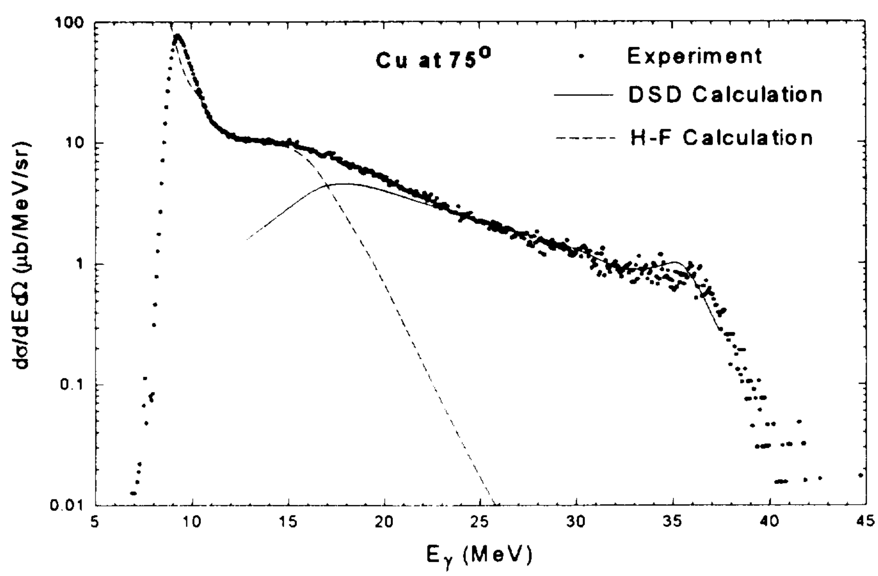
At the initial meeting of this CRP, we introduced an extension of the Direct-Semidirect (DSD) Model that treats radiative capture to unbound final states and also to bound single-particle configurations that subsequently damp into the dense background of neighboring states. This model was applied to the ^{89}Y(p,γ) reaction with polarized 19.6-MeV protons. A description of the model and this first application have since been published (W. E. Parker *et al.*, Phys. Rev. **C52**, 252 (1995)). We found that the extended DSD model, supplemented by a Hauser-Feshbach contribution, successfully explained the spectrum from 10 MeV to the endpoint near 28 MeV without requiring additional mechanisms, such as bremsstrahlung or multistep. In the contribution to this meeting we apply the model to two new regimes, capture of 34 MeV protons and 14 MeV neutrons.

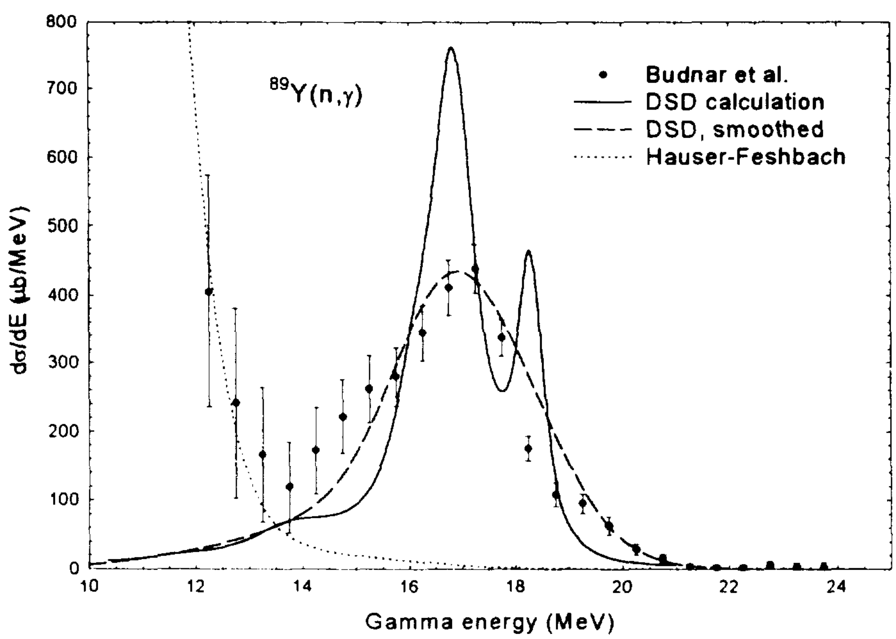
The data on 34-MeV proton capture are taken from the thesis of S. J. Luke (University of Washington, 1992, unpublished). These data include spectra from approximately 10 to 40 MeV on targets of natural Cu, Ag, and Au, together with angular distributions at 6 to 8 angles in the range 40°-135°. The calculations were made with the same parameters as for the ^{89}Y(p,γ) case, with appropriate variations taking into account the incident and final state energies as well as the target Z and A. No further adjustment was made except for the final state well depth which was chosen to match known single-particle energies. In addition to direct E1, E2, and E3 radiation as well as E1 semidirect, we have included convective-current direct M1 and M2. The magnetic radiations are important at forward angles, and their inclusion is a new result in the present work. An example of the agreement with data is shown in the following figure for the spectrum on a Cu target at 75°. The fall in the spectrum below 10 MeV is due to an electronic cutoff.



The agreement with the Ag spectra is of similar quality. The DSD calculations for Au fall about a factor of 2 below the data, but we do not feel this represents a serious discrepancy since the parameters semidirect form factor were not adjusted from their values in the medium-weight nuclei. The agreement with the shapes of the angular distributions is very good for all three targets.

Comparison of the model with 14-MeV neutron capture data is hampered by an insufficiency of experimental data covering a wide gamma energy range. Two sets of data that include a wide range of target masses are those of Rigaud *et al.* (Nucl. Phys. **A173**, 551 (1971) and references therein), and Budnar *et al.* (IAEA Report INDC(YUG)-6 (1979)). The former set was measured with a NaI spectrometer, while a pair spectrometer was employed for the latter. Unfortunately, there are significant discrepancies between the spectra reported by these two groups when the same or nearby targets were measured. We have carried out calculations for ^{59}Co and ^{89}Y, again using parameters similar to those for the ^{89}Y(p,γ) reaction. The results for 14-MeV neutron capture on ^{89}Y, compared with the data of Budnar *et al.*, are shown below. The solid line is the DSD calculation, while the dashed line is the same calculation smeared by the experimental resolution. The combination of the smeared DSD and Hauser-Feshbach calculations is in excellent agreement with the experiment. In particular, the dip near 14 MeV gamma energy is reproduced. However, the experimental data of Rigaud *et al.* are very different in magnitude and shape; there is neither a peak near 17 MeV nor a dip near 14 MeV.

We conclude that the extended DSD model appears to work well in the cases treated here. Additional careful measurements of neutron capture gamma spectra in the 14 MeV region would be very useful in clarifying the discrepancies between existing data noted above. This work was supported by the Lawrence Livermore National Laboratory under USDOE Contract No. W-7405-ENG-48.



Specialists' Meeting on Measurement, Calculation and Evaluation of Photon Production Data, Vienna, May 21-24, 1996

ATLAS OF NEUTRON CAPTURE CROSS SECTIONS

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ABSTRACT

This contribution describes the work performed to assemble the first version of the NGATLAS data base of neutron capture cross-sections for neutron energies in the 0-20 MeV energy range. The starter was the latest version of EAF-4.1. This version contains cross section data for all target nuclides which have half-lives longer than 0.5 days extended by actinides up to Cm-248. Cross sections to isomeric states are listed separately and if the isomers live longer than 0.5 day they are also included as targets. Energy dependent isomeric branching ratios are based on a combination of the experimental information with data based on systematic. The NGATLAS includes 739 target nuclides with 972 reactions. An internal validation against experimental cross sctions [2] at thermal, 30 kev and 14.5 MeV neutron energies together with resonance integral data is included. The data at 14.5 MeV are further inspected against the cross section sysmatic.

Table 1. Origin of data in NGATLAS

Data source	Number of reactions
JEF-2.2	390
EFF-2.4	11
ENDF/B-VI	16
JENDL-3.1	38
JENDL-3.2	3
LANL (BR)	9
ADL-3	7
FISPRO (ECN)	9
MASGAM+SIGECN	73
MASGAM (ECN)	411
NGAMMA (ECN)	1
SIGECN	1
ESTIMATE (ECN)	3
Total	972

The sources of data selected from other libraries are quoted in lower section of this table, were calculated and evaluated with the codes FISPRO, MASGAM, SIG and NGAMMA within the EAF programme. Details on calculations, renormalizations, data corrections and generation of the point-wise files can be found in Refs. [1,3] and are discussed in this contribution.

In the content and validation table all reactions are listed with their data sources. If the experimental informations is available, the corresponding C/E values for the three above mentioned energies are quoted together with a C/S (systematic) value at 14.5 MeV for all reactions.

A draft of the final product of this work, a graphical presentation of all reaction cross sections, is shown and disscussed.

References:

[1] J. Kopecky and D. Nierop, The European Activation File EAF-4 - Summary Documentation - ECN-C--95-072 (December 1995).

[2] J. Kopecky, Experimental Data Base compiled for Renormalizations and Validation of EAF-4.1 Cross Sections, 3. edition, EAF-Doc-008 (January 1996).

[3] J. Kopecky, M.G. Delfini, H.A.J. van der Kamp and D. Nierop, Revisions and Extensions of Neutron Capture Cross Sections in the European Activation File EAF-3, ECN-C--92-051, (July 1992).

Status of Experimental and Evaluated Data for γ-ray Production at 14 MeV Neutron Incident Energy

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The experimental data on discrete γ-ray production cross-sections from (n,xγ) reaction at 14MeV neutron energy, measured in different laboratories beginning from sixties up to today, are reviewed and compiled.

Totally 36 nuclei from Li to Bi, those which are requested in WRENDA 93/94 and/or included in general purposes FENDL-1 library, were selected for compilation (see Table). For every nucleus all γ-ray transitions, confirmed either at least by two experiments or excited level scheme, were regarded. The unresolved transitions and obviously erroneous experimental results were skipped.

Finally, the estimated cross sections and its uncertainties for every γ-ray transition and nucleus were calculated by weighting the individual experiment data taking into account the reported uncertainties.

Critical examination of experimental data base and comparison with accuracy, requested in WRENDA (typically 5-10%), have shown that estimated uncertainties for (see Table):

i. V and Cr satisfy the requirements,
ii. Be, Mn, Pb and Bi - exceed 50%,
iii. other elements have order of 15-50%.
iv. Cs, Ba, Ta and W the experimental data are not available.

The status of discrete γ-ray production sections, stored in FENDL-1, ENDF/B6 and BROND-2 libraries, was checked as well. From this analysis it was found out that:

i. agreement within experimental uncertainties is reached for following elements (and libraries): ^{6}Li (FENDL-1), ^{7}Li (FENDL-1, BROND-2), ^{9}Be (FENDL-1), ^{10}B (FENDL-1), ^{12}C (FENDL-1, BROND-2), ^{14}N (ENDF/B6), ^{27}Al (ENDF/B6), Fe (FENDL-1), Pb (FENDL-1).
ii. for elements heavier than Na the evaluated cross sections are presented as sum of discrete transitions and continues energy distributions.
iii. for many of those nuclei the discrete part of cross sections are underestimated.
iv. for Ge and Cs there are no evaluation of γ-ray yields in ENDF/B6 and BROND-2 libraries.

Table. List of elements included in compilation and comparison of estimated experimental data uncertainty with requested one.

N	Element	Request(Priority)	FENDL-1	Experim. Uncert.
1	Li	15%(2)	+	75%
2	Be	4-15%(2)	+	114%
3	B		+	31%
4	C	4-10%(2)	+	24%
5	N		+	34%
6	O	4-10%(2)	+	36%
7	F	15%(2)	+	24%
8	Na		+	19%
9	Mg		+	35%
10	Al		+	33%
11	Si	5-10%(2)	+	18%
12	P		+	15%
13	S		+	22%
14	Cl		+	35%
15	K		+	14%
16	Ca		+	25%
17	Ti		+	22%
18	V	15%(1)	+	16%
19	Cr	10%(1)	+	12%
20	Mn	10%(1)	+	152%
21	Fe	10%(1)	+	36%
22	Co		+	28%
23	Ni	10%(1)	+	25%
24	Cu	10%(1)	+	44%
25	Ge	10%(2)		33%
26	Zr		+	ND
27	Nb	10%(1)	+	8%
28	Mo	15%(1)	+	ND
29	Sn		+	ND
30	I	10%(1)		11%
31	Cs	10%(2)		ND
32	Ba		+	ND
33	Ta		+	ND
34	W		+	ND
35	Pb		+	ND
36	Bi	10%(1)	+	60%

Comment: + - means that this element is included in FENDL-1 library,
ND - means No experimental Data are available for this element

JAERI's Activities on Photon Production Data

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Abstract

Summarized are activities on photon production data at JAERI. The activities consists of evaluation of photon production data for JENDL Fusion File, benchmark tests of JENDL and FENDL-1 data, and calculation of photon production data in the framework of the Quantum Molecular Dynamics.

The capture cross sections of ^{12}C and ^{16}O were evaluated for JENDL Fusion File by taking account of the direct radiative capture calculations obtained by A. Mengoni (ENEA). The presently evaluated data are in good agreement with the measurements of Igashira et al. in the keV region, describing the behavior of p-wave capture which is in proportion to v.

Photon production data on Fe and Ni were updated for JENDL Fusion File by using statistical-model calculations. According to the results of benchmark tests, the calculations with the updated data reproduce the integral measurements on gamma-ray heating.

Benchmark tests of evaluated photon production data have been continued by analyzing the integral experiments performed at OKTAVIAN and FNS. The calculations with JENDL Fusion File are in good agreement with the integral measurements.

Preliminary calculation of photon production data in the high energy region has been done in the framework of the Quantum Molecular Dynamics approach. The quasi-deuteron model was used to describe photon absorption in the low energy region. Above pion production threshold, pion production channels were included in the calculation. The neutron-proton bremsstrahlung obtained with the one-boson-exchange model was incorporated into QMD codes.

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PRESENT STATUS OF EXPERIMENTAL GAMMA-RAY STRENGTH FUNCTIONS

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ABSTRACT

Previous compilation [1] of photon-strength functions, based on experimental data from resonance- or thermal-neutron capture and photonuclear reactions, has been reviewed. No new measurements have been performed since and thus this data base of experimental f_{E1} and f_{M1} values, as compiled in [1], will be frozen and documented as a recommended set. Derived systematics of f_{E1} and f_{M1} values as a function of atomic mass "A" are reviewed in view of their use in statistical-mode calculations.

References:

[1] J. Kopecky and M. Uhl, Present Status of Experimental Gamma-Ray Strength Functions, INDC(NDS)-334, May 1995, p. 103.

TEST OF PHOTON PRODUCTION DATA IN INTEGRAL EXPERIMENTS WITH 14 MEV NEUTRONS

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Experimental photon and neutron flux spectra from benchmark arrangements consisting of iron or stainless steel are compared with Monte Carlo calculations based on nuclear data of the ITER-reference library FENDL-1 and of European Fusion Files. Spectral fluxes represent detailed information on the neutron and photon transport in integral arrangements. The comparison between experiment and calculation enables sensitive tests of the calculational tools (transport codes and nuclear data) of the reactor design. Spectral fluxes are basic weighting functions for different integral quantities of special importance for the reactor design like reaction rates, nuclear heating and material activation.

Iron is the main element of the shield blanket and vacuum vessel of a fusion reactor and of fundamental interest for such investigations. SS-316 steel is structural material of the ITER design. The neutron field on the back of the arrangements producing the photos observed is typical for the flux spectrum in fusion reactor shield blankets. Because the attenuation length of photons is of the order of -cm, the measured photons are produced by the measured neutron field, which allows a sensitive test of neutron induced photon production data.

The geometry of the experiments is sensitive to shield penetration and streaming problems of fusion reactor design and allows an integral test of double differential nuclear data used in the libraries. Slabs of dimension 1m x 1m x 0.3m with and without vertical gaps are irradiated with 14 MeV neutrons from a pulsed beam neutron generator with pulse width of 1.5 ns and frequency of 2.5 MHz. The source position was 19 cm far from the front of the iron slab and a shielded detector for the measurement of neutrons and photons penetrating and leaking the slab was arranged behind the back of the slab in a distance of 3 m. A NE-213 scintillation detector (5.08 cm x 10.16 cm ⊘) with well described response matrices for neutron and photon events allows the simultaneous measurement of photon and neutron spectra with one detector. All events- N are recorded two-dimensionally as N(ph,t) both for neutron and photon events, where ph- is the pulse height and t- the time of arrival. Compton- and proton recoil spectra (ph-spectra) are unfolded to obtain the energy spectra. For neutron events also time spectra contain spectroscopic information, whereas the time structure of the photon field is used for the selection of relevant photon events, that enables an effective background reduction.

Coupled neutron photon transport calculations are performed with the Monte Carlo code: MCNP4A on the base of EFF-1, EFF-2 and FENDL-1 data files. The full energy and time dependence of the complex neutron and photon transport process is calculated to follow strictly the experimental concept of the measurement, so that calculated fluences can be compared directly with the measured one.

First analyses of photon fluence spectra from the iron benchmark based on MCNP-calculations with EFF-1 data presented at the first RCM in Bologna (November 1994) have shown, that the measured photon fluxes are underestimated by the calculations for all assemblies investigated. Such discrepancies are also observed for neutron flux spectra, which can be explained by the neglect of preequilibrium reaction parts and the incorrect consideration of the angular dependence of inelastic neutron scattering in EFF-1 data.

By the present calculations with EFF-2 and FENDL-1 data the discrepancies are reduced both for neutron and photon flux spectra as it can be seen from integral values of tables 1.1, 1.2 and from the spectral flux distributions of figs. 1.1 - 1.2. The photon production data are not different in EFF-1 and EFF-2 data and so the better description of the neutron induced photon flux spectra is mainly caused by an increase of the calculated neutron flux. The results from EFF-3 calculations *[A. Hogenbirk, a. J. Konning, H. Gruppelaar, Validation of the EFF-3.0 Evaluation for ^{56}Fe, Report, ECN Petten, EFF-DOC-382]* analysing the TUD iron benchmark without gap, have shown, that a further improvement in neutron flux calculations up to the level of correspondence with measured flux spectra is obtained with consideration of the self shielding of inelastic partial neutron cross sections for ^{56}Fe. The increasing neutron flux is connected with an increasing photon production up to the level of full correspondence with measured photon flux spectra. It seems that the used photon production data for iron in EFF-data files are good quantities, then the earlier discrepancies between the measured and calculated photon flux spectra disappear with the better description of neutron flux spectra by use of developed EFF- data files. For FENDL-1 calculations, the improvement in the description of the integral neutron flux is comparabel with such from EFF-2 calculations, but not so the improvement in photon flux spectra.

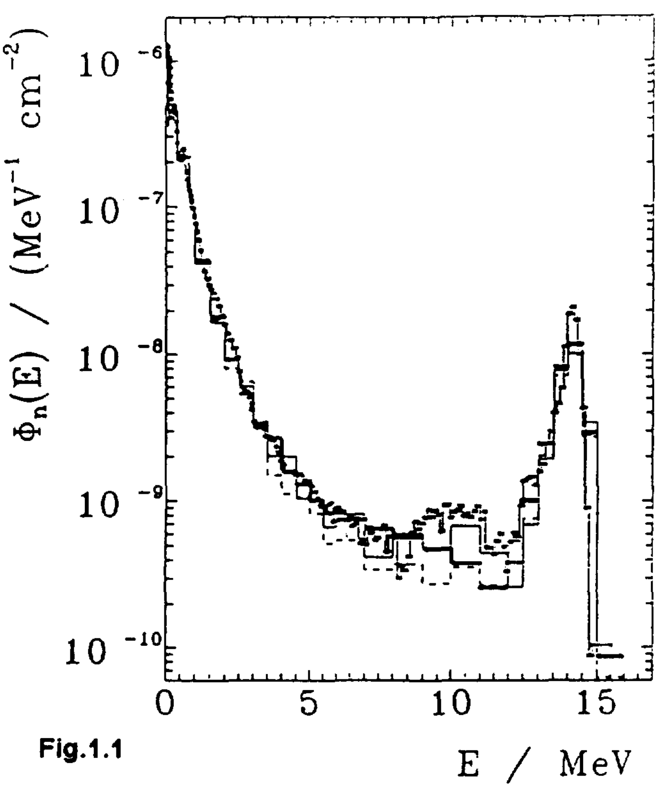

Fig.1.1

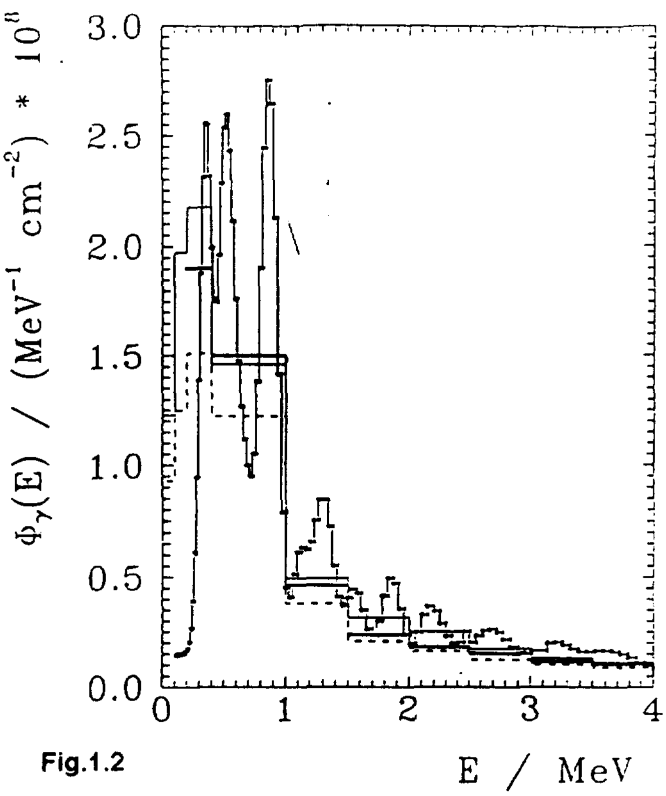

Fig.1.2

Fig. 1 Comparison of measured and calculated spectral neutron- (Fig.1.1) and photon fluences (Fig.1.2) for the iron benchmark without gap for different data files. experiment(x), EFF-1 (dashed line), EFF-2 (full line), FENDL-1 (fat full line)

Tab.1.1 Integral photon fluence (10^{-8} / cm^2 / sn) in the measured energy range E ($0.3 \leq E$ / MeV $\leq$ 8.0) for different iron assemblies and integrated c/e-values for different data files. (b-gap width [cm] / x- gap distance from center [cm])

b/x	experiment	c/e		
		EFF-1	EFF-2	FENDL-1
0/0	2.76±0.15	0.62±0.04	0.80±0.05	0.76±0.04
5/10	3.98±0.21	0.76±0.04	0.95±0.05	0.86±0.05
5/20	3.64±0.20	0.73±0.05	0.88±0.05	0.80±0.04

Tab.1.2 Integrated c/e values of neutron fluence for different data files (iron benchmark)

energy range	without gap		
[MeV]	EFF-1	EFF-2	FENDL-1
0.04≤ ≤ 1.0	0.86±0.10	0.89±0.10	0.88±0.10
1.0≤ ≤ 5.0	0.90±0.06	0.95±0.06	0.94±0.06
5.0≤ ≤10.0	0.65±0.05	0.92±0.08	1.00±0.07
10.0≤ ≤15.0	0.77±0.04	0.87±0.04	0.87±0.05

INTERNATIONAL ATOMIC ENERGY AGENCY

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

Agency's Headquarters in Vienna, Austria
21 to 24 May 1996

Scientific Secretary: Pavel OBLOŽINSKÝ

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