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INDC International Nuclear Data Committee

Summary Report

1st Research Coordination Meeting

Updating Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions

IAEA Headquarters
Vienna, Austria

4 to 8 April 2016

Prepared by

S. Goriely
Université Libre de Bruxelles
Brussels, Belgium

and

P. Dimitriou
Nuclear Data Section, IAEA
Vienna, Austria

July 2016

IAEA Nuclear Data Section
Vienna International Centre, P.O. Box 100, 1400 Vienna, Austria

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International Atomic Energy Agency
Vienna International Centre
PO Box 100
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Austria

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ABSTRACT
A summary is given of the 1st Research Coordination Meeting of the new IAEA Co-ordinated Research Project (CRP) on Updating the Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions. Participants presented their work, reviewed the current status of the field with regards to measurements, theoretical models and evaluations, discussed the scope of the work to be undertaken and agreed on a list of priorities and task assignments necessary to achieve the goals of the CRP. A summary of the presentations and discussions is presented in this report.

July 2016

Contents

1. Introduction

Photonuclear data, describing interactions of photons with atomic nuclei, are of importance for a variety of applications such as (i) radiation shielding and radiation transport analyses (in particular for the production of photo-neutrons with energies above 8 MeV), (ii) calculation of absorbed dose in the human body during radiotherapy, (iii) activation analyses, safeguards and inspection technologies (identification of materials through radiation induced by photonuclear reactions using portable bremsstrahlung devices), (iv) nuclear waste transmutation, (v) fission and fusion reactor technologies, and (vi) astrophysical nucleosynthesis. Photons are commonly produced as bremsstrahlung radiation by electron accelerators which are relatively simple machines present in many hospitals, industries and laboratories. In response to growing needs for photonuclear data, the IAEA held a Coordinated Research Project (CRP) under the title "Compilation and Evaluation of Photonuclear Data for Applications" between 1996 and 1999. This CRP produced three major results: the IAEA Photonuclear Data Library; a Handbook on Photonuclear Data for Applications [1.1]; and additions of compiled experimental photonuclear cross sections in the EXFOR database. The Photonuclear Data Library which is available at the IAEA website (http://www-nds.iaea.org/photonuclear) includes photon absorption data, total and partial photo-neutron reaction cross sections for 164 isotopes, primarily for structural, shielding, biological and fissionable materials.

Although this database has been extremely useful to a broad user community, it has become evident that it needs to be revised, especially since

(i) some of the data are unreliable and discrepant,
(ii) for 37 isotopes there exist data that have not been evaluated yet,
(iii) improved evaluation techniques are available,
(iv) new data have been published in recent years.

Photon strength functions (PSF) describe the average response of the nucleus to an electromagnetic probe, and are thus important quantities for the theoretical modelling of nuclear reactions. As such they are relevant sources of input information for other databases such as the IAEA Reference Input Parameter Library (RIPL) [1.2], and evaluated data files such as Evaluated Gamma Activation File (EGAF) [1.3], Evaluated Nuclear Structure and Decay File (ENSDF) [1.4], and transport files in ENDF-6 format, which are also supported by the IAEA. In the past two decades, there has been considerable growth in the amount of reaction data measured to determine integrated photon strength functions. Quite often the different experimental techniques lead to discrepant results and users are faced with the dilemma of trying to decide which (if any) amongst the divergent data they should adopt. It is therefore important that all these experimental data are evaluated by experts who will recommend the most reliable data for use in the various applications. The evaluation of nuclear data consists of several systematic steps. These include a bibliographic compilation, a compilation of experimental data, followed by a critical analysis of the measurement techniques used, together with evaluations based on theoretical modelling.

To address the needs for compilation, evaluation and recommendation of reliable data for photonuclear cross sections and photon strength functions, an IAEA Consultants' Meeting on "Compilation and Evaluation of reaction gamma-ray data" was held from 11 to 13 November 2013 [1.5]. The Consultants Meeting reviewed the status of photonuclear data in general, and recommended a new CRP to revise the photonuclear data library and generate a dedicated database of compiled and evaluated/recommended photon strength functions. The scope and deliverables of such an activity are discussed in detail in [1.5].

The proposal for a new CRP was strongly endorsed by the Nuclear Data Section advisory body, the International Nuclear Data Committee (INDC) in June 2014, and was approved by the IAEA Nuclear Applications Committee for Coordinated Research Activities in July 2015.

The new CRP is foreseen to run from 2016 to 2020, with 3 Research Coordination Meetings (RCMs) to be held at appropriate intervals. It comprises 14 participants and three advisers from 15 countries (Belgium, Czech Republic, Germany, Hungary, Japan, Netherlands, Norway, People's Republic of China, Romania, Russian Federation, Slovakia, South Korea, South Africa, Ukraine, and USA).

Main objectives
The CRPs main objectives are to:

- Update the IAEA Photonuclear Data Library
- Generate a dedicated database for Photon Strength Functions

Specific Objectives
The specific objectives for both photonuclear data and photon strength functions, that will require extensive activities and will help achieve the main deliverables mentioned above, are as follows:

- Measurements,
- compilation of existing data,
- assessment / recommendation of data,
- evaluation of data (on the basis of models),
- dissemination (data library/database).

The 1st Research Coordination Meeting (RCM) of the CRP was held at the IAEA Headquarters, Vienna, from 4 to 8 April 2016. Sixteen experts including CRP participants and advisers from 13 countries attended the meeting, which was opened on Monday morning with the Welcome Address by the Director of the Division of Physical and Chemical Sciences, Meera Venkatesh, who stressed the importance of nuclear data for applications and basic sciences and wished the participants success in their endeavors within the CRP. The Scientific Secretary, P. Dimitriou (IAEA) then briefly introduced the CRP, the motivation, goals, and expected outcome for the Member States (MS). P. Oblozinsky (Slovakia) was elected chairman of the meeting, and S. Goriely (Belgium) was designated rapporteur. The preliminary agenda was adopted with the addition of two presentations by IAEA staff (A. Koning, Section Head, and S. Simakov).

The meeting continued with presentations from participants followed by extensive technical discussions on the proposed program of work that led to assignments of tasks and responsibilities (actions). A complete list of actions is given in Appendix 3. Summaries of the presentations are given in Section 2, while the technical discussions are described in Section 3. The Meeting Agenda and Participants list are available in Annexes 1 and 2, respectively. Links to the presentations are found in Annex 3.

References
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2. Summary of participants' presentations

2.1. Total and partial photo-neutron cross section measurements by direct neutron-multiplicity sorting, H. Utsunomiya

The Phoenix Collaboration[1] has been formed for the CRP F41032 with the aim of providing: 1) new data of total and partial (γ,xn) cross sections with x=1-3 for 11 nuclides from ^{209}Bi to ^{9}Be for updating the photonuclear data library in collaboration with the Skobeltsyn Institute of Nuclear Physics of the Lomonosov Moscow State University (MSU) and the Extreme Light Infrastructure-Nuclear Physics (ELI-NP) and 2) new data of (γ,n) cross sections for 18 nuclides from ^{205}Tl to ^{58}Ni for generating a reference database for photon strength functions (PSF) in collaboration with the University of Oslo**.** The main purposes of the proposed measurements are to resolve the long-standing problem of the discrepancy between the Lawrence Livermore National Laboratory and Saclay data of total and partial photo-neutron cross sections and to provide PSF data that will be used (i) to obtain a unified understanding of (γ,n) and (n,γ) cross sections over isotopic chains with the γ-ray strength function method and (ii) to provide absolute normalizations to the PSF deduced from the Oslo particle-γ data and the nuclear resonance fluorescence (γ,γ') data.

The experiments will be performed at the NewSUBARU synchrotron radiation facility by using quasi-monochromatic γ-ray beams produced in the Compton backscattering of laser photons with relativistic electrons. The (γ,xn) data will be acquired using (i) the flat-efficiency neutron detector recently developed for direct neutron-multiplicity sorting and (ii) high-energy laser Compton-scattering (LCS) γ-ray beams produced with the Talon laser (λ=532 nm) under the operational condition at 1W - 1kHz. The (γ,n) data will be obtained using (i) the high-efficiency neutron detector which has been used for many years in the past and (ii) the low-energy LCS γ-ray beams produced with the INAZUMA Nd:YVO_4 laser (λ=1064 nm) at 35W (max) - 20kHz.

[1] **Pho**to**e**xcitation and **n**eutron em**i**ssion cross (**x**) sections

The Konan, MSU, ELI-NP, and Oslo teams are responsible for different (γ,xn) and (γ,n) measurements of as follows:

1. (γ,xn) data with x=1-3 for 11 nuclei for updating the photonuclear data library:
   Konan team: ^{197}Au, ^{181}Ta, ^{139}La, ^{9}Be
   ELI-NP team: ^{209}Bi, ^{169}Tm, ^{165}Ho, ^{159}Tb
   MSU team: ^{103}Rh, ^{89}Y, ^{59}Co

2. (γ,n) data for 18 nuclei for generating a reference database for photon strength functions:
   Konan team: ^{160}Gd, ^{158}Gd, ^{157}Gd, ^{156}Gd, ^{64}Ni, ^{60}Ni, ^{58}Ni
   Oslo team: ^{205}Tl, ^{203}Tl, ^{192}Os, ^{185}Re, ^{184}W, ^{183}W, ^{182}W, ^{89}Y, ^{68}Zn, ^{66}Zn, ^{64}Zn

We have obtained (γ,xn) data for ^{209}Bi and ^{9}Be and (γ,n) data for ^{203,205}Tl and ^{89}Y in 2015 for the CRP. The cross sections will become available in December 2016. The data acquisition during the period of the CRP is scheduled as follows. The cross sections will become available as of the date given in the parentheses:

2016
(γ,xn)（x=1-3）: ^{197}Au, ^{169}Tm, ^{89}Y (Dec/2017)
PSF (γ,n) : ^{192}Os, ^{185}Re, ^{64}Ni, ^{60}Ni, ^{58}Ni (Dec/2017)

2017
(γ,xn) （x=1-3）: ^{181}Ta, ^{165}Ho, ^{59}Co (Dec/2018)
PSF (γ,n): ^{184}W, ^{183}W, ^{182}W, ^{68}Zn, ^{66}Zn (Dec/2018)

2018
(γ,xn) （x=1-3）: ^{159}Tb, ^{139}La, ^{103}Rh (2019)
PSF (γ,n): ^{160}Gd, ^{158}Gd, ^{157}Gd, ^{156}Gd, ^{64}Zn (2019)

Finally, the Phoenix Collaboration is in need of suitable target samples to carry out the measurements listed above: Irradiation samples of approximately 10g are required for the (γ,xn) cross section measurement. As a result, at the moment (γ,xn) measurements are limited to samples with 100% natural abundance. In contrast, the (γ,n) cross section measurement for the PSF database requires isotope samples. The following isotope samples of 0.5 – 1.0g are requested for the measurement campaign mentioned above: ^{184}W, ^{183}W, ^{182}W, ^{160}Gd, ^{158}Gd, ^{157}Gd, ^{156}Gd, ^{68}Zn, ^{66}Zn, and ^{64}Zn.

2.2. Evaluation of partial and total photo-neutron reactions cross sections using new objective physical data reliability criteria, V.V. Varlamov

Most of the partial photo-neutron reactions cross sections were obtained using quasi-monoenergetic annihilation photon beams at the Lawrence Livermore National Laboratory (USA) and Saclay (France). Both laboratories employed the same method to identify reactions based on the assumption that the neutrons from partial reactions (γ,1n), (γ,2n) and (γ,3n) have quite different energies. It is well-known that these data suffer from significant systematic discrepancies: in many cases for the same nuclei, the (γ,1n) reaction cross sections are noticeably larger at Saclay, but the (γ,2n) cross sections vice versa are larger at Livermore and disagreements among the two reach almost 100 %. In view of this situation, and with the aim of investigating, understanding and resolving the observed disagreements, the IAEA

Photonuclear Data Library (PDL) was generated within the IAEA CRP (TECDOC-1178, 2000). Evaluations based on various models were completed for many isotopes that were specified as important primarily for structural, shielding, biological and fissionable materials. The IAEA PDL has been extremely useful to a broad community, but it is now evident that it needs to be revised and updated for the following reasons: 1) new objective physical criteria of data reliability have been proposed and it has been shown that they are not satisfied by many experimental partial photo-neutron reaction cross sections, for example for nuclei ^{94}Zr, ^{115}In, ^{116}Sn, ^{159}Tb, ^{181}Ta, ^{208}Pb, 2) improved evaluation techniques have been proposed and the new evaluated cross sections disagree with the previous ones; 3) for many isotopes there exist now experimental data that are yet to be evaluated.

The following ratios have been proposed as objective physical criteria of data reliability,

$$F_i = \frac{\sigma(\gamma, in)}{\sigma(\gamma, sn)}$$

where σ(γ,in) are the definite partial reaction cross sections, with i = 1 for (γ,1n) reaction, i = 2 for (γ,2n) reaction, etc., and σ(γ,sn) is the neutron yield reaction cross section[2] with

$$\sigma(\gamma, sn) = [\sigma(\gamma, 1n) + 2\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n) + \cdots].$$

According to the definition, F_1 cannot exceed the value 1.00, similarly F_2 cannot exceed the value of 0.50, F_3 the value of 0.33, etc. Larger values of these functions will lead to an incorrect (physically unreliable) determination of the corresponding σ(γ,in). Because all the terms in the F_i ratios are cross sections, negative values of these ratios are simply incorrect and due to the use of incorrect cross-section data.

A combined experimental-theoretical method for the evaluation of partial reaction cross sections using similar reliability criteria has been developed. It is based on using the experimental value $\sigma^{exp}(\gamma,sn)$, which does not depend on neutron multiplicity sorting, and the correction functions F^{theor} calculated using the Combined Model of Photonuclear Reactions (CMPNR):

$$\sigma_i^{eval} = F_i^{theor} \times \sigma^{exp}(\gamma, sn).$$

The competition of partial reactions is thus in accordance with the equations of the model and their corresponding sum is equal to $\sigma^{exp}(\gamma,sn)$. In many cases the evaluated partial reaction cross sections were found to differ noticeably from the experimental data and previous evaluations.

For the purpose of the CRP, energy dependencies of ratios $F^{theor}{}_i$ will be obtained for several nuclides, such as $^{63,65}Cu$, ^{75}As, $^{78,89,82}Se$, ^{89}Y, ^{103}Rh, $^{117\text{-}124}Sn$, ^{133}Cs, ^{138}Ba, ^{139}La, $^{140,142}Ce$, ^{141}Pr, $^{145,148}Nd$, ^{160}Gd, ^{165}Ho, ^{186}W, ^{197}Au, in addition to the nuclei mentioned in point (2) above. Cross sections for partial photo-neutron reactions (γ,1n), (γ,2n) and (γ,3n) will be evaluated for GDR energies using the above mentioned experimental-theoretical method.

[2] Note that the definition of σ(γ,sn) as the neutron yield cross section in this section is in contrast with the definition given in the previous CRP [1.1] which is also adopted by this new CRP, where σ(γ,sn) is the total photoneutron cross section also known as σ(γ,tot n). It is however in agreement with Dietrich S.S. and Berman B.L., Atlas of Photoneutron Cross Sections Obtained With Monoenergetic Photons, *Atomic Data and Nuclear Data Tables* 38, 199 (1988).

The new cross sections will be compared with new experimental cross-section data measured by the PHOENIX collaboration (see Section 2.1), and the results of the multi- nucleon reaction yields measurements using the activation method on the race-track microtron of the MSU SINP (Russia).

The main reason partial cross-section data are unreliable is that the measured neutron energy is not directly linked to the neutron multiplicity, therefore, for selected nuclei (^{116}Sn, ^{139}La, ^{156}Tb, ^{181}Ta, ^{197}Au, ^{208}Pb, ^{209}Bi) neutron emission spectra will also be calculated and analyzed in the frame of the CMPNR.

For the nuclei for which we shall perform complete evaluations, we shall also provide the evaluated data in ENDF-6 format files. Recommendations for updating the IAEA Photonuclear Data Library will also be formulated.

2.3. Evaluation of photonuclear data library by taking into account new experimental data and evaluation methodologies, N. Iwamoto

The previous JENDL photonuclear data library was released in 2004 [1]. Since then, a new photonuclear data library is under development. The content and status of the new library were presented at the meeting. Almost all of the nuclear data are newly evaluated, including more than 110 new nuclides. The evaluation of photonuclear data has been done by dividing the nuclide mass region into three mass regions, light nuclides ($Z \leq 20$), material nuclides ($20<Z<30$), and medium to heavy nuclides ($Z \geq 30$). The resonance structure was taken into account for the light nuclides. The photonuclear data were evaluated by the ALICE-F and CCONE [2] codes for the material and medium to heavy nuclides, respectively. The photon energy range was considered from 1 (particle threshold) to 140 MeV in the CCONE (ALICE-F) evaluation. The evaluations were performed using available experimental data, and taking into account modifications recommended in the literature [3-4]. The new evaluations are significantly improved and have solved the inconsistency between nuclide and particle production cross sections, and the large discrepancies with experimental data observed in the previous library. The new JENDL photonuclear data library is planned to be released in FY2016.

The nuclear models related to the photonuclear reactions in the CCONE code were introduced. Special care has been taken to describe the photon strength function of the E1 transition. Various models (e.g., SLO, EGLO [5], and MLO [6]) together with a function which reads numerical tables (e.g., RIPL-3 [7]) are included. The quasi-deuteron disintegration process is also incorporated as it has been shown to be important for photon energies above 40 MeV [8]. The applicability of the CCONE code to photon induced reactions and the comparison of the calculated results with existing evaluated and experimental data were presented for the ^{148}Sm(γ,1n), (γ,2n), (γ,3n), (γ,4n) and (γ,5n) reactions, and ^{239}Pu(γ,f), (γ,1n), and (γ,2n) reactions.

The aim of this project is to produce reliable photonuclear data using nuclear reaction models on the basis of new experimental data and evaluation methodologies recommended in this CRP. Our detailed work plans for the 3 years of the CRP were presented. In the first year the available experimental data and evaluated nuclear data will be compared with preliminary results calculated with the CCONE code for the nuclides included in the 1999 Photonuclear Data library, and will be reviewed for the nuclides which are planned to be measured in the course of the CRP.

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2.4. Update of the photonuclear cross sections, Young-Sik Cho

Photonuclear data are very important especially for safety and medical applications. Since the release of the IAEA Photonuclear Data Library in 2000, new experimental data have been produced, with some of them showing disagreement with the evaluated ones. To resolve the disagreement the evaluated data need to be updated taking into account the new measurements and advanced theoretical models.

The Nuclear Data Center at Korea Atomic Energy Research Institute evaluated the photonuclear data for 144 isotopes for IAEA CRP in 1999, and 124 of them were adopted in the IAEA Photonuclear Data Library. Although this library covers a broad range of isotopes, experimental photonuclear data for 37 isotopes have still to be evaluated, and thus need to be considered in this CRP. The KAERI group plans to evaluate the 21 isotopes which have not yet been evaluated and currently are not planned to be evaluated by other evaluators for this CRP. They include C-14, As-75, Se-76, 78, 82, Ce-140, 142, Nd-142, 143, 144, 145, 146, 148, 150, Eu-153, Lu-175, and Os-186, 188, 189, 190, 192.

The first step will be to collect the new experimental data from various public sources including EXFOR, Photonuclear Data Index at CDFE and scientific journals. Then the phenomenological and/or microscopic models available in the EMPIRE and TALYS codes for calculating photonuclear reactions will be reviewed, and the best models and parameters which reproduce the existing measurements will be determined for each isotope. The photonuclear cross sections will be evaluated up to 200 MeV, accordingly, and provided in ENDF-6 format.

2.5. Analysis and evaluation of photoreaction data, D. Filipescu

The characteristics of the gamma ray source currently under implementation at the future Extreme Light Infrastructure – Nuclear Physics facility (ELI-NP) were presented. ELI-NP is expected to be a main provider of photonuclear experimental data in the energy range up to 20 MeV. During 2015 – 2018, the ELI-NP team will participate in the Phoenix Collaboration (Konan University, IFIN-HH (ELI-NP), Moscow State University, University of Oslo) to measure (γ,xn) reaction cross sections at energies starting from the neutron threshold up to ~40 MeV at the NewSUBARU facility.
The ELI-NP team is responsible for developing a data analysis procedure to be used for obtaining absolute (γ,xn), where x = 1, 2, 3, …, reaction cross sections. The procedure will be validated on data obtained from full Geant4 simulations of the experiment. In order to perform such simulations, the neutron source will be generated using results of Monte Carlo statistical model calculations which will be provided by Toshihiko Kawano (LANL). The

procedure will be applied by the ELI-NP team on the following nuclei: ^{209}Bi (already measured in 2015), ^{169}Tm (to be measured in 2016), ^{165}Ho (2017), and ^{159}Tb (2018).

The current status of the data analysis performed on the ^{209}Bi data was reported. The data were taken using the flat efficiency neutron detector designed for (γ,xn) measurements, electron beams with energies up to 1100 MeV along with a 532 nm wavelength laser. The laser beam frequency was reduced from 16 kHz to 2 kHz using a Pockels cell, an additional optical element which partially blocked 7 out of 8 consecutive laser beam bunches. So far, data files created by the data acquisition system have been read and sorted into "collective" events format with one event consisting of all signals (neutron counters and gamma ray beam flux monitor signals) acquired between two consecutive 2 kHz clock signals. A method for filtering out the "leakage" component from both neutron and flux monitor spectra has been developed. Preliminary Fx factor results have been obtained and presented.

In addition, full evaluations of photon induced reactions on the following nuclei which will be measured by the Phoenix Collaboration will be performed:

- ^{209}Bi data to be made available by 12/2016; additionally, 148Nd will also be evaluated to take into account the new data from NewSUBARU;
- ^{197}Au, ^{89}Y, ^{169}Tm data to be made available by 12/2017;
- ^{181}Ta, ^{165}Ho, ^{59}Co data to be made available by 12/2018;
- ^{139}La, ^{159}Tb, ^{103}Rh data to be made available by 12/2019.

In addition to 209Bi, the photonuclear cross sections for 148Nd that have already been measured at NewSUBARU will be evaluated.

The energy range of evaluation will be extended below the neutron emission threshold based on existing experimental data. Statistical model calculations will be carried out using the EMPIRE code system and suitable GDR and nuclear level density parameters will be investigated for obtaining a good description of the new experimental photo-neutron data. Consistent sets of GDR parameters will be provided.

2.6. Evaluation of photonuclear cross sections and photon strength function at CNDC, Ruirui Xu

The planned evaluations of photonuclear cross section and photon strength functions (PSF) at CNDC are summarized in the following.

Photonuclear cross section

1. The first step is to extend the energy limits of the present theoretical calculation. The main theoretical codes utilized in our previous evaluation are GUNF and GLUNF. Because the reaction information is treated rigorously and the complexity increases rapidly with increasing incident energy due to the opening of more complex channels, it is difficult to develop them to a higher energy. Currently, the energy range for GLUNF for light nuclei is extended to incident photon energy 50MeV, and in GUNF, for middle-heavy nuclei, it remains at 30MeV. In order to calculate the data at higher energy, the MEND code, which is used for nuclear data evaluations up to 200MeV, is going to be employed in our study. At the same time, we shall also perform comparisons of our calculations with the results obtained with TALYS or EMPIRE cod. In conclusion, the evaluation of the experimental data will be performed in two parts: using GLUNF and GUNF for the lower energy region and MEND for the higher energy region.

2. The second step will be paid to review the nuclei with new available measurements, in particular to clarify the deviations among different evaluations and measurements. In addition to the evaluated libraries, we shall also consider evaluations performed by Varlamov et al, and other authors, and we shall also duly take into account the recommended corrections to the published experimental. Besides, the new version of GUNF will incorporate the function to evaluate the more fine-structured cross sections on discrete levels of each reaction, which will allow us to take more experimental data like (γ,γ') into our consideration. We have completed the survey of the literature and experimental databases for available experimental data for each nuclide. The next step will be to perform the evaluation as follows.

3. We have initially committed to evaluating the data of 12 isotopes including ^{9}Be, ^{50,52,53,54}Cr, ^{51}V, ^{91,92,96}Zr, ^{180,183}W, ^{209}Bi. In order to obtain good evaluations, the other stable isotopes belonging to the same elements above should also be evaluated simultaneously. Moreover, we are going to evaluate the light nuclei ^{6,7}Li, ^{10,11}B based on the new theoretical calculation and experimental evaluation available. The corresponding source codes for calculations of ^{6,7}Li, ^{10,11}B have been developed recently.

Photon strength functions
Our work will focus on theoretical calculations of PSF. The relativistic QRPA and other empirical formula will be used at the same time, and systematic calculations will be performed for most of the stable and unstable nuclei near to the β-stability line; meanwhile, the obtained PSF parameters will be utilized in the calculation of the photonuclear cross sections. The results will be compared with the results from HFB+QRPA (see Section 2.11).

2.7. E1 and M1 strength functions at low energy, R. Schwengner

Results of photon-scattering experiments using the γELBE bremsstrahlung facility [1] at the electron accelerator ELBE [2,3] of Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and using quasi-monoenergetic, polarized g beams at the HIγS facility [4] operated by the Triangle Universities Nuclear Laboratory (TUNL) in Durham, North Carolina, were presented.

To deduce photoabsorption cross sections at high excitation energy and thus high level density, unresolved strength in the quasicontinuum of nuclear states is taken into account. For this purpose, the spectrum of γ rays scattered from the target in atomic processes is simulated by using the code GEANT4 [5] and subtracted from the response-corrected experimental spectrum. The contributions of unresolved strength to the spectra are demonstrated for cases with high level density, ^{139}La [6], and with low density, ^{208}Pb [7], respectively.

In the analysis of the spectra measured by using bremsstrahlung at γELBE, simulations of statistical γ-ray cascades using the code γDEX are performed to estimate intensities of inelastic transitions to low-lying excited states [8]. In these simulations, level densities with parameters taken from Ref. [9] and a parity distribution of the level densities according to Ref. [10] are used. For the input strength functions, the phenomenological expressions provided by the RIPL-3 data base [11] are applied. It is shown that simulated average branching ratios of ground-state transitions are compatible with model-independent branching ratios obtained from spectra measured by using monoenergetic γ beams at HIγS [8,12], which serves as a proof of the simulations. Absorption cross sections are deduced by applying the simulated average branching ratios of the ground-state transitions.

Electric dipole (E1) strength in the energy region of the pygmy dipole resonance (PDR) is discussed for nuclides around A = 90 [13-21], for ^{114}Cd [22], for nuclides around A = 130 [6,8,23], for ^{181}Ta [24] and for ^{196}Pt [25].

Magnetic dipole (M1) strength in the region of the spin-flip resonance is considered for ^{90}Zr [26] and for ^{128,134}Xe [12] on the basis of experiments at HIγS.

The low-energy upbend of dipole strength functions, observed in various experiments, has been described in shell-model calculations as caused by many M1 transitions between close-lying states generated by recoupling the proton and neutron spins [27,28]. Recent shell-model calculations of E1 strength functions for ^{44,46}Ti [29] revealed that the contribution of E1 strength to the low-energy upbend is negligible. All calculations have been done for a few nuclides near shell closures so far. To study the development of the low-energy M1 strength with increasing deformation, large-scale shell-model calculations for a series of Fe isotopes using the code NuShellX [30] were performed. It is shown that the low-energy enhancement of the M1 strength gets weaker with increasing nuclear deformation while a bump developsaround a γ-ray energy of 3 MeV, in the energy region of the scissors mode.

E2 strength functions calculated within the shell model show a bell-like shape at very low energy [31]. This is in contrast to the description by a Lorentzian recommended in RIPL-3 [11], which decreases toward low energy, but produces an unphysical pole at $E_\gamma = 0$.

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2.8. M1 photon strength function and capture cross section for deformed nuclei, T. Kawano

A recent systematic study on the M1 photon strength function in the fission product and actinide regions, with a particular focus on the relation between the nuclear deformation and neutron radiative capture cross section enhancement was presented. Statistical Hauser-Feshbach calculations with the width fluctuation correction for the capture process in the fast energy region are still unsatisfactory, in particular to obtain reasonably accurate capture cross sections. This is mainly due to relatively large uncertainties in the model parameters used: the level density, the parity distribution in the continuum, and the photon strength function. In Ref. [1], authors showed that the calculated neutron capture cross section for a deformed system strongly depends on the M1 scissors mode, although the amplitude of collective motion is expected to be small. This is indeed consistent with the fact that a global calculation of neutron capture in the fission product region by [2], where the target nuclei are often strongly deformed, tends to underestimate the experimental data. The M1 photon strength function corresponding to the scissors mode might play an important role in de-excitation of a compound nucleus, which impacts not only calculated capture cross sections, but also the gamma-ray spectra, the isomeric state production, and so on.

Starting with a global description of the E1 Giant Dipole Resonance in the generalized Lorentzian form, it was assumed that the underestimation of calculated capture cross section for deformed nuclei is mainly due to a missing M1 scissors mode. Instead of comparing the Hauser-Feshbach calculations with the experimental data directly, about a hundred evaluated capture cross sections at 100 keV in the fission product region were considered. The selected capture data are evaluated based on experiments. A Lorentzian shape was assumed for the M1 scissors mode, and the strength (width x peak cross section) was estimated by comparison with the data. Using the obtained relationship between the nuclear deformation and the M1 strength, capture cross sections were calculated and compared with experimental data. It was demonstrated that the M1 scissors mode could be very important to improve the prediction of capture cross sections. Comparisons of the average gamma width in a wide mass range were also shown, leading to the conclusion that the Hauser-Feshbach predictive capability can be significantly improved in the mass 150 - 200 region, as well as in the actinide region.

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2.9. Development of formats for a photon strength function database and evaluation of thermal neutron capture photon strengths, R.B. Firestone

Summary of photon strength definitions: Photon decay and photoabsorption strengths $f^{M,EL}$ are linked by the principle of detailed balance where, at equilibrium, each elementary process should be equilibrated by its reverse process. For γ-ray decay the strength is defined as $f^{M,EL}(E_\gamma) = \frac{\Gamma_\gamma \rho(E_\gamma, J^\pi)}{E_\gamma^3}$, where $\Gamma_\gamma = P_\gamma \Gamma_0$, Γ_0 is the level width, P_γ is the γ-ray transition probability, and $\rho(E_\gamma,J^\pi)=1/D_0$ is the level density. For γ-ray absorption the strength is defined as $f^{M,EL}(E_\gamma)=\frac{\sigma_\gamma^{E,ML}(E_\gamma)}{3(\pi\hbar c)^2E_\gamma}$ where $\sigma_\gamma^{E,ML}(E_\gamma)$ is the energy smoothed photoabsorption cross section. Theoretical photon strengths are commonly given by standard Lorentzian type models such as the Brink-Axel or by the single particle Weisskopf model and can be compared with experiment. Experimental measurements of photon strengths often depend on level density assumptions where two models, constant temperature and back-shifted Fermi gas, are often employed. These level density models may break down when details of spin and parity distribution are considered.

Photon strength database: The photon strength function database should be organized as a nuclear structure database of levels and gammas for each experimental dataset. Data records should be defined and stored in a spreadsheet for later conversion to XML, ENSDF and other dissemination formats. Datasets for each experiment need to specify A, Z, and experimental type, and transition data may be cross sections or relative/absolute intensities, possibly binned or for single transitions. Additional information on experimental level energies, widths, and multipolarities should be included. Data should be reported in both tabular are graphical presentations.

Primary γ-ray photon strengths: A library of individual transition photon strengths from the EGAF database will be provided for the CRP database. These strengths are defined as $f_\gamma=\Gamma_\gamma/E_\gamma^{2L+1}$ where $\Gamma_\gamma=\sigma_\gamma/\sigma_0$ is the capture state width, σ_γ is the primary γ-ray cross section from EGAF, and σ_0 is the total thermal neutron cross section from Mughabghab's Atlas [1]. The multipolarities of the primary γ-rays are often known because the J^π of the capture state and many final states are experimentally known. The complete, detailed photon strength to low lying levels is generally measured with these data. Average photon strengths can be determined by binning the strengths of transitions by energy, and the distribution of photon strengths can be compared to Porter-Thomas predictions.

Resonance data: A library of average resonance capture (ARC) data will be provided for the CRP database. These data sample an ensemble of transitions typically at 2- and 24-keV. They provide unique information on the relative E1, M1, E2,… photon strengths. These data will primarily be extracted from ENSDF for evaluation.

^{56}Fe(n,γ): The recent ^{56}Fe(n,γ) measurement determined a >99% complete ^{57}Fe decay scheme containing 448 γ-rays depopulating 98 levels and the capture state including 90 primary γ-ray transitions. These data will be discussed at the Statistical Properties of Nuclei Workshop at the European Center for Theoretical Studies (ECT*) in July. This dataset provides nearly complete information of the primary ^{57}Fe M1, E1 photon strengths down to very low energies. E1 strengths appear to follow Brink-Axel predictions while M1 transitions show a strong increase in strength at low energies. The strengths of secondary M1 transitions which showed constant photon strengths at all energies were also determined. This difference in M1 strengths appears to be associated with the observation that the primary M1 transitions are between negative parity states while secondary M1 transitions connect positive parity states. Preliminary shell model calculations by R. Schwengner confirm this difference. It was also determined that E1 and M1 photon strengths are independent of level energy although E2 strengths may have significant level energy dependence. The distributions of primary and secondary E1, M1, and E2 photon strengths were also compared and were found to be inconsistent with Porter-Thomas [2] predictions and more comparable to a chi-squared distribution with n=2.

Resonance level density: The ^{57}Fe resonance data is nearly complete $J^{\pi}=1/2^{\pm},3/2^{\pm},5/2^{+}$ levels. Each resonance spin/parity distribution was fit to the constant temperature mode $N(E) = \exp\left[(E - E_0)/_T\right]$, where *N(E)* is the sequential transition number for the transition of energy *E, T* is the "temperature", and E_0 is the energy of the first transition with the same spin/parity. It was found that the spin distributions deviated significantly from spin cutoff predictions and each spin corresponded to a different temperature. Nevertheless, the total level density measured with these data coincided with constant temperature model prediction using the parameters of von Egidy et al [3].

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2.10. Update of and measurement for the PGAA Data Library for Photon Strength Functions and development of prompt gamma-ray spectrum modelling, T. Belgya

In recent years, a lot of work was invested in measuring and modelling the low energy photon strength functions (PSF). A very active community was organized around this topic. Not only were experimental facilities developed, but new strength function models were discovered to explain certain features of the observed gamma-ray spectra.

In the presentation a comprehensive introduction to the Budapest Research Reactor (BRR) and the Prompt Gamma Activation (PGAA) and Neutron Induced Prompt-gamma Spectroscopy (NIPS) facilities [1] was given. These facilities can provide high quality and high resolution gamma-ray spectra that can be used to test the current statistical decay models and strength functions.

The method used to obtain partial gamma ray cross sections from (n,γ) experiments was subsequently presented in detail to highlight the type of direct data that can be provided to the CRP for testing and validating PSF. This was followed by the description of the current PGAA data library [2, 3] that will be updated with the recent measurements and with those planned to be measured within this CRP.

The measurements performed at the BRR are new, high-statistics measurements of gamma-ray spectra produced by radiative capture reactions on ^{232}Th and ^{238}U samples. Once the spectra are obtained, they are unfolded [4] and normalized to the previously measured partial gamma-ray production cross sections (briefly partial cross section). This provides a firm data set for modelling the radiative capture gamma-ray spectra and can help in the development of the required low-lying decay scheme. This later process is very time consuming, but can add important updates to the decay schemes used in nuclear model calculations.

The treatment of the measured data was also presented in detail using the example of the recently measured neutron capture gamma-ray spectrum of $^{113}Cd(n,\gamma)^{114}Cd$. In this treatment the unfolding procedure was based on the Oslo prescription for ^{114}Cd [4], which yields an absolute gamma-ray spectrum that is suitable for testing various models including those under development in the BRR laboratory. The result of such an unfolding is shown in Fig. 1. It is clearly shown that a large part of the spectrum peaking at about 2.5 MeV in the 0 to 6 MeV range cannot be resolved. It consists of a continuum under a large number of resolvable peaks, which represents a substantial part of the total intensity of the whole spectrum. Below a few tenths of a barn the unfolding has large uncertainties.

For the understanding/analysis of the shape of this spectrum a new bin type statistical model (called BITS) is under development. Preliminary results for the description of the spectrum were presented. The best description could be achieved with the inclusion of low energy enhancement, in addition to the TLO E1 and RIPL M1 and E2 strength function prescriptions.

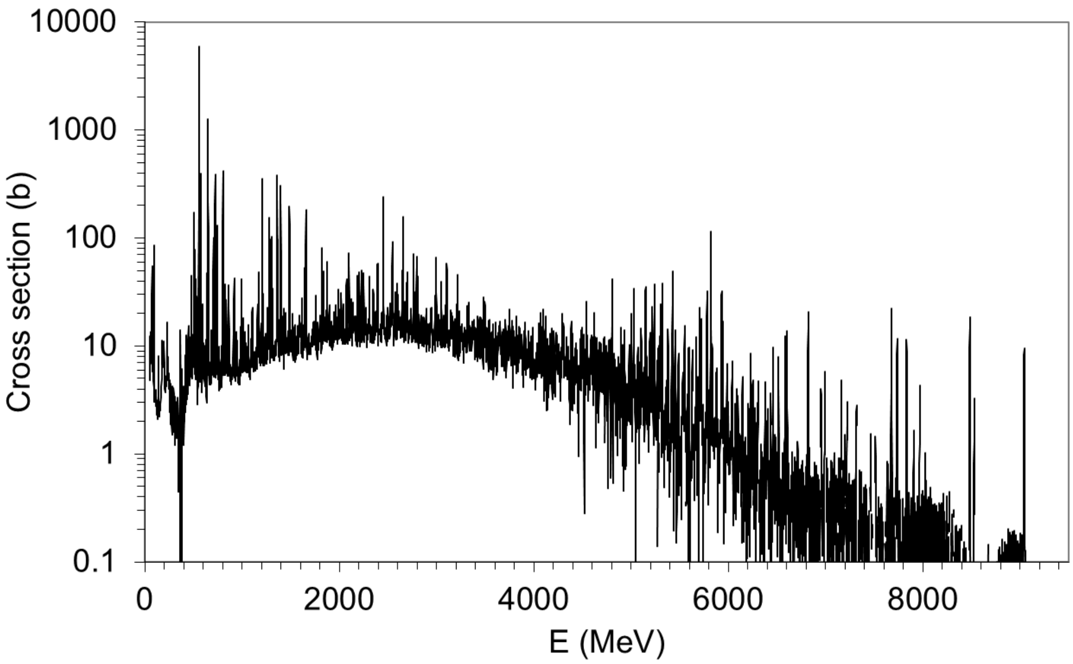

FIG.1: ^{114}Cd absolute intensity spectrum from ^{113}Cd radiative capture reaction.

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2.11. Microscopic description of the photon strength function, S. Goriely

The photon strength function remains one of the fundamental ingredients in reaction theory and has been traditionally estimated within the Lorentzian representation of the giant dipole resonance. Microscopic approaches, such as HFB+QRPA, are usually not used for practical applications or data evaluation, because of the numerical difficulty associated with large-scale predictions and the fine-tuning of the model required to reproduce accurately experimental data set. We propose to describe the experimental photon strength function compiled in the present CRP on the basis of QRPA calculations. Both large-scale Skyrme-HFB + QRPA [1] and Gogny-HFB + QRPA [2] calculations of the E1 photon strength function have been performed and shown to be able to describe relatively well photoabsorption data, in particular the correct peak energy and width of the giant dipole resonance (GDR), after inclusion of some phenomenological corrections. Such corrections are needed to take into account the effects beyond the standard 2-quasiparticle QRPA excitations and the coupling between the single-particle and low-lying collective phonon degrees of freedom.

Skyrme-HFB + QRPA calculations have been obtained in the spherical approximation and deformation effects phenomenologically included to properly describe the splitting of the GDR. The Skyrme-HFB + QRPA calculation originally based on the BSk7 interaction [1] has now been re-estimated on the basis of the more recent BSk27 interaction. Both interactions give relatively similar predictions. The folding procedure to correct effects beyond QRPA includes only one parameter, i.e. the so-called interference factor introduced in Eq. 18 in Ref. [1], which has been adjusted to reproduce at best the experimental photoabsorption cross sections of spherical nuclei.

In the case of the Gogny-HFB + QRPA, the calculations have been performed essentially with the D1M interaction, and three prescriptions proposed for the folding correction procedure. Two of these prescriptions assume that the energy shift depends on the energy-dependent number of 4-quasiparticle states, a property that significantly improves the description of GDR data. The parameters for each of these prescriptions have been adjusted to reproduce experimental photoabsorption data at best for each nucleus separately [2]. For nuclei without experimental data an interpolation of such parameters is proposed. Similarly, at present, calculations have been made only for even-even nuclei and an interpolation procedure applied to odd-A and odd-odd nuclei. The Gogny-HFB + QRPA is an axially-symmetric deformed calculation and consequently includes deformation effects self-consistently.

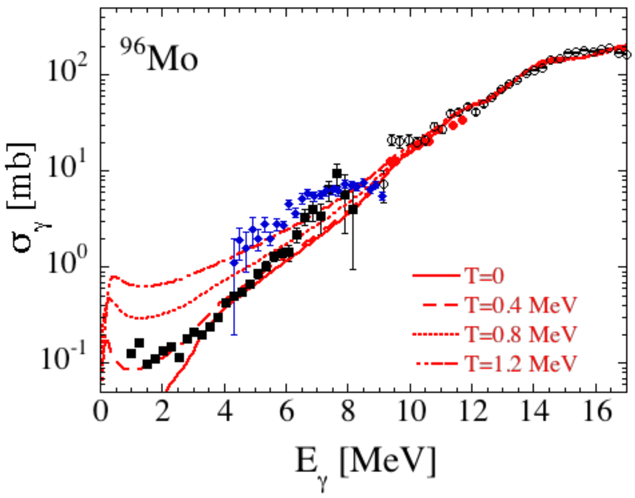

FIG.1: Temperature effects on the ^{96}Mo Skyrme-HFB + QRPA E1 strength function.

For the de-excitation E1 strength function, a temperature-dependent correction factor taken from the theory of Fermi liquids [3] is introduced in the expression of the GDR width to take the collision of quasiparticles into account, in a similar way as done for empirical models. This factor reads $\Gamma=\Gamma_0$ x $[1 + 4\pi T^2/E_\gamma]$. Figure 1 illustrates in the specific case of ^{96}Mo the impact of such a temperature-dependent factor on the E1 strength function. In particular, an enhancement of the strength at very low energy can be described provided of course this upbend is of E1 character.

M1 strength: The same axially symmetric deformed Gogny-HFB + QRPA model has been applied to the estimate of the M1 strength function. We adopt the same phenomenological corrections for the M1 strength as the one adopted for the E1 strength in the simple Model 0 of Ref. [2], i.e. a systematic energy shift of -2 MeV and a Lorentzian broadening with a width ranging between 0.5 and 2.5 MeV. A first comparison with existing experimental data for ^{106}Pd is shown in Fig. 2 to be quite encouraging. The scissors mode at low energy is also seen (Fig. 2) to be naturally described in the deformed QRPA calculation by the K=1+ component. Such a scissors mode obtained within the QRPA framework is found to affect significantly the <Γγ> estimate, as discussed by Kawano in the present meeting in the framework of an empirical Lorentzian model. The Gogny-HFB + QRPA predictions of the M1 strength will be studied more systematically, compared with available experimental data and made available for the CRP.

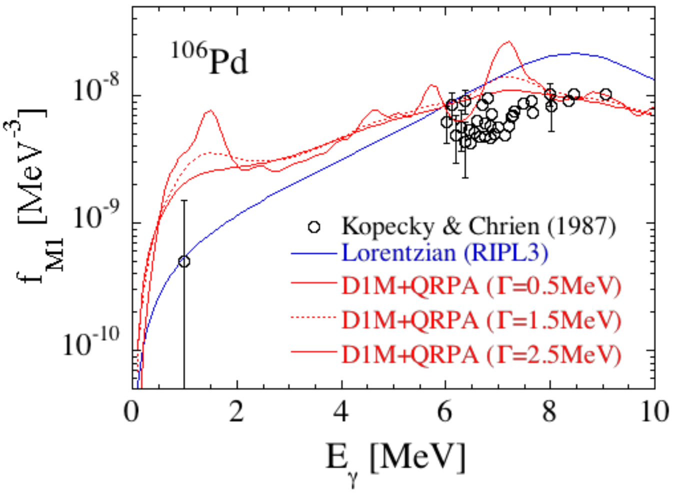

FIG.2: Gogny-HFB + QRPA prediction of the ^{106}Pd M1 strength function.

For the present CRP, both the Skyrme- and Gogny-HFB + QRPA strengths will be used to fit (or evaluate) experimental E1 and M1 photon strength functions, but also to predict them for nuclei for which data is not available. A full library of E1 and M1 strength functions for a few thousands nuclei of interest in nuclear applications will be developed.

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2.12. Improvements and testing practical expressions for photon strength functions of E1 gamma-transitions, V.A. Plujko

The closed-form description of the E1 PSF was presented which allows for the nuclear response of two nuclear states – the low-energy state (pygmy dipole resonance, PDR) and the isovector electric giant dipole resonance (GDR). The analytical expression for the nuclear response function $\chi(\varepsilon_\gamma)$ is taken from the model of two coupled damped oscillators [1]:

$$\chi(\varepsilon_\gamma) = P(\varepsilon_\gamma; GDR, PDR) + P(\varepsilon_\gamma; PDR, GDR)$$

with

$$P(\varepsilon_\gamma;k,l)=\frac{z_k{}^2+\dfrac{z_k z_l i\varepsilon_\gamma \gamma}{E_l^2-\varepsilon_\gamma{}^2+i\varepsilon_\gamma(\Gamma_l+\gamma)}}{E_k^2-\varepsilon_\gamma{}^2+i\varepsilon_\gamma(\Gamma_k+\gamma)+\dfrac{\gamma^2\varepsilon_\gamma{}^2}{E_l^2-\varepsilon_\gamma{}^2+i\varepsilon_\gamma(\Gamma_l+\gamma)}},$$

where E_k,Γ_k and z_k are the energy, width and contribution of the *k* state, respectively; γ is the coupling parameter between the two excitation modes.

A general expression [2-4] relating the PSF and the imaginary part of the electromagnetic response function is used. In the case of independent modes ($\gamma = 0$), this expression corresponds to the model of two independent Lorentzians.

The proposed PSF model approximating the response of two coupled excited states to the E1 field (TSE model) is fitted to the experimental data on photoabsorption cross-sections for tin isotopes ^{130}Sn , ^{132}Sn [5]. The parameters and chi-square deviations of the theoretical calculations from experimental data are determined. The fit using the TSE model gives a smaller value of the chi-square deviation in comparison with calculations assuming independent modes. So, the proposed approach can be considered as a simple practical method both for the description of the PSF with excitations of low-energy and high-energy states and for studying the coupling between these states. It will be used in the analysis of all recent experimental data on the E1 PSF.

A revision of the tables of GDR parameters of Ref. [4] including uncertainties was presented. These new parameters were obtained from fitting photoabsorption cross sections near the GDR range to updated experimental and estimated data using the SLO&SMLO models (files: *ivgdr_slo_exp.dat*; *ivgdr_mlo_exp.dat*). These parameters can also be used as a first approximation in the TSE approach. A draft table of experimental parameters for PDR compiled from different articles has also been prepared (*pdf_exp-draft.dat*).

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2.13. Photon strength functions below the separation energies: challenges and opportunities, M. Wiedeking

An incredible wealth of information can be obtained from experimental investigations of the low-energy tail of the Giant Electric Dipole Resonance. The Photon Strength Function (PSF), which represents the ability of nuclear matter to absorb and emit photons, is one of the quantities that can be successfully used to extract information in the region of the quasi-continuum. However, it is becoming increasingly apparent that no single measurement can provide sufficient insight to fully understand the observed features of the PSF. Instead, most of the knowledge of the underlying nuclear structure is obtained by combining results from several experimental approaches and techniques. Over the last decade, significant experimental effort has been invested to study the gamma-ray decay from the region of high-level density below the particle separation energies at many laboratories worldwide. Collaborative measurements have taken place, selecting specific nuclear systems and extracting the PSF with several experimental methods or beam/target combinations.

In the presentation, the differences observed in the PSF obtained from different measurements [1,2,3] were discussed. In particular the following four issues and their potential impact on data evaluation were addressed:

1) Do different experimental techniques yield the same results?
2) Do different reactions give the same PSFs?
3) Are data sets always properly normalized?
4) Are all sources of uncertainties properly treated?

The presentation focused on the experimental data available for the ^{74}Ge and ^{95}Mo isotopes. These two isotopes have been the subject of several collaborative studies including several institutes, therefore they are excellent cases to investigate consistencies and/or differences between the different measurements. How this effort can be extended within the CRP and lead to assessment and evaluation of the data was also discussed:

For ^{74}Ge three PSF data sets are already available from the reactions ^{74}Ge(γ,γ') [4], ^{74}Ge(^{3}He,^{3}He') [5] and ^{74}Ge(^{4}He,^{4}He') [6], as a result of an international effort including several institutes. The different data were compared and the inconsistencies were discussed. The discussion focused on the availability of "old" data obtained using previous generations detection equipment versus "new" data obtained with advanced modern detection systems, and the impact on conclusions drawn which may depend on the completeness of the data. Issues related to data evaluation, such as (1) whether data obtained from (γ,γ') reactions and from hadronic probes can be expected to be in agreement; and (2) the impact of matching data from different measurements were also addressed.

For ^{95}Mo the discussion focused on (1) the Ratio Method to determine the PSF [7], (2) the spin dependence of gamma and neutron widths near the separation energy [8], and (3) the comparison of ^{95}Mo data with models which reproduce data from other techniques [9]. Some of the issues that were raised are as follows: i) not all measurements may extract the same information, ii) the normalization of data sets may depend on features such as angular momentum barrier effects, iii) uncertainties may not always be properly considered, and iv) all previous points have implications for the evaluation of the PSF data.

It was emphasized that ideally all possible measurements are performed on a given nucleonic system to obtain and understand the "global" PSF. While for ^{74}Ge and some Mo isotopes a variety of measurements is available, there is a need to identify other nuclei across the nuclear chart as possible test cases on which the community can focus both experimental and theoretical efforts to improve our understanding of the PSF and underlying resonance features.

New measurements and analyses related to this CRP are proposed for ^{74}Ge using the Ratio Method which is a completely independent technique from the other three analyses already performed. Hence, this proposed measurement will provide another unique set of data to enhance our understanding of the PSF in ^{74}Ge. Furthermore, measurements on the isotopes ^{180,181,182}Ta will be analysed with the Oslo Method. Quasi-continuum states in these Ta isotopes are populated through several reactions. In particular, ^{181}Ta will be populated in three different reactions (^{3}He and deuteron beams and two different energies for the deuteron reaction) which will in turn provide three independent data sets for ^{181}Ta, two for ^{180}Ta and one for ^{182}Ta. This effort will provide information on the independence of the PSF on charged particle reactions. Additionally, the PSF from (γ,γ') data is already available for ^{181}Ta from the ELBE facility [10] which will facilitate the comparison between techniques.

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2.14. Computer code DICEBOX and gamma-ray strength functions from coincidence measurement of photons emitted in radiative neutron capture, M. Krticka

The presentation was divided in two parts. In the first part, the experiments used for obtaining the coincidence spectra of gamma rays from radiative neutron capture, which can be used for obtaining information on the γ ray photon strength functions (γSF), were introduced. Specifically, two experiments were described in detail: (i) multi-step cascade (MSC) spectra following neutron capture on isolated resonance measured using 4π BaF_2 highly-segmented detector, and (ii) two-step cascades (TSC) spectra following thermal neutron capture measured with two Ge detectors. The MSC spectra have been obtained using the DANCE detector at Los Alamos. There are several other facilities which might provide these spectra in the future. The measurements of TSC come mainly from the measurement at the reactor at Rez near Prague.

Information on γSF can be obtained only from comparison of experimental spectra with outcomes from simulations. Experimental data for several nuclei in rare-earth and Mo regions have been shown. A wealth of information on the scissors mode has been obtained for rare-earth nuclei. MSC data for Gd isotopes indicated that there is an odd-even mass dependence of the scissors mode strength. In the case of ^{96}Mo and ^{98}Mo, the spectra from both TSC and MSC experiments are inconsistent with an existence of a strong low-energy enhancement of γSF observed in reactions using charged-particle projectile. It has been stressed that the coincidence data from radiative neutron capture cannot give direct information on the absolute value of γSF. On the other hand, the data are sensitive to the energy dependence of γSF and in some cases there is also sensitivity to the transition type – for instance, the resonance near E_γ=3 MeV in well-deformed rare-earth nuclei has been proved to be of M1 type in these experiments. As a result, the resonance surely corresponds to so-called scissors mode.

The above results from these coincidence γ ray spectra were obtained from comparison with simulations. The simulations consist of two steps: (i) generation of γ decay within the statistical model of nucleus, and (ii) simulations of detector response to simulated γ cascades.

The GEANT4 based code has been used for simulation of the DANCE detector response, which is very complicated. The detector response relevant for the TSC experiment is significantly simpler and the knowledge of the peak and total efficiency of used Ge detectors is sufficient. The γ cascades have been generated using the DICEBOX code.

The second part of the presentation was devoted to the introduction of the DICEBOX code. This Monte Carlo code generates the γ decay of the nucleus. In the past it has been used especially for generating cascades from individual neutron resonances and thermal neutron capture. In addition, it has also been used for several studies of γ decay based on the nuclear resonance fluorescence experiments and cascades produced with the code were also used in testing the Oslo method. The algorithm of the DICEBOX code allows correct treatment of Porter-Thomas fluctuations of individual γ transitions and, as a result, correct assessment of the uncertainties inherent to the γ decay. There are many quantities which can be obtained from the simulation of γ cascades as information on properties of all levels, which are hit in each cascade (level energy, spin and parity), as well as on each transition (type, multipolarity, mixing ratio) is available.

The IAEA Consultants Meeting [1] proposed to make the DICEBOX code available to the public. This is the scope of the proposed research project – “Dissemination of the DICEBOX Code for Analysis of γ-Ray Data”. To achieve the goal of the project, several different versions of the code – which differ in the “definition” of initial state – will be integrated into one final version. In addition, the relevant documentation and description of the code will be prepared before the program dissemination.

Reference

[1] INDC(NDS)-0649 Summary Report of the Consultants' Meeting on Compilation and Evaluation of Reaction Gamma-ray Data, IAEA, Vienna, December 2013.

2.15. Photon strength function measurements at the Oslo cyclotron, S. Siem

In Oslo a unique technique to extract simultaneously the level density and photon strength function from primary γ-ray spectra has been developed. An overview of the method and the results was given. One such example is the unexpected increase in the photon strength function for low energy gammas that has been observed. This has been shown to strongly increase the neutron capture cross sections if also present in neutron rich nuclei. Therefore the Oslo method was further developed to study more exotic neutron rich nuclei, by inverse kinematics experiments and the β-Oslo method. Another application of photon strength functions is in cross section calculations, which are used as input in reactor simulations. In Oslo a huge scissors mode resonance has been observed in several actinide nuclei that have been measured. This scissors mode can lead to an increased neutron capture cross section and should be included in new libraries used as input into reactor simulation codes. Photon strength functions have been measured by several different experimental groups using different experimental techniques. Having all these data compiled together in one user-friendly database (which is one of the goals of the CRP) would be very useful for the community.

To address the above data needs, the University of Oslo plans to compile all the photon strength function data measured at the Oslo Cyclotron Laboratory (including among others isotopes from Fe, V, Sc, Ge, Y, Mo, Pd, Sn, La, Sm, Er, Yb, Dy, Au, Pb, Np, Th, U and Pu) in a format suitable for inclusion in the CRP database. New measurements of photon strength functions for Ni, Sm, Nd and actinide nuclides will also be performed for inclusion in the CRP database.

Finally, soon the Oslo Cyclotron Laboratory will have an array of 30 large volume LaBr3 detectors (OSCAR), which will make possible new and even better measurements of the photon strength function.

3. Technical Discussions

In the following we present a summary of the discussions that ensued regarding the specific objectives and technical aspects of the proposed program of work within the CRP. Some of the discussions led to the assignment of additional tasks which were deemed necessary in order to achieve the goals of the CRP. Working groups led by CRP participants were formed to deal with the agreed tasks.

3.1. Photonuclear Data Library

3.1.1. Content of library

The existing IAEA Photonuclear Data Library, which was the result of a CRP from 1996 to 1999 [1.1] included 164 nuclei which were identified as important for applications such as radiation shielding design and radiation transport analyses, dosimetry calculations for medical applications, physics and technology of fission and fusion reactors, safeguards and inspection technologies, nuclear waste transmutation and nuclear astrophysics. The list of 164 nuclides comprises the major isotopes of the following list of important structural, shielding, bremmstrahlung, biological, fissionable materials:

- structural, shielding and bremmstrahlung target materials:
  Be, Al, Si, Ti, V, Cr, Fe, Co, Ni, Cu, Zn, Zr, Mo, Sn, Ta, W, Pb
- biological materials:
  C, N, O, Na, S, P, Cl, Ca
- fissionable materials:
  Th, U, Np, Pu
- other materials: an additional 124 isotopes were evaluated comprising the following materials H, K, Ge, Sr, Nb, Pd, Ag, Cd, Sb, Te, I, Cs, Sm, Tb.

All the above 164 nuclides will be revisited and updated in this new CRP, to take into account new experimental data and new evaluations of these data on the basis of the correction function method developed by Varlamov et al (see below, Sect. 3.1.4).

In addition, 37 isotopes that were not considered in the previous CRP, but for which experimental data have become available, will also be evaluated. These are the isotopes of the following elements:

- new materials:
  H, He, Li, B, C, F, Sc, As, Se, Y, Rh, In, La, Ba, Ce, Nd, Eu, Tm, Gd, Lu, Os, Np

An effort should be made to address specific user needs in this CRP, e.g. Isotope production - ^{39}K; IRDFF; Medical applications - e.g ^{195m}Pt; Isomer production; Gamma resonance technology - e.g ^{14}N

Action on IAEA, Kawano: prepare a preliminary list of top priority nuclides for which photonuclear cross-section data are required for applications (including nuclei in the list mentioned above) by 12/2016. The complete list will be made available by the 2nd RCM.

3.1.2. New measurements

Coordinator: Utsunomiya

New measurements of (γ,xn) cross sections will be performed within the CRP by the Phoenix collaboration (see section 2.1) at the NewSUBARU synchrotron radiation facility in Japan. The measurement campaign will last throughout the CRP and will produce new partial photonuclear cross sections by means of the direct neutron-multiplicity sorting method. The target nuclei and timeline of the measurements are listed in Appendix 2.

Action on Utsunomiya, Filipescu: collect the new measurements when they are ready for publication and submit to IAEA for distribution among evaluators and inclusion in the EXFOR database.

3.1.3. Compilation of data

Coordinator: Dimitriou
Since the previous IAEA CRP (1999), there's been a significant effort to incorporate the existing published photonuclear cross-section data in EXFOR [3.1]. However, many data may still be missing from EXFOR, so in order to help evaluators have easy access to all available published data, participants agreed to the following:

Action on Dimitriou (IAEA): investigate the completeness of the EXFOR database with respect to photonuclear cross-section data (with special emphasis on data published in the periods after 2000 and before 1975) and report back to the CRP by 06/2017.

Action on evaluators (Cho, Xu, Varlamov, Kawano, Iwamoto, Filipescu): send references of published photonuclear data to Dimitriou (IAEA) for inclusion in EXFOR (continuous throughout CRP). In case of data corrected by evaluators, data (and references) will be sent to IAEA with additional explanations about corrections. The IAEA will then make this information available to the other evaluators of the CRP.

3.1.4. Correction of data using F_i factors

Coordinator: Varlamov
The method of checking the reliability of and correcting partial photo-neutron cross-section data by means of correction factors developed by Varlamov et al (see Section 2.2) was discussed at length. Participants suggested a more thorough investigation of the uncertainties of the correction factors. For the purpose of updating and evaluating the photonuclear data, it was agreed that all existing corrected data should be distributed to photonuclear data evaluators as they become available. In more detail:

Action on Varlamov: provide the IAEA with the list of EXFOR entries of available corrected photo-neutron cross-section data for $^{91,94}Zr$, ^{115}In, ^{116}Sn, ^{159}Tb, ^{181}Ta, ^{197}Au, ^{208}Pb targets.

Additional photo-neutron cross-section data will be evaluated in 2016: $^{63,65}Cu$, ^{133}Cs, ^{141}Pr, ^{80}Se, ^{89}Y, ^{138}Ba. More evaluations/corrections using the F_i factor method will be performed in 2017-2018 but the nuclides are yet to be determined.

Action on Varlamov: Provide new corrected data on $^{63,65}Cu$, ^{133}Cs, ^{141}Pr, ^{80}Se, ^{89}Y, ^{138}Ba to the IAEA and CRP evaluators by 09/2016. Subsequently, provide new corrected data as they become available to the IAEA for distribution among CRP evaluators. (Continuous action)

A more detailed estimate of energy-dependent uncertainties on the F_i factors will be performed for the ^{181}Ta test case. The uncertainties will include the sensitivity to model inputs as well as reaction models. Calculations of the Fi factors will be performed by Iwamoto (CCONE), Kawano (CoH3), Dimitriou (EMPIRE), Goriely (TALYS), Xu (GUNF), Varlamov (CMPNR).

Action on Kawano: to coordinate the above sensitivity study and report on the progress by 09/2016 (at ND2016 conference).

3.1.5. Evaluation of photonuclear data

Coordinator: Kawano

The specifics of the evaluations of the photonuclear cross-section data were discussed at length. The main characteristics of the new evaluations to be performed within the CRP were agreed as follows:

- The energy range will be extended up to 200 MeV for all new evaluated files, where feasible. Some evaluations may be kept up to 140 MeV (or 30 MeV for actinides) if the evaluations are taken from 1999 Photonuclear Data Library, or if the codes used in the evaluations are limited in energy range up to 30 or 50 MeV.
- For specific light nuclei for which gamma resonance studies exist and data on experimental resonances are available (gamma resonance technology), point-wise experimental resonances should be included in the evaluated data files (ENDF-6) by hand.
- Evaluators will have to consider the corrected photonuclear cross-section data if they have been made available by Varlamov et al (a list of EXFOR entries will be distributed, and all the upcoming corrections will be flagged in the final table of photonuclear cross-section evaluations by Dimitriou (see Appendix 1).
- Details of the modelling used for each evaluation will be provided in the descriptive part of the ENDF-6 file (MF=1; MT=451).
- Deliverables of the evaluation: partial cross sections, particle spectra in ENDF6 format (MF=3 or 6). For this purpose, the MSU (Varlamov) evaluation will be converted into ENDF-6 format in collaboration with IAEA, while the ELI-NP evaluation will provide ENDF-6 files to Kawano for validation.
- The timeline for delivering the evaluation will be according to contracts and agreements.
- Other evaluated library files (JENDL, CENDL, LANL, BOFOD, EPNDL, KAERI, TENDL) will also be made available through the database.
- Based on ENDF-6 files, IAEA will generate human-readable ascii files that will be made available on the Photonuclear Data Library as well.

A complete list of the photonuclear data that will be re-evaluated along with the responsible persons is presented in Appendix 1.

Certain issues in the modelling of the pre-compound component were raised by Kawano. The fact that the commonly used multistep compound scattering models and exciton model enhance the absorption of incident photon in the 2p1h doorway states compared to 1p1h or 2p2h initial doorway states may result in an overestimation of the pre-equilibrium cross section at higher emission energies. This may also impact the determination of the correction F_i factors (See Sect. 3.1.4). The need for further investigation into these modelling aspects was agreed.

Action on Kawano: to explore the effect of over-enhancement of absorption of incident photon flux into 1p1h states for two test cases (one light and one heavy nucleus) will be worked out by Kawano. Discussion with code developers will take place at the ND 2016 meeting and the results will be disseminated among all the CRP evaluators.

The new evaluations and ENDF-6 files will be reviewed by an expert committee that will be formed for this sole purpose. The committee's first meeting will take place after the end of the first contractual year of the CRP when the first evaluated files are due to be submitted to the IAEA. The review committee will be coordinated by Kawano.

Action on Iwamoto: to send plots with comparisons of new JAEA and existing IAEA Photonuclear Data Library evaluations to Dimitriou (IAEA) by 12/2016 for uploading on the CRP web site [3.2].

Once the new evaluated photonuclear cross-section data become available, the following activities will also be undertaken:

- The Atlas of GDR parameters will be updated by Varlamov and Plujko.
- Photon Strength Functions (PSF) will be extracted from the total photo-neutron/ photoabsorption cross section, Coordinator: Plujko
    - timeline for delivery into PSF database will follow the schedule for the evaluation/correction procedure (see above)
    - energy range and error bars will be provided
    - Extracted PSF will be compared with different models (MLO, TLO, QRPA).
        - QRPA tables will be made available by Goriely
        - TLO input parameters (in particular deformations) will be provided by Schwengner.

3.1.6. Dissemination of photonuclear data

Coordinator: Dimitriou
The evaluated photonuclear data will be disseminated to the user community through a new user-friendly retrieval interface. The specifics of this retrieval interface were discussed and the following was agreed:

- Search criteria will be introduced;
- Plotting capabilities will be provided allowing the user to compare experimental data from EXFOR with available evaluations from different libraries, as well as with user provided calculations (different options will be investigated by the IAEA);
- Downloading of data in ENDF-6 format will be maintained;
- Downloading of data in ascii files (X Y tables) will be introduced for easy use by the broader user community.

Action on Dimitriou (IAEA): propose a preliminary web interface by the time of the 2nd RCM.

3.2. Photon Strength Function

Following the detailed discussions on the updating of the Photonuclear Data Library, participants focussed on the second part of the CRP, the generation of a dedicated database for Photon Strength Functions (PSF).

The new database will include experimentally extracted PSF, accompanied with detailed information on the methods used to extract them, the normalizations and uncertainties involved, as well as theoretical and empirical PSF, assessments and recommendations in cases where the different data differ. Efforts will also be made to validate the measured and calculated PSFs using the thermal neutron capture spectra and Multi-Step Cascade methods. A summary of the technical discussions and resulting assignments is given in the following sections.

3.2.1. New measurements

Coordinator: Wiedeking
New measurements of PSF will be performed to enrich the PSF database and provide data for comparison with existing models. The experimental techniques that will be used have been discussed in detail in Ref. [1.5]:

- Photon scattering (NRF)
- Charged-particle reactions (Oslo method, Ratio method)
- Neutron capture reactions
- Photonuclear absorption

The groups that will be performing the measurements are listed in Appendix 2 along with the nuclides that will be measured and the expected delivery time.

Action on Wiedeking: send new data to Dimitriou (IAEA) in a simple format (cf section 3.2.2 below).

3.2.2. Compilation of all existing and new PSF data with error bars

Coordinator: Dimitriou
Apart from the new experimental data on PSFs, all existing data will also be collected and compiled in the PSF database. The following participants were assigned the responsibility of collecting the data produced at various facilities using different techniques:

- Elbe & Higs (Schwengner)
- Oslo (Siem) – look into reviewing the model-dependent uncertainties in their measured data
- iThemba, Darmstadt (Wiedeking)
- ARC, EGAF (Firestone, Kopecky)

Action on Firestone, Kopecky, Schwengner, Siem, Wiedeking: to send the collected data to P. Dimitriou (IAEA) in a simple format as described below by 12/2016.

Specifications of PSF data files

- Proposed name of the PSF files: f1/fe1/fm1_exp/the_zzz_aaa_comment.dat
- Each PSF data file will include PSF for a given multipolarity (E1 and M1 in different files) with a 4-line header :

  #Z,A, Energy range, number of columns,

#explanation of columns, E1/M1/E2/M2/Total,
#author of the file,
#title line "E dE f df"

- Proposed data format to be adopted in all PSF data files:
  (E, dE, f, df) in the fortran format 2f10.3,1p,2e12.3
- Each PSF data file will be accompanied by
  1) a readme file on how PSF was extracted (measurement technique, normalisation details, analysis method, references….) and
  2) an extra file, if needed, with additional experimental data.

For the different measurement techniques, the readme file and extra file will contain the following information:

- Photon scattering experiments:
  1. readme file: description of the continuum correction, branching ratios included in the corrections, uncertainties.
  2. Additional data file: integrated cross sections, parities of resolved states.
- Oslo method:
  1. readme file: s-wave spacing and total NLD at neutron binding energy, maximum spin, $<\Gamma_\gamma>$ used for normalization, treatment of theoretical, statistical and systematic uncertainties.
  2. Additional data file: level density corresponding to the PSF.
- Ratio measurements (iThemba):
  1. readme file: uncertainties, normalization per energy interval, branching ratio information.
  2. Additional data file: None.
- Proton inelastic (Darmstadt) – to be investigated by Wiedeking.
- ARC data (the main PSF file will include E1/M1 ratios in bins or normalized strength by a method that still needs to be confirmed. **Action** on: Firestone & Krticka):
  1. readme file: uncertainty treatment; filter; normalisation of the data.
  2. Additional data file: σ_γ or P_γ transition and multipolarities.
- EGAF (the main PSF file will include average strength in bins by a method that still needs to be confirmed. **Action** on: Firestone and Krticka):
  1. readme file: uncertainty treatment; width of the capture state.
  2. Additional data file: individual transition strength with multipolarities.

Proposed name of the readme file:
f1/fe1/fm1_exp/the_zzz_aaa_comment.readme

Proposed name of the additional file:
f1/fe1/fm1_exp/the_zzz_aaa_comment.add

Action on Dimitriou (IAEA): Send samples of these files to the CRP participants by 10/2016.

Action on Belgya: Explore possibility of extracting relative PSF from thermal capture data by 2nd RCM.

3.2.3. Assessment of data/techniques and recommendations

Coordinator: Siem

Obvious discrepancies exist between the PSF data extracted from the different experimental techniques. One of the main objectives of this CRP is to try to understand the reasons for these discrepancies by performing in-depth assessments of the different techniques. The ultimate goal is to recommend reliable PSF data both below and above the neutron threshold. To achieve these goals, CRP participants agreed to the following actions:

- Model-dependent uncertainty analysis will be performed on both the NRF and Oslo method for the test case of ^{89}Y by 12/2016 – **Action** on: Schwengner, Siem.
- Subsequently, existing NRF and Oslo data for ^{74}Ge, ^{96,98}Mo, ^{139}La, ^{181}Ta, ^{196}Pt will be assessed with full uncertainty analysis. PSF data will be recommended with error bars by 2nd RCM – **Action** on: Schwengner, Siem, Wiedeking.
- PSF shape extracted from the Oslo and Ratio methods will be compared for ^{74}Ge similarly to what was done for ^{95}Mo by 12/2018 – **Action** on: Wiedeking, Krticka.
- Validation of the assessed and recommended PSF will be performed by Multi-Step Cascade method for the cases of ^{96,98}Mo including a full uncertainty analysis of the Nuclear Level Density models by 2nd RCM – **Action** on: Krticka.
- Compatibility of thermal capture, NRF & Oslo PSF data for the case of ^{196}Pt will be checked by 2nd RCM – **Action** on: Belgya.
- Compatibility between recommended PSF and the extracted one from photonuclear data will be studied as soon as the corresponding PSF below and above threshold is made available to the CRP by 2nd RCM – **Action** on: Siem and Plujko.
- An update on experimental evidence for the multipolarity of the low-energy upbend will be given at the 2nd RCM – **Action** on: Wiedeking.
- The spin dependence of PSF-related observables will be investigated by 2nd RCM – **Action** on: Krticka and Firestone.

3.2.4. Theoretical calculations of PSF

Coordinator: Goriely
Experimentally determined PSFs will be extensively compared with theoretical model calculations, with the aim to improve the parameters of the models and enhance their predictive power, but also to gain insight in the nuclear structure effects on the electromagnetic response of the atomic nucleus. Global models will be developed to describe all the available photon strength function data and they will be made available to the user community from the new PSF database. To achieve these objectives, participants adopted the following plan of actions:

- Experimental PSF data will be made available to theorists (Goriely, Plujko) as soon as they are submitted to IAEA by 12/2016 – **Action** on: Dimitriou (IAEA)
- The following global models of PSFs (E1, M1, total) will be adjusted to recommended (experimental) strength functions
    - Empirical (Lorentzian-type) by 2nd RCM – **Action** on: Plujko.
    - HFB+QRPA by 2nd RCM – **Action** on: Goriely.
- Shell model calculations of M1 PSF in relation with the upbend and the scissors mode will be explored by 2nd RCM – **Action** on: Schwengner.
- Empirical prescription for M1 PSF will be provided by 2nd RCM – **Action** on: Kawano.
- Comparisons between existing global models (combinations of MLO/TSE parameterizations which should be kept as simple as possible, QRPA) and experimental PSF extending to energies below the neutron threshold will be completed by the 2nd RCM – **Action** on: Plujko, Goriely.

- From the above comparison, global empirical and microscopic prescriptions (for E1 and M1 PSF) will be recommended and provided for all nuclei across the nuclear chart by the 3rd RCM – **Action** on: Plujko, Kawano, Goriely.
- Validation of the different adjusted PSF models on experimental (n,γ) cross sections and <Γ_γ> data will be performed whenever data are available by the 2nd RCM – **Action** on Kawano, Goriely.

Additional testing/validation, Coordinator, Krticka

Specific recommended (adjusted) PSF will be provided by Plujko and Goriely for validation on the following experimental data:

- Two-Step Cascade (TSC) and Multi-Step Cascade (MSC) data for: ^{155,156,157,158,159}Gd (MSC & TSC), ^{96,98}Mo (MSC & TSC), ^{239}U (MSC), by 09/2018 (availability of data for other nuclides will be checked) – **Action** on: Krticka.
- Single spectra from thermal capture for ^{78}Se, ^{114}Cd, ^{233}Th, ^{239}U, ^{196}Pt by 09/2018 – **Action** on: Belgya.

The final validation will be presented at the 3rd RCM.

3.2.5. Dicebox package

Coordinator: Krticka
Dicebox is a Monte Carlo code that simulates the gamma cascades of a decaying compound nucleus with proper treatment of Porter-Thomas fluctuations. It has been widely used in the analysis of experimental gamma ray spectra obtained in photon scattering experiments and/or radiative neutron capture experiments. However, to date there is no dedicated distribution site of the code, and the documentation is limited.

One of the deliverables of this CRP is the dissemination of a complete Dicebox code package that would include the source code, documentation, scripts for input file preparation, and sample input/output files. The package will be prepared in the course of the CRP. A first demonstration will be made at the 2nd RCM and a first version of the package will be made available from the IAEA web site by 12/2017 – **Action** on Krticka, Firestone.

3.2.6. PSF database interface

Coordinator: Dimitriou
The new dedicated PSF database will make all existing experimental data available to the user. Apart from experimental data, it will also provide access to global and local prescriptions for calculating PSFs, using either empirical or semi-microscopic models. Recommendations will be made when and if possible.

To make access to all these data easy and straightforward, a user-friendly retrieval interface will be built by the IAEA. The interface will allow the user to search for data using various criteria:

- By Z,A
- By multipolarity
- By measurement technique
- By theoretical models

Plotting tools will also be provided for online comparison of experimental and theoretical PSFs. The user will also have the option to upload his/her own data sets to compare with those available in the database.

Action on Dimitriou in collaboration with Firestone and Belgya: prepare a proposal for a web interface for presentation to and approval by the CRP by the 2nd RCM.

References

[3.1] Towards a More Complete and Accurate Experimental Nuclear Reaction Data Library (EXFOR): International Collaboration Between Nuclear Reaction Data Centres (NRDC), N. Otuka, et al, Nucl. Data Sheets 120 (2014) 272; https://www-nds.iaea.org/exfor/exfor.htm

[3.2] https://www-nds.iaea.org/CRP-photonuclear/

4. Summary and Recommendations

The 1st RCM of the new CRP on Updating the Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions was held from 4 to 8 April 2016, at the IAEA Headquarters in Vienna.

All the groups participating in the CRP were represented at the meeting, and their work plans were presented and discussed. The technical discussions were split into two parts: the updating of the Photonuclear Data Library, and the new database for Photon Strength Functions. Participants reviewed the scope of the CRP, which covers i) measurements, ii) compilation and evaluation, iii) assessments, and iv) theoretical modelling for both parts mentioned above, and agreed on additional tasks that need to be carried out in order to achieve the goals of the CRP. Assignments are listed in Appendix 3 indicating responsible persons and deadlines.

In addition to the discussions and new actions, CRP participants also agreed to make an effort to attend the Oslo Workshop on Level densities and Strength Functions in 2017 and hold an interim meeting there to discuss the progress of their work.

It was suggested that the CRP objectives, results, and databases should be presented at conferences and workshops such as ECT*, ND (Nuclear Data for Science and Technology), Capture Gamma-ray Spectroscopy conference, Varenna Conference on Nuclear reaction Mechanisms, Oslo Workshops on Nuclear Level Densities and Strength Functions.

The CRP should be duly acknowledged in publications related to the CRP work with the following phrase: “This work was performed within the IAEA CRP on Updating the Photonuclear data Library and generating a Reference Database for Photon Strength Functions (F410 32)”.

Finally, participants agreed to hold the 2nd RCM in Autumn 2017.

Photo nuclear	1999	2016	2016	2016	Photo nuclear	1999	2016	2016	2016	Photo nuclear	1999	2016	2016	2016	New Data	2016
Nuclides	IAEA	CNDC	JENDL	OTHER	Nuclides	IAEA 1999	CNDC	JENDL	OTHER	Nuclides	IAEA	CNDC	JENDL	OTHER	Nuclides	
H-2	JENDL		Y		Ge-73	KAERI		Y		Pr-141 (Fi)*	KAERI		Y	MSU	H-3	
Be-9	CNDC	Y	Y		Ge-74	KAERI		Y		Sm-144	KAERI		Y		He-3	
C-12	LANL		Y		Ge-76	KAERI		Y		Sm-147	KAERI		Y		Li-6	JENDL/ CNDC
C-13	KAERI		Y		Sr-84	KAERI		Y		Sm-148	KAERI		Y		Li-7	JENDL/ CNDC
N-14	JENDL		Y		Sr-86	KAERI		Y		Sm-149	KAERI		Y		B-10	JENDL/ CNDC
N-15	KAERI		Y		Sr-87	KAERI		Y		Sm-150	KAERI		Y		B-11	JENDL/ CNDC
0-16	LANL		Y		Sr-88	KAERI		Y		Sm-151	KAERI		Y		C-14	KAERI
0-17	KAERI		Y		Sr-90	KAERI		Y		Sm-152	KAERI		Y		F-19	JENDL
0-18	KAERI		Y		Zr-90	KAERI		Y	MSU	Sm-154	KAERI		Y		Sc-45(Fi)*	JENDL/ MSU
Na-23	KAERI		Y		Zr-91 (Fi)	CNDC	Y	Y		Tb-158	KAERI		Y		As-75(Fi)*	KAERI/ MSU
Mg-24	KAERI		Y		Zr-92	CNDC	Y	Y	MSU	Tb-159 (Fi)	KAERI		Y	MSU/ ELI-NP	Se-76(Fi)*	KAERI/ MSU
Mg-25	KAERI		Y		Zr-93	KAERI		Y		Ho-165 (Fi)*	KAERI		Y	ELI-NP /MSU	Se-78(Fi)*	KAERI/ MSU
Mg-26	KAERI		Y		Zr-94 (Fi)	KAERI		Y	MSU	Ta-181 (Fi)	JENDL		Y	MSU/ ELI-NP	Se-80(Fi)*	MSU
Al-27	LANL		Y		Zr-96	CNDC	Y	Y		W-180	CNDC	Y	Y		Se-82(Fi)*	KAERI/ MSU
Si-27	KAERI		Y		Nb-93	KAERI		Y		W-182	JENDL		Y		Y-89(Fi)*	MSU/ ELI-NP
Si-28	KAERI		Y		Nb-94	KAERI		Y		W-183	CNDC	Y	Y		Rh-103(Fi)*	ELI-NP /MSU

Si-29	KAERI		Y		Mo-92	KAERI		Y		W-184	LANL		Y		In-115 (Fi)	MSU
Si-30	KAERI		Y		Mo-94	KAERI		Y		W-186 (Fi)*	JENDL		Y	MSU	La-139(Fi)*	ELI-NP /MSU
S-32	KAERI		Y		Mo-95	KAERI		Y		Au-197 (Fi)	KAERI		Y	MSU/ ELI-NP	Ba-138 (Fi)*	MSU
S-33	KAERI		Y		Mo-96	KAERI		Y		Pb-206	LANL		Y		Ce-140(Fi)*	KAERI/ MSU
S-34	KAERI		Y		Mo-97	KAERI		Y		Pb-207	LANL		Y		Ce-142(Fi)*	KAERI/ MSU
S-36	KAERI		Y		Mo-98	KAERI		Y		Pb-208 (Fi)	LANL		Y	MSU	Nd-142	KAERI
Cl-35	KAERI		Y		Mo-100	KAERI		Y		Bi-209	CNDC	Y	Y	ELI-NP	Nd-143	KAERI
Cl-37	KAERI		Y		Pd-102	KAERI		Y		Th-232	BOFOD		Y		Nd-144	KAERI
Ar-36	KAERI		Y		Pd-104	KAERI		Y		U-233	BOFOD		Y		Nd-145(Fi)*	KAERI/ MSU
Ar-38	KAERI		Y		Pd-105	KAERI		Y		U-234	BOFOD		Y		Nd-146	KAERI
Ar-40	KAERI		Y		Pd-106	KAERI		Y		U-235	BOFOD		Y		Nd-148(Fi)*	KAERI/ ELI-NP /MSU
K-39	KAERI		Y		Pd-107	KAERI		Y		U-236	BOFOD		Y		Nd-150	KAERI
K-40	KAERI		Y		Pd-108	KAERI		Y		U-238	BOFOD		Y		Eu-153(Fi)*	KAERI/ MSU
K-41	KAERI		Y		Pd-110	KAERI		Y		Pu-238	BOFOD		Y		Tm-169	ELI-NP
Ca-40	LANL		Y		Ag-107	KAERI		Y		Pu-239	BOFOD		Y		Gd-160(Fi)*	JENDL/ MSU
Ca-42	KAERI		Y		Ag-108	KAERI		Y		Pu-241	BOFOD		Y		Lu-175	KAERI
Ca-43	KAERI		Y		Ag-109	KAERI		Y					Y		Os-186	KAERI
Ca-44	KAERI		Y		Cd-106	KAERI		Y					Y		Os-188(Fi)	KAERI
Ca-46	KAERI		Y		Cd-108	KAERI		Y					Y		Os-189(Fi)	KAERI
Ca-48	KAERI		Y		Cd-110	KAERI		Y					Y		Os-190(Fi)	KAERI
Ti-46	KAERI		Y		Cd-111	KAERI		Y					Y		Os-192(Fi)	KAERI
Ti-47	KAERI		Y		Cd-112	KAERI		Y					Y		Np-237	JENDL
Ti-48	KAERI		Y		Cd-113	KAERI		Y					Y			

Ti-49	KAERI		Y		Cd-114	KAERI		Y					Y			
Ti-50	KAERI		Y		Cd-116	KAERI		Y					Y			
V-51	CNDC	Y	Y		Sn-112	KAERI	Y	Y				Y	Y			
Cr-50	CNDC	Y	Y		Sn-114	KAERI	Y	Y				Y	Y			
Cr-52	CNDC	Y	Y		Sn-115	KAERI	Y	Y				Y	Y			
Cr-53	CNDC	Y	Y		Sn-116 (Fi)	KAERI	Y	Y	MSU			Y	Y			
Cr-54	CNDC	Y	Y		Sn-117 (Fi)*	KAERI	Y	Y	MSU			Y	Y			
Mn-55	KAERI		Y		Sn-118 (Fi)*	KAERI		Y	MSU				Y			
Fe-54	JENDL		Y		Sn-119 (Fi)*	KAERI		Y	MSU				Y			
Fe-56	JENDL		Y		Sn-120 (Fi)*	KAERI		Y	MSU				Y			
Fe-57	KAERI		Y		Sn-122 (Fi)*	KAERI		Y	MSU				Y			
Fe-58	KAERI		Y		Sn-124 (Fi)*	KAERI		Y	MSU				Y			
Co-59	KAERI		Y	ELI-NP	Sb-121	KAERI		Y					Y			
Ni-58	JENDL		Y		Sb-123	KAERI		Y					Y			
Ni-60	KAERI		Y		Te-120	KAERI		Y					Y			
Ni-61	KAERI		Y		Te-122	KAERI		Y					Y			
Ni-62	KAERI		Y		Te-123	KAERI		Y					Y			
Ni-64	KAERI		Y		Te-124	KAERI		Y					Y			
Cu-63 (Fi)*	LANL		Y	MSU	Te-125	KAERI		Y					Y			
Cu-65 (Fi)*	JENDL		Y	MSU	Te-126	KAERI		Y					Y			
Zn-64	JENDL		Y		Te-128	KAERI		Y					Y			
Zn-66	KAERI		Y		Te-130	KAERI		Y					Y			
Zn-67	KAERI		Y		I-127	KAERI		Y					Y			
Zn-68	KAERI		Y		I-129	KAERI		Y					Y			
Zn-70	KAERI		Y		Cs-133 (Fi)*	KAERI		Y					Y			
Ge-70	KAERI		Y		Cs-135	KAERI		Y					Y			
Ge-72	KAERI		Y		Cs-137	KAERI		Y					Y			

Measurements of (γ,xn) cross sections at NewSUBARU Facility.

CSI	Target Nuclides	Time of delivery
H. Utsunomiya (Konan Univ.)	^{9}Be ^{197}Au ^{181}Ta ^{139}La	12/2016 12/2017 12/2018 2019
D. Filipescu (ELI-NP)	^{209}Bi ^{169}Tm ^{165}Ho ^{159}Tb	12/2016 12/2017 12/2018 2019
V.V. Varlamov (Moscow State Univ.)	^{89}Y ^{59}Co ^{103}Rh	12/2017 12/2018 2019

Measurements of Photon Strength Functions within the CRP.

CSI	Nuclides	Technique
S. Siem (Oslo)	^{111,112,113}Sn, ^{92}Mo (12/2016) ^{152,153}Sm (12/2018), ^{186}W (12/2017) ^{144,145,148,149,150,151}Nd (12/2017) ^{234}U, ^{240}Pu (12/2016) ^{203,205}Tl (12/2016); ^{192}Os (12/2017), ^{185}Re (12/2017); ^{182,183,184}W (12/2018); ^{89}Y (12/2016); ^{64}Zn (2019), ^{66,68}Zn (12/2018)	Oslo charged-particles (γ,n)
M. Wiedeking (iThemba)	^{74}Ge (12/2017), ^{180,181,182}Ta (12/2016) ^{154,155}Sm (05/2018)	Ge (ratio method) ; Ta (Oslo method)
R. Schwengner (HZDR)	^{80}Se (12/2016); ^{54}Fe (12/2017); A~60 (^{62}Ni, ^{64}Zn tbc) (03/2019)	At Elbe and/or Higs (^{54}Fe)
T. Belgya (HAS)	^{233}Th, ^{239}U (12/2017)	By thermal n-capture
H. Utsunomiya (Konan)	^{156,157,158,160}Gd (2019) ^{58,60,64}Ni (12/2017)	(γ,n)

*Some of these experiments could be strongly facilitated if targets could be provided. These concern about ~0.5g, either in metal powder or oxide form for ^{192}Os, ^{156,157,158,160}Gd, ^{182,183,184}W, ^{64,66,68}Zn isotopes.

No	Action	Responsible	Deadline
1	Prepare a preliminary list of top priority nuclides for which photonuclear data are important for applications.	Dimitriou (IAEA), Kawano	Preliminary list: 12/2016. Complete list: 2nd RCM
2	Collect the new measurements when they are ready for publication and submit to Dimitriou (IAEA) for distribution among evaluators and inclusion in the EXFOR database	Utsunomiya, Filipescu	Continuous
3	Investigate the completeness of the EXFOR database with respect to photonuclear cross-section data (with special emphasis on data published in the periods after 2000 and before 1975).	Dimitriou (IAEA)	06/2017
4	Send references of published photonuclear data to Dimitriou (IAEA) for inclusion in EXFOR In case of data corrected by evaluators, data (and references) should be sent to IAEA with additional explanations about corrections.	Cho, Xu, Varlamov, Kawano, Iwamoto, Filipescu	Continuous
5	Provide Dimitriou (IAEA) with the list of EXFOR entries of available corrected photo-neutron cross-section data for ^{91,94}Zr, ^{115}In, ^{116}Sn, ^{159}Tb, ^{181}Ta, ^{197}Au, ^{208}Pb targets.	Varlamov	After 1st RCM (05/2016).
6	Provide new corrected data on ^{63,65}Cu, ^{133}Cs, ^{141}Pr, ^{80}Se, ^{89}Y, ^{138}Ba to Dimitriou (IAEA) for distribution to CRP evaluators. In general: provide new corrected data as they become available to the IAEA for distribution among CRP evaluators.	Varlamov	09/2016 Continuous
7	Coordinate the sensitivity study on the F_i correction factors and report on the conclusions.	Kawano	09//2016 (at ND2016 conference)
8	Explore the effect of over-enhancement of absorption of incident photon flux into 1p1h states for two test cases (one light and one heavy nucleus). Discussion with code developers will take place at the ND 2016 meeting and the results will be disseminated among all the CRP evaluators.	Kawano	ND2016 Conference
9	**S**end plots with comparisons of new JAEA and existing IAEA Photonuclear Data Library evaluations to Dimitriou (IAEA) for uploading on the CRP web site.	Iwamoto	12/2016
10	Organize the first meeting of the Photonuclear Evaluation Committee to review the first round of evaluations.	Dimitriou (IAEA)	In 2017/before 2nd RCM
11	The Atlas of GDR parameters will be updated.	Varlamov, Plujko	When new evaluated photonuclear data become available

12	Photon Strength Functions (PSF) will be extracted from the total photo-neutron/ photoabsorption cross section and also compared with models: • QRPA calculations • TLO parameters	Coordinator Plujko Goriely Schwengner	2nd RCM
13	Propose a preliminary web interface for the photonuclear data library.	Dimitriou (IAEA)	2nd RCM
14	**S**end new PSF experimental data to Dimitriou (IAEA) in a simple format.	Wiedeking	Continuous
15	Send the collected experimental PSF data to Dimitriou (IAEA) in a simple format.	Firestone, Kopecky, Schwengner, Siem, Wiedeking	12/2016
16	Send samples of the format of the experimental PSF data files to the CRP participants.	Dimitriou (IAEA)	10/2016
17	Explore possibility of extracting relative PSF from thermal capture data.	Belgya	2nd RCM
18	Model-dependent uncertainty analysis will be performed on both the NRF and Oslo method for the test case of ^{89}Y.	Schwengner, Siem	by 12/2016
19	Subsequently, existing NRF and Oslo data for ^{74}Ge, $^{96,98}Mo$, ^{139}La, ^{181}Ta, ^{196}Pt will be assessed with full uncertainty analysis. PSF data will be recommended with error bars.	Schwengner, Siem, Wiedeking.	2nd RCM
20	PSF shape extracted from the Oslo and Ratio methods will be compared for ^{74}Ge similarly to the case of ^{95}Mo.	Wiedeking, Krticka.	by 12/2018
21	Validation of the assessed and recommended PSF will be performed by Multi-Step Cascade method for the cases of $^{96,98}Mo$ including a full uncertainty analysis of Nuclear Level Density models.	Krticka	2nd RCM
22	Compatibility of thermal capture, NRF & Oslo PSF data for the case of ^{196}Pt will be checked.	Belgya	2nd RCM
23	Compatibility between recommended PSF and the extracted one from photonuclear data will be studied as soon as the corresponding PSF below and above threshold is made available to the CRP.	Siem and Plujko	By or after 2nd RCM
24	An update on the available experimental evidence for the multipolarity of the low-energy upbend will be given at the 2nd RCM.	Wiedeking	2nd RCM
25	The spin dependence of PSF-related observables will be investigated.	Krticka and Firestone	2nd RCM
26	Experimental PSF data will be made available to theorists (Goriely, Plujko) as soon as they are submitted to IAEA.	Dimitriou (IAEA)	12/2016

27	The following global models of PSFs (E1, M1, total) will be adjusted to recommended (experimental) strength functions: Empirical (Lorentzian-type) HFB+QRPA	 Plujko Goriely	2^{nd} RCM
28	Shell model calculations of M1 PSF in relation with the upbend and the scissors mode will be explored.	Schwengner	2^{nd} RCM
29	Empirical prescription for M1 PSF will be provided.	Kawano	2^{nd} RCM
30	Comparisons between existing global models (combinations of MLO/TSE parameterizations which should be kept as simple as possible, and QRPA) and experimental PSF extending to energies below the neutron threshold will be performed.	Plujko, Goriely	2^{nd} RCM
31	From the above comparison, global empirical and microscopic prescriptions (for E1 and M1 SF) will be provided for all nuclei across the nuclear chart.	Plujko, Kawano, Goriely	3^{rd} RCM
32	Validation of the different adjusted PSF models on experimental (n,γ) cross sections and $<\Gamma_\gamma>$ data will be performed when data are available.	Kawano, Goriely.	After 2^{nd} RCM
33	Validation of adjusted PSF models on other available Two-Step Cascade (TSC) and Multi-Step Cascade (MSC) data: ^{155,156,157,158,159}Gd (MSC & TSC), ^{96,98}Mo (MSC & TSC), ^{239}U (MSC) (availability of data for other nuclides will be checked)	Krticka	09/2018
34	Validation of adjusted PSF models on single spectra from thermal capture for ^{78}Se, ^{114}Cd, ^{233}Th, ^{239}U, ^{196}Pt.	Belgya	09/2018
35	A first demonstration of the new DICEBOX software package will be made at the 2^{nd} RCM and a first version of the package will be made available from the IAEA web site.	Krticka, Firestone	12/2017
36	Prepare a proposal for the PSF database web interface for presentation to and approval by the CRP.	Dimitriou (IAEA), Firestone, Belgya	2^{nd} RCM

1st Research Coordination Meeting (RCM) of the CRP on

Updating the Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions

IAEA Headquarters, Vienna, Austria
4-8 April 2016
Meeting Room VIC C0454

Preliminary AGENDA

Monday, 4 April

08:30 - 09:30 **Registration** (IAEA Registration desk, Gate 1)

09:30 - 10:00 **Opening Session**

Welcoming address (Meera Venkatesh, Director NAPC)
Introduction (Paraskevi Dimitriou, Scientific Secretary)
Election of Chairman and Rapporteur
Adoption of Agenda
Administrative matters

10:30 - 12:30 **Presentations by participants (about 40 min each)**

1. *Gamma-ray Strength Functions: The Stone Age at BNL*, J. Kopecky, JUKO Research, The Netherlands
2. *Total and partial photoneutron cross section measurements by direct neutron-multiplicity sorting,* H. Utsunomiya, Konan University, Japan
3. *Evaluation of partial and total photoneutron reactions cross sections using new objective physical data reliability criteria,* V.V. Varlamov, Moscow State University, Russian Federation

Coffee break as needed

12:30 – 14:30 ***Lunch***

14:30 – 18:00 **Presentations by participants (cont'd)**

4. *Evaluation of photonuclear data library by taking into account new experimental data and evaluation methodologies,* N. Iwamoto, JAEA, Japan
5. *Update of the photonuclear cross sections,* Y-S. Cho, KAERI, S. Korea
6. *Analysis and evaluation of photoreaction data*, D. Filipescu, IFIN-HH/ELI-NP, Romania
7. *Evaluation for Photonuclear Cross Sections and γ-Ray Strength Functions at CIAE,* R. Xu, CIAE, China

Coffee break as needed

Tuesday, 5 April

09:00 - 12:30 Presentations by participants (about 40 min each)

8. *E1 and M1 Strength Functions at Low Energy*, R. Schwengner, HZDR, Germany
9. *M1 Photon Strength Function and Capture Cross Section for Deformed Nuclei*, T. Kawano, LANL, USA
10. *Development of formats for a Photon Strength Function database and evaluation of thermal neutron capture photon strengths*, R. Firestone, University of California, Berkely, USA
11. *Update of and measurement for the PGAA Data Library for Photon Strength Functions and Development of Prompt Gamma-ray Spectrum Modelling,* T. Belgya, CER / Hungarian Academy of Sciences, Hungary

Coffee break as needed

12:30 – 14:00 Lunch

14:00 – 18:00 Presentations by participants (cont'd)

12. *Microscopic description of the photon strength function*, S. Goriely, Université Libre de Bruxelles, Belgium
13. *Improvements and Testing Practical Expressions for Photon Strength Functions of E1 Gamma-Transitions,* V. Plujko, Taras Shevchenko National University, Ukraine
14. *Photon strength functions below the separation energies – challenges and opportunities,* M. Wiedeking, iThemba LABS, S. Africa
15. *Photon strength function measurements at the Oslo Cyclotron*, S. Siem, University of Oslo, Norway
16. *Computer code DICEBOX and gamma-ray strength functions from coincidence measurement of photons emitted in radiative neutron capture,* M. Krticka, Charles University in Prague, Czech Rep.

Coffee break as needed

19:00 Dinner in a restaurant (see separate information)

Wednesday, 6 April

09:00 - 12:30 Round Table Discussion

17. *Updated RIPL Discrete Levels Segment*, M. Verpelli (IAEA), 15 min
18. *Overview of Scope of CRP-Introduction to discussion*, P. Dimitriou (IAEA), 15 min

Coffee break as needed

12:30 – 14:00 Lunch

14:00 – 18:00 Round table discussion (cont'd)

Coffee break as needed

Thursday, 7 April

09:00 - 12:30 Round Table Discussion

Coffee break as needed

12:30 – 14:00 Lunch

14:00 – 18:00 Round table discussion (cont'd)

Coffee break as needed

Friday, 8 April

09:00 - 12:30 Drafting of the meeting summary report

Coffee break in-between

13:00 Closing of the meeting

Topics for Discussion

- Individual work plans
- Work needed for updating the Photonuclear Data Library in addition to individual work plans: nuclides that have not been assigned, neutron spectra, angular distributions, Atlas of GDR parameters etc
- User friendly interface for Photonuclear Data Library
- Content, structure and formats for new Photon Strength Function Database
- Actions/assignments

1st Research Coordination Meeting on
"Updating Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions"
IAEA, Vienna, Austria
4-8 April 2016

LIST OF PARTICIPANTS

BELGIUM

Stephane GORIELY
Universite Libre de Bruxelles
CP-226
Campus de la Plaine
Boulevard du Triomphe
1050 Brussels
E-mail: sgoriely@ulb.ac.be

CHINA (cancelled)

Ruirui XU
China Nuclear Data Center
China Institute of Atomic Energy
P.O. Box 275 (41)
102413 Beijing
E-mail: xuruirui@ciae.ac.cn

CZECH REPUBLIC

Milan KRTICKA
Charles University in Prague
V Holesovickach 2
18000 Prague 8
E-mail: krticka@ipnp.troja.mff.cuni.cz

GERMANY

Ronald SCHWENGNER
Helmholtz Zentrum Dresden-Rossendorf (HZDR)
Bautzner Landstrasse 400
Dresden 01328
E-mail: r.schwengner@hzdr.de

HUNGARY

Tamas BELGYA
Centre for Energy Research
Hungarian Academy of Sciences
Konkoly Thege Miklos 29-33
1525 Budapest
E-mail: belgya.tamas@energia.mta.hu

JAPAN

Nobuyuki IWAMOTO
Japan Atomic Energy Agency (JAEA)
2-4 Shirakata, Tokai-mura
Naka-gun
Ibaraki 319-1195
E-mail: iwamoto.nobuyuki@jaea.go.jp

Hiroaki UTSUNOMIYA
Konan University
Department of Physics
8-9-1 Okamoto, Higashinada
E-mail: hiro@center.konan-u.ac.jp

KOREA, Republic of

Young Sik CHO
Nuclear Data Center
Korea Atomic Energy Research Institute
Daedeok-Daero 989-111
Yuseong, Daejeon
E-mail: yscho@kaeri.re.kr

NETHERLANDS

Jiri KOPECKY
JUKO Research
Kalmanstraat 4
Alkmaar 1817
E-mail: juko@planet.nl

NORWAY

Sunniva SIEM
University of Oslo
Sem Saelands vel 24
P.O. Box 1048
Oslo 0316
E-mail: sunniva.siem@fys.uio.no

ROMANIA

Dan Mihai FILIPESCU
Horia Hulubei National Institute (IFIN-HH)
30 Reactorului St.
P.O. Box MG-6
76900 Bucuresti-Magurele
E-mail: dan.filipescu@eli-np.ro

RUSSIAN FEDERATION

Vladimir V. VARLAMOV
Lomonosov Moscow State University
Skobeltsyn Institute of Nuclear Physics
Leninskie Gory ½
119991 Moscow
E-mail: varlamov@depni.sinp.msu.ru
vvvarlamov@gmail.com

SLOVAKIA

Pavel OBLOZINSKY
Na Riviere 30
Bratislava 84104
E-mail: oblozin@gmail.com

SOUTH AFRICA

Mathis WIEDEKING
iThemba LABS
National Research Foundation
Meiring Naude Road
P.O. Box 2600
Pretoria Gauteng 0001
E-mail: wiedeking@tlabs.ac.za

UKRAINE

Vladimir PLUJKO
Nuclear Physics Department
Faculty of Physics
Taras Shevchenko National University
Volodymyrska 60
Kyiv 01601
E-mail: plujko@gmail.com

UNITED STATES OF AMERICA

Richard B. FIRESTONE
University of California, Berkely
Berkeley CA 94720
E-mail: rbfirestone@lbl.gov

Toshihiko KAWANO
T2, MS B283
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos NM 87545
E-mail: kawano@lanl.gov

IAEA

Paraskevi (Vivian) DIMITROU
Tel. +43-1-2600 21708
E-mail: p.dimitriou@iaea.org

Arjan KONING
Tel. +43-1-2600 21709
E-mail: a.koning@iaea.org

Roberto CAPOTE NOY
Tel. +43-1-2600 21713
E-mail: roberto.capotenoy@iaea.org

Marco VERPELLI
Tel. +43-1-2600 21723
E-mail: m.verpelli@iaea.org

All:
International Atomic Energy Agency
(IAEA)
NAPC / Nuclear Data Section
Vienna International Centre, P.O. Box 100
1400 Vienna
AUSTRIA

Author	Title	Link
J. Kopecky	Gamma-ray Strength Functions (The Stone Age at and around BNL)	PPT
H. Utsunomiya	Total and partial photoneutron cross section measurements by direct neutron-multiplicity sorting	PDF
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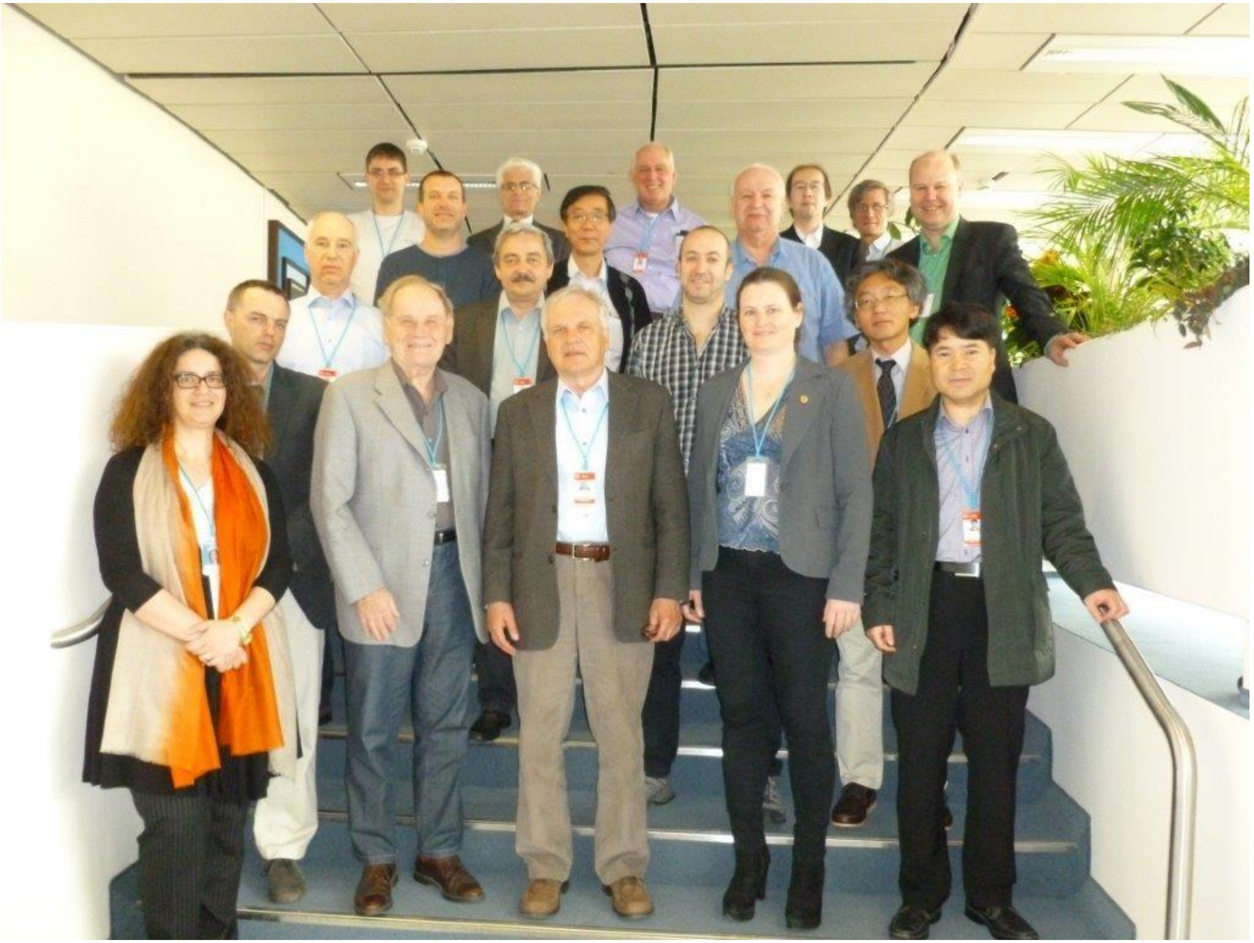
M. Verpelli	Updated RIPL discrete levels file	PPT
S. Simakov	Photonuclear data needs for IRDFF CRP	PDF



Nuclear Data Section
International Atomic Energy Agency
Vienna International Centre,
P.O. Box 100
A-1400 Vienna, Austria

E-mail: nds.contact-point@iaea.org
Fax: (43-1) 26007
Telephone: (43-1) 2600 21725
Web: http://www-nds.iaea.org