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Summary Report
2nd Research Coordination Meeting

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

16 to 20 October 2017
IAEA Headquarters
Vienna, Austria

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January 2018

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ABSTRACT

A summary is given of the 2nd Research Coordination Meeting of the IAEA Co-ordinated Research Project (CRP) on Updating the Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions. Participants presented their progress reports, reviewed the list of actions assigned at the previous meeting and agreed on the 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.

January 2018

Contents

1. Introduction

The CRP on Updating the Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions (2016-2020) has two main objectives:

- Updating the IAEA Photonuclear Data Library released in 1999 [1.1]
- Generate a dedicated database for Photon Strength Functions

The CRP proposal and program were based on the recommendations of the Consultants' Meeting held at the IAEA from 11 to 13 November 2013 [1.2].

Specific Objectives

The two objectives will be achieved by a series of activities listed below:

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

Progress of the activities and individual tasks assigned to the participants of the CRP will be discussed and reviewed at three Research Coordination Meetings to ensure the goals of the CRP are achieved in a timely manner.

The 1st Research Coordination Meeting (RCM) of the CRP was held at the IAEA Headquarters, Vienna, from 4 to 8 April 2016. Sixteen CRP participants and advisers from 13 countries attended the meeting to review the CRP program and agree on additional actions required for the timely achievement of the objectives. The summary report of the meeting is available in Ref. [1.3].

The 2nd RCM was held at the IAEA Headquarters, Vienna, from 16 to 20 October 2017. The meeting was attended by 21 participants, including 3 advisors and 2 IAEA staff. The Section Head of the Nuclear Data Section, A. Koning, welcomed participants to the meeting on Monday morning, while the scientific secretary of the CRP, P. Dimitriou, gave a summary of the status of the CRP and the goals of the meeting. P. Oblozinsky (Slovakia) was elected chairman of the meeting, and S. Goriely (Belgium) and M. Wiedeking (South Africa) were designated rapporteurs. The preliminary agenda was adopted without any changes and the meeting continued with presentations from participants followed by extensive technical discussions on the program of work and future action needs. Summaries of the presentations are given in Section 2, while the technical discussions are described in Section 3. A complete list of actions is given in Appendix 2. The Meeting Agenda and Participants list are available in Annexes 1 and 2, respectively. Links to the presentations are found in Annex 3.

References

[1.1] Handbook on photonuclear data for applications. Cross-sections and spectra. Final report of a co-ordinated research project 1996 – 1999. IAEA-TECDOC-1178, 2000. Available at: https://www-nds.iaea.org/publications/tecdocs/iaea-tecdoc-1178/

[1.2] P. Dimitriou, R.B. Firestone, S. Siem, Compilation and Evaluation of Reaction Gamma-ray Data, Consultants' Meeting 4-6 November 2013, IAEA Report INDC(NDS)-0649, December 2013.
Available at http://www-nds.iaea.org/publications/indc/indc-nds-0649/

[1.3] S. Goriely and P. Dimitriou, Summary Report of the 1st RCM of the CRP on Updating the IAEA Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions, 4–8 April 2016, IAEA Report INDC(NDS)-0712, July 2016. Available at: https://www-nds.iaea.org/publications/indc/indc-nds-0712/

2. Summary of participants' presentations

2.1. The PHOENIX collaboration for the IAEA-CRP F41032, Hiroaki Utsunomiya, Konan University

I. Data acquisition at the New SUBARU facility

(1) 2015 and 2016:

- (γ,xn) data for the updated photonuclear data library: we have acquired (γ,xn) data for ^{9}Be and ^{209}Bi in 2015 and for ^{89}Y, ^{169}Tm, and ^{197}Au in 2016.
- (γ,n) data for the reference database of photon strength functions: we have acquired (γ,n) data for ^{89}Y, ^{203}Tl, and ^{205}Tl in 2015 and ^{13}C, ^{58}Ni, ^{60}Ni, ^{61}Ni, ^{64}Ni, ^{137}Ba, ^{138}Ba, ^{185}Re, and ^{192}Os in 2016.

(2) 2017:

- (γ,xn) data for the updated photonuclear data library: we have finished the first experiment to acquire (γ,xn) data for ^{89}Y, ^{169}Tm, and ^{197}Au during July 17-30 followed by the second experiment for a complete acquisition during November 6-20 in collaboration with the ELI-NP, Moscow State University, Technische Universität Darmstadt and Shanghai Institute of Nuclear Applied Physics.

- (γ,n) data for the reference database of photon strength functions: we plan to acquire (γ,n) data for ^{64}Zn, ^{66}Zn, ^{68}Zn, ^{182}W, ^{183}W and ^{184}W during December 4 – 18 in collaboration with the University of Oslo.

(3) 2018:

2018 is the final year of experimental activities for the IAEA-CRP. We will acquire (γ,xn) data for ^{103}Rh, ^{139}La, and ^{159}Tb and (γ,n) data for ^{156}Gd, ^{157}Gd, ^{158}Gd, and ^{160}Gd in the first half of 2018 to allow sufficient time for reduction and evaluation of the data.

II. Publications

The methodology paper for direct neutron-multiplicity sorting with a flat-efficiency detector which forms a solid experimental basis of the PHOENIX collaboration was published [1]. The ^{209}Bi data were also published [2].

With the publication of the ^{209}Bi data, we have established the standard of data reduction based on the methodology of neutron- multiplicity sorting.

However, there is a puzzling issue in the large ^{209}Bi(γ,1n) cross section (30 – 50mb) at 35 – 40 MeV. The statistical model predicts small (γ,1n) cross sections (3 – 4 mb) though the model prediction can be artificially enhanced by tuning the statistical model parameters within a reasonable range or the Levinger parameter involved in the quasi-deuteron model. However, the large (γ,1n) cross section is most likely experimental, being caused by soft γ-rays due to e+ - e- pair production and Compton scattering of the laser Compton scattered γ-rays in a thick (10cm) ^{209}Bi target. We address this issue in an erratum paper.

There is another puzzle that the mean kinetic energies of neutrons emitted near one-neutron threshold are rather close to the maximum energies expected in the ground state decay, which is difficult to understand in terms of E1 excitation within the statistical model calculation.

The ground state decay may be allowed in p-wave neutron emission after M1 excitation. This issue needs to be addressed experimentally in the future.

III. Talks

The following three invited talks were given on behalf of the PHOENIX collaboration.

(1) H. Utsunomiya," A Unified Understanding of (γ,n) and (n,γ) Reactions and Direct Neutron-multiplicity Sorting", ND2016, International Conference on Nuclear Data for Science and Technology, 11-16 September 2016, Bruges, Belgium
(2) H. Utsunomiya, "Gamma-ray strength functions and a new dimension of partial GDR cross section measurements", Oslo Workshop, 6th Workshop on Nuclear Level Density and Gamma strength, Oslo, May 8 -12, 2017
(3) H. Utsunomiya, "Photoneutron Reaction Data for Nuclear Physics and Astrophysics", CGS16, 16th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics (CGS16), 18-22 September 2017, Shanghai Jiao Tong University

IV. Experimental complication

It turned out that many of the multi-photon spectra in the 2016 data have suffered from quenching as a result of saturation at the photomultiplier tube of the NaI(Tl) detector due to a high voltage applied to the PMT. The photon-flux is accurately determined from the multi-photon spectra which originally follow the Poisson distribution. We can restore the original Poisson distributions from the quenched spectra using a saturation curve formulated properly (H. Utsunomiya et al., "Photon-flux determination by the Poisson-fitting technique with quenching corrections", submitted to Nuclear Instruments and Method A). However, the restoration procedure takes extra time in addition the standard data reduction. As a result, a delay from a few to several months is foreseen before the final cross sections of the 2016 data will be provided by the ELI-NP, Moscow State University, and Konan University in 2018.

References

[1] H. Utsunomiya et al., "Direct neutron-multiplicity sorting with a flat-efficiency detector", Nuclear Instruments and Methods A 871 (2017) 135-141.
[2] I. Gheorghe et al., "Photoneutron cross-section measurements in the ^{209}Bi(γ,xn) reaction with a new method of direct neutron-multiplicity sorting", Phys. Rev. C **96** (2017) 044604.

2.2. Analysis and evaluation of photoreaction data, Dan Filipescu, IFIN-HH/ELI-NP

During 2015 – 2018, the ELI-NP team participated in the Phoenix Collaboration (Konan University, IFIN-HH (ELI-NP), Moscow State University, University of Oslo) that performed (γ,xn) reaction cross section measurements at the New SUBARU facility at energies starting from the neutron threshold up to ~40 MeV.

The ELI-NP team is responsible for developing a data analysis procedure to obtain absolute (γ,xn), where x = 1, 2, 3, …, reaction cross sections from the raw measured data. The procedure was validated on data obtained from full Geant4 simulations of the experiment. For this purpose, the neutron source was generated using the Monte Carlo statistical model calculations provided by Toshihiko Kawano (LANL).

The procedure was applied by the ELI-NP team to the data obtained for ^{209}Bi nucleus (already measured in 2015) and partly to the data for ^{169}Tm (measured in 2016) and ^{165}Ho (measured in 2017), and will be applied to the data that will be obtained for ^{159}Tb (to be measured in 2018). Details of the experimental and data analysis technique applied to ^{209}Bi were presented. The energy unfolding procedure was recently updated by taking into account the electromagnetic interactions of the incident photon beam in the ^{209}Bi targets. A comparison was shown between the ^{209}Bi(γ,xn) cross sections obtained using the current new method and the previous method (in which the incident photon self-attenuation is corrected using an analytical factor but the resulting secondary photons are not considered). We obtain a decrease of the ^{209}Bi(γ,n) cross section for energies above 20 MeV, while the rest of the data remain unchanged.

We propose to perform full evaluations of photon-induced reactions on the nuclei which will be measured by the Phoenix Collaboration:

- ^{209}Bi data to be made available by 03/2018;
- ^{197}Au, ^{89}Y, ^{169}Tm data to be made available by 03/2018;
- ^{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.

Preliminary results of the evaluation of the cross sections for photon induced reactions on ^{209}Bi, ^{197}Au, ^{148}Nd, ^{169}Tm and ^{89}Y were presented, along with the preliminary experimental results for ^{169}Tm and ^{165}Ho.

2.3. Evaluation of partial and total photoneutron reaction cross sections using new objective physical data reliability criteria, Vladimir V. Varlamov, Moscow State University

The following ratios have been proposed as objective physical criteria of partial photoneutron reaction cross section data reliability,

$$F_i = \sigma(\gamma,in)/\sigma(\gamma,xn) \quad (1)$$

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, xn) is the neutron yield cross section (see Sect. 3.1),

$$\sigma(\gamma,xn) = \sigma(\gamma,1n) + 2\sigma(\gamma,2n) + 3\sigma(\gamma,3n) + \ldots \quad (2)$$

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.

A combined experimental-theoretical method for the evaluation of partial reaction cross sections using data reliability criteria has been developed. It is based on using the experimental value $\sigma^{exp}(\gamma,xn)$, which is rather independent of the problem regarding the neutron multiplicity sorting because all detected neutrons are included, and the correction functions F^{theor} calculated using the Combined Model of Photonuclear Reactions (CMPNR):

$$\sigma^{eval}(\gamma, in) = F_i^{theor}\sigma^{exp}(\gamma, xn) = [\sigma^{th}(\gamma, in)/\sigma^{th}(\gamma, xn)]\sigma^{exp}(\gamma, xn). \quad (3)$$

This method ensures that the competition of partial reactions is in accordance with the model and their corresponding sum is equal to $\sigma^{exp}(\gamma,xn)$. Details can be found in Ref. [1.3].

Furthermore, it has been shown that the partial reaction cross sections obtained by using F_i^{theor} (Eq. (3)) for ^{181}Ta, ^{197}Au and ^{209}Bi nuclei agree with the corresponding experimental results obtained from the activation method. In this method, contrary to the method of neutron multiplicity sorting, the direct identification of each partial reaction is based on the final nuclei.

To conclude, in the following evaluations the data are judged to be unreliable if the following criteria are observed:

- **F_i^{exp} values larger** than the definite upper limits;
- **negative values of σ^{exp}**(γ, in) and correspondingly of F_i^{exp};
- noticeable **differences between F_i^{exp} and F_i^{theor}**.

1. The 1st CRP year

The work plan for the first year included:

1. Energy dependencies of multiplicity transitional functions Fi^{exp} will be obtained from experimental data in the energy range of the Giant Dipole Resonance (GDR) for 9 new nuclei (^{63,65}Cu, ^{80}Se, ^{89}Y, ^{133}Cs, ^{138}Ba, ^{141}Pr, ^{165}Ho, ^{186}W).
2. The analysis of experimental partial reactions cross sections will be carried out using reliability criteria. If there are any doubts about data reliability we'll use experimental-theoretical method of partial reaction cross section evaluation.
3. For all 9 nuclei mentioned above the evaluated cross sections for partial reactions (γ,n), (γ,2n), and (γ,3n) and also total photoneutron reaction (γ,tot) = (γ,n) + (γ,2n) + (γ,3n) will be obtained for energies of GDR by experimentally-theoretical method. Integrated cross sections will be calculated for various photon energy regions.
4. For selected nuclei (^{181}Ta, ^{208}Pb, ^{209}Bi, etc.) neutron emission spectra will be calculated in the frame of the CMPNR.

Results obtained:

- All the tasks listed above were completed.
- The new evaluated cross section data for all nuclei mentioned with the exception of ^{165}Ho were published (^{63,65}Cu and ^{80}Se [1], ^{89}Y [3, 4], ^{133}Cs, ^{138}Ba [2], ^{141}Pr, ^{186}W [5]) and included into the international nuclear reaction database EXFOR.
- Neutron emission spectra for ^{141}Pr, ^{186}W were calculated and published [5].

2. The 2nd CRP year

The work plan included:

1. The energy dependencies of multiplicity transitional functions F_i^{exp} and F_i^{theor} will be obtained and compared for the energy range of Giant Dipole Resonance (GDR) for ^{103}Rh, ^{139}La, ^{165}Ho, ^{197}Au and additionally for ^{117,118,119,120,122,124}Sn.
2. For all 9 nuclei mentioned above the evaluated cross sections for partial reactions and correspondent integrated cross sections will be obtained for energies of GDR by experimentally-theoretical method.
3. For selected nuclei (^{116}Sn, ^{139}La, ^{156}Tb, ^{197}Au,) neutron emission spectra will be calculated in the frame of the CMPNR.

Results obtained up to 2nd RCM

- Neutron emissin spectra were calculated and published for ^{181}Ta, ^{208}Pb, ^{209}Bi [6] and additionally for ^{116}Sn [7].
- Fi^{exp} for all nuclei were compared with F_i^{theor}- calculated in the frame of the CMPNR. Noticeably disagreements were obtained.
- New data for evaluated partial and total photonuclear reaction cross sections for ^{139}La [8], ^{140,142}Ce and ^{197}Au [9] were obtained and published.
- In addition to the working plan new evaluated partial and total photoneutron reaction cross section data for ^{59}Co [10], ^{90,92}Zr and ^{98}Mo [11] were obtained.

- New data were obtained and prepared for publication (^{103}Rh, ^{139}La, ^{165}Ho, Bull. Russ. Ac. Sci.).
- For all nuclei evaluated photoneutron reaction reaction cross sections integrated cross sections were obtained for various energy ranges.
- All published evaluated partial and total reactions cross sections data were included into the international nuclear reaction database EXFOR.

References

[1] V.V. Varlamov, A.I. Davydov, M.A. Makarov, V.N. Orlin, N.N. Peskov, Bull. Rus. Acad. Sci. Phys. **80** (2016) 317.

[2] V.V. Varlamov, B.S. Ishkhanov, V.N. Orlin, N.N. Peskov, Physics of Atomic Nuclei **79** (2016) 501.

[3] V.V. Varlamov, Ishkhanov BS, Orlin VN, Peskov NN, Stepanov ME, EPJ Web of Conferences, 146 (2017) 05005.

[4] V.V. Varlamov, A.I. Davydov, V.N. Orlin, N.N. Peskov, Bull. Rus. Acad. Sci. Phys. **81** (2017) 664.

[5] V.V. Varlamov, V.N. Orlin, N.N. Peskov, Bull. Rus. Acad. Sci. Phys., **81** (2017) 670.

[6] V.V. Varlamov, V.N. Orlin, N.N. Peskov, International Conference «Nucleus-2017» (67th Meeting on Nuclear Spectroscopy and Atomic Nucleus Structure), September 12-15, Almaty, Kazakhstan, Abstracts, Institute of Nuclear Physics, 2017, page 31.

[7] V.V. Varlamov, B.S. Ishkhanov, A.A. Kuznetsov, V.N. Orlin, A.A. Proshyakov, Memoirs of the Faculty of Physics, Lomonosov Moscow State University, № 3, 2017, 173202.

[8] V.V. Varlamov., V.D. Kaydarova, N.N. Peskov, International Conference «Nucleus-2017» (67th Meeting on Nuclear Spectroscopy and Atomic Nucleus Structure), September 12-15, Almaty, Kazakhstan, Abstracts, Institute of Nuclear Physics, 2017, page 28.

[9] V. Varlamov, B. Ishkhanov, V. Orlin, Phys Rev. C **96** (2017) 044606.

[10] V.V.Varlamov, A.I.Davydov, B.S.Ishkhanov, Eur. Phys. J. A **53** (2017) 180.

[11] V.V. Varlamov, V.D. Kaidarova, M.E. Stepanov, Moscow University Physics Bulletin Physics. Astronomy (accepted).

2.4. Evaluation of photonuclear data library by taking into account new experimental data and evaluation methodologies, Nobuyuki Iwamoto, JAEA

Progress on the photonuclear data evaluation from the first meeting was reported. The release procedure of new JENDL/PD library is now ongoing. The release date was set to 28 December 2017. For the new IAEA Photonuclear Data (PD) library nuclear data were evaluated by the CCONE code for 107 nuclides which were already included in the previous IAEA library. In addition, three nuclides (^{45}Sc, ^{160}Gd, ^{237}Np) were newly evaluated. The energy range was expanded to 200 MeV. In total, the data of 173 nuclides were prepared for the new IAEA PD library.

The examples of comparison plots were shown for (γ,xn), (γ,1nx), (γ,2nx) and (γ,sn) reactions. Experimental data were taken from recent EXFOR database. In the photon energy region higher than 20 MeV, cross section data except for fission reaction were included in MF/MT=3,6/5 in the ENDF-6 format. The (γ,xn) reaction cross section is neutron yield cross section which is correctly retrieved from the ENDF-6 format. The one-neutron production cross section, namely (γ,1nx), is composed of typically the sum of (γ,n), (γ,np) and (γ,nα) reaction cross sections. However, due to the lack of those exclusive cross sections in the format, it was assumed in the case of ^{208}Pb that the (γ,1nx) is equal to the ^{207}Pb production cross section. This assumption is valid for nuclides with a large mass number. The fitted results for ^{208}Pb are in reasonable agreement with the data of Harvey et al. and Veyssiere et al. which were corrected by the factors recommended by Berman et al. [1].

Detailed estimate of energy-dependent uncertainties on the F_i factors proposed by Varlamov [1.3] was reported in the case of ^{181}Ta. The uncertainty of F_i factors for photon strength function was investigated by adopting the eight Lorentzian types. The results were consistent with those obtained with the TALYS code as reported in Sect. 3.5 in this report, though the latter indicates large uncertainties above the threshold energy of (γ,3n) reaction. The differences between CMPNR and the present calculations for F_1 and F_3 become large when F_1 is below 0.1 and the (γ,4n) reaction channel is open, respectively.

Experimental data for ^{129}I not yet in EXFOR were reported. Horikawa et al. [2] measured the inclusive photoneutron yield cross sections for ^{129}I at the NewSUBARU facility (BL01). The photon beam was semi-monochromatic LCS gamma-rays which were adjusted to be linearly and circularly polarized. The comparison among IAEA, TENDL-2015 and the present cross sections was made. The result is almost consistent for all libraries.

The remaining and planned works are to send the comparison plots after the release of new JENDL/PD library, to re-evaluate the photonuclear data with new experimental data taken in the framework of the CRP, and to evaluate the data of nuclides newly included in IAEA PD library by the CCONE code.

References

[1] B.L. Berman, *et al.*, Phys. Rev. C**36** (1987) 1286-1292.
[2] K. Horikawa, *et al.*, Review of Laser Engineering **39** (2011) 445-447.

2.5. Progress Report for Update of the Photonuclear Cross Sections, Young-Sik Cho, Korea Atomic Energy Research Institute

1. Nuclides to be evaluated

Originally an update of the photonuclear cross sections for ^{12,13}C, ^{14,15}N, ^{16,17,18}O, ^{24,25,26}Mg, ^{27,28,29,30}Si, ^{32,33,34,36}S, ^{35,37}Cl, ^{39,40,41}K, ^{40,42,43,44,46,48}Ca, ^{63,65}Cu, ^{64}Zn, ^{93,94}Nb, and ^{121,123}Sb was planned for this CRP. These nuclides are in the existing IAEA photonuclear library and were chosen as they seem to still have some room to improve. However, after discussion at the first RCM, the plan was changed to evaluate the new nuclides which are not in the IAEA library. The nuclides under evaluation are listed in Table 1, including the additional ones with the new F_i-corrected data.

TABLE 1. THE NUCLIDES UNDER EVALUATION

Nuclides not in the IAEA library	^{14}C, ^{75}As, ^{76,78,82}Se, ^{140,142,143,144,145,146,148,150}Ce, ^{153}Eu, ^{175}Lu, ^{186,188,189,190,192}Os
Nuclides with the new Fi-corrected data	^{63,65}Cu, ^{91,94}Zr, ^{115}In, ^{116}Sn, ^{133}Cs, ^{138}Ba, ^{159}Tb, ^{181}Ta, ^{197}Au, ^{208}Pb, ^{209}Bi

2. Evaluation methods

Experimental data and F_i-corrected data were mainly collected from the EXFOR database. The experimental data produced under this CRP are also planned to be used for the evaluation work in the future. As for the nuclear reaction model code, the TALYS code was used as it was considered appropriate for the automatic model parameter tuning system which are being employed to facilitate the evaluation work. The optical model parameters, the level density-related parameters and the GDR parameters were adjusted to fit the calculated cross sections to the experimental data or the F_i-corrected data, if any, for the nuclides in Table 1. The exciton model for the pre-equilibrium reaction, the Brink-Axel Lorentzian for the gamma-ray strength function, and the constant temperature model for the level densities were used in these evaluations.

3. Evaluation results

One example result of the photonuclear cross section evaluations is shown in Figure 1.

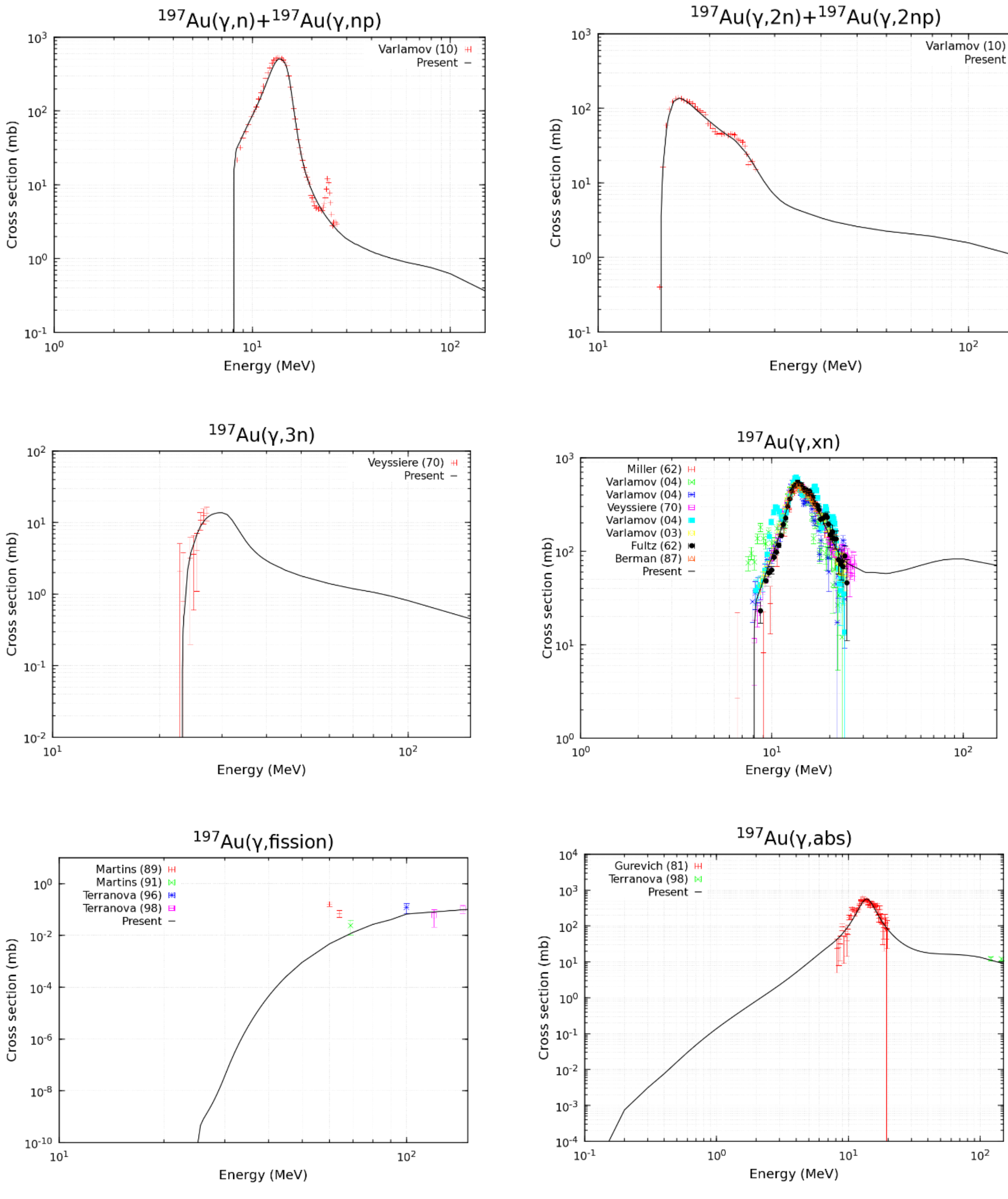


FIG. 1. Photonuclear cross sections for ^{197}Au.

Here the reaction model parameters were adjusted to fit the calculations to the F_i-corrected data and the measured fission cross sections. Overall, the calculated cross sections well reproduce the reference data.

2.6. Progress on the Photonuclear Data and PSF Evaluation at CNDC, R.R. Xu, X. Tao, China Institute of Atomic Energy

The current research plan at CNDC includes:

- Total update of evaluation of photonuclear data for 28 nuclei: ^{6,7}Li, ^{10,11}B, ^{9}Be, ^{27}Al, ^{51}V, ^{50,52,53,54}Cr, ^{54,56,57,58}Fe, ^{63,65}Cu, ^{90,91,92,94,96}Zr, ^{180,182,183,184,186}W, ^{209}Bi. Among them, 12 nuclei are listed in this CRP contract: ^{9}Be, ^{51}V, ^{50,52,53,54}Cr, ^{91,92,96}Zr, ^{180,183}W, ^{209}Bi, because they have been adopted in the previous IAEA Photonuclear Data (PD) Library 1999.
- Development of theoretical tools for calculations up to 200 MeV, and extensive theoretical calculations of photonuclear cross sections using the latest codes: GMEND and GLUNF.
- Assessment of experimental data for relevant nuclei in order to recommend experimental data to be used in the evaluation.
- Systematic comparison of calculated and recommended experimental photonuclear data to improve the models and codes.
- Systematic study of impact of models of photo strength functions on the photo-absorption cross sections and parameter adjustment.
- Assembly of photonuclear data file in ENDF-6 format so that it can be included in the CRP PD library for broader dissemination.

- **Improvement of the methods at CNDC:**

(1) By now, the theoretical code MEND-g which is based on the MEND code has been extended by H. Cai to calculate photonuclear reaction cross sections of medium-heavy nuclei up to 200 MeV. Besides the equilibrium emission process, the pre-equilibrium process with the door state 2p-2h is also included. In addition, up to eighteen emission channels are considered in MEND-g below 200 MeV, which leads to calculations of more than 570 million reactions.

(2) As for the calculation for light nuclei in the medium-high energy region, the GLUNF codes for ^{6,7}Li, ^{9}Be, ^{10,11}B, ^{12}C developed at CNDC by J.S. Zhang are used. In these codes, the open channels are specially analysed for each nucleus, and when the 2nd particle emission is considered, the total number of open channels are shown as: ^{6}Li(12), ^{7}Li(12), ^{9}Be(26), ^{10}B (24), ^{11}B(35), ^{12}C(143).

(3) Photon strength function (PSF) used in calculations of the photo-absorption cross sections are also discussed in our work. The code, named CPSF, is specially built by Y. Tian at CIAE. Six empirical functions, SLO, MLO1, MLO2, MLO3, EGLO, GFL, are compiled in CPSF, and a semi-microscopic model, RQRPA, is also introduced to produce the PSF values.

- **Results in the PSF and PD evaluations:**

(1) In our evaluations, the PSF parameters are normally adjusted to the recommended experimental photo-absorption data and (γ,1n) cross sections. Values are recommended according to the best χ^2 fit or from eye-judgement; The PSF parameters are also extrapolated to the related isotopes for which experimental data are scarce. Some preliminary results of PSF parameters in our work are shown in the presentation.

(2) Some examples are presented to elaborate the evaluation methodology that includes both experimental data assessment and theoretical calculation. For instance, in the evaluation for isotopes of W, the coherence of experimental data for (γ,abs), (γ,1n), (γ,np), (γ,2n), (γ,2np), (γ,3n) from different measurements was analysed, and the data were adjusted according to our results.

(3) A presentation was given by Xi Tao (CNDC) on the evaluation procedure for ^{52}Cr. In this work, a new evaluation of ^{52}Cr was performed. Using the F_i-factor method similar to Varlamov's, the measured (γ,abs), (γ,n), (γ,p) cross sections were assessed and adjusted for our theoretical calculation. The (γ,xn) cross sections measured by B.S.Ishkhanov was revised by factor 0.81. The results of theoretical calculations by MEND-g were in good agreement with the experimental data. The ^{52}Cr(γ,abs) data were fitting by adjusting the PSF, and the fitted PSF was used to calculate the absorption cross sections of the other isotopes, ^{50}Cr, ^{53}Cr, and ^{54}C. The preliminary results of ^{50}Cr, ^{53}Cr, and ^{54}Cr were shown.

- **Theoretical F_i for neutron multiplicity:**

F_i is key to evaluating experimental partial neutron emission cross sections from the experimental σ(γ,xn). We derived the theoretical F_i values of ^{181}Ta using the MEND-g code, and compared F_1, F_2, F_3 with the calculations by EMPIRE-3.2, TALYS, CCONE, COH, and the evaluation by Varlamov.

2.7. Simplest Expression for E1 PSF and renewed databases for GDR parameters, V.A. Plujko, Taras Shevchenko National University

In the report, results are presented on modification, testing and validation of the simple expressions for the photon strength functions (PSF) using new and revised experimental data [1].

Updated values and corresponding uncertainties of Isovector Giant Dipole Resonance (GDR) parameters are determined. These quantities were obtained by the least-squares fitting of theoretical photoabsorption cross sections to experimental data. The theoretical photoabsorption cross sections were taken as a sum of the components corresponding to the excitation of the GDR and quasideuteron photodisintegration. The GDR component of the photoabsorption cross section was calculated within the framework of two different Lorentzian models: a Standard Lorentzian (SLO) model and a Simplified version of the Modified Lorentzian (SMLO) approach [2-4]. For deformed nuclei, an approximation applied to axially deformed nuclei was adopted.

The systematics of the GDR parameters was determined from the data tables of GDR parameters in ranges of axially deformed (150<A<190, 220<A<253) and spherical nuclei. For average GDR energy, it was found $E_r = e_1\sqrt{4NZ/A^2}\cdot A^{-1/3}/(1.0+e_2A^{-1/3})^{1/2}$ (MeV) with the values e_1=137.0 ± 6.6, e_2=10.46 ± 1.48 for SLO model and e_1=134.0 ± 6.0, e_2=9.65 ± 1.30 for SMLO model. For resonance width systematics, the power expression $\Gamma_r = c\,E_r^{\delta}$ (MeV) was taken and the new values of parameters c,δ were found, namely, c=0.30 ± 0.17, δ=1.00 ± 0.20 for SLO and c=0.33 ± 0.20, δ=0.98 ± 0.22 for SMLO. The mean values of GDR strength in units of the Thomas-Reiche-Kuhn sum rule was found to be equal to s=1.155 ± 0.013 for SLO and s=1.188 ± 0.015 for SMLO.

Comparisons between existing global Lorentzian models (SLO, EGLO, SMLO, TLO) [2-6] and experimental data for photoabsorption and gamma-decay were performed. On average, SMLO for E1 transitions and SLO for M1 were determined at gamma-ray energies till 30 MeV as the most suited model within criterion of minimal value of f rms deviation factor,

$$f = \exp\left[\frac{1}{n}\sum_{i=1}^{n}\ln^2\left[\sigma_{\mathrm{model}}\left(\varepsilon_{\gamma,i}\right)/\sigma_{\mathrm{exp}}\left(\varepsilon_{\gamma,i}\right)\right]\right]^{1/2}.$$

This work is partially supported by the IAEA through the CRP on Updating the Photonuclear Data Library and generating a Reference Database for Photon Strength Functions (#F41032).

References

[1] Compilation and Evaluation of γ-Ray Data, IAEA Report INDC(NDS)-0649, P. Dimitriou, R.B. Firestone and S. Siem, 2013; https://www-nds.iaea.org/publications/indc/indc-nds-0649.pdf.

[2] T. Belgya, *et al.*, Handbook for calculations of nuclear reaction data: Reference Input Parameter Library-2, IAEA-TECDOC-1506, 2005; http://www-nds.iaea.org/RIPL-2/.

[3] R. Capote, *et al.*, Nucl. Data Sheets **110** (2009) 3107; http://www-nds.iaea.org/RIPL-3/

[4] V.A. Plujko, R. Capote, O.M. Gorbachenko, At. Data Nucl. Data Tables **567** (2011) 97.

[5] J. Kopecky, in Handbook for calculations of nuclear reaction data. Reference Input Parameter Library (RIPL), IAEA-TEDOC-1034, 1998, Ch.6; http://www-nds.iaea.or.at/ripl/

[6] A.R. Junghans, *et al.*, Phys. Lett. B**670** (2008) 200.

2.8. Microscopic description of the photon strength function, S. Goriely, Université Libre de Bruxelles

As detailed in the first RCM in 2016 [1.3], the HFB+QRPA method based on the Gogny D1M interaction have been applied to calculate the E1 [1] and M1 [2] photoabsorption strength functions for a large set of nuclei. To reproduce experimental data, some phenomenological corrections need to be included to take the effects beyond the standard 1p-1h QRPA excitations, the coupling between the single-particle and low-lying collective phonon degrees of freedom, as well as the damping of the collective motions into account. These effects have been included systematically, as simple energy or mass dependent expressions of the energy shift and width of the Lorentzian function used to fold the QRPA strength [1-2]. With such empirical corrections, it was shown that it is possible to reproduce satisfactorily the photoabsorption measurements, as well as the ARC, Oslo and NRF data compiled in the present CRP. Note that for the M1 strength, the low energy scissors mode is naturally described in the deformed QRPA calculation by the K=1+ component. The QRPA scissors mode is in good agreement with available data in the rare-earth region [2] and found to affect significantly $<\Gamma\gamma>$ as well as the neutron-capture cross section of deformed nuclei.

As far as the photoexcitation strength function is concerned, we propose new expressions inspired from the shell model predictions [3] for both the E1 and M1 strength. More specifically, the photoexcitation strength function is expressed as

$$f_{E1}(\varepsilon_\gamma)=f_{QRPA}(\varepsilon_\gamma) + f_0\, U \,/\, [1+\exp(\varepsilon_\gamma - \varepsilon_0)] \qquad (1)$$

$$f_{M1}(\varepsilon_\gamma)= f_{QRPA}(\varepsilon_\gamma) + C \exp(-\eta\, \varepsilon_\gamma)\, [1 + F\, \varepsilon_\gamma^3] \qquad (2)$$

where f_{QRPA} is the D1M+QRPA strength at a photon energy ε_γ, U (in MeV) is the excitation energy of the initial state and f_0~5 10^{-10} MeV^{-4}, ε_0~5MeV, C~10^{-7} MeV^{-3}, η~2MeV^{-1} and F~0.4MeV are free parameters adjusted on the shell model results [3]. While the E1 zero limit (Eq. 1) is found to have a rather small effect on the average radiative width $<\Gamma\gamma>$ and radiative neutron capture cross sections, the above-given M1 upbend form at low energy (Eq. 2) plays a significant role. The final D1M+QRPA plus zero limit (Eqs. 1-2) gives rise to $<\Gamma\gamma>$ in fair agreement with experimental data (Fig. 1), and in contrast to the RIPL-3 GLO model which significantly underestimates the radiative width (like SMLO does, see below).

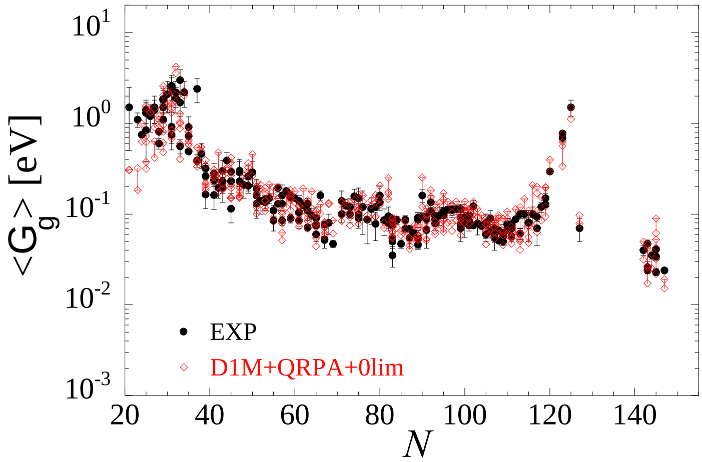


FIG.1. Comparison between experimental (RIPL-3) and Gogny-HFB+QRPA plus zero limit prediction of the average radiative width <Γγ> as a function of the neutron number. The errors bars on the theoretical predictions are obtained with different nuclear level density models, all tuned to reproduce the s-wave spacings at the binding energy.

A full library of E1 and M1 strength functions for a few thousand nuclei of interest in nuclear applications is being constructed. A systematic comparison has been made with the SLO and SMLO models proposed by V. Plujko. While for nuclei close to the valley of β-stability, a rather similar E1 strength in the giant dipole region is predicted, at low energies, the D1M+QRPA strength is systematically lower than the SLO and larger than the SMLO. For exotic n-rich nuclei, non-Lorentzian shapes are predicted by the QRPA approach which is therefore in strong disagreement with the SLO and SMLO approaches. The SLO also tends to overestimate <Γγ>, while the SMLO (neglecting the temperature effects) largely underestimates <Γγ>, as shown in Fig. 2.

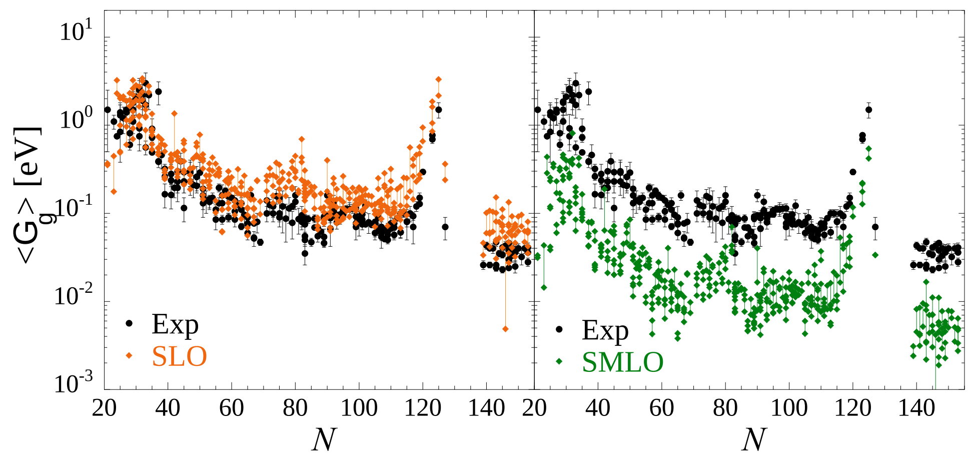


FIG. 2: Same as Fig.1 for the SLO and SMLO models

Large differences are found in the predictions of the neutron capture Maxwellian-averaged cross section (MACS) when using the S(M)LO models or the D1M+QRPA plus zero limit approach, as illustrated in Fig.3 for the SMLO case.

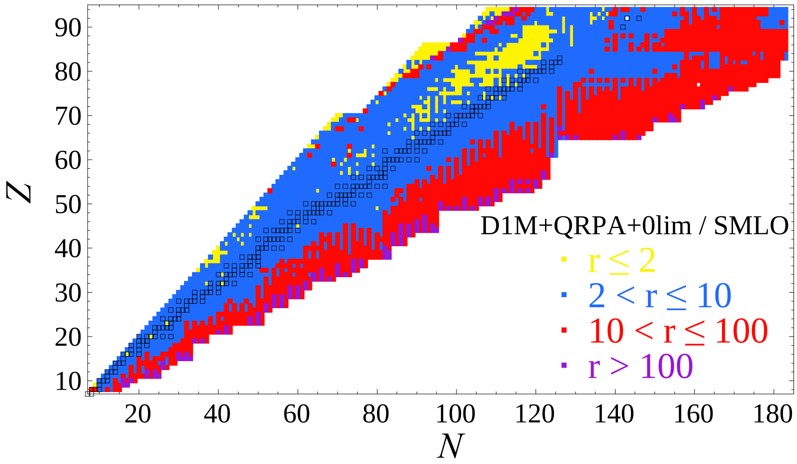


FIG.3: Ratio of the MACS at T=10^9K obtained with the D1M+QRPA plus zero limit approach with respect to those obtained with the SMLO models.

References

[1] M. Martini, S. Péru, S. Goriely, S. Hilaire, F. Lechaftois, Phys. Rev. C**94** (2016) 014304.
[2] S. Goriely, S. Hilaire, S. Péru, M. Martini, et al., Phys. Rev. C**94** (2016) 044306.
[3] K. Sieja, Phys. Rev. Lett. **119** (2017) 052502.

2.9. Progress report on empirical model for M1 scissors mode, F_i-values for ^{181}Ta and evaluation of photo-induced reactions on ^{39,41}K, Toshihiko Kawano, Los Alamos National Laboratory

Kawano presented three topics; the final result of the M1 scissors mode estimation, inter-comparison of the calculated F-values, and evaluation of the photo-induced reaction on ^{39,41}K.

The strength of the M1 scissors mode was estimated by comparing the statistical Hauser-Feshbach calculations with evaluated neutron capture cross sections, and the result was published in [1].

The F-values for ^{181}Ta were calculated with 6 nuclear reaction model codes, CMPNR, TALYS, CCONE, CoH3, Empire, and MEND-g, from the threshold energy of (γ,n) channel up to 40 MeV. These calculations were performed by the CRP participants using default model input parameters. It was reported that TALYS, CCONE and Empire results are not so different in general, while CoH3 gives smaller value and CMPNR stays high. Kawano explained that the smaller F-values are due to a damping factor applied to the bound 1p-1h configuration in CoH3, as well as an approximation made to the quasi-deuteron absorption part. By removing this approximation, in which the quasi-deuteron process is initiated as a 1p-1h configuration both in the neutron and proton shells, the calculated F_1 value in the 20 MeV region increases to the level of other model code predictions. However, this has a very modest impact on the calculation at higher energies.

The photo-nuclear data evaluation for ^{39,41}K was performed at LANL [2], primarily focused on the production of radio-active isotopes. The statistical model calculation is performed with the CoH3 code, and the calculated ^{39}K(γ,n)^{38m}K cross section is compared with the available experimental data. The calculation was extended to ^{41}K using the parameter systematics. It was reported that the experimental data of Webb et al. (1971) [3] could have a large systematic uncertainty by comparing the neighboring nuclei. Kawano mentioned that the meta-state production data in the evaluated photonuclear data library could be important for some database users.

References

[1] T. Kawano, *et al.*, Phys. Rev. C **96**, 024612 (2017).
[2] T. Kawano, *et al.*, LANL report LA-UR 14-20531, 2017.
[3] D.V. Webb, et al., Nucl. Phys. A **171** (1971) 324.

2.10. ARC Atlas contribution, Jura Kopecky, JUKO Research

Resonance capture is the direct experimental way to determine the partial radiative width in a single-channel reaction mode and to convert it into the gamma-ray strength function. Experimentally, either the capture by discrete resonances (using TOF spectrometry) or by a large number of resonances measured simultaneously (using filtered neutron beam) can be used. In this report, the *Average Resonance Capture* (ARC) data, measured at different filter beam facilities, are revisited and re-analysed. This includes all measurements made between 1970 and 1990 currently recovered, some of which are only partially exploited. The majority of these measurements were devoted to the spectroscopy of low lying final states and only a very limited number addressed the *Photon Strength Function* (PSF) properties. The main aim of this work is to establish a complete data base of ARC measurements.

The final Atlas file will include the selection of the best entries converted in PSF format for verification of different strength-function models. The final Atlas_f(L) /2017/ data base includes 50 nuclides between A = 76 and 250, adopted from boron and 2 keV experiments, with 10 and 40 nuclides, respectively and the complete information is given in IAEA report INDC(NDs)-0738 (http://int-nds.iaea.org/publications/indc/indc-nds-0737.pdf) .

The covered transition E_γ range is about 3 MeV broad below the neutron separation energy. The absolute calibration into the 10^{-8} MeV^{-3} scale has been done by a comparison with DRC <f(E1)> data from INDC(NED)-013. The M1 data, corrected for p-wave contributions, have been verified against DRC measurements, and are in a good agreement. The plot-book of all ARC data can be requested from the author as JUKOLIB-ARC-2017 report.

2.11. Database of Experimental Photon Strengths, Richard B. Firestone, University of California at Berkeley

The first draft of a database of primary neutron capture photon strength data from thermal (EGAF [1]), Resonance (Literature), and Average Resonance Capture (ARC, literature) measurements has been prepared. It contains >14,000 E1, M1, E2, and unknown multipolarity primary γ-ray photon strength measurements. The data have been averaged in a separate database of >2,500 binned thermal, resonance, and ARC E1, M1, E2, and unknown multipolarity measurements for the systematic study of photon strength as a function of A, Z, N, γ-ray energy, J^π, and other variables. These databases contain traditional reduced photon strengths proportional to single particle strengths and can be compared to conventional reaction photon strengths, defined as the average photon strength multiplied by the level density, when dividing by D0, the s-wave level separation at the neutron separation energy S_n. An additional correction to the photon strength is required to account for unobserved, weak transitions. This correction can be made by comparing the number of levels expected to be populated in a given energy bin to the number of levels actually populated and determining fraction of total photon strength this represents. From the experimental level schemes we find that ≈60-80% of levels that are expected to be populated by dipole transitions and assuming a Porter-Thomas distribution [2] of photon strengths this should represent >97% of the total photon strength.

The global systematics of photon strengths as a function of odd or even Z or N have been investigated for E1, M1, and E2 transitions. In all cases it is observed that photon strength increases dramatically with decreasing Z or N and there is a substantial increase in photon strength near the ^{208}Pb doubly magic closed shell. Photon strength also increases with decreasing γ-ray energy for all multipolarities. In addition there are significant differences in the average photon strengths for odd-odd, even-even, and even-Z/odd-N nuclei. The E1/M1 and M1/E2 photon strength ratios have also been investigated. Both ratios increase rapidly as a function of A for even-even nuclei. For odd-odd and even-Z/odd-N nuclei the average E1/M1 photon strength ratio is nearly constant for all A and the M1/E2 photon strength ratio decreases rapidly with increasing A. The global average E1/M1 ratio has been compared with the evaluation of Kopecky [3]. Both evaluations agree closely when compared as a function of A, there is a substantial discrepancy when compared as a function of primary γ-ray energy. Finally, the photon strengths have been compared as a function of spin of the capture state. For even-A nuclei both E1 and M1 photon strengths are larger for low-spin rather that high-spin capture states, and for odd-A nuclei this trend is also true for E1 transitions but the opposite trend is observed for M1 transitions.

The photon strength trends show significant fluctuations for individual nuclei. While they may provide a guide for developing a better theoretical understanding of photon strength it is best to evaluate the photon strengths of each nucleus independently for applied purposes. This has been demonstrated for ^{57}Fe which has an unusually complete set of primary photon strengths form E1, M1, E2, and M2 transitions. The primary photon strengths have been divided into 1 MeV bins and corrected for missing transitions assuming a constant temperature level density model. E1 photon strengths decrease exponentially from 7.6-1.5 MeV, M1 photon strengths are nearly constant from 5-2.5 MeV and increase exponentially from 2.5-0.5 MeV, E2 photon strengths increase exponentially from 5-2.5 MeV, and a single M2 photon strength measurement is four orders of magnitude weaker than a comparable energy E1 transition. However, a completely different picture emerges for the photon strength deexciting levels below the neutron separation energy in ^{57}Fe. There E1 photon strengths are nearly constant from 0-3 MeV and 50× stronger than comparable primary E1 γ-rays, while M1 photon strengths increase more gradually from 0-5 MeV with comparable strengths to primary γ-rays near 5 MeV. A major difference in these two regimes of ^{57}Fe photon strength is that the capture state in ^{57}Fe is positive parity while the lower levels that were considered have negative parity. Recent shell model calculations by Schwengner confirm these observations predicting a strong, low energy photon strength upbend for M1 transitions from positive parity states and a much smaller increase in strength for M1 transitions from negative parity states.

The new photon strength library will be completed by the 3rd RCM of the CRP with a special format for dissemination by the IAEA Nuclear Data Section. The feasibility of adding photon strength data from the broader ENSDF library will be considered. In addition, photon strengths inferred from this library will be compared with values from the Oslo and (γ,γ') libraries and provided for contribution to the reaction photon strength database.

References

[1] Database of Prompt Gamma Rays from Slow Neutron Capture for Elemental Analysis R.B. Firestone, H. D. Choi, R.M. Lindstrom, G.L. Molnar, et al, IAEA STI/PUB/1263 (2007).

[2] C.E. Porter and R.G. Thomas, Phys. Rev. **104** (1956) 483.

[3] Atlas of Average Resonance Capture Data, J. Kopecky, NDC(NDS)-0738 (2017) (http://int-nds.iaea.org/publications/indc/indc-nds-0737.pdf) .

2.12. Evaluation of γ-Ray Strength Functions, Ronald Schwengner, Helmholtz-Zentrum Dresden-Rossendorf

Results of photon-scattering experiments using the γELBE bremsstrahlung facility [1] at the electron accelerator ELBE of Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and using light-ion reactions at the Oslo cyclotron laboratory (OCL) of the University of Oslo are compared for nuclides selected as benchmark nuclides during the first RCM in 2016. These benchmark nuclides are ^{74}Ge, ^{89}Y, ^{96}Mo, ^{98}Mo, ^{139}La and ^{181}Ta.

For the Mo isotopes, possible uncertainties not taken into account in the analyses described in Refs. [2,3] may result from the normalization of the simulated atomic background. As a consequence of an increase of the background by a factor of about 1.3, the dipole strength function is reduced and comes closer to the one deduced from OCL experiments [4]. However, there is still no overall agreement of γELBE and OCL values. In addition to the magnitude, the shapes of the strength functions differ, which may be due to the different population of states in (α,α') and (^{3}He,^{3}He') or (p,p') reactions. A variation of the level density models was carried out in the cascade simulations for ^{96}Mo. The back-shifted Fermi gas and constant-temperature models with the parameters from Ref. [5] give comparable results, whereas the level density used in Ref. [4] results in a different magnitude and shape for the strength function.

The strength function deduced from the (γ,γ') experiment for ^{89}Y at γELBE [6] is after a maximum correction by a factor of 1.09 still considerably higher than the upper limit of the strength function deduced from the (d,p) experiment at OCL [7]. Moreover, the (γ,γ') strength function includes characteristic resonance-like structures around 6 MeV that correlate with prominent peaks in the measured γ-ray spectra caused by intense dipole transitions to the ground state. Obviously, the deexciting 1- states are not populated with a comparable intensity in the (d,p) experiment.

In the case of ^{74}Ge, a good agreement of the strength functions deduced from (γ,γ') [8] and (^{3}He,^{3}He') [9] experiments is achieved. New results for 80Se from γELBE were published [10].

New data from experiments at γELBE and HIγS are presented for ^{54}Fe. They include prominent E1 and M1 transitions from about 6 to 11 MeV. The analysis of the quasicontinuum is in progress. Experiments at γELBE were also performed for ^{66}Zn and are currently analyzed.

The development of the low-energy M1 strength was investigated using the shell-model code NuShellX@MSU [11] for the isotopes ^{60}Fe, ^{64}Fe, ^{68}Fe [12]. The calculations show that the low-energy enhancement of M1 strength becomes weaker when going from ^{60}Fe to ^{68}Fe, i.e. when going into the open shell and successively occupying the neutron g9/2 orbit. At the same time, a bump develops around 3 MeV, which can be attributed to the scissors mode. The sum of the strengths in the low-energy upbend and in the scissors resonance stays nearly constant, hence strength is shifted from low energy to the scissors region. The calculated summed M1 strength in the scissors region is about three times greater than that found in (γ,γ') experiments, which is in agreement with the findings of light-ion induced experiments [13].

References

[1] R. Schwengner *et al.*, Nucl. Instrum. Methods A **555** (2005) 211.
[2] G. Rusev *et al.*, Phys. Rev. C **77** (2008) 064321.
[3] G. Rusev *et al.*, Phys. Rev. C **79** (2009) 014303.
[4] H. Utsunomiya *et al.*, Phys. Rev. C **88** (2013) 015805.
[5] T. von Egidy and D. Bucurescu, Rev. C **80** (2009) 054310.

[6] N. Benouaret *et al*., Phys. Rev. C **79** (2009) 014303.
[7] A.C. Larsen *et al*., Phys. Rev. C **93** (2016) 045810.
[8] R. Massarczyk *et al.,* Phys. Rev. C **92** (2015) 044309.
[9] T. Renstrøm *et al.,* Phys. Rev. C **93** (2016) 064302.
[10] A. Makinaga *et al.,* Phys. Rev. C **94** (2016) 044304.
[11] B.A. Brown and W.D.M. Rae, Nucl. Data Sheets **120** (2014) 115.
[12] R. Schwengner, S. Frauendorf, and B.A. Brown, Phys. Rev. Lett. **118** (2017) 092502.
[13] A. Simon *et al.,* Phys. Rev. C **93** (2016) 034303.

2.13. Measurements of Photon Strength Functions, Mathis Wiedeking, iThemba LABS

The importance of complementary measurements is becoming increasingly apparent. A full understanding of the total photon strength function (PSF) and its individual resonances can only be achieved by coordinated measurements utilizing different techniques and reactions. Such experimental efforts make available a wide range of data to unravel the many details of the PSF and provide important benchmarks. These are valuable additions to any database as stated in the Summary Report of the Consultants Meeting for this CRP, which recommends to "…perform benchmark comparisons of data from multiple experiments using different techniques on a given isotope" [1.3].

The three contractual projects intend to provide such complementary data and are briefly summarized:

(1) Stable and extremely low abundant neutron-deficient nuclei are referred to as p-nuclei. One of them is 180Ta which is one of the least abundant isotopes found in the solar system and is also a special case since the abundance information is based on a 77 keV excited state with a half live of more than 1015 years while the ground state in ^{180}Ta has a life time of only ~8 hours. Results from ^{180}Ta abundance calculations are generally debatable due to uncertainties in the nucleosynthesis processes leading to the production of ^{180}Ta but also due to uncertainties in the nuclear reaction rates arising from nuclear input such as optical potentials, nuclear level densities and photon strength functions [2]. We have, for the first time, measured the low-energy part of the PSF in ^{180}Ta, ^{181}Ta, and ^{182}Ta. The region of the quasi-continuum was populated through several reactions: ^{181}Ta(^{3}He,^{4}He)^{180}Ta, ^{181}Ta(d,t)^{180}Ta, ^{181}Ta(^{3}He,^{3}He')^{181}Ta, ^{181}Ta(d,d') and ^{181}Ta(d,p)^{182}Ta. The PSFs were extracted with the Oslo Method independently for each of the different reactions. The PSFs show good agreement with one another as may be expected for neighboring isotopes. For ^{181}Ta, data from a (γ,γ') measurement are also available [3] and show reasonable agreement in the region of high excitation energies (below the neutron separation energy).

(2) The rare earth isotopic chain of Samarium provides an excellent opportunity to systematically investigate the evolution of nuclear structure effects from the near spherical (β_2=0.09) ^{144}Sm isotope to the highly-deformed system ^{154}Sm (β_2=0.34). As the nuclear shape changes, statistical properties, such as the nuclear level density and PSF are expected to be affected. In particular resonance modes, such as the Pygmy Dipole (PDR) and Scissors resonances (SR) may reveal interesting features as their evolution is investigated across several nuclei in an isotopic chain. Our work will investigate these two features in particular the PDF and SR: a) In recent years there has been a surge in experimental studies of the PDR states lying on the low-energy tail of the isovector giant dipole resonance. The PDR has been interpreted as an exotic mode of excitation due to the motion of a weakly bound neutron excess against an almost inert proton-neutron core [4]. The photo-absorption cross section of 154Sm, deduced from inelastic proton scattering shows the surprising presence of two bumps with centroids at ~6 MeV and ~8 MeV [5]. This resonance-like structure was assigned to the PDR in this deformed nucleus 154Sm. Since this PDR shows the same energy ratio as the two peaks

observed in the GDR, a tentative interpretation of this splitting could be connected to the splitting of the resonance structure with respect to their K quantum number. This interpretation would lead to a macroscopic picture of a deformed proton-neutron saturated core, oscillating against a neutron skin along two different axes. An experiment at iThemba LABS was also performed, using the inelastic scattering of alpha particles to excite the PDR in ^{154}Sm and subsequently detect its γ-ray decay [6]. Most reliable knowledge can be obtained when results from several different experiments are compared and to complement the data we have performed the ^{154}Sm(d,d') experiment to measure the PSF with the Oslo Method. b) The strength of the SR mode is proportional to the square of the ground state deformation; hence even-even nuclei were initially considered to be the best candidates to exhibit well developed SR modes. However, it soon became apparent that this mode is also present in odd-even and odd-odd systems, although its intensity may be fragmented significantly enough to elude detection [7]. Recent work in the actinide region has uncovered that the SR exhibits a double bump structure, independent on the evenness or oddness of nucleonic numbers [8]. It is interesting to speculate that one of these structures is due to the isovector spin scissors mode which was only recently proposed [9]. However, such a splitting has not been reported for any of the rare-earth nuclei. The isotopes ^{148,149}Sm have already been measured, and a weak structure was identified to be due to the SR [10]. With data already available on these weakly deformed Sm nuclei, our measurements for the heavier Sm isotopes will be quite beneficial for our understanding on the evolution of the SR as the isotopic chain transitions from near spherical to very deformed.

(3) The shape of the PSF to individual discrete states has been extracted for ^{74}Ge using the Ratio Method [11] which utilizes primary γ-ray decays from defined excitation energy regions to low-lying discrete states. This approach has the potential to provide insight into the validity of the Brink hypothesis which stipulates that the PSF is only dependent on the γ-ray energy. The investigation of ^{74}Ge through the Ratio Method is appealing since this nucleus has already been studied using several other analytical methods and reactions ((γ,γ') from ELBE [12], (α,α') from iThemba LABS [13] and (^{3}He,^{3}He') [14] from the University of Oslo). ^{74}Ge was populated through the (p,p') reaction at a beam energy of 18 MeV utilizing a silicon particle telescope and Clover-type γ-ray detectors. The Ratio Method analysis has been completed but unfortunately statistics is not sufficient to extract primary γ-rays for to any states but the two lowest 2+ states at 596 and 1204 keV. For these two states the ratio was obtained albeit with large uncertainties due to low statistics. This makes a meaningful comparison to other data difficult.

References

[1] Byelikov et al., Phys. Rev. Lett. **98** (2008) 082501.
[2] Goriely et al., A&A 375 (2001) 35.
[3] Makinaga et al, Phys. Rev. C **90** (2014) 044301.
[4] Paar, Vretenar, Khan, and Colo, Rep. Prog. Phys. **70** (2007) 691.
[5] Krugmann Ph.D. thesis, Technische Universitaet Darmstadt 2014.
[6] Pellegri, private communication.
[7] Heyde, von Neumann-Cosel, and Richter, Rev. Mod. Phys. **82** (2010) 2365.
[8] Guttormsen et al., Phys. Rev. Lett. **109** (2012) 162502.
[9] Balbutsev, Molodtsova, and Schuck, Phys. Rev. C **88** (2013) 014306.
[10] Siem et al., Phys. Rev. C **65** (2002) 044318.
[11] Wiedeking et al., Phys. Rev. Lett. **108** (2012) 1625033.
[12] Massarczyk et al., Phys. Rev. C **92** (2015) 044309.
[13] Negi et al., Phys. Rev. C **94** (2016) 024332.
[14] Renstrøm et al, Phys. Rev. C **93** (2016) 064302.

2.14. Validation of Photon Strength Functions and DICEBOX code, Milan Krticka, Charles University in Prague

(1) Calculations made with the DICEBOX code using photon strength function (PSF) models based on the “Oslo recommended data” were compared with the coincidence spectra from resonance neutron capture measured with the DANCE detector for ^{96,98}Mo isotopes. There are several problems related to the definition of models that are used in simulations. In the present simulations, it was assumed that “Oslo strength function data” correspond to the sum of E1 and M1 strength. The simulation then required a partition of this sum into individual E1 and M1 parts. This partition is not unique but in the simulations we used only one of the possible partitions. In addition, an extrapolation of the gamma strength to low gamma energies (Oslo data end at about 1.5 MeV) and eventually also to “high” energies (close to neutron separation energy) is needed in the simulations. Different ways of extrapolating can lead to very different shapes of the PSF. Several extrapolations to low gamma energies was tested. They mainly served as a possible test of the presence of the low-energy enhancement (upbend). In addition, it was shown that predictions depend on the level density model. Tests with a few different level density models were presented. The comparison indicates that models containing a “strong” low-energy enhancement – assumed so far in simulations in M1 strength – are not compatible with the experimental data for both isotopes.

(2) Predictions for the singles gamma-ray spectrum from thermal neutron capture on ^{195}Pt obtained with models based on Oslo data were briefly compared with spectra measured at Budapest. It was stressed that similar problems with partition of the strength function into the E1 and M1 parts and extrapolation to low and high gamma energies arise. One possible partition into E1 and M1 strength was tested together with two different extrapolations of the strength function to low gamma energies. The experimental spectra were not reproduced satisfactory by the simulations. However, only one model of level density (constant-temperature model) was tested.

(3) Finally, the current status of the preparation of the code DICEBOX was reported. This fortran code, that allows simulation of gamma cascades including all the fluctuations expected within the statistical model, should become available to public via the IAEA web page during the current CRP. The code itself and a few examples of input files is ready for such a publication. However, the code manual is expected to be prepared by the end of the calendar year. The publication of the package, which will include the code, the manual and examples, is planned for the first months of 2018.

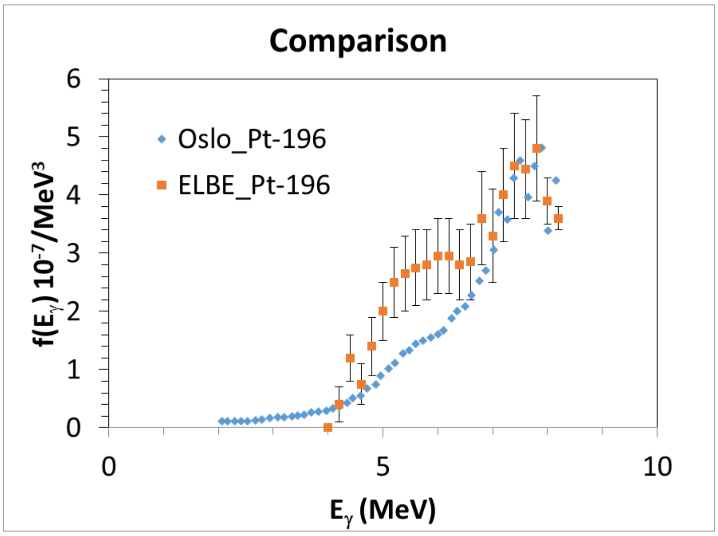
2.15. Update on (n,γ) studies of photon strength functions at Budapest, Tamás Belgya, Centre for Energy Research

A report on the following actions is given (number in parentheses is from the action table [1.3]):

(1) <u>Explore possibility of extracting relative PSF from thermal capture data (#17):</u> Photo Strength Functions (PSF) cannot be measured directly. Measurements of partial γ-decay width or partial level lifetime can be related to this quantity via corresponding PSF defining equations. Bartholomev et al. [1] have already identified the possible ways of measurements of strength functions. For the case of (n,γ), (p,γ), (γ,γ) etc. capture reactions, they recommend that “PSF can be obtained from calculating the shape of the unfolded experimental γ-ray spectral distribution using different trial strength functions until good agreement is observed.”. However, this method provides relative PFS. One way of calibrating is to determine the total relative gamma-decay width Γtot,rel using the obtained relative PFSs and then converting to absolute values using a conversion factor C which can be obtained as a ratio of the know Γtot,literature and the γtot,rel. id est C = Γtot,literature / Γtot,rel. The form of trial PSF can be

any already known prescription with adjustable parameters, but can also be a flexible function with free parameters (or individual amplitudes at suitable gamma energies). This work was completed for thermal capture spectrum of ^{114}Cd(n,γ).

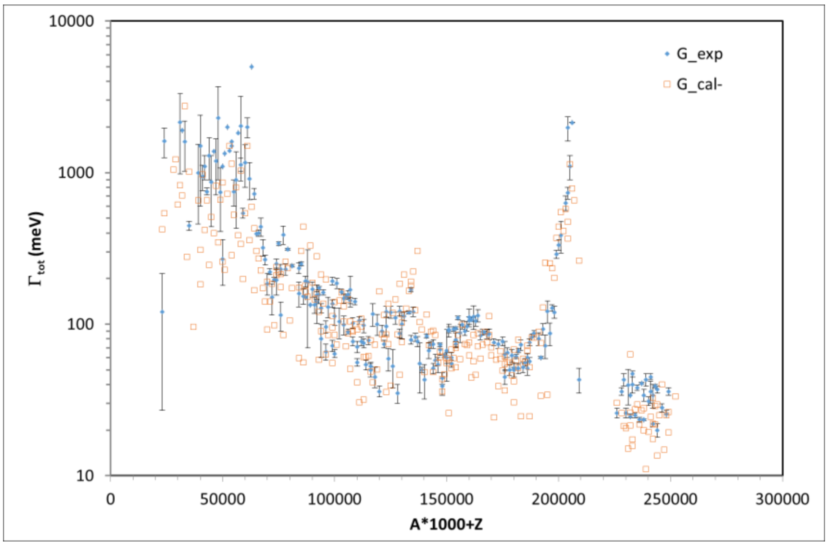
(2) Compatibility of thermal capture, NRF & Oslo PSF data for the case of ^{196}Pt (compound nucleus) will be checked (#22): (n,γ) and NRF [2] experiments were combined to prove that the two different sets of data can be described by a common set of PSF. The resulting PSF were compared with the PSF derived from the Oslo method [3]. A comparison is shown in the following figure:



While the uncertainty on the OSLO results is not given, the agreement is acceptable with the comment that a significant bump is observed in the NRF-(n,γ) data at around 5.5 MeV. A similar bump can be seen on the OSLO data, but with much smaller amplitude.

(3) Prepare a proposal for the PSF database web interface for presentation to and approval by the CRP (#36): The group involved in this action (Dimitriou, Zerkin for IAEA and Firestone) agreed that the best option would be if an EXFOR-like user interface was created by the IAEA for the strength function database, including experimental and theoretical data with the possibility of uploading user-defined data for graphical comparison.

In addition to the above work, total gamma decay width at binding energy were calculated with TLO E1, RIPL M1 and E2 strength functions for all of the 272 nuclei for which experimental result were listed by Mughabghab [4]. A comparison is shown in the following figure:



New thermal capture measurements were performed on a depleted (^{235}U 18 times less than natural) ^{238}U sample, but it turned out that about 30% of the data is coming from ^{235}U radiative capture, thus the experiment should be repeated with higher depletion. Efforts are being made to obtain such a sample from IRMM.

(n,γ) measurements were completed in spring 2017 within the Chanda project entitled as "Investigation of the gamma-strength function of Th-232 nucleus from thermal neutron capture" in collaboration with Department of Physics, Eskisehir Osmangazi University, Turkey. The measurement will be the PhD work of Celal Asici with the supervision of prof. Emel Algin at the Eskisehir Osmangazi University. Analysis of data will start in November 2017 with a visit of Celal Asici to Budapest.

This work was supported by the project number F41032 of IAEA and the EU FP7 CHANDA project.

References

[1] G.A. Bartholomev, E.D. Earle, A.J. Ferguson, J.W. Knowles, M.A. Lone, Gamma-Ray Strength Functions, in: M. Baranger, E. Vogt (Eds.), Adv. Nucl. Phys. **7**, Plenum Press, 1973: pp. 229–329.

[2] R. Massarczyk, G. Schramm, T. Belgya, R. Schwengner, R. Beyer, D. Bemmerer, Z. Elekes, E. Grosse, R. Hannaske, A.R. Junghans, Z. Kis, T. Kögler, C. Lorenz, K. Schmidt, L. Szentmiklósi, A. Wagner, J.L. Weil, Role of electric and magnetic dipole strength functions in the Cd 114 (γ,γ′) and Cd 113 (n,γ) reactions, Phys. Rev. C **93** (2016). doi:10.1103/PhysRevC.93.014301.

[3] F. Giacoppo, F.L.B. Garrote, T.K. Eriksen, A. Görgen, M. Guttormsen, T.W. Hagen, A.C. Larsen, Observation of low-lying resonances in the quasicontinuum of enhanced astrophysical reaction rates, EPJ Web of Conferences 93 (2015). doi:10.1051/epjconf/20159301039.

[4] S. Mughabghab, Atlas of Neutron Resonances, 5th Edition, Elsevier Science, 2006.

3. Technical Discussion

3.1. Definitions and notation

The definitions and notations to be used in this CRP [1.3] for photonuclear cross sections are those adopted by the previous CRP on Photonuclear Data Library (1996-1999) [1.1]. CRP participants were advised to use the same notations and definitions in their presentations and publications to ensure homogeneity and consistency with CRP reports and publications.

According to the photonuclear cross-section definitions in [1.1].

Exclusive cross section is a term used to describe an individual nuclear reaction of a specific, unique type, where all the secondary particles (ejectiles, residual nucleus) are known. For example, (γ,2n), (γ,p), (γ,np) each indicate particular reactions where the particles in the incident and outgoing channels are all identified and known.

Inclusive cross section, on the other hand is used to describe a process that includes all nuclear reactions leading to the production of a particular emission product. The emission product can be neutron(s), proton(s), gamma-rays(s) or a residual nucleus.

If neutrons are detected in an inclusive emission measurement, then the cross section is the inclusive photoneutron yield cross section, that includes the multiplicity of emitted neutrons:

$$\sigma(\gamma,xn) = \sigma(\gamma,n) + \sigma(\gamma,np) + \sigma(\gamma,n2p) + 2\sigma(\gamma,2n) + 2\sigma(\gamma,2np) + 3\sigma(\gamma,3n) + \cdots + \bar{\nu}(\gamma,F),$$

where $\bar{\nu}$ is the average multiplicity of photofission neutrons.

The total photoneutron cross section is given by:

$$\sigma(\gamma,sn) = \sigma(\gamma,n) + \sigma(\gamma,np) + \sigma(\gamma,n2p) + \sigma(\gamma,2n) + \sigma(\gamma,2np) + \sigma(\gamma,3n) + \cdots + \sigma(\gamma,F).$$

The sum of this cross section with the photo-charged-particle reaction cross section gives the total photoabsorption reaction cross section:

$$\sigma(\gamma,abs) = \sigma(\gamma,sn) + \sigma(\gamma,p) + \sigma(\gamma,2p) + \cdots + \sigma(\gamma,d) + \sigma(\gamma,dp) + \cdots + \sigma(\gamma,\alpha) + \cdots$$

For heavy nuclei the photoabsoprtion cross section can be approximated by the first term of the above equation

$$\sigma(\gamma,abs) \cong \sigma(\gamma,sn).$$

The most important symbols used throughout this document and the CRP are:

$\sigma(\gamma,abs)$	Photoabsorption cross section
$\sigma(\gamma,1n)$	Single photoneutron cross section
$\sigma(\gamma,1nx)$	Sum of cross sections with a single neutron in the final state (1*n*+1*np*+1*nα*+1*n*…)
$\sigma(\gamma,2n)$	Double photoneutron cross section
$\sigma(\gamma,2nx)$	Sum of cross sections with two neutrons in the final state (2*n*+2*np*+2*nα*+2*n*…)
$\sigma(\gamma,sn)$	Total photoneutron cross sections also known as $\sigma(\gamma,tot)$
$\sigma(\gamma,xn)$	Photoneutron yield or photoproduction cross section

3.2. Content of the Photonuclear Data Library – new priority nuclides

All the 164 nuclei which were identified as important for a wide range of applications and were included in the previous CRP (1999) are being revised by the CRP. In addition, 37 nuclei for which photonuclear data has become available since 1999, are being added to the updated library. At the 1st RCM it was also agreed that other possible user needs that may have emerged since 1999 should be explored, and an action was placed on Kawano and Dimitriou to provide an updated priority list.

Kawano presented his evaluation of $^{39,41}K(\gamma,n)$ which was triggered by the emerging interest in production of radioactive isotopes of K, Ar, Cl and P for medical applications (see Sect. 2.9 and presentation in Annex 3).

Dimitriou gave a list of the photonuclear reactions considered as alternative production routes of the most important radioisotopes used in theranostics applications based on reports from IAEA CRPs dealing with nuclear data for medical applications [3.1,3.2]. These include: highly enriched $^{100}Mo(\gamma,n)^{99}Mo$ and $^{238}U(\gamma,f)^{99}Mo$, $^{68}Zn(\gamma,p)^{67}Cu$, $^{48}Ca(\gamma,n)^{47}Ca\text{-}\rightarrow{}^{47}Sc$, $^{104}Pd(\gamma,n)^{103}Pd$, $^{54}Cr\ (\gamma,n)^{51}Cr$, $^{65}Cu(\gamma,n)^{64}Cu$, $^{48}Ti(\gamma,p)^{47}Sc$ and $^{46}Ti\ (\gamma,2n)^{44}Ti\rightarrow{}^{44}Sc$, which are already included in the IAEA PD library.

The advent of new facilities producing γ beams of high intensity and brilliance is opening new possibilities for cancer theranostic applications. The potential of photoproduction of medical radioisotopes with higher specific activity and at a much lower cost than the conventional methods using (n,f) or (n,γ) from a nuclear reactor or charged-ion beams from a particle accelerator means that new photoproduction routes of medical isotopes can be considered, such as (Refs [3.1-3.3]):

$^{170}Er(\gamma,n)^{169}Er$, $^{165}Er\ (\gamma,n)^{164}Er$, $^{187}Re(\gamma,n)^{186}Re$, $^{226}Ra(\gamma,n)^{225}Ra$ with decay to ^{225}Ac and ^{213}Bi and $^{132}Xe(\gamma,p)^{131}I$, $^{162}Dy(\gamma,p)^{161}T$, $^{178}Hf(\gamma,p)^{177}Lu$.

These reactions should be considered by the CRP and included in the Updated Photonuclear Data Library. However, at present experimental photonuclear cross-section data exist only for the following cases:

$^{187}Re(\gamma,n)^{186}Re$, $^{194}Pt(\gamma,tot)$, $^{178}Hf(\gamma,2n)^{176}Hf$, $^{178}Hf(\gamma,abs)$.

The above-listed cases will be evaluated and presented at the 3rd RCM. For the rest of the reactions in the list, the CRP participants would strongly recommend that measurements be performed.

In addition to the radioisotopes produced via photonuclear reactions, Ref. [3.3] lists several isomers that can be produced adequately by means of targeted photoexcitation (γ,γ'). The availability and quality of these data will also be addressed by the CRP participants. Work on updating the priority list of nuclides will continue until the 3rd RCM.

3.3. New photoneutron cross-section data

New measurements of photoneutron cross sections at NewSUBARU performed by the PHOENIX collaboration in 2016 are being analysed and delivered:

The (γ,xn) data measured in 2016 by Utsunomiya et al on Au, Tm, Y isotopes will be delivered by March 2018.

The (γ,n) data measured by the Oslo group on Os, Re, Ba, Ni isotopes will be sent to the CRP participants by early 2018 (13C is postponed to later in 2018). All data will be shared with CRP participants who commit themselves not to publish or disseminate them before publication by the experimentalists.

The (γ,xn) data on 9Be by Utsunomiya et al are now available and will be distributed to the CRP participants.

3.4. Photonuclear data in EXFOR

The completeness of EXFOR has been checked by V. Semkova using a special search tool available on the CINDA interface (http://www-nds.iaea.org/cinda/) that was developed by V. Zerkin.

The search tool revealed that about 170 publications from NSR are not compiled in EXFOR; many of the published data concern elastic and inelastic cross sections. The CRP will continue the effort to include all the data in EXFOR with the following actions:

Action on Varlamov to check the list of missing data from EXFOR produced through CINDA, sort out the photoneutron cross-section data in his region of relevance and compile the data for EXFOR. Also provide the list to Dimitriou for dissemination.

Action on Schwengner to check the list of missing data from EXFOR produced through CINDA, prioritize the publications for elastic and inelastic cross sections data and send the list to Dimitriou IAEA for dissemination.

Action on Dimitriou to submit the list of priority articles for compilation in EXFOR to NRDC. Deadline March 2018

The effort of finding missing data in EXFOR is to be continued by individual evaluators as well. So far, N. Iwamoto has found data on ^{129}I missing from EXFOR and has submitted them to IAEA.

3.5. Evaluation of photoneutron cross section - F_i corrections

A more detailed estimate of energy-dependent uncertainties on the F_i factors was performed for the ^{181}Ta following an action from 1st RCM. Calculations of the F_i factors were performed using different codes: Iwamoto (CCONE), Kawano (CoH3), Dimitriou (EMPIRE), Goriely (TALYS), Xu (MEND-g), Varlamov (CMPNR). The comparison of the results obtained from the different codes would indicate the sensitivity to model inputs as well as reaction models. Some of the results are shown in Figure 3.1. It is clear from the figure that. models and parameter uncertainties in the F_i function obtained with the various codes are larger than the usual 10% uncertainty included in the CMPNR evaluation of Varlamov, and therefore need to be considered in the evaluation of the experimental data using this approach.

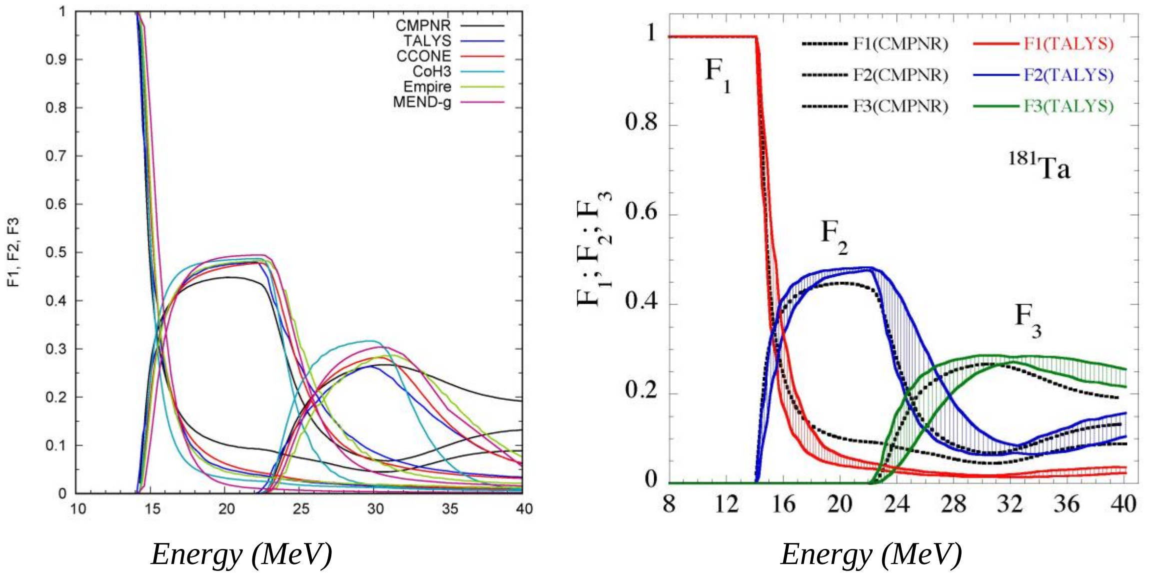


FIG.3.1. Left: F_i correction functions for ^{181}Ta obtained with different codes: CoH3, CCONE, TALYS, EMPIRE, MEND-g, CMPNR. Right: F_i correction functions obtained with TALYS for ^{181}Ta but using different model inputs (OMPs, NDLs, PFS).

The original comparison of F_i obtained from the different codes mentioned above showed some large differences between the CoH3 F_i and the rest of the codes, with the former underestimating F_1 and overestimating F_2 etc. As was mentioned in Sect. 2.9 this was due to the treatment of pre-equilibrium photon-induced reactions. The new calculations of CoH3 are closer to what CCONE, TALYS and EMPIRE and GUNF give. However, the differences with CMPNR remain larger than 10%.

It is still not clear how the F_i corrections should be treated, and if there should be a common approach adopted by all the evaluators of the CRP. Currently, each evaluator has his/her own unique approach: either adopt the F_i at face value, or use them as an indication of problematic data and revise similarly or disregard them completely and adopt different evaluation of data. These differences in the approach can lead to different evaluations which nevertheless require justification before the evaluation review committee makes the final selection of evaluations for the updated Photonuclear Data Library.

The JENDL photonuclear (PD) library was released on 28 December 2017. This will allow N. Iwamoto complete the action from the 1st RCM and provide the IAEA extensive plots of the new evaluations for all the nuclides included in the new library.

In addition, N. Iwamoto has already provided plots comparing his new JENDL/PD-2016 evaluations with Varlamov's evaluation for ^{91}Zr, ^{159}Tb, ^{197}Au. The two evaluations are rather different as they are based on a different assessment of the partial photoneutron experimental cross sections. Iwamoto's approach does not agree with Varlamov's F_i correction method. As mentioned previously, these different assessments need to be thoroughly justified and submitted to the review committee for consideration.

To help clarify further how these different approaches affect the evaluation, it was suggested that all CRP evaluators should evaluate the photonuclear cross-section data of ^{209}Bi.

Action on Kawano: coordinate the evaluation of ^{209}Bi by all CRP evaluators. Deadline is 03/2018.

Action on Dimitriou: organise the review committee meeting in 1st or 2nd week of July 2018.

3.6. Atlas of GDR parameters

Following an action from the 1st RCM, the Atlas of GDR parameters has been updated by Plujko (see Sect. 2.7) in consultation with Varlamov:

The GDR parameters were determined from least-squares fits of Lorentz-like curves to photoabsorption cross sections (γ,abs) or photoneutron cross-sections (γ,sn) available in EXFOR. If none of the above mentioned cross-section data were available, the combination of partial cross sections closest to (γ,abs) was used. The GDR parameter tables have been submitted to IAEA, and include the GDR energies and strengths in fractions of the TKR energy-weighted sum rules, as well as their uncertainties for 144 isotopes from ^{6}Li to ^{239}Pu and 19 elements of natural isotopic composition (480 entries on the whole).

Action on Plujko: GDR parameter tables including the cross sections at the GDR energies in addition to the fraction of the EWSR will be provided by January 2018.

3.7. PSF database

In addition to the GDR parameter tables, experimental PSF files have been prepared for all available experimentally derived PSF data (GDR, Oslo method, NRF, ARC) by (Wiedeking, Schwengner, Siem, Plujko, Kopecky/Dimitriou) using the CRP format adopted at the 1st RCM [1.3]. The files have been used by Goriely and Dimitriou for extensive comparisons and some comments and requests for corrections were listed:

GDR PSF files:

In case of multiple entries of GDR parameters in the GDR parameter file for a given nucleus, the 1st line corresponds to the recommended parameters. It was suggested that, correspondingly, the recommended PSF will be included in a file labeled as "rec". This file should be further checked with respect to the (γ,n) data of Utsunomiya where available.

Action on Plujko to perform this by 01/2018.

The experimental GDR PSF need to be corrected close to the neutron threshold to discard values at energies below typically S_n+1.5 MeV. The data should be checked if extracted from (γ,1n).

Action on Plujko to perform this by 01/2018.

TLO PSFs need to be provided in tabulated form similar to SMLO, SLO and QRPA.

Action on Schwengner to deliver these tables by 07/2018. Plujko to send the list of nuclei and energy grid for which these tables are needed by 01/2018.

Other PSF files (Oslo, NRF):

- NRF files: 2f10.3, 2e12.3 → 2f10.3, 2e13.3
- Oslo files: Numerous "tab" instead of "blanks"!
- f1_exp_040_091_OMdp.txt → f1_exp_040_091_OMdp.dat
- f1_exp_042_095_RM.txt → f1_exp_042_095_RM.dat
- Readme files in dos format → not "universally" readable; use "linux" format
- The author's name corresponds to the author *responsible* for preparing the datafile (not students).
- The Oslo data with statistical and model-dependent uncertainties should be included in one unique file; extra column will be provided.
- The best (latest) analysis of the Oslo data will be kept only.

To help in the retrieval of the datafiles through the online retrieval system, additional keywords need to be defined and added in the datafiles (feedback from V. Zerkin).

Action on Dimitriou to provide a fortran program that would read any input file and produce as output a datafile in the correct format with the required keywords. Deadline 01/2018.

Action on Wiedeking to make sure that all the experimental PSF datafiles are sent back corrected to the IAEA by end of February 2018.

Action on Firestone to send some sample datafiles with his thermal neutron capture strengths that will be treated separately from the PSF datafiles. B(E1) and B(M1) will be provided, extending the compilation to ENSDF data. D0 will also be provided. Deadline 10/2018.

Firestone will also provide a comparison of his compilation of strengths for ^{57}Fe with the Oslo data by 12/2017.

PSF files based on the ARC Atlas by Kopecky have been prepared (Dimitriou).

3.8. Assessment and validation of PSF data

A more detailed analysis of the Oslo and NRF PSF data has been presented (see Sect. 2.12). Some cases can be reconciled such as ^{74}Ge, ^{98}Mo, ^{181}Ta, and recommendations will be provided for the database and final CRP publication. However, the discrepancies between the corresponding data for ^{96}Mo and ^{139}La cannot be explained. Since the full uncertainty analysis has not been done for these latter cases, it is important to do that first before a final recommendation is given:

Action on Schwengner to perform a full uncertainty analysis for ^{139}La by 07/2018.

Action on Siem to perform a full uncertainty analysis for ^{96}Mo by 05/2018.

The uncertainty analysis will consider different NLD parameters and models.

PSF data will be recommended with error bars for ^{74}Ge, ^{98}Mo and ^{181}Ta by the 3rd RCM.

Furthermore, the Oslo and NRF data for ^{89}Y, ^{92}Mo, ^{94}Mo will be looked at after the detailed analysis on ^{96}Mo is completed and a recommendation is provided.

It was also agreed that recommendations should be provided in cases where more than one data set measured using the same method exists. This concerns the Oslo data obtained for the same nucleus by different measurements, different reactions or different detectors.

Action on Siem to provide such recommendations by 08/2018.

The possibility to validate relative PSF from thermal capture data has been shown by Belgya for the ^{114}Cd test case.

Action on Belgya to prepare a detailed report to be submitted by the 3rd RCM and included in the final CRP publication by 01/2018.

Validation of the Oslo PSF was performed by Multi-Step Cascade (TSC) method for the case of ^{96}Mo, including a full uncertainty analysis of the Nuclear Level Density (NLD) dependence. The ^{96}Mo case was presented at the meeting but was inconclusive due to the absence of upper and lower limits in the Oslo data. Sensitivity to the NLD models was shown however to be non-negligible. The ^{98}Mo case remains to be done, however Krticka needs the upper and lower limits of the NLD and PSF from Oslo. Correlated NLD and PSF need to be provided, if possible. The assessment of the uncertainties will be explored. NRF data cannot be used because of the small energy range available.

Action on Dimitriou to send the upper and lower limits of the Oslo NLD and PSF for ^{98}Mo to Krticka 01/2018.

Action on Krticka to test the input for ^{98,96}Mo as soon as he received the upper/lower limits by 02/2018 and 05/2018, respectively.

The compatibility of Oslo and NRF PSF data with thermal neutron capture spectra has been completed by Belgya/Krticka. Further tests on sensitivity to NLDs will be done.

Action on Belgya and Krticka to test the impact of different NLD models in their simulations of thermal neutron capture spectra for ^{114}Cd (Belgya) and ^{196}Pt (Krticka) by 02/2018.

The PSF shapes extracted from the Oslo and Ratio methods were compared for ^{95}Mo and showed to be compatible. The same exercise was repeated for ^{74}Ge following an action from the 1st RCM (see Appendix 2), but unfortunately statistics were not sufficient to extract primary γ-rays to any states but the two lowest 2+ states at 596 and 1204 keV. For these two states the ratio was obtained albeit with large uncertainties due to low statistics. This makes a meaningful comparison to other data difficult. However, the data obtained with the Ratio Method on ^{56}Fe have very good statistics and are more suitable for such a comparison.

Action on Wiedeking and Krticka to compare PSF shapes extracted from Ratio and Oslo method for ^{56}Fe. Deadline is 09/2018.

Wiedeking presented an update on measurements exploring the spin-nature of the low-energy upbend.

An **Action** was placed on Firestone to investigate the spin dependence of the PSF-related observables by 01/2018.

3.9. Theoretical calculations of PSF

E1, M1 and total E/M PSFs have been calculated for all 144 nuclides in the experimental GDR database using the SLO and SMLO empirical parameterizations (Sect. 2.6), and QRPA models (Sect. 2.7)

QRPA calculations have were shown to be compatible with the experimental PSF, however, the SLO and SMLO parameterizations do not reproduce the low-energy part of the experimental PSFs. Plujko is planning as a first step, to use the QRPA predictions to improve the low-energy range of the SMLO predictions, and as a second step to use the experimental PSF data themselves.

Action on Plujko to improve the low-energy behaviour of SLO and SMLO parameterizations by 06/2018.

A global empirical model for M1 scissors mode has been developed by Kawano using the FRDM (1995) deformation parameters (tables to be included). The M1 scissors contribution needs to be added to the RIPL-3 spin-flip M1 component for the GLO E/M prescription.

Action on Kawano to provide tables of parameters of M1 by 01/2018.

Action on Goriely to present an extensive comparison of empirical & QRPA predictions of the M1 and E1 at the 3rd RCM. Deadline 10/2018.

The validation of the different adjusted PSF models on experimental (n,γ) cross sections and $\langle\Gamma_\gamma\rangle$ data will be performed and presented at the 3rd RCM. Experimental MACS at 30keV may be also considered.

Action on Kawano to provide the 200keV n-capture cross section to Goriely for the validation via the (n,γ) experimental data by the 3rd RCM.

QRPA predictions of E1 and M1 can also be tested in TSC and MSC data (Krticka). Similar tests with SMLO need to be done.

Action on Krticka and Goriely to collaborate on validating QRPA PSFs. Deadline 02/2018.

Action on Krticka and Plujko to collaborate on validating the SMLO PSFs. Deadline 08/2018.

Validation of adjusted PSF models can also be done through simulations of thermal capture spectra.

Action on Belgya to perform such simulations using model PSFs for ^{78}Se, ^{114}Cd, ^{232}Th, ^{239}U and ^{196}Pt. Deadline 09/2018.

New proposal: to improve the M1 phenomenological model for both the spin-flip and scissors mode based on the CRP data and other available experimental data.

Action on Goriely to develop an improved empirical M1 model including spin-flip and scissors mode by 07/2018.

3.10. PSF database

The PSF interface is under development. The interface link will be sent to the participants for further testing (04/2018) and should be finalized by the 3rd RCM.

3.11. Miscellaneous

The DICEBOX code will be made available on the IAEA web server as soon as the package is completed with manual, and an agreement between the IAEA and authors of the code is signed.

Participants also discussed the final CRP publication. After considering the advantages and disadvantages of publishing the final document as an IAEA document or a refereed paper in Nuclear Data Sheets (NDS), it was decided to go for the latter.

A proposal was made to split the publication into two different papers: one on photonuclear data and one on photon strength function.

The list of authors was discussed and it was agreed that the list would include only the CSI and those who might have a significant contribution to the manuscript and content. A justification would be required for including a co-author other than a CSI and it will be at the discretion of the CRP participants to accept.

A preliminary submission date was set to **August 2019** with a view for an official publication in January 2020. The above submission date however requires that the complete preliminary draft is ready by the 3rd RCM, March 2019 the latest. Individual dates for completion of the two papers were also given.

For each one of the articles a lead author was assigned to be responsible for the content. The IAEA will coordinate the process with editing, reading, graphics, submission, etc ...

Photonuclear data: Lead author Kawano (first full draft by July 2018)

Photon strength function: Lead author Goriely (first full draft by May 2018)

The outlines of the two separate articles are given in Appendix 3 (Photon Strength Functions) and 4 (Photonuclear Data Library).

Notes/guidelines on preparation of document:

- NDS Tex macros to be used from the start (Goriely to send them & make available on the IAEA PSF website)
- References in bibtex file including titles (at least 3 authors) e.g. \cite{Krticka97a}
- High quality figures in pdf format with large fonts and legends
- Cleaning of the editing will be done by IAEA (Dimitriou)

The decision on the exact titles of the two publications, as well as on the exact list of authors was deferred to the 3rd RCM.

References

[3.1] Summary Report of the Technical Meeting on Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data, A.L. Nichols, S.M. Qaim, R. Capote Noy, INDC(NDS)-0596, Vienna, Sept. 2011. (https://www-nds.iaea.org/publications/indc/indc-nds-0596.pdf)

[3.2] Summary Report from the Third Research Coordination Meeting, 30 May-3 June 2016, Vienna, Austria, A.L. Nichols, F.M. Nortier, R. Capote Noy, INDC(NDS)-0717, Vienna, January 2017. (https://www-nds.iaea.org/publications/indc/indc-nds-0717.pdf)

[3.3] D. Habs and U. Köster, Appl. Phys. B **103** (2011) 501-519.

4. Summary

The 2nd RCM of the CRP on Updating the Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions was held from 16 to 20 October 2017 at the IAEA Headquarters in Vienna.

The meeting was attended by all the CRP members and advisors. The program included presentations of progress reports and discussions on technical issues regarding measurements, compilation, evaluation and theoretical calculations. The assignments were reviewed and additional actions were adopted to ensure the goals of the CRP are achieved in time.

In addition to the technical discussions, participants also agreed on the outline of the final CRP publication, the publisher and tentative submission timeline.

The importance of acknowledging the CRP effort in presentations and relevant publications was stressed once again. Particularly in presentations and publications of work done within the CRP, the following phrase could be used:

"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 3rd and final RCM on 17-21 December 2018.

Appendix 1

Photonuclear data evaluations during CRP 2016-2019

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	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
C-13	KAERI		Y		Sr-84	KAERI		Y		Sm-148	KAERI		Y		Li-7	JENDL
N-14	JENDL		Y		Sr-86	KAERI		Y		Sm-149	KAERI		Y		B-10	JENDL
N-15	KAERI		Y		Sr-87	KAERI		Y		Sm-150	KAERI		Y		B-11	JENDL
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	KAERI	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/KAERI	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/ KAERI	Ta-181 (Fi)	JENDL		Y	MSU/ELI-NP/KAERI	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/ KAERI

Appendix 1
Photonuclear data evaluations during CRP 2016-2019

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/KAERI	Ba-138 (Fi)*	MSU/ KAERI
S-33	KAERI		Y		Mo-96	KAERI		Y		Pb-206	LANL		Y		Ce-140(Fi)*	MSU/ KAERI
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/KAERI	Nd-142	KAERI
Cl-35	KAERI		Y		Mo-100	KAERI		Y		Bi-209	CNDC	Y	Y	ELI-NP/KAERI	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							Os-186	KAERI
Ca-44	KAERI		Y		Cd-106	KAERI		Y							Os-188(Fi)	KAERI
Ca-46	KAERI		Y		Cd-108	KAERI		Y							Os-189(Fi)	KAERI

Appendix 1
Photonuclear data evaluations during CRP 2016-2019

Ca-48	KAERI		Y		Cd-110	KAERI		Y							Os-190(Fi)	KAERI
Ti-46	KAERI		Y		Cd-111	KAERI		Y							Os-192(Fi)	KAERI
Ti-47	KAERI		Y		Cd-112	KAERI		Y							Np-237	JENDL
Ti-48	KAERI		Y		Cd-113	KAERI		Y								
Ti-49	KAERI		Y		Cd-114	KAERI		Y								
Ti-50	KAERI		Y		Cd-116	KAERI		Y								
V-51	CNDC	Y	Y		Sn-112	KAERI	Y	Y								
Cr-50	CNDC	Y	Y		Sn-114	KAERI	Y	Y								
Cr-52	CNDC	Y	Y		Sn-115	KAERI	Y	Y								
Cr-53	CNDC	Y	Y		Sn-116 (Fi)	KAERI	Y	Y	MSU/ KAERI							
Cr-54	CNDC	Y	Y		Sn-117 (Fi)*	KAERI	Y	Y	MSU							
Mn-55	KAERI		Y		Sn-118 (Fi)*	KAERI		Y	MSU							
Fe-54	JENDL		Y		Sn-119 (Fi)*	KAERI		Y	MSU							
Fe-56	JENDL		Y		Sn-120 (Fi)*	KAERI		Y	MSU							
Fe-57	KAERI		Y		Sn-122 (Fi)*	KAERI		Y	MSU							
Fe-58	KAERI		Y		Sn-124 (Fi)*	KAERI		Y	MSU							
Co-59	KAERI		Y	ELI-NP	Sb-121	KAERI		Y								
Ni-58	JENDL		Y		Sb-123	KAERI		Y								
Ni-60	KAERI		Y		Te-120	KAERI		Y								
Ni-61	KAERI		Y		Te-122	KAERI		Y								
Ni-62	KAERI		Y		Te-123	KAERI		Y								
Ni-64	KAERI		Y		Te-124	KAERI		Y								

Appendix 1
Photonuclear data evaluations during CRP 2016-2019

Cu-63 (Fi)*	LANL		Y	MSU	Te-125	KAERI		Y								
Cu-65 (Fi)*	JENDL		Y	MSU	Te-126	KAERI		Y								
Zn-64	JENDL		Y		Te-128	KAERI		Y								
Zn-66	KAERI		Y		Te-130	KAERI		Y								
Zn-67	KAERI		Y		I-127	KAERI		Y								
Zn-68	KAERI		Y		I-129	KAERI		Y								
Zn-70	KAERI		Y		Cs-133 (Fi)*	KAERI		Y	KAERI							
Ge-70	KAERI		Y		Cs-135	KAERI		Y								
Ge-72	KAERI		Y		Cs-137	KAERI		Y								

Appendix 2

List of Actions – revised at 2nd RCM, 16-20 October 2017

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 Extended list: 2nd RCM **Complete list: 3nd RCM – in progress**
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 Siem	Continuous **Au, Tm, Y in 07/2018** **Os, Re, Ba, Ni in 12/2017** **^{13}C 3rd RCM**
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 **Ongoing**
3a	Missing NSR references: compile list of priorities for photonuclear and for (γ,γ') publications (based on CINDA search)	Varlamov, Schwengner	03/2018
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, Firestone	Continuous – **evaluators should search in NSR, private communication, and/or google**
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)-completed **Continuous for regular updates.**

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 **-completed** **Continuous for regular updates.**
7	Coordinate the sensitivity study on the F_i correction factors and report on the conclusions.	Kawano	09/2016 (ND2016)-**completed**
7a	Evaluation on ^{209}Bi to explore model dependencies on evaluation and send results to Kawano	Cho, Xu, Varlamov, Kawano, Iwamoto, Filipescu	03/2018 Has to precede review meeting (week 1 or 2 07/2018).
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-**completed**
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-**postponed to 02/2018**
9b	Compare with Varlamov evaluation for ^{91}Zr, ^{159}Tb, ^{197}Au		11/2017
10	Organize the first meeting of the Photonuclear Evaluation Committee to review the first round of evaluations.	Dimitriou (IAEA)	In 2017 / before 2nd RCM – **postponed to week 1 or 2 07/2018**

11	The Atlas of GDR parameters will be updated.	Varlamov, Plujko	When new evaluated photonuclear data become available- **completed**
11a	Provide additional column of cross section values at the declared GDR peak energies The PSF obtained from the recommended data from this Atlas will be labeled accordingly		Additional column: 01/2018 01/2018
12	Photon Strength Functions (PSF) will be extracted from the total photo-neutron/ photo-absorption cross section and also compared with models. • QRPA calculations • TSE **List of nuclei and energy grid to be sent to Schwengner** • TLO tables	Plujko Goriely Plujko Plujko Schwengner	2nd RCM: preliminary data received draft received 07/2018 10/2017 07/2018
12a	Look at nuclei where (g,1n) has been used to extract GDR PSF. PSF will be corrected close to neutron separation energy Sn.	Plujko/Dimitriou Plujko	01/2018 01/2018
13	Propose a preliminary web interface for the photonuclear data library.	Dimitriou (IAEA)	2nd RCM – ongoing See action 36
14	Send the collected experimental PSF data to Dimitriou (IAEA) in a simple format	Wiedeking	Continuous-Preliminary files sent

14a	Resend new corrected PSF experimental datafiles (include cols with stat. errors, upper and lower limits) to Dimitriou (IAEA)		Corrected files will be resent by end of 02/2018.
14b	Circulate program that creates datafiles in the required format. Key words need to be defined and added to files.	Dimitriou / IAEA Belgya	02/2018 01/2018
15	Send the collected transition strength data to Dimitriou (IAEA) in a simple format in separate files (B(M1), B(E1)….) - Provide separate compilation ^{57}Fe comparison with Oslo data ARC	Firestone Firestone Kopecky	10/2018 – 02/2018 Completed
16	Send samples of the format of the experimental PSF data files to the CRP participants.	Dimitriou (IAEA)	10/2016 -Completed
17	Explore possibility of extracting/validating relative PSF from thermal capture spectra.	Belgya	Completed
17a	Prepare a detailed report for inclusion in summary.		11/2017
18	Model-dependent uncertainty analysis will be performed on both the NRF and Oslo method for the test case of ^{89}Y. The analysis will be done for ^{96}Mo instead of ^{89}Y.	Schwengner, Siem	12/2016 - postponed to 03/2018
18a	Oslo will provide upper/lower uncertainties for ^{96}Mo	Siem	03/2018
19	Existing NRF and Oslo data for will be further assessed with uncertainty analysis.	Schwengner, Siem, Wiedeking.	By 2nd RCM – partially done, extended to 3rd RCM

	^{139}La uncertainty analysis **PSF data will be recommended with error bars for ^{74}Ge, ^{181}Ta.** **Consider ^{89}Y, ^{92}Mo, ^{94}Mo after the complete analysis on ^{96}Mo.** **Provide recommended PSF for which more than one data set exists.**	Schwengner Schwengner, Siem, Wiedeking. Schwengner, Siem, Wiedeking Wiedeking, Siem, Schwengner	07/2018 By 3rd RCM 08/2018 08/2018
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 2nd RCM-completed
20a	Similarly for ^{56}Fe .		by 09/2018
21	Validation of the assessed and recommended PSF will be performed by Multi-Step Cascade method for the cases of ^{98}Mo including a full uncertainty analysis of Nuclear Level Density models.	Krticka	2nd RCM partially done
21a	Assessment of uncertainties will be explored.		01/2018
22	Compatibility of thermal capture & Oslo PSF data for the case of ^{196}Pt will be checked.	Krticka/Belgya	Completed
22a	Sensitivity check on level density for ^{114}Cd ^{196}Pt	 Belgya Krticka	 10/2017 11/2017
23	Compatibility between recommended PSF at low energies and the extracted one from photonuclear data will be studied as soon as corresponding data become available. This action is incorporated in Action 27. See below	Plujko, Siem	See 27

24	An update on the available experimental evidence for the multipolarity of the low-energy upbend will be given at the 2nd RCM.	Wiedeking	Completed
25	The spin dependence of PSF-related observables will be investigated.	Firestone	2nd RCM – extended to 01/2018
26	Experimental PSF data will be made available to theorists (Goriely, Plujko) as soon as they are submitted to IAEA.	Dimitriou (IAEA)	Continuous
27	The following global models of PSFs (E1, M1, total) will be adjusted to recommended (experimental) strength functions: HFB+QRPA SLO/SMLO	 Goriely Plujko	 completed completed
27a	Modification of SMLO model to reproduce low-energy PSF data. M1 contributions required (see 29 and 37)	Plujko Goriely	06/2018 3rd RCM
28	Shell model calculations of M1 PSF in relation with the upbend and the scissors mode will be explored.	Schwengner	2nd RCM - completed
29	Empirical prescription for M1 PSF, including spin-flip & scissors, will be provided together with the RIPL E1 parameterization (tables of parameters).	Kawano	2nd RCM-completed for scissors mode Tables to be submitted by 02/2018
30	Comparisons between existing global models and experimental PSF extending to energies below the neutron threshold will be performed This action is incorporated in Actions 12 and 27	Plujko, Goriely	2nd RCM partially done

31	Comparison between global empirical and microscopic prescriptions (for E1 and M1 SF) will be provided for all nuclei across the nuclear chart.	Plujko, Goriely	3rd RCM – revised to 10/2018
32	Validation of the different adjusted PSF models on experimental (n,γ) cross sections and <Γ_γ> data will be performed when data are available.	Kawano, Goriely.	After 2nd RCM – extended to 3rd 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) For QRPA For modified SMLO (see 27)	Krticka	 02/2018 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 2nd RCM and a first version of the package will be made available from the IAEA web site. Agreement preparation	Krticka Dimitriou (IAEA)	12/2017-postponed to 01/2018 02/2018
36	Prepare a proposal for the PSF database web interface for presentation to and approval by the CRP.	Dimitriou (IAEA), Firestone, Belgya	2nd RCM - preliminary version 04/2018 Final version 3rd RCM
37	Proposal to improve the M1 systematics within the Lorentzian approach for spin-flip and scissors mode.	Goriely/Kopecky	06/2018

Appendix 3

Outline of the final publication on "Photon Strength Functions"

1. **Introduction**
2. **Experimental methods (coordinator: Krticka)** (~ 5p)
   - NRF (Schwengner)
   - Oslo method (Siem)
   - Ratio method (Wiedeking)
   - ARC data (Kopecky)
   - Photonuclear data (Plujko)
   - Inelastic (p,p') & partial reaction cross section (Wiedeking/Krticka)
   - Methods for validations
     - Thermal n-capture (Belgya/Firestone)
     - Multi-step cascade (Krticka)
3. **Evaluation of PSF from experiments (coordinator: Wiedeking)** (~ 20p)
   - Compilation of PSF (Wiedeking)
   - Uncertainty analysis on test cases
     - NRF (Schwengner)
     - Oslo (Wiedeking/Siem)
     - Photodata (Plujko)
     - Others - (p,g), (p,p'), n-capture, .. (Belgya)
   - Assessment & recommendation experimental PSF
     - Oslo PSF (Siem)
     - Oslo vs NRF PSF (Schwengner)
     - Photodata (Plujko)
   - Information from individual transitions in thermal capture data (Firestone) (~ 2p)
4. **PSF models (coordinator: Goriely)** (~ 10p)
   - Phenomenological models E1 & M1 (Plujko/Goriely)
   - Mean-Field + QRPA models E1 & M1 (Goriely)
5. **Comparison between experimental and models (coordinator: Goriely)** (~ 10p)
6. **Validation of theoretical models (coordinator: Goriely)** (~ 5p)
   - Multi-step cascade (Krticka)
   - Thermal n-capture (Belgya)
   - Average radiative width (Goriely)
   - radiative n-capture at 30 & 200keV (Goriely)
7. **Comparison between models for experimentally unknown nuclei (coordinator: Goriely - 5p)**
8. **Final database (coordinator: Dimitriou)** (~ 5p)
9. **Final recommendations (coordinator: Goriely)** (~ 5p)
10. **Conclusions**

Outline of the paper on “Photonuclear Data Library”

The outline will be quite similar to the CRP IAEA-TECDOC-1178 (2000)

1. **Introduction (coordinator: Dimitriou)** (~ 3p)
2. **Available experimental data (coordinator: Varlamov)** (~ 10p)
3. **Nuclear models (coordinator: Kawano)** (~ 15p)
4. **Evaluation (coordinator: Kawano)** (~ 20p)
   - CNDC
   - KAERI
   - JAEA
   - MSU SINP
   - IFIN-HH
   - LANL
   - IAEA
5. **Content of the Library (coordinator: Kawano)** (~ 5p)
6. **Database web interface (coordinator: Dimitriou)** (~ 3p)
7. **Conclusions**
8. **Annex: GDR atlas (Plujko)** (~ 30p)

Note:

- Main text will be published in NDS with the atlas of GDR parameters either in the paper or as a supplement paper.
- Extensive figures with comparison to be published in INDC(NDS)

2nd 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
16 – 20 October 2017
Meeting Room M0E100

Preliminary AGENDA

Monday, 16 October

08:30 - 09:00 **Registration** (IAEA Registration desk, Gate 1)

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

- Welcoming address (Arjan Koning, Section Head)
- Introduction (Paraskevi Dimitriou, Scientific Secretary)
- Election of Chairman and Rapporteur
- Adoption of Agenda
- Administrative matters

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

1. H. Utsunomiya, Konan University, Japan
2. D. Filipescu, IFIN-HH/ELI-NP, Romania
3. V.V. Varlamov, Moscow State University, Russian Federation
4. A. Koning, NDS-IAEA, Austria
5.

12:30 – 14:00 ***Lunch***

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

6. N. Iwamoto, JAEA, Japan
7. Y-S. Cho, KAERI, S. Korea
8. R. Xu, CIAE, China
9. T. Xi, CIAE, China
10. V. Plujko, Taras Shevchenko National University, Ukraine

Coffee breaks as needed

Tuesday, 17 October

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

11. S. Goriely, Université Libre de Bruxelles, Belgium
12. T. Kawano, LANL, USA
13. J. Kopecky, Juko Research, The Netherlands
14. R. Firestone, University of California, Berkeley, USA

12:30 – 14:00 Lunch

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

15. R. Schwengner, HZDR, Germany
16. S. Siem, University of Oslo, Norway
17. M. Wiedeking, iThemba LABS, S. Africa
18. M. Krticka, Charles University in Prague, Czech Rep.
19. T. Belgya, CER / Hungarian Academy of Sciences, Hungary

Coffee breaks as needed

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

Wednesday, 18 October

09:00 - 12:30 Round Table Discussion

20. P. Dimitriou, NDS-IAEA, Austria

Topics for discussion

1. γ-induced preequilibrium reactions
2. F_i correction functions
3. Exp. strength functions below S_n
4. Models
5. CRP database/formats
6. EXFOR database (V. Semkova)

12:30 – 14:00 Lunch

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

Coffee breaks as needed

Thursday, 19 October

09:00 - 12:30 Round Table Discussion

12:30 – 14:00 Lunch

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

Coffee breaks as needed

Friday, 20 October

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

Coffee break as needed

12:30 Closing of the meeting

2nd Research Coordination Meeting on
"Updating Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions"
IAEA, Vienna, Austria
16-20 October 2017

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2nd Research Coordination Meeting on
"Updating Photonuclear Data Library and Generating a Reference Database for Photon Strength Functions"
IAEA, Vienna, Austria
16-20 October 2017

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