CDFE 2024/2025

status report on photonuclear data processing activity

for the Technical Meeting of the International Network of Nuclear Reaction Data Centres
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The report shortly describes the main photonuclear data processing results obtained in the CDFE for the period of time from the previous Meeting (the IAEA's Headquarters, Vienna, Austria, 14 - 17 May 2024).

The CDFE total permanent staff:
3 professional, 3 general service officer, 1 student of the MSU Physics Faculty.

The main CDFE fields of activity were the following:

- compilation of new photonuclear reaction data;
- correction of old data in accordance with the comments of the NRDC experts;
-- new (unpublished before) data obtaining;
- photoneutron reaction cross-section evaluation.

CDFE EXFOR Compilation

8 new CDFE EXFOR m130 – m137 TRANSes and *prelim.m138* one have been produced and transmitted to the IAEA NDS.

All TRANSes contain both 10 new ENTRYs and *69 old ENTRYs* corrected in accordance with the new EXFOR format rules and comments and recommendations of the NRDC experts, first of all, Naohiko Otsuka and Svetlana Dunaeva.

On the whole new CDFE TRANSes have been produced in the reported period:

TRANS	*Old*	New	Total (SUBENTs)
m130	*11*	0	11 (68)
m131	*12*	0	12 (64)
m132	*4*	3	7 (79)
m133	*3*	1	4 (55)
m134	*5*	0	5 (55)
m135	*12*	1	13 (48)
m136	*2*	4	6 (33)
m137	14	0	14 (75)
prelim.m138	*6*	1	*7 (74)*
Common	*69*	10	79 (551)

The main CDFE scientific activity is analysis of reliability of cross sections obtained in various experiments

and

evaluation of photoneutron reaction cross sections satisfied objective physical criteria of data reliability

2 objective physical absolutely hard data reliability criteria:

1) F_i – definitely positive values (cross-section – dimension of area (barn, cm^2));

2)

$$F_1 = \frac{\sigma(\gamma, 1n)}{\sigma(\gamma, 1n) + 2\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n) + \ldots} < 1.00$$

$$F_2 = \frac{\sigma(\gamma, 2n)}{\sigma(\gamma, 1n) + 2\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n) + \ldots} < 0.50$$

$$F_3 = \frac{\sigma(\gamma, 3n)}{\sigma(\gamma, 1n) + 2\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n) + \ldots} < 0.33$$

$F_4 < 0.250$, $F_5 < 0.200$, $F_6 < 0.166$, $F_7 < 0.143$, $F_8 < 0.125$, …

3) 3-rd not hard (soft) criterion - F_i^{exp} and F_i^{theor} agreement (closeness).

Cross-section evaluation experimental-theoretical method:

$$\sigma^{eval}(\gamma, in) = F_i^{theor}(\gamma, in) \bullet \sigma^{exp}(\gamma, Sn),$$

where $\sigma^{exp}(\gamma, Sn) = (\gamma, 1n) + 2(\gamma, 2n) + 3(\gamma, 3n) + \ldots$ is experimental one,
and $F_i^{theor} = \sigma^{theor}(\gamma, in)/\sigma^{theor}(\gamma, Sn)$ are calculated in the combined model of photonuclear reactions

Newly evaluated photoneutron reaction cross sections

It was found before that for about 50 nuclei from ^{51}V to ^{209}Bi experimental cross sections obtained on the beams of quasi-monoenergetic annihilation photons using the method for photoneutron multiplicity sorting are more-less not reliable because of significant systematic uncertainties.

The method was direct determination of partial reaction cross sections σ(γ, 1n), σ(γ, 2n), as well as σ(γ, 3n), and after that using simple summation - total photoneutron reaction cross section σ(γ, tot) = σ(γ, 1n)+σ(γ, 2n) and neutron yield cross section σ(γ, sn) = σ(γ, 1n)+2σ(γ, 2n).

The program of evaluation of reliable partial photoneutron reaction cross sections using the experimental-theoretical method based on objective physical criteria was continued for data obtained using quite different method in experiments with bremsstrahlung.

The method is quite different, may-called inverse: determination of neutron yield cross section σ(γ, sn) = σ(γ, 1n)+2σ(γ, 2n), introducing corrections calculated using statistical theory in it, determination of σ(γ, tot) = σ(γ, 1n)+σ(γ, 2n) and after that – partial reaction contributions σ(γ, 1n) and σ(γ, 2n) using the natural subtracting/summation procedures.

New (unpublished before) photoneutron reaction cross sections were obtained for several nuclei:

- ^{51}V, ^{52}Cr, ^{59}Co, ^{58,60}Ni: $\sigma(\gamma, 2n) = \sigma^{publ}(\gamma, tot) - \sigma^{publ}(\gamma, 1n)$;
  $\sigma(\gamma, sn) = \sigma^{publ}(\gamma, tot) + \sigma(\gamma, 2n)$;

- ^{90}Zr, ^{115}In: $\sigma(\gamma, 2n) = \sigma^{publ}(\gamma, sn) - \sigma^{publ}(\gamma, tot)$;
  $\sigma(\gamma, 1n) = \sigma^{publ}(\gamma, tot) - \sigma(\gamma, 2n)$;

- ^{127}I: $\sigma(\gamma, 1n) = \sigma^{publ}(\gamma, tot) - \sigma^{publ}(\gamma, 2n)$;
  $\sigma(\gamma, sn) = \sigma^{publ}(\gamma, tot) + \sigma(\gamma, 2n)$;

- ^{165}Ho: $\sigma(\gamma, tot) = \sigma^{publ}(\gamma, sn) - \sigma^{publ}(\gamma, 2n)$;
  $\sigma(\gamma, 1n) = \sigma^{publ}(\gamma, sn) - 2\sigma^{publ}(\gamma, 2n)$.

New photoneutron reaction cross sections

Unpublished data for ^{52}Cr, cross sections of reactions

^{52}Cr(γ, 2n)^{50}Cr

and

^{52}Cr(γ, sn)

are really new because those were not obtained in experiments with annihilation photons.

Unpublished data for ^{68}Zn, cross sections of reactions

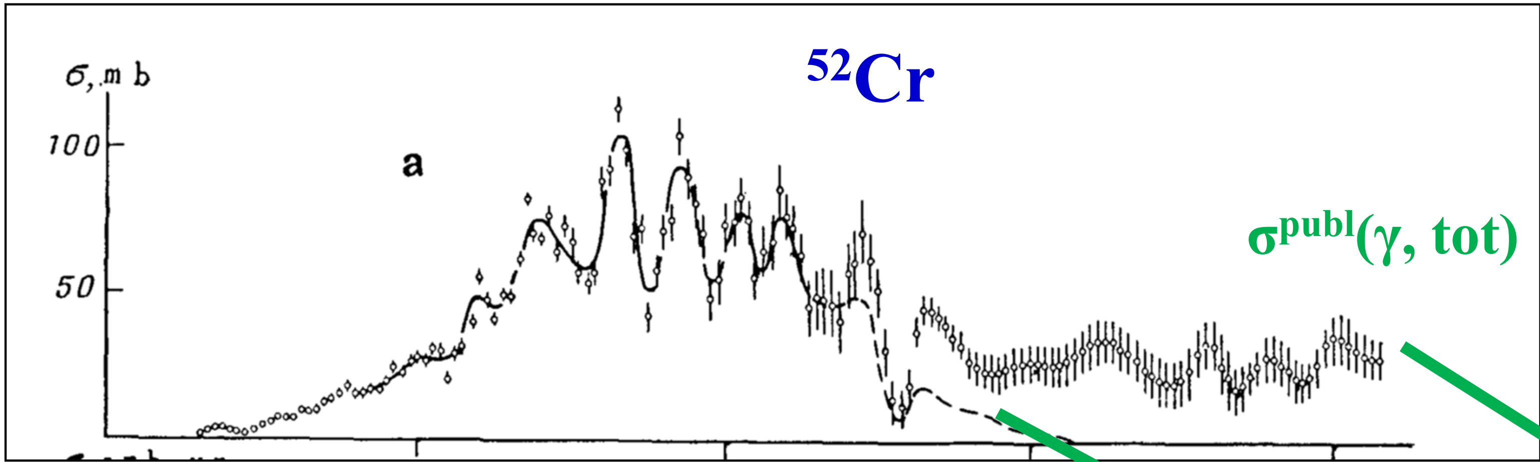
^{68}Zn(γ, 1n)^{67}Zn,

^{68}Zn(γ, 2n)^{66}Zn

and

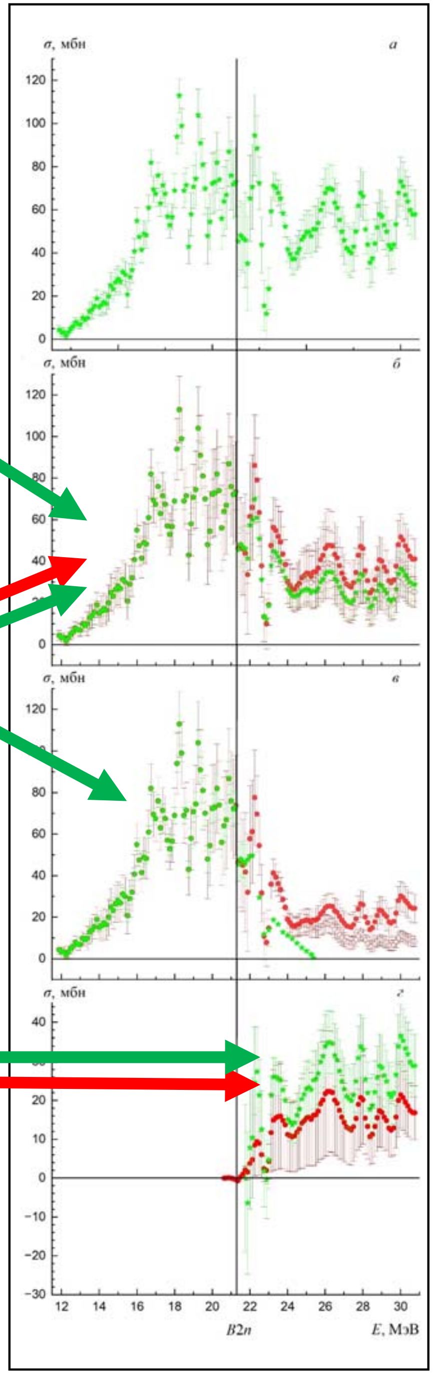
^{68}Zn(γ, tot),

were obtained at first time using experimental-theoretical method because the only one σ^{publ}(γ, sn) was obtained in experiment using bremsstrahlung and nothing was obtained for ^{68}Zn in experiments with annihilation photons.



$\sigma^{publ}(\gamma, tot)$

$\sigma^{publ}(\gamma, 1n)$



New photoneutron reaction cross sections

$\sigma^{unpubl}(\gamma, 2n) = \sigma^{publ}(\gamma, tot) - \sigma^{publ}(\gamma, 1n)$

$\sigma^{unpubl}(\gamma, sn) = \sigma^{publ}(\gamma, tot) + \sigma^{unpubl}(\gamma, 2n)$

Unpublished data for ^{52}Cr, cross sections of reactions

^{52}Cr(γ, sn)

and

^{52}Cr(γ, 2n)^{50}Cr

are really new because those were not obtained in experiments with annihilation photons.

Green - experimental

Red - evaluated

New photoneutron reaction cross sections

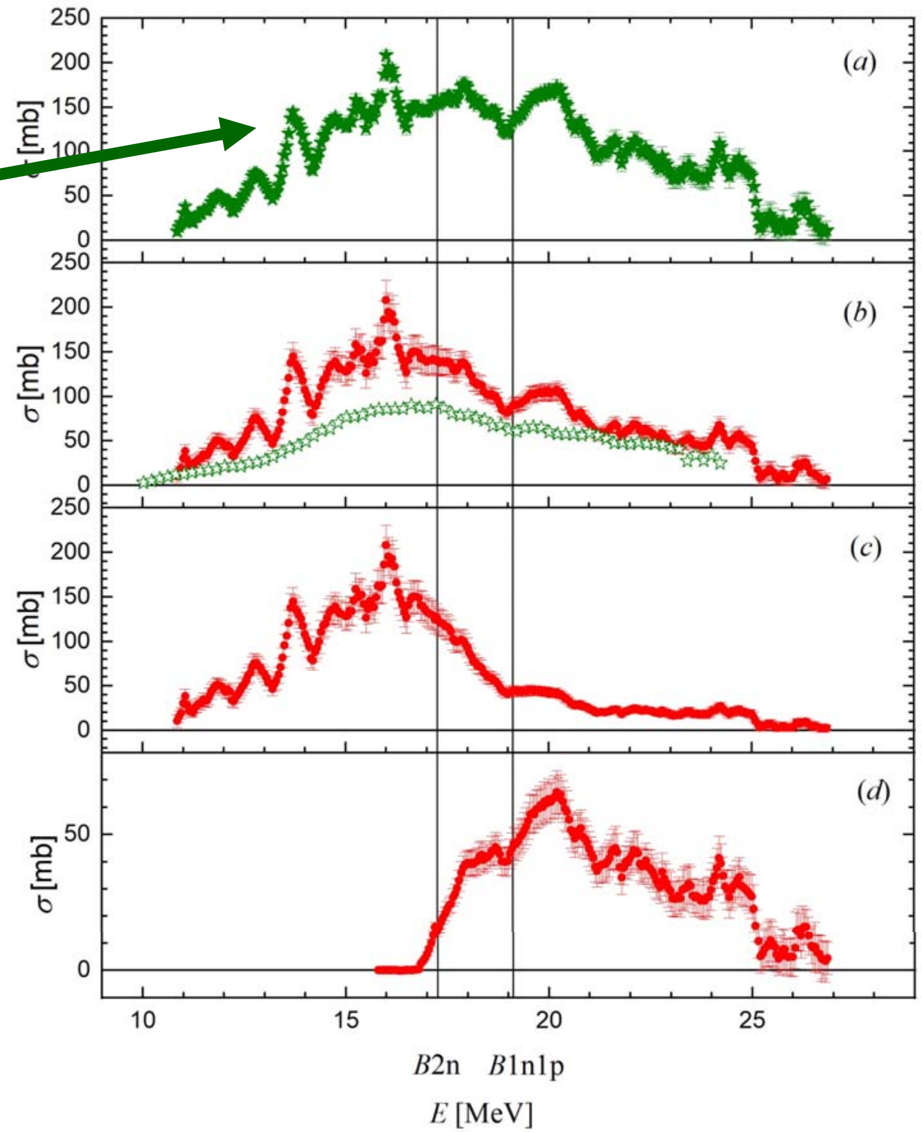
Unpublished data for ^{68}Zn

Because the only one $\sigma^{publ}(\gamma,sn)$ was obtained for ^{68}Zn in experiment using bremsstrahlung and nothing was obtained in experiments with annihilation photons data for reactions

$^{68}Zn(\gamma, 1n)^{67}Zn$,
$^{68}Zn(\gamma, 2n)^{66}Zn$
and
$^{68}Zn(\gamma, tot)$

were obtained at first time using experimental-theoretical method.

^{68}Zn



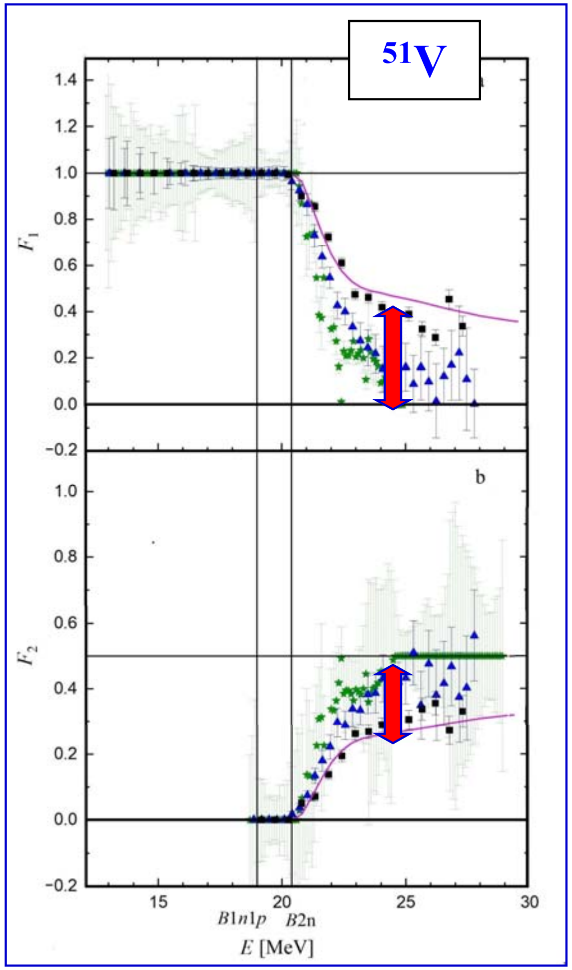
New evaluated photoneutron reaction cross sections meeting the physical criteria of reliability

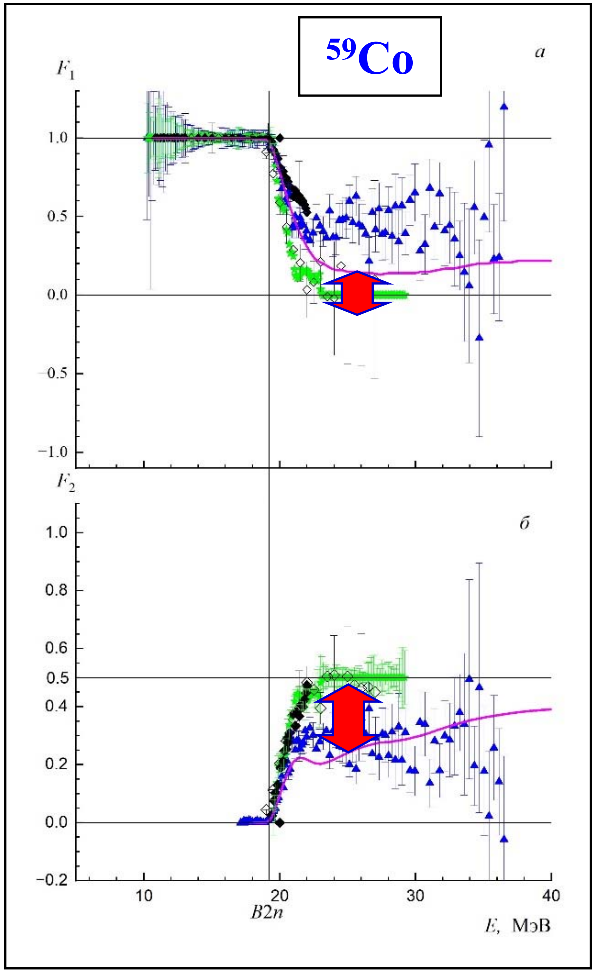
For all of nuclei mentioned new evaluated cross sections meeting physical criteria were obtained using experimental-theoretical method. It was found that in cases of relatively heavy nuclei (^{90}Zr, ^{115}In, ^{127}I, and ^{165}Ho) and relatively light nuclei (^{51}V, ^{52}Cr, ^{59}Co, ^{68}Zn, ^{58,60}Ni) the situations with data reliability are different.

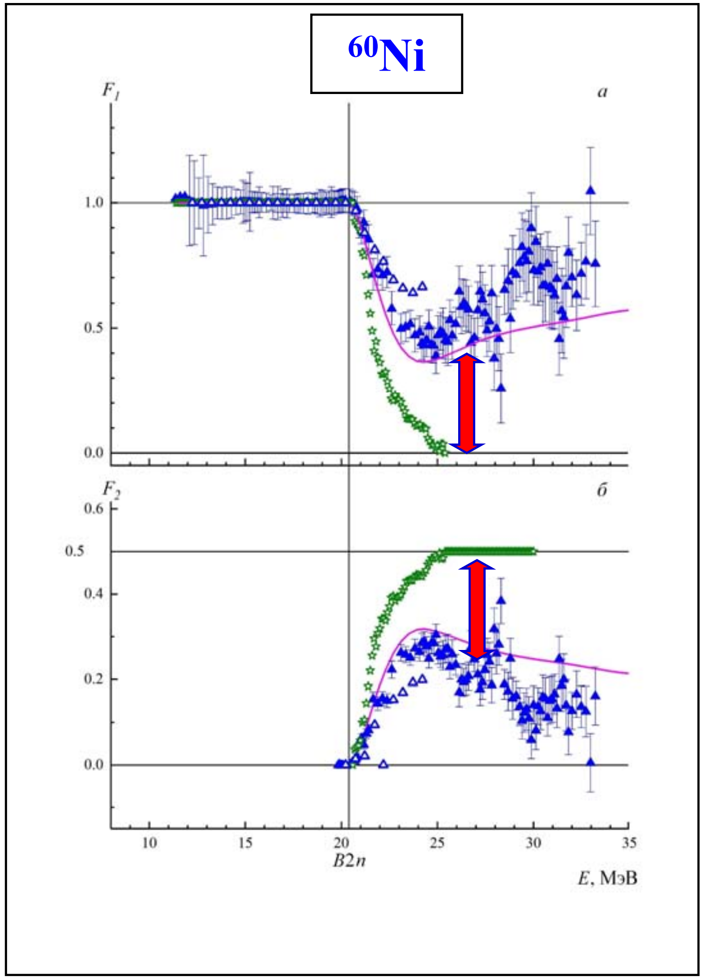
It was shown that in cases of relatively light nuclei experimental partial photoneutron reaction cross sections are not reliable because of some shortcomings of undirect (statistical theory corrections) method of determination: σ(γ, 1n) are unreliably underestimated, but σ(γ, 2n) vice versa overestimated.

It was shown, in particular, that the main source of such method systematic uncertainties is that the contributions of (γ,1n1p) reaction were not taken into account. In light nuclei this two-nucleon neutron-proton reaction has parameters close to those of reaction (γ, 2n) and reduces accuracy of statistical theory corrections.

Typical examples of unreliable underestimations of σ(γ, 1n) and overestimation of σ(γ, 2n).







Significant disagreements: F_1^{exp} are underestimated, but F_2^{exp} – overestimated.

2024/2025 Main Publications

(Atom. Data Nucl. Data Tables, Eur. Phys. J., Phys. Atom. Nucl., Bull. Rus. Acad. Sci.)

1. V.V.Varlamov, A.I.Davydov, I.A.Mostakov. Reliability of ^{51}V photoneutron reaction cross sections obtained using bremsstrahlung. Eur. Phys. J. A. 60, 44 (2024) 1–8.
2. S.S.Belyshev, V.V.Varlamov, L.Z.Dzhilavyan, A.A.Kuznetsov, A.M.Lapik, A.L.Polonski, A.V.Rusakov, V.I.Shvedunov. On activation studies of photonuclear reactions on gamma-beams from backward Compton scattering at E gamma < 40 MeV. Moscow University Physics Bulletin. 79, N. 1 (2024) 7–13.
3. V.V.Varlamov, A.I.Davydov. Photonuclear experiments: from the bremsstrahlung to backward Compton scattering photons. Moscow University Physics Bulletin. 79, N 2 (2024) 178–185.
4. V.V.Varlamov, A.I.Davydov, I.A.Mostakov. Reliability of cross sections of the photoneutron reactions on ^{51}V and ^{59}Co nuclei in the bremsstrahlung beam experiments. Bull. Rus. Acad. Sci. Phys., 88, № 8 (2024) 1211–1217.
5. V.V.Varlamov, A.I.Davydov, I.A.Mostakov, V.N.Orlin. Photoneutron reaction cross sections for ^{90}Zr in different experiments. Phys. Atom. Nucl. 87, N5 (2024) 575–585.
6. V.V.Varlamov, A.I.Davydov, I.A.Mostakov, V.N.Orlin. ^{52}Cr photoneutron reactions in experiments with bremsstrahlung. Phys. Atom. Nucl., 87, N6 (2024) 669–677.
7. V.V.Varlamov, A.I.Davydov, I.A.Mostakov, V.N.Orlin. New data on photoneutron reaction cross sections for ^{68}Zn. Phys. Atom. Nucl., 87, N2 (2024) S264–S273.
8. V.V.Varlamov, A.I.Davydov, V.N.Orlin. Photonuclear partial reaction cross sections: systematic uncertainties and reliability. Atomic Data and Nuclear Data Tables, 161, 101697 (2025) 1–14.
9. V.V. Varlamov and A.I. Davydov. Photodisintegration of ^{109}Ag: problems and new data. Eur. Phys. J, A 61, 107 (2025) 1–5.
10. V.V.Varlamov, A.I.Davydov, I.A.Mostakov, V.N.Orlin. Photoneutron reaction cross sections for light and medium-heavy nuclei in experiments on the beams of bremsstrahlung. Bull. Rus. Acad. Sci. Phys., 89, № 8 (2025), in print.
11. V.V.Varlamov, A.I.Davydov, I.A.Mostakov, V.N.Orlin. Photoneutron reaction cross sections for ^{115}In. Phys. Atom. Nucl., 88, (2025), in print.

Short-term (2025/2026) CDFE Program

The main items of CDFE (2025/2026) program, main priorities and most important tasks are traditional and the following:

- new photonuclear data compilation using EXFOR format, production of new TRANSes (trans.m139, trans.m140, etc.);

- corrections of old ENTRYs in accordance with new EXFOR coding rules and the NRDC Network experts's comments and recommendations;

- analysis of total and partial photonuclear reaction cross sections obtained in various experiments, carried out using different sources of photons (bremsstrahlung, quasi-monoenergetic annihilation photons, laser Compton backscattering photons) reliability using the objective physical criteria;

- evaluation of new cross sections meeting those criteria using the experimental-theoretical method.

THANKS A LOT

FOR ATTENTION !