29th International Scientific Conference of Young Scientists and Specialists

Isospin splitting of the giant dipole resonance in medium and heavy nuclei

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Table of Contents

Giant dipole resonance of atomic nuclei

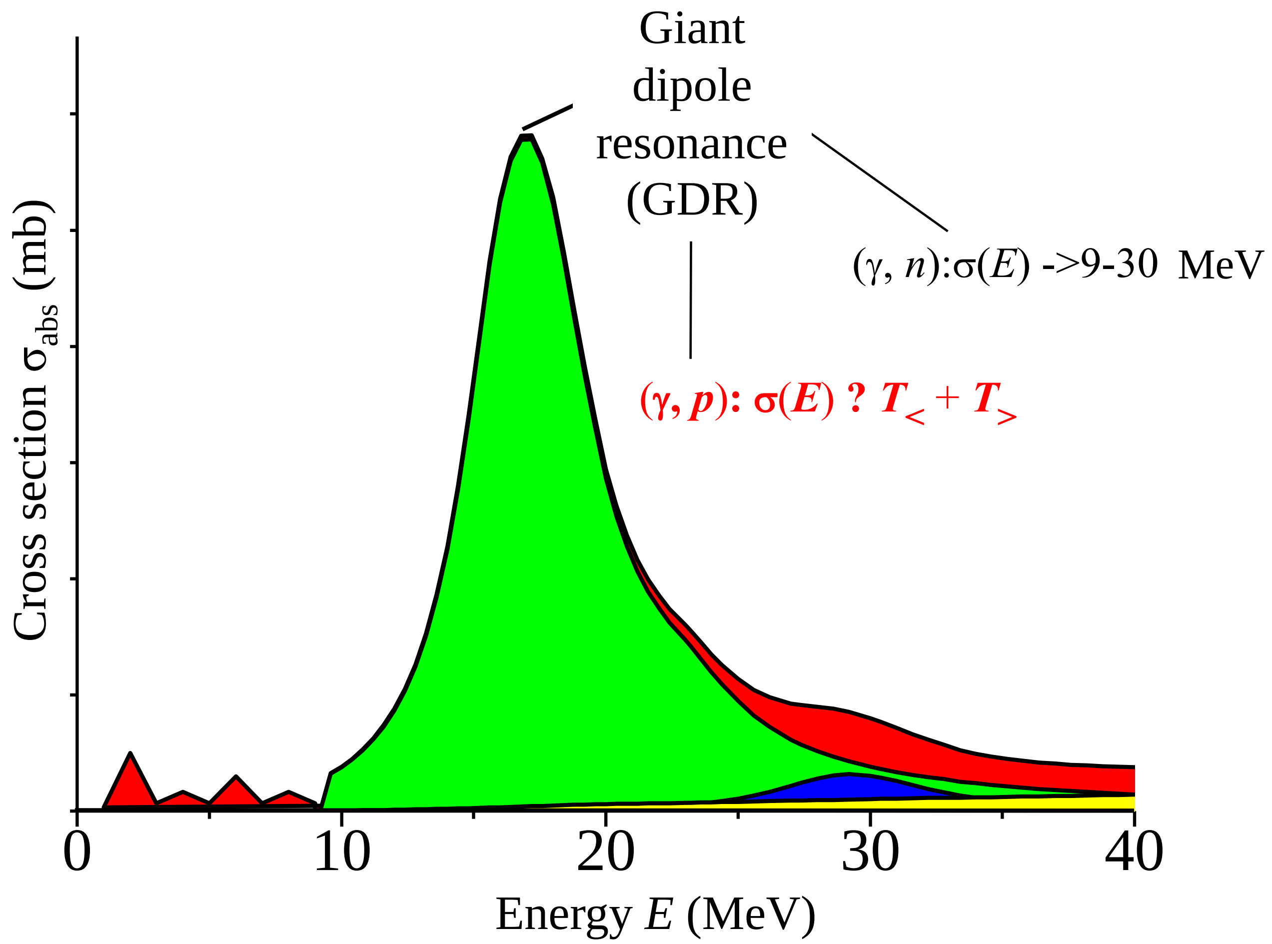


Figure 1. A schematic representation of photon absorption by an atomic nucleus

$$\sigma_{GDR}(E_\gamma) = \sigma_{T<}(E_\gamma) + \sigma_{T>}(E_\gamma)$$

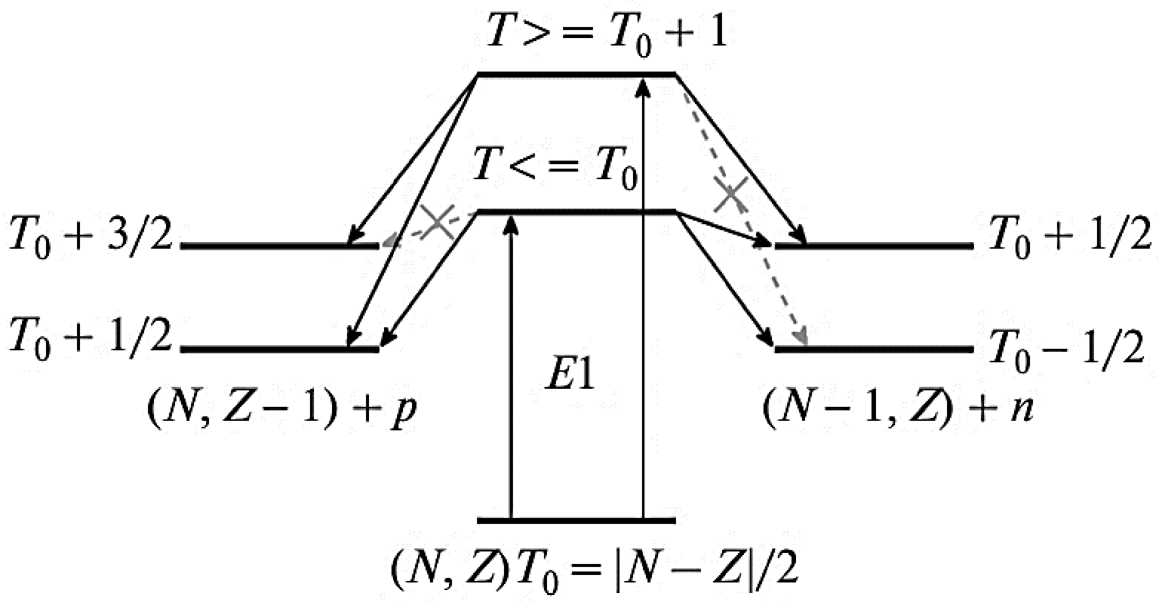
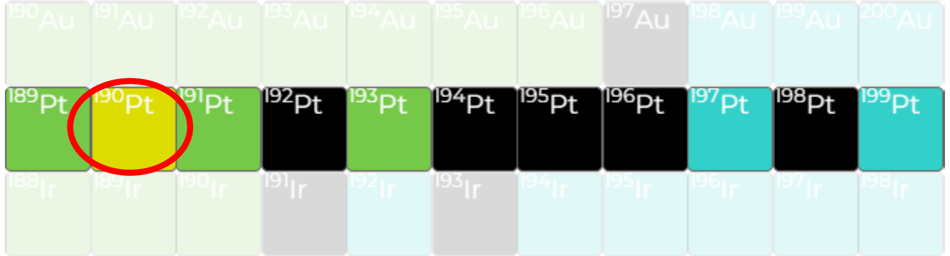
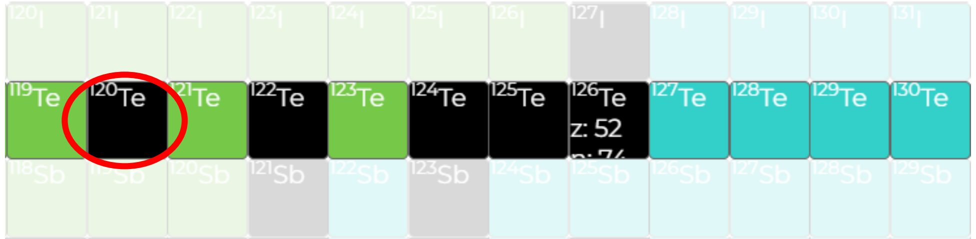


Figure 2. Scheme of excitation of states T< and T> in the nucleus (N, Z) and their decay through neutron and proton channels

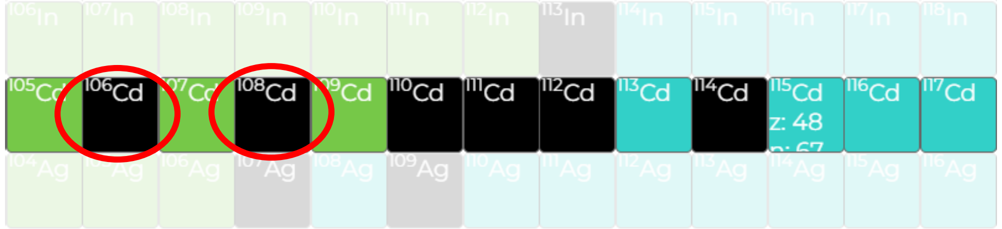
Objects of study and existing data on photonuclear reactions on them



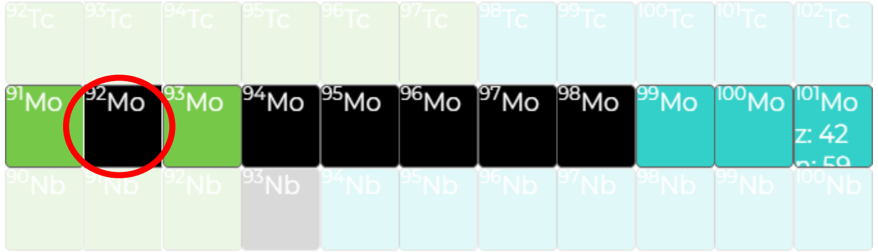
Z = 78: cross section of the reaction (γ,n) + (γ,pn) + (γ,2n) in 8–24 MeV



Z = 52 : cross section of the reactions (γ,n), (γ,n)+ (γ,np) and (γ,2n)+ (γ,2np) in 8–26 MeV



Z = 48: relative yields of the reaction(γ,n) and (γ,p) in 23,55,60 MeV



Z = 42: cross section of the reactions (γ,n) and (γ,2n), (γ,n)+ (γ,np) in 10–29 MeV

Z = 34: cross section of the reaction(γ,n) and (γ,2n), (γ,n)+ (γ,np) in 9–28 MeV

EXPERIMENTAL TECHNIQUES ON BREMSSTRAHLUNG BEAMS FROM ELECTRON ACCELERATORS

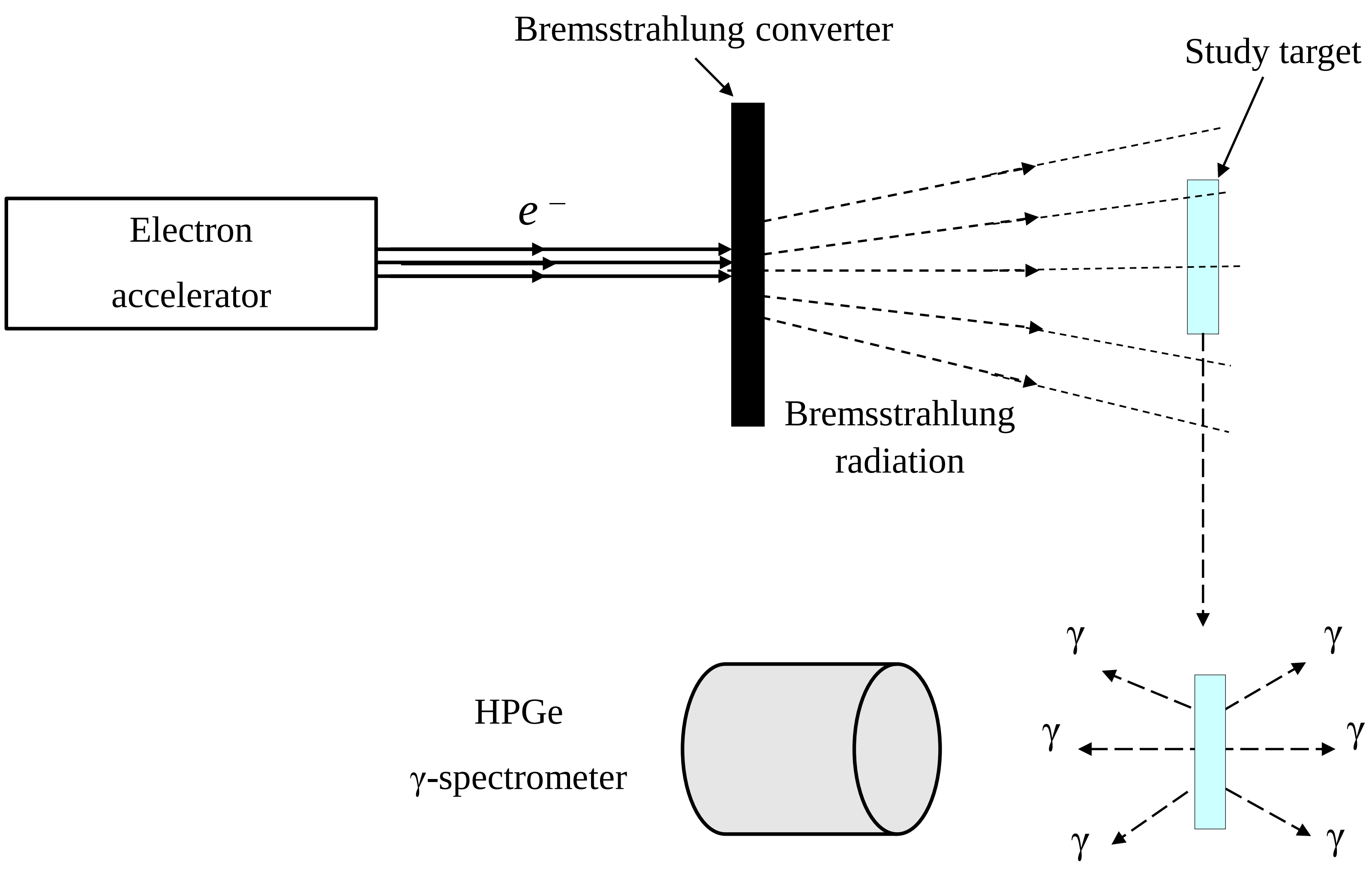


Figure 3. Geometry of irradiation and sample measurements

Determination of yields of photonuclear reactions

The experimental value of the reaction product yield is calculated using the formula:

$$Y_{эксп} = \frac{S \cdot C_{abs}}{\varepsilon \cdot I_\gamma} \frac{t_{real}}{t_{live}} \frac{1}{N} \frac{1}{N_e} \frac{e^{\lambda \cdot t_{cool}}}{1-e^{-\lambda \cdot t_{real}}} \frac{\lambda \cdot t_{irr}}{1-e^{-\lambda \cdot t_{irr}}}, \qquad (1)$$

where

S is the full-energy-peak area,

C_{abs} is the correction for self-absorption of γ rays in the sample,

ε is the full-energy-peak detector efficiency,

I_γ is the γ emission probability,

N is the number of atoms in the activation sample,

N_e is the integral number of incident electrons,

λ is the decay constant,

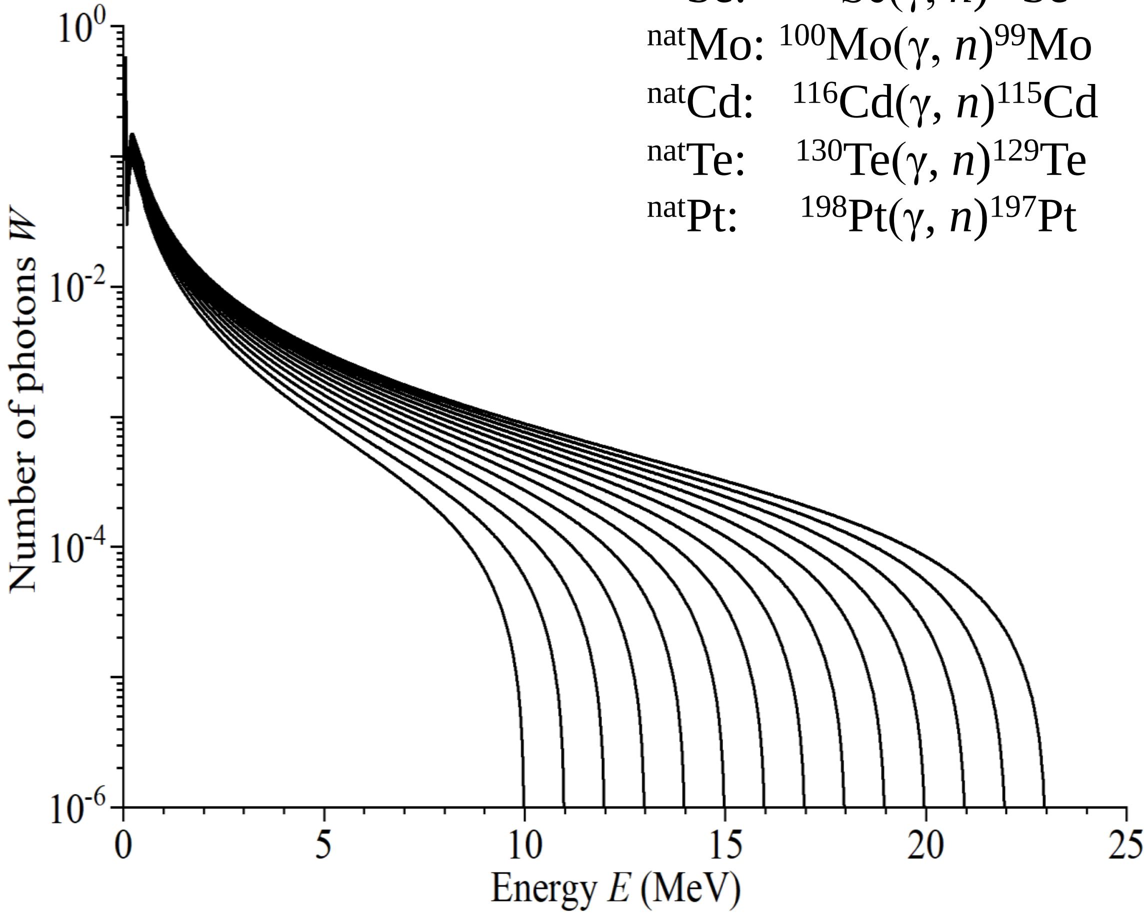
t_{irr} and t_{cool} are the irradiation time and the cooling time, respectively,

t_{live} and t_{real} are the real time and live time of the measurement, respectively

$$\frac{\Delta Y}{Y} = \sqrt{\left(\frac{\Delta S}{S}\right)^2 + \left(\frac{\Delta \varepsilon}{\varepsilon}\right)^2 + \left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta N_e}{N_e}\right)^2}$$

What to compare the obtained results with?

Calculated yield values



^{nat}Se: ^{82}Se(γ, n)^{81}Se
^{nat}Mo: ^{100}Mo(γ, n)^{99}Mo
^{nat}Cd: ^{116}Cd(γ, n)^{115}Cd
^{nat}Te: ^{130}Te(γ, n)^{129}Te
^{nat}Pt: ^{198}Pt(γ, n)^{197}Pt

Figure 4. The distribution density of the number of bremsstrahlung photons at the energies of 10-23 MeV

The theoretical value of the reaction product yield is calculated using the formula:

$$Y_{theor} = \sum_i \eta_i \int_{E_{i\,th}}^{E_{\gamma max}} \sigma_i(E) W(E, E_{\gamma max}) dE \qquad (2)$$

where the index i corresponds to the number of the reaction contributing to the production of the studied isotope,

η_i — is the percentage of the studied isotope in a natural mixture,

$\sigma_i(E)$ is the photonuclear reactions cross section which calculated by TALYS and combined models of photonucleon reactions (CMPR)

$W(E, E_{\gamma max})$ is the distribution density of the number of bremsstrahlung photons over energy per one electron of the accelerator

$$Y_{rel,i} = \frac{\eta_i \int_{E_{thr}}^{E_{\gamma max}} \sigma_i(E) W(E, E_{\gamma max}) dE}{\eta \int_{E_{thr}}^{E_{\gamma max}} \sigma_{(\gamma,n)}(E) W(E, E_{\gamma max}) dE} \qquad (3)$$

How to calculate the cross section?

Calculation of cross sections for photonuclear reactions

$$\sigma_{\text{TALYS}}(E_\gamma) = \sigma_{GDR}(E_\gamma) + \sigma_{QD}(E_\gamma)$$

$$\sigma_{\text{КМФР}}(E_\gamma) = \sigma_{GDR}(E_\gamma) + \sigma_{QD}(E_\gamma) + \sigma_{IVQR}(E_\gamma) + \sigma_{GDR2}(E_\gamma) \quad \rightarrow \quad \text{КМФР: } \sigma_{GDR}(E_\gamma) = \sigma_{T<}(E_\gamma) + \sigma_{T>}(E_\gamma)$$

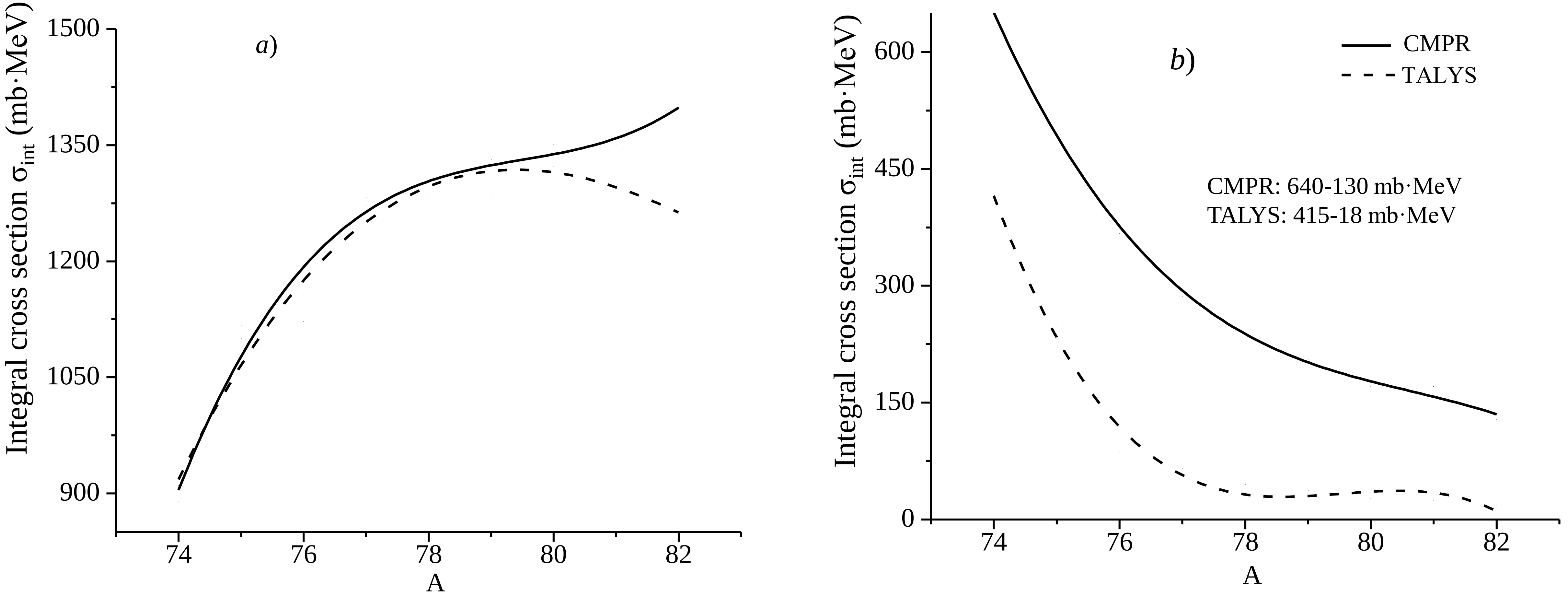
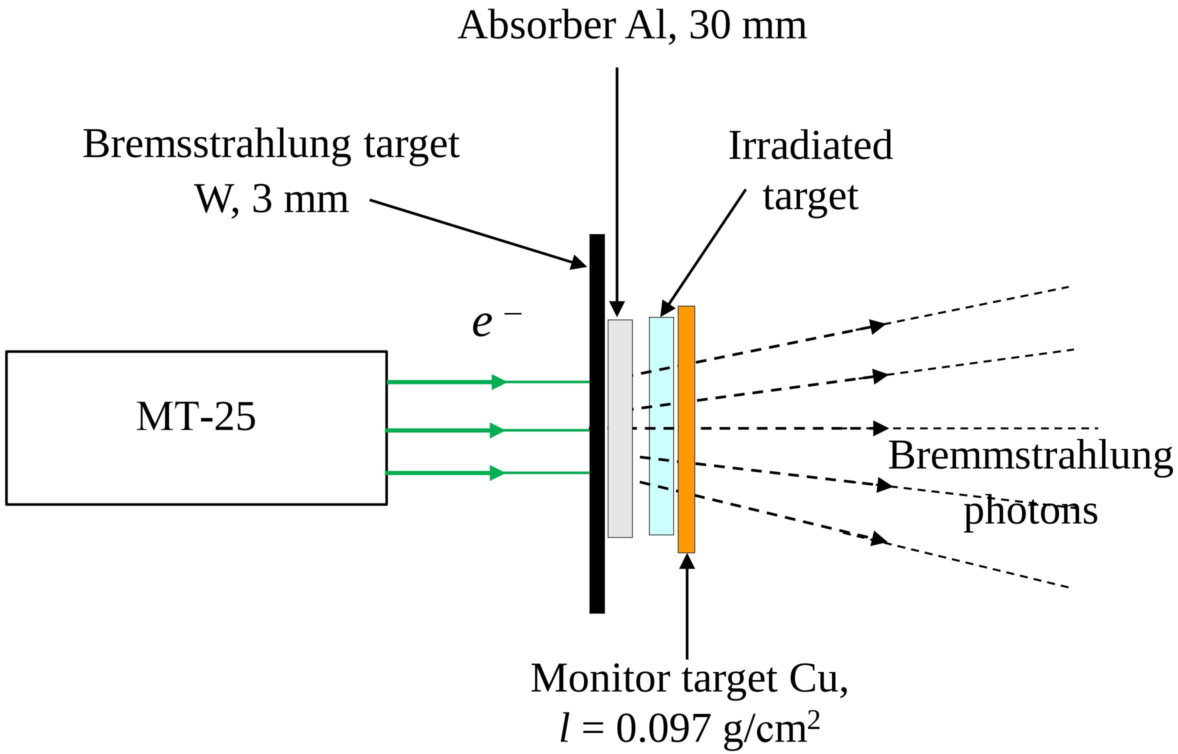


Figure 5. Calculation of cross sections for photoneutron (*a*) and photoproton (*b*) reactions based on the TALYS code and CMPR

Irradiations on MT-25 FLNR JINR



Reaction in monitor – $^{65}Cu(\gamma,n)^{64}Cu$

Figure 6. Scheme of irradiation

Table 1. Main parameters of experiments

Energy of electrons, MeV	Integral charge, mC	Irradiation time, min
10–13	10	50
14–23	5	25

Efficiency of the detector

For each irradiation, spectra were measured with measurement durations of 10 min, 30 min, 1 hour, 12 hours and 1 day.

γ-ray sources: ^{60}Co, ^{109}Cd, ^{134}Cs, ^{137}Cs, ^{152}Eu and ^{241}Am

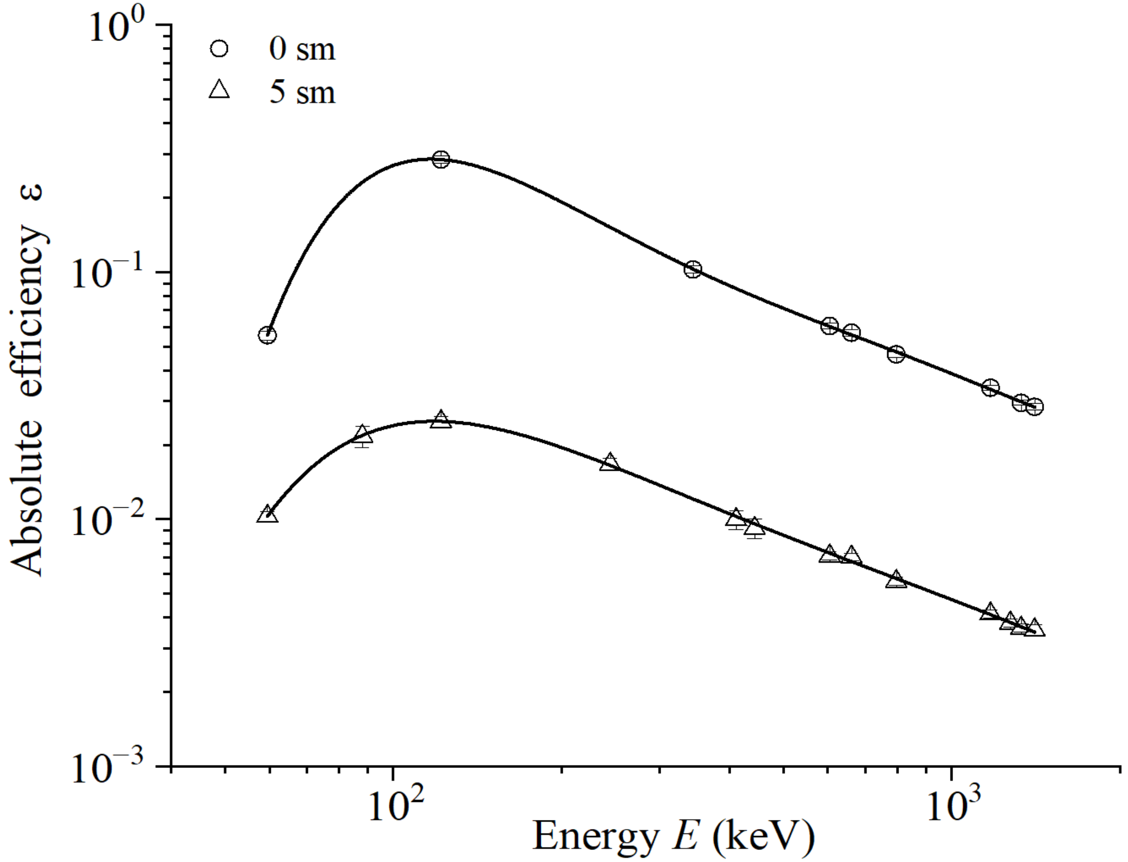


Figure 7. Absolute efficiency curves for positions at different distances from the target to the detector

Examples of γ-spectra of an irradiated target

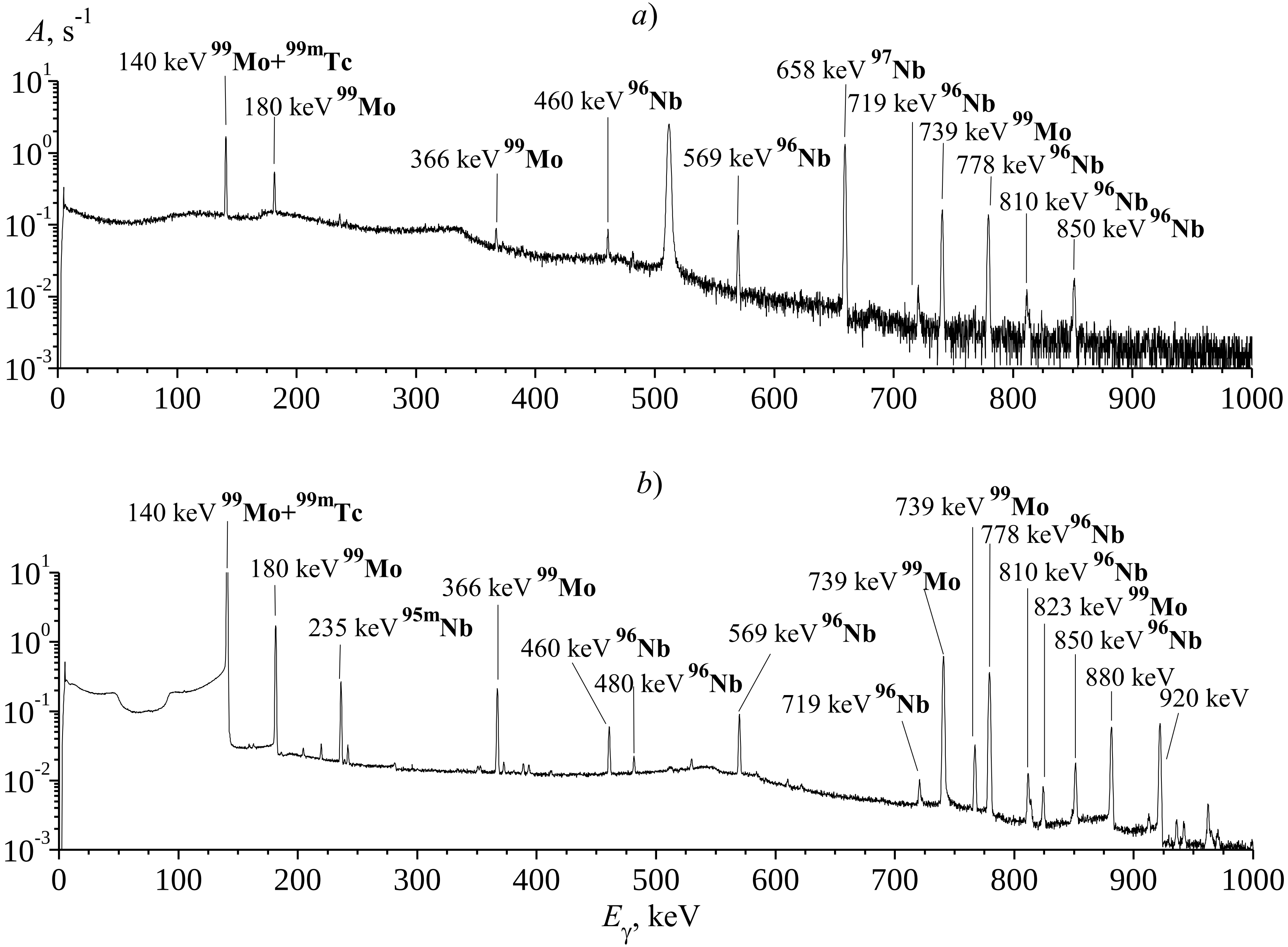


Figure 8. Spectra of residual activity of the irradiated sample of natMo (top to bottom) 1.5 h (a) and 2 days (b) after irradiation. The spectra measurement durations were 1 h (a) and 1 day (b), respectively. The bremsstrahlung end-point energy used for the irradiation was 23 MeV

Let's analyze the experimental results

Results of reactions ^{nat}Se(γ, p) and ^{nat}Mo(γ, p)

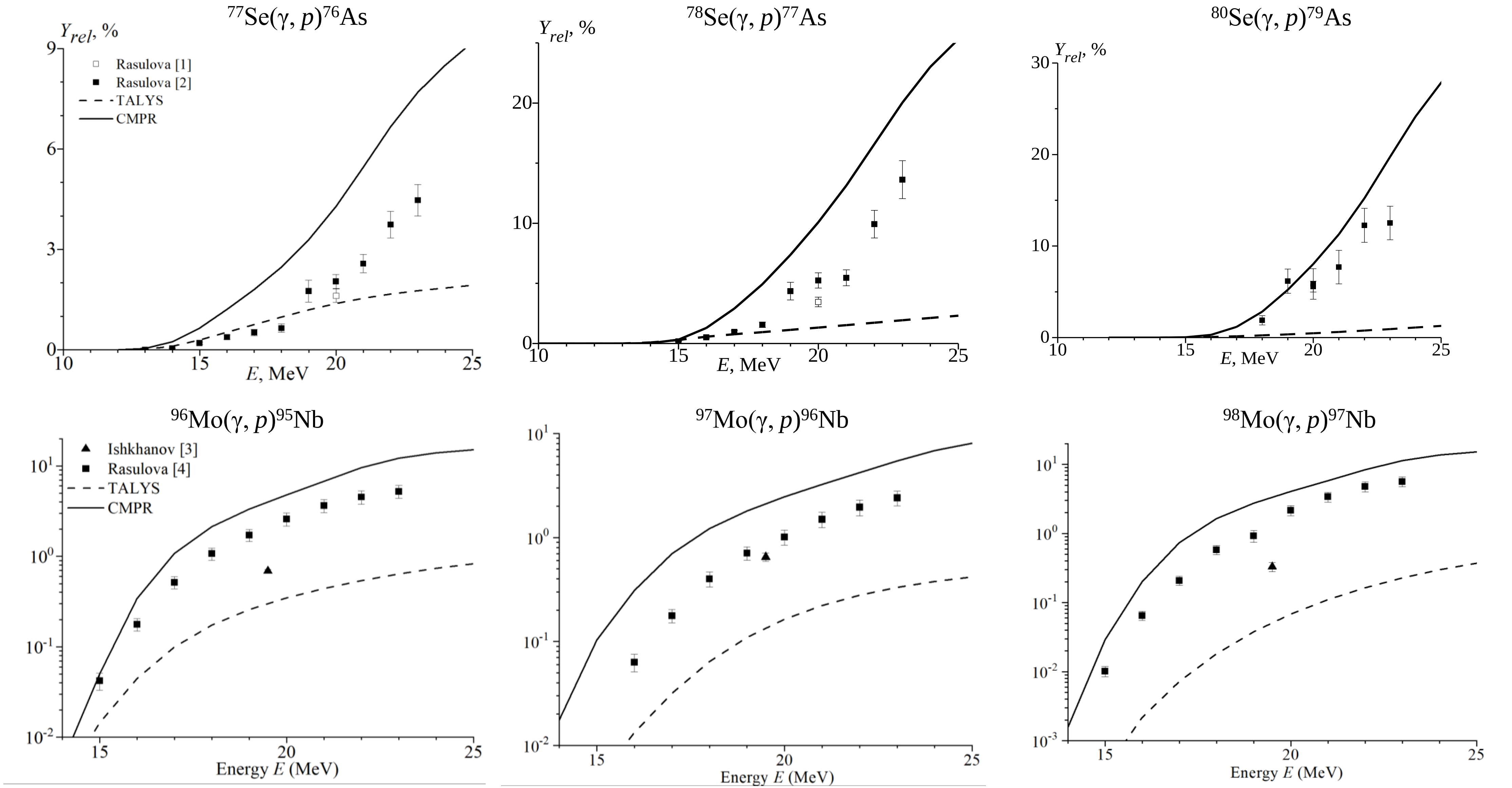


Figure 9. Relative yields of photoproton reactions in the GDR region

[1] Rasulova F.A. et. al.. NIM A, 1045: 168428 (2023).
[2] Rasulova F.A., et. al. Chinese Physics C, 48: 024002 (2024).
[3] Ishkhanov B.S. et.al. Physics of Atomic Nuclei, 77, 1362 (2014).
[4] Rasulova F.A., et. al. Physical Review C, 111, 024604 (2025).

Results of reactions $^{nat}Cd(\gamma, p)^{111,112,113,115}Ag$

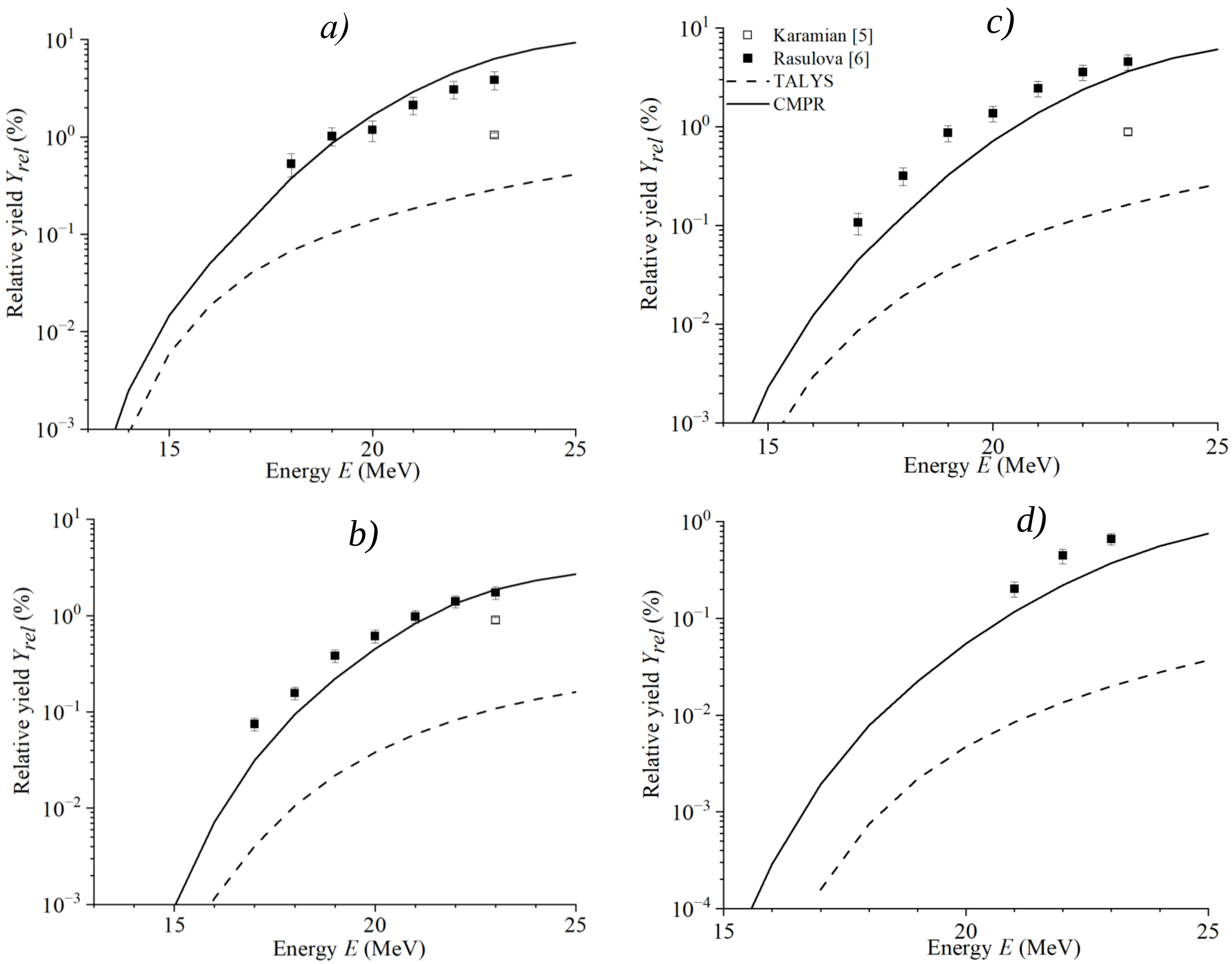


Figure 10. Relative yields of photoproton reactions in the GDR region

a) $^{112}Cd(\gamma, p)^{111}Ag$
$T_{1/2}$= 7,45 d
342 keV (6,7%)

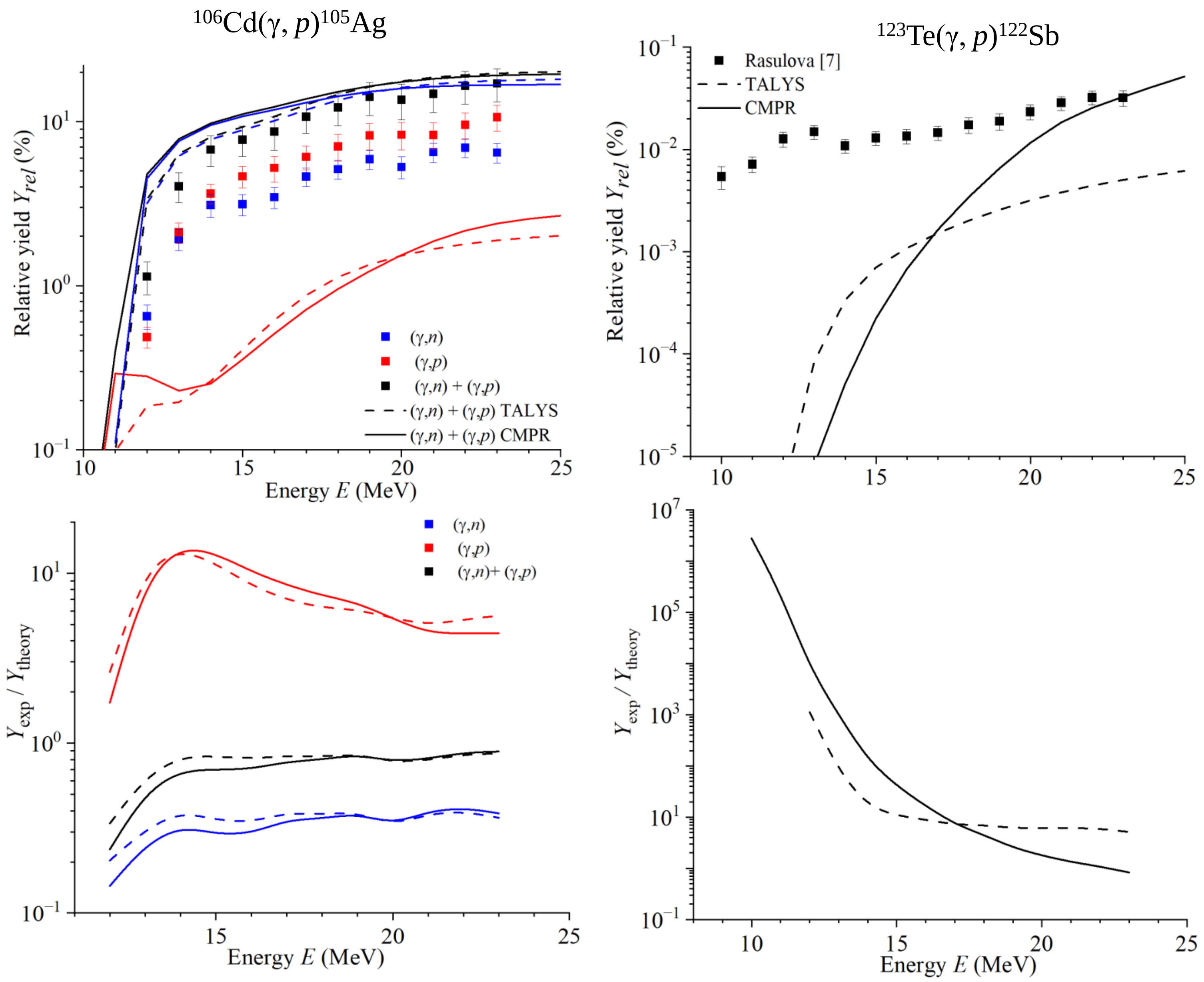
b) $^{113}Cd(\gamma, p)^{112}Ag$
$T_{1/2}$= 3 h
617 keV (43%)

c) $^{114}Cd(\gamma, p)^{113}Ag$
$T_{1/2}$= 5 h
298 keV (10%)

d) $^{116}Cd(\gamma, p)^{115}Ag$
$T_{1/2}$= 20 min
229 keV (18%)

[5] Karamian S.A. et.al. Physics of Atomic Nuclei, 78, 757 (2015).
[6] Rasulova F.A., et. al. Physical Review C (submitted).

Results of reactions $^{106}Cd(\gamma, p)^{105}Ag$ and $^{123}Te(\gamma, p)^{122}Sb$



$^{106}_{48}Cd$:

$$\varepsilon_f(p) = -0.5\left[B_p\left({}^{107}_{49}In\right) + B_p\left({}^{105}_{47}Ag\right)\right] = -4.3 \text{ МэВ},$$

$$\varepsilon_f(n) = -0.5\left[B_n\left({}^{107}_{48}Cd\right) + B_n\left({}^{105}_{48}Cd\right)\right] = -8.2 \text{ МэВ}$$

$^{123}_{52}Te$:

$$\varepsilon_f(p) = -0.5\left[B_p\left({}^{124}_{53}I\right) + B_p\left({}^{122}_{51}Sb\right)\right] = -5.95 \text{ МэВ},$$

$$\varepsilon_f(n) = -0.5\left[B_n\left({}^{124}_{52}Te\right) + B_n\left({}^{122}_{52}Te\right)\right] = -9.63 \text{ МэВ}$$

$$\varepsilon_f(p) > \varepsilon_f(n) \ \rightarrow \text{Параметры}_{OP}(p) > \text{Параметры}_{OP}(n)$$

Figure 11. (*a*) Relative yields; (*b*) ratio of experimental and theoretical yields

Results of reactions $^{nat}Te(\gamma, p)^{124,127,129}Sb$

$^{125}Te(\gamma, p)^{124}Sb$
$T_{1/2}$= 60.2 d
603 keV (98%)
1691 keV (48%)

$^{128}Te(\gamma, p)^{127}Sb$
$T_{1/2}$= 3.8 d
473 keV (26%)
686 keV (37%)

$^{130}Te(\gamma, p)^{129}Sb$
$T_{1/2}$= 4.4 h
813 keV (48%)
915 keV (23%)

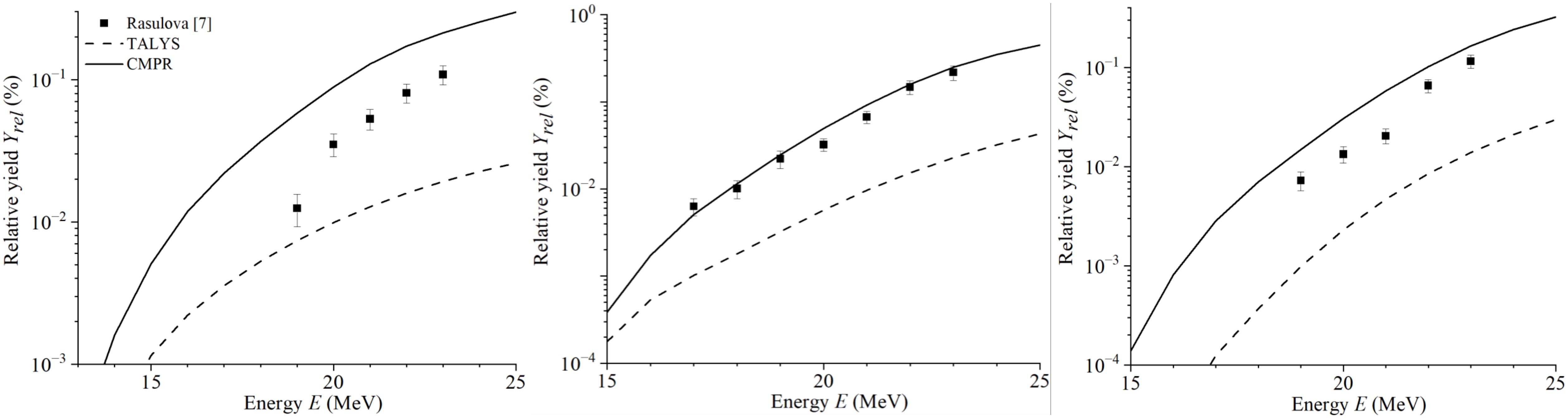


Figure 12. Relative yields of photoproton reactions in the GDR region

[7] Rasulova F.A., et. al. Chinese Physics C (submitted).

Results of reactions $^{nat}Pt(\gamma, p)^{194,195}Ir$

$^{195}Pt(\gamma, p)^{194}Ir$

$T_{1/2}$= 19 h

328 keV (13%)

$^{195m}_{77}Ir \xrightarrow[T_{1/2}=3.7h]{IT: 5\%} {}^{195g}_{77}Ir \xrightarrow[T_{1/2}=2.3\ h]{\beta^-} {}^{195}_{78}Pt$

130 keV (1.4%)
211 keV (2.5%)

433 keV (10%)
685 keV (11%)

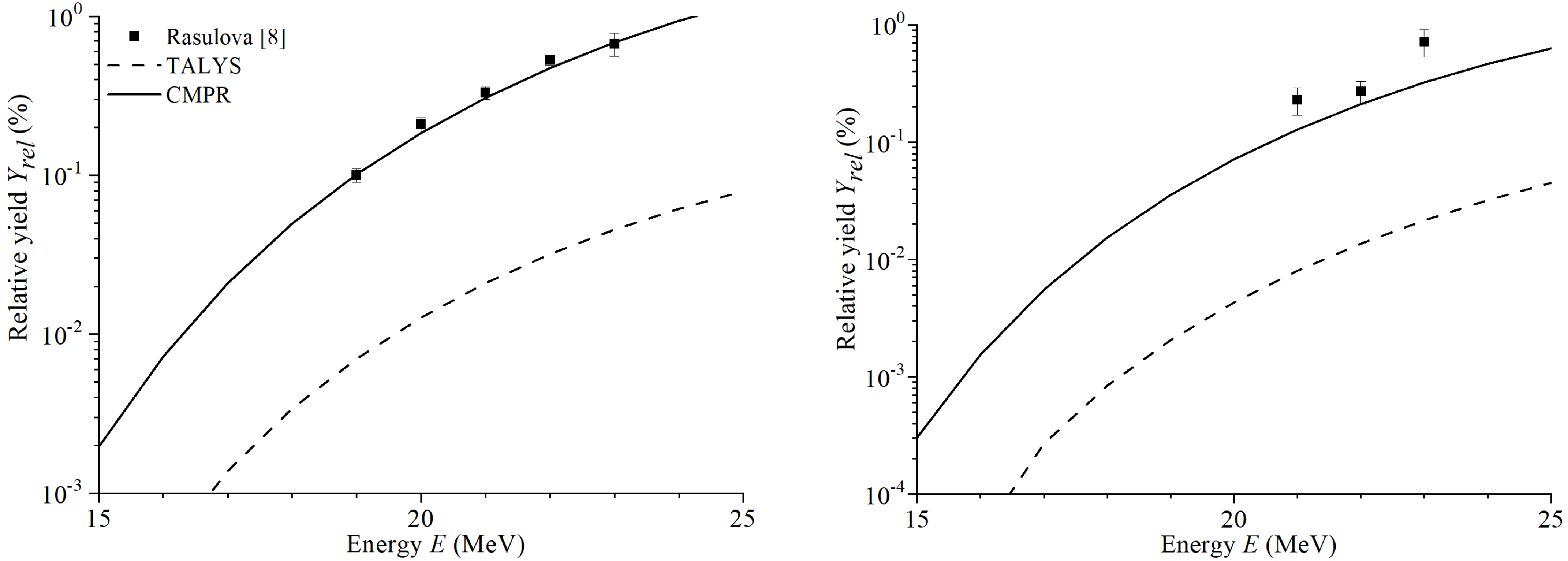
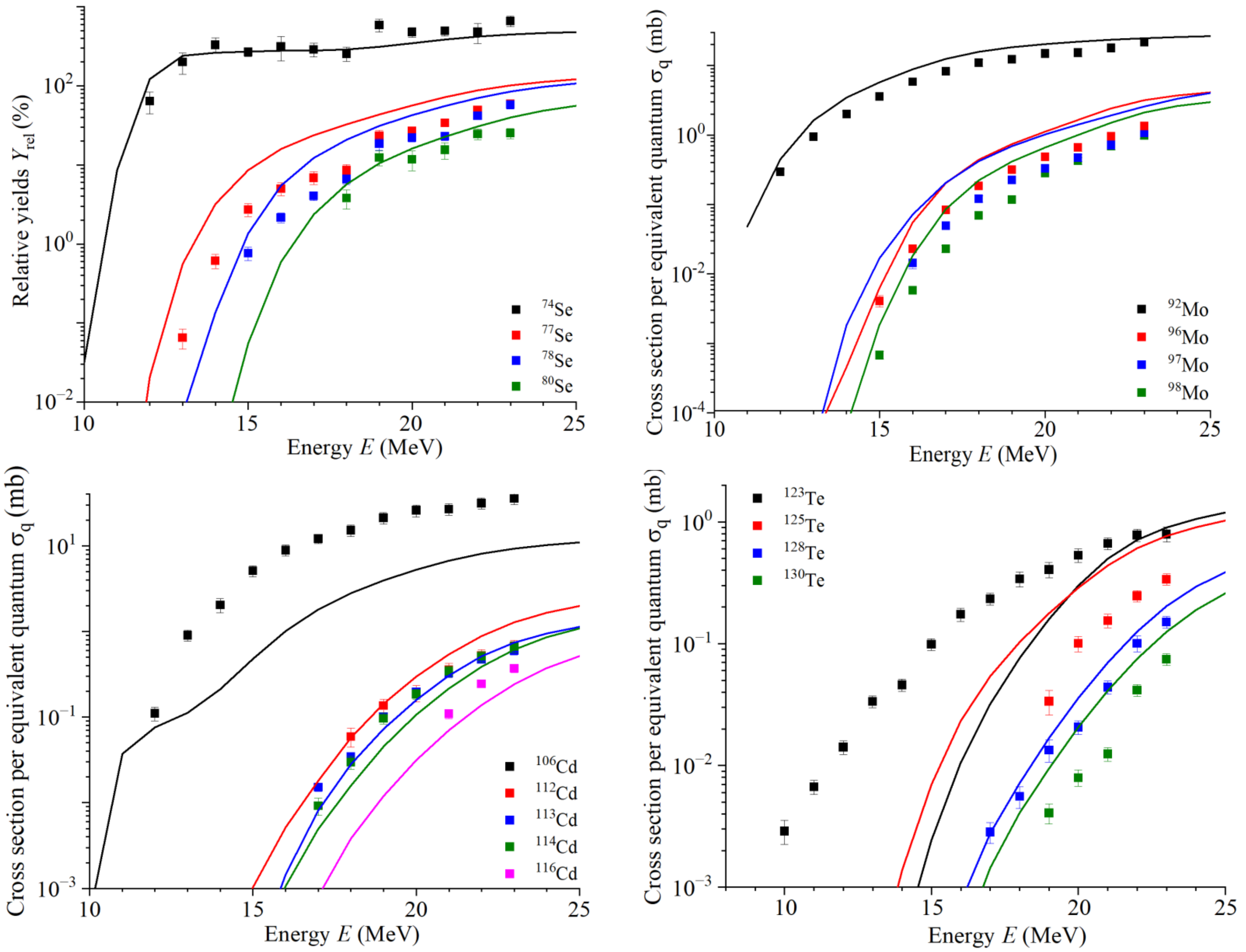


Figure 13. Relative yields of photoproton reactions in the GDR region

[8] Rasulova F.A., et. al. Physical Review C (Accepted).

Summary of the research results



Lighter isotopes have a higher probability of proton release:

1) as nuclear mass increases, a smaller percentage of the γ-quantum energy is transformed into the internal energy of the nucleus;

2) the energy needed to extract a proton from an isotope grows with the number of neutrons in the isotope.

Figure 14. Cross sections per equivalent quantum of photoproton reactions in the case of a monoisotope (with calculated curves using the CMPR)

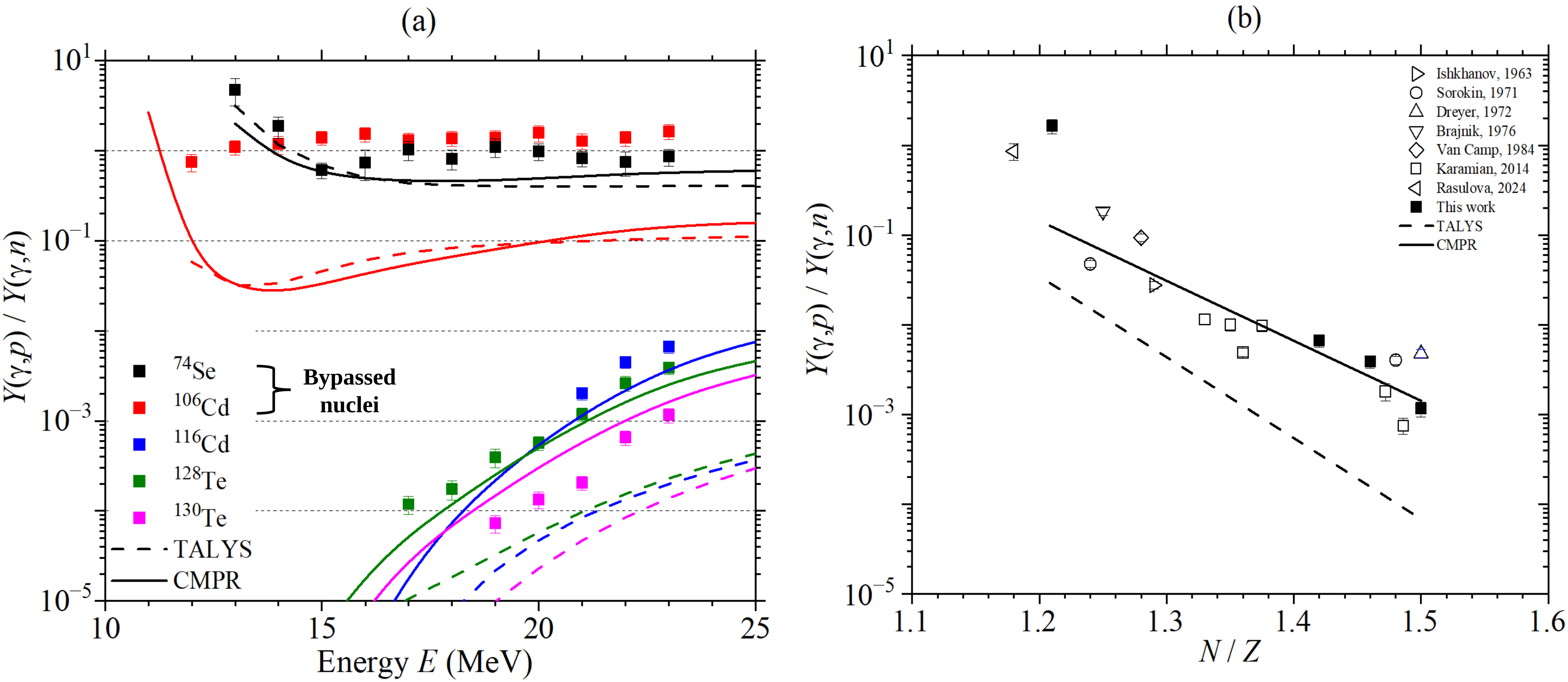


Figure 15. The ratio of the reaction yield (γ,p) to the reaction yield (γ,n) as a function of:
a) the accelerator electron energy; *b*) the proton-neutron ratio N/Z (E = 23 MeV)

Conclusion

- For the first time, the relative yields for photoproton reactions were determined when irradiating a target with ^{nat}Se, ^{nat}Mo, ^{nat}Cd, ^{nat}Te and ^{nat}Pt in a bremsstrahlung field in the photon energy range of 10–23 MeV.

- Taking into account isospin splitting in the CMPR allows one to describe experimental data on reactions with proton emission.

- Using the activation method on a beam of bremsstrahlung photons, it is possible to successfully conduct studies of photonuclear reactions on targets with complex isotopic composition.

Publications

1. Rasulova F.A., Aksenov N.V., Alekseev S.I., Aliev R.A., Belyshev S.S., Chuprakov I., Fursova N.Yu., Madumarov A.S., Khushvaktov J.H., Kuznetsov A.A., Yuldashev B.S. ***Photonuclear reactions on the stable isotopes of selenium at bremsstrahlung end-point energies of 10-23 MeV*** // **Chinese Physics C**. – 2024. – Vol. 48. – № 2 – p. 024002. (IF=3.6)

2. Rasulova F.A., Aksenov N.V., Alekseev S.I., Belyshev S.S., Chuprakov I., Fursova N.Yu., Madumarov A.S., Khushvaktov J.H., Kuznetsov A.A. ***Photonuclear reactions on stable isotopes of molybdenum at bremsstrahlung end-point energies of 10-23 MeV*** // **Phy. Rev. C** – 2025. – Vol. 111. – p. 024604.

3. Rasulova F.A., Aksenov N.V., Alekseev S.I., Belyshev S.S., Bozhikov G. A., Chuprakov I., Fursova N.Yu., Madumarov A.S., Khushvaktov J.H., Kuznetsov A.A. ***Photonuclear reactions on stable isotopes of platinum at bremsstrahlung end-point energies of 10-23 MeV*** **// Phy. Rev. C** – Accepted.

4. Rasulova F.A., Aksenov N.V., Alekseev S.I., Belyshev S.S., Bozhikov G. A., Chuprakov I., Fursova N.Yu., Madumarov A.S., Khushvaktov J.H., Kuznetsov A.A. ***Photonuclear reactions on stable isotopes of cadmium at bremsstrahlung end-point energies of 10-23 MeV*** **// Phy. Rev. C** – submitted.

5. Rasulova F.A., Aksenov N.V., Alekseev S.I., Belyshev S.S., Bozhikov G. A., Chuprakov I., Fursova N.Yu., Madumarov A.S., Khushvaktov J.H., Kuznetsov A.A. ***Photonuclear reactions on stable isotopes of tellurium at bremsstrahlung end-point energies of 10-23 MeV*** **// Phy. Rev. C** – submitted.

The results of the study were discussed at *the 75th International Conference "NUCLEUS-2025"* and *the 29th International Conference on Charged Particle Accelerators RuPAC'25.*

Scientific significance of the results and citation of the articles

M1049 [1] 2024 F.A.Rasulova+ J,CPH/C,48,024002,2024 Jour: Chinese Physics C, Vol.48, p.024002 (2024)

1) + Jour: Chinese Physics C, Vol.48, p.024002 (2024)
Photonuclear reactions on stable isotopes of selenium at bremsstrahlung end-point energies of 10-23 MeV.
F.A.Rasulova, N.V.Aksenov, S.I.Alekseev, R.A.Aliev, S.S.Belyshev, I.Chuprakov, N.Yu.Fursova, A.S.Madumarov, J.H.Khushvaktov, A.A.Kuznetsov, B.S.Yuldashev

M1049001	Info	X4	X4+	general information				
M1049002	Info	X4	X4+	T4	Pt:11	1.30e7	2.30e7	(34-SE-0(G,X)34-SE-73-G,,SIG,,BRA)/(34-SE-0(G,X)34-SE-81,,SIG,,BRA)
M1049003	Info	X4	X4+	T4	Pt:11	1.30e7	2.30e7	(34-SE-0(G,X)34-SE-73-M,,SIG,,BRA)/(34-SE-0(G,X)34-SE-81,,SIG,,BRA)
M1049004	Info	X4	X4+	T4	Pt:11	1.30e7	2.30e7	(34-SE-0(G,X)34-SE-73,,SIG,,BRA)/(34-SE-0(G,X)34-SE-81,,SIG,,BRA)
M1049005	Info	X4	X4+	T4	Pt:12	1.20e7	2.30e7	(34-SE-0(G,X)34-SE-75,,SIG,,BRA)/(34-SE-0(G,X)34-SE-81,,SIG,,BRA)
M1049006	Info	X4	X4+	T4	Pt:14	1.00e7	2.30e7	34-SE-0(G,X)34-SE-81-G/T,,SIG/RAT,,BRA
M1049007	Info	X4	X4+	T4	Pt:14	1.00e7	2.30e7	34-SE-0(G,X)34-SE-81-M/T,,SIG/RAT,,BRA
M1049008	Info	X4	X4+	T4	Pt:12	1.20e7	2.30e7	(34-SE-0(G,X)33-AS-73,,SIG,,BRA)/(34-SE-0(G,X)34-SE-81,,SIG,,BRA)
M1049009	Info	X4	X4+	T4	Pt:11	1.30e7	2.30e7	(34-SE-0(G,X)33-AS-76,,SIG,,BRA)/(34-SE-0(G,X)34-SE-81,,SIG,,BRA)
M1049010	Info	X4	X4+	T4	Pt:9	1.50e7	2.30e7	(34-SE-0(G,X)33-AS-77,,SIG,,BRA)/(34-SE-0(G,X)34-SE-81,,SIG,,BRA)
M1049011	Info	X4	X4+	T4	Pt:6	1.80e7	2.30e7	(34-SE-0(G,X)33-AS-79,,SIG,,BRA)/(34-SE-0(G,X)34-SE-81,,SIG,,BRA)

1. The origin of low-abundance neutron-deficient stable isotopes and the relevant cross section measurements. Chinese Science Bulletin, 69: 3088 - 3098 (2024) (IF=1.2)

M1059 [1] 2025 F.A.Rasulova+ J,PR/C,111,024604,2025 Jour: Physical Review, Part C, Nuclear Physics, Vol.111, p.024604 (2025)

1) + Jour: Physical Review, Part C, Nuclear Physics, Vol.111, p.024604 (2025) DOI: 10.1103/PhysRevC.111.024604 NSR:2025RA05
Photonuclear reactions on stable isotopes of molybdenum at bremsstrahlung endpoint energies of 10--23 MeV
F.A.Rasulova, N.V.Aksenov, S.I.Alekseev, S.S.Belyshev, I.Chuprakov, N.Yu.Fursova, A.S.Madumarov, J.H.Khushvaktov, A.A.Kuznetsov

M1059001	Info	X4	X4+	general information				
M1059002	Info	X4	X4+	T4	Pt:14	1.00e7	2.30e7	42-MO-0(G,X)42-MO-99,,SIG,,BRA
M1059003	Info	X4	X4+	T4	Pt:14	1.00e7	2.30e7	42-MO-0(G,X)42-MO-99,,SIG,,BRA/MSC
M1059004	Info	X4	X4+	T4	Pt:8	1.60e7	2.30e7	42-MO-0(G,X)42-MO-91-G,M+,SIG,,BRA
M1059005	Info	X4	X4+	T4	Pt:8	1.60e7	2.30e7	42-MO-0(G,X)42-MO-91-G,M+,SIG,,BRA/MSC
M1059006	Info	X4	X4+	T4	Pt:8	1.60e7	2.30e7	42-MO-0(G,X)40-ZR-88,,SIG,,BRA
M1059007	Info	X4	X4+	T4	Pt:8	1.60e7	2.30e7	42-MO-0(G,X)40-ZR-88,,SIG,,BRA/MSC
M1059008	Info	X4	X4+	T4	Pt:12	1.20e7	2.30e7	42-MO-0(G,X)41-NB-91-M,,SIG,,BRA
M1059009	Info	X4	X4+	T4	Pt:12	1.20e7	2.30e7	42-MO-0(G,X)41-NB-91-M,,SIG,,BRA/MSC
M1059010	Info	X4	X4+	T4	Pt:9	1.50e7	2.30e7	42-MO-0(G,X)41-NB-95-M,,SIG,,BRA
M1059011	Info	X4	X4+	T4	Pt:9	1.50e7	2.30e7	42-MO-0(G,X)41-NB-95-M,,SIG,,BRA/MSC
M1059012	Info	X4	X4+	T4	Pt:8	1.60e7	2.30e7	42-MO-0(G,X)41-NB-96,,SIG,,BRA
M1059013	Info	X4	X4+	T4	Pt:8	1.60e7	2.30e7	42-MO-0(G,X)41-NB-96,,SIG,,BRA/MSC
M1059014	Info	X4	X4+	T4	Pt:9	1.50e7	2.30e7	42-MO-0(G,X)41-NB-97,,SIG,,BRA

1. Electric dipole polarizability constraints on neutron skin and symmetry energy. Front. Phys. 13:1629987 (2025) (IF=2.1)

2. Study of the radiation environment during ^{1}H irradiation of metallic ^{nat}Mo target: The accelerator pathway for ^{99m}Tc production. Radiation Physics and Chemistry, 239: 113293 (2026) (IF=3.3)

Thank you for attention!