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ISOMERIC RATIOS IN SOME INVERSE (γ, n) AND (n, γ) REACTIONS

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INTRODUCTION

The isomeric ratio (IR), the ratio of the probabilities for forming isomeric and ground states, provides diverse information about nuclear structure and nuclear reaction mechanism. In this work, we investigate IRs in some inverse (γ, n) and (n, γ) reactions, which lead to the same residual nucleus with near the same excitation energy by activation method using off-line gamma spectroscopy. Namely, they are IRs of isomeric pairs $^{137m,g}Ce$, $^{115m,g}Cd$, $^{109m,g}Pd$ and $^{81m,g}Se$ in inverse (γ, n) and (n, γ) reactions. Inverse reactions, including photonuclear and thermal neutron capture reactions play important role in astrophysics. The photon and neutron source were constructed at the electron accelerator Microtron MT25 of FLNR, JINR, Dubna, Russia. In the other hand, theoretical calculation of IRs by combination of Talys 1.95 code and GEANT4 simulation tool was used for (γ, n) photonuclear reactions.

EXPERIMENTAL PROCEDURE

Experimental set-up

The IRs in the (γ, *n*) and (*n*, γ) reactions were studied at the bremsstrahlung photon beam, thermal neutron flux constructed at the electron accelerator Microtron MT-25 (Fig.1).

Fig. 1. MT-25 accelerator at JINR, Dubna, Russia

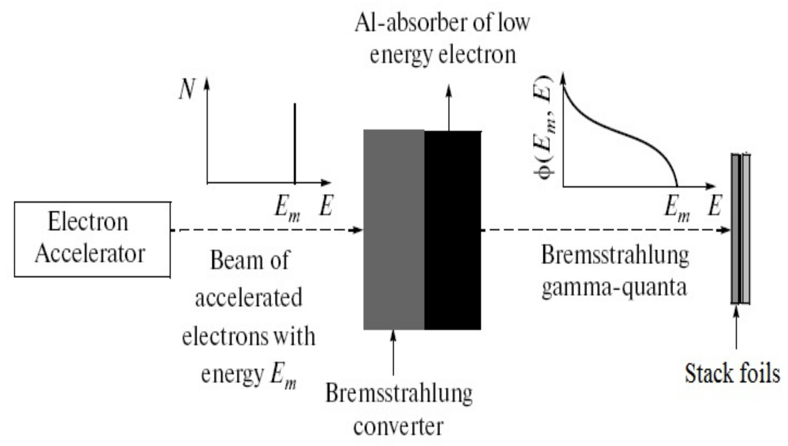

Fig.2 Experimental set-up for the study of photonuclear reaction

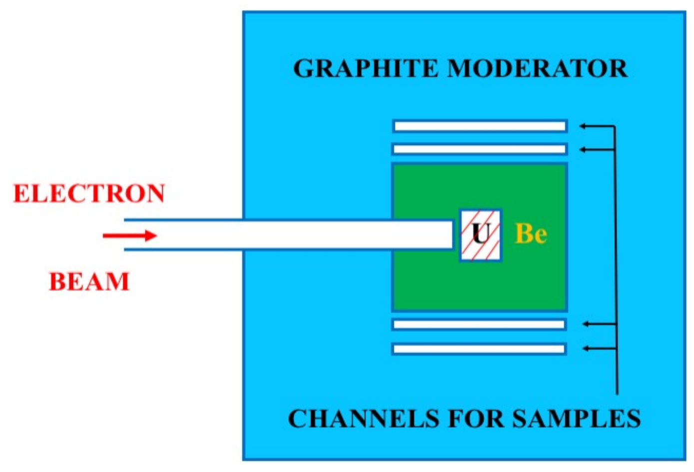

Fig.3. Scheme for production of thermal neutrons

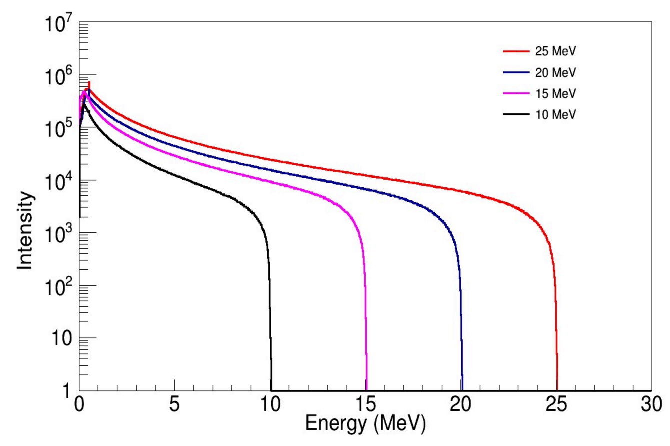

Fig.4. Bremsstrahlung spectra calculated by Geant4

Sample preparation, irradiation and measurement

99.99% purity Ce_2O_3, CdO, PdO and SeO_2 powder packed in aluminum capsule in disk shape of 1 cm diameter. The samples were irradiated at the bremsstrahlung flux of end-point energy of 25 MeV and thermal neutrons (Fig.2 and Fig.3). High-energy resolution HPGe detector with conventional electronics was used for measuring gamma spectroscopy.

Calculation of the theoretical isomeric ratio

$$IR = \frac{Y_g}{Y_m} = \frac{N_0 \int_{E_{th}^m}^{E_\gamma^m} \sigma_m(E)\phi(E)dE}{N_0 \int_{E_{th}^g}^{E_\gamma^m} \sigma_g(E)\phi(E)dE}$$

Where E_g^m - the bremsstrahlung end-point energy, $\phi(E)$ – the bremsstrahlung photon flux, N_0 - the number of the target nuclei; $\sigma_m(E)$ and $\sigma_g(E)$ - the cross sections of the isomeric and ground states; E_{th}^m and E_{th}^g - the threshold reaction energies for the isomeric and ground state respectively.

Calculation of the experimental isomeric ratio

Basing on the activation equation, *IR* was calculated using the expression:

$$\frac{1}{IR} = \frac{\frac{S_g \varepsilon_m I_m}{S_m \varepsilon_g I_g}\Lambda_3\Lambda_6\Lambda_9 - \Lambda_1\Lambda_5\Lambda_8 - \Lambda_3\Lambda_4\Lambda_8 - \Lambda_3\Lambda_6\Lambda_7}{\Lambda_2\Lambda_5\Lambda_8}$$

Where *S*, *ε* and *I* – counts, efficiencies and intensities of interested gamma rays and Λ_i (i = 1 ~ 9) are expressions related to the irradiation, cooling and measurement time as in ref.[1].

RESULTS

Spectra of Ce, Cd, Pd and Se samples irradiated by 25 MeV bremsstrahlung

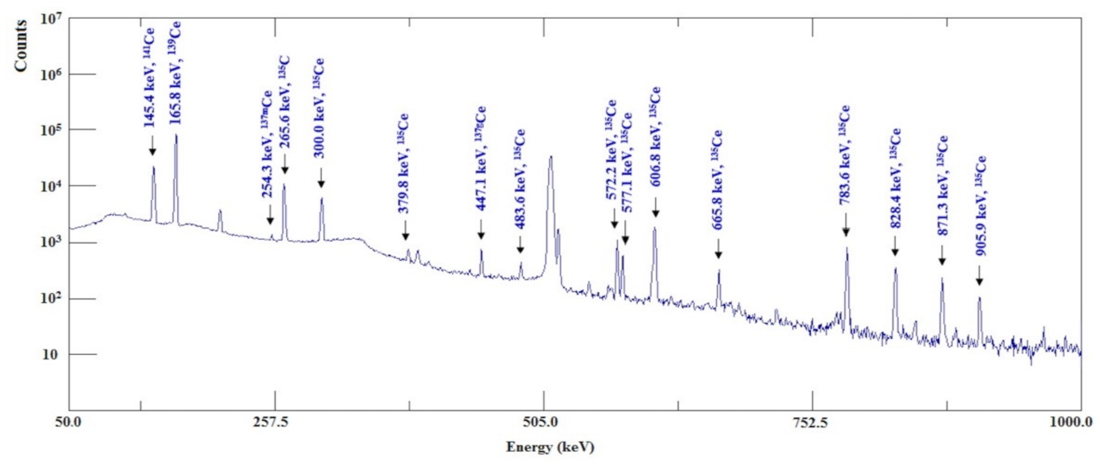

Fig. 5 Spectrum of Ce-sample irradiated by bremsstrahlung

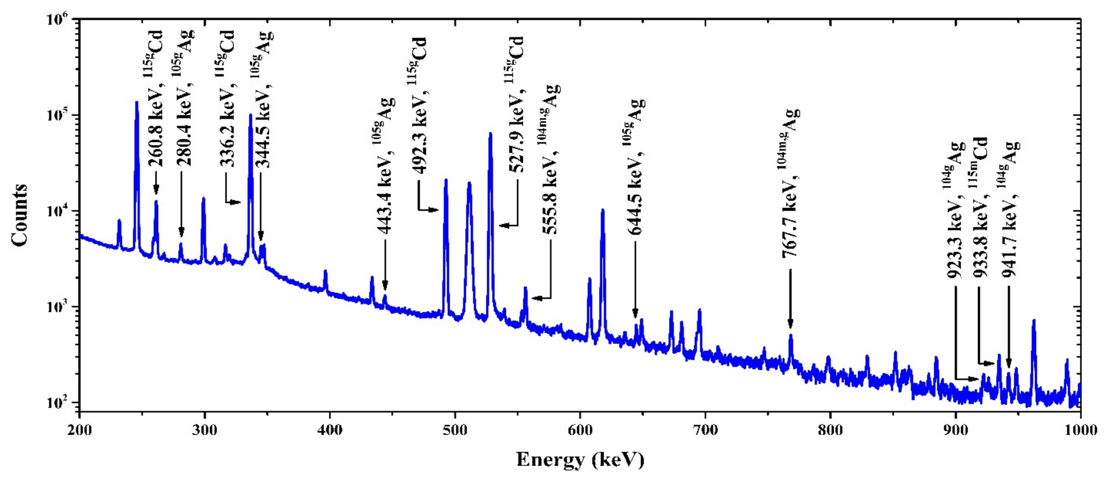

Fig. 6 Spectrum of Ce-sample irradiated by bremsstrahlung

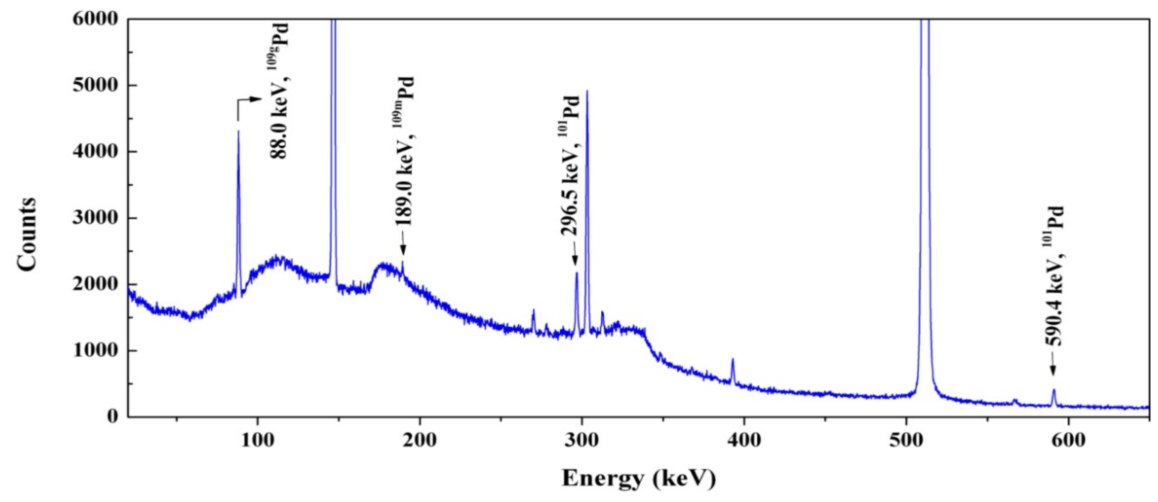

Fig. 7 Spectrum of Pd-sample irradiated by bremsstrahlung

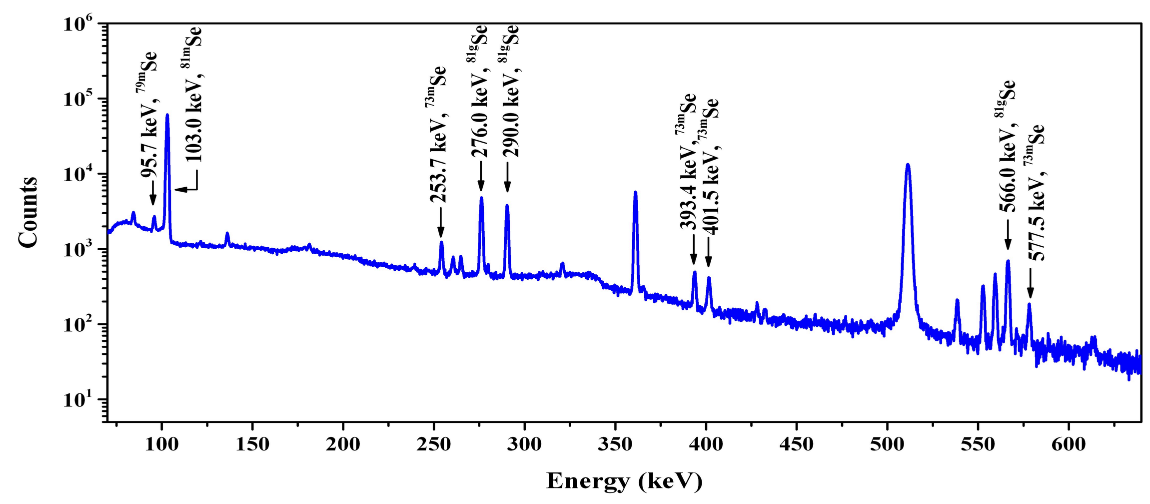

Fig. 8 Spectrum of Se-sample irradiated by bremsstrahlung

Spectra of Ce, Cd, Pd and Se samples irradiated by thermal neutrons

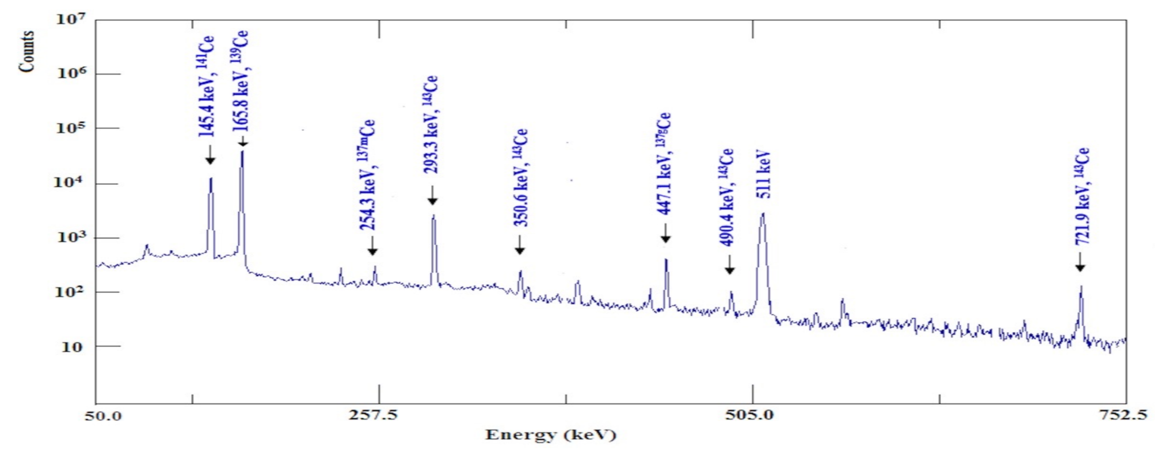

Fig. 9 Spectrum of Ce-sample irradiated by thermal neutrons

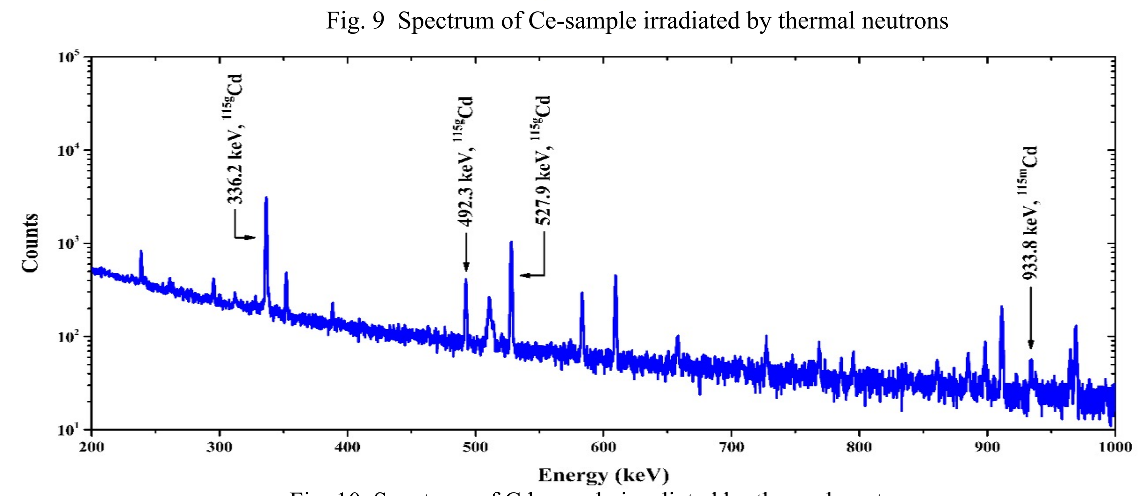

Fig. 10 Spectrum of Cd-sample irradiated by thermal neutrons

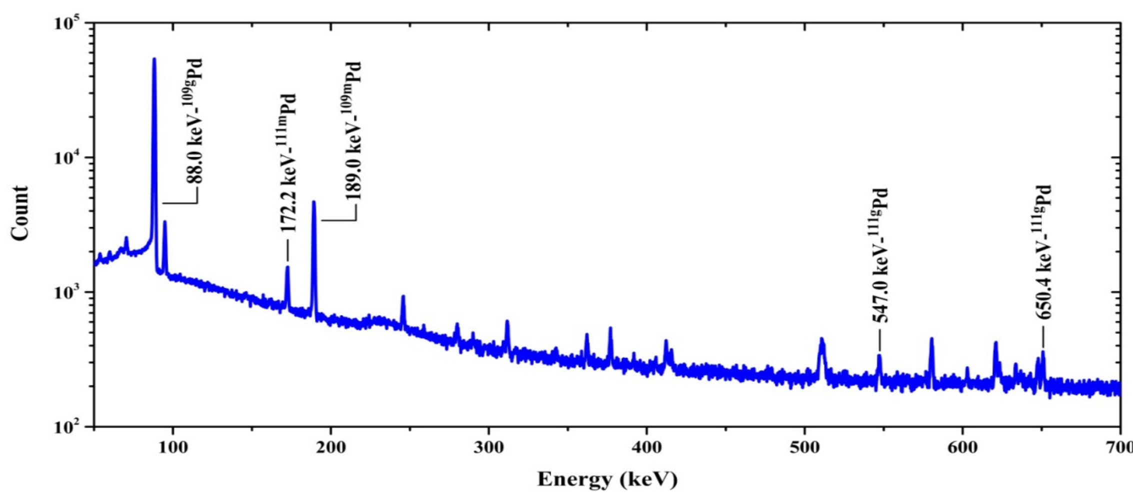

Fig. 11 Spectrum of Pd-sample irradiated by thermal neutrons

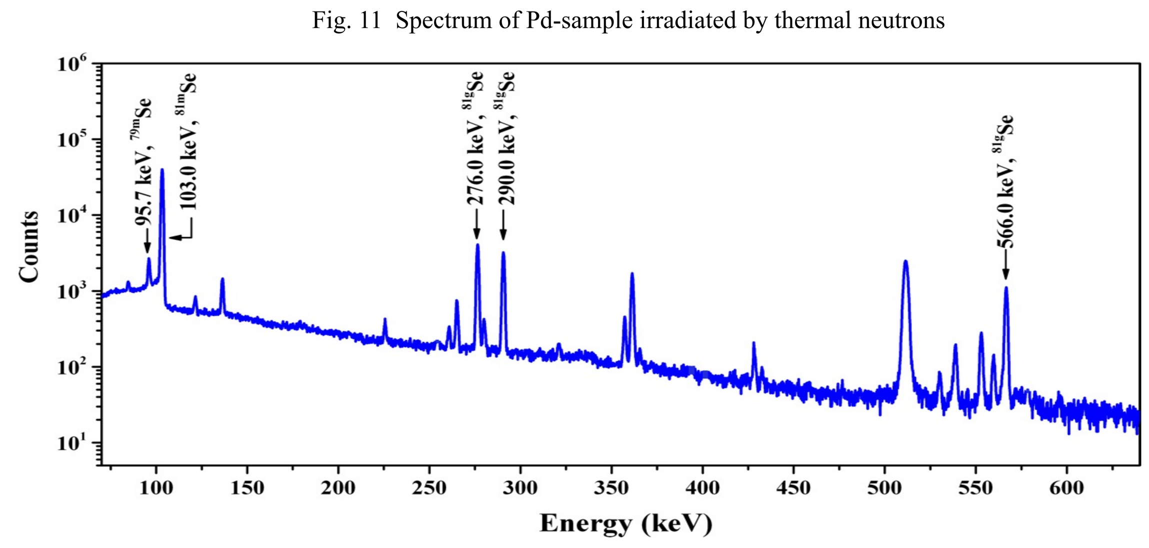

Fig. 12 Spectrum of Se-sample irradiated by thermal neutrons

RESULTS

Table 1. The isomeric ratio of the investigated (γ, n) and (n, γ) reactions

Nuclear Reaction and Product	Type of Projectile	Product Exc. Energy [MeV]	Isomeric Ratio IR
$^{138}Ce(\gamma, n)^{137m,g}Ce$	25 MeV Bremsstrahlung	5.5	0.221(22) [This work] 0.19(2) [2]
$^{136}Ce(n, \gamma)^{137m,g}Ce$	Thermal neutron	7.4	0.112(11) [This work] 0.109(10) [1], 0.15(1) [3] 0.088(6) [4]
$^{116}Cd(\gamma, n)^{115m,g}Cd$	25 MeV Bremsstrahlung	5.8	0.165(16) [This work] 0.168(20) [5]
$^{114}Cd(n, \gamma)^{115m,g}Cd$	Thermal neutron	6.1	0.116(12) [This work] 0.099(33) [6]
$^{110}Pd(\gamma, n)^{109m,g}Pd$	25 MeV Bremsstrahlung	6.3	0.069(7) [This work] 0.065(3) [7]
$^{108}Pd(n, \gamma)^{109m,g}Pd$	Thermal neutron	6.1	0.023(2) [This work] 0.018(5) [8], 0.028(5) [9]
$^{82}Se(\gamma, n)^{81m,g}Se$	25 MeV Bremsstrahlung	6.9	0.556(55) [This work] 0.56(2) [10]
$^{80}Se(n, \gamma)^{81m,g}Se$	Thermal neutron	6.7	0.114 (14) [This work] 0.204(24) [3], 0.136(11) [9], 0.096(9) [11]

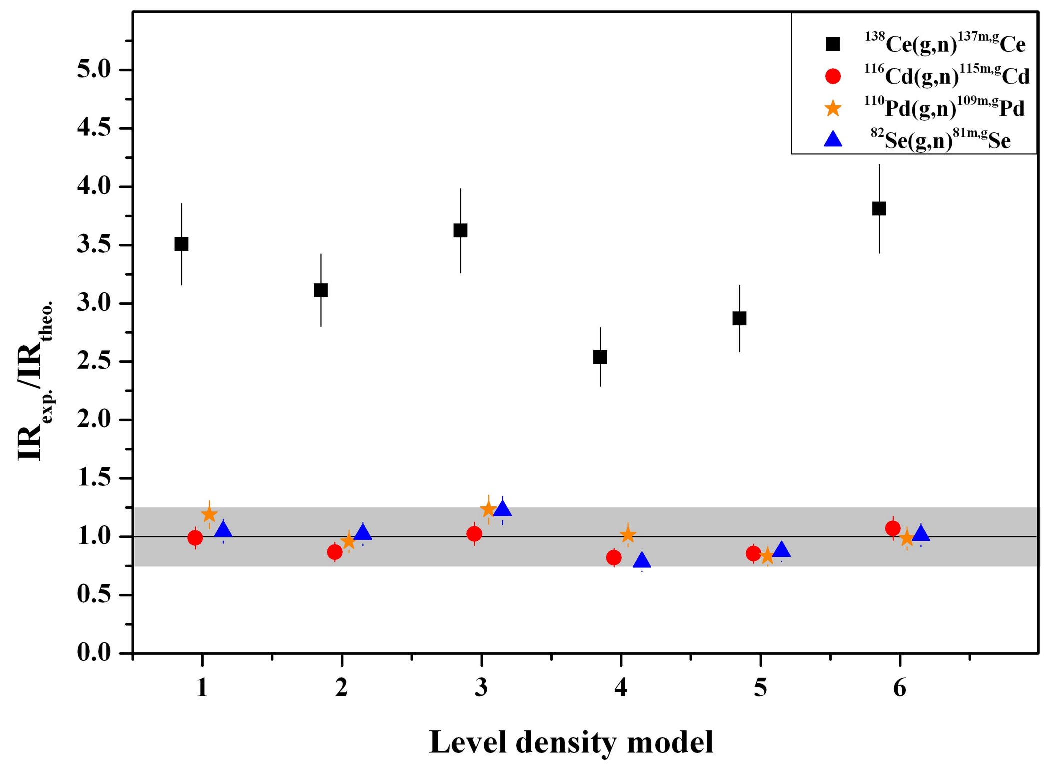

Fig. 13. Measured ($IR_{exp.}$) and calculated ($IR_{theo.}$) isomeric ratios of $^{138}Ce(\gamma,n)^{137m,g}Ce$, $^{116}Cd(\gamma,n)^{115m,g}Cd$, $^{110}Pd(\gamma,n)^{109m,g}Pd$ and $^{82}Se(\gamma,n)^{81m,g}Se$ induced by 25 MeV bremsstrahlung. The theoretical IR calculated by the six level density models of Talys code 1.95 with the Goriely T-dependent HFB model for gamma – ray strength function.

CONCLUSIONS

- The isomeric ratios of isomeric pairs $^{137m,g}Ce$, $^{115m,g}Cd$, $^{109m,g}Pd$ and $^{81m,g}Se$ obtained from inverse reactions (γ, n) and (n, γ) have been measured by the activation method. The experimental results show that the IRs in (γ, n) reactions are significantly higher than that in (n, γ) reactions. This trend can be explained by the intake momentum and impulse, transfered to the target nuclei from the projectiles, namely the higher the intake momentum and impulse the higher the isomeric ratio.
- For the (γ, n) reactions, the IRs in this work and the data in mentioned references in the error limit are in good agreement. Likewise, for the (n, γ) reactions, in the error limit, our result and the data from the references are in good agreement except for $^{81m,g}Se$ to be considerably less than that from refs. [3].
- Talys 1.8 code and Geant4 simulation tool were used for theoretical IR calculation of $^{137m,g}Ce$, $^{115m,g}Cd$, $^{109m,g}Pd$ and $^{81m,g}Se$ produced from (γ, n) reaction. In general, the obtained results of calculation are consistent with the experimental results, except the case of $^{138}Ce(\gamma, n)^{137m,g}Ce$ reaction requiring the level density and strength function models to be more detailed.

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