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# EXCITATION [illegible] HIGH SPIN ISOMERS $^{180m}$Hf, [illegible]Os AND $^{204m}$Pb IN $(\gamma, \gamma')$ REACTIONS

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Балабанов Н.П. и др. E15-93-370
Возбуждения высокоспиновых изомеров
$^{180m}$Hf, $^{190m}$Os и $^{204m}$Pb в $(\gamma, \gamma')$ реакциях

Возбуждение изомерных состояний $^{180}$Hf($J^{\pi}_{m} = 8^{-}$), $^{190}$Os($J^{\pi}_{m} = 10^{-}$) и $^{204}$Pb($J^{\pi}_{m} = 9^{-}$) изучалось в реакции $(\gamma, \gamma')$. Сечения возбуждения и изомерные отношения измерялись с использованием активационной методики в интервале энергий $\gamma$-квантов $6 \div 15$ МэВ. Экспериментальные результаты сравниваются с теоретическими расчетами. Обсуждаются относительные распределения различных $\gamma$-мультипольностей в процессе заселения изомерных состояний.

Работа выполнена в Лаборатории ядерных реакций ОИЯИ.

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Excitation of the High-Spin Isomers $^{180m}$Hf, $^{190m}$Os and $^{204m}$Pb
in $(\gamma, \gamma')$ Reactions

Excitation of isomeric states of $^{180}$Hf($J^{\pi}_{m} = 8^{-}$), $^{190}$Os($J^{\pi}_{m} = 10^{-}$) and $^{204}$Pb($J^{\pi}_{m} = 9^{-}$) is studied for $(\gamma, \gamma')$ reactions. The cross-sections and isomeric ratios are measured using activation technique in the energy region from 6 up to 15 MeV. Experimental results were compared with statistical theory predictions. A relative contribution of different $\gamma$-ray multipolarities into the process of the population of isomeric states excited in the photoabsorption reaction and $\gamma$-cascade is investigated.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

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## I. Introduction

In the even-even nuclei there are observed high-spin isomers with spins up to 30ħ and half-lives up to several years [1]. Usually investigations of these isomers have been performed in reaction induced by protons, α-particles and heavy ions but their investigation in $(\gamma,\gamma')$ reactions, however, is of great interest. Firstly, since there are not Coulomb barrier and binding energy for γ-quanta, one can obtain excited nuclei both in the region above nucleon threshold and below it. Secondly, the momentum being introduced into nucleus by γ-quantum is not varied with energy increase (it is 1ħ at dipole absorption and 2ħ at quadruple one). Therefore, for an even-even nucleus the spin and parity of the initial compound states are unambiguously determined ($1^-, 1^+$ or $2^+$) and γ-quanta cascade leads to an isomeric state.

In the present work there have been investigated $(\gamma,\gamma')$ reactions producing high-spin isomers of nuclei belonging to three different regions: strongly deformed ($^{180}$Hf), transitional ($^{190}$Os) and spherical ($^{204}$Pb). The experimental isomeric ratios have been compared with statistical model calculations and parameters describing γ-cascades have been obtained.

## II. Experimental method

The present investigations have been carried out on the beam of bremsstrahlung gamma quanta of the microtron MT-25 FLNR, JINR, Dubna in the energy region from 6 to 15 MeV. The electron beam extracted from the accelerator microtron chamber was directed on a tungsten stopping target by means of a system of quadruple lenses. The target

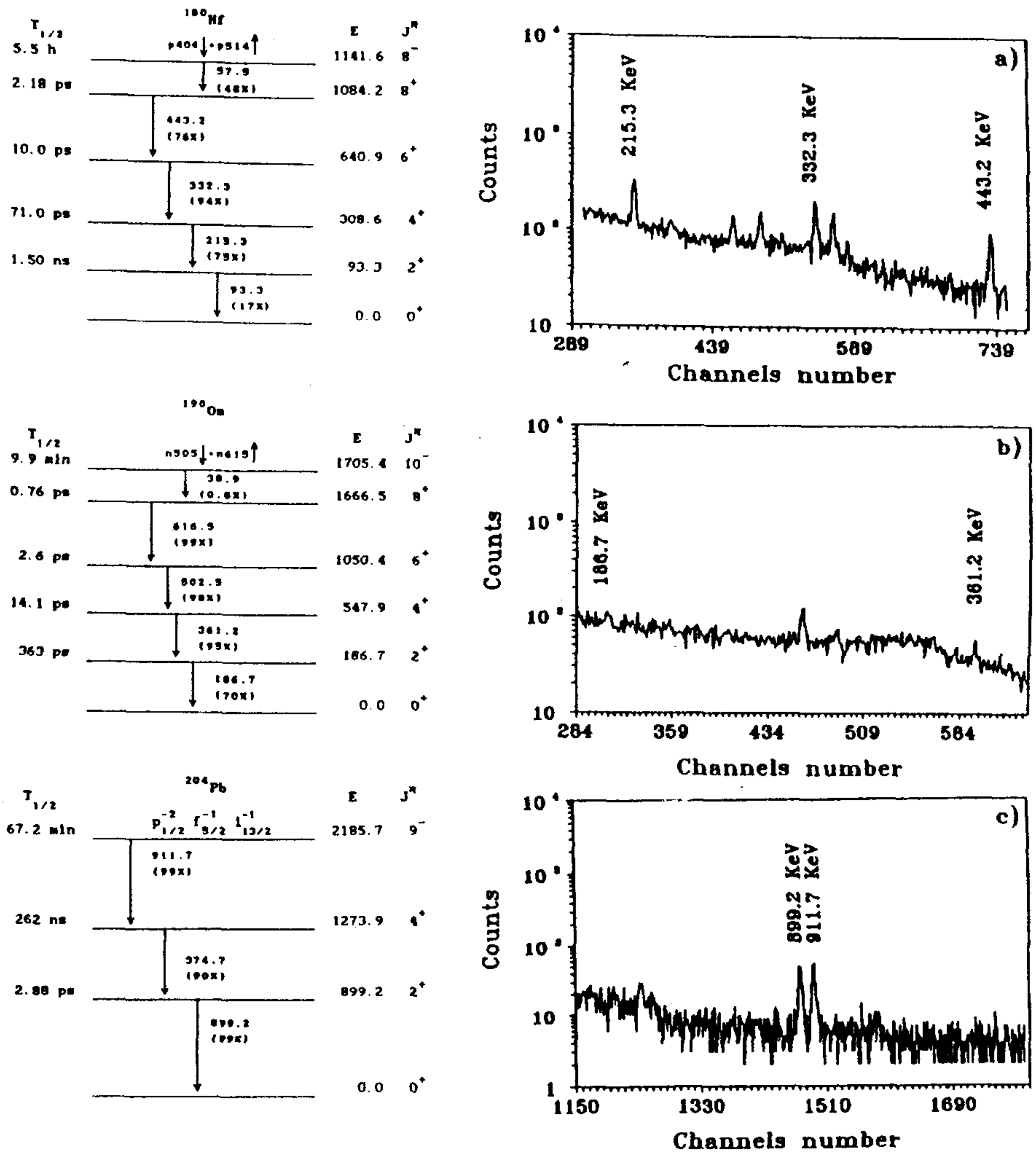


**Fig. 1.** Decay scheme and obtained $\gamma$-ray spectra for investigated nuclei: a) $^{180}Hf(\gamma,\gamma')^{180m}Hf$; b) $^{190}Os(\gamma,\gamma')^{190m}Os$; c) $^{204}Pb(\gamma,\gamma')^{204m}Pb$.

The influence of fast neutron in (2) was computed using the expression:

$$S^{(n,n')}=n\varepsilon_D I_\gamma f(t_{irr},\ t_{col},\ t_m)\Omega I_o Y_n\int_0^{E_{nmax}}\sigma^{(n,n')}(E_n)N(E_n,\ E_{nmax})dE_n \quad (4)$$

where $I_o$-number of electrons reaching the bremsstrahlung target; $Y_n$-neutrons yield per one electron [7]; $\sigma^{(n,n')}(E_n)$-(n,n') reaction cross-section [8,9,10]; $N(E_n,E_{nmax})$-normalized neutron spectrum distributions [11]; $E_{nmax}$-maximum neutron energy; Ω-geometrical factor. Our calculations show that at electron energies below 9 MeV the influence of fast neutrons for all the investigated nuclei is less than 1%. With energy increase up to 15 MeV,however, it increases up to 15-20%.

The accuracy of the yields depends on uncertainties in the determination of photo-peak areas. It depends mainly on the quantity of investigated nuclei in the target, the conditions of the irradiation, cooling and measuring times, end-point energy of the bremsstrahlung spectrum and neutron contribution to isomer productions. It was about 5-30% for $^{180m}$Hf and $^{204m}$Pb and 15-60% for $^{190m}$Os. From the obtained yields the cross-sections have been restored by method of minimization of the directioned discrepancy [12]. In Fig.2 and Fig.3 there are shown the experimental cross-sections-$\sigma^m$ and isomeric ratios $\eta=\sigma^m/\sigma^{tot.}$ ($\sigma^{tot.}$-total photo-absorption cross-section) versus γ-quanta energy. The errors in cross-section values have been determined by the error limits after multiple cross-sections restoration with the random variation of initial data distributed by the Poisons law.

The cross-sections of the investigated reactions have a resonance

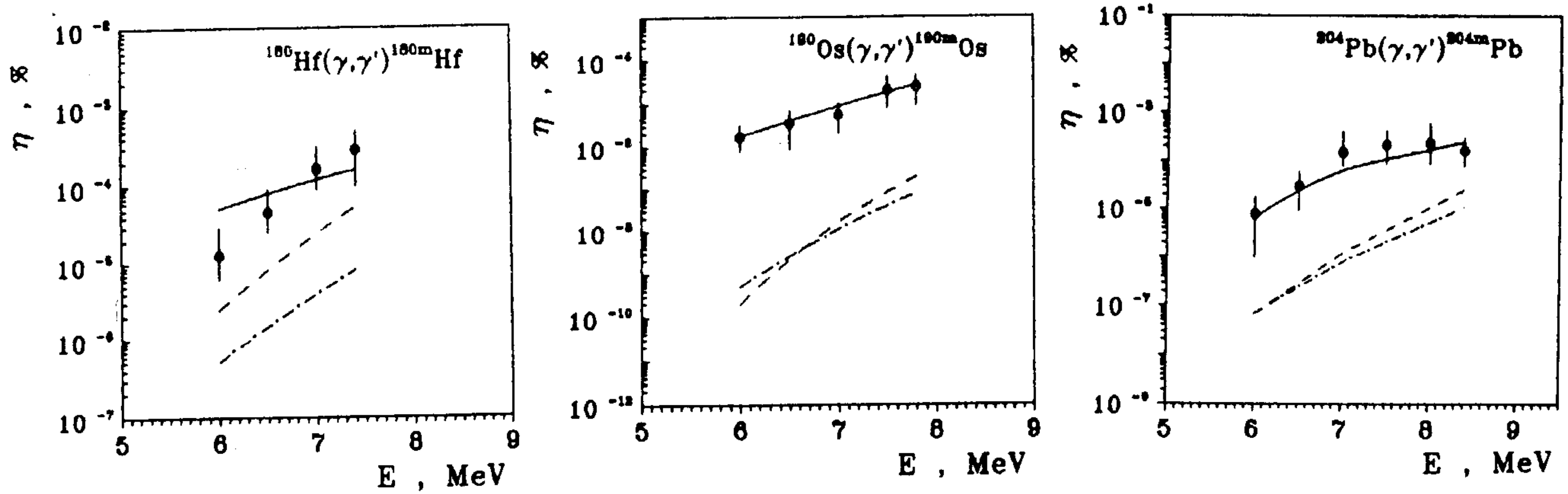


**Fig.3.** Isomeric ratios $\eta$ of the investigated reactions as a function of $\gamma$-quanta energy: ⫯ -experimental data; ——— -calculation with taking account of the nature of initial and final states;

-·-·-·- -calculation with RSF on the giant resonance model;

– – – – -calculation with RSF on the constant values.

$\omega_\pi = \frac{1-(-1)^L \pi_o \pi}{2}$, XL-parity and multipolarity of the $\gamma$-quantum.

The gamma ray cascade and the population of low levels ($E^*_f, J_f, \pi_f$) have been calculated using the algoritm described in [14]. The probability of a radiative transition from a nuclear state i ($E^*_i, J_i, \pi_i$) to a state f is given by:

$$dW_{if} = \frac{\Gamma_{if}}{\Gamma^i_{tot}} \rho(E^*_f, J_f^{\pi_f}) dE_f \qquad (6)$$

where $\Gamma_{if}$ and $\Gamma^i_{tot} = \sum_f \Gamma_{if}$ are the partial and the total widths of the initial state, $\rho(E^*_f, J_f^{\pi_f})$-level density for the final state.

The characteristics of the levels in the lowest excitation energy region $E^* \le E^*_{cut}$ ($E^*_{cut}$-excitation energy of the last known low-lying level) are taken from [15,16,17]:

$$\rho(E^*, J^\pi) = \sum_{f=1}^{N} \delta(E^* - E^*_f) \delta_{JJ_f} \delta_{\pi\pi_f} \qquad (7)$$

where N is the number of the known low-lying levels.

The level densities for excitation energies $E^* > E^*_X$, have been obtained using the Fermi-gas model [18]:

$$\rho_H(E^*, J^\pi) = f(J) \frac{\exp\left[2(a(E^* - \Delta))^{1/2}\right]}{12(2)^{1/2} \sigma a^{1/4} (E^* - \Delta)^{5/4}} \qquad (8)$$

where $E^*_X$ is the matching energy; a-level density parametr; $\Delta$-pairing energy [19];

$$\sigma^2 = (6/\pi^2) 0.146 A^{2/3} \; (a(E^* - \Delta))^{1/2} \qquad (9)$$

spin cut-off parametr;

$$f(J) = \frac{(2J+1)}{2\sigma^2} \exp\left[- \frac{(J+1/2)^2}{2\sigma^2}\right] \qquad (10)$$

spin dependence of the level densities.

For excitation energies below $E^*_X$ the level densities have been described by the constant tempetature model [18]:

parametrization (7-13), then the possibility to describe populated states quantitatively the adequancy of the accepted ratios between the radiative transitions. According to the assumed calculation scheme, $\gamma$-transitions can be divided into three classes: CC', CS' and SS' (where C and C' conditionally denote the initial and final highly-excited compound states respectively, and S and S'-initial and final simple low-excited states (see Fig.4). Gamma transitation probabilities of SS' type for all nuclei have been taken from spectroscopical data [15,16,17].For the descriptin of CC' and CS' transitions, radiative strength functions (RSF) are used:

$$S^{XL}_{if} = \frac{\Gamma^{XL}_{if}}{D_l E^{2L+1}_{\gamma}} \qquad (14)$$

At the present there vas experimental data on RSF of CS'-type obtained from measurements of partial and total widths of neutron resonances [21], from measurements of continuous $\gamma$-spectra after capture of thermal and resonance neutrons [22], and also $\gamma$-ray spectra of (d,p$\gamma$) [22] and (n,$\alpha\gamma$) [23] reactions. On the basis of their analysis the RSF is described by a constant strength function model (model 1) [18,21,24]: $S^{E1}_{CS'}=4.10^{-9}A^{2/3}CE1$ MeV$^{-3}$; $S^{M1}_{CS'}=2.10^{-8}CM1$ MeV$^{-3}$ и $S^{E2}_{CS'}= 3.5410^{-14}A^{4/3}CE2$ MeV$^{-5}$, where CE1, CM1 and CE2 are normalization constants; or by the giant resonance model (model 2) [13,18,25]:

$$S^{E1}_{CS'} = \frac{\sigma^{D}_{tot}(E_{\gamma})}{3(\pi\hbar c)^2 E_{\gamma}}, \text{ MeV}^{-3} \qquad (15)$$

$$S^{E2}_{CS'} = \frac{1}{5(\pi\hbar c)^2 E^3_{\gamma}} \left[ \sigma^{Q}_{T=0}(E_{\gamma}) + 1.8\sigma^{Q}_{T=1}(E_{\gamma}) \right], \text{ MeV}^{-5} \qquad (16)$$

where $\sigma^{D}_{tot}(E_{\gamma}) = \sum_{j=1}^{N} \sigma_{mj}\left[1+\left(E^2_{\gamma}-E^2_{mj}\right)^2 \Big/ \left(E_{\gamma}\Gamma_{j}\right)^2\right]^{-1}$, N=1 for spherical nuclei and N=2 for deformed ones; $\sigma_{mj}$, $E_{mj}$ и $\Gamma_j$-are the parameters of the giant dipole resonance [26], and $\sigma^{Q}_{T=0}(E_{\gamma})$ and $\sigma^{Q}_{T=1}(E_{\gamma})$- total photoabsorption cross-sections of isoscalar (T=0) and isovector (T=1) giant quadrupole resonance [25].

Calculations for the investigated isomeric states populations (made with the use of both models for RSF and assumption about the indepedence of initial and final states $S_{CC'}(E_\gamma)=S_{CS'}(E_\gamma)$ [14]) are shown in Fig.3. As seen from the figure, theoretical calculations poorly agree with the experimental values and in most cases the coefficient of divergence is of one order. Even after reasonable variation of level density parametr a in (8) and spin cut-off parametr $\sigma$ (9) one has succeeded in reproducing of only qualitative experimental results and at the same time quantatitative values are sensibly differed. Using experimental data about excitation functions of reactions $(\gamma,\gamma')$ existing in literature for wide range of nuclei [27,28] for which difference of spins of the ground and isomeric states is relatively small ($\Delta J$=3-6) we have calculated cross-sections of these reactions using the both models for RSF. The obtained results show that isomeric ratios turn out to be less sensitive to different types of RSF and the both models well reproduce experimental results. As level density expotentially increases with excitation energy increase, then probability of populated levels with spin much more differed from spin of the ground state is mainly determined by the RSF compound-compound (C-C') $\gamma$-transitions ($E_\gamma \leq 2$ MeV). On the one hand, the use of the model 1 for RSF with a normalization to experimental data of the C-S transitions leads to the increase of E1 part and decrease of E2-transitions part. On the other hand the use of the model 2 as showun in Fig.5 leads to the decrease of partial radiative widths $\Gamma^{E1}_{if}$ и $\Gamma^{E2}_{if}$ as $S^{E1(E2)}_{CC'}$ $E_\gamma(E^3_\gamma)$. However, as shown by theoretical estimates [31,32] and the known experimental data [23], RSF of $S^{E1}_{CC'}$ type practicaly do not depend on $\gamma$-quanta energy and $S^{E1}_{CC'} \approx S^{M1}_{CC'}$, and ratios of partial widths for M1 and E2 transitions $\Gamma^{M1}_{if}/\Gamma^{E2}_{if} \approx 10$. In view

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