Cascade population of levels and probable phase transition in vicinity of the excitation energy \( \approx 0.5B_n \) of heavy nucleus

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From the comparison of absolute intensities of the two-step \( \gamma \)-cascades and known intensities of their primary and secondary transitions, the cascade and total population of about \( \sim 100 \) levels of \(^{181}\)Hf and \(^{184,185,187}\)W excited in thermal neutron capture was determined. These experimental results and intensities of two-step cascades to the low-lying levels of mentioned nuclei were reproduced in calculation using level densities with clearly expressed step-like structure. Radiative strength functions of the primary transitions following \( \gamma \)-decay of these compound nuclei to the levels in the region of pointed structure are considerably enhanced. Moreover, population of levels below 3 MeV can be reproduced only with accounting for local and rather considerable increase in radiative strength functions of the secondary transitions to the levels in vicinities of break points in energy dependence of level density and significant decrease of that to lower-lying states.

Simultaneous change in both level density and strength functions in the same excitation region of a nucleus corresponds to the definition of the second-order phase transition.

1 Introduction

Sufficient progress in understanding of the processing occurring in a nucleus at the excitation below the neutron binding energy was achieved from analysis [1] of intensities

\[
I_{\gamma\gamma} = F(E_1) = \sum_{\lambda,f} \frac{\Gamma_{\lambda i} \Gamma_{if}}{\Gamma_\lambda} = \sum_{\lambda,f} \frac{\Gamma_{\lambda i}}{<\Gamma_{\lambda i}> m_{\lambda i} n_{\lambda i}} \frac{\Gamma_{if}}{<\Gamma_{if}> m_{if}}
\]

(1)

of the two-step \( \gamma \)-cascades in function of the primary transition energy obtained within the method [2]. This analysis was carried out for a group of nuclei from \(^{28}\)Al to \(^{200}\)Hg for which the coinciding \( \gamma \)-quanta following thermal neutron capture were measured. Comparison of the experimental and calculated intensities of the cascades with the total energy \( E_1 + E_2 = B_n - E_f \) (with energy of final levels \( E_f < 1 \) MeV) for 51 nuclei shown that existing notions of the cascade \( \gamma \)-decay process need very serious correction. There is no other way to improve accuracy of model calculation of the cascade \( \gamma \)-decay parameters of a nucleus.

Qualitative interpretation of the all totality of the data obtained in investigations of two-step cascade testifies that structure of the wave functions of the levels noticeably differs for the excitation regions above and below 0.5\( B_n \). In the frameworks of modern theoretical notions of energy dependence of nuclear level density, this change is related with the process of breaking of paired nucleons. As a consequence, both level density and probability of their
excitation (de-excitation) seriously differs from the predictions of models considering nucleus as a pure fermion system (for instance, [3,4]).

Significance of this conclusion follows from the fact that so simple models are used up to now for both analysis of the experiment and calculation of \(\gamma\)-ray spectra and neutron cross-sections of interaction with nuclei. Specific of the data obtained in [1], however, requires not only transition to more realistic models of level density \(\rho\) and radiative strength functions \(k = \Gamma_{\lambda_i}/(E_\gamma^3 \times A^{2/3} \times D_{\lambda})\) (like [5,6] and [7], respectively) but also more precise their parameterization and further development. The necessity of further theoretical development follows not only from unsatisfactory correspondence between the model notions and experiment but also from a need in more precise interpretation of processes occurring in nucleus. Development of new methods of analysis of existing experimental data is oriented to this goal, as well.

2 New possibilities of the experiment

A bulk of information on the intensities

\[ i_{\gamma\gamma} = i_1 \times i_2 / \sum i_2, \]  

experimentally resolved individual cascades was obtained for all 51 studied nuclei. Their parameters, including most probable quanta ordering, were derived from the experiment up to the excitation energy of the cascade intermediate levels 3 -5 MeV by means of the original method of analysis created in Dubna. One of the important element of this method is the quantitative algorithm [8] of improvement of energy resolution without decrease in efficiency in the spectra with equal total energy \(E_1 + E_2 = \text{const.}\)

Experiments in Riga and Řež allowed measurements [9-11] of most complete spectra of intensities of the primary \(i_1\) and secondary \(i_2\) \(\gamma\)-transitions up to the neutron binding energy \(B_n\) in \(^{181}\text{Hf}\) and even-odd isotopes of W following thermal neutron capture in corresponding target nuclei. Analogous data for \(^{184}\text{W}\) were obtained in Gatchina [12]. The data on \(i_1\) and \(i_2\) are available and for some other nuclei but their poor statistics do not allow one to repeat in full measure analysis described below (except \(^{118}\text{Sn}\)).

3 Method of analysis

From the eq. (2) for the totality of the data on \(i_{\gamma\gamma}, i_1\) and \(i_2\) one can determine the total population \(P = \sum i_2\) for about 100 levels up to the excitation energy of 3-4 MeV and higher. Difference of \(P\) and intensity of primary transition \(i_1\) to each of these levels is equal to sum of their population by two-step, three-step and so on cascades. It can be calculated within different assumptions and models of level density excited at the thermal neutron capture and radiative strength functions of cascade \(\gamma\)-transitions (including \(\rho\) and \(k\) values obtained according to [1]).

The region of the maximum discrepancy between the experiment and different variants of calculation shows where and in what direction should be modified model description of the cascade \(\gamma\)-decay process.

It is clear that at present it is impossible to determine population of all without exclusion intermediate levels of two-step cascade even at low excitation energy (owing to the detection
threshold of intensities $i_{\gamma\gamma}$, $i_1$ and $i_2$). Therefore, it is worth while to compare experiment and calculation for values of $P - i_1$ summed over small excitation energy intervals and consider these sums as the lower estimates for each of intervals. Comparison of this kind was carried out by us for different nuclei. Results of this analysis and other experimental data for compound nuclei $^{181}$Hf and $^{184,185,187}$W are presented below (for them there was stored maximum information of needed type).

A degree of discrepancy between the calculated population $P - i_1$ and its unknown experimental value is determined by both incompleteness of the data on intensities of cascades and single transitions and possible strong influence of the structure of the wave function of the excited level on probability of its cascade population (such influence for the levels with the excitation energy higher than 2-3 MeV is confirmed by strong fluctuation of other levels).

The primary dipole transitions of cascades excite in the considered even-odd isotopes the levels with $J^\pi = 1/2^\pm, 3/2^\pm$, and in $^{184}$W - levels of both parities in the spin window 0-2. Cascade population of these levels is determined not only by the averaged intensity of the ended by them cascades but also intensity of three-step, four-step an so on cascades. The latter appear at depopulation of levels from wider spin window. Therefore, it seems insufficient to relate large dispersion of population of the cascade intermediate levels only with difference in their spins.

4 Systematic errors of population of levels

The minimum possible systematic error of level population can be achieved only at the maximum possible positive correlation of systematic errors which, according to eq. (2), determine its magnitude. I.e., when absolute intensities $i_{\gamma\gamma}$ are determined [14] using their relative values and absolute intensities $i_1 \times i_2 / \Sigma i_2$ calculated using the data like those listed in [9-12] for several cascades proceeding through the lowest-lying levels. Decay scheme of these levels is usually well established and, correspondingly, the $\Sigma i_2$ value has minimum error. In this approach of normalization of the experimental data, the magnitude and sign of the error $\delta i_{\gamma\gamma}$ of intensity of any cascade strongly correlates with the mean error of intensity $\delta i_1$ of its primary transition, and the total relative error of population $P - i_1$ is mainly determined by the total relative error of the $i_2$ values.

In modern experiment [9-12,13] the error of values $i_1$ and $i_2$ is mainly determined by the error [15] of capture cross-section of thermal neutrons in the isotope under investigation. In majority of cases it does not exceed 5-10%. Therefore, the level population from eq. (2) has a precision determined only by systematic errors in the data [9-13] and random errors of concrete values $i_1$ and $i_2$. The only problem in determination of $P - i_1$ is unresolved doublets of the cascade secondary transitions $i_2$ and (to less extent due to less density of peaks in the spectra) primary transitions $i_1$. Partially the multiplets can be identified and resolved by approximation of single spectra of HPGe detector using information on the two-step cascades and known decay scheme of the nucleus under consideration. These data should be obtained in the experiment on the thermal neutron capture in the highly enriched target. In other cases intensity $i_2$ can be distributed between the cascades in which such multiplet is proportional to $i_{\gamma\gamma}$ or they can be excluded procedure of determination of $P$ in plenty of the data on $i_{\gamma\gamma}$, $i_1$ and $i_2$ for the same intermediate level of cascade.
Some data for the nuclei considered here are listed in Table.

Table. $N_{2\gamma}$ is the probable total number of levels populated by the primary E1 and M1 transitions below 3 MeV in even-odd nuclei and 4 MeV in $^{184}$W estimated for the level density shown in Fig. 4; $N_c$ is the experimental number of the resolved two-step cascades, $N_i$ is the number of levels for which the cascade population was determined and portion (percent) of multiplets of secondary transitions with multiplicity $M$. $\sum i_1$ and $\sum i_2$ are the total intensities (% per decay) of primary and secondary transitions of cascades, respectively, involved in analysis. $E_f$ is the energy of the cascade final level, and $d = \sum i_\gamma \times E_\gamma / B_n$ is the part of the total $\gamma$-spectrum observed in [9-12].

| Nucleus | $N_{2\gamma}$ | $N_c$ | $N_i$ | $(M = 2)$ | $(M \geq 3)$ | $\sum i_1$, % | $\sum i_2$, % | $E_f$, keV | $d$ |
|--------|----------------|-------|-------|-----------|-------------|----------|----------|---------|----|
| $^{181}$Hf | 260 | 69(58) | 61 | $\leq 14$ | $\leq 14$ | 0 | 91.6 | 35.3 | 332 | 0.63 |
| $^{184}$W | 135 | 105(104) | 78 | $\leq 16$ | $\leq 2$ | 55.3 | 107.2 | 364 | 0.82 |
| $^{185}$W | 156 | 150(136) | 135 | $\leq 24$ | $\leq 25$ | 53.3 | 74.8 | 1068 | 0.60 |
| $^{187}$W | 200 | 121(120) | 112 | $\leq 25$ | $\leq 17$ | 41.2 | 65.6 | 303 | 0.47 |

Exceeding of $N_c$ over $N_i$ is caused by both better background conditions of registration of cascades to the low-lying levels as compared with the experiment on determination of $i_1$ and $i_2$ and the use of the of improving energy resolution [8]. Table does not include cascades with excitation energy of intermediate levels higher than 3-4 MeV for which $i_1$ and $i_2$ are unknown. In the brackets for $N_c$ are given values of this parameter corresponding to $E_{ex} \leq 3$ MeV (or 4 MeV for $^{184}$W).

5 Results

Comparison between the obtained population of the excited states were performed in two variants:

(a) the population of each from $N_i$ intermediate levels (including intensity of the primary transition populating it) was compared (Fig. 1) with several variants of the calculation;

(b) the total cascade population $P - i_1$ corresponding to the 200 keV interval of the excitation energy was compared (Fig. 2) with the same calculation.

A necessity in two these variants follows, first of all, from the presence of the detection threshold of intensities that limits a possibility to get information on all levels of the studied nucleus. In the second, owing to the presence of systematic errors in determination of $i_1$ and $i_2$, the $P - i_1$ value is negative in some cases (this is possible due to low cascade population of level as compared with $i_1$). But the calculated total population $P$ of levels depends on the model predicted values of level density and radiative strength functions weaker than cascade population $P - i_1$. This is caused by the inevitable compensation of an influence on population of change in, for example, $\rho$ by corresponding change in $k$ to the cascade primary transitions. That is why, it is necessary to get additional confirmation for considerable discrepancy between the experimental and calculated sums of $P - i_1$. This is provided by analogous comparison of the experimental and calculated total populations of individual levels.
Fig. 1. The total population of intermediate levels of two-step cascades (points with bars), thin line represents calculation within models [3,4]. Dashed line shows results of calculation using data [1]. Thick line shows results of calculation using level density [1], and corresponding strength functions of secondary transitions are multiplied by function \( h \) set by equations (3) and (4).

The number of available for calculation variants of energy dependence of strength functions and level density is large enough. But general rules of change in population of levels with the change in their excitation energy can be arrived with the use of only three variants of calculation:

(a) level density is taken according to any model of non-interacting Fermi-gas; strength function of E1 transitions is set by known extrapolations of the Giant electric dipole resonance in the region below \( B_n \), \( k(M1) = \text{const} \) with normalization of \( k(M1)/k(E1) \) to the experiment;

(b) one can use \( \rho \) and \( k \) providing precise reproduction [1] dependence of the two-step cascade intensities on the primary transition energy;

(c) one can select a set of \( \rho \) and \( k \) which simultaneously reproduce \( I_{\gamma\gamma} = F(E1) \), \( \Gamma_{\gamma} \) and maximum precisely reproduce \( P - i_1 \).
Fig. 2. The same as in Fig. 1 for the total cascade population of levels in the 200 keV energy bins.

Variant (c) can be realized in iterative process: strength function \( k \) of the secondary transitions obtained according to [1] are changed in the way providing better reproduction \( P - i_1 \). It is enough for this to multiply strength functions of secondary transitions to the levels lying below some boundary energy by the function \( h \) which contains few narrow enough peaks. Energy dependence of the form of these peaks can be determined by analogy with the specific heat of macro-system in the vicinity of the second order phase transition as:

\[
h = 1 + \alpha \times (\ln(|U_c - U_1|) - \ln(|U_c - U|)) \quad \text{in the case of } \ U < U_c, \quad (3)
\]

\[
h = 1 + \alpha \times (\ln(|U_c - U_2|) - \ln(|U_c - U|)) \quad \text{in the case of } \ U > U_c, \quad (4)
\]

with some parameters \( U_1, U_2, \) and \( U_c \). The condition \( (U_c - U_1) \neq (U_2 - U_c) \) provides required asymmetry of peaks and some more precise reproduction of cascade population of levels at the "tails" of peaks as compared with the Lorentz curve, for instance.

In the best variant tested by us, their amplitude \( \alpha \) increases from zero at \( U = B_n \) to maximum possible value (shown in figs. 4, 5) when the excitation energy \( U \) decreases. Positions of the peaks, their amplitude and shape are quite unambiguously determined by values \( P - i_1 \). The correction functions found in this way are then included in analysis [1] to determine \( \rho \) and \( k \) providing correct reproduction of cascade intensity.
The cascade intensities are shown in Fig. 3 and corresponding level densities and radiative strength functions together with the functions $h$ are presented in figs. 4 and 5. Then this cycle is repeated one time when we use the hypotheses of linearly increasing distortions in values $k(E1)$ and $k(M1)$ as decreasing the energy of decaying levels and several times — for the hypotheses $\alpha = const$. For minimization of the fitted parameters it was assumed that the correcting functions (figs. 4, 5) are equal for both electric and magnetic $\gamma$-transitions.

For all of the nuclei under consideration, the maximum value of $h$ is observed in vicinity of transition of level density from the practically constant value (the region of step-like structure) to the region of practically exponential increase. Besides, there is observed correlation of maxima $k(E1) + k(M1)$ and $h$ with further simultaneous decrease in their values when $E_1$ increases. This effect can be explained only by considerable influence of structure of level on strength functions of populating it $\gamma$-transition. Moreover, one can assume such influence over whole interval of the levels excited in the $(n, \gamma)$ reaction.

Large enough number of hypothesis used for solution of this problem is inevitable. But and in this case all conclusions about the $\gamma$-decay process of compound nuclei should be considered rather as qualitative than as quantitative. So, the presence of the clearly expressed “step-like structure” in level density and corresponding increase of $k(E1) + k(M1)$ (Fig. 5) can be considered with high probability as established.
Fig. 4. The number of intermediate levels of two-step cascades in the case of different functional dependence of strength functions for primary and secondary cascade transitions. Dashed line shows values of function $h$ for excitation energy $B_n - E_1$. Solid line represents predictions according to model [4].

But the number and shape of these "steps" can be revealed most probably in future experiments. The same should be said about parameters of correcting functions $h$. If in region of excitations corresponding to considerable increase of $k$ for the second, third and so on cascade is no doubts then concrete parameters of function $h$ most probably should be considered as preliminary. They should be used for planning further experiments. In this respect is the region $h < 1$. It is impossible to conclude whether the strength of $\gamma$-transitions is redistributed from the lower-lying levels excited by them to the higher-lying or this structure of $h$ caused only increase of $k(E1) + k(M1)$ in Fig. 5. But it should be noted that observed values of $P - i_1$ for the considered nuclei could not be reproduced without noticeable decrease of $k$ for the secondary transitions at low excitations.

Even the circumstance that we obtained only the lower estimation for $P - i_1$ cannot be possible explanation for this problem. At the decrease of the excitation energy, the portion of the unobserved population must decrease. It should be noted that the possibility of existence of specific dependence of product $k \times h$ does not contradict the studied theoretically [6] regularity of fragmentation of simple state with any structure over nuclear levels. One of the most important qualitative conclusion of this analysis is that the strength of this state can concentrate in asymmetric peaks with "tails" in the region of high excitation energy.
The populations determined according to [1], density of the excited levels and parameters of strength functions depend the fluctuations of intensities of the primary transitions to the ground and low-lying excited states \((U < 0.5 \text{ MeV})\) which are not taken into account in this method. These transitions were not observed in cascades owing corresponding detection threshold and, therefore, only their mean values were included in calculation. This can increase discrepancy between \(\rho\) and \(k\) shown in figs. 4, 5 and corresponding model predictions. This is of maximum importance for \(^{181}\text{Hf}\) where intensity of direct transition to the ground state is 23\% [13].

### 6 Possible changes in model notions about the cascade \(\gamma\)-decay process of compound nuclei

According to method [1], the region of \(\rho\) and \(k\) values allowing reproduction of the experimentally obtained function \(I_{\gamma\gamma}(E_1)\) with parameter \(\chi^2/f << 1\) has been determined. Corresponding results for \(^{181}\text{Hf}\) and \(^{185,187}\text{W}\) were published in [1] and [17], respectively. Estimation of influence of most important source of systematic error on parameters of the cascade \(\gamma\)-decay were published in [18]. As for the nuclei studied earlier, level density required for description of \(I_{\gamma\gamma}(E_1)\) is noticeably less than predictions of the model of non-interacting Fermi-gas. This level density qualitatively corresponds to developed by A.V.Ignatyuk and Yu.V.Sokolov notions of step-like energy dependence of level density what is the result of
breaking of Cooper pair (or several pairs [5]) of nucleons at corresponding excitation energy of a nucleus.

In the frameworks of the generalized model of superfluid nucleus [5], level density above the phase transition from the superfluid to normal state is mainly determined by many-quasiparticle excitations. Below this energy, the properties of a nucleus are strongly affected by boson branch of nuclear excitations. One can accept as a hypotheses that this influence manifests itself not only in decrease of level density as compared with excitation of pure fermion system but also in change of ratio of the mean reduced probabilities of \( \gamma \)-transitions to the levels above and below the point of phase transition. It should be noted that due to the lack of experimental data the authors of the generalized model of superfluid nucleus [5] introduced in their model fixed value of the energy of the phase transition. This energy corresponds to known value for the infinite and homogeneous boson system. Experimental data [1] provide the grounds to consider this energy for a nucleus as an infinite and inhomogeneous mixture of fermi- and bose-systems only as a parameter. Its possible magnitude should approximately two times less than that adopted in [5].

All previous experiments on investigation of general picture of the cascade \( \gamma \)-decay below \( B_n \) could not reveal this circumstance owing to insufficient resolution of the used spectrometers, moreover, in the case when decrease in level density is compensated by increase in the intensities of transitions populating them. Calculations of total population \( P \) for different \( \rho \) and \( k \) testify to this possibility: relative variation of the population for the tested functional dependences changes weaker than for \( P - i_1 \).

Precise reproduction of the experimental dependence \( P - i_1 = f(E_{ex}) \) cannot be achieved using a set of standard models for \( \rho \) and \( k \) [3,4] or values of these parameters obtained according to method [1]. In the first case one can consider obtained result as additional argument conforming conclusion [1] about inapplicability of the models like [4] for predictions of \( \rho \) below \( B_n \) with the precision achieved in the experiment. In the second case one should take into account probability of the dependence \( k = \phi(E_\gamma, E_i) \) on not only \( \gamma \)-quantum energy but also excitation energy of the cascade intermediate level \( E_i \). Analogous conclusion was obtained from both comparison [17] of the experimental and calculated intensities of two-step cascades to the levels with excitation energy up to 2 MeV and comparison [19] of the experimental and calculated total \( \gamma \)-ray spectra in large group of nuclei. Qualitatively, from the point of view of theoretical notions of a nucleus, it is not a surprise: different structure of levels connected by \( \gamma \)-transition causes difference in their matrix elements. But the degree of influence of this difference on the mean value of matrix element below \( B_n \) in a nucleus can be revealed (and included in expression (1)) only experimentally. At present, most probably, this can be done only in indirect way by selection of parameters \( \rho \) and \( k \) which provide precise reproduction of any known experimental spectra. Direct proof of difference in energy dependences of the \( \gamma \)-transition strength functions on the structure of connected levels would require determination of their absolute intensities.

Modern experiment does not provide this opportunity. The probability of considerable strengthening of matrix elements of \( \gamma \)-transitions in some interval of excitation energy of the cascade intermediate levels was tested in this work. The basis for this hypotheses is impossibility to reproduce the data shown in figs. 1 and 2 in calculation using the same form of dependence \( k = \phi(E_\gamma) \) for the primary and all following quanta of cascades.

The lack of experimental information on \( \gamma \)-transitions depopulating levels with \( 2 \leq E_{ex} < B_n \) does not allow one to such practical questions as:
(a) how does the local enhancement of matrix element of $\gamma$-transition change the value of $k$ obtained in analysis [1] for a given energy of decaying level?

(b) whether this enhancement lead to redistribution of reduced intensities of $\gamma$-transitions to different final levels (in particular, to decrease in $k$ values for final level with energy $0.5\text{MeV} < E_f < 2.5 \text{MeV}$)?

So, hypotheses of local enhancement of radiative strength functions of secondary transitions to the levels in the region of “step-like” structure in level density allows one not only precisely to calculate cascade population of levels below 3-4 MeV but also to reproduce the dependence $I_{\gamma}^f = f(E_1)$ using practically the same for different nuclei dependences $\rho = \psi(E_{ex})$ and $k = \phi(E_\gamma)$.

Results presented in this work should be considered as a qualitative description of the processes occurring in a nucleus. This calculation cannot pretend for quantitative reproduction of the experimental data cannot also due to the following reasons:

(a) impossibility to decrease error in determination the number $N_{2\gamma}$ of the observed cascade intermediate levels up to several tens of percent in the experiment carried out for single compound state (there is no possibility to exclude or estimate correlation of the reduced neutron width with partial radative widths of primary transitions);

(b) impossibility to estimate the total cascade population of levels for which $i_{\gamma\gamma}$ is lying below the detection threshold or for that intermediate levels for which $i_1$ and $i_2$ are unknown;

(c) possible inadequacy of the used hypothesis and model notions to the experiment.

Nevertheless, even with these limitations one can conclude that observed cascade population can be reproduced only in calculation assuming considerable enhancement of the radiative strength functions of $\gamma$-transitions to the levels from the interval $\approx 1 \text{MeV}$ in vicinity of the excitation energy of 3-4 MeV.

7 Possibility of experimental test of enhancement of radiative strength functions in the region $0.5B_n$

Direct proof of local enhancement of radiative strength functions for the transitions to the levels with $E_{ex} \approx 3 \text{MeV}$ of even-odd heavy deformed nucleus requires one to determine reduced relative probability of $\gamma$-transitions from higher-lying levels in the energy $E_\gamma$ interval from several hundreds keV to several MeV. This problem cannot be solved by means of classic nuclear spectroscopy using all types of detectors and methods for determination of the energies of excited levels and their decay modes.

The only realistic way of its solution is experimental measuring of intensity distributions of the two-step cascades to all possible their final levels up to the excitation energy 3 MeV and higher of heavy deformed even-odd nucleus. For even-even lighter nuclei this energy must exceed 4-5 MeV. At the useful statistics of several thousands of events for each spectrum $E_1 + E_2 = B_n - E_f = const$, some part of secondary $\gamma$-transitions will be resolved as the pairs of individual peaks. Analyzing these data by means of the developed methods one can determine intensities of the secondary $\gamma$-transitions to the levels with $E_f \leq 3 - 4 \text{MeV}$ and to get a large set of reduced probabilities of $\gamma$-transitions in the region of interest.

The only reason why were not obtained up to now [14] is that corresponding peaks with decreasing areas (i.e., peaks with decreasing energy) are located on increasing Compton background in the sum coincidence spectrum. Potential possibility to solve this problem is
selection of the cases of simultaneous absorption of full energy of three successive quanta of cascades to the ground and first excited state in form of peaks in the sum amplitude spectrum of three coinciding pulses. Because the energies of the secondary transitions of two-step cascades are known (and can be determined in the same experiment) then it is possible to get distributions of two-step cascades to final levels with $E_f > 1$ MeV. This can be done also using the systems with several HPGe detectors or pair of such detectors with suppression of the Compton background. In both cases efficiency must be not less than that of detectors in modern “crystal-balls”.

8 Conclusion

The second order phase transition is characterized by abrupt change in properties of a system as changing its energy. If abrupt enough change in level density (i.e., in fact - of nuclear specific heat) was established earlier experimentally [1] with high enough probability then the results of the performed analysis also testify to abrupt change in reduced probability of $\gamma$-transitions in rather narrow region of nuclear excitations.

The obtained results are independent complementary confirmation of the existence in a nucleus of the excitation energy region where abrupt change of its structure occurs. Supposedly, there is the transition from the domination of vibrational excitations to domination of many-quasi-particle excitations. I.e., there is an analog of the phase transition from the superfluid to usual state of so very specific system as nucleus.

The data obtained for the excitation energy region of interest should be considered only as indication to possible existence of such transition. Quantitative information can be useful for planning of more detailed experiments on investigation of the problem of interest - dynamics of breaking of Cooper pairs in different final heterogeneous systems.
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