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FOUR-DETECTOR SPECTROMETER FOR INVESTIGATING COMPLEX CASCADE γ-DECAY

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I. INTRODUCTION

The interest in systematic study of the two-step γ-decay cascades peculiarities for complex (especially deformed) nuclei in the excitation energy interval 2 MeV$\div B_n$ (B_n is the neutron binding energy) had been awaked at LNP JINR in 1982 [1]. The technique of amplitude summation of coinciding pulses [2] (named SACP) offers a good tool to study the cascades intensity for $E_c = (E_1 + E_2) \leq B_n$. Spectroscopic analysis and particularities of this method are presented elsewhere [3]. A well developed method for spectroscopic information analysis of the two-step γ-cascades is presented in [4] and the dependence of the cascade intensity on their primary transition energy is shown in [5].

Although this method had provided, for the first time, valuable information about the excited states in the region $\simeq$ 2 MeV $\div B_n$,it still needs further developements to satisfy the requirements for studying γ-decay cascades. A spectrometer consisting of two Ge(Li) detectors with a relative efficiency of about 10% (to that of a 76 mm diameter by 76 mm thick NaI(Tl) crystal at E_γ=1332 keV) will permit one to measure cascades leading to some low-lying levels if only the final cascade level energy does not exceed $\simeq$ 1 MeV [6]. The use of such a spectrometer limits the observable part of the primary γ-transitions to a value of 30 $\div$ 70% of the total primary transtion intensity. Cascades to higher levels were also noticed in earlier γ-γ coincidence experiments. However, at that time, it was not possible to discriminate them from the continuous background distribution which is mainly due to the Compton scattering of higher γ-quanta energies.

In this work we demonstrate that a multidetector spectrometer (MDS) which consists of three (or more) detectors may provide a convenient method to handle the problem of γ-cascades between a compound state and a large enough number of low-lying levels. An algorithm for the multicoincidence analysis is developed and applied to determine the cascades intensity distribution. Examples based on experimental study of thermal neutron reaction on natural Gadolinium targets, and measurements using ^{22}Na, ^{56}Co, and ^{60}Co radioactive sources are presented. Conclusions concerning the possibilities and sensivity of the method are discussed.

II. THE METHOD

The method is based on the use of a spectrometer consisting of two Ge(Li) detectors, to measure the coincident amplitudes of the first two quanta in a cascade, and two (or more) NaI(Tl) crystals, to register the other quanta (third, fourth, etc..) which are in coincidence with the first two ones registered by the two Ge(Li) detectors.

Now let, for example, a compound state with an energy B_n decay through three different γ-cascade transitions. Let E_1 and E_2 be the energies registered by the two germanium detectors respectively and let E_3 be the energy of the third quantum of cascade registered by any of the NaI(Tl) detectors. Then, we have

$$E_1 + E_2 + E_3 = B_n$$

If one chooses to satisfy the condition $E_3 > E^*$ (E^* being the excitation energy of the second intermediate state of the cascade), then only the cascades with sum energy $E_1+E_2 < B_n-E_3$ are possible to be registered. In practical terms this means that the cascades with $E_1+E_2 > B_n-E_3$ cannot be registered. Thus the system permits, in principle, to measure only the cases of full absorption; and consequently the continuous distribution under the peaks may decrease to zero as it will be shown later.

It is clear that the idea of generalisation of this approach to the case of measuring N cascades using a multicoincidence system of M detectors (M > N) seems obvious.

III. THE EXPERIMENT

The above-described method was applied to the measurement of the successive γ-decay of compound states populated in slow neutron capture. The spectrometer used in the experiment consisted of two horizontal Ge(Li) detectors and two NaI(Tl) scintillation detectors. The energy resolution of each of the germanium detectors was about ≃ 3.5 keV; while it was about ≃ (10÷12)% for the NaI crystals at the same energy, 1332 keV. The time resolution of any pair of detectors was about ≃ 10 ÷ 12 nsec for a ^{60}Co radioactive source. The relative efficiencies of the two germanium detectors were about 5 and 10% with respect to a NaI crystal of(76×76 mm^2) dimensions. The NaI crystals used in the experiment measure 150×100 mm^2. The use of such big detectors provides maximum efficiency but, on the other hand leads to a relatively poor resolution. The efficiency of the pair of germanium detectors in our experimental geometery was about ≃ 2×10^{-5}unit/decay for the sum peak of ^{60}Co. The experimental arrangement is shown in fig.1. Lead filters of 2.5 g/cm^2 are used to minimize the detection of the back scattered γ-quanta between germanium detectors.

The block diagram of the multi-coincidence arrangement used in the experment is illustrated in fig.2. The system can, simultaneously, deal with four γ-quanta. Pulses from the NaI detectors are accounted for only when they are in coincidence with the other two pulses registered by the germanium detectors. For this purpose a set of delay lines is used. The time window for the selected coincidences in both FCU and CU, (fig.2), was = 3τ. This allows (using a source having ≃ 10^5 decay/sec) the detection of over 99.9% of the true coincidences and less than 0.4% of false coincidences.

The block diagram of the control units is shown in fig.3. It consists of :

- an adapted IBM personal computer; PC(AT or XT),
- spectroscopic ADC units of 8192 channels,
- time-digital convertors; TC,

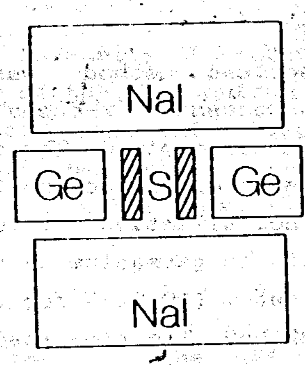

FIGURE 1 : Experimental set-up geometery for the Ge(Li) and the NaI(Tl) detectors.

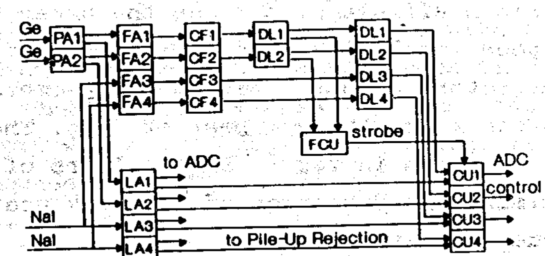

FIGURE 2 : Block diagram of the multi-coincidence system.

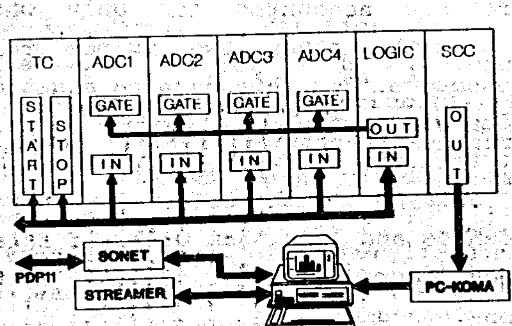

FIGURE 3 : Block diagrame of the control system.

- CAMAC; special control circuits (SCC),
- interface board KOMA for the conection between the PC and the CAMAC.

The interface board transfers the spectroscopic information from the SCC to the computer memory through a direct access channel. The PC memory accepts an input data rate of up to 1.25 M.byte/sec. The SCC controls the work of the ADC's and also transfers information about the ADC and TC units (in operation) to the interface board.

The measurements may be carried out according to one of the following two regimes :

- the multi-dimensional regime where the information is registered only when the selected ADC's are in simultaneous operation,
- the multi-channel regime where the selected ADC's are interrogated independently after the information transfer process.

The electronics used in this system has been described earlier [7-10].

A multi-purpose software program, using the PC, is performed to realise :

- the control of the experiment,
- the choice of the required information; by a digital window selection,
- the registration of integral spectra for each parameter,
- the graphic display of different spectra on the PC screen,
- the recording processes using either a hard disk or a magnetic tape or by transferring spectra to the PDP 11/70 computer through a local network.

IV. RESULTS AND DISCUSSION

The measured spectrum, using the technique of summed amplitudes of coinciding pulses (SACP), for the ^{22}Na and ^{60}Co radioactive sources is shown in fig.4. The upper part of the figure presents the coincidence pulses from the two germanium detectors only (in absence of pulses from the third NaI detector); while the lower part corresponds to the coincidence pulses from the germanium detectors when they are in coincidence with a third pulse (of an energy ≥1100 keV) registered by any of the NaI detectors.

The figure clearly shows a considerable continuous background distribution in the upper part and a remarkable absence of it in the lower part of the figure. It is also true that the peak intensity decreases, for the same storing time, by a factor of 5÷10 times (dependent on the experimental geometery); but the absence of the background is the privilege which enables one to build the intensity distribution even for weak two-step γ-decay cascade transitions.

In complex nuclei, there are always a lot of cascade pairs with E_1+E_2 = const.; especially when the cascade energy is large enough. For some of these cascades, the intensity is so small that it merges in a continuous distribution; the case of neutron resonances of deformed nuclei. In such cases, the absence of the background facilitates the study of the γ-decay cascades.

Figure 5 shows an analogous SACP spectrum from a ^{56}Co radioactive source. In this example, the cascade energy is comparable with that of the neutron binding energy in even-odd deformed nuclei. It is clearly seen from the lower part of the figure that the background under the peaks is considerably suppressed, by about several orders of magnitudes, according to the threshold energy applied to the third detector. The values (R) of the ratio between the background (area under the peak) and the peak area at different cascade energies with different threshold energies (E_3) are listed in table 1.

Described here is a method for measuring triple γ-coincidences. This method can be applied to the study of the γ-cascade transitions in complex nuclei. As an illustration, a target of natural Gadolinium was irradiated in a beam of thermal neutrons from the IBR-30 pulsed reactor (JINR,DUBNA).

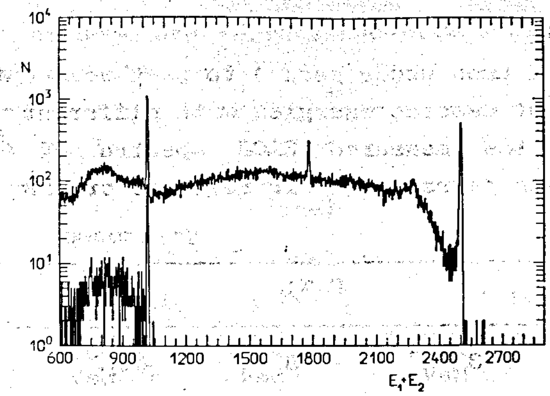

FIGURE 4 : A spectrum of summed amplitudes of coinciding pulses (SACP) for ^{60}Co and ^{22}Na radioactive sources measured with two Ge(Li) detectors. The lower part shows the same spectrum when using the third, NaI(Tl), detector with a threshold energy $E_3\geq$ 1100 keV.

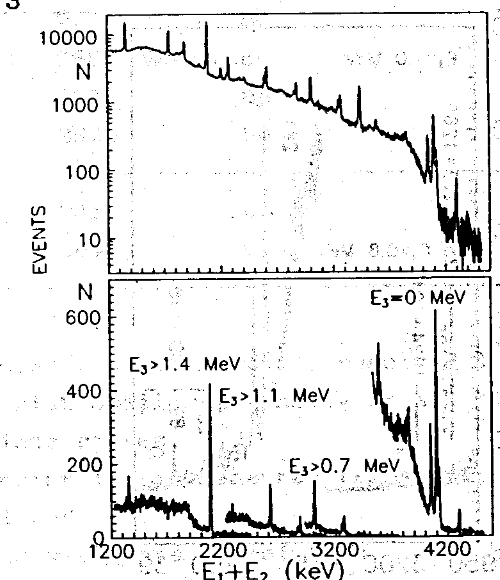

FIGURE 5 : The upper part displays a SACP spectrum for ^{56}CO, as in fig. 4 , while the lower part shows the same spectrum but taken at different threshold energy, E_3.

TABLE 1.

Background (area under peak) to peak area ratios (R) for some different cascade energies with different threshold energies E_3 from the measured SACP spectra of ^{56}Co. The values in brackets represent their relative errors

	R(%)			
Cascade energy MeV	$E_3>1.4$ MeV	$E_3>1.1$ MeV	$E_3>0.7$ MeV	$E_3=0$ MeV
2.09	14(3)	37(3)	68(5)	68(5)
2.60	--	45(5)	112(5)	204(2)
3.00	--	31(6)	110(7)	296(4)
3.26	--	--	52(4)	242(3)
4.10	--	--	--	32(3)

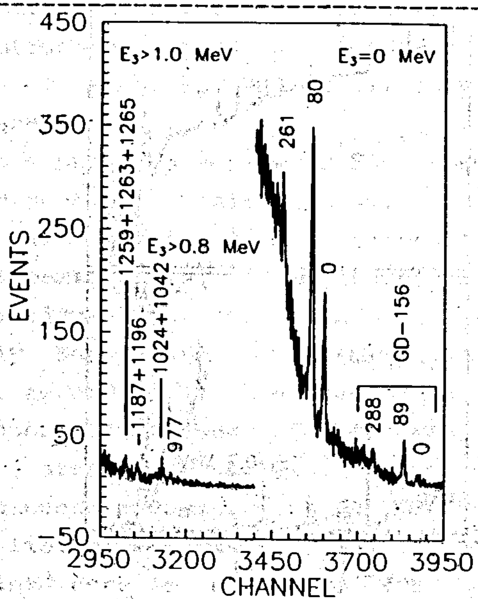

FIGURE 6 : Parts of SACP spectra for some γ-cascades induced by thermal neutron capture on natural Gadolinium target applying different threshold energies E_3. The part to the right corresponds to $E_3 = 0$; i.e without using any of the NaI detectors.

TABLE 2.

A list of some new intense two-step γ-decay cascades in ^{158}Gd compound state

Transitions			Intensity
primary (keV)	secondary (keV)	final level (keV)	(per 10^4 decay)
5972	1965	0	12 (1)
5678	2259	0	10 (2)
5577	2360	0	5 (2)
5281	2657	0	5 (2)
5135	2802	0	7 (1)
5662	2195	80	20 (3)
5653	2204	80	11 (3)
5177	2680	80	30 (3)
5058	2800	80	16 (3)
4929	2929	80	17 (3)
5660	2016	261	11 (2)
5236	2440	261	9 (3)

Remarks

a) many unknown (experimentally resolved) cascades are observed with smaller intensity or at higher energy intermediate states.

b) average error in the measured transition energies was about $\simeq$ 1 keV.

c) comparison with data in ref.[11].

Parts of different SACP spectra measured in this experiment are presented in fig.6. The low efficiency of the germanium detectors used (5 and 10%) explains the low data acquisition rate in the measured SACP spectra. However, we have succeeded in reporting some new intense two-step cascades comparing to [11]. Some of these cascades for ^{158}Gd compound states are given in table 2. The average error in the measured transition energies was about ≃ 1 keV. There are many other cascades, observed experimentally, not listed in the table either because of their low intesity or because they are leading to higher intermediate level states. Thus the technique of triple coincidences of γ-quanta allows one, as it is shown in fig.6, to detect cascades leading to final levels with energies E_f > 1 MeV, i.e the cascades leading to the ground and first two excited states in case of ^{158}Gd. The use of more efficient detectors (of about 30% or greater) will provide better possibilities of accounting for cascades leading to final states with energies E_f> 1 MeV. The necessary statistics needed in such cases (about 5000 ÷ 10000 events for each sum peak) may take about 200 hours to measure.

This technique provides, in addition to that reported in [3], a method for measuring cascades between excited states at energies ($E^* \simeq$ 1÷ 3 MeV) with a considerable improvement of the peak to background ratio. This allows one to construct the γ-decay schemes for complex nuclei (in the excitation energy region up to 3 MeV and higher) and to reveal the γ-decay modes of all low-lying states; in a narrow enough spin window. This information is necessary, for instance, to solve the problem of two phonon states in deformed nuclei [12], and to determine the total width of 1^+ states (by measuring their branching ratios for different decay modes) in even-even deformed nuclei through which the giant magnetic dipole resonance is fragmented [13].

In our experience it is quite sufficient just to study the two-step γ-cascade transitions in complex deformed nuclei

in the excitation energy region arround 2 MeV (and higher) above the ground state; as these cascades (in the even-even and even-odd deformed nuclei) contain about 50 ÷ 90% of the total intensity of primary transitions.

V. CONCLUSIONS

The results of this experiment illustrate the possibilities of using the multi-coincidence technique to measure γ-decay cascades in comlex deformed nuclei and we may conclude that :

- the method provides a considerable improvement of the line shape of the SACP spectra and gives better values for the background to paek area ratio. Moreover, the background, in some cases, can be compeletely cancelled,
- the method succeeds to resolve some cascades in some complex measurements such as the cases of irradiating an isotopic admixtures,
- the method, if high efficiency detectors are used, is a good tool to study the important practical cases; such as β-decay and mono-energetic neutron capture,
- the method, in principle, can be used to identify the γ-cascades of two or more transitions by making use of other reactions; in which the energy dispersion of γ-radiation does not much exceed the energy resolution of the used sodium iodied crystals.

REFERENCES

1. A.A.Bogdzel et al., JINR preprint P15-82-706, Dubna, 1982.
2. A.M.Hoogenboom , Nucl. Instr. and Meth., V.3, 57 (1958).
3. S.T.Boneva et al., Particles and Nuclei, V.22, 479 (1991).
4. Y.P.Popov et al., Izv. Akad. Nauk. SSSR, Ser. Fiz., V.48, 891 (1984).
5. S.T.Boneva et al., Z. Phys. A-Hadrons and Nuclei, 338, 319 (1991).
6. S.T.Boneva et al., Izv. Akad. Nauk. SSSR. Ser. Fiz., V.52, 2082 (1988).
7. A.A.Bogdzel et al., JINR preprint 13-84-145, Dubna, 1984.
8. A.A.Bogdzel et al., JINR preprint 13-84-386, Dubna, 1984.
9. V.F.Boreiko et al., JINR preprint P10-85-661, Dubna, 1985.
10. I.P.Barabash et al., JINR preprint 11-8522, Dubna, 1975.
11. R.C.Greenwood et al., Nucl. Phys., A304, 327 (1978).
12. H.G.Börner et al., Phys. Rev. Lett., 66, 691 (1991).
13. D.Frekers et al., Phys. Lett., B224, 178 (1990).

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