Vol. 26(1995) *ACTA PHYSICA POLONICA B* No 2–3

DOES THE COMPOUND NUCLEUS REMEMBER ITS WAY OF FORMATION ?; HOT GDR SPECTROSCOPY IN THE Yb–Dy REGION*

Z. ŻELAZNY[1], J.J. GAARDHØJE, A. MAJ[2] AND T.S. TVETER[3]
University of Copenhagen, Niels Bohr Institute
Blegdamsvej 17, D-2100 Copenhagen, Denmark

F. CAMERA, M. MATTIUZZI, A. BRACCO, B. MILLION
AND M. PIGNANELLI
University of Milan, Department of Physics
Via Celoria 16, I-20133 Milano, Italy

(Received January 24, 1995)

A difference method has been applied to determine the first chance GDR photon emission accompanying a deexcitation of the hot compound systems of ^{162}Yb and ^{158}Dy produced in heavy ion fusion reactions with 3 various projectile-target combinations. The GDR difference yield has turned out to be surprisingly small for the heaviest projectiles (Ti) being in dramatic conflict with the statistical model (code CASCADE) prediction, while for the lightest beam (O) an agreement with the model has been observed. For the intermediate (Si) projectiles a strong dependence of the difference yield on the transferred angular momentum has been noticed. With increasing I the difference yield decreases and reaches zero for the highest transferred I (50 $\hbar$). Recently additional checks with better definition of the fusion events applying the PPAC and CS HPGe detectors have been performed.

PACS numbers: 24.30. Cz, 24.60. Dr

---

* Presented at the XXIX Zakopane School of Physics, Zakopane, Poland, September 5–14, 1994.

[1] Permanent address: Institute of Experimental Physics, University of Warsaw, 00-681 Warsaw, Poland.

[2] Permanent address: Niewodniczański Institute of Nuclear Physics, 31-342 Kraków, Poland.

[3] Permanent address: Institute of Physics, University of Oslo, Blindern, Oslo, Norway

1. Introduction

In this paper we briefly discuss some specific aspects of the experimental results obtained within the HECTOR collaboration. Part of these results was already presented in the Gull Lake Conference [1]. For the description of the HECTOR set-up and some experimental details the reader is referred to two other papers from this conference: Bracco *et al.* [2] and Mattiuzzi *et al.* [3]. We concentrate on one of the important issues in the hot GDR experimental research, namely the necessity to define observable quantities to narrow regions in the excitation energy (E_x) versus angular momentum (I) in order to improve the sensitivity to different models of nuclear structure at finite temperature.

2. The method

The improvement of the experimental selectivity can be achieved by the difference method. It was proposed already 10 years ago by Gaardhøje et al.[4] and discussed by Maj *et al.* [5, 6]. The experimental conditions at that time were not sufficiently powerful to measure precisely the angular momentum of the considered compound system. That was an important limitation of the applicability of the method. Recently, we have upgraded our experimental apparatus (the HECTOR array) with a high efficiency, 38 element, multiplicity filter (HELENA) that enables us to carry out a satisfactory determination of the I of the emitting nucleus. This makes it possible to extend our method to higher angular momenta and thus to heavier projectiles.

The basic idea of the method can be inferred from Fig.1. Two nuclei with mass numbers differing by one neutron are produced in two heavy-ion fusion reactions. The excitation energies are chosen so that they differ by the average energy removed by the first evaporated neutron. The gamma ray emission from these two nuclei and from their daughters is measured and the resulting energy spectra are subtracted after normalization to the same number of fusion reactions. It is important that both spectra which are used in the subtraction procedure should correspond to the same range of angular momentum. This is why the application of a good multiplicity filter is crucial for the method. The subtraction procedure is based on the assumption that the nuclei populated after the first neutron emission undergo the same decay pattern as the nuclei produced directly by fusion at the same excitation energy. This situation is realized if the nuclei are thermalized at both situations prior to the deexcitation.

If the gamma ray emission associated with the GDR decay is statistical, the yield of high energy gamma rays in the GDR region should be larger for the reaction with larger E_x, reflecting the additional chance to decay by gamma ray emission. Thus, the difference spectrum should contain the gamma rays emitted directly from the heaviest compound nucleus, so to say the first step (or first chance) gamma emission.

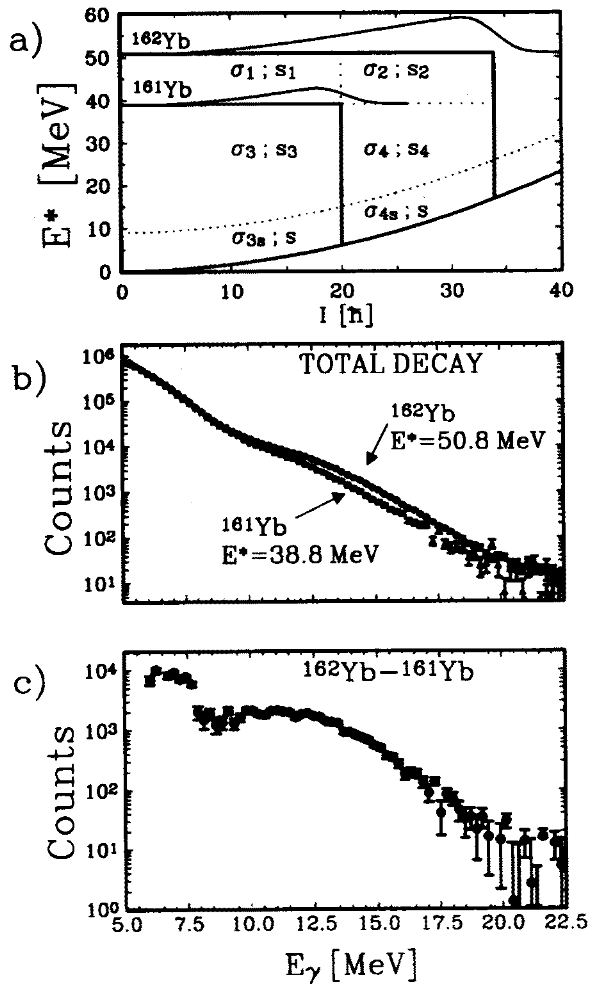

Fig. 1. Illustration of the difference method applied to the ^{162,161}Yb nuclei formed with the ^{17,18}O beam. The lower panel shows the measured difference yield which amounts to about 35 per cent of the total yield in the transition energy range 12-20 MeV. Taken from [5].

An essential part of the method is the proper normalization of the two spectra prior to the subtraction procedure. We have chosen to make them corresponding to the same number of the fusion reactions. The number of fusion reactions is determined with the use of the multiplicity filter. During the experiments we store on magnetic tape not only events in which a high energy gamma ray was detected in coincidence with a number of low energy transitions in the multiplicity filter, but also a certain fraction of the events in which only the multiplicity filter was triggered. The latter type of events we call the scaled-down singles events. In general, the number of such singles events is not proportional to the number of fusion reactions due to the presence of strong non-fusion reaction channels such as fission and deeply inelastic events. But these non-fusion events lead to relatively small multiplicities of low energy gamma rays. In contrast, complete fusion events are associated with large angular momentum transfer and thus lead to high multiplicities observed with our multiplicity filter. We have found out that the gamma ray spectra gated with folds lower than 12 are obviously contaminated with the non-fusion events while those gated with folds higher than 12 are most likely due to complete fusion events. The premise (but not the proof) is that for folds $F > 12$ the experimental fold spectrum has the shape which agrees well with the model prediction which assumes pure fusion. Under these circumstances we believe that by selecting events in coincidence with the folds of low energy gamma rays higher than 12 we have isolated pure complete fusion events and our normalization with singles ($F > 12$) is valid. Recent additional measurement with gating on the fusion recoil peak of the time of flight spectrum measured with the parallel plates avalanche counter (PPAC) detector confirms this conclusion [3].

3. Results

So far we have applied the difference method for the three following cases:

$$^{17,18}\mathrm{O} + ^{144}\mathrm{Sm} \longrightarrow ^{161,162}\mathrm{Yb},\ E_x = 51,\ 39\mathrm{MeV}\,,$$

$$^{48}\mathrm{Ti} + ^{113,114}\mathrm{Cd} \longrightarrow ^{161,162}\mathrm{Yb},\ E_x = 75,\ 63\mathrm{MeV}\,,$$

$$^{29,28}\mathrm{Si} + ^{128,130}\mathrm{Te} \longrightarrow ^{157,158}\mathrm{Dy},\ E_x = 75,\ 63\mathrm{MeV}\,.$$

Spectra measured for 2 different projectile energies constitute a basis for subtraction procedure. In all our experiments we have tried to form a similar compound system which deexcites emitting almost uniquely neutrons. For Si projectiles we have not been able to find a convenient target to produce the desired Yb isotopes. Instead, we have produced the ^{157,158}Dy isotopes which are isotonic with ^{161,162}Yb.

Figure 2 presents our results together with the predictions of the statistical model code CASCADE [7] calculated for the ^{48}Ti + ^{113,114}Cd case. We have plotted the intensity of the difference spectrum (integrated within the range of 12–20 MeV gamma transition energies) expressed as a percent-

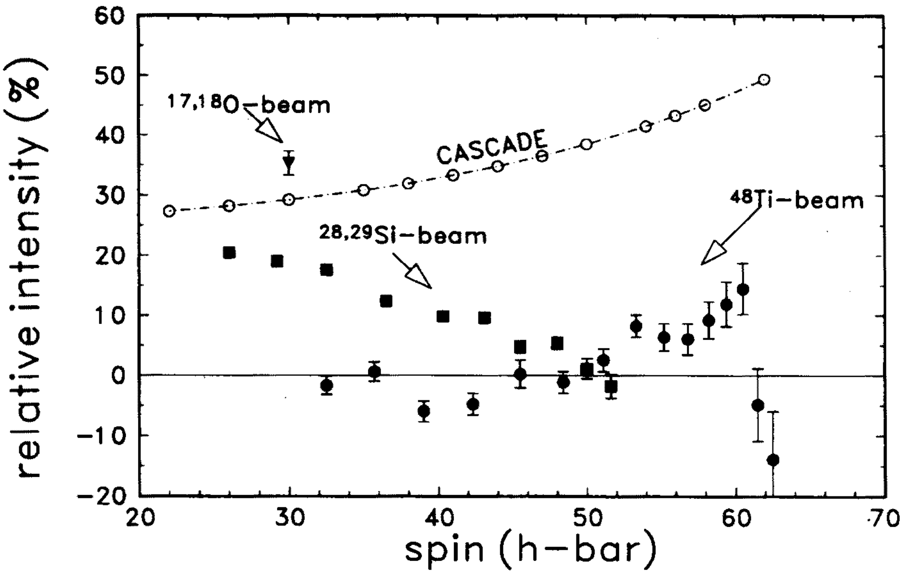

Fig. 2. The solid points show the fraction of counts in the difference spectrum in the range $E_\gamma = 12$–20 MeV relative to the number of counts in the ^{162}Yb (or ^{158}Dy) spectrum. The open points show the fraction expected in the CASCADE calculations for the Ti + Cd reactions. Note that in the Oxygen projectiles case the E_x is about 20 MeV lower than for the other cases.

age of the intensity of the total spectrum (integrated within similar gamma energy range) measured for the reaction with higher E_x. This relative intensity of the difference spectrum has been plotted versus angular momentum of the compound system.

Data concerning oxygen projectiles were measured with our previous, less selective multiplicity filter which is why we cannot discuss the spin dependence of the results. It is seen that the experimental point determined for the oxygen beam (solid triangle) agrees well with the CASCADE model prediction (open circles). (Even more so than is visible in the figure because the CASCADE calculations performed for the O + Sm system are a few percent higher than those for Ti + Cd shown in the figure.) Surprisingly, we find a completely different situation for the same compound system but produced using titanium projectiles (solid circles) where the experimental difference yield is far below the one expected by the model. For the Ti beam data we observe the dramatic lack of the intensity of the difference spectrum. This intensity is approximately equal to zero for the I smaller than $55\hbar$ and then for the highest available angular momenta (where the statistical uncertainty is very large) we observe a non-zero but still very little effect. This result is in conflict with our understanding of the statistical deexcitation mechanism which implies that the higher E_x the larger total probability of emitting the GDR photon.

The third group of experimental points in Fig. 2 (solid squares) presents results obtained with the intermediate (compared to the O and Ti) silicon beam leading to a very similar compound system. This time we observe a clear dependence of the difference yield on the transferred angular momentum. At high angular momentum the conflict with the CASCADE prediction is largest, while at low I the determined yield agrees with the model. For I about $50\hbar$ (the highest available in this reaction) the difference yield reaches zero pointing out that there is no any extra GDR photon yield in spite of the fact that the E_x of the two reactions differ by 12 MeV.

Because we consider the possibility that our definition of fusion events based on the multiplicity of low energy gamma rays is not reliable enough ("leakage" of two-body events into singles would ruin our normalization in the subtraction procedure because the cross section for deeply inelastic events is large here) we have recently made 2 additional short measurements for the Ti + Cd system including an 80% Compton suppressed HPGe detector in the set-up and (in a separate run) using in addition 2 PPAC detectors to select fusion events. Unfortunately these short checks could only be done at lower by 9 MeV E_x in comparison with the previous measurements. With the use of Ge detector the high energy photon spectra have been gated by several identified low energy gamma transitions belonging to the ^{158}Yb fusion residue. Unfortunately statistics is very poor. The obtained relative intensity (for all folds) of the difference spectrum equals 13 $\pm$ 30% which is inconclusive result for our puzzle. A much higher efficiency for the discrete line detection is necessary to seriously address this question.

In the PPAC run the high energy photon spectra have been gated by the fusion recoil peak, visible in Fig. 3, in the TOF spectrum measured by PPAC. Again, very low statistics of the high energy photon spectra has not allowed to study dependence on I and thus we have used the all folds projections to perform the subtraction procedure. The intensity of the difference spectrum obtained in this check equals 34 $\pm$ 20% and slightly disagrees with the previous results shown in Fig. 2 but one should keep in mind that the E_x is lower here by 9 MeV.

We do not have any satisfactory explanation for the experimental observations we are hereby reporting. The angular momentum dependence observed for the Si beam results makes it tempting to think about some pre-equilibrium effects as an explanation. Because, the higher angular momentum is transferred in the more peripheral collision and, therefore, corresponding to the longer lasting time of the equilibration. According to Feldmeier calculations [8] performed using the one-body dissipation model of heavy ion collisions of Świątecki and co-workers [9], the collision time

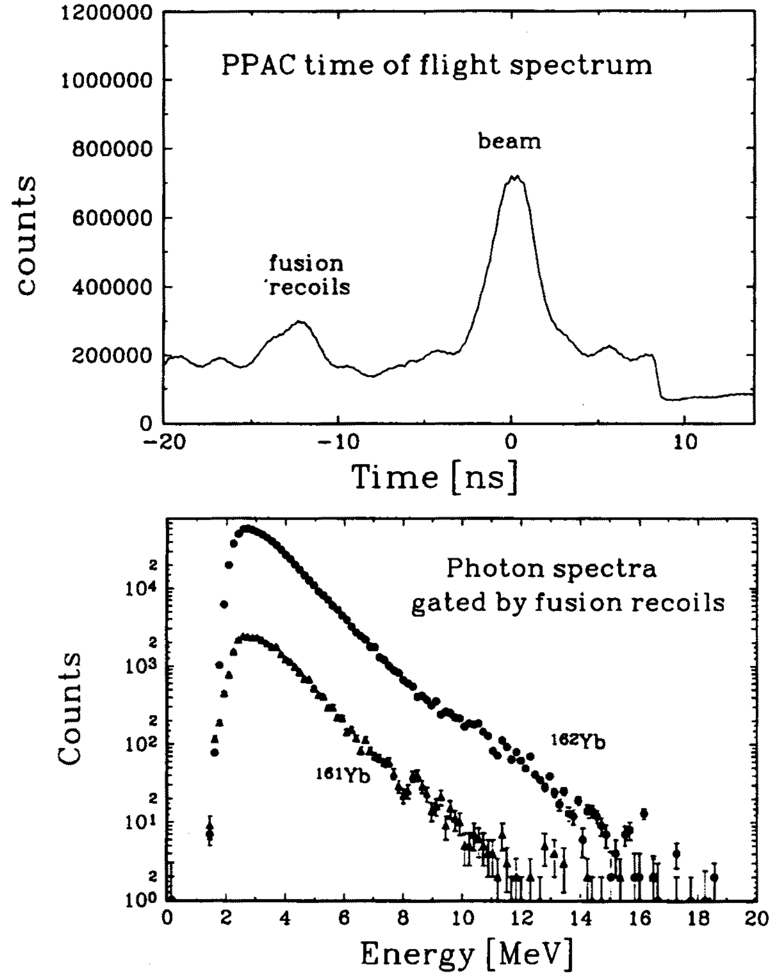

Fig. 3. Time of flight spectrum measured with the PPAC detector (top). The fusion recoil peak and the beam peak are shown. In the bottom are presented for both measured reactions the gamma ray spectra corresponding to the whole range of I (all folds projection) and gated by the recoil peak. One can see the excess of high energy (GDR) photons in the spectrum corresponding to higher E_x reaction.

(from the thermalization of the deformation degrees of freedom point of view) for the Ti+Cd system (1×10^{-20} s) may be about 5 times longer than the one for the O+Sm system (2×10^{-21} s). Thus it may approach the neutron emission lifetime (6.5×10^{-20} s) for a typical here nuclear temperature $T = 2$ MeV.

Several papers reporting not fully understood experimental observations for nearly symmetric heavy ion collisions close to the Coulomb barrier were published during last several years. Among them are *e.g.* Kühn *et al.* [10], Janssens *et al.* [11] (reporting the suppression of the neutron emission) and Thoennessen and Beene [12] (speculating about the preequilibrium effects in the GDR strength function). The present contribution joins this group of challenging puzzles.

One of the authors (Z. Ż) appreciates a partial support from the Polish State Committee for Scientific Research, Grant No. 2 0209 91 01.

REFERENCES

[1] Z. Żelazny *et al.*, *Nucl. Phys.* **A569**, 1c (1994).
[2] A. Bracco *et al.*, *Acta Phys. Pol.* **B26**, 407 (1995.
[3] M. Matiuzzi *et al.*, *Acta Phys. Pol.* **B26**, 467 (1995).
[4] J.J. Gaardhøje *et al.*, *Phys. Lett.* **B139**, 273 (1984).
[5] A. Maj *et al.*, *Phys. Lett.* **B291**, 385 (1992).
[6] A. Maj *et al.*, *Nucl. Phys.* **A571**, 185 (1994).
[7] F. Pühlhofer, *Nucl. Phys.* **A280**, 267 (1977).
[8] H. Feldmeier, *Rep. Prog. Phys.* **50**, 915 (1987).
[9] J. Blocki *et al.*, *Ann. Phys.* (N.Y.) **113**, 330 (1978).
[10] W. Kühn *et al.*, Phys. Rev. Lett. **51**, 1858 (1983).
[11] R.V.F. Janssens *et al.*, *Phys. Lett.* **181B**, 16 (1986).
[12] M. Thoennessen, J.R. Beene, *Nucl. Phys.* **A557**, 247c (1993).