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HOT NUCLEI : HIGH TEMPERATURES, HIGH ANGULAR MOMENTA. TOWARDS NUCLEAR DISASSEMBLY.

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ABSTRACT

A review is made of the present status concerning the production of hot nuclei above 5 MeV temperature, concentrating mainly on the possible experimental evidences for the attainment of a critical temperature, on the existence of dynamical limitations to the energy deposition and on the experimental signatures for the formation of hot spinning nuclei. The data strongly suggest a nuclear disassembly in collisions involving very heavy ions at moderate incident velocities. Furthermore, hot nuclei seem to be quite stable against rotation on a short time scale.

I - INTRODUCTION

The development of heavy ion facilities has offered to the experimentalists the opportunity to investigate the domain of hot nuclei. Intermediate energy heavy ion beams appeared indeed to be the best tool to produce and study nuclei under extreme conditions of temperature and pressure[1,2].

What is the highest excitation energy that a nucleus can accomodate ? Is the concept of a critical temperature meaningful ? Is it possible to reach a point where either a liquid gaz phase transition or mechanical instabilities could occur ? Are there some dynamical limitations to excitation energy deposition ? How stable is a hot nucleus against rotation ? What is the influence of the angular momentum on the decay process ?

From a large set of experiments, one gets now partial answers to these exciting and fundamental questions and some of these points will be debated in this paper. The emphasis will be put on the possible evidence for the existence of a critical temperature above which the system becomes unstable as well as on the possibility to form hot spinning nuclei for large and intermediate impact parameters.

How to define a hot nucleus ? the word nucleus means that one has to deal with a self bound system, even for a short while, at high temperatures ($T>3$ MeV i.e.

a region where shell effects can be neglected). Furthermore, as we are going to use the concept of temperature, this implies a relaxation of the intrinsic degrees. These hot nuclei should then be in thermal equilibrium and it raises immediately the problem of using the concept itself of a hot nucleus at high temperature. The difficulty relies on the time needed for the two colliding ions to form a composite object and reach an equilibrium state for which a temperature can be defined[2,3).

A comparison is made in Fig. 1 between the neutron decay half-life of a Pb compound nucleus as a function of temperature and some characteristic time associated with the relaxation of various degrees of freedom (the intrinsic degrees, the giant dipole resonance and the nuclear fission). It stresses the very sharp decrease of the half life with increasing temperature and it is easily seen that for T ~ 6 MeV, the thermalization time becomes similar to the neutron decay time ! At such high temperatures, the characteristic time for energy dissipation and the decay time start to overlap and consequently, one would be unable to decouple the probability of formation of the compound system from its decay properties. This automatically introduces the role of the dynamics and of non equilibrium processes. Moreover, as shown also in Fig. 1, the collective degrees of freedom have quite large relaxation times, indicating that the hypothesis of equal life-times for the different decay channels (light particles, fission) which is contained in the standard statistical model and the Weisskopf formula is no more fulfilled. Large consequences are then expected for the decay of these hot systems.

This paper is intended to focuse on two main aspects of the production and the decay of hot nuclei. The first one has to deal with the attainment of some critical temperature above which the system becomes unstable. This problem has given rise to extensive experimental and theoretical studies[1,2). The main questions are dealing with the experimental signatures of the existence of such critical temperatures and obviously with the optimum experimental conditions. The influence of the entrance channel will be discussed and it will be shown that there are some dynamical limitations to the energy deposition. Evidences for a complete disassembly of the Pb + Au system will be given when triggering on the most violent collisions. The second aspect which has not been tackled very often is concerning the angular momentum that a nucleus can accomodate. It will be shown that such hot nuclei can also store quite large angular momenta and that consequently, they appear to be quite stable against rotation on a short time scale.

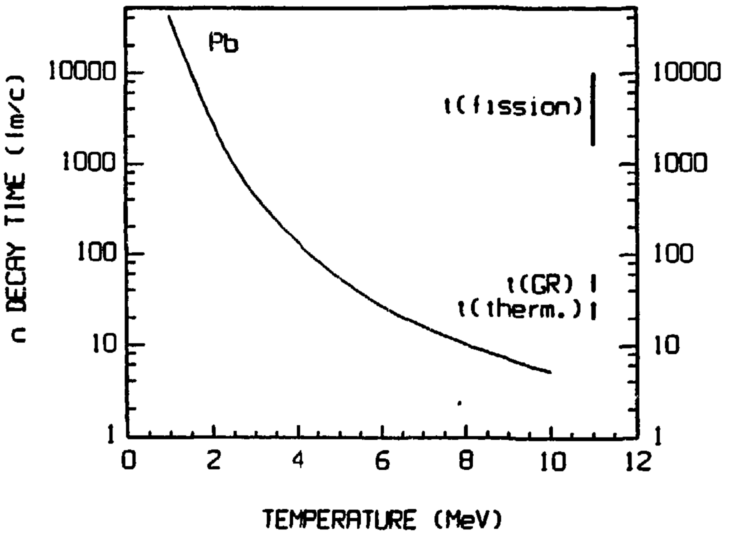

Fig. 1 : Evolution of the neutron decay half-life of a ^{208}Pb nucleus as a function of its temperature. A comparison is made with typical relaxation times (thermalization time, the giant resonance mode and nuclear fission).

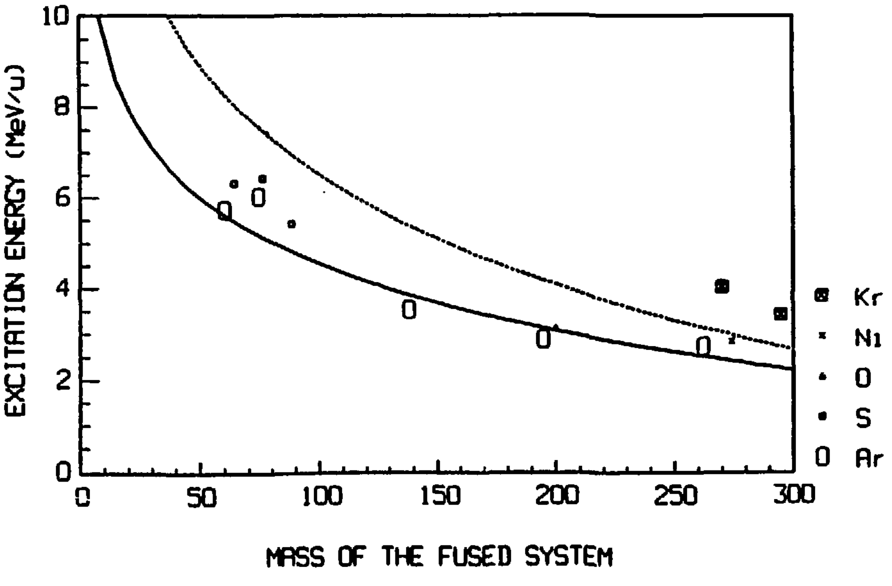

Fig. 2.: Systematics of the highest excitation energy per nucleon reached so far in heavy ion collisions for a given mass of the fused system. The data are compared to static calculations[4] using the hot liquid drop model and a soft nuclear EOS. The two curves correspond to different surface tension coefficients.

II - EVIDENCE FOR THE EXISTENCE OF A LIMITING TEMPERATURE ?

How hot can be a self bound system in thermal equilibrium ? A partial answer to this question, can be obtained from Fig. 2 which shows the highest excitation energy per nucleon (E*/A) reached so far experimentally for a given mass of the composite system. These values are displayed over the mass range 60-300 and they evolve from 6.5 MeV/u for the light systems down to about 3 MeV/u for the heaviest ones. This would correspond to a temperature decreasing from almost 7 MeV down to 4.5 MeV. This trend seems to be well predicted by static calculations as those of Levit and Bonche[4] which are shown in the figure. In such calculations, the limit of stability is influenced by the balance between Coulomb, Bulk and surface energies, inducing a significant dependence of $T_{\lim}$ on the nuclear charge. Both curves in Fig. 2 result from a calculation using a soft nuclear equation of state with an incompressibility modulus K = 220 MeV (different surface tension coefficients have been used).

Does it mean that one has a comprehensive picture of the problem and that static approaches are quite successfull to account for the existing data ? This might not be so sure if one notices the large differences observed for heavy systems when using different projectiles as Ar and Kr[5,6]. (excitation energies are differing by more than 1 MeV/u). Obviously, the entrance channel plays a very important role and it might well be that the values indicated in Fig. 2 result from such limitations and have nothing to do with the intrinsic properties of the nucleus itself.

Furthermore, experimental evidences are needed before to ascertain that we have reached some critical point where the system becomes unstable. In the next section, we shall concentrate on these two points.

III - THE EFFECT OF THE ENTRANCE CHANNEL ON THE ENERGY DEPOSIT

In order to shed light on the influence of the dynamics of the entrance channel, essentially two parameters can be varied, the bombarding energy and the mass asymmetry of the system.

III.1. The influence of the bombarding energy

The influence of the bombarding energy on the thermal energy deposit has been carefully studied by Jiang et al.[5] for the systems Ar + Au and Ar + Th in the energy range 27 - 77 A.MeV. The results are summarized in Fig. 3 for the system

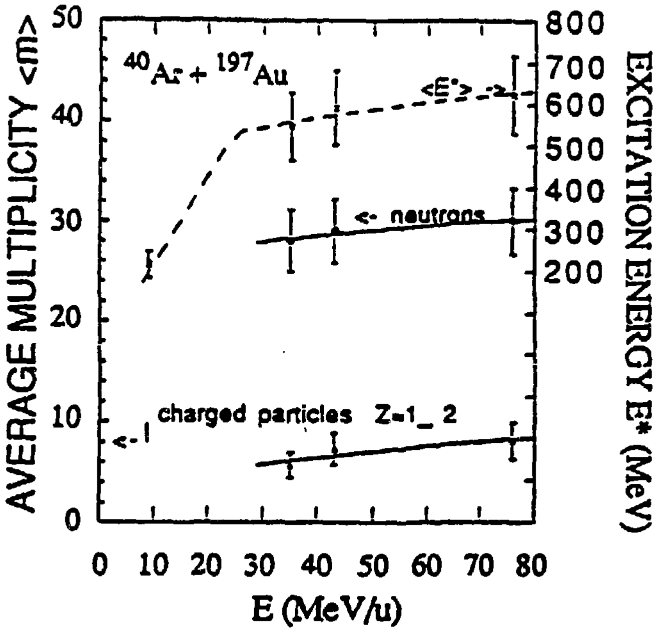

Fig. 3. : Evolution with bombarding energy of the total number of neutrons (circles) corrected for detector efficiency and evaporated charged particles (triangles) summed over Z = 1,2 released from the most dissipative collisions. From these multiplicities, the excitation energies (crosses) have been estimated5).

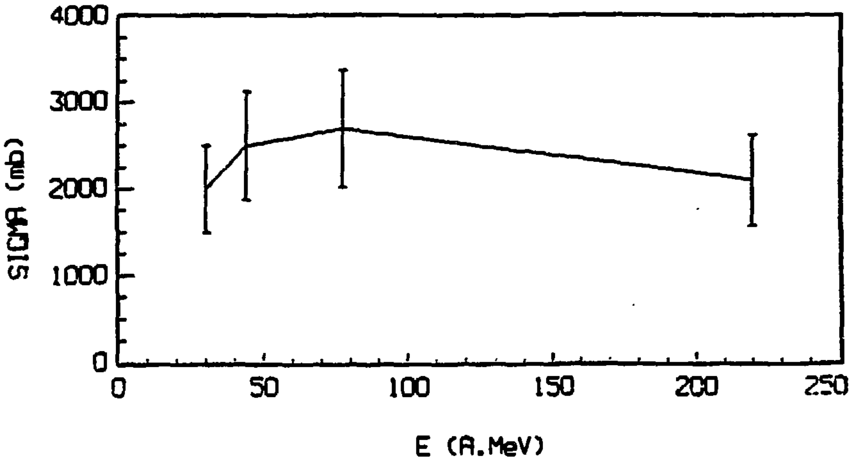

Fig. 4. : Evolution with the bombarding energy of the IMF cross section in the reaction Ar + Au. Data at 30 and 220 A.MeV are extracted from Ref. 8, those at 44 and 77 A.MeV from Ref. 7.

Ar+ Au. In such experiments, the most probable multiplicity of neutrons evaporated by the hot composite system has been measured using a 4 π neutron detector. The associated light charged particles have been detected in the backward direction. A soft saturation of the number of evaporated light particles (≈ 35 neutrons and 5 light charged particles) is observed above a very moderate value of the incident energy, i.e. 30 A.MeV.

Assuming a sequential emission of these particles, the primary thermal energy deposited in the system has been estimated. It is shown to increase very weakly from 620 up to 700 MeV in this wide incident energy range (30- 77 A.MeV). When increasing the bombarding energy, preequilibrium processes seem to pump most of the additional available energy. Would it mean that such a soft saturation indicates that the limiting temperature has been reached ? Would it be the case, one should then observe some change in the decay process. The saturation observed in the light particle emission is obviously a clear indication that the hot system has not undergone a complete vaporization ! Looking at the excitation function for the emission of intermediate mass fragments (IMF) may provide the key to our problem. Fig. 4 shows the evolution of the IMF cross section in the energy range 27-220 A.MeV for the same system Ar + Au[7,8).(It has been checked at 44 and 77 A.MeV that these fragments were associated with the very dissipative collisions). This cross section remains more or less constant around 2 - 2.5 barns, a value corresponding to an emission of one IMF per dissipative collision on the average.The fragment emission is clearly not becoming a dominant decay mode with increasing energy and it may rule out their formation through a dynamical process.

Consequently, from these experiments, there is no sign for having reached a critical temperature for the Ar + Au system. Most dissipative collisions have suffered a dynamical limitation of the thermal energy deposit. It does not exclude the possibility, for the most central collisions, associated with small cross sections, to get a sizeable increase of the maximum energy deposited in the system. This has been predicted by recent calculations and indeed observed in very exclusive experiments[9). But again, this, by no mean becomes a dominant process over a significant range of impact parameter.

III.2 - Mass asymmetry effects in the entrance channel

It has been shown in the previous section that the most probable deposited thermal energy remains almost independant of the bombarding energy (≈ 2.6 MeV/u for the Ar + Au system). Another manifestation of entrance channel effects is to look at the dependance of the deposited energy on the projectile-target combination. Such a dependance is displayed in Fig. 5 which shows the amount of excitation energy for reactions involving various projectiles, from nitrogen to krypton, impinging very heavy targets (Ar, Th, U) at a very moderate incident velocity, ≈ 30 A.MeV. A steep increase of the most probable excitation energy per nucleon is observed with increasing projectile mass, from 1.8 MeV/u for N induced reactions up to 4.5 MeV/u for Kr induced reactions[5,6,10]. It is then quite clear that the limits reached in these experiments are not those characterizing the intrinsic properties of the nuclear systems. They are more likely to reflect the influence of the collision dynamics on the efficiency of heat generation mechanism. Keeping a moderate incident velocity allows to minimize direct processes as preequilibrium emission. It has been shown already that around 30 A.MeV, the most probable linear momentum transfered to the target amounts to about 75 % - 80 % of the initial projectile momentum. Extrapolating our present knowledge on the systematics of linear momentum transfer for much more massive projectiles would indicate that even for such very heavy systems, temperatures close to 7 MeV are within the reach of the experimentalist.

IV - THE Pb + Au SYSTEM. TOWARDS NUCLEAR DISASSEMBLY

It was when tempting to extend this systematics to the heaviest projectile-target combination and the almost symmetric system Pb + Au has been recently studied at 29 A.MeV[12]. For such a system, the available excitation energy per nucleon is close to 7.5 MeV. Extrapolating from the previous systematics would indicate that an average energy deposition exceeding 6 MeV/u could reasonably be expected. The aim of such an experiment was to search for changes in the decay process which could be clearly correlated with the attainment of a critical temperature. In the experiment, the charged distribution of the products has been essentially measured with a forward angle hodoscope ($6° \leq \theta \leq 20°$) and the filter on the degree of violence of the collision (strongly correlated with the impact parameter) was provided by the 4 π detector ORION giving an event by event measurement of the neutron multiplicity M_n with a high efficiency[13]. A global information on the energy dissipation is already provided in Fig. 6 by the inclusive neutron multiplicity distribution. The shape of this distribution is quite similar in character to those measured previously for the Ar + Au and Kr + Au systems at comparable beam velocities[5,6]. The very dominant feature is the presence of two components which can roughly be related to peripheral (low

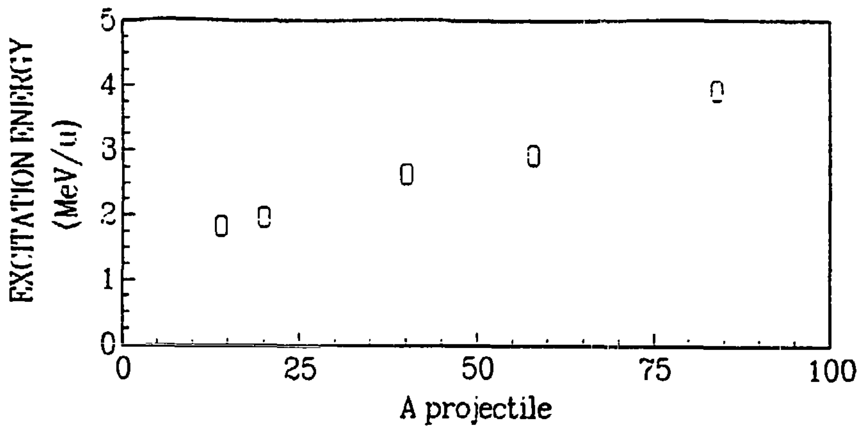

Fig. 5.: Experimental systematics of the excitation energy deposit for heavy ion projectiles impinging a heavy target (Au, Th or U) at 30 A.MeV. Data are extracted from Ref. 5, 6, 10.

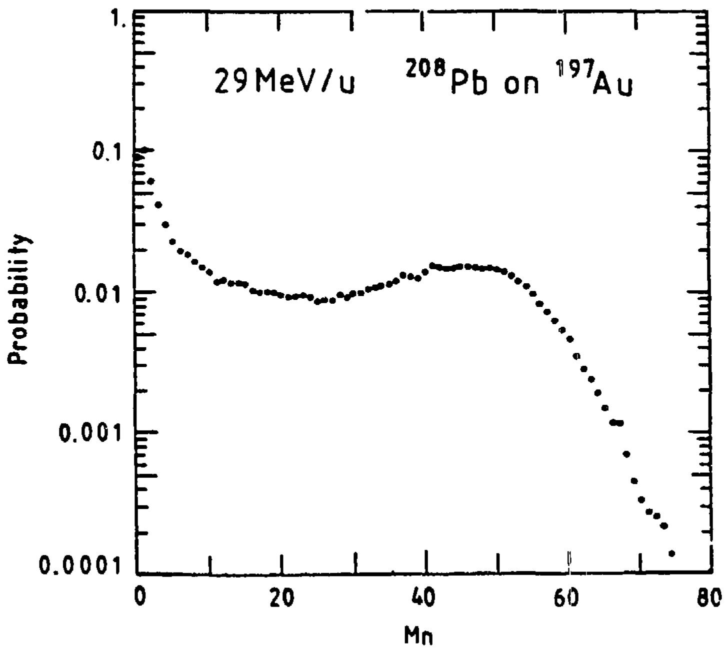

Fig. 6. : Inclusive neutron multiplicity distribution, as measured (no efficiency correction) for the system ^{208}Pb + ^{197}Au at 29 A.MeV. (Ref. 12).

$M_n$values) and more central collisions (high M_n values). This broad bump at a high multiplicity is centered at a significantly higher M_n value ($M_n \approx 50$) than with lighter systems. Moreover, this value corresponds to approximately 78 neutrons when corrected for detection efficiency. This represents almost one-third of all neutrons of the system, a much larger fraction than observed earlier in the Ar + Au and Kr + Au experiments. A more quantitative comparison is made in Fig. 7 between the three systems Ar + Au, Kr + Au and Pb + Au, where the fraction of the neutron excess of the system observed as free neutrons (as determined at the centroid of the high multiplicity bump) is plotted versus the neutron excess of the system. The striking feature is the observation of a fraction approaching 100 % for the system Pb + Au. This means that all charged products must have an average N/Z ratio close to unity, which is already a very strong indication for the system to have disassembled into rather light fragments. It is then very likely that higher temperatures are thus attained with increasingly symmetric beam-target combinations.

Exclusive measurements of charged products shed more light on the drastic evolution of the decay processes according to the degree of violence of the collision, the later being selected through the measurement of the associated neutron multiplicity M_n with the 4 π detector ORION. Fig. 8 displays the distribution of these reaction products in the Energy Versus Atomic Number plane gated by 6 different neutron multiplicity

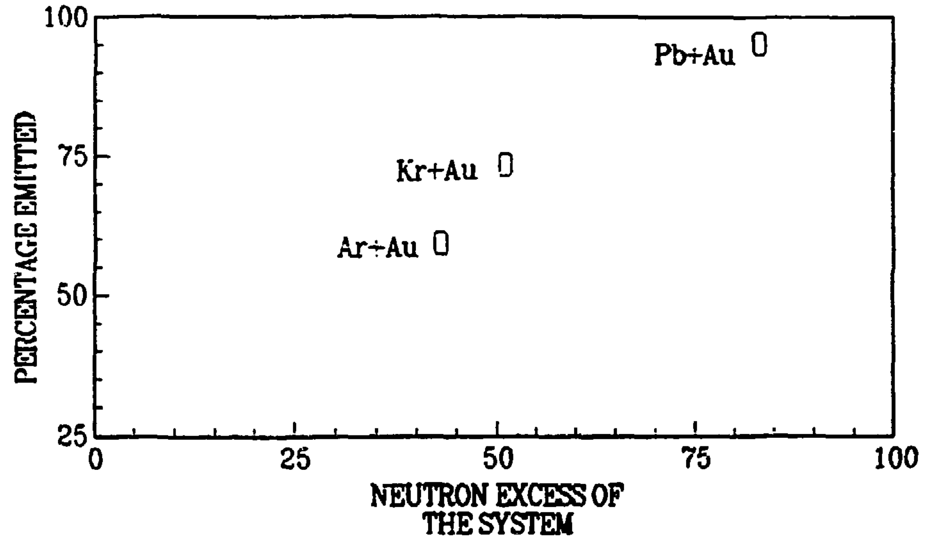

Fig. 7. : Most probable fraction of the neutron excess of the system as a function of the neutron excess contained in the (Ar, Kr, Pb) + Au system, studied at E_{lab} close to 30 A.MeV (Ref. 5, 6, 12).

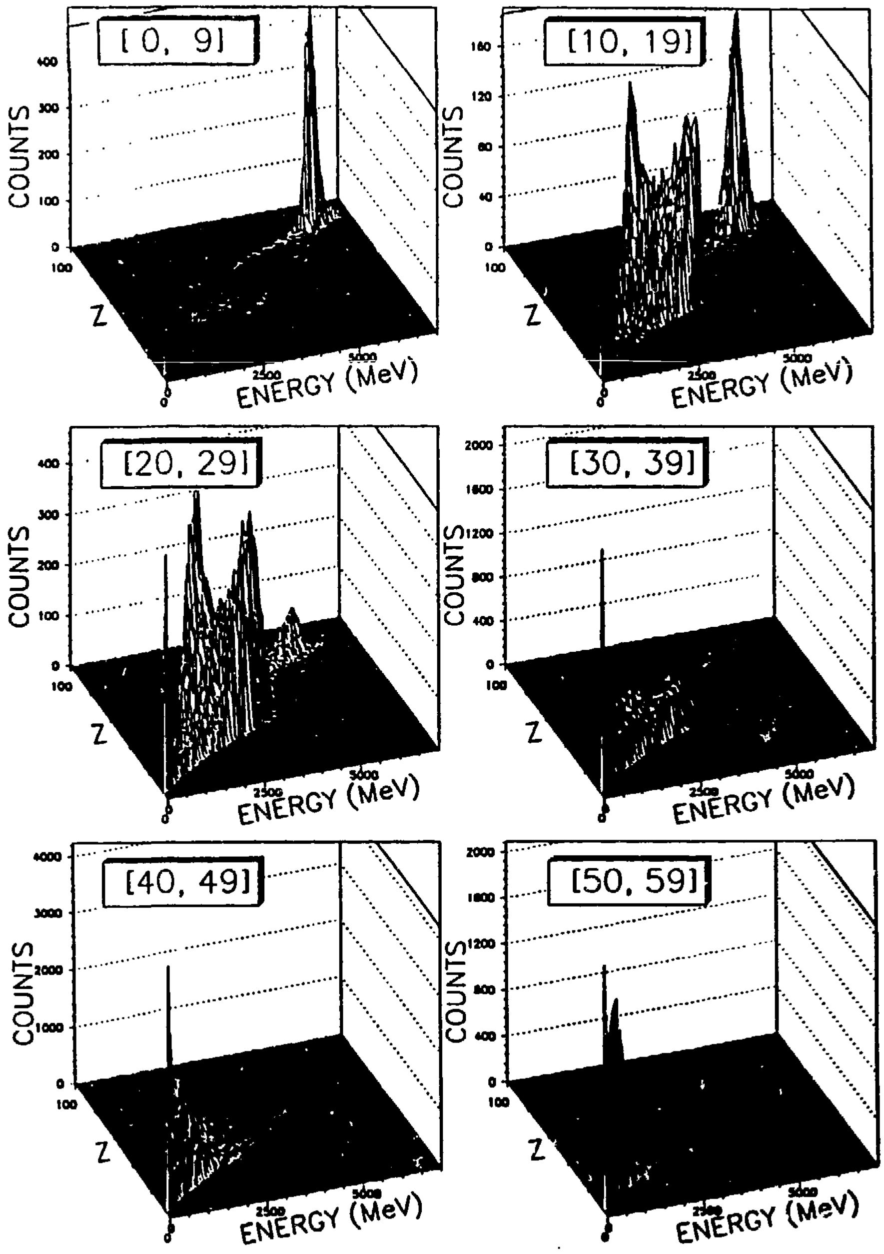

Fig. 8. : Distribution of reaction products detected between 6° and 20° for the Pb + Au system, as a function of their atomic number and kinetic energy for several neutron multiplicity gates (Ref. 12, 14).

bins[12,14]. For low M_n values (gate 1), the picture is dominated by elastic and quasi-elastic reactions. For the intermediate impact parameters (M_n = 10,19 and 20,29), two components are now present : the first one consists of heavy projectile-like residues originating from partially damped collisions. The second component corresponds to the sequential binary fission of the excited projectile. The double hump which is observed reflects the two kinematical solutions which are beeing observed when the recoil velocity of the fission fragments.

When selecting larger M_n values, the distribution undergoes important changes. The former components, the projectile-like fragments and the fission fragments progressively vanish and at the same time the light fragment production becomes the dominant process. Fig. 9 demonstrates even more clearly the change in the decay process according to the value of the associated neutron multiplicity (i.e. the impact parameter). It shows the emission probability as a function of M_n for a typical intermediate mass fragment (Z = 42). As IMF emission is growing continuously with decreasing impact parameter, the binary fission is a dominant process only for intermediate impact parameters and it disappears for the most violent collisions. In that case, one has to deal either with successive binary fission decays or a prompt multifragment production. An attempt to distinguish between those two different processes is out of the reach of such an experiment and would require the use of a 4 π charged product detector. For these small impact parameters, the nuclear system appears indeed to disassemble in a large number of neutrons (more than 80 after detector efficiency correction) and a copious number of intermediate mass fragments, their yields decreasing exponentially with increasing atomic number. Massive fragments did not survive for these most dissipative central collisions.

This disassembly is by no means a rare process as it represents about 25 % of the total reaction cross section. If one assumes this process to occur for the most central collisions, this would imply that all impact parameters below b = 6 fm are leading to a disassembly. The available energy (~ 7.3 MeV/u) is obviously efficiently used in the system Pb + Au, at such a very moderate incident bombarding energy, to heat-up the system (presumably up to the critical temperature) and lead to the observed nuclear disassembly. This would strongly favour the hypothesis of a thermal disassembly. A dynamical disassembly seems less likely to occur as the same available energy of 7.3 MeV/u for the Ar + Au system (implying a bombarding energy of 53 MeV/u) does not lead at all to such a high cross section for the IMF production (see Fig. 4).

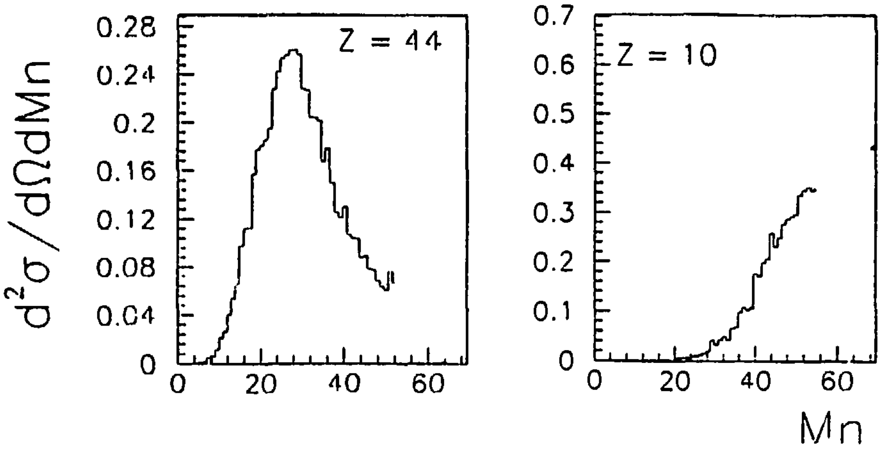

Fig.9.: Evolution with the neutron multiplicity (as measured) of the emission probability for a typical IMF (Z = 10) and a typical fission fragment (Z = 42) in the reaction Pb + Au at 29 A.MeV (Ref. 14).

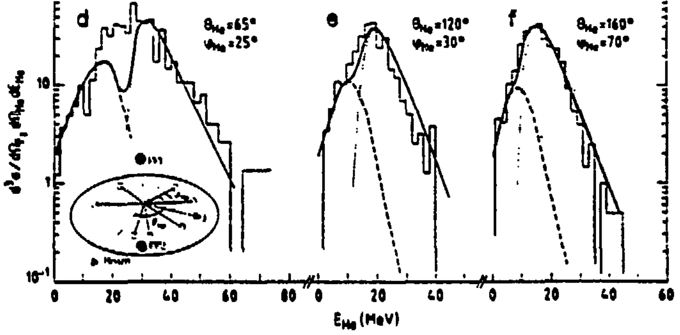

Fig.10.:Calculated spectra for alpha particles emitted by the composite nucleus (dotted lines), by the fission fragments (dashed lines) and their sum (full lines) compared to in-plane (φ = 90°) and out of plane (φ = 25°, 30°, 70°) experimental spectra. The reaction is 27 A.MeV Ar + U (Ref. 17).

For this Pb + Au reaction, the limit of the existence of a real nucleus has probably been reached and it seems quite probable that one has to deal with a hot blob of nuclear matter for these very central collisions.

V - THE PRODUCTION OF HOT SPINNING NUCLEI

At first sight, it seems straightforward that, in any dissipative phenomenon, kinetic energy dissipation has to be more or less strongly connected with angular momentum transfer. It is then worth trying to determine the amount of angular momentum transferred during the formation of hot nuclei and study their effect on the decay properties of such systems. The ultimate question would be obviously to determine how much angular momentum the nucleus can accomodate without undergoing a multifragmentation process.

Unfortunatly, very few experiments have been dealing with such measurements. We shall try to show, through a few examples, that the nucleus is indeed quite stable against rotation.

V.1 - Experimental evidences

An estimate of the angular momentum deposited in these incomplete fusion reactions can be made in an indirect way either by detecting γ-rays[15)] or by measuring the azimuthal angular distributions of light charged particles or fission fragments or looking at correlations between emitted particles[16-18)]. However a quantitative estimate of the intrinsic spin of the emitter can be made only using the statistical model which implies that one has to deal with a fully thermalized composite nucleus.

The first example is concerning the system Ar + U at 27 A.MeV for which the in plane and the out of plane (OOP) distributions of the α-particles have been measured, the reaction plane being defined by the detection of the fission fragments[17)]. Typical experimental energy spectra for He are shown in Fig. 10 together with calculated ones assuming two sources for these particles, the composite nucleus and the fission fragments. The simulations demonstrate clearly that the major contribution arises from the emission by the composite nucleus (> 85 %) before scission, which is obviously a necessary condition to extract an angular momentum information from the OOP distribution. This distribution is essentially sensitive to the ratio [illegible]T where J_0 is the spin of the parent nucleus, I the moment of inertia and T the temperature[19)]. The extraction of J_0 from the experiments implies an attempt to single out the effects of these different parameters : temperature, spin and deformation. The method is detailed by Jacquet et al.[17]. A precise analysis indicates that the experimental results (anisotropy, energy spectra) are well reproduced assuming a temperature T close to 4.5 MeV, a quite large deformation (axis ratio 2 : 1) and a r.m.s value of the angular momentum for the hot emitter $J_{r.m.s} \approx 120\ \hbar$.This value is a minimum value as it is an average over the whole deexcitation chain of the composite nucleus from the moment it is formed up to scission. If one takes into account this fractional loss of the angular momentum, the value which has been extracted is then in agreement with an estimate of $J_{r.m.s}$ from the measurement of the fusion cross-section. The striking result is that such hot and heavy composite systems seem to accomodate large values of angular momentum. For the Ar + U case, maximum values of 160-200 ħ have been reached.

Another example has been recently discussed by Ethvignot et al.[18]. The role of angular momentum has been studied by measuring correlations between emitted particles. The system Ar + Ag has been investigated in the bombarding energy range 7-34 A.MeV. Examples of these azimuthal distributions are shown in Fig. 11 for various pairs of emitted particles. The largest anisotropies are observed for heavier ejectiles, which have more spin-off energy.The curves in the figure result from simulations within the statistical model framework and are able to provide a very satisfactory description of all experimental data. Again, one has here a clear evidence that very highly excited nuclei ($T \approx 5$ MeV) have been formed with spins as high as 130 ħ. Moreover, due to the averaging over the whole deexcitation chain, the maximum spin values have been obviously underestimated. (Cross sections for central collisions at 27 A.MeV are comparable with incident partial waves extending up to 200).

V.2 - Hot nuclei are quite stable against rotation

It may appear quite amazing that hot nuclei with high thermal excitation ($T \approx 5$ MeV) can be so stable against rotation. The large angular momenta involved in the above reactions are indeed much larger than the ones corresponding to the limit of stability against fission[20]. Such a comparison with the rotating liquid drop model (RDLM) is shown in Fig. 12. While the RDLM limit is 80 ħ for an U nucleus, the data for the Ar + U system are fully compatible with $J_{max} \approx 160\ \hbar$.

Why such high angular momenta ? The reason lies probably in the fact that we are dealing with different timescales. It is now well known that the fission process is strongly hindered in the early stage of the collision as compared to the predictions of

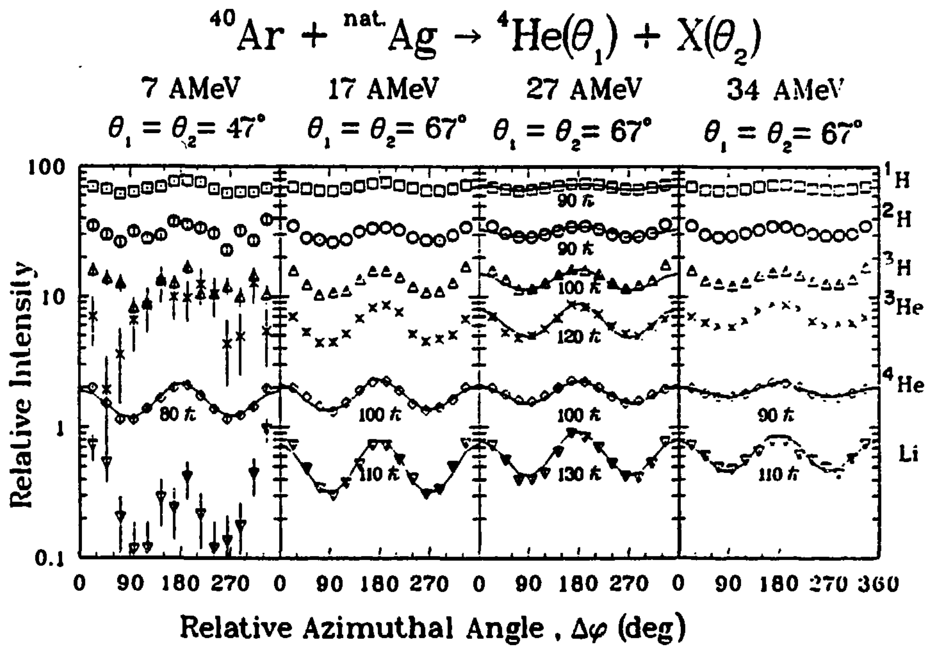

Fig.11.: Azimuthal angular correlations for ^{4}He-X pairs. The curves are statistical model calculations. Values of the angular momentum indicated in the figure are the J_{max} values used in the calculation. (Ref. 18).

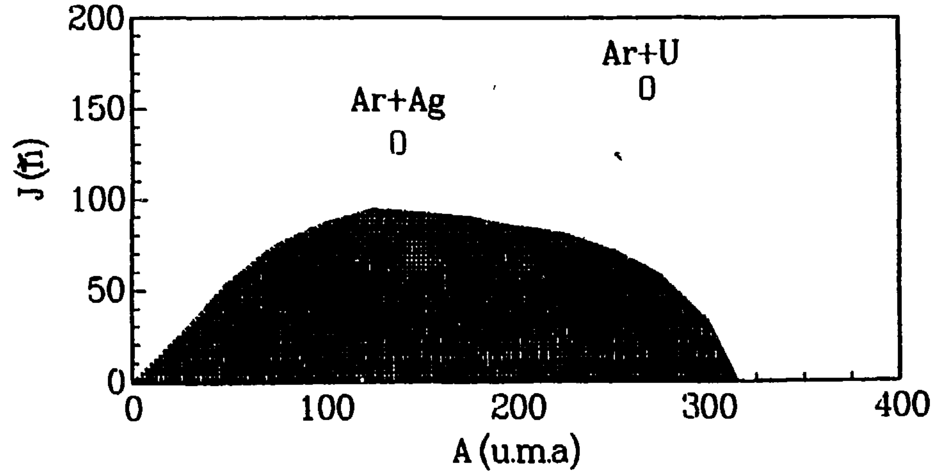

Fig.12.: The values of J_{max} found for the Ar + Ag and Ar + U systems are compared to the limits predicted by the rotating liquid drop model.

static calculations. This is explained through dynamical models where the collective motion of the nucleons towards the scission point is a very slow process as compared to one evaporation step[21,22].

Coming back to Fig. 1, one sees that the scission time is almost two orders of magnitude shorter than the time for particle evaporation at T = 5 MeV. The limit of stability for fission is a limit on a very long timescale (t > 2000 fm/c) as in the experiments described previously, the α particle emission allows to get a snapshot of the hot composite system at a very early stage of the deexcitation. Consequently, it tells us that the nucleus is quite stable against rotation over a very short timescale (T ≤ 100 fm/c). This is confirmed by recent calculations showing clearly that a hot rotating nucleus can be very stable against fission and that particle evaporation at high angular momentum can stabilize the nucleus so strongly that binary fission may even be totally suppressed[24].

The final question would be to know how much angular momentum can the nucleus accomodate. Would high angular momenta help to destabilize the system and induce more easily a multifragmentation process ? De Paula et al.[25] have performed calculations for Au nuclei based on molecular dynamics and restructured aggregation. It indicates that at T = O, the critical angular momentum for multifragmentation is close to 450 ħ ! As mentioned by these authors, it means that a lot of excitation energy would then be stored into this collective mode at the expense of the thermal energy which again might tend to stabilize the system. Anyhow, such high values of the spin should play a significant role in the decay process. This has to be taken into account seriously in any calculation

VI - CONCLUSION

This paper was intended to give a short review of the experimental data concerning both the production of hot nuclei up to some critical temperature and the possibility to induce very large angular momentum transfer.

It has been shown that in most cases the apparent limitations in the temperature of the system do not reflect the intrinsic properties of the nuclei but are essentially related to the dynamics of the entrance channel. The highest thermal energies are reached for symmetric systems at moderate incident bombarding energies (≈ 30 A.MeV). For the Pb + Au system, the central collisions (b < 6 fm) lead to a nuclear disassembly ; the system disintegrates into a large number of nucleons and small fragments.

What is the stability of a hot nucleus against rotation ? Recent experiments demonstrate clearly that nuclei can easily accomodate very large angular momenta ($J > 150\ \hbar$), much larger than the limit of stability predicted by the rotating liquid drop model. The nucleus appears then to be remarquably stable against rotation at least on a short time scale ($t \approx 100$-300 fm/c).

In the future, it would be interesting to investigate very properly the effect of both the temperature and the spin on the decay process. Recent measurements indicate that peripheral reactions are most suited to undertake such studies[26]. Pretty hot nuclei could be obtained in these collisions for which a precise determination of the impact parameter can be achieved experimentally at variance with fusion like reactions which have been discussed in this paper. This would allow to prepare uncompressed hot nuclei with well defined values of the temperature and the spin.

REFERENCES

1. E. Suraud et al., Prog. Part. Nucl. Phys. 23, 357 (1989)
2. D. Guerreau, in : Nuclear Matter and heavy ion collisions, (Plenum, New York, 1989), p. 187.
3. D. Brink, Nucl. Phys. A519, 3c (1990).
4. S. Levit and P. Bonche, Nucl. Phys. A437, 426 (1985).
5. D.X. Jiang et al., Nucl. Phys. A503, 560 (1989).
6. E. Crema et al., Phys. Lett. 258, 266 (1991).
7. A. Sokolov, Ph.D Thesis (Paris, 1990) and to be published.
8. A. Milkau et al., GSI Preprint, GSI 91-08, 1991.
9. M. Louvel et al., Contribution to this Symposium.
10. M. Fatyga et al., Phys. Rev. Lett. 55, 1376 (1985).
11. E.C. Pollaco et al., Nucl. Phys. A488 (1988) 319c.
12. E. Piasecki et al., Phys. Rev. Lett. 66, 1291 (1991).
13. J. Galin, XXIth Summer School on Nucl. Phys., Mikolajki (Poland, 1990), Ganil Preprint P 90-17 ; X.M. Wang et al., to be published.
14. S.Bresson et al., to be published.
15. K. Hagel et al., Nucl. Phys. A486, 429 (1988).
16. R. Lacey et al., Phys. Rev. C37, 2540 (1988).
17. D. Jacquet et al., Nucl. Phys. A511, 195 (1990).
18. T. Ethvignot et al., Phys. Rev. C43, R2035 (1991).
19. N.N. Ajitamand et al., Phys. Rev. C34, 877 (1986).
20. Cohen et al., Ann. Phys. 82, 557 (1974).
21. P. Grangé et al., Phys. Rev. C27, 2063 (1983).
22. C. Grégoire et al. Z. Phys. A329, 497 (1988).
23. D. Hilscher et al. Phys. Rev. Lett. 62, 1099 (1989).
24. F. Garcias et al. Phys. Lett. B255, 311 (1991).
25. L. De Paula et al., Phys. Lett. B258, 251 (1991).
26. J. Galin , First Biennal Workshop on Nucl. Phys., Megève (France, 1991). GANIL Preprint P 91-10 ; S. Bresson et al., to be published.