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Hot Nuclei and Fragmentation

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Abstract: A review is made of the present status concerning the production of nuclei above 5 MeV temperature. Considerable progress has been made recently on the understanding of the formation and the fate of such hot nuclei. It appears that the nucleus seems more stable against temperature than predicted by static calculations. However, the occurence of multifragment production at high excitation energies is now well established. The various experimental features of the fragmentation process are discussed.

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1. INTRODUCTION

The investigation of extreme states, and especially incoherent excitations leading to the formation of the so-called hot nuclei is one of the most efficient way to progress in our knowledge of the atomic nucleus and has gien rise to numerous experimental as well as theoretical studies [MO88, SU90, GU91, GR93]. Let us recall with a definition of a hot nucleus: the word nucleus implies that a self-bound system has been formed, even for a very short time, at high temperature (T>3-4 MeV), and that the intrinsic degrees have been relaxed, i.e. it is implied that a thermal equilibrium has been achieved.

The starting point of this long story is probably the paper on the compound nucleus by Niels Bohr in 1936 [BO36] describing the formation of an excited nucleus in a nuclear reaction. This is indeed the first step: how to form such a hot nucleus? This point will not be developped in this paper. Let us just mention that heavy ion collisions in the medium energy range (30-100 A.MeV) appear to be the best tool for such investigations. One now knows reasonably well how to form and characterize a hot nucleus [GU89, GU91]. This has opened-up a large field for studying intrinsic properties as a function of the temperature T, such as the level densities [NA92], angular momentum effects [GUE91, BR92], fission decay [HI93] , onset of complex fragment emission (IMF), and the coupling wih collective modes [GA92].

However, this paper is intended to essentially focuse on the fate of the hot nucleus at high T and concentrate on the following question-marks: what is the highest temperature a nucleus can sustain before to become unstable? Is the concept of a critical T meaningful? At such T, are we facing a complete disassembly of the nuclear system? Does this multifragmentation of the system occur through a statistical process or is it a dynamical break-up? Is it possible to identify some kind of liquid-gas phase transition and get information on the nuclear equation of state? Can we reach the spinodal region at low densities where mechanical instabilities might develop and in which fluctuations are strongly amplified leading finally to the multifragmentation process?

After a short chapter on the characteristic times of the reaction, the evidence for the existence of a critical temperature will be discussed. The third part will be devoted to the onset of the nuclear disassembly. Finally the last section will be focused on the various facets of the multifragment emission and their possible origins. In this paper, the dynamical calculations will not be emphasize; the reader will refer to the paper by Randrup at this same conference [RA93].

2. CHARACTERISTIC TIMES

One must be aware that there are some limitations which may prevent from forming such very hot nuclei. This may arise from the intrinsic properties of the hot nucleus itself but also from entrance channel dynamical limitations. Such limitations are also connected with the characteristic times of the collision [ER60, FE87, GU89, BR90, BO92]. It has been stressed already that the existence of a hot nucleus implies that a thermal equilibrium has been achieved. This obviously requires a decoupling between the entrance and exit channel. This was pointed-out already more than 30 years ago by Ericson [ER60]: *"Under which circumstances such an intermediate system can exist in the case of very excited nuclei... This is largely a question of relative magnitude of the relaxation time for the formation of an equilibrium system as compared to the lifetime of the nucleus in equilibrium"*.

A comparison is made in Fig.1 between the neutron decay half-life of a Pb compound nucleus as a function of T and typical relaxation times (for the intrinsic degrees, the giant dipole resonance and the nuclear fission). Despite a very short thermalization time (only a few n-n collisions are needed, i.e ≈20 fm/c), it is seen that for T≈6 MeV the characteristic time for energy dissipation and the decay time start to overlap. One may then observe a dependance of the deexcitation on the mode of formation. This introduces naturally the role of the dynamics, the onset of preequilibrium emission and at some point, the assumption of sequential decay may not be valid anymore.

Moreover, quite large relaxation times are associated with the collective degrees. For fission, the prescission time has been measured and is larger than 2000 fm/c [HI92], a value far above the neutron decay time, indicating that the hypothesis of equal lifetimes for the different decay channels is not fullfilled: this is the failure of the standard statistical model. Even at high T, the system cools down by evaporating particles during the slow descent towards scission which finally occurs at very low excitation energies (whatever the initial excitation of the system was) [HI92, SC89]. If one wants to learn about the nucleus at high T, it is then better not to look at fission as it will only give you a snapshot of the system after it has cooled down quite a lot. It is highly necessary to focuse on observables

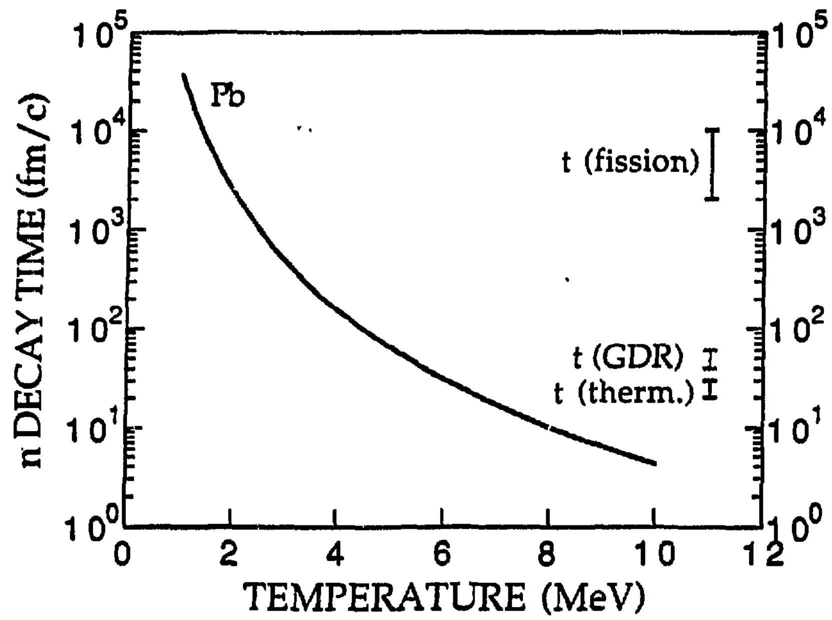

Fig.1 Evolution of the neutron decay half-life of a ^{208}Pb nucleus as a function of its temperature. A comparison is made with typical relaxation times (thermalization time, the giant resonance mode and nuclear fission).

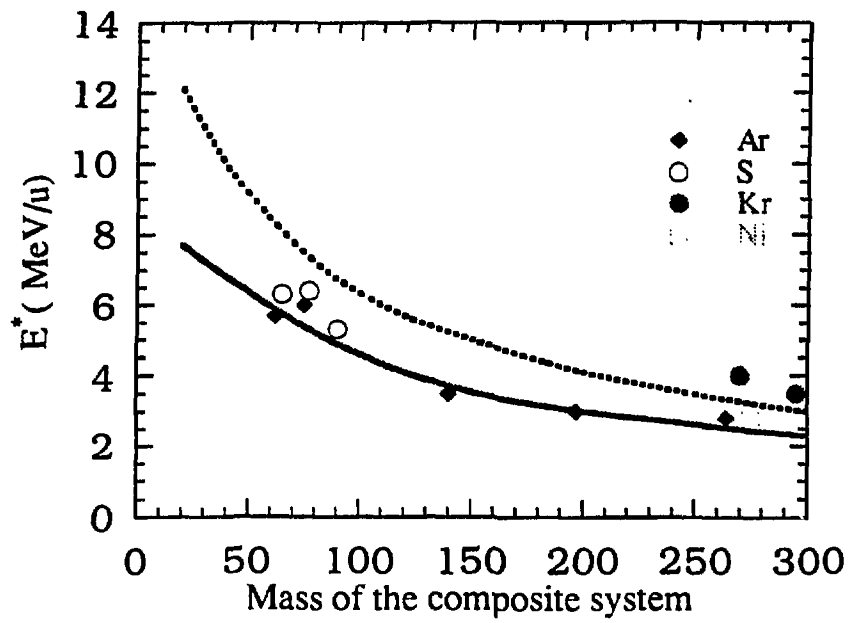

Fig.2 Systematics of the highest excitation energy per nucleon reached in heavy ion collisions for a given mass of the composite system. The data are compared with static calculations [LE85] using the hot liquid drop model and a soft equation of state.

The two curves correspond to different surface tension coefficients.

which tell something about the primary hot system.
What about the giant dipole resonance? The GDR is a beautiful signature of the collectivity of the nucleus. Therefore, it has been thought that the disappearance of the GDR at high excitation energy would sign for the measurement of the critical temperature for the existence of a nucleus. However, estimates of the equilibrium time have been made [BR90, BO91]. Bortignon et al have looked at the coupling of the GDR with the compound states; it turns out that at T≈ 4.5-5 MeV, the widths for the GDR and the particle emission become equivalent. This would explain why above this T value, one observes a saturation of the width of the GDR as well as its strengh [KA92]. At this temperature, one would then observe a transition from a real compound nucleus (where all the degrees of freedom are equilibrated) to a composite system (in which all the collective degrees might not be relaxed). However it should be mentioned that other explanations have been pointed out [GA92, CO93].

The comparison of these various nuclear times indicate that there might be some conceptual problems defining the existence of a very hot nucleus . Therefore, the concept of a real hot nucleus above 5-6 MeV is a fragile concept.

3. TOWARDS THE CRITICAL TEMPERATURE

As mentioned previously, one of the key-questions relates to the maximum thermal energy a nucleus can sustain without breaking apart. Fig.2 shows the highest excitation energy reached so far for a given mass of the composite system. A limited number of measurements are reported for which various projectiles have been used from S to Kr in the energy range 30-70 A.MeV. These values, which are evolving from about 7 MeV/u for the light systems down to 3 MeV/u for the heaviest ones, are compared to the hot liquid drop model of Levit and Bonche [LE85]. All these kinds of static calculations [see also BO85, SU87] consider a hot nucleus in equilibrium with a surrounding vapor and the instability of the hot nucleus is mainly governed by the balance between the surface tension and the coulomb repulsion which explains the dependance observed with the atomic number (or mass) of the system. At first sight, the experimental results seem to be in good agreement with such calculations using a soft equation of state (solid line in fig.2).
However, very recent data obtained at GANIL on the system $^{208}Pb+^{197}Au$ at 29 A.MeV seem to be at variance with this systematics [AB93]. In this experiment, the various decay channels have been measured using a large solid angle experimental array. Fig.3a displays the distribution of the light charged particle (LCP) multiplicity M_{LCP} for events with 2, 3, 4 and more than 4 fragments in the exit channel. Fig.3b shows for the same events the total kinetic energy loss distribution (TKEL). The strong correlation between the TKEL and the LCP values is obvious and shows clearly that M_{LCP} is a quite good observable to gate on the degree of violence of the collision, i.e. on the energy deposition in the system. Let us presently focuse on the two-body exit channel. This 2-fold distribution is

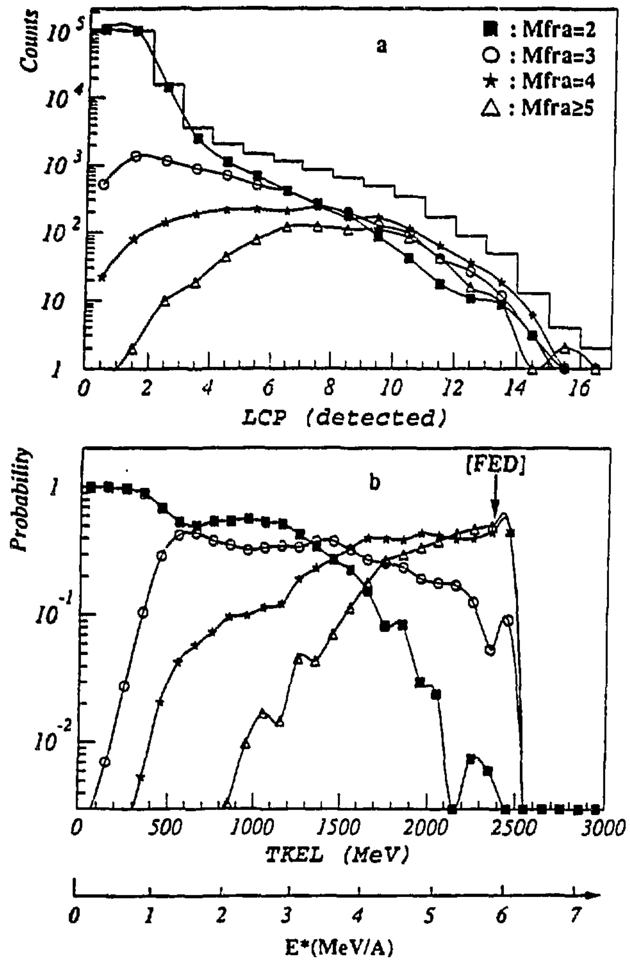

Fig.3 The reaction $^{208}Pb+^{197}Au$ at 29 A.MeV; (a)Light charged particle multiplicity distributions, (b) total kinetic energy loss distributions, for various associated multiplicities M_{frag} of complex fragments [AB93].

extending to very large TKEL values, in fact up to the full energy damping (indicated by the arrow in the figure): a pure two-body process can survive to very violent collisions! Assuming that the preequilibrium emission is negligible at this moderate incident energy, this complete damping of the relative motion would correspond to an excitation energy deposit of ≈6 MeV/u in each fragment (or T≈7 MeV). This is far higher than the predictions of any static calculation (for a Au-like nucleus, the critical excitation energy is predicted to be close to 3.5 MeV/u). This large and unexpected value seems to indicate that the nucleus can accomodate much more energy than previously expected. It might indicate that, up to now, with lighter beams, one was facing mainly entrance channel dynamical limitations which were preventing us from heating enough the nucleus. In order to minimize the preequilibrium emission and favor a thermalization of the whole system, the best conditions are fulfilled when using heavy and symmetric systems at moderate incident velocities instead of a light projectile-heavyy target combination at higher energy.

Much work remains to be done concerning the systematics of critical temperatures. In particular, the effect of the isospin degree of freedom would be worth beeing investigated on a large N/Z range [BE89]. This could be made possible in the near future when radioactive beam facilities will be available.

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4. TOWARDS NUCLEAR DISASSEMBLY

From the above discussion, it is clear that the nucleus can be heated up to quite high temperatures. How do such very hot nuclei behave? Are there evidences for decay changes which could be correlated with the attainment of a critical temperature? It is now well established that at sufficiently high energy, a large enhancement of complex fragment (the so-called intermediate mass fragments) emission is observed [BA93, BI93, NA92, PI91, RO93, SO91]. Moreover, there are now evidences for the occurence of a total disassembly of the nuclear system [GUE91, OG91. In the following we shall illustrate this transition towards multifragmentation through the reaction $^{208}Pb+^{197}Au$ at 29 A.MeV studied at GANIL [PI91, BR93]. In this experiment, the global information on the energy dissipation (and also the impact parameter) was provided by an event by event mesurement of the associated neutron multiplicity M_n. Fig.4 shows the inclusive

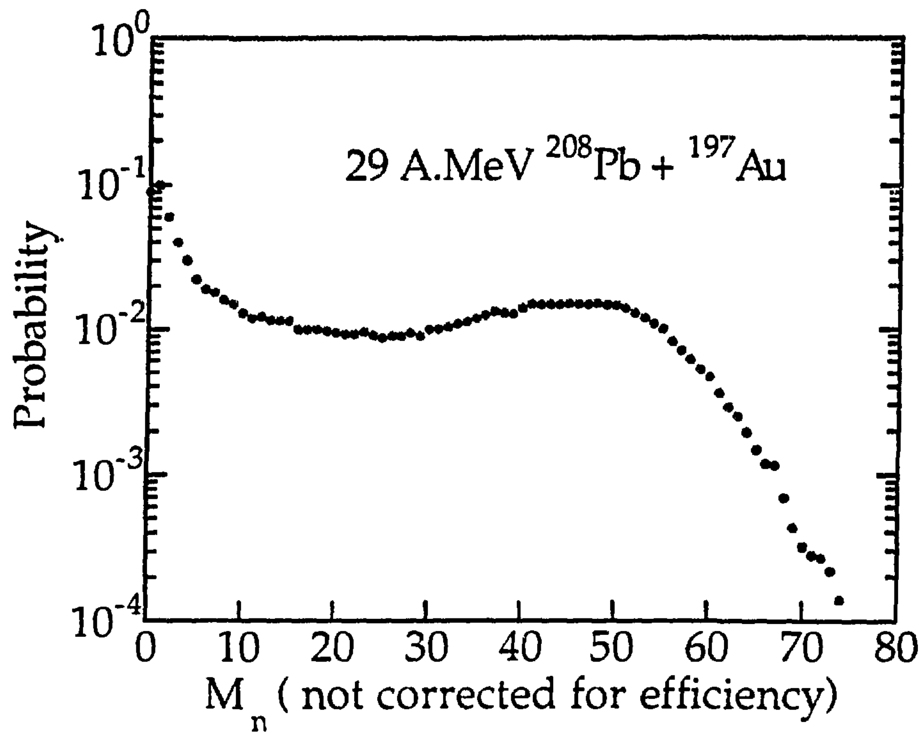

Fig.4 Inclusive neutron multiplicity distribution for the system $^{208}Pb+^{197}Au$ at 29 A.MeV (no correction has been applied for the detector efficiency) [PI91].

neutron multiplicity distribution (not corrected for the efficiency of the 4Π ORION detector. The main feature is the presence of two components which can roughly be attributed to peripheral (low M_n values) and more central collisions (high M_n values). The bump is centered at M_n≈50 (78 after efficiency correction), a value characteristic from a very large energy disipation. Using this observable as a gate on the degree of violence of the collision, one can look now at the evolution of the Z distribution of the reaction products as displayed in fig.5 for

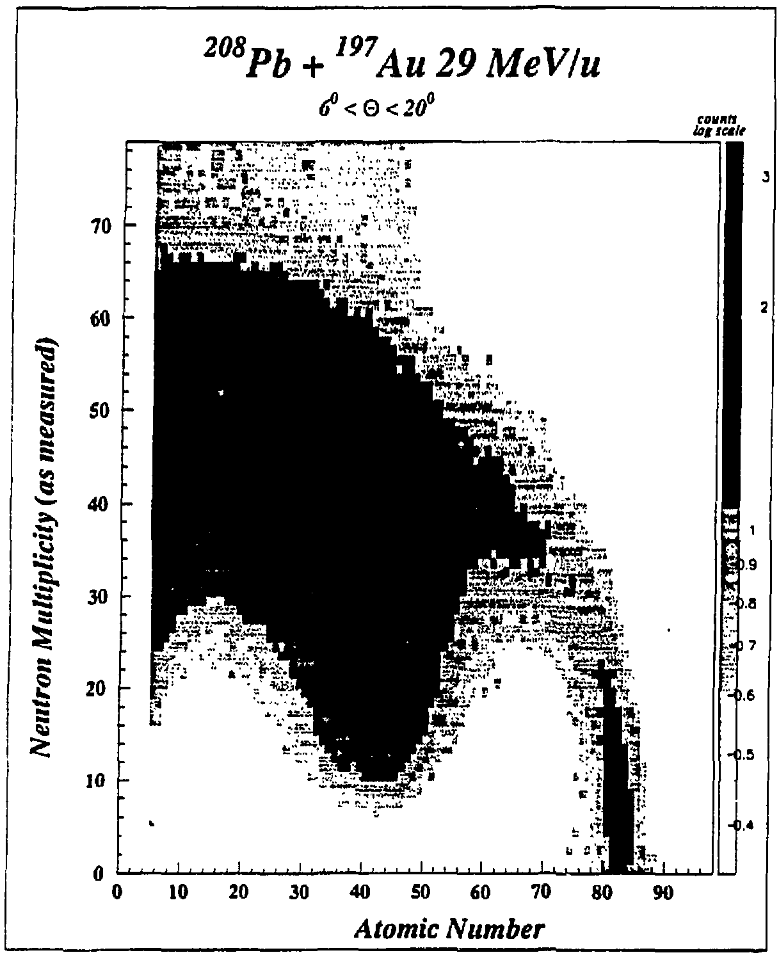

Fig.5 Atomic number versus neutron multiplicity plot for reaction products, observed in the forward direction (6°-20°), in the reaction $^{208}Pb + ^{197}Au$ at 29 A. Mev.

increasing values of the associated neutron multiplicity M_n. For the most gentle collisions, the only decay mode is evaporation. Then the binary fission sets in, dominates for the intermediate impact parameters and finally disappears for the most violent collisions (high M_n values) where the multifragmentation takes place with a copious emission of complex fragments (up to 7 fragments with Z>3 can be detected in a single event [AB93]). This transition from binary fission to multifragmentation has been also clearly identified by Bizard et al [BI93] for the systems 60 A.MeV Ar+Au and 44 A.MeV Kr+Au. It is shown that the fragmentation dominates when the excitation energy in the system exceeds ≈5 MeV per nucleon.

Is there a clear evidence for a disassembly of the system? Combining the results presented in Fig.3 and 5, it is clear that for the small impact parameters, the system disassembles into a large number of neutrons (M_n>80), light charged particles (>15) and complex fragments. In most cases, massive fragments do not survive for these strongly dissipative collisions where, as mentioned previously, the dissipated energy may be as high as 2.4 GeV (6 Mev per nucleon). A use of a symmetric system such as Pb+Au seems to be very efficient to reach the nuclear disassembly: this is best seen in Fig.6 where, for the three systems Ar+Au [JI89], Kr+Au [CR91] and Pb+Au, the evolution of the fraction of the neutron excess of

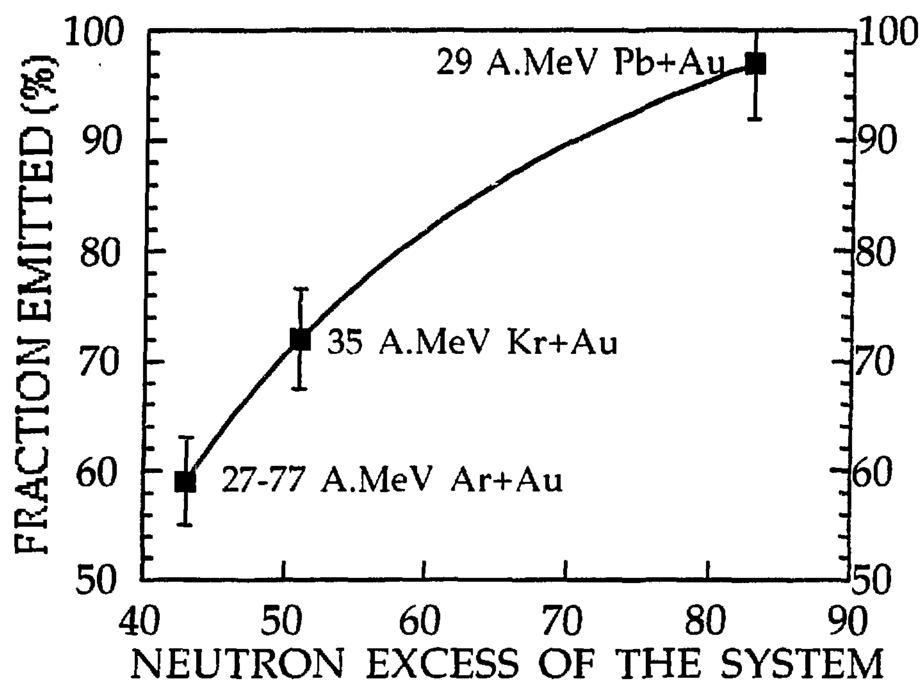

Fig.6 Most probable fraction of the neutron excess of the system observed as free neutrons for the three reactions (Ar,Kr,Pb)+Au around 30 A.MeV [GUE91] (for the Ar+Au reaction, it has been shown that this value remains almost constant in the range 27-77 A.MeV [JI89]).

the system observed as free neutrons is plotted versus the neutron excess of the system. This fraction is approaching 100% for the system Pb+Au which implies that all charged products must have an average N/Z ratio close to unity. This striking feature is again in favour of a complete disassembly of the system into light fragments. Furthermore, this is not a rare process as it represents more than 25% of the reaction cross-section. For this very heavy system, the limit of the existence of a real nucleus has been probably reached.

5. THE ORIGIN(S) OF MULTIFRAGMENTATION

In the previous section, it has been shown that the multifragmentation is now a well established process. However, the question is to know if one can identify a **new** decay mode or could it be simply understood in the framework of the standard statistical theory?

5.1 Time scales for fragment emission

An important question concerns the time scale associated with this fragment emission as it may strongly help to differenciate between the different theories. The study of fragment-fragment correlation functions may provide this information [AR90, KI91, KI92, BO93]. An example is shown in Fig.7 for the

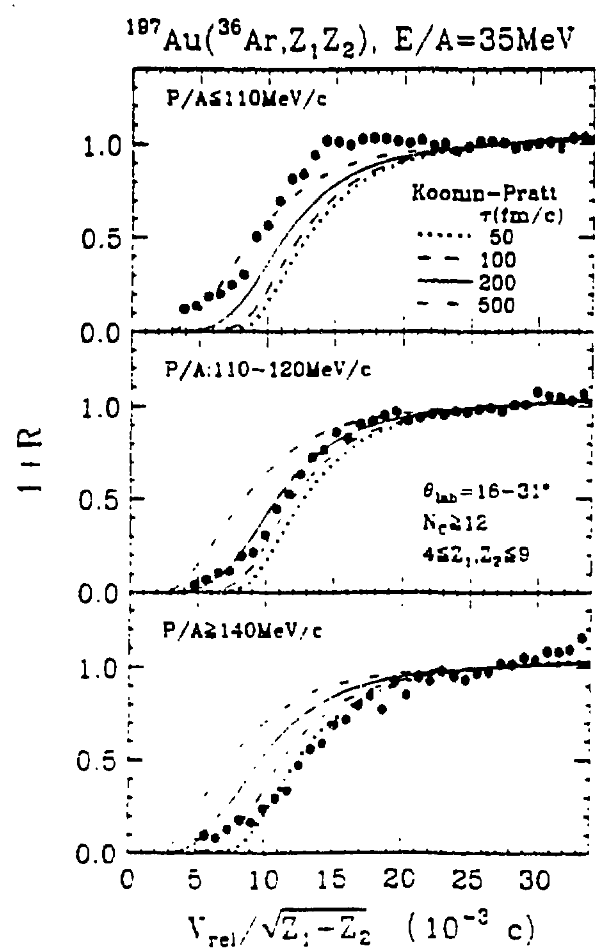

Fig.7 Two-fragment correlation functions summed over all Z combinations (9≥Z≥4) for different momentum cuts of the fragment pair. Central collisions are selected. Curves show calculations with the Koonin-Pratt formula and various emission times [KI92].

reaction $^{36}Ar+^{197}Au$ at 35A.MeV for central collisions (large particle multiplicities) and for various values of the total momentum per nucleon of the coincident fragment pair [KI92]. The experimental correlations are compared with the calculations using the Koonin-Pratt formula and various emission times. It appears that the emission of energetic fragments is governed by small timescales (t<100 fm/c), a signature of nonequilibrium processes, while for lower kinetic energies (close to the coulomb barrier), the fragments are emitted on a much larger time scale (t>300 fm/c), fully compatible with a statistical emission from an equilibrated system. The situation is slightly different at higher incident energy: for the system Xe+Au at 50 A.MeV [BO93], central collisions are characterized by broad anisotropic distributions in the velocity space, and lifetimes becoming too short (t<100 fm/c) to make possible a separation of the sources. Such experiments show clearly that fragments may be emitted at different stages of the reaction. It is clear that one needs dynamical calculations to follow the time evolution of the system [RA93].

5.2 Prompt or sequential fragmentation?

Another information can be extracted from the fragment-fragment correlations. It may allow to distinguish between a prompt multifragmentation and a chain of sequential binary decays. The later process would imply that the fragment will interact only with the splitting partner and one does not expect any correlation between fragments issued from two different splittings Relative angle and relative velocity distributions are quite sensitive to these different hypothesis [GA93]. For moderate excitation energies (≈3 MeV/u) the fragment emission seems fully compatible with a sequential emission [BI92]. The situation is quite different for higher energy deposition as demonstrated for the system Kr+Au at 60 A.MeV [LO93]. This is nicely illustrated in Fig.8 where the experimental data

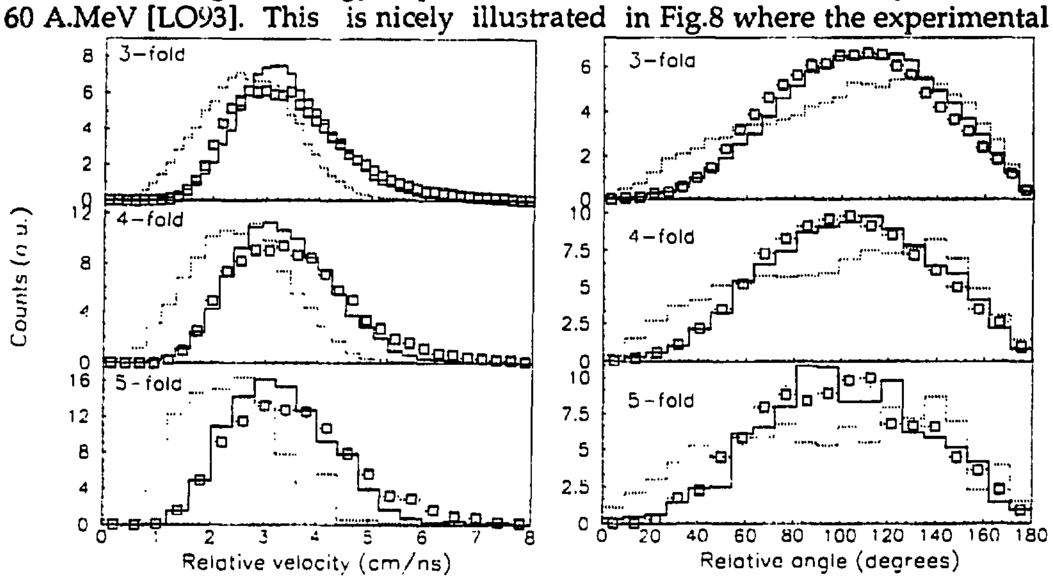

Fig.8 (a) Relative velocity and (b) relative angle distributions between fragments taken two by two for three different fragment multiplicities. The histograms correspond to calculations (dashed curve is the sequential model, solid curve is the simultaneous model) [LO93]. The reaction studied is Kr+Au at 60 A.MeV.

obtained for central collisions and equilibrated events are compared with two models, a purely sequential binary decay [CH88] and a simultaneous multifragment break-up [LO90] which is an extension of the binary fission transition-state formulation. A very nice agreement is obtained with the prompt model where all the fragments interact strongly: in that case, small relative angles and velocities are forbidden, mainly due to the strong repulsive coulomb interaction.
However, the onset of a prompt fragmentation at high excitation energy may indicate that one could be facing a semantic problem: if the emission time becomes of the order of 10^{-22} sec, an intermediate compound system is not really established before the occurence of the next decay and a quasi-simultaeous emission will follow naturally. Anyhow a clear transition from a sequential to a prompt emission seems to occur above 4 MeV per nucleon excitation energy.

5.3 Statistical fragmentation?

Several statistical models have been developped in order to account for this multifragment emission. As mentioned before, the first group deals with a purely sequential process as the one simulated in the Gemini code [CH88]. The second one includes the statistical prompt multifragmentation models, the Berlin and the Copenhagen models [BON85, GR90]. An intermediate model is the *Rapid massive cluster formation* model (RMCF)[FR90]. In the later, it is assumed that the increasing deposited excitation energy leads to high thermal pressure and hence to an expansion of the nuclear system. The model then describes the statistical decay of an homogeneously expanding system; the evaporation, although sequential, occurs in a very short time interval and the whole process is controlled by the nuclear compressibility.

Both the Berlin and the Copenhagen models assume the formation of a hot, equilibrated and dense system. During the expansion phase, density fluctuations induce the production of fragments and particles which are strongly interacting. When the freeze-out density is reached ($\approx 0.2\rho_0$), the interaction ceases and the partition sum is then calculated (from that point, the fragments separate on coulomb trajectories and are free). The intensity of the multifragmentation channel is strongly depending of the excitation energy of the system as illustrated in Fig.9 which shows the relative yields of the various outgoing channels calculated with the Berlin model for a ^{197}Au compound nucleus. The dominant decay mode evolves progressively from a standard evaporation or fission process at low energy towards multifragmentation for intermediate excitation energies ($\approx$1500 MeV) and finally to a complete vaporisation of the hot system at high energies.

In order to test any of these statistical fragmentation models and compare them to the data, one obviously needs to determine the initial conditions, mainly the size of the fragmenting nucleus and its excitation energy. This is achieved by using hybrid model calculations in which the early stage (initial compression and energy deposition) is simulated by BUU-like calculations and the static

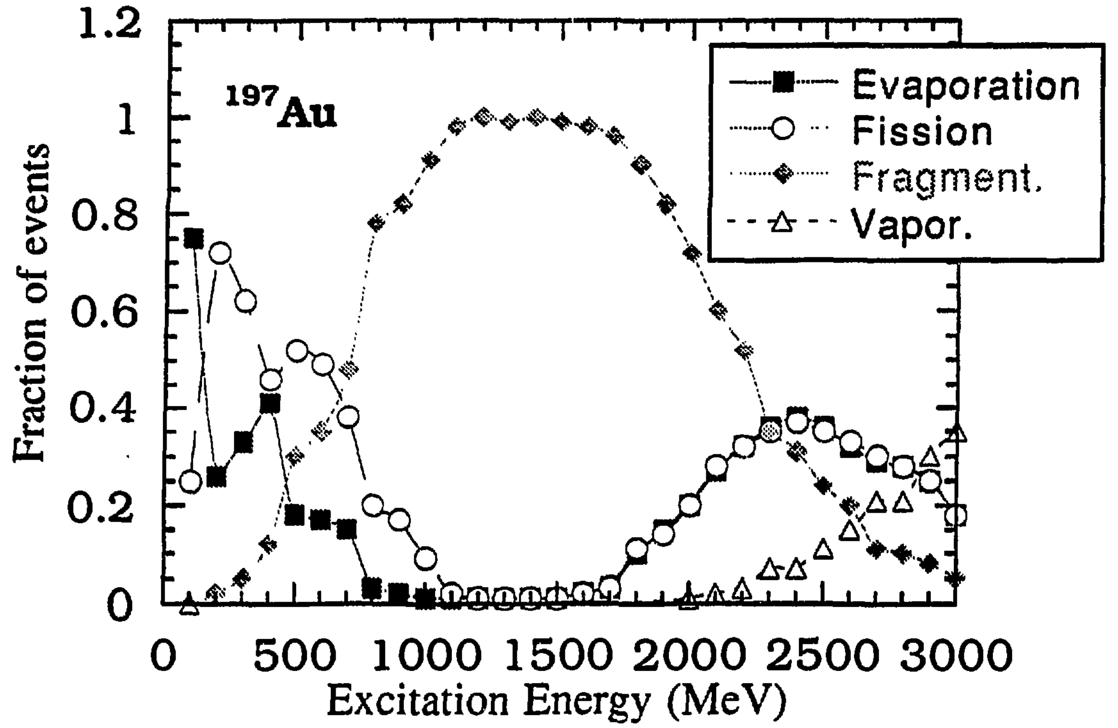

Fig.9 Relative yields of the various outgoing channels as a function of the excitation energy calculated with the Berlin model for a ^{197}Au nucleus [GR93].

equilibrium decay stage by the statistical models [HU92, CO92, BOW92, CO93]. The delicate problem is to choose the time at which the dynamical calculation has to be stopped. Signs indicating that the system has reached an equilibrated configuration may be the constancy of the kinetic energy of the emitted particles or the vanishing of the quadrupole moment of the momentum distribution.
An example of such a comparison is shown in Fig.10 displaying the ALADIN results concerning the reaction 600 A.MeV Au+Cu [HU92, OG91]. It shows the correlation between the mean fragment multiplicity (M_{IMF}) and Z_{bound}, the later being defined as the total charge of all bound clusters ($Z \geq 2$). This value is strongly connected to the degree of violence of the collision and hence to the impact parameter. Very small Z_{bound} values indicate the occurence of a complete vaporization of the system while large values sign for normal particle evaporation from low excited systems. The bell-shape distribution has been interpreted by the authors as the signature of the rise and fall of multifragmentation and is very similar to the calculated fragmentation channel as displayed in Fig.9. These data are compared in Fig.10 with the GEMINI code, the Berlin and the Copenhagen model respectively. It is obvious that the purely sequential model is unable to account for the experiment while a reasonable agreement is obtained with the prompt models. However, the RMCF model (not shown in the figure) is also able to reproduce the data (with a compressibility

modulus K=144).

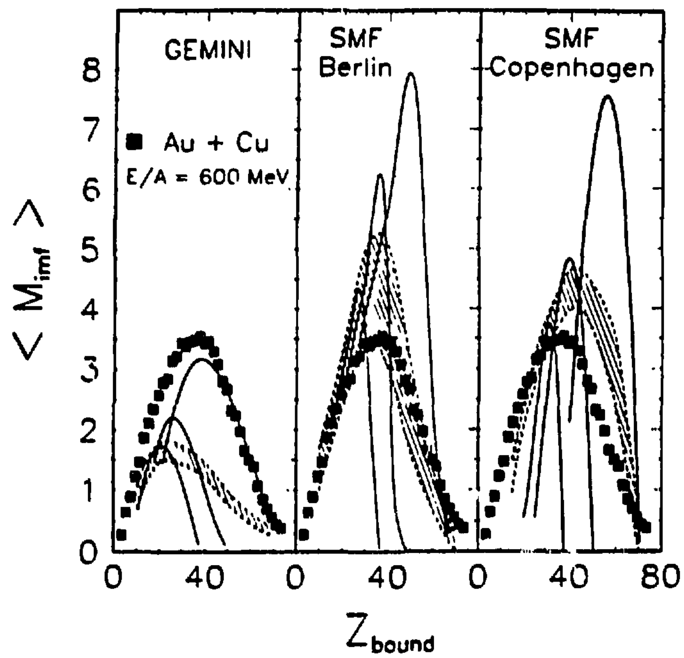

Fig.10 Comparison of the M_{IMF}-Z_{bound} correlation for the reaction Au+Cu at 600 A.MeV with predictions of various statistical models. The shaded bands are the predictions obtained using initial conditions deduced from BUU calculations (for more details, see [HU92]).

A good agreement seems then to be observed with all statistical models in which *low* nuclear densities are involved. It remains now to find a clear experimental signature for compression and expansion of the system.

The second remark is that the use of such statistical models implies a complete decoupling between entrance and exit channel and that a complete thermal equilibrium has been reached before any fragment emission, a condition which may not be fulfilled. It might indeed be difficult to disentangle the fragment emission from the various stages of the reaction. However up to now, the experimental results are quite contradictory. While a coupious nonequilibrium fragment emision is observed by Wile et al [WI92], and Sokolov et al [SO92], Roussel-Chomaz et al [RO93], when studying La induced reactions on various targets, have shown that the excitation functions for multifragment events are independant of the target-projectile combination, which would indicate that the decay properties of the intermediate system depends essentially on its excitation energy and no effect of the dynamics of the entrance channel seems to be identified. Decisive experiments remain to be done in this domain before to get a clear picture of the whole process.

5.4 Critical behaviour in finite size systems?

One key question has to deal with the possible relation between multifragmentation and the existence of a critical behaviour in finite size systems and a possible phase transition. This idea has been explored for instance by using the concept of percolation. When looking at the conditional moments of the fragment size distributions as well as the fluctuations in a three dimensionnal cubic lattice, a signal of a phase transition was observed by Campi[CA88]. More recent data were also analysed that way and a remarkable agreement is observed with the experiment [LY92]. An example is given in Fig.11 where the ALADIN

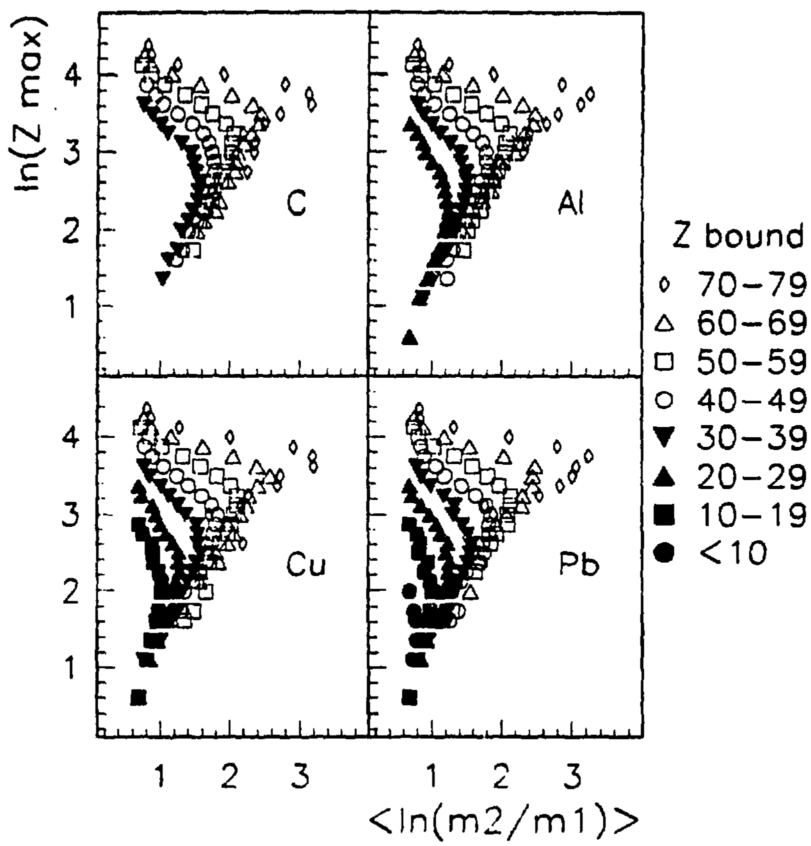

Fig.11 Correlation between Z_{max} and the ratio of the charge moments for 600 A.MeV Au collisions on various targets and various cuts in Z_{bound} [LY92].For more details, see text.

results for various Z_{bound} values are represented through the correlation between Z_{max} (the largest fragment Z) and the ratio of the charge moments m_2/m_1 (where $m_k=\Sigma Z^k$) [LY92]. It clearly shows two well defined branches, which may be attributed to the under-critical branch (for large Z_{max}) at the liquid-gas coexistence and a super-critical branch (for small Z_{max}). The junction point is the critical point where the fluctuations are maximal. Increasing the degree of violence of the collision (lower Z_{bound}) leads to populate the supercritical part. As mentioned by Gross [GR93], this behaviour is equivalent to what is observed when looking at the droplet distribution in a macroscopic liquid-gas transition. The main difference relies on the finiteness of the nuclear system which induces much more fluctuations.

Such representation allows to sign rather clearly for the existence of a critical behaviour in *finite* nuclear systems. However these plots do not tell anything about the nature of the transition. One possibility is to compare such experimental plots with the calculated ones using various nuclear models. Such a comparison has been performed for the system $^{40}Ca+^{40}Ca$ at 35 A.MeV [NA92]. Once again, the results agree quite well with a prompt model (in the present case, the Berlin model), unlike the sequential binary treatments.

It should be mentioned that another approach to study critical fluctuations has been introduced by Ploszajczak [PO91] using the intermittency method.

Such methods as the percolation or intermittency may be used as an extremely powerful tool in order to search for a critical behaviour in nuclear systems. However, this kind of analysis requires high quality experimental data, mainly a *complete* identification of the outgoing channels event by event. Unfortunately, such data are presently very scarce, due to the lack, up to very recently, of sufficiently performing 4Π detectors.

5.5 Search for "exotic" processes

Besides the explanations of multifragment production through statistical models like the ones discussed before or dynamical models as the spinodal instability, there has been recently speculative theoretical work on the possible existence of "exotic" decay processes for hot nuclei [BA92, MO92, BO93, XU93]. Such calculations have been performed using a BUU-like equation, which includes both a mean field term as well as a collision term and properly accounts for the coulomb interaction. The common conclusion of these various works is that instabilities may develop in the nuclear system without the need of many-body correlations.

Moretto et al [MO93] show the onset of Rayleigh-Taylor surface instabilities; during the collision, there is the formation of a disk which may, depending on its thickness, break into several fragments. This fragmentation occurs only when using a soft equation of state (K=200 MeV). Xu et al [XU93] predict the formation of metastable nuclei with quite exotic shapes which may then eventually undergo multifragmentation. These metastable shapes could be a toroidal nucleus (using a stiff EOS) or a bubble nucleus (with the soft EOS). One should stress that the instability of such nuclei was studied long time ago by Wong [WO72].

Recently Borderie et al [BO93], using Landau-Vlasov calculations, have shown the occurence of large Coulomb instabilities in heavy ion collisions between very heavy nuclei like the reaction $^{155}Gd+^{238}U$ at 35 A.MeV. Fig.12 shows the result of their calculation. The time evolution of the density profiles as it results from the Landau-Vlasov simulation, is displayed for this system (the calculation has been performed here for a rather central collision (the impact parameter is 3 fm).

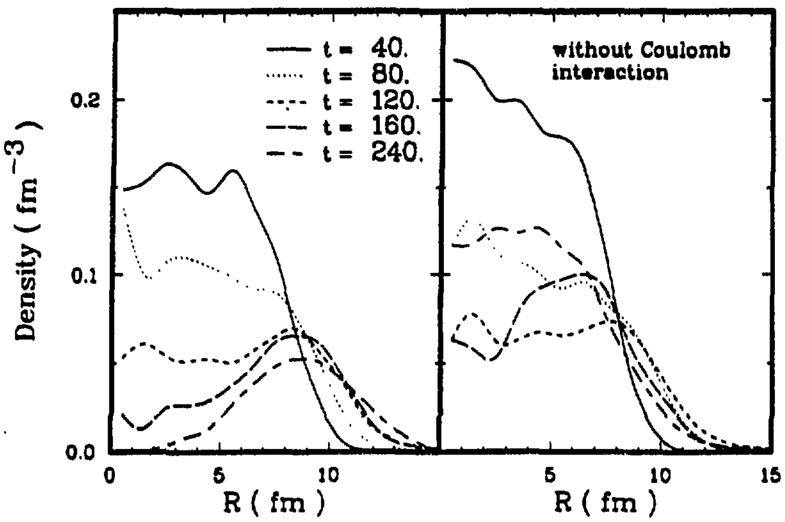

Fig.12 Density profiles at different times (in fm/c) calculated in a Laudau-Vlasov simulation for the system $^{155}Gd+^{238}U$ at 35 A.MeV [BO93]. The formation of a bubble nucleus is clearly seen at large interaction times when the Coulomb interaction is turned on.

After a slight compression phase, the system expands and after about 140 fm/c, it enters a bubble geometry with extremely low densities in the central part of the composite sytem.
The search of unambiguous experimental observations of such a process in the future would be very challenging.

6. CONCLUSION

This paper intended to review the present status concerning the production and the fate of hot nuclei above 5 MeV temperature. The last ten years have led to considerable progress in the understanding of the behaviour of such nuclear systems.
The short characteristic times of the collision in many cases prevents the available energy from being fully converted into heat and the preequilibrium emission plays an important role when increasing the incident energy. However, it is now established that hot nuclei can be formed up to temperatures as high as 6-7 MeV and the nucleus seems then to be more stable than predicted by previous static calculations.
It is also quite clear now that above some critical temperature, a complete disassembly of the system may occur leading to a copious emission of complex fragments, in addition to the light particles (n, p, α). What is still under discussion is the origin of this fragmentation process. Nevertheless, our understanding of the mechanism has been improved quite recently. Several

statistical models, which assume the fragment emission from a rather dilute system, work surprisingly well. One must however question ourselves on the hypothesis of a complete thermal equilibrium which is implied in such models. Furthermore, it is obvious that the dynamics should play a key role in the process and hence complete dynamical and exact calculations are strongly needed.

Another important feature is that there are now strong indications for the fragmentation process to become a prompt process above an excitation energy of 4-5 MeV per nucleon.

A few available results show also some clues for the existence of a critical behaviour in finite systems. In order to confirm this statement, and to efficiently use the percolation or intermittency-type analysis, more exclusive experimental data are needed with 4Π detectors insuring a complete identification of all outgoing channels. This will be the case for example with the INDRA detector which recently run into operation at GANIL. Such devices might help also to search for possible exotic decay processes arising from Coulomb instabilities.

The connexion with the nuclear equation of state is a more delicate problem. In order to make a real significant progress in that direction, one first needs to clearly understand the effects due to the finite size of the nucleus, the influence of the Coulomb field and last but not the least to correctly treat the dynamics of the collision.

It was mentioned in the introduction that the story of hot nuclei started in 1936 with the paper by Niels Bohr in Nature entitled *"Neutron capture and nuclear constitution"*. [BO36]. It is worth quoting here a few sentences of this 57 year's old paper which not only stresses already the formation of hot nuclei but also the possible occurence of the disassembly of the system at higher energies!

"Even if we could experiment with neutrons or protons of energies of more than a hundred million volts, we should still expect that the excess energy of such particles, when they penetrate into a nucleus of not too small mass, would in the first place be divided among the nuclear particles with the result that a liberation of any of these would necessitate a subsequent energy concentration. Instead of the ordinary coarse of nuclear reactions we may, however, in such cases expect that in general not one but several charged or uncharged particles will eventually leave the nucleus as a result of the encounter.

For still more violent impacts, with particles of energies of about a thousand million volts, we must even be prepared for the collision to lead to an explosion of the whole nucleus..."

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