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NUCLEUS EXCITATION AND DEEXCITATION FOLLOWING p̄-ANNIHILATION AT REST

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Abstract: The evolution of a nucleus after p̄-annihilation at rest is studied. The process is divided into two successive phases: a rapid phase, described by an intranuclear cascade model and a slow phase, akin to an evaporation process. The distribution of the residue masses after the second phase is calculated and compared to the recent radiochemical measurements for ^{98}Mo. The evolution of the number of pions, and the distribution of the number of fast ejected nucleons and of participants is studied. The latter two are fitted by negative binomials. The meaning of this observation is discussed. The mass dependence of several quantities, like the maximum excitation energy and the average mass loss is also investigated. Finally, the possibility of a multifragmentation is discussed.

1. Introduction

The fate of a nucleus after an antiproton has annihilated on it is an important question. Already approached experimentally almost three decades ago [1-2]), this question has been revived with the availability of intense p̄ beams at the LEAR facility. It has also raised theoretical speculations [3-5]) in the past years. The expectation of possible exotic phenomena, like the formation of large bags and the violent disintegration of the target, has not yet been fulfilled by the first experimental results of LEAR [6-8]), which seem to broadly confirm the picture of a conventional hadronic cascade initiated by the pions resulting from the annihilation of the antiproton by a nucleon of the target with ordinary (free space) properties. Let us notice however the indications collected by experiment of ref. [9]) in favour of peculiar annihilation events. Nevertheless, p̄-nucleus interactions are interesting from the strictly nuclear point of view, even in the absence of violent explosions. Indeed, it is an alternative way, besides proton–nucleus, hadron–nucleus in general, and nucleus–nucleus interactions, for the study of energy deposition in a nuclear system and the subsequent reaction of this system.

Progressive accumulation of more precise data calls for models. As for the other systems mentioned above, the intranuclear cascade (INC) model, with its conceptual simplicity and large predictive power, appears as an appropriate tool to study the p̄-nucleus interaction, dominated by multiple scattering.

The INC model has been used in many works [10-16]) devoted to p̄-nucleus annihilation in flight. It has been applied to at rest annihilation in ref. [17]) and in our previous work [13]). The present study is motivated by four points:

(i) Our previous INC calculations [12,13]) did not allow a precise definition of the residual nucleus; here, we have improved upon this point, introducing a static mean field where nucleons can travel inside and from which they can escape.

(ii) There exist recent radiochemical measurements [18]) of the residual nuclide distribution with which we want to compare our predictions.

(iii) We want to study the distribution of the ejectile multiplicity, which could perhaps bear some simple information on the dynamics of the process.

(iv) There is a general belief that if a nucleus is moderately excited, it evaporates gently a few nucleons, but if the excitation energy becomes large enough, the nucleus breaks quickly into a few big fragments. We want here to see whether a picture consistent with the first possibility can explain the measured residue distributions.

In sect. 2, we briefly review the main ingredients of our INC model. In sect. 3, we examine the energy transfer from the pions and the excitation of the nuclei in the cascade. In sect. 4, we derive the distribution of the residual mass after the emission of fast ejectiles and a slower phase of evaporation, and we compare our predictions with experiment for ^{98}Mo. In sect. 5, we comment on the multiplicity distributions for the pions, the fast ejectiles and the participant nucleons; the latter two are fitted by a negative binomial distribution. The predicted mass dependence of the annihilation process is given in sect. 6. Sect. 7 considers our results in the context of violent versus soft annihilations. Sect. 8 contains our conclusion.

2. The model

Our INC model has been successfully applied to the relativistic heavy ion collisions [19]), to p-nucleus interactions [20]) and to anti-proton nucleus annihilation.

For the last case, the model predicts the behaviour of the nucleus under the flow of energy and matter generated by the annihilation, when the following assumptions are made:

(i) the initial process of annihilation takes place on a single nucleon and creates a point-like emission of pions;

(ii) the propagation of the pions is governed by the existence of the Δ-resonance; the motion of the pions and the baryons (nucleons and deltas) consists in straight-line segments between point-like events, either collisions or decays, in free space;

(iii) the cohesion of the bulk of the nucleus is ensured by the presence of a potential well for the baryons; the latter can however escape if their energy is large enough.

We refer to previous papers [12,13]) for the details of the treatment of the collisions; we emphasize here the essential lines and describe the new aspects.

The initial system is constructed as a set of nucleons with their momentum vectors chosen at random according to a uniform distribution inside the Fermi sphere; their position is generated according to a trapezoidal distribution in the radial distance which approximates a Woods–Saxon shape.

The annihilation site is determined by choosing the radial distance from the nucleus centre according to a gaussian distribution which has the same mean and variance as the product of the wave function of the antiprotonic Coulomb state ($n=6$, $l=5$ in the Mo case) with the nuclear density. Annihilation flashes pions from that site at time $t=0$; the multiplicity and kinematical distributions simulate the observed properties of non-strange $\bar{p}p$ annihilation at rest.

The pions which penetrate the nucleus trigger a cascade of interactions according to the possible events:

$$\pi+N \leftrightarrows \Delta,\ NN \to NN,\ N\Delta \to N\Delta,\ NN \leftrightarrows \Delta N,\ \Delta\Delta \to \Delta\Delta,\ \pi NN \to NN\,. \qquad (2.1)$$

Reaction $\pi NN \to NN$ is allowed only below the Δ-mass range. We have extended the Δ-mass range used previously ($1140 < M_\Delta < 1320$) towards higher (πN) effective masses; a cross section with a fixed value of 30 mb has been chosen over the range which covers the $N^*(J, I) = (\frac{1}{2}, \frac{1}{2})$ and $(\frac{3}{2}, \frac{1}{2})$ resonances.

We suppress the nucleon–nucleon collisions unless one partner at least has previously been involved in one interaction at least. Nucleons in this case are called participants. A Pauli blocking is applied by requiring the exclusion principle for the nucleons to be obeyed. The depth of the potential is 40 MeV. When a baryon hits the nuclear surface with a negative (kinetic and potential) energy, it is reflected geometrically; otherwise, it has a chance to be transmitted, decided according to the value of the transmission factor.

The radius of the potential well depends upon the momentum of the particle: it is linearly increasing between the radii R_1 and R_2 defining the trapezoidal density distribution. Owing to this prescription and the Pauli blocking, the nucleus and its density and momentum distributions are almost perfectly stable in the absence of external perturbations.

3. Transfer of energy

Let us call W_{ann} the total energy released to the pions in the annihilation and K^0_{A-1} the kinetic energy of the nucleons (except the one which is annihilated) inside the nucleus at time $t=0$. Let W_π be the total energy of the free pion component, at later times, K_{res} the kinetic energy of the A_{res} baryons remaining inside the nucleus and W_{ej} the total energy of the baryons which have left the potential well (the ejectiles). We have

$$\begin{aligned} W_{tot} &= W_{ann} + (K^0_{A-1} - (A-1)V_0) + (A-1)M \\ &= W_\pi + (K_{res} - A_{res}V_0) + A_{res}M + W_{ej}\,. \end{aligned} \qquad (3.1)$$

We define E^* as

$$E^* = K_{res} - \left(\frac{A_{res}}{A-1}\right)^{5/3} K^0_{A-1}\,, \qquad (3.2)$$

which allows us to write

$$W_{tot} = W_\pi + \left[\left(\frac{A_{res}}{A-1} \right)^{5/3} K^0_{A-1} - A_{res} V_0 \right] + E^* + A_{res} M + W_{ej} \,. \tag{3.3}$$

The terms in the brackets can be considered as the smallest energy contained in the well enclosing A_{res} nucleons, i.e., it can be regarded as the ground state energy of the residual nucleus, if we neglect the modification of the mean field. (This should be a good approximation for not too large a number of ejectiles.) The quantity E^* can thus be considered as the excitation energy.

We show in fig. 1 the evolution of the total energy $\langle W_\pi \rangle$ of the pions (not included in Δ's). Hereafter, the brackets indicate an average over events. Let us notice that eq. (3.3) holds event by event as well as on the average. A rapid drop of $\langle W_\pi \rangle$ is observed, which is followed by some rise for light nuclei. The drop corresponds to a rapid transformation of the pions entering the nucleus into Δ's, which leads on a rapid equilibrium between a Δ-state and a free pion state, when average over events is considered. In light nuclei, the Δ's have a larger chance to escape than in heavy nuclei and therefore restitute more energy to the multipion system.

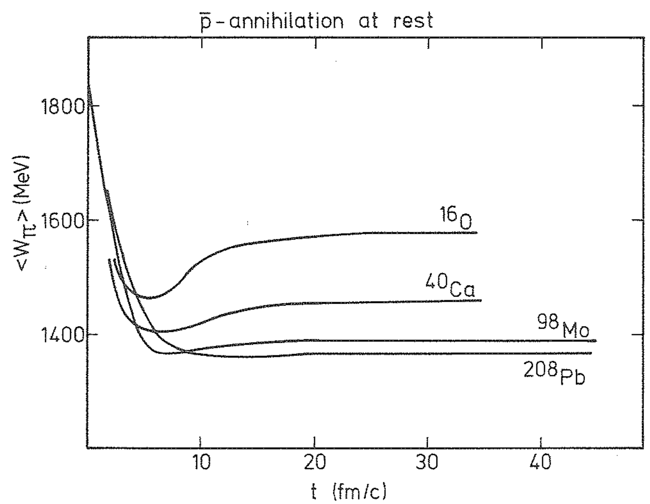

Fig. 1. Time evolution of the average (total) energy of the multipion system after p̄-annihilation on several targets, as calculated in the INC model.

Fig. 2 shows that the rapid transfer of energy from the pions to the baryons creates a rapid rise in the nuclear excitation energy E^* (note that the latter contains the mass difference between Δ and N). However, this excitation energy culminates and starts decreasing due to the ejection of baryons. The maximum of $\langle E^* \rangle$ saturates as a function of nuclear mass, since the same maximum value is reached in Mo and

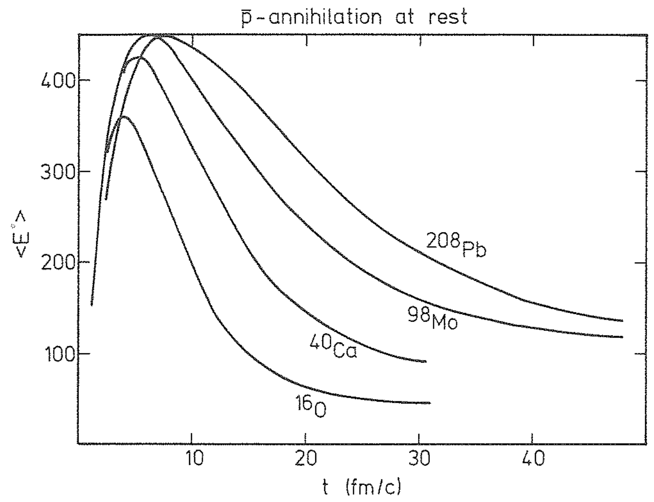

Fig. 2. Time evolution of the average excitation energy E^* of the target residue after p̄-annihilation on ^{98}Mo nuclei. See text for detail.

Pb. The slight shift in time is due to the fact that annihilation in Pb is slightly more peripheral. The rate of decrease of $\langle E^* \rangle$, however, is slower for heavier targets, which is also a simple geometrical effect.

Nucleons are ejected from the nucleus once the excitation energy approaches its peak region, i.e. at 5–6 fm/c in Mo and Pb, as seen in fig. 3. The ejection process quenches off only very slowly.

A measure of the activity of the cascade is given by the increase in the number of participants. The evolution of their mean number is also given in fig. 3.

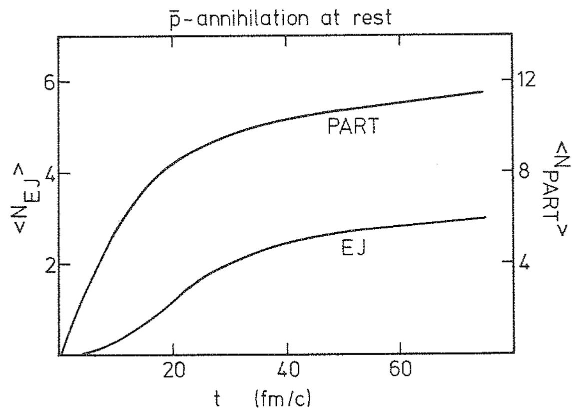

Fig. 3. Time evolution of the average number of ejectiles (left scale) and of participants (right scale) after p̄-annihilation on ^{98}Mo nuclei.

4. The residual mass distribution

As time proceeds, nucleons escape from the nucleus. The mean kinetic energy per ejectile decreases regularly with time; at the beginning, it is about 110 MeV for lead and 125 MeV for oxygen. These nucleons are very likely ejected after a single kick. The evolution of the average kinetic energy of the ejectiles is given in fig. 4 for the example of ^{98}Mo. As time goes on, nucleons have less and less chance to be ejected after a single kick and, at very late times, the motion inside the nucleus becomes more and more chaotic, the energy is more and more spread out and the ejection of nucleons resembles more and more evaporation: fluctuations may concentrate enough energy on a single nucleon to eject it. The onset of evaporation seems to be reflected in fig. 4 by a change, admittedly smooth, in the slope of the curve close to 30 fm/c. Obviously, our simple cascade model is too crude to handle the evaporation process correctly, for which residual interactions are believed to play an important role. Therefore, we stopped the cascade at 30 fm/c (in Mo) and turned to a simple evaporation model for the rest of the process, assuming that the excitation energy which is left must thereon be considered as a bulk excitation energy.

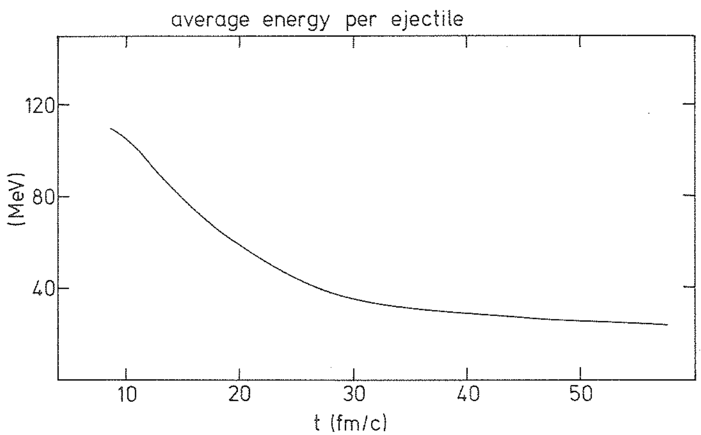

Fig. 4. Time evolution of the average kinetic energy of an ejectile after p̄-annihilation on ^{98}Mo nuclei.

The output of the cascade provides us with an already large frequency table whose entries are the mass of the residue and its excitation energy. Applying to these data a sophisticated evaporation code is very costly. Moreover, such a detailed calculation is not really necessary in view of the uncertainties of the radiochemical method and of the problem of void events (see below). As we are interested in the gross features of the residual mass distribution, we simply assume that an average amount (ΔE) of energy is sufficient to emit a neutron. This seems quite reasonable in the light of intensive studies of evaporation which have been performed in the past [21-22]. The precise value of ΔE depends upon the nature of the partners contributing to the reaction: it is larger for heavy ions than for proton-induced reactions [23]). For (multi-) pion-induced reactions, we did not find any indication in the literature. One can consider however that $\Delta E = 20$ MeV is a reasonable value. Nevertheless, we made also an estimate for $\Delta E = 15$ MeV.

We compare in fig. 5 our predictions for the residue mass distribution with the experimental results of Moser *et al.* [18]). To smear out the odd-even effect, we plot the result by bins of $\Delta A_{res} = 2$. The full circles are the yields deduced by the authors of ref. [18]) from their observed yields of radioactive nuclides. It is supposed to represent the residual mass distribution after nucleon emission and prior to β and γ emission.

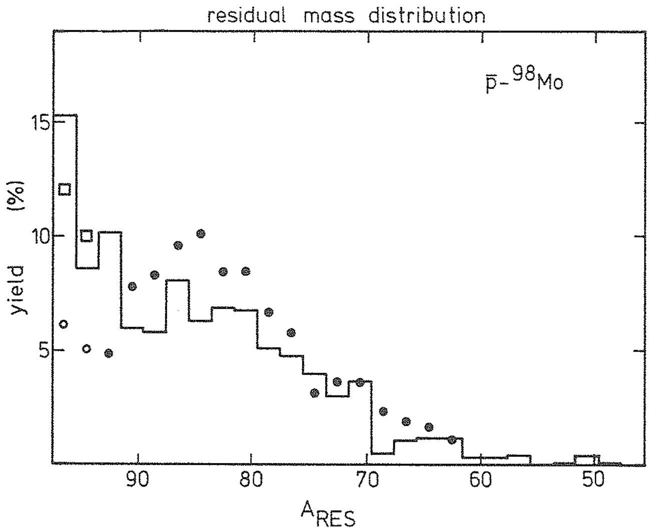

Fig. 5. Comparison between our predictions (histogram) and the measurements of ref. [18]) (dots and squares) for the residue mass distribution. See text for detail.

The method used by the authors of ref. [18]) consists in measuring γ-ray lines of deexcitation of residual nuclei. All stable nuclei and some radioactive ones (with too short or too long lifetimes) could not be detected. These authors used an interpolation procedure to obtain, from the experimental yields with $31 \leqslant Z \leqslant 40$, the yields for the undetected nuclei. This allowed them to provide yields as a function of mass number A_{res}; they correspond to the full circles of fig. 5. As the procedure is not reliable for residual nuclei close to the target mass $A_{res} \leqslant A-3$, the directly measured yields only are available (empty circles in the figure). We estimate that the yield should be multiplied by roughly a factor of two at least; the empty squares in fig. 5 correspond to the factor 2, used as an indicative trend. The accumulation of residues at A_{res} values corresponding to the loss of a small number ($\leqslant 5$) of nucleons, predicted by the model, seems to be realized to a certain extent in actual annihilations.

The INC prediction for $A_{res}=97$ calls for some comments. It corresponds to a void cascade, i.e. a process where all the pions (from low multiplicity annihilations) either completely miss the nucleus or do not interact when crossing it. In the INC model, the probability of producing a void cascade is rather large. These void cascades seem to be observed experimentally, since the residue $A_{res}=97$ is detected and its presence cannot be explained as a product of an evaporation chain. One cannot however be completely sure that the rate of observed events $A_{res}=97$ can entirely be assigned to the rate of void cascade events in the INC model. Indeed, the latter describes the hard processes with rather large momentum transfer but neglects soft processes. Consequently, a void cascade event (in the sense of the INC) can actually contain soft collisions. If the latter produces a sufficiently small perturbation, the $A=97$ nucleus deexcites by γ-emission only and then can be detected by the method of ref. [11]). It is dubious however that the soft process could not give, at least part of the time, sufficient excitation to produce the evaporation of a neutron.

In view of the rather unclear situation for low mass emission, we have made another comparison considering $A_{res}\leq 93$ only, for which the treatment of the measured yields has given estimated total yields (full circles); we have normalized data and model predictions to the same total yield for $A_{res}\leq 93$. The result is shown in fig. 6 which exhibits a satisfactory agreement between theory and experiment, not only for the overall shape but also for the decreasing tail at small mass number.

When $\langle \Delta E\rangle = 15$ MeV is used, the average value of $\langle A_{res}\rangle$ is shifted by 2 to 3 units only, but the distribution is then much broader than the experimental one.

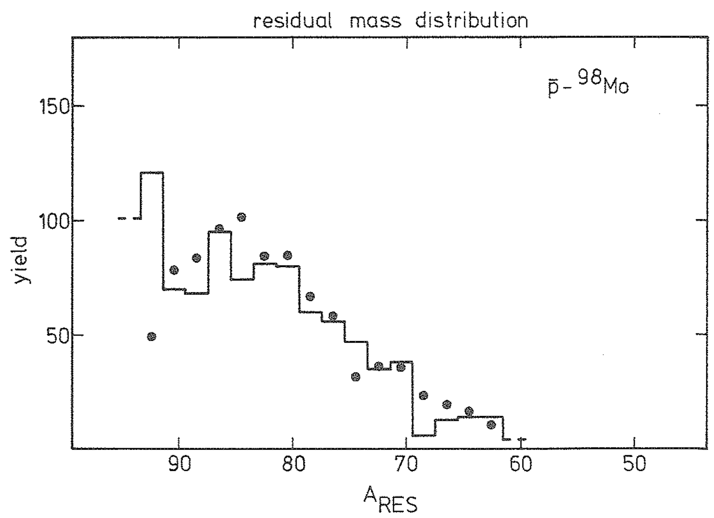

Fig. 6. Comparison between our predictions (histogram) and the data of ref. [18]) for the residual mass A_{res} distribution for $62\leq A_{res}\leq 93$. See text for detail.

In conclusion, one can divide the emitted nucleons in two categories: a small number (mean value 4) of nucleons emitted in a hot phase as the result of hard collisions and the rest which originate in the deexcitation of the residue left over after the hot phase. The correlation factor between the excitation energy and the number of fast ejected nucleons after the hot phase is not large (0.49) and the long tail predicted in fig. 6 is essentially due to a wide spread of the excitation energy. It is noteworthy, however, that there is one percent of "violet events", in which the number of ejectiles is larger than or equal to 12 and the number of evaporated nucleons larger than 18.

5. Particle number multiplicities

5.1. PIONS

The number of free pions rapidly decreases after the annihilation, as a result of the Δ-formation. We give, in fig. 7, the evolution of the number of pions and deltas (for Mo and O targets). The number of Δ's saturates because the equilibrium between the Δ-decay and the Δ-formation settles rapidly. Afterwards, both Δ-particles and free pions start to escape from the nucleus. As a consequence, the number of pions increases. This behaviour is enhanced for a small target, like ^{16}O (see fig. 7).

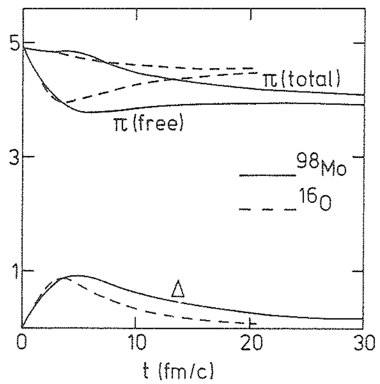

Fig. 7. Time evolution of the average numbers of free pions, deltas and total pions following $\bar{p}$-annihilation.

On the average, 4.91 pions are produced by the annihilation. For a medium-heavy nucleus like ^{98}Mo, only 41% of the pions interact with nucleons. Globally, 16% of the primordial pions are absorbed. This figure is consistent with previous calculations [13,17]) and with measurements in emulsions [1,2]).

5.2. FAST EJECTILES

We show in fig. 8 the multiplicity distribution for the number of fast ejectiles (for short, we denote by this the particles escaping the nucleus before the evaporation phase) along with the one for the number of participants (after 30 fm/c) in ^{98}Mo. Both distributions are very well fitted by the negative binomial function:

$$P(n;\bar{n},k)=\frac{k(k+1)\cdots(k+n-1)}{n!}\left(\frac{\bar{n}}{\bar{n}+k}\right)^{n}\left(\frac{k}{\bar{n}+k}\right)^{k}, \tag{5.1}$$

where the parameter $\bar{n}$ indicates the average value of n. This distribution has been shown to be very successful to describe particle multiplicity in very high energy process [24]). It has been suggested [25]) that such a distribution could indicate a production mechanism by which particles are produced in independent groups ("clans"), with some special distribution for the number of particles inside a clan (although it seems that the conditions on the form of this distribution are not so strict). The work of ref. [26]) strongly indicates that the ejection of particles after annihilation could closely follow such a pattern. Of course, one expects that each of the interacting pions is the head of a class generation. In fact, the values of $\bar{n}$ and k can be converted into $\bar{N}$ and $\bar{n}_c$, supposed to be the average number of clans and the average number of particles inside the clans through the relations

$$\bar{N}=k\ln\left(1+\frac{\bar{n}}{k}\right), \qquad \bar{n}_c=\frac{\bar{n}}{\bar{N}}. \tag{5.2}$$

For the fast ejectiles in p̄-Mo, $\bar{N}=3.13$ and $\bar{n}_c=1.45$. We recall that the number of interacting pions $\bar{n}^{\pi}_{\rm int}$ is slightly larger than 2. Therefore, we think that these figures grossly support the picture of the independent clans initiated by the pions. The

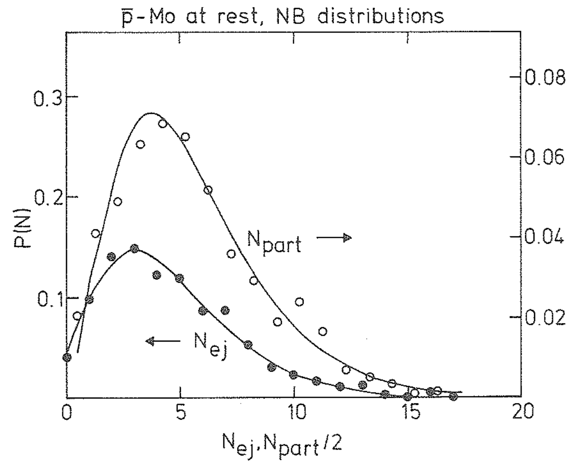

Fig. 8. Fit of the INC distributions for ejectiles (full dots) and for the participants (open dots), respectively, by negative binomials (eq. (5.1)). See text for detail.

discrepancy between $\bar{N}$ and $\bar{n}^{\pi}_{\rm int}$ is easily attributed to the possible communication between the initially separated clans. For p̄-Pb, in the same interpretation, there is 4.27 clans, which, on the average, contain 1.69 nucleons. It is natural that clans are bigger in heavier targets. Similarly, according to the same picture, it is expected that the clans for the participants are bigger than the clans for the ejectiles. Indeed, for p̄-Mo, the fit yields $\bar{n}_c(\text{part}) = 2.24$. But the fit indicates also an average number of clans for the participants $\bar{N} = 4.47$ quite larger than the corresponding number for the fast ejectiles, which is less intuitive.

6. Mass dependence

We briefly discuss the mass dependence of various quantities, given in fig. 9. First, we consider the average number of participants $N_{\rm part}$. One can see that the mass dependence is weaker than linear: it is close to $A^{0.43}$. This means that there are proportionally less nucleons involved in a heavy target compared to a small one. A similar observation can be made for the average number of ejectiles $\langle N_{\rm ej}\rangle$ and the average number $\langle \Delta A\rangle$ of emitted (fast+evaporated) nucleons.

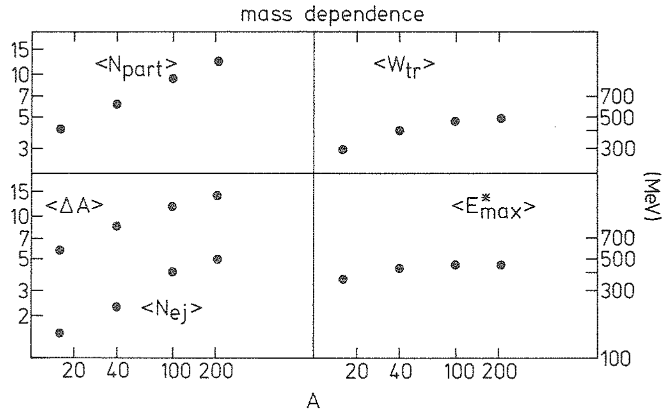

Fig. 9. Mass dependence of the average number of participants $\langle N_{\rm part}\rangle$, of the average number of ejectiles $\langle N_{\rm ej}\rangle$, of the average number of emitted nucleons (fast ejectiles + evaporated ones) $\langle \Delta A\rangle$, of the average energy transferred from the pion system to the nucleon system $\langle W_{\rm tr}\rangle$, and of the average maximum excitation energy gained by the target, respectively. The scales are logarithmic.

The mass dependence of the maximum target excitation energy $\langle E^*_{\rm max}\rangle$ is given in the lower right corner of fig. 9: there is a small increase for small mass targets and a rapid saturation to a value of about 450 MeV. This value results from the transformation of pions into Δ's which, as we said, is limited by the onset of the equilibrium between Δ-decay and Δ-formation. The slight decrease for small A is a geometrical effect resulting from the easier escape from small systems.

The upper right corner gives the mass dependence of the average energy transfer $\langle W_{tr} \rangle$ between the multipion system and the nucleon systems. This variation closely follows the one of $\langle E^*_{max} \rangle$ although the saturation is not so pronounced. For Pb, $\langle W_{tr} \rangle$ amounts to ~500 MeV, but the bulk limit, i.e. the limit for a semi-infinite nucleus, would be ~900 MeV, because, ultimately, the interacting pions would be absorbed. It should be noticed that the energy transfer $\langle W_{tr} \rangle$ increases with A much more slowly than $\langle N_{ej} \rangle$. Therefore, the average energy of the ejectiles should decrease with increasing mass, which, of course, reflects a slowing down of the nucleons, kicked by the pions, on their way out of the nucleus.

7. Violent versus soft annihilations

One of our motivations was the search for a possible multifragmentation of a nucleus in p̄-annihilation at rest. This possibility was raised in ref. [13]). A strong interest has arisen for the possible study of nuclear multifragmentation, i.e. the sudden breakup of the nucleus into several pieces. Many authors think that such a phenomenon would appear suddenly for a minimum energy deposit inside the nucleus.

Our philosophy here was to see whether a realistic model without possibility of a multifragmentation could explain the observed residual mass distribution. Our analysis seems to indicate that this is indeed the case. Even more, the data themselves seem to rule out multifragmentation, although it is not sure that the γ-ray detector of ref. [18]) was tuned up to detect eventually multifragmentation events.

Other arguments reinforce our belief that the p̄-annihilation at rest is rather gentle.

(i) The INC model is the most appropriate for the first stages after the annihilation where the collisions are the most violent. Nevertheless, the model predicts an excitation energy in the target of less than 500 MeV, i.e. of the order of 2 to 4 MeV per nucleon. This is about (and certainly not clearly above) what is believed to be the threshold for the onset of multifragmentation [27,28]). However, one has to keep in mind that about 250 MeV is stored in the mass of the Δ-particles, whereas refs. [27,28]) consider thermal excitation essentially.

(ii) The perturbation of the density is rather small as described by fig. 10, which shows the time evolution of a Mo nucleus after annihilation. The p̄ annihilates at the surface of the top of the nucleus. The perturbation of the density is not very sizeable, certainly much smaller than what is caused by 1 GeV protons [20]). A curious feature is to be noticed. The nucleons are escaping first in the backward direction with respect to the penetrating interacting pions. But, in the overall, there are more particles ejected in the forward direction [14]).

(iii) Our analysis of the ejectile number distribution as well as of their average value strongly suggests that the interacting pions are more or less propagating independently, hitting a few nucleons on their path, but without provoking a strongly collective perturbation of the system.

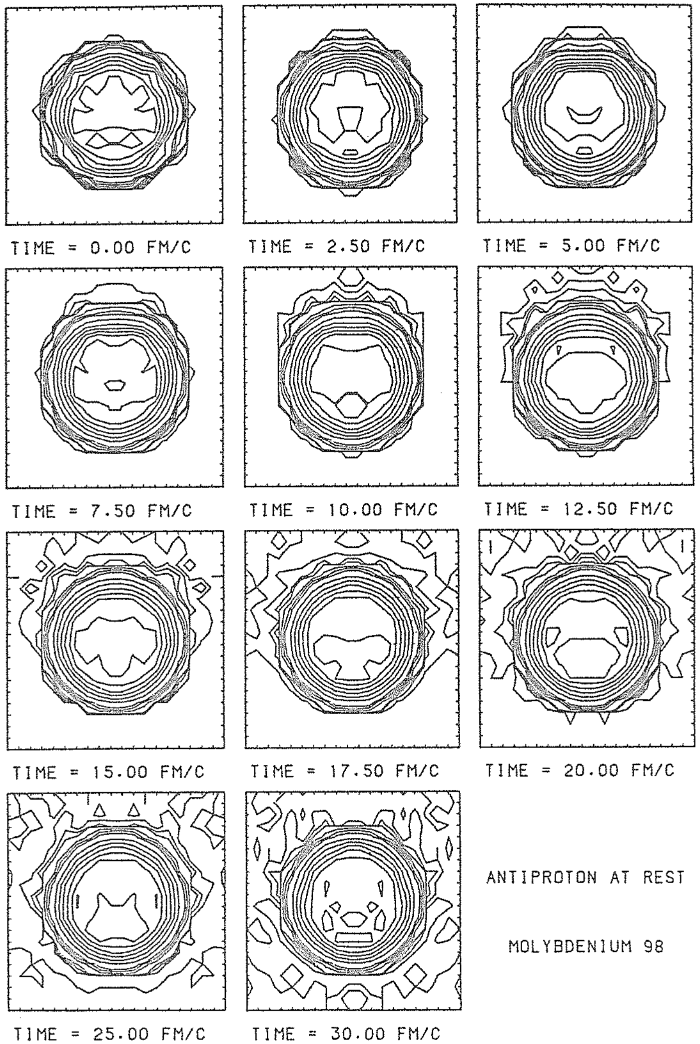

Fig. 10. Nuclear density plots at various times after $\bar{p}$-^{98}Mo annihilation at rest. The annihilation site is at the top of the nucleus. The curves correspond to isodensity levels, starting from outside, of 1, 4, 7, 10, 40, 70, 100, 200, 300, 400, 500, 600, 700 units (this last figure corresponds to $\rho_0 = 0.17\ \mathrm{fm}^{-3}$), respectively, inside an equatorial slice of 2 fm thickness.

In conclusion, it is likely that multifragmentation events are rather infrequent in $\bar{p}$-annihilation at rest, certainly below the level of 10%, the degree of accuracy to which our model reproduces the mass yield. Of course, it cannot be excluded that, owing to fluctuations, the excitation energy happens to be much larger than the average. In our simulation for $\bar{p}$-^{98}Mo, we observed that, at $t = 30\ \mathrm{fm}/c$, the excitation energy is above 450 MeV, i.e. 2.5 times the average value, for 5% of the events. Therefore, if one wants to study multifragmentation with $\bar{p}$-annihilation, one has to turn to in flight annihilations. Throughout the usual LEAR energy domain, the energy transfer does not seem to increase so much as to provide qualitatively better conditions. Presumably, one should go up to 1 GeV antiprotons [13,15]). But, this question should be investigated further. Of course, in this energy domain, the energy deposit is probably not distributed throughout the nucleus.

8. Discussion and conclusion

In this paper, we have refined our analysis of the p̄-annihilation at rest, testing again the simplest picture of the process: the antiproton annihilates on a single nucleon, liberating in a single point a few pions which cascade through the nucleus. We have shown that this single picture, supplemented by an evaporation model, satisfactorily describes the recent measurements of the residue distribution, in view of the limited accuracy of the radiochemical method. Incidentally, it would be desirable to have direct mass and charge identification. Let us also notice that our results are highly consistent with those of ref. [17]).

Antiproton–nucleus annihilations have been studied to detect two possible interesting phenomena: unusual annihilations and multifragmentation of the nucleus. As for the second one, we have at length underlined that p̄-annihilation at rest is too gentle a process, more akin to a spallation followed by evaporation. Multifragmentation would be favoured by the use of high energy antiprotons. This, of course, holds within the INC model, but drastic departures from the INC do not seem very likely. For instance, we looked at the effect of changing the mass spectrum of the Δ-particles. Even assuming a single mass of 1238 MeV does change the energy transfer by less than a few percent.

To our knowledge, there are no real indications for unusual p̄-annihilations. At least, there is no indication for much larger energy transfer than expected by the INC. Of course, unusual annihilations may leave more subtle traces, like the enhancement of strange particle production (this could have been observed already [9]), or like a modification of the multiplicity distribution for the annihilation pions. Of course, their average number, more or less fixed by the energy released, is not expected to change, but the width of the distribution may be affected by the fact that annihilation takes place in the field of other nucleons. Therefore, we think that particle number distributions deserve a careful analysis.

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