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ENERGY LOSS AND STOPPING OF HADRONS IN NUCLEAR MATTER

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1. INTRODUCTION

The subject matter in this work is to discuss the energy losses and energy deposition of high energy hadrons in target nuclei; we call "high" the energies if higher than the pion production threshold. We consider here the hadron energy loss by target nucleon emission and target fragments evaporation only.

One of the current interests in studies of the incident hadron energy deposition in target nuclei is to find whether and how we can produce high enough excited states of nuclear matter. But, the question "How do hadrons deposit their kinetic energy in nuclear matter?" must find its answer primarily in experiments. We try to show how it is possible to achieve it just now.

The hadron energy lost in a target nucleus should influence the observed emission of "fast" nucleons, of kinetic energy from about 20 to about 400 MeV, and the observed evaporation of target fragments - mainly nucleons, deuterons, tritons and alpha particles; may be, it manifests itself in the residual target nucleus decay as well. For that reason, in order to investigate experimentally the energy loss and energy deposition of hadrons in target nuclei, we should use such a sample of hadron-nucleus collisions in which fast nucleon emission, target fragments evaporation, and residual target decays occur in the purest form. Such a sample can be selected, in fact - as we will show it - from hadron-nucleus collision events.

In our previous paper /1/, we have shown that pion-xenon nucleus collisions at momenta smaller than about 4 GeV/c occur in which incident pion is completely stopped and deposited its kinetic energy inside the target nucleus without causing particle production. We call these events simply "stopped" events later on. We were able to identify, as well, events in which incident pion underwent a deflection only in its passage through the target nucleus without causing particle production; this kind of events we observed at incident pion momenta higher than about 2 GeV/c, and, as it can be concluded /1/, it should occur at any momentum higher than pion production threshold. We call these events shortly "projectile deflected" events later on. In both the cases, pion-xenon nucleus collisions cause the emission of fast nucleons and the evaporation of light target fragments; decays of the residual target nucleus into heavy fragments occur as well. Identical fast nucleon emission and light fragment evaporation accompany any-type of the pion-xenon nucleus collisions. Energy spectra, angular and momentum distributions of the fast protons emitted do not depend on the multiplicity n_π of secondary pions, when $n_\pi \geq 0$. Similarly, characteristics of evaporated light fragments do not depend on the multiplicity n_π of secondary pions, as we can conclude from experimental data[2-4].

These facts and results of our experimental investigations of hadron-nucleus collisions, described in our works cited in the above-mentioned paper[1], allow one to conclude that fast nucleon emission and target fragment evaporation processes do not depend on the particle production process. We hope, therefore, that an information about energy deposition in target nuclei obtained in studies of the stopped events will throw light on the energy loss of high energy hadrons in nuclear matter in any-type hadron-nucleus collisions too. We limit ourselves here, therefore, to appropriate analysis of the samples of the stopped and of the incident hadron deflected events mainly, in which the incident hadron energy deposition occurs in its purest form. In an analysis of the stopped events, the energy balance in this kind of hadron-nucleus collision events may be performed.

The present paper is arranged as follows. After the introduction, in section 1, we survey shortly and adequately, in section 2, properties of the fast nucleon emission, discovered in our experiments[1,5], and of characteristics of the target fragment evaporation[2-4]. In section 3 we present the energy balance in the stopped events. Section 4 contains discussion and results; we describe in it the picture of the energy deposition process in hadron-nucleus collisions - as prompted by experiments, and we present quantitative analysis of incident hadron energy loss in its passage through an atomic nucleus.

2. PROPERTIES OF THE NUCLEON EMISSION AND TARGET FRAGMENT EVAPORATION PROCESSES

Experimental data presented in our papers[1,5], and in the papers referred to in them, allowed to conclude that:

a) Any high energy hadron causes the emission of fast nucleons from the target nucleus when passes through it; the intensity of this emission, expressed by the multiplicity n_N of the emitted nucleons, equals the number of nucleons contained within the cylindrical volume $\pi D_0^2 \lambda$ centered on the incident hadron path λ inside the nucleus, where D_0 is the nucleon diameter. Of course, some "straggling" of n_N occurs, but we do not take it here into account, for simplicity. The number n_N of the nucleons emitted is, therefore, a measure of the length λ of the incident hadron path in nuclear matter, when λ is expressed in number of nucleons per the area $S = \pi D_0^2$. Because the ratio between the number of neutrons and the number of protons in an atomic nucleus can be treated as radially independent and is nearly $(A - Z)/Z$, where A and Z are the mass and charge numbers[6,7], the path length λ can be measured in the number n_p of protons per the area S too. The fraction of collision events with proton multiplicity n_p larger than the number of protons contained inside the volume $\pi D_0^2 D$ centered on the target nucleus diameter D is small - no more than about ten percent - in hadron-nucleus collisions at any energy of incident hadron, therefore, n_p is a good measure of the nuclear matter thickness λ the hadron falls on as well, when λ is measured in number of protons per S and n_p is equal to or it is smaller than the number of protons contained within the volume $\pi D_0^2 D$ or, in other words, when n_p (protons/S) $\leq$ D (protons/S).

b) Hadrons lose monotonically a fraction of their energy causing fast nucleon emission[1]; the energy loss ϵ_h for the emission of one fast nucleon depends on the sort of the hadron h - pion, for example, loses in average $\epsilon_\pi \approx 0.180$ GeV of its energy; and proton, $\epsilon_p \approx 0.36$ GeV, as it was determined experimentally[1]. And so, the hadron energy loss spent on the fast nucleon emission depends simply on the path length λ in nucleons/S of this hadron in nuclear matter.

c) The fast nucleon emission intensity in hadron-nucleus collisions is related to the fragment evaporation intensity in them - simple relation exists between the mean number $\langle n_b \rangle$ of the evaporated charged target fragments and the number n_p of the emitted fast protons: $\langle n_b \rangle \approx a n_p + b$, where a and b are constant quantities; for proton-emulsion nuclei collisions $a = 1.21$ and $b = 1.49$, as it has been shown experimentally in Winzeler's work[2]. The mean energy of the evaporated fragments is independent of the incident hadron energy[2-4]. The hadron energy loss spent on the fragment evaporation depends on the path length λ of the hadron in nuclear matter as well, therefore. But a shift in time between the fast nucleon emission process and fragment evaporation process exists, because evident difference in energy and angular characteristics of the emitted fast nucleons and of the evaporated target fragments is observed.

d) Energy and momentum spectra, and angular distributions of the fast nucleons emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum are identical in the sample of events with particle production and in the sample of events without particle production, in particular in the sample of stopped events, as we know from the analysis of fast protons emitted. Energy spectra and angular distributions of fast protons in pion-xenon nucleus collisions at 3.5 GeV/c are the same as corresponding energy spectra and angular distributions of fast protons emitted in proton-emulsion nuclei collisions at 300-400 GeV/c momentum. The mean energy of the target fragments evaporated in hadron-nucleus collisions does not depend on incident hadron energy, as it can be concluded from available experimental data from proton-emulsion nuclei collision studies /4/. The multiplicity n_p distributions of fast protons in proton- AgBr nuclei collisions at 4.5, 67, 200, and 400 GeV/c momentum of the incident proton are practically identical; the same is observed in pion- AgBr nuclei collisions at 17, 60, 200 GeV/c momentum /4,8,9/. There are no marked differences between energy spectra and angular distributions of fast protons emitted in proton- AgBr nuclei collisions at 4.5 GeV/c momentum in two classes of events - with and without particle production /10/.

e/ energy and momentum spectra, and angular distributions of the emitted fast protons may be reproduced quantitatively, if observed protons are treated as products of the decay of two-nucleon systems formed in nuclear matter when low energy pions are absorbed by two nucleon associations /11/.

f) Angular distributions of the evaporated fragments are almost isotropic; it indicates that the residual target nucleus is not accelerated markedly.

The above presented properties of the fast nucleon emission process and of the target fragment evaporation process in hadron-nucleus collisions allow one to conclude that:

1. Energy loss of incident hadron, spent on the fast nucleon emission and target fragment evaporation, depends definitely and simply on the nuclear matter layer thickness λ in the target nucleus the incident hadron interacted with.

2. At incident hadron energy smaller than a few GeV the distribution of the thicknesses λ depends on the collision impact parameter d and on the incident hadron energy E_h; at incident hadron energy E_h larger than a few GeV the distribution of λ's does not depend on E_h, it depends only on the collision impact parameter distribution.

3. Fast nucleon emission and target fragment evaporation processes proceed identically in events with and without particle production.

The conclusions allow us to limit ourselves to a discussion about the stopped events only, in analysing energy deposition of incident hadrons in target nuclei. We start our analysis with a discussion about energy balance in stopped pion-xenon nucleus collision events recorded in our experiments /1,5/.

3. ENERGY BALANCE IN THE STOPPED HADRON-NUCLEUS COLLISION EVENTS

The problem to be discussed now is concerned with the energy balance in the stopped events recorded in studying pion-xenon nucleus collisions at 3.5 GeV/c momentum /12-19/, in the 180 litre xenon bubble chamber /20/. In this type of events the incident hadron (pion) is completely stopped and deposited its energy E_h in the target xenon nucleus. The kinetic energy of the incident hadron is $E_h \simeq 3.2$ GeV, because a small portion ~ 0.2 GeV of it is lost by ionization inside the chamber. In result of such a collision, in average $<n_p> = 7.4$ fast protons and $<n_n> = [(A-Z)/Z]<n_p>$ fast neutrons, or simply $<n_N> = (A/Z)<n_p>$ fast nucleons are emitted. The average number $<n_N>$ fluctuates in a known manner, but we do not take this fluctuation into account here, for simplicity; this simplification will not influence our final results. The mean kinetic energy of the emitted fast nucleons is $<E_{kN}> \simeq 90$ MeV, as is known from fast proton mean energy $<E_{kp}>$ measurements. The total mean kinetic energy of emitted $<n_N>$ fast nucleons $<\Sigma E_{kN}>$ is then:

$$<\Sigma E_{kN}> = \frac{A}{Z} <n_p> <E_{kp}> , \qquad (1)$$

where $<n_p>$ and $<E_{kp}>$ are measurable quantities.

The total mean kinetic energy of the emitted fast nucleons (1) is one of parts of the incident hadron energy E_h lost in its passage through the target nucleus. Another fraction of E_h manifests itself as the mean energy of all evaporated target fragments. The average multiplicity $<n_b>$ of the charged fragments is:

$$<n_b> = a \cdot n_p + b , \qquad (2)$$

because of the relation between $<n_b>$ and n_p in proton-emulsion nuclei collisions /2/; we will show later that this relation should be valid for any hadron-nucleus collision. But, the neutrons among the target fragments are evaporated, too. Because the ratio between the number of evaporated protons and the number of evaporated neutrons should be as $Z/(A-Z)$, and protons are represented in about $k = 50\%$ of the target charged fragments, we expect that $<n_b> k \frac{A}{Z}$ nucleons are evaporated; other evaporated target fragments are $(1-k)<n_b>$ deuterons, tritons and alpha particles. The mean kinetic energy of the evaporated fragments is /4/ $<E_{kb}> \simeq 20$ MeV, then the fraction $<\Sigma E_{kf}>$ of the incident hadron energy deposited in the target nucleus and carried away in the target fragment evaporation process is then, in average:

$$\langle \Sigma E_{hf} \rangle = (\langle n_p \rangle + b)\left(k \frac{A+Z}{Z} - 1\right)\langle E_{kb} \rangle . \tag{3}$$

In relation (3) all the quantities on the right-hand side are measurable ones, but for pion-xenon nucleus collisions we have not measured the quantities a and b, and we take here $a = 1.21$ and $b = 1.50$ as for proton-AgBr collisions[2]; we will discuss about the correctness of such an approximation later.

For the sample of the stopped pion-xenon nucleus collision events under consideration, we have: $\langle \Sigma E_{kN} \rangle \approx 1.6$ GeV, and $\langle \Sigma E_{kf} \rangle \approx 0.32$ GeV, what gives a shortage of the total incident hadron energy lost in the target nucleus $\Delta E \approx 1.2$ GeV, where

$$\Delta E = E_h - \langle \Sigma E_{kN} \rangle - \langle \Sigma E_{kf} \rangle . \tag{4}$$

The fraction ΔE of the incident hadron energy E_h cannot be explained simply; it does not manifest itself in any simple manner - as target fragment evaporation or fast nucleon emission. In fact, the almost isotropic angular distribution of the target fragments indicates that the target nucleus is not accelerated markedly in the collision. The decay of the locally destroyed and unstable residual target into smaller stable fragments proceeds probably due to an unstable nucleon configuration, caused in the hadron-nucleus collision process, after fast nucleon emission and target fragment evaporation. For this reason, the fraction ΔE of deposited energy E_h should find its explanation in some other way; finally its meaning must be find in an experiment, but now we try to give one of the most probable explanations here.

We know that the emitted fast nucleons should be treated not as knocked out simply from the target nucleus, but as a result of decays of two- or more nucleon systems formed inside the target nucleus when slow pions are absorbed by two or more nucleons[11,19]. But, where are the slow pions from? They must appear inside the target nucleus around the incident hadron course, and it is very probable that the fraction ΔE of the incident hadron energy is used for the low energy pion extraction in nuclear matter. Let us estimate an energy used for one pion extraction. In average, in the stopped events under discussion, $\langle n_N \rangle \approx 18$ fast nucleons are emitted. These nucleons appear from decay of $\langle n_N \rangle/2$ pairs of nucleons. Each of the pairs is formed in result of the absorption of one pion, then $\langle n_N \rangle/2$ pions appear in average, and the energy ϵ for an extraction of one pion is $\epsilon = \Delta E/(\langle n_N \rangle/2) \approx 133$ MeV. In other words, the energy used for one pion extraction is approximately as large as the pion rest mass, $\epsilon \approx m_\pi$. The pion extraction energy, or the pion extraction potential, may be treated as an analogue to the ionization potential in charged particle interaction with an atom.

Clearly speaking, we come to a conclusion that high energy hadron causes an appearance of slow pions around its course in nuclear matter, similarly as a fast charged particle causes the appearance of electrons around its course in passage through a material, in the ionization process. By analogy we call this process, consisting in the slow pion appearance around hadron course in nuclear matter, the pionization process in nuclear matter. We should look for other experimentally testable effects, in other experiments, which could support our conclusion formulated here.

Taking into account the pion extraction energy $\epsilon \approx m_\pi$, we can estimate the mean hadron energy lost in nuclear matter by fast nucleon emission in traversing a path $\lambda = n_N$ (nucleons/S); this energy loss is:

$$\langle \Delta E_{hN} \rangle = \frac{1}{2} \langle n_N \rangle \cdot \epsilon + \langle n_N \rangle \langle E_{kN} \rangle = \langle n_p \rangle \frac{A}{Z} \left(\frac{1}{2}\epsilon + \langle E_{kp} \rangle\right), \tag{5}$$

where $\langle E_{kN} \rangle$ is mean kinetic energy of emitted fast nucleon; $\langle E_{kN} \rangle$ is accepted as large as $\langle E_{kp} \rangle$.

The hadron energy lost by fast nucleon emission on the path $\lambda = 1$ (nucleon/S) is, in average:

$$\langle \Delta\epsilon_{hN} \rangle = \frac{1}{2}\epsilon + \langle E_{kN} \rangle , \tag{6}$$

and the energy lost on the path $\lambda = 1$ (proton/S) is:

$$\langle \Delta\epsilon_{hp} \rangle = \frac{A}{Z}\left(\frac{\epsilon}{2} + \langle E_{kp} \rangle\right). \tag{7}$$

The incident hadron energy lost by fast nucleon emission and by target fragment evaporation on the path length $\lambda = 1$ (nucleon/S) is then in average:

$$\langle \Delta E_h \rangle \equiv \epsilon_\ell = \langle \Delta\epsilon_{hN} \rangle + \langle \Delta\epsilon_{hf} \rangle , \tag{8}$$

in MeV/(nucleon/S), where $\langle \Delta\epsilon_{hf} \rangle$ is the mean hadron energy lost on the hadron path length $\lambda = 1$ (nucleon/S) by target fragments evaporation; $\langle \Delta\epsilon_{hf} \rangle$ can be obtained simply from relation (3).

For incident pions $\langle \Delta E_h \rangle \equiv \langle \Delta E_\pi \rangle \approx 180$ (MeV/(nucleon/S) at about 3 GeV of the incident hadron kinetic energy[1]; for incident protons, at the same energy $\langle \Delta E_p \rangle \approx 360$ (MeV/(nucleon/S)). Experimental data available now indicate that $\langle \Delta E_h \rangle$ does not change markedly with E_h change.

4. DISCUSSION AND RESULTS

In this section we discuss firstly abut energy- and A-dependence of the incident hadron energy deposition in target nuclei. Secondly, we would like to show that the relation

$\langle n_b \rangle = 1.21\, n_g + 1.49$ can be applied practically for any hadron-nucleus collision. Thirdly, looking back at the previous remarks and results, we present a first draft of an experimental picture of the process of energy loss by projectile hadrons in nuclear matter by nucleon emission and target fragment evaporation.

Energy loss of a hadron in its passage through an atomic nucleus along a path λ in (nucleons/S) depends on the length of this path; experimental data indicate that the dependence is the same in the stopped events, in the hadron deflected events, and in any-type collision events. The stopped events occur when the incident hadron energy $E_h \lesssim \epsilon_\ell D = \epsilon_\ell \cdot \lambda_{max}$, where ϵ_ℓ is the mean energy loss of the hadron per one path length unit, in (MeV/(nucleon/S)), and D is the target nucleus diameter, in (nucleons/S), or the maximum target thickness. Then, the total energy loss ΔE_h increases firstly with E_h increase, up to $E_h \simeq \epsilon_\ell D$. When $E_h > \epsilon_\ell D$, the total energy loss ΔE_h is growing constant and in average it is equal to $\langle \Delta E_h \rangle \simeq \epsilon_\ell \langle \lambda \rangle$, where $\langle \lambda \rangle$ (nucleons/S) is the mean thickness of nuclear matter layer the incident hadron fall on - it is the mean target nucleus thickness, in other words. The maximum value of the energy loss at $E_h > \epsilon_\ell D$ is $\langle \Delta E_h \rangle_{max} = \epsilon_\ell \cdot D$, where D is the target diameter length in nucleons per S. Because λ_{max} and $\langle \lambda \rangle$ depend on the mass number A, then $\langle \Delta E_h \rangle_{max}$ and $\langle \Delta E_h \rangle$ depend, in the same manner, on A; $\langle \Delta E_h \rangle_{max}$ is proportional to $3.07\, A^{1/3}$ and $\langle \Delta E_h \rangle$ is proportional to $1.50\, A^{1/3}$, when $E_h > \epsilon_\ell \cdot D = \epsilon_\ell \cdot \lambda_{max}$; and when A is large enough - practically it is true for $A \geq 12$.

The total energy loss ΔE_h consists of two clearly different parts: one part ΔE_h^I is lost by the fast nucleon emission and the other part ΔE_h^{II} is lost by the target fragment evaporation. Let us denote the mean energy loss by fast nucleon emission as $\langle \Delta \epsilon_{hN} \rangle \equiv \epsilon_{em}$, on hadron path length unit, and the mean energy loss by target fragment evaporation on hadron path unit as $\langle \Delta \epsilon_{hf} \rangle \equiv \epsilon_{ev}$ in (MeV/(nucleon/S)), then:

$$\langle \Delta E_h^I \rangle = \epsilon_{em} \langle \lambda \rangle , \qquad (9)$$

$$\langle \Delta E_h^I \rangle_{max} = \epsilon_{em} \lambda_{max} = \epsilon_{em} \cdot D , \qquad (10)$$

and

$$\langle \Delta E_h^{II} \rangle = \epsilon_{ev} \langle \lambda \rangle , \qquad (11)$$

$$\langle \Delta E_h^{II} \rangle_{max} = \epsilon_{ev} \lambda_{max} = \epsilon_{ev} \cdot D . \qquad (12)$$

The quantities ϵ_{em} and ϵ_{ev} can be estimated experimentally, using the data available /1-4/; for example, for the incident pion $\epsilon_{em} \simeq 180$ (MeV/(nucleon/S)) and $\epsilon_{ev} \simeq 16$ (MeV/(nucleon/S)).

For pion-uranium nucleus collisions the mean energy lost by nucleon emission $\langle \Delta E_h^I \rangle \simeq 1.65$ GeV and the mean energy lost by target fragment evaporation $\langle \Delta E_h^{II} \rangle \simeq 0.18$ GeV; the maximum energy lost is $\langle \Delta E_h^I \rangle_{max} \simeq 3.45$ GeV and $\langle \Delta E_h^{II} \rangle_{max} \simeq 0.37$ GeV.

Somebody expected that a higher incident hadron energy would result in a greater excitation of the target nuclei providing that they have enough stopping power; but at higher energies target nuclei would become transparent, so that there must be optimum energy for generation of highly excited nuclear matter. This optimum energy is determined by simple formula

$$E_{h\,opt} \simeq \epsilon_\ell \cdot D ; \qquad (13)$$

at higher energies total energy loss does not increase, at smaller energies total energy loss is smaller.

In the energy balance performed in foregoing section the relation $\langle n_b \rangle = 1.21\, n_g + 1.49$ plays important role. We accepted that n_g and $\langle n_b \rangle$ obey this relation at any energy for any target nucleus. Here we will show that it is so in fact. We know that the number of fast protons emitted is $n_p = \pi D_o^2 \lambda$, where λ is in protons/S. The connection between $\langle n_b \rangle$ and $n_g = n_p$ indicates that $\langle n_b \rangle$ should be λ-dependent as well, with some "straggling". Therefore, we expect that the number of evaporated fragments n_b should be determined by the surface layer of nuclear matter centered on the volume $\pi D_o^2 \lambda$ which fast nucleons where emitted from. Therefore, the number of the charged fragments will correspond to the volume of the pipe $[\pi (3/2\, D_o)^2 - \pi D_o^2]\, \lambda = \pi\, 5/4\, D_o^2 \cdot \lambda$, and then the relation between $\langle n_b \rangle$ and n_g will be: $(5/4\, \pi D_o^2 \lambda)/(\pi D_o^2 \lambda) = 1.25$, what is as large as the coefficient $a = 1.21$ is, and it is constant for any target nucleus and independent of the incident hadron energy and identity. When $n_p = n_g = 0$, $(A - Z)/Z$ fast neutrons are emitted however, and $a \cdot (A - Z)/Z$ target fragments will be emitted as well. The mean number of the evaporated fragments will be $\langle n_b \rangle = a \cdot (A - Z)/Z$, and then $b = a \cdot (A - Z)/Z$. From relation (2) we have then:

$$\langle n_b \rangle = a \cdot \left(n_p + \frac{A - Z}{Z}\right) . \qquad (14)$$

Explicitly, relation (14) may be rewritten as

$$\langle n_b \rangle = 1.25 \left(n_p + \frac{A - Z}{Z}\right) . \qquad (14')$$

For Ag nucleus $a = 1.25$ and $b = a \cdot (A - Z)/Z = 1.62$; for Br nucleus $a = 1.25$ and $b = a \cdot (A - Z)/Z = 1.60$; for AgBr nuclei it will be $\langle n_b \rangle = 1.25\, n_g + 1.60$, what is in agreement with $\langle n_b \rangle = 1.21\, n_g + 1.49$ given in Winzeler's work /2/. For xenon nucleus $\langle n_b \rangle = 1.25\, n_g + 1.74$ and does not differ markedly from that for

AgBr nuclei. We are correct, therefore, using the data from Winzeler's work for the analysis of the pion-xenon nucleus data, in section 3. We note that the quantities a and b do not depend on incident hadron energy and identity; the quantity does not depend on the target mass number A, but b depends on the relation $(A-Z)/Z$.

The physical meaning of the relation (14') should find its support in results of other experiments, although.

The method of treatment of the data, on fast proton emission and target fragment evaporation in hadron-nucleus collisions, applied in the present study, allows to analyse quantitatively and qualitatively stopping and energy deposition of high energy hadrons in target nuclei. Experimental study of hadron-nucleus collisions at energies smaller than a few GeV shows that incident hadrons lose monotonically their kinetic energy in passage through nuclear matter and are often completely stopped and deposited their energy in target nuclei, when the targets are large enough; at higher energies hadrons lose a fraction of their energy. In both the cases, the hadron energy loss process proceeds in a strictly definite manner - it is determined by formulas (4)-(14).

It is reasonable to conclude, looking back at the above obtained results, that in any collision case the energy loss influences definite part of the target nucleus only, what leads to a definite destruction of the target nucleus, as it is shown for example in the figure.

The energy losses in a target nucleus are expensed by the fast nucleon emission and by the target fragments evaporation; the fast nucleon emission comes from the cylindrical volume $\pi D_o^2\lambda$ centered on the hadron path; the target fragment evaporation comes from the pipe $\pi[(1.5D_o)^2-D_o^2]\lambda$ centered on the hadron path λ or, in other words, from the surface of the destroyed part of the residual nucleus (fig.)

The destruction of the target nucleus causes probably an instable residual nucleus state, with an unusual unstable nucleon configuration. To this configuration corresponds some inner nuclear energy and the residual nucleus must pass to stable lighter fragments.

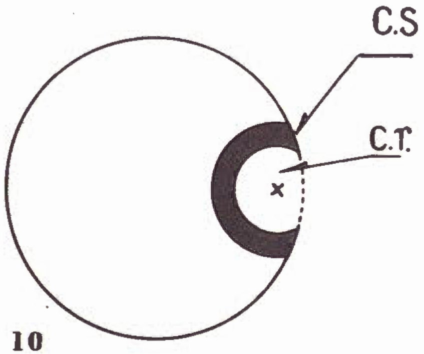

Fig. Schematic view of the mostly frequent destruction of the target nucleus in hadron-nucleus collisions. c.r. - the cylindrical region the fast nucleons are emitted from, centered on the hadron course h ; c.s. - cylindrical surface the target fragments evaporate from; x - the point at which incident hadron fell perpendicularly to the picture plane.

The picture presented here, of the fast nucleon emission process and of the target fragment evaporation process, has its support in experiments; the suggested picture of the instable residual nucleus decays into stable fragments must find its support in experiments, it may be tested in studying characteristics of the heavier fragments in hadron-nucleus collisions.

Because the diameter of the region of the target nucleus involved in the nucleon emission and fragment evaporation processes is as large as about $3D_o$,and the radius of the heaviest nucleus is about $5D_o$,and the hadron-nucleus collisions with large impact parameters are mostly frequant, the evaporation of the target fragments comes predominantly from the surface region of the destructed part of the residual nucleus (fig.).

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Стругальский З. E1-84-194
Потери энергий и остановки адронов в ядерной материи

Исследуются потери энергии и остановки адронов в ядерной материи при использовании набора случаев столкновений пион-ксенон,в которых падающий пион поглощается полностью в ядре-мишени, не вызывая рождения частиц. Анализ событий этого типа позволяет заключить, что адроны теряют регулярно часть своей кинетической энергии, приводят к испусканию нуклонов и испарению ядерных фрагментов из ядра-мишени. Потери энергии адронов в ядерной материи можно выразить с помощью простых формул в терминах кратностей испущенных протонов и испаренных фрагментов и их средних энергий.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1984

Strugalski Z. E1-84-194
Energy Loss and Stopping of Hadrons in Nuclear Matter

Energy loss and stopping of hadrons in nuclear matter is studied using the data on the pion-xenon nucleus collision events in which incident pion is completely stopped and deposits its energy inside the target nucleus causing intensive emission of nucleons and evaporation of target fragments without particle production. The analysis of the stopped events allows one to conclude that hadrons lose monotonically a fraction of their energy by fast nucleon emission and target fragment evaporation. Energy loss of a hadron in nuclear matter is expressible by simple formulas in terms of the multiplicities of emitted nucleons and evaporated fragments and their mean energies.

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1984