СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E1-98-99

Z.Strugalski*, E.Strugalska-Gola*

NUCLEAR ENERGY RELEASE IN HADRON-NUCLEUS COLLISIONS

Address for correspondence:
*Institute of Atomic Energy, 05-400 Otwock-Swierk, Poland

1998

I. INTRODUCTION

The collisions of high energy hadrons with atomic nuclei cause intranuclear reactions in the nuclear targets. «High» means here the kinetic energy over the pion production threshold.

The reactions develop themselves in two stages: the «fast» one, lasting from nearly 10^{-24} up to about 10^{-22} s and the «slow» one, lasting from 10^{-22} up to nearly 10^{-16} s. The first of the stages is due to the hadron interaction with intranuclear matter — in its passing through the nucleus; the second one does not involved any action of the incident hadron, the locally damaged residual target nucleus *transmutes itself from* an instable stage into some stable — one, or more stable stages.

Such mechanism of the intranuclear reactions induced by hadronic projectiles leads to a possibility of an occurrence of energy overcompensating nuclear reactions.

The induced by the fast hadrons intranuclear reactions are in fact the artificial nuclear reactions one of which has been observed in nature in the Hahn-Strassman historical observations.

Energy will be released from any group of bound particles that can be rearranged into a system that has a greater binding energy. The rearrangements may be realised in nuclear reactions. A nuclear reaction is a process in which nucleons are added to, removed from, or rearranged within a target nucleus under bombardment by hadrons, nuclei or gamma radiation.

It is customary to use a shorthand notation for specifying nuclaer reactions:

$$X(a,b)Y, \tag{1}$$

where the first quantity X specifies the target nucleus and the last quantity Y specifies the residual nucleus; a is the incident particle and b is the outgoing particle; instead of a and b may be placed an incident nucleus or the yield of the nuclear reaction. This notation will be used later not only for the simplest type of nuclear reactions, but for all the reactions, e.g.:

$$^{131}\mathrm{Xe}(p,b)\ \mathrm{Re}\ ^{131}\mathrm{Xe}. \tag{2}$$

In all nuclear reactions a balance of protons and neutrons in the initial and final states should be conserved.

The mass-energy balance in a nuclear reaction will be calculated by using exactly the same method as that used in calculating binding energies, namely - the combined mass of the target nucleus and the bombarding particle should be compared with the combined mass of the residual nucleus and the outgoing particles.

The difference in energies between the initial and final states in a nuclear reaction is called usually the *Q-value* for the reaction and it is given in energy units. *A positive Q-value* means that *energy is released, a negative Q-value* means that *energy must be supplied.* When Q values are positive, nuclear reaction induced in the hadron-nucleus collision will be called the overcompensated one.

2. SUBJECT MATTER

Considerations about nuclear energy release processes in the hadron-nucleus collision induced nuclear reactions [1] are subject matter in this communication. It became clear that such considerations may be really experimentally based and successful when the mechanisms of the hadron-nucleus collision processes at energies higher than the pion production threshold [1,2] are recognized.

Obviously, the most adequate sample of the hadron-nucleus collision events for such a study are those in which the hadron-nucleus collisions without particle production, at energies larger than the pion production threshold, are collected [3,4]. In fact, it has been shown [5] that the nucleon emission process is not affected by the particle production processes. Energy, momentum spectra and angular distributions are practically the same in both the samples — without and with particle production [6].

At 3.5 GeV/c, the events with the stopped projectiles inside the Xe target nucleus are such in which pions traversed the target nucleus along its diameter [7]. The samples of the stopping and energy deposition of hadrons in target nuclei, being under discussion here, are collected using material sampled in our previous experimental works [1—6, 8—20].

Within the context of the considerations of this paper, three of our previous experimental investigations are of fundamental importance [21—23]. In the first two of the works the results of experimental investigations of two-dimensional distributions of the emission angle Θ_{π^0} and the total energy E_{π^0} in the lab.c.s. were obtained for three channels of interactions:

$$\pi^- + \mathrm{Xe} \rightarrow \pi^0 + A', \tag{3}$$

$$\pi^- + \mathrm{Xe} \rightarrow \pi^0 + p + A', \tag{4}$$

$$\pi^- + \mathrm{Xe} \rightarrow \pi^0 + \pi^- + A', \tag{5}$$

where A' is the residual nucleus. A considerable correlation has been observed between Θ_{π^0} and E_{π^0} kinematically corresponding to the emission of the observed π^0 mesons from the collisions of primary π^- mesons with the intranuclear effective target which mass coincides with that of pion [2,3,23]. In the third one of the works, search for correlations between protons emitted in high energy hadron-nucleus collisions has been performed using the events at 3.5 GeV/c momentum. As a result, it has been obtained that the clustering of protons is an experimental fact — outside the limits of statistical errors, for the multiplicities of the emitted protons $k < 8$ [23].

The experimentally based mechanisms of the hadron nucleus collision process and of the hadron-nucleus collision induced nuclear reactions should be described here — before to discuss about the nuclear energy release in fast hadron-nucleus collisions. The subject matter in this paper are, therefore — in the next sections, the descriptions of the mechanisms.

3. MECHANISMS OF THE COLLISION PROCESSES

Mechanisms of high energy hadron-nucleus and nucleus-nucleus collision processes have been depicted in our former works [24], as prompted experimentally.

Four main phenomena are usually observed when hadrons collide with atomic nuclei:

a) The passage of the hadronic projectile or its successors through intranuclear matter, accompanied by the emission of nucleons with kinetic energy from about 20 up to about 500 MeV from the strong interaction region; we call them the «fast» nucleons later;

b) The production of hadrons;

c) The evaporation of the target fragments including the target nucleons of kinetic energy smaller than about 10—20 MeV;

d) The fission of residual target nucleus into nuclear fragments.

The interaction of the incident hadron passing in intranuclear matter is localized in small cylindrical volume, with the radius as large as the strong interaction range is, centered on the hadron course inside the nucleus. Particles are produced via intermediate objects («generons») produced in $2 \rightarrow 2$ endoergic collision reactions of the hadrons and its successors with downstream nucleons. The particle production process goes on the background of the projectile passage through intranuclear matter and it is localized along the projectile course, within the tube of the radius R_s as large as the strong interaction range, centered on the hadron course. At the incident hadron energies large enough — larger than a few GeV, the particle production process does not disturb the «fast» nucleon emission.

After the passage of the incident hadron and its successors through the target nucleus, after about 10^{-22} s, the residual target nucleus is locally damaged and usually instable. After next about 10^{-16} s it may evaporate isotropically nucleons and light nuclear fragments — as D, T, α particles. The evaporation goes from the damage surfaces [1,25] in the residual target nucleus.

The residual target nucleus, after the evaporation of the nuclear fragments, may be instable then as well. It may decay, therefore, in some stable smaller pieces; the collision process is exhausted [7].

4. THE NUCLEAR REACTIONS INDUCED IN THE HADRON-NUCLEUS COLLISION PROCESS

In the light of many experimental investigations of the hadron-nucleus collision processes [1],the nuclear reaction induced by hadron-nucleus collision consists of two stages: the fast stage starting at the moment of impact of the colliding bodies and the slow stage starting practically a long time after the projectile-nucleus interaction ending — when the incident hadron and its successors left the target nucleus. The first stage lasts about 10^{-24}—10^{-22} s, the slow stage — from about 10^{-22} s up to about 10^{-16} s.

In the first, fast stage, fast nucleons are ejected (≈ 20—500 MeV) and the target nucleus is damaged locally, and it becomes to be in an instable nucleon configuration. It leads to starting of the second stage — the slow one. The residual nucleus should be transformed into some equilibrium state or states of its separate parts [1].

In the fast stage of the nuclear collision, the target damage is realized on an account of a portion of the incident hadron energy.

The second stage of the nuclear reaction is on the account of internal nuclear energy of the residual damaged target nucleus.

5. ENERGY BALANCE IN THE NUCLEAR REACTIONS INDUCED IN HADRON-NUCLEUS COLLISIONS

Incident hadrons — pions, nucleons, kaons and other strongly interacting particles lose their kinetic energy in passing through layers of intranuclear matter due to electromagnetic and strong interactions with downstream nucleons. The *range-energy relation in intranuclear matter for pions and protons* was obtained experimentally [27]. The average energy loss per nucleon/S was determined as well [4,7]; for pions it is $\varepsilon_\pi = 0.18$ GeV/nucleon/S, for protons $\varepsilon_p = 0.36$ GeV/nucleon/S [7], where $S = \pi R_h^2 \approx \pi D_0^2$, D_0 is the diameter of the nucleon as large approximately as the strong interaction range R_s.

The nuclear energy release in the hadron-nucleus collision induced nuclear reactions may manifest itself in the «fast» nucleon emission — in the first stage of the collision; in the nucleons and light nuclear fragment evaporation — in the second stage of the collision; and in decays of residual target nuclei into two or more stable pieces — in the final stage of the collision induced nuclear reaction [26]. The portion of the incident hadron energy carried away in the particle generation process may be not taken into account. The particle production goes through intermediate objects or generons which behave themselves, in passing through layers of intranuclear matter, as the nucleons do it; they decay into observed «created» pions and other particles — after having left the parent nucleus [26].

Possible effects of the particle production process on the nucleon emission and target fragment evaporation in hadron-nucleus collisions were investigated. It was found that the particle production process does not influence the nucleon emission and the fragment evaporation processes [28]. For the nuclear energy release investigations, the simplest of hadron-nucleus collision events may be analysed, therefore. Namely, such collision events in which the incident hadrons in passing through the target nuclei, are absorbed in them or stopped in them, or passed them without causing the particle production [4].

5.1. ***Energy balance in events with the incident hadron stopped inside the target nucleus***. The problem to be discussed now is concerned with the energy balance in the fast stage of collisions, in such events when the projectile hadron (e.g., pion, proton) is completely stopped inside the target Xe-nucleus, accompanied by fast nucleon emission (with kinetic energies from about 20 up to about 500 MeV).

The events under study were photographed in 180 litre xenon bubble chamber of the institute of Theoretical and Experimental Physics at Moscow, exposed to 3.5 GeV/c negatively charged pion beam from the ITEPh accelerator. In such conditions for the chamber expositions, the incident pion is completely stopped in the central pion-xenon nucleus collisions.

In such sample of the events, the energy of the incident pion lost in the target xenon nucleus is $E_h \approx 3.2$ GeV, because a small portion — ≈ 0.3 GeV of it is lost by ionization inside the bubble chamber. In result of such a collision, in average $\langle n_p \rangle = 7.4$ fast protons and $\langle n_n \rangle = [(A-Z)/Z] \langle n_p \rangle$ fast neutrons, or simply $\langle n_N \rangle = (A/Z) \langle n_p \rangle$ fast nucleons are emitted. The average number $\langle n_N \rangle$ 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 $\langle E_{kN} \rangle \approx 90$ MeV, as is known from fast proton mean energy $\langle E_{kp} \rangle$ measurements.

The total mean kinetic energy of the emitted $\langle n \rangle$ fast k nucleons $\langle \overset{k}{\Sigma} E_{kN_p} \rangle$ is then:

$$\langle \overset{k}{\Sigma} E_{kN_p} \rangle = (A/Z) \langle n_p \rangle \langle E_{kp} \rangle, \tag{6}$$

where $\langle n_p \rangle$ and $\langle E_{kp} \rangle$ are measurable quantities; A and Z are the mass- and charge-numbers.

The total mean kinetic energy of the ejected fast nucleons (6) is one of parts of the incident hadron kinetic energy $\Delta_1 E$ lost in its passage through the target nucleus. Another part of the incident hadron energy E_h could be the energy lost for the particle production process through the intermediate object (generon). But, only the events without particle production are analysed in this section, the mean kinetic energy of the emitted nucleons:

$$\langle \Sigma E_{kN} \rangle = \Delta_l E \leq E_h \tag{7}$$

is in fact equal to or smaller than the kinetic energy E_h of the incident hadron.

Then, all the hadron kinetic energy is lost for the fast nucleon emission and for the target nucleus to damage (and to excite), therefore. This stage of the collision induced nuclear reaction lasts from about 10^{-24} to 10^{-22} s. The second stage of the reaction lasts from about 10^{-22} s up to about 10^{-16} s, and this nuclear reaction taking place in this second (slow) stage is caused by the target damage and a transition of the residual target from its instable nucleon configuration into a stable one. The residual nucleus structure transition is realized due to the internal energy of the residual (damaged as well) nucleus. This energy release manifests itself in the nucleons and light nuclear fragments evaporation from the residual target nucleus.

5.2. ***Energy balance in the second stage — when the damaged residual target nucleus transits itself into a stable stage, in evaporating slow nucleons and light nuclear fragments.*** The average multiplicity $\langle n_d \rangle$ of the evaporated charged fragments is connected with the multiplicity n_p of the emitted fast protons — ejected in the fast stage (the first stage) of the hadron-nucleus collision induced nuclear reaction [25]:

$$\langle n_d \rangle = 1.25(n_p + (A - Z)/Z). \tag{8}$$

This relation is valid for any hadron-nucleus collision [29].

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, it be reasonable to expect that $\langle n_d \rangle k(A/Z)$ nucleons are evaporated. Other evaporated target fragments are $(1 - k) \langle n_d \rangle$ deuterons, tritons and α particles.

The mean kinetic energy of the evaporated fragments is [30] $\langle E_{kd} \rangle \approx 20$ MeV, then the kinetic energy $\langle \Sigma E_{kf} \rangle$ of the fragments is, in average:

$$\langle \Sigma E_{kf} \rangle = \langle E_{kd} \rangle k(A/Z) \langle n_d \rangle + (1 - k) \langle n_d \rangle. \tag{9}$$

This is the second part $\Delta_2 E$ of the mean nuclear energy — released in the slow stage of the nuclear reaction induced by the projectile hadron.

Summing up, the energy released in both the stages of the nuclear reactions in the hadron-nucleus collisions is:

$$\langle E_r \rangle = \langle \Delta_1 E \rangle + \langle \Delta_2 E \rangle. \tag{10}$$

6. QUANTITATIVE ESTIMATIONS

Let us evaluate the energy release quantitatively, for the case under considerations — for $\pi^- + \mathrm{Xe}$ nuclear collisions without hadron production at 3.5 GeV/c momentum. It should be remembered that at this projectile momentum value, for the events when projectile is stopped inside the target $^{131}\mathrm{Xe}_{54}$ nucleus, the collisions are central and the projectiles cover the nuclear layer as thick as the target nucleus diameter is.

Finally, the residual target-nucleus, after the evaporation of the light nuclear fragments, in the second stage of the intranuclear reaction, may be instable more — and it should decay still into stable two or more final smaller nuclei.

In this final decay, some intranuclear energy should be released — more.

Formula (10) will be, therefore:

$$\langle \Delta_r E \rangle = \langle \Delta_1 E \rangle + \langle \Delta_2 E \rangle + \langle \Delta_3 E \rangle, \tag{10'}$$

where $\langle \Delta_3 E \rangle$ is the mean energy released in the final decay of the residual instable nucleus into smaller stable two or more parts.

6.1. ***Energy released in the fast stage of the nuclear reaction.*** The process in which the energy release is manifesting itself clearly is the emission of fast nucleons (20—500 MeV of kinetic energy). The mean value $\langle \Delta_1 E \rangle$ of this energy is estimated by measurements of the proton energy; it is:

$$\langle E_1 \rangle \simeq 1746 \text{ MeV}. \tag{11}$$

This is a part of the incident hadron energy E_h lost in the passage through intranuclear matter. In passing through the target nucleus the projectile hadron damaged it and, this way — induced the nuclear reaction, its fast and slow stages.

The portion of the incident hadron energy E_h is lost as well:

$$\Delta = E_h - \Delta_1 E = 1454 \text{ MeV}. \tag{12}$$

This considerably large part, ≈ 80 MeV per emitted nucleon, in average, is lost additionally inside the target nucleus. No any observable effects indicate this energy loss. Where is it lost? We will try to find an answer!

6.2. ***Energy released in the slow stage of the nuclear reaction***. The nuclear energy released in this stage is due to the internal energy of the damaged residual target nucleus. It manifests itself in the nuclear fragment evaporation. This energy is estimated from kinetic energy evaporations by measurements — mainly in nuclear photoemulsions. The mean value of it is given by formula (9)

$$\langle E_{kf} \rangle = 624 \text{ MeV}. \tag{13}$$

It is the second portion of the mean energy released in the nuclear reaction induced in hadron-nucleus collision.

6.3. ***Energy released in both the stages of the nuclear reaction***. The total energy released in both the stages of the nuclear reaction together is, in average:

$$\langle E_r \rangle = \langle \Delta_1 E \rangle + \langle \Delta_2 E \rangle = 2370 \text{ MeV}. \tag{14}$$

The nuclear energy $\Delta_3 E$ will not be estimated now in this paper. We should write therefore:

$$\langle \Delta E_r \rangle = \langle \Delta_1 E \rangle + \langle \Delta_2 E \rangle = 2370 \text{ MeV} \tag{14'}$$

instead of the relation (14).

6.4. ***Q-value***. In the context of the considerations here, the difference in energies between the final and initial stages in the nuclear reactions is:

$$Q = \langle \Delta E_r \rangle - E_h, \tag{15}$$

where $\langle \Delta E_r \rangle$ is defined by formula (14′) and E_h is the incident hadron initial energy. The value of Q cannot be here estimated quantitatively, because the $\Delta_3 E$ value — of the energy released in the residual nucleus final decay into stable smaller two or more nuclei should be determined in some other experiments.

The Q-value is negative, it amounts $Q = (\Delta_1 E + \Delta_2 E) - E_h = -0.8$ GeV for the central collision of 3.2 GeV pions with xenon nuclei, and it does not take into account the mean energy released in the residual nucleus decay into stable final two or more nuclei.

It is not excluded that the energy overcompensating hadron-nucleus collisions may occur. It should be a consequence of the mechanism of nuclear energy release in the intranuclear reactions induced in hadron-nucleus collisions.

7. CONCLUSIONS AND REMARKS

The target nuclei in high energy hadron-nucleus collisions release always some part of their internal energy in the second «slow» stage of the nuclear reaction induced by the projectile hadron in the target nucleus. The residual target nucleus, damaged in the «fast» stage of the collision — and instable therefore, is transiting itself to some stable state or a few separate stable states of its smaller parts. The intranuclear energy release in the slow stage manifests itself by the emission of relatively slow light nuclear fragments — nucleons, D, T, α particles, and finally by the occurring sometimes decays of the residual target nucleus into two or more heavier fragments.

Additionally, some portion of the projectile hadron energy lost in its passage through the target nucleus (in the fast stage of the collsion process) is released by the fast (20—500 MeV) nucleons emission.

The recognition of this mechanism of the intranuclear energy release was based on following crucial experiments:

1. The damage of the target nucleus by the incident hadron is local, and the number of the fast nucleons emitted from the target equals the number of the nucleons met around the hadron course in intranuclear matter (within the cylindrical region around the hadron course with the radius as large as the strong interaction range R_h is, $R_h \approx D_0$, where D_0 is the nucleon diameter) [5-8].

2. The mean number $\langle n_f \rangle$ of the light fragments «evaporated» from the residual target nucleus depends simply on the number of the emitted fast nucleons from the target nucleus [25,26].

3. The fast nucleon emission and the light of the nuclear fragments evaporation do not depend on that the hadron production in the collision occurs or not [28].

In experiments and observations the target nuclei were used as some subnuclear detectors [31,32].

Results are applicable in nuclear fuels searching for, in nuclear transmutations technologies, in nuclear chemistry, in biology and medicine.

REFERENCES

1. Strugalski Z., Strugalska-Gola E. — The Mechanisms of the Hadron-Nucleus Collision Processes and of the Hadron-Nucleus Collision Induced Nuclear Reactions — In the Light of Experimental Data. JINR, El-97-177, Dubna, 1997; references in it.
2. Strugalska-Gola E. et al. — The Picture of the Nuclei Disintegration Mechanism — from Hadron-Nucleus and Nucleus-Nucleus Collisions Experimental Investigations at High Energies. JINR, El-97-129, Dubna, 1997; references in it.
3. Strugalski Z. et al. — Experimental Study of the Pion-Xenon Nucleus Collisions without Particle Production at 3.5 GeV/c Momentum. JINR, El-85-888, Dubna, 1985; references in it.
4. Strugalski Z. — Energy Loss and Stopping of Hadrons in Nuclear Matter. JINR, El-84-194, Dubna, 1984; references in it.
5. Strugalski Z. — The Laws of Nucleon Emission and Target Fragment Evaporation in Collisions of High Energy Hadrons with Atomic Nuclei. JINR, El-84-853, Dubna, 1984; references in it.
6. Strugalski Z. — Retardation of Hadrons in Passing through Intranuclear Matter. JINR, El-88-639, Dubna, 1988; references in it.
7. Strugalski Z. — Stopping and Energy Deposition of Hadrons in Target Nuclei. JINR, El-83-850, Dubna, 1983; references in it.
8. Strugalski Z., Pluta J. — Energy and Angular Distributions of Protons Ejected in Pion-Xe Nucleus Interactions at 3.5 GeV/c Momentum. Journal of Nucl.Phys. (Russian), 1974, v.27, p.504; JINR, Pl-7730, Dubna, 1974; see also references and figures in it.
9. Strugalski Z. et al. — Proton Spectra in High-Energy Pion-Nuclei Collisions Not Accompanied by Multiparticle Production. JINR, El-11975, Dubna, 1978.
10. Strugalski Z. — Monotonous Braking of High Energy Hadrons in Nuclear Matter. JINR, El-12086, Dubna, 1979.
11. Strugalski Z. et al. — Energy Spectra of Protons Emitted in Pion-Xenon Nuclei Collision Events without Multiparticle Production. JINR, El-12087, Dubna, 1979.
12. Strugalski Z. — High Energy Hadron-Nuclei Collisions Causing Intensive Emission of Fast Nucleons Not Accompanied by the Multiple Pion Creation. JINR, El-12522, Dubna, 1979; 8 International Conf. on High Energy Phys. and Nuclear Structure. Vancouver, Canada, 1979.
13. Strugalski Z. et al. — Experimental Study of the Pion-Xenon Nucleus Collisions without Particle Production at 3.5 GeV/c Momentum: General Data. JINR, El-82-718, Dubna, 1982; references in it.
14. Strugalski Z. et al. — Experimental Study of the Pion-Xenon Nucleus Collisions without Particle Production at 3.5 GeV/c Momentum: Asymmetry in Proton Emission. JINR, El-82-719, Dubna, 1982.
15. Strugalski Z. et al. — Experimental Study of the Pion-Xenon Nucleus Collisions without Particle Production at 3.5 GeV/c Momentum: Energy and Momentum Spectra of Emitted Protons. JINR, El-82-841, Dubna, 1982.
16Strugalski Z. et al. — Experimental Study of the Pion-Xenon Nucleus Collisions without Particle Production at 3.5 GeV/c Momentum: Angular Distributions of Emitted Protons. JINR, El-83-234, Dubna, 1983.
17. Strugalski Z. — Energy and Momentum Spectra of Nucleons Emitted in High Energy Hadron-Nucleus Collisions. JINR, El-83-155, Dubna, 1983.
18. Strugalski Z. — Angular Distributions of Nucleons Emitted in High Energy Hadron-Nucleus Collisions. JINR, El-83-344, Dubna, 1983.
19. Strugalska-Gola E. — Characteristics of the Pion and Proton Emission in Collisions of Fast Hadrons with Atomic Nuclei (in Polish). PhD Thesis - Warsaw University of Technology, Dept.of Technical Physics and Applied Mathematics, Institute of Physics. Warsaw, Poland, 1996.
20. Strugalski Z. — Energy and A-Dependences of the Nucleon Emission Intensity in Hadron-Nucleus Collisions. JINR, El-83-851, Dubna, 1983.
21. Ohrimenko L.S. et al. — Neutral Pion Emission in Negative Pion-Xenon Interactions at 3.5 GeV/c and the Problem on the Intranuclear Effective Target. (Russian) JINR, Pl-9691, Dubna, 1976.
22. Ohrimenko L.S. et al. — Neutral Pion Generation in Collisions of Pions with Xenon Nuclei at 2.4 and 3.5 GeV/c and the Question Connected with the Effective Target. (Russian) JINR, Pl-9807, Dubna, 1976.
23. Mulas E., Strugalski Z. — Search for Correlations between Protons Emitted in High Energy Hadron-Nucleus Collisions. JINR, El-94-216, Dubna, 1994; references in it.
24. Strugalski Z. — Mechanisms of High Energy Hadron-Nucleus and Nucleus-Nucleus Collision Processes. JINR, El-94-295, Dubna, 1994; references in it.
25. Strugalski Z. — The Evaporation of Singly and Multiply Electrically Charged Slow Target Fragments in Hadron-Nucleus Collision Reactions. JINR, El-95-231, Dubna, 1995; references in it.
26. Strugalski Z., Jedrzejec H., Mulas E., Strugalska-Gola E. — Final Stage of High Energy Hadron-Nucleus Nuclear Collision Reactions. JINR, El-96-1, Dubna, 1996.
27. Strugalski Z., Dessoky A. E., Mulas E., Hassan N. — The Behaviour of Generons in Intranuclear Matter. JINR, El-93-322, Dubna, 1993.
28. Strugalski Z. — Search for Effects of the Particle Production Process on the Nucleon Emission and Target Fragment Evaporation in Collisions of Hadrons with Atomic Nuclei. JINR, El-84-854, Dubna, 1984.
29. Otterlund I. et al. — Nuclear Phys., 1978, v.B142, p.445.

30. Tolstov K.D. — Atoms and Nuclei, 1981, v.301, p. 39.
31. Strugalski Z. — The Target Nucleus as an Indicator of Various Properties of the Hadron-Nucleon and Hadron-Nucleus Collision Processes. JINR, E1-80-548, Dubna, 1980; references in it.
32. Strugalski Z. — Study of the Particle Production Process Using Nuclear Targets, I-III. JINR, E1-81-576, E1-81-577, E1-82-287, Dubna, 1981-1982; references in it.

Received by Publishing Department
on April 20, 1998.