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INTERNUCLEAR CASCADES AT HIGH ENERGIES

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Межъядерные каскады при высоких энергиях

Обсуждаются методы монте-карловского моделирования каскадов частиц возникающих в блоках вещества под действием высокоэнергетических адронов и ядер. Хорошее согласие с опытом дает гибридная модель, основанная на некогерентном внутриядерном каскаде для частиц и ядер с энергиями, не превышающими несколько ГэВ/нуклон, и приближении кварк-глюонных струн для больших энергий. Распады возбужденных остаточных ядер в обоих случаях рассчитываются на основе испарительного каскада. Разработана версия модели, применимая для энергий вплоть до 100 ГэВ/нуклон. Более аккуратный расчет неупругих адрон- и ион-ядерных взаимодействий позволяет распространить ее и на более высокие энергии - вплоть до 10^3-10^4 ГэВ/нуклон.

Работа выполнена в Лаборатории вычислительной техники и автоматизации ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1989

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Internuclear Cascades at High Energies

Methods of Monte-Carlo simulation of particle cascades forced in material samples by high energy hadrons and nuclei are discussed. It appears that a hybrid model based on noncoherent intranuclear cascade mechanism for particles and nuclei with energies under several GeV/nucleon and quark-gluon string approach at high energies is in good agreement with experiment. Decays of excited residual nuclei are calculated by means of evaporation cascade mechanism in both cases. A version of the model is developed, which could be applied at energies up to 100 GeV/nucleon. More accurate calculation procedure for inelastic hadron- and ion-nucleus interactions allows one to spread its application to higher energies - up to 10^3-10^4 GeV/nucleon.

The investigation has been performed at the Laboratory of Computing Technique and Automation , JINR.

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Introduction

Detailed simulation of internuclear cascades and attendant nuclear processes initiated by hadrons and nuclei with energies about several GeV/nucleon and above in gaseous and condensed matter is of great interest in construction of high current ion accelerator shielding, super high energy hadron accelerator shielding (profound review of this problem see in ref./1/) and particularly in investigation of radiation effects of cosmic radiation on equipment and biological objects in space and at high altitudes in the earth atmosphere. Cascade calculations at low energies could be performed with high accuracy using a cascade-evaporation model of hadron and ion-nucleus interactions /2,3/. As for proton part of cosmic radiation, one could thus move forward in the region of high energies - up to T=20-30 GeV[1)]. In this case violations of noncoherent intranuclear cascade mechanism do not effect much the characteristics of particles produced, especially while taking into consideration the huge samples, where the main contribution is made by low energy interactions. A set of respective computer programs is described in our report /5/.

More complicated situation takes place if simulating the radiation effects in thin foils and films, where secondary nuclear interactions are practically absent and inaccuracies of high energy collision calculations are quite evident, and also during the simulation of cascades, initiated by high energy ions, where noncoherent intranuclear cascade process is substantially violated even at energies of several GeV/nucleon /6/.

[1)] If one takes into account the trailing effect - that is the decrease of the nucleon density in the cascade process /4/.

In this case one can succeed only when using the quark-gluon string model, originally proposed for hadron-hadron collisions description /7,9/ and spreaded over the nucleus-nucleus interactions later on /9-14/. Though this model is far from its completion and it is not clear yet how to consider interactions of strings and particles produced during their decay with intranuclear nucleons, one can think that the relative contribution of these interactions is insignificant and at first it could be taken into account using approximate approaches[2]. One is forced to believe this primarily when comparing the experimental and calculated multiplicities of particles, knocked out of the nucleus. For example, while the fraction of π^--mesons produced because of the intranuclear "multiplication" $(\langle n_{exp}\rangle - \langle n_{th}\rangle)/(\langle n_{exp}\rangle)$, where $\langle n_{th}\rangle$ is calculated without consideration of the intranuclear interactions of particles produced comes to not more than 20-30% in case of proton interactions with tantalum nucleus at T=3.3 GeV, at T=9 GeV it is already roughly 3 times less. At T=200 GeV, the uppermost energy at which the yield of π^--mesons in hadron-nucleus reactions has been measured, the experimental and theoretical multiplicities are practically the same /13/. The same conclusions could be also derived for inelastic collisions of high energy ions. Relative contribution of intranuclear "multiplication" is even smaller in this case than in hadron-nucleus collisions. Besides one must bear in mind that the values of momenta and angles of emitted

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[2] To achieve this goal different approaches are developed in the mentioned refs.: the way of considering string interactions with nucleons inside the nucleus on a phenomenological basis has been proposed in ref./9/; in refs./10,11/ string interactions are not considered, but the possibility of string formation in successive interactions of projectile hadron with several nucleons in target nucleus and certain phenomenological "formation time" is introduced for each particle produced in string decay, during this time, the particle stays inert and does not interact with other particles; finally, it is suggested in refs./13,14/ similar to the models of the leading barion not to consider the interactions of secondary particles at all.

particles in hadron- and ion-nucleus collisions are determined mainly by kinematics of transition from the centre of mass system of objects, interacting inside the nucleus to the laboratory system, that is why the different models come to practically coincident results when they are used to calculate these quantities.

In the energy range exceeding several dozens of GeV the most detailed is perhaps the model developed by Amelin /9/, however, as for practical results, only a slight difference is observed from the results of the model described in refs./12-14/. Along with this the latter takes into account the processes of diffraction dissociation to low mass states, playing an important role at T<10GeV/nucleon, which makes it possible to use it at lower energies, that is about T=3-4 GeV/nucleon. Besides it is due to the fact that many inessential details in internuclear cascade calculations are neglected, this approach is more simple in use and requires considerably less computation time. Performing several additional improvements of the model (which are being discussed in details later), we united it with the cascade-evaporation model of nuclear interactions, thus receiving computer modes, useful for Monte-Carlo simulation of radiation effects on material samples in the whole range of cosmic energies which appears to be of considerable interest to us.

The main goal of our paper is to describe the peculiarities of such hybrid model and to demonstrate its potentialities by comparison with the data of the experiment on irradiation of a copper target by protons and carbon ions with energies T=3.65 GeV/nucleon carried at the JINR /15,16/. First we shall discuss the problem of mating the two employed models of nuclear interactions, then we proceed to the discussion of internuclear cascade.

Nuclear Interactions at T<10 GeV/nucleon

As a boundary energy dividing the realms of "cascade" and "string" models of inelastic hadron- and ion-nucleus collisions we have chosen T=3.5 GeV/nucleon.

Physical mechanism and parameters of the cascade model are described in details in refs./2,4,6/, and its computer realization

– in refs. /17,18/. The string model is discussed in papers /12–14/. The main feature, distinguishing it from the other string models (see refs./9–11/) consists in the fact that: 1) the number of collisions of projectile hadron (nucleon, when projectile ion is considered) with target nucleus, that is the number of so-called "wounded" nucleons, and the number of quark-gluon strings produced during the interaction process, are determined using the Glauber theory of diffraction interactions (to make a comparison with the cascade model let us mention that in the latter case all the intranuclear interactions are taken to be absolutely independent, which helps to consider partially their coherent behaviour); 2) the processes of diffraction dissociation are taken into account more thoroughly; 3) the interactions of secondary particles with intranuclear nucleons are absolutely ignored; 4) the excitation energy of residual nuclei is supposed to be equal to the product of the number of "holes" which appear in the nucleus when all the "wounded" nucleons emerged from it and a certain phenomenological constant ε=23 MeV which means an average excitation energy falling on a "hole". Such approximate approach simplifies the calculation procedure, while the results do not distinguish much as compared with the data received from more accurate calculations used in cascade models, where the excitation energy is determined from energy-momentum conservation laws, based on the known characteristics of all the particles which left the nucleus.

Table 1 and figs.1,2 show how the results related to negative π-mesons agree with the experiment at energies close to that, chosen as a boundary energy[3)]. In the energy range of interest (T<10 GeV/nucleon) it is easy to define them during the measurements because the amount of other negatively charged particles is still rather small, and, which is of the utmost importance, unlike protons and neutrons escaping the nucleus which include both shower particles and intranuclear recoil nucleons as well as evaporation particles, all π^--mesons are produced only in high energy interactions. That is why the data presented characterize the accuracy of the description of the first collision

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[3)] The data on the errors concerning this calculation and the other ones are purely statistical.

Table 1.

Average momentum, emittance angle and multiplicity of π^--mesons at T=3.3 GeV/nucleon. The results of calculations carried out using the string and cascade models are marked with SM and CM respectively. Experimental data are taken from refs./19,20/.

Interaction	Model	<p>,GeV/c	<θ>,deg	<n>
1	2	3	4	5
	exper	0.53 ± 0.03	49.4 ± 1.7	0.33 ± 0.02
pC	SM	0.49 ± 0.001	47.3 ± 0.1	0.24 ± 0.001
	CM	0.43 ± 0.02	55.0 ± 2.0	0.48 ± 0.02
	exper	0.58 ± 0.03	44.2 ± 1.0	0.60 ± 0.03
dC	SM	0.60 ± 0.001	45.3 ± 0.1	0.50 ± 0.001
	CM	0.53 ± 0.01	47.5 ± 1.0	0.78 ± 0.02
	exper	0.63 ± 0.03	43.2 ± 1.1	1.02 ± 0.03
αC	SM	0.61 ± 0.02	41.6 ± 1.2	0.72 ± 0.02
	CM	0.56 ± 0.01	46.1 ± 1.2	1.16 ± 0.03
	exper	0.62 ± 0.03	40.0 ± 0.7	1.50 ± 0.05
CC	SM	0.62 ± 0.01	40.0 ± 0.9	1.23 ± 0.03
	CM	0.59 ± 0.01	41.4 ± 1.0	1.70 ± 0.04
	exper	0.48 ± 0.01	51.6 ± 0.6	3.2 ± 0.1
CTa	SM	0.49 ± 0.01	54.0 ± 1.5	3.4 ± 0.1
	CM	0.36 ± 0.02	66.0 ± 4.5	5.9 ± 0.4

of the projectile proton or the projectile ion with the nucleons in the target nucleus in the model (taking into account the coherent behaviour depending on the Glauber collision multiplicity mentioned above).

It is clear that in the vicinity of the boundary energy the string model leads to a lesser π^--meson multiplicity in comparison with the experiment, while the cascade model provides the reverse results that is the greater meson multiplicity. This discrepancy increases alongside with the transition to heavier colliding nuclei. Besides, the calculations have shown that the values <n> calculated via the string model remain close to those in experiment, in the case of the cascade model the discrepancy with experiment is rapidly increasing with the energy increase (see also ref./6/). Average momenta and emittance angles of the mesons are close to experimental regardless to the model used in the calculation though the cascade model as a rule gives somewhat wider angular distribution and evidently lesser values of <p>.

The data obtained with the string model only are presented in figs.1 and 2. There is no practical difference of these results

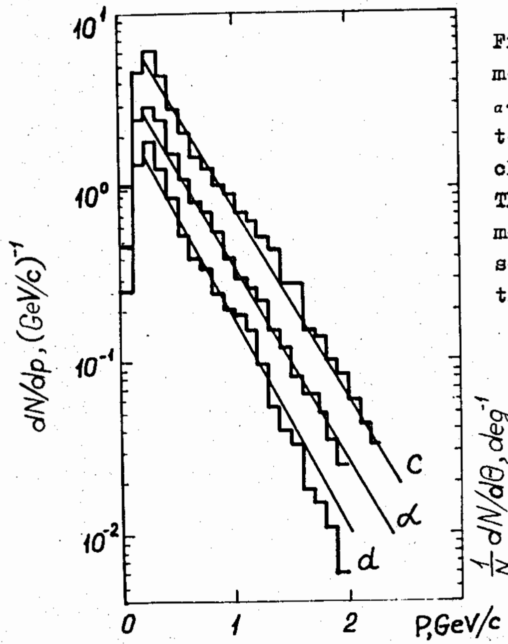

Fig.1. Momentum spectra of π^--mesons produced in deuteron, α-particle and carbon ion interactions with tantalum nuclei at T=3.3 GeV/nucleon. The histograms are string model calculation data, the solid line is an approximation of experimental data/21/.

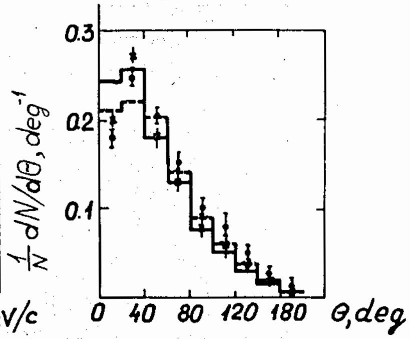

Fig.2. Angular distributions of π^--mesons at T=3.3 GeV/nucleon. Solid and dashed lines present the string model calculation data for deuteron and carbon ion interactions with tantalum nucleus respectively. The respective experimental data from ref./21/ are shown with o and x marks.

with the cascade model calculations. Excellent agreement of calculated and measured angular and momenta characteristics is not surprising because it comes from the reasons of kinematic character mentioned above[4].

Additional information on high energy collisions and on successive intranuclear interactions contribution can be obtained from the "cascade protons", which include all protons escaping the nucleus except those, which are produced during the decay of excited residual nucleus.

Experimental and theoretical data for cascade protons are presented in Table 2 and in fig.3. In the case of light projectile

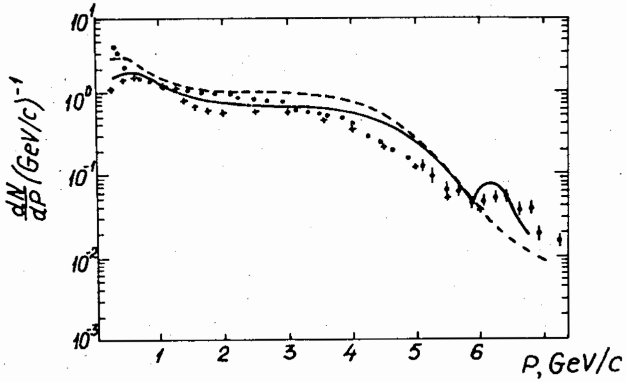

Fig.3. Momentum specrum of the cascade protons oroduced in inelastic interactions of two carbon nuclei at T=3.3 GeV/nucleon. Solid and dashed lines stand for string and cascade model calculation results respectively. The results of calculations based on the string model leaving out of consideration the "overheated bubble" are shown with crosses. The experimental data from ref./19/ are shown with dots.

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[4] Quite satisfactory agreement with experiment of the data on the average momenta and angles maintains even at energies of dozens of GeV/nucleon in the case of the cascade model, where theoretical multiplicity <n> is already considerably different from the experiment.

Table 2.

Average momentum, emittance angle and multiplicity of the cascade protons at T=3.3 GeV/nucleon. All designations are the same as in Table 1. The multiplicity calculated using the phenomenological correction related to cascade of particles is shown. Experimental data are taken from refs./25,26/.

Interaction	Model	$\langle p \rangle$, GeV/c	$\langle \theta \rangle$, deg	$\langle n \rangle$
1	2	3	4	5
pC	exper	1.44 ± 0.06	38.2 ± 1.0	1.83 ± 0.1
	SM	1.62 ± 0.003	31.0 ± 0.06	1.46 ± 0.003
	SM + bubble	1.47 ± 0.003	38.7 ± 0.08	1.76 ± 0.004
	CM	1.16 ± 0.04	43.3 ± 1.5	2.15 ± 0.08
dC	exper	1.50 ± 0.04	38.0 ± 0.07	1.95 ± 0.08
	SM	1.60 ± 0.003	30.1 ± 0.06	1.59 ± 0.03
	SM + bubble	1.53 ± 0.003	39.4 ± 0.08	1.88 ± 0.004
	CM	1.12 ± 0.02	42.6 ± 0.9	2.46 ± 0.05
αC	exper	1.63 ± 0.04	34.7 ± 0.5	3.06 ± 0.1
	SM	1.71 ± 0.05	27.0 ± 0.8	2.0 ± 0.06
	SM + bubble	1.77 ± 0.05	34.1 ± 1.0	2.63 ± 0.08
	CM	1.48 ± 0.04	35.4 ± 0.9	3.33 ± 0.09
CC	exper	2.00 ± 0.03	28.1 ± 0.4	4.30 ± 0.1
	SM	1.90 ± 0.04	25.3 ± 0.6	3.50 ± 0.08
	SM + bubble	2.00 ± 0.04	29.1 ± 0.6	4.06 ± 0.09
	CM	1.93 ± 0.05	28.0 ± 0.7	4.99 ± 0.1
CTa	exper	1.05 ± 0.01	49.6 ± 0.4	15.2 ± 0.6
	SM	1.14 ± 0.03	36.0 ± 0.8	10.0 ± 0.3
	SM + bubble	1.13 ± 0.03	48.4 ± 1.4	14.0 ± 0.4
	CM	0.96 ± 0.06	47.0 ± 3.1	17.0 ± 1.1

particles the cascade model overstates the $\langle \theta \rangle$ values and provides somewhat understated values of $\langle p \rangle$ similar to the π^--meson case, when heavier ions are considered, these discrepancies vanish. Concerning the string model, the situation is reversed: average angles of proton emission are somewhat lesser than experimental, while proton momenta $\langle p \rangle$ are overestimated to some extent. As for momentum distribution the cascade model provides good description in the region of small and intermediate values, which makes the main contribution, and appears to provide worse representation at higher energies, which could be explained with inaccuracies of the employed phenomenological description of nucleon-nucleon interactions in their utmost high energy region /2/. The string model making use of a significantly better quark-gluon representation of hadron interactions, is in good agreement with the experiment at high energy part of the spectrum as it is evident from fig.3, on the other hand, the agreement is poor at $p<0.5$ GeV/c, where the main contribution is coming from recoiling nucleons which are left out of consideration in the model employed. These recoil nucleons are produced in intranuclear interactions ("multiplication") of secondary particles. The number of recoil nucleons near the chosen boundary energy T=3.5 GeV/nucleon is sufficiently large, that is why the string model developed in /12-14/ requires modifications in this aspect. The same conclusion follows from the comparison of calculated and experimental multiplicities $\langle n_p \rangle$ in Table 2. When the values obtained with the cascade model are close to or slightly exceed those in the experiment, the data received with the help of the string model are evidently lower.

As is mentioned above, in the region of high energies the mechanism of intranuclear interactions of secondary particles is not clear yet. Hence, we confine ourselves to a simple phenomenological improvement of the string model, which impose modest computational requirements. Let us suppose that the nuclear matter around each "wounded" nucleon is overheated, which results in receiving additional energy by intranuclear nucleons which escape the nucleus afterwards /22/. Radius of this overheated "bubble" $r_0=1.4-1.8$ fm. is a phenomenological parameter being defined from the comparison of the multiplicities of nucleons produced with the experiment. In the energy range of interest which does not exceed several dozens of Gev/nucleon, the value of r_0 remains practically constant. This reflects the experimental fact of weak dependence of the number of recoil nucleons escaping the nucleus on the energy of projectile particle (this is confirmed in particular by weak energy dependence of g-particle multiplicity in photoemulsion measurements).

Longitudinal and transverse momenta of nucleons in the overheated "bubble" (while taking into consideration binding energies and Fermi motion) are defined from the respective phenomenological expressions (for more details see /23/). Their charges are simulated, using the relation between charge and mass numbers of the nucleus.

The mean values corrected in such a mannner are shown in Table 3. In the limits of calculated errors they are in good agreement

Table 3.

Average characteristics of the particles produced in the carbon ions interactions with copper nuclei at T=3.65 GeV/nucleon. Both models take into account the evaporation process.

Particle	Model	$\langle p \rangle$,GeV/c	$\langle \Theta \rangle$,deg	$\langle n \rangle$
p	SM + bubble	1.7 ± 0.1	$47. \pm 3.1$	$15. \pm 1.0$
	CM	1.4 ± 0.1	$50. \pm 2.5$	17.5 ± 0.9
n	SM + bubble	1.4 ± 0.1	$54. \pm 3.5$	$17. \pm 1.1$
	CM	1.2 ± 0.1	53.5 ± 2.7	$20. \pm 1.0$
d	SM + bubble	1.5 ± 0.1	$73. \pm 4.7$	1.2 ± 0.1
	CM	1.3 ± 0.1	$88. \pm 4.4$	1.1 ± 0.1
He^3,He^4	SM + bubble	2.9 ± 0.3	67.5 ± 8.1	0.69 ± 0.08
	CM	1.9 ± 0.1	$77. \pm 5.5$	0.55 ± 0.04
α	SM + bubble	4.7 ± 0.3	$62. \pm 4.0$	0.9 ± 0.1
	CM	4.0 ± 0.2	$67. \pm 3.4$	0.8 ± 0.04

with the experiment. The discrepancy in the region of the small momenta in fig.3 is also eliminated, the rest of the dN/dp curve stays practically unchanged.

Summarized characteristics of heavy particles calculated with the help of the cascade and string models are compared in Table 3. They include the contributions of both high energy and evaporation stages of the interaction process. (A transition of excited residual nuclei to the ground state is calculated in both cases with the standard evaporation model /2,3/). The string model gives lesser multiplicities of protons and neutrons than the cascade one, which as is well known (see e.g. ref./6/) overestimates it in comparison with the experiment. The number of deutrons and heavier fragments emitted are close to each other in both cases (it is important to take them into consideration because their existence causes considerable ionization damages in the matter). The same could be said about the other characteristics.

Thus, the high energy string model /12-14/ that includes the necessary improvements, concerning the secondary particles interactions, is perfectly mating with the low energy cascade model. Being used together the both models can serve as the basic approach for the internuclear cascade calculations in different samples. The analysis of the accuracy of the approximations employed here permits one to assert that the developed hybrid model can be used up to the energies of T=100 GeV/nucleon. To achieve even greater energies, the respective corrections to the string model should be provided (that is to take into account multipomeron exchanges, antinucleon contribution etc.. Most of these details have already been emploued in ref./11/).

Hadron Cascade Simulation in the Matter

Table 4 demonstrates the average characteristics of internuclear cascade initiated by protons and ^{12}C ions with energy T=3.65 Gev/nucleon and T=9 Gev/nucleon in cylindrical copper target 13cm x 10 cm.dia. Due to the fact that the first nuclear interaction of projectile particles with ^{64}Cu nuclei as a rule takes place at the energies lesser than the initial one because of the ionization energy losses, the data calculated both with the help of the hybrid and cascade-evaporation models are presented in the Table. The hybrid model takes into consideration the nucleon production in the region of the "overheated bubble". The low energy neutron cascade simulation in all cases are carried out by using the standard 26-group system of neutron cross-sections /5,24/.

Unlike the inclusive approach described in ref./1/, all our calculations are performed exclusively with strict consideration of energy-momentum conservation laws in each hadron- and ion-nucleus interaction[5)].

For the computation capabilities to be improved the model employs a method of statistical weights with the subsequent use of multiple splittings and Russian roulette.

As one would expect both calculations at T=3.65 GeV/nucleon come to practically similar results. The yeild of neutrons and charged particles with the energies exceeding 20 MeV is in good agreement with that measured in refs./15,16/. Calculated angular and energy distributions of these particles (see figs.4 and 5) are also in good agreement with the experiment. Limited cascade branching in the case of ^{12}C ions is explained by the greater energy losses in ionization process thanks to which they undergo the first nuclear interaction at lesser energies than protons on the average.

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5) Taking advantage of the occasion, we emphasize another important difference between our program complex "CASCADE" and its development to high energy region discussed in the present paper and the "MARS" complex described in ref./1/. The latter represents a rigid set of the well developed programs, each of them being oriented to solve a rather limited range of specific problems. The "CASCADE" complex is also a set of the developed program modules, relating to separate stages of the calculation procedure. The most variable nuclear processes in the material samples can be simulated by means of their combination. However, each new problem usually requires respective adaptation. Figuratively speaking, the "CASCADE" complex resembles a children designer set with spare parts which allows one to create a large variety of different models by their combination.

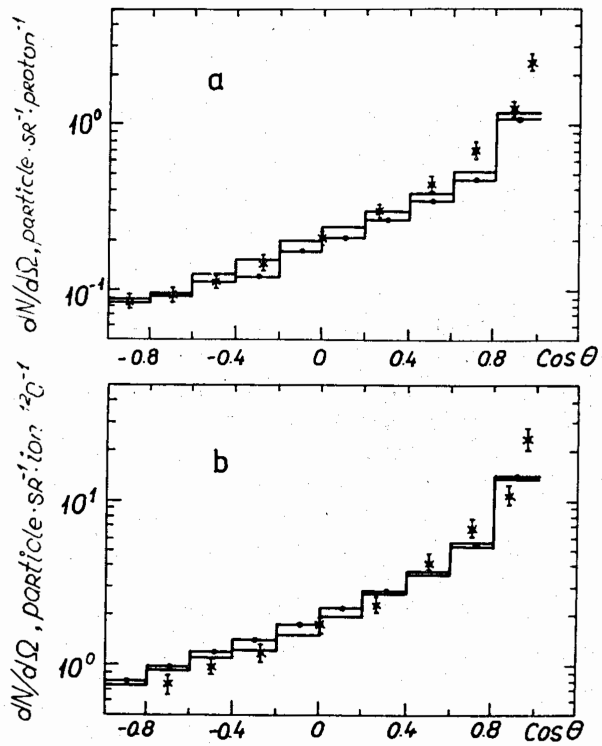
Calculations based on the cruder cascade model of nuclear interactions provide a significantly more developed cascade at 9 GeV/nucleon: in the case of the target irradiated by protons replacing the hybrid model by the cascade one gives a 30% increase in the number of "branches" of the cascade "tree", in the carbon ions irradiation case – about 70 %. At the same time the intensities of internuclear cascade, initiated by protons and ions, differ insignificantly.

TABLE 4.

Average characteristics of internuclear cascade, initiated by protons and carbon ions in the copper target. In the carbon ion case the data are presented on a per nucleon basis. HM stays for the hybrid model and CM – for cascade-evaporation one. The calculated data for the cascade-evaporation model at T=3.65 GeV/nucleon are from ref./27/.

Characteristic	Model	T=3.65		T=9	
		p	C	p	C
The number of nuclear interactions the target	HM	18,4±0.6	15±0.9	23±1	20.8±1
	CM	20.2±1	18±0.8	30±1	33.6±1
The number of inelastic interactions	HM	5.6±0.2	4.5±0.3	7±0.1	6.4±0.1
	CM	6.±0.3	5.2±0.2	9.2±0.3	10.2±0.3
The number of hadrons escaping the target at T>20MeV	exper	4.8±0.9	3.7±0.5	–	–
	HM	4.1±0.1	3.6±0.2	5.9±0.2	5.2±0.2
	CM	3.9±0.3	3.7±0.2	6.8±0.2	7.1±0.2
The number of neutrons escaping the target at T>20 MeV	HM	2.8±0.1	2.5±0.1	3.6±0.15	3.4±0.15
	CM	2.7±0.2	2.7±0.2	4.5±0.15	4.9±0.15
The same as above at T<20 MeV	HM	6.8±0.2	6.5±0.4	0.86±0.05	0.74±0.05
	CM	7.4±0.3	6.6±0.3	1.2±0.05	1.24±0.05

Fig.4. Angular distributions of hadrons with energies exceeding 20 MeV escaping the copper target which has been irradiated by protons (a) and carbon ions (b) at T=3.65 GeV/nucleon. Solid and dashed lines represent the results of calculations based on the hybrid and cascade models. The experimental points are taken from refs. /15,16/.



Analysis of the presented data derived via the hybrid model shows that it could be used to study different nuclear processes being prompted in targets by hadrons and nuclei with energies up to T=100 Gev/nucleon, while more accurate simulation procedure of inelastic hadron-nucleus interactions is used, this energy limit is bounded to be raised to $T=10^3-10^4$ GeV/nucleon. The model makes it possible to calculate angular and energy distributions of different particles at any point of the target, energy deposition, isotope production. The Monte-Carlo method is of a great value when complex geometry targets are considered (naturally, calculation requirements as a rule increase due to the increase in the number of selection criteria).

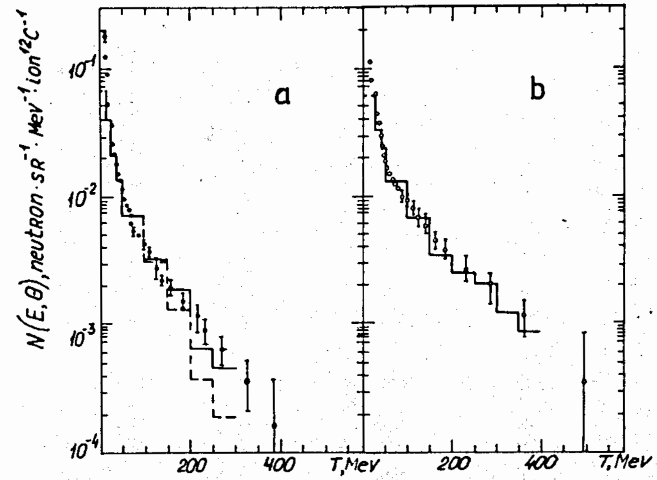


Fig.5. Energy spectra of neutrons escaping the copper target irradiated by carbon ions at T=3.65 GeV/nucleon at angles $\theta=105^\circ$ (a) and 71° (b). All designations are similar to those in fig.4. The experimental points are taken from refs./15,16/.

Greater accuracy and possibility of detailed consideration of varied nuclear effects are believed to be a merit of the model under discussion in comparison with other known models. A version of the model useful in calculation of the processes, observed in targets at different altitudes in the Earth atmosphere, which takes into account respective changes in primary particle flux (hadron or proton) while passing through the air layers with different density.

In conclusion we are glad to take advantage of the occasion to express our sincere gratitude to S.Yu.Shmakov and V.V.Uzhinski for multiple discussions and valuable advices.

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