сообщения
объединенного
института
ядерных
исследований
дубна

E2-91-137

V.S.Barashenkov, A.Polanski, A.N.Sosnin,
S.Yu.Shmakov

APPLICABILITY OF CASCADE-EVAPORATION MODEL TO THE CALCULATION OF RADIATION DAMAGES DUE TO IONS WITH ENERGIES T > 1 GeV

1991

The cascade-evaporation model of nuclear reactions is in good agreement with the experiment over a wide range from several dozens of MeV up to several GeV. At these energies it has not only "purely scientific" aspect but is also important in some applications because it is the basis of Monte-Carlo simulation of different nuclear effects, appearing in matter under the influence of beams of high energy particles and nuclei. Accompanied by some modification, the model could be used also at higher energies, also in this case it is not as adequate and its results are evidently dependent on its concrete realization.

It was pointed out many times before that at energies lesser than several GeV there is a qualitative discrepancy between the cascade calculation and experiment, however, these difficulties are not important, because, as a rule, they can be solved or significantly decreased by appropriate selection of the model parameter values or with the help of some improvement of the calculation algorithm. More serious, qualitative discrepancies between calculated distributions of nuclear fragments and experiment are found [1]. In spite of the fact that in their absolute values they correspond to only a small action of the cross-section of inelastic interaction (~ 1%), their confirmaon will indicate some qualitatively different mechanism of nuclear reaction.

Our purpose is to analyse once again the experimental data from [1] ing on a thoroughly developed and employed for many years in our laboory model of internuclear cascades considering the competing processes evaporation and fission of excited after-cascade residual nuclei. The deed description of the model could be found in [2-4]. Now let us point , that it takes into account the competition of evaporation and fission cesses in excited nuclei, remaining after the completion of the cascade preequilibrium processes. Calculation of internuclear cascades is perford in diffuse nucleon clouds, the space distribution of which is defined n experiments on electron scattering. The number of nucleons in the ds (Fermi particles) is equal to mass numbers of striking nuclei in the nning of the process and gradually decreases due to knocking out of eons by the growing shower of cascading particles (the so-called Trailing t). Therefore, the coordinates of all nucleons are simulated in the being of the collision and are redefined during the calculation procedure nding on the cascade development. At a starting point t, corresponding moment when nuclei come into contact, all particle collisions permitted

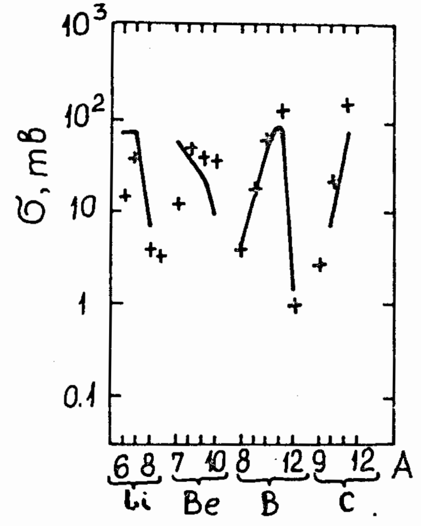


Fig.1. Cross-section of light fragment production in interactions of ^{12}C ions with ^{108}Ag nuclei. Curves — experiment [1], + — calculated results.

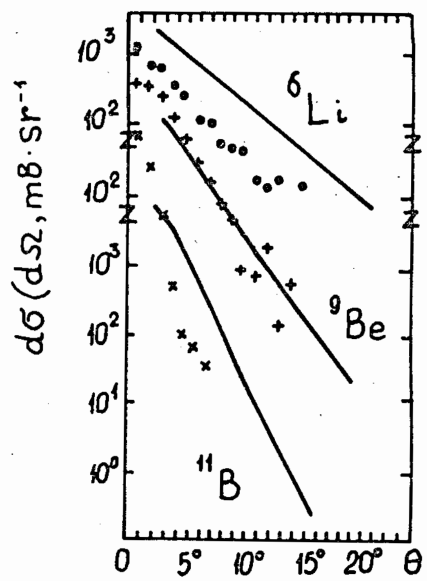


Fig.2. Angular distributions of light fragments in reaction $^{12}C + {}^{108}Ag$. Curves — experiment [1]; with o, •, x marks the calculated results are shown.

by kinematics and the Pauli principle are simulated. Only that one which takes place earlier than the others — that is after $\Delta t = \min t_i$ — is chosen; after that the positions of the interacting nuclei and all the cascading particles (nucleons and produced pions) are moved to a new position corresponding to a moment of time $t = t + \Delta t$. Then the calculation procedure is repeated until all the cascade particles in the colliding nuclei are exhausted.

As in [1], we consider separately all light, middle and heavy weight fragments with mass numbers A close to the target nucleus, produced in interactions of ^{12}C ions with an energy of 85 MeV/nucleon with heavy nuclei.

Cross-sections related to the light fragment production, which masses are close to the mass of an incoming ion ^{12}C, their angular and energy distributions are shown in figs.1-3. Although the cascade-evaporation model itself is not that good when applied to the nuclei with $A \leqslant 12$, than to heavy nuclei, the agreement between calculations and experiment appears to be satisfactory. No significant discrepances are evident here. More definite distinctions take place for ^{6}Li fragments, however, they could be diminished by corresponding selection of the model parameters. (For each fragment type there is a sharp decrease of cross-section while moving to lower A, the posi-

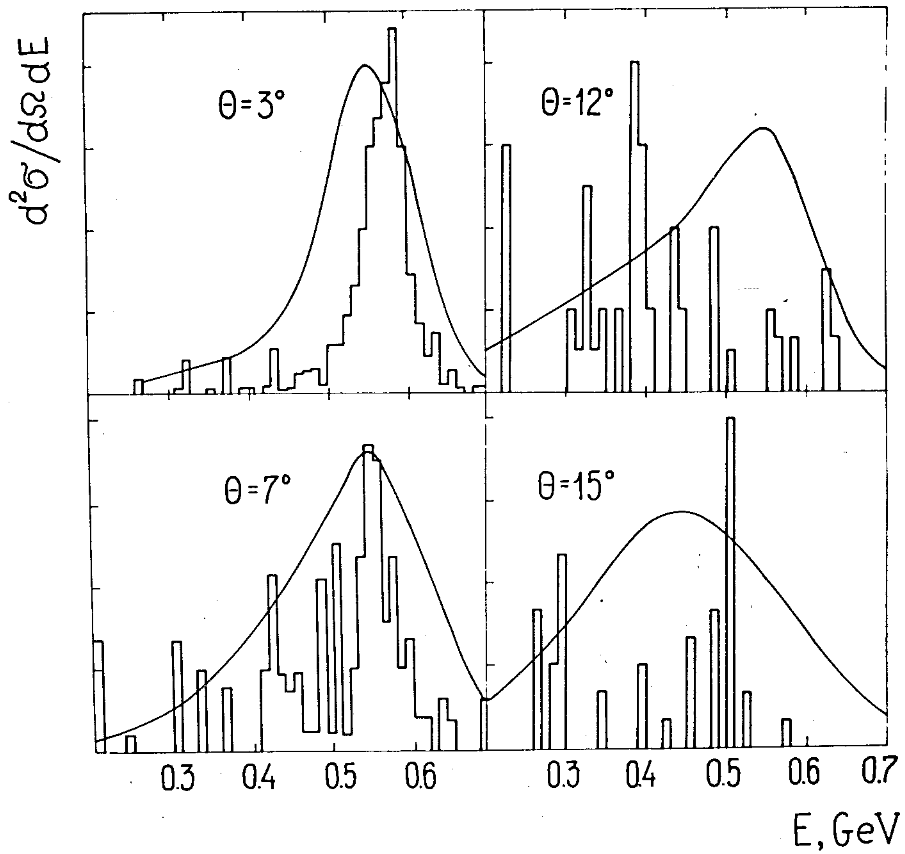


Fig.3. Energy spectra of ^{7}Be fragments, produced in ^{12}C + ^{108}Ag reaction at different angles. Curves — fitted experimental data /1/, histograms — calculation ($\Delta B = 2.5°$).;

tion of the maximum is sensitive to details of the calculation and ^{6}Li nucleus is just close to the maximum). It should be also noted that the probability for a fragment to escape at angles $B \geqslant 10°$ is rather low (see fig.2), that is why the Monte-Carlo spectra in fig.3 in this region are highly inaccurate and characterize only the value of the magnitude.

Cross sections of middle and heavy fragment production are shown in fig.4. It is pointed out in /1/ that cascade-evaporation calculations conform to the experiment only in the region of $A \geqslant 80$, as for the theoretical yeild of lighter fragments, it is many times less than that observed in experiment. As is clear from the figure, our calculated results do not confirm this conclusion, they describe the experiment well throughout the whole range of middle and heavy wieght fragments.

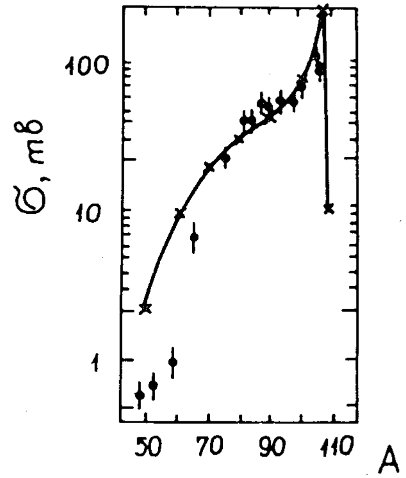
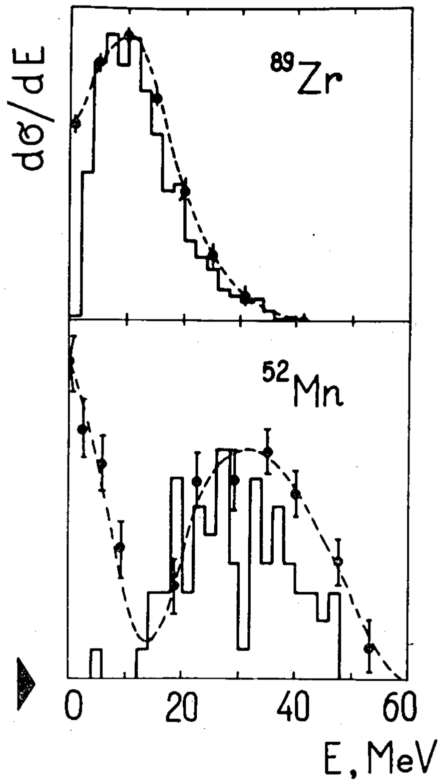


Fig.4. Mass distribution of fragments of target nucleus in reaction ^{12}C + ^{108}Ag. Marks ● correspond to experiment /1/, marks x and the connecting curve — calculation.

Fig.5. Energy spectrum of fragments ^{52}Mn ($50 \leqslant A \leqslant 55$) and ^{89}Zr ($85 \leqslant A \leqslant 89$), produced in reaction ^{12}C + ^{112}Sn. Dashed line — experiment /1/, histogram — calculation. Average energy of experimental and theoretical values for fragments <E> are shown.



The contribution of fission and preequilibrium processes in the region $A = A_t + A_p \cong 70$ is small and weakly influences the cross-section value. The main reason of the difference between our data and the calculated results obtained in /1/, is the trailing effect, which makes the mass number of an after-cascade nucleus significantly less.

Calculated and measured spectra of very heavy (Zr) and middle (Mn) fragments are compared in fig.5. In the first case there is a good agreement. Particularly, the mean theoretical value of energy $\langle E\rangle^{theor} = 12$ MeV is very close to the experimental, $\langle E\rangle^{exp} = 9.9$ MeV. In the Mn case a structure in the experimental spectrum is observed, which is impossible to reconstruct in the framework of the cascade-evaporation mechanism. Respectively, the calculated dependence of the mean kinetic energy of the fragment on its mass is reproducing only the high energy component of the experimental spectrum (average values $\langle E\rangle^{theor} = 29.3$ MeV, $\langle E\rangle^{exp} = 31.5$ MeV (see fig.6).

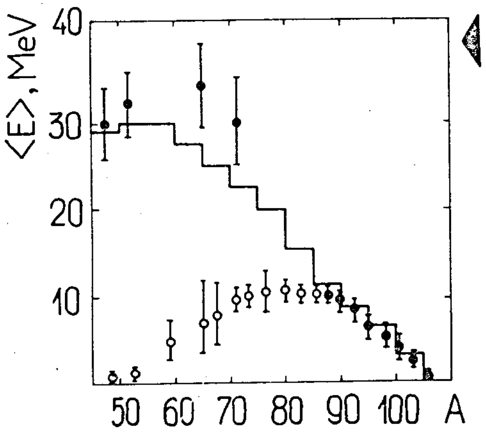


Fig.6. Dependence of average kinetic energy of a fragment on its mass number. The experimental data [1] for low energy component are shown with o marks.

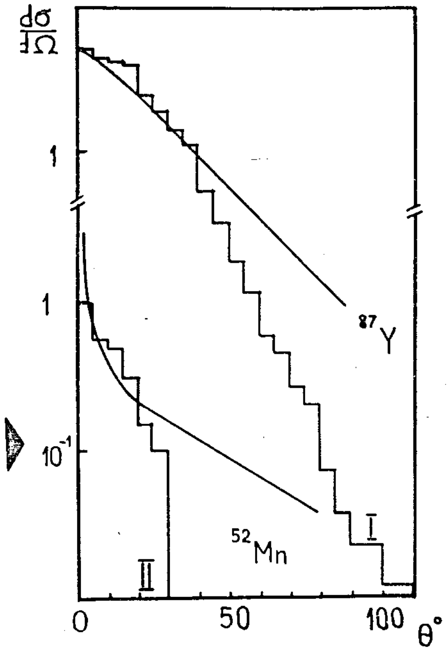


Fig.7. Angular distribution of fragments ^{53}Mn and ^{87}Y, produced in $^{12}C + ^{108}Ag$ collisions. Curves — experiment [1], histograms I and II — calculation for $85 < A < 90$ and $50 < A < 55$ respectively. So far as in [1] only relative values of fragment production cross section are provided, theoretical histograms shown in fig.7 are normalized on experimental data from [1] at the point $\theta' = 0°$. Integrals of experimental curves are normalized on corresponding calculated values.

It is still not clear (and imposes some doubts), why there is so many practically halted fragments ($<E> \cong 0$). The assumption that they are probably due to fission of aftercascade nuclei, expressed in [1] is not confirmed by our calculations. When excluded from the model, the fission process has very little effect on the form of the curves in figs. 5 and 6.

For heavy fragments this discrepancy appears only at wide angles. The model does not describe also the tails of angular distributions of fragments at wide angles. Apparently, it is this region that corresponds to such practically near-halted fragments.

All these details require further experimental and theoretical study.

REFERENCES

1. Mougey J. — Nucl.Phys., 1982, A387, p.109.
2. Barashenkov V.S. et al. — Uspekhi Fiz.Nauk, 1973, 109, p. 91 (in Russian).
3. Barashenkov V.S. et al. — Sov.Journ.Nucl.Phys., 1984, 39, p.1133 (in Russian).
4. Barashenkov V.S. et al. — Nucl. Phys., 1980, A338, p.413.

Received by Publishing Department
on March 25, 1991.

Барашенков В.С. и др. E2-91-137
Применимость каскадно-испарительной модели к вычислениям радиационных повреждений, возникающих вследствие ионов с энергией T > 1 ГэВ

При использовании примера неупругих соударений ионов C^{12} с ядрами при энергии 1,02 ГэВ были оценены (с помощью каскадно-испарительной модели) свойства ядерных фрагментов и ядер отдачи, которые дают основной вклад в радиационные повреждения полупроводников и сверхпроводников. Модель принимает во внимание уменьшение ядерной плотности взаимодействующих ядер вследствие каскадных процессов, вклад предравновесных процессов, конкурирующих с процессами деления возбужденных послекаскадных ядер. Вычисленные данные находятся в хорошем согласии с экспериментом. Тем не менее, некоторые особенности, касающиеся рождения умеренно-тяжелых фрагментов, соответствующего примерно 1% неупругого сечения (и, соответственно, малому вкладу в радиационные повреждения) качественно противоречат предсказаниям модели и отражают влияние некоторых качественно отличающихся механизмов реакции.

Работа выполнена в Лаборатории вычислительной техники и автоматизации ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1991

Barashenkov V.S. et al. E2-91-137
Applicability of Cascade-Evaporation Model to the Calculation of Radiation Damages Due to Ions with Energies T > 1 GeV

Using an example of inelastic collisions of ^{12}C-ions with nuclei at 1.02 GeV the accuracy of cascade-evaporation model in prediction of properties of nuclear fragments and recoil nuclei, which make a main contribution to the radiation damages in semi- and superconductors, is analysed. The model takes into account a decrease in nuclear density of the interacting nuclei due to the cascade process, contribution of preequilibrium processes in competition with excited-aftercascade-nuclei fission. The calculated data are in good agreement with the experiment. However some of its features concerning the production of moderately heavy fragments and corresponding to approximately 1% in inelastic interaction cross-section (and to small contribution of radiation damages respectively) contradict qualitatively the model predictions and indicate the influence of some essentially different mechanism of reaction.

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

Communication of the Joint Institute for Nuclear Research. Dubna 1991