TARGET MASS DEPENDENCE OF INTERMEDIATE MASS FRAGMENT PRODUCTION AT 1 GEV PROTON-NUCLEUS COLLISIONS

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A main goal of the experiment was to investigate evolution of a process of an intermediate mass fragment (IMF) ($Z_F \geq 3$) production as a function of target mass in a wide range of nuclei from *Al* to *Au*.

Identification of IMF has been performed by two identical systems including time-of-flight spectrometers and Bragg ionization chambers. A combination of the TOF measurement with an information about energy, a maximum of energy losses (Bragg peak) and a range of detected fragment, provided by a Bragg ionization chamber, has allowed reliable identification of IMF with a charge up to 19. The spectrometers were mounted at the angles 30° and 126° with respect to the beam direction. At these angles double differential cross sections of fragments were measured. To estimate multiplicity of the fragment production additionally two large-area parallel plate avalanche counters (the solid angle is about 1 sr) which detected the fragments with $Z_F \geq 3$ in coincidence with either of the TOF spectrometers were used. Experimental set-up and the method of fragment identification were described in details in [1].

As a result charge yields, parameters of energy spectra of fragments, longitudinal component of velocity of a decaying system and multiplicity of IMF production have been obtained for *Al*, *Ni*, *Ag* and *Au* targets. The preliminary results have been reported in [2].

For example in Fig.1 the energy spectra of nitrogen fragments measured at the angle 126° for different targets are presented. All the spectra were fitted by the modified Maxwell distribution [3] and the results of approximation are shown in Fig.1 by solid lines.

Values of total cross sections σ_F as a function of the fragment charge for all the targets are given in Fig.2. The charge yields of *Li* and *Be* fragments for *Ag* and *Au* targets have been taken from [4]. The solid lines in Fig.2 are the fit of experimental data with the function $\sigma(Z_F) \sim Z_F^{-\tau}$. One can see that the fragment charge distributions follow a power law only for *Ni* and *Ag* targets. As concerned the gold target the fragment cross sections fall according to the power law only in the range $Z_F = 3-10$ and then level off. The fit of the experimental cross sections presented in Fig.2, gives the following values of the parameter τ : (2.38 ± 0.2) $(3 \leq Z_F \leq 13)$ for *Ni*; (2.88 ± 0.2) $(3 \leq Z_F \leq 15)$ for *Ag* and (3.11 ± 0.2) $(3 \leq Z_F \leq 10)$ for *Au*. In the case of *Al* target it is obvious that the charge distribution cannot be fitted by power law. It should be noted that the values of τ increase with increasing the target mass in the range of nuclei from *Ni* to *Au*.

The target mass dependence of integral cross section of IMF σ_s is shown in Fig.3. The values of σ_s were determined by summation of individual cross sections for fragments with Z_F from 3 to 8. As one can see from Fig.3, the values of σ_s decrease with increasing the target mass up to the nuclei near light rare-earth elements and then they increase for heavier nuclei.

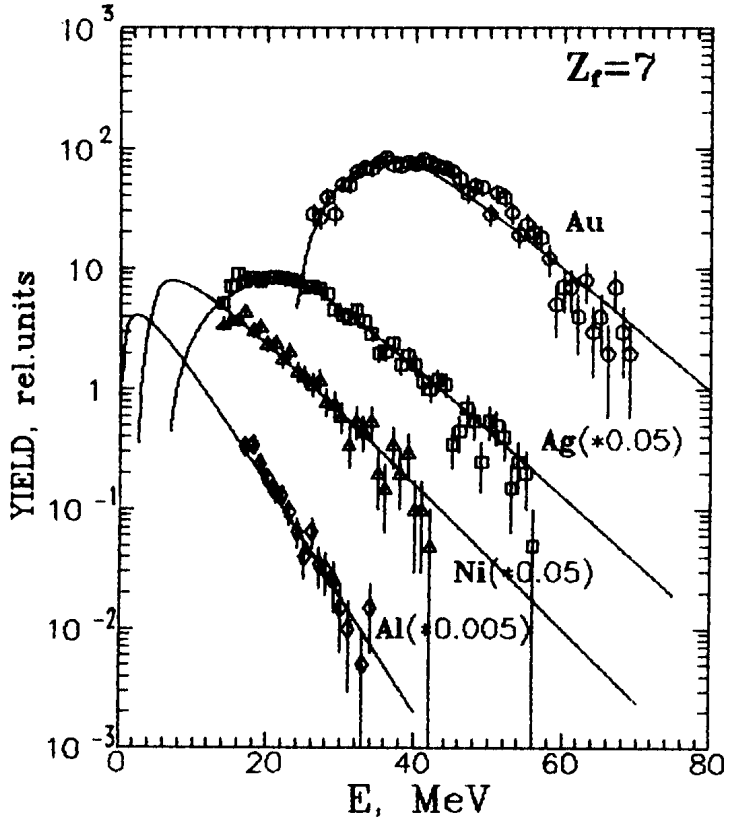

Fig.1. Energy spectra of nitrogen fragments emitted at 126° to the proton beam

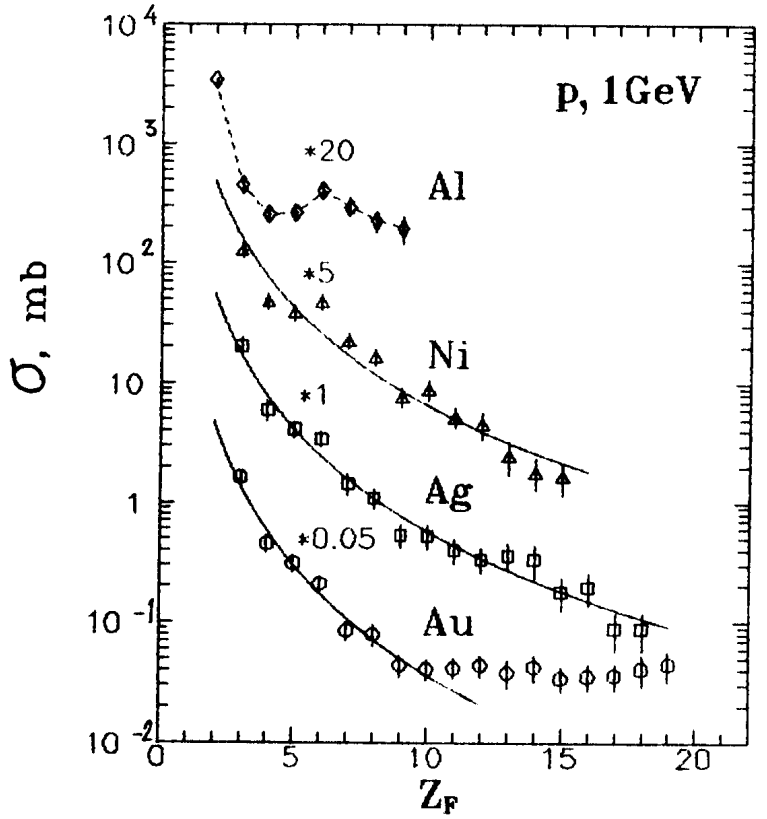

Fig.2. Charge distribution of fragments for four targets studied

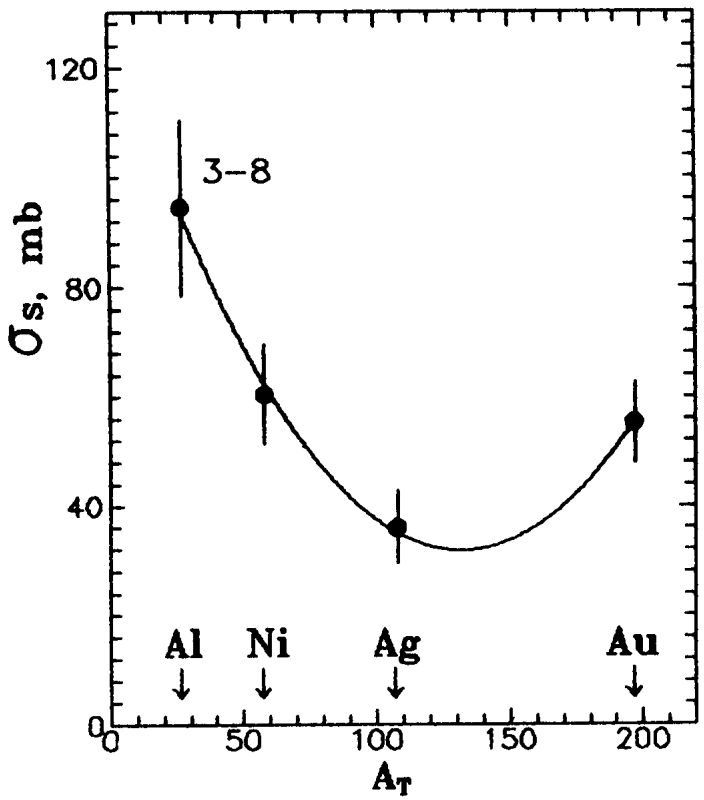

Fig.3. Integral cross sections of fragment production ($3 \leq Z_F \leq 8$) as a function of target mass

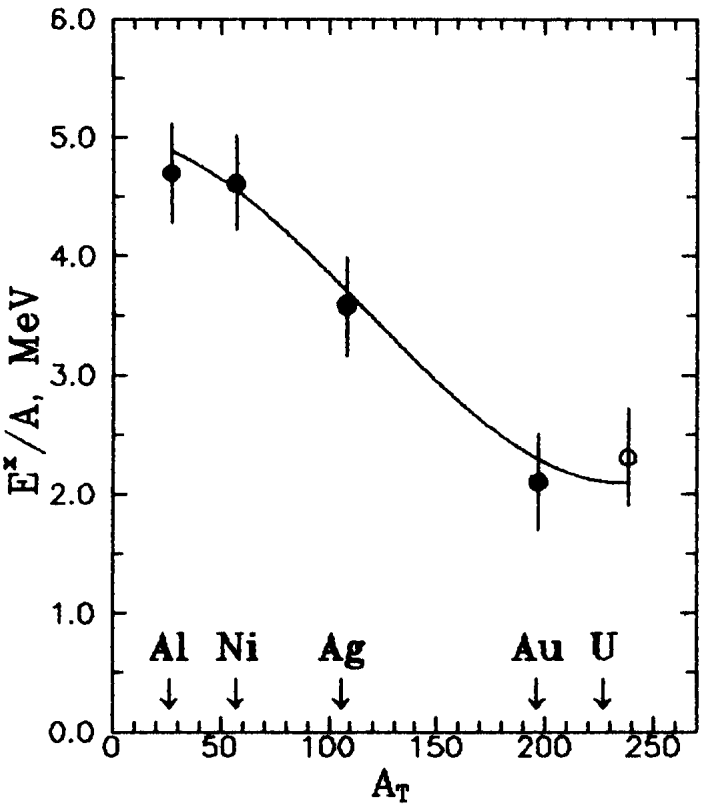

Fig.4. Dependence of average excitation energy per nucleon $\langle E^*/A \rangle$ of decaying nuclei on target mass. Open circle — data from [4]

The values of longitudinal component of velocity $\beta_{||}$ were obtained from the kinematic shift in two spectra measured at 30^o and 126^o. Neglecting in first approximation the dependence of $\beta_{||}$ on Z_F we have averaged the values determined for individual fragments. The following average values of $\langle\beta_{||}\rangle$ for each target have been obtained: (0.0114 ± 0.0010) for Al; (0.0112 ± 0.0010) for Ni; (0.0087 ± 0.0010) for Ag and (0.0051 ± 0.0010) for Au targets.

Using the dependence of excitation energy on $\langle\beta_{||}\rangle$ obtained in framework of intranuclear cascade model [5] the average excitation energy per nucleon E^*/A of nuclei emitting fragments has been determined: (4.7 ± 0.4) MeV/A for Al; (4.6 ± 0.4) MeV/A for Ni; (3.6 ± 0.4) MeV/A for Ag and (2.1 ± 0.4) MeV/A for Au targets. The mean excitation energy per nucleon decreases with increasing target mass as it is shown in Fig.4. It is interesting to point out that the values E^*/A for all targets do not exceed a threshold of multifragmentation process (3–5) MeV/A predicted by some theoretical models [6]. The above findings lead us to a conclusion that the contribution of multifragmentation process on IMF production should be small at 1 GeV proton energy. It is in agreement with the evaluation of fragment multiplicities which have been obtained on the basis of measured rations of coincidence events to single ones assuming isotropic distribution of multiple events. The number of coincidence events does not exceed a few percent of inclusive cross section for all targets, displaying a small increase from Au to Ni. These ratios are 0.4%, 1.6% and 2.4% for Au, Ag and Ni respectively.

On the basis of the obtained results it can be concluded that the IMF production at 1 GeV proton-nucleus collisions is mainly a result of binary decay of excited nuclei, produced at the first stage of the interaction of protons with a nuclei.

Summarizing, the results of the experiments demonstrate that:

1. the contribution of multifragmentation process at the interaction of 1 GeV protons with nuclei does not exceed (1–2.5)% of inclusive cross sections;

2. the integral cross section of the IMF production decreases with increasing the target mass up to nuclei of light rare-earth elements and then increases for heavier nuclei;

3. the fragment charge distributions follow a power law dependence only for Ni and Ag targets. As concerned Au target the IMF cross sections are described by a power law in the restricted range $Z_F = 3 - 10$ and then level off;

4. the average excitation energy per nucleon of nuclei emitting fragments increases from 2.1 MeV/A for Au to 4.7 MeV/A for Al with the target mass decreasing.

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