Fragmentation of the uranium nuclei in iron-nickel pallasite medium: theoretical estimation of the fragment nuclei superposition with the primary galactic cosmic ray nuclus abundance

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The simulation results of high energy (400 and 1000 MeV/nucleon) uranium nuclei fragmentation in their interactions with iron and nickel nuclei from pallasite matrix are presented.

Key words: olivine, galactic cosmic ray,charge particle tracks, uranium nuclei fragmentation, iron nickel target

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Introduction

Track analysis of Galaxy cosmic ray (GCR) nuclear component charge spectrum has been carried out by LPI Elementary Particle Laboratory and GEOKHI Cosmology Laboratory since 2006 in the frame of OLIMPIA project [*Ginzburg et al., 2005*]. Olivine crystals extracted from iron-nickel pallacite matrix were used as experimental material.

Method of the nucleus charge identification is based on empirical dependence of the longitudinal track etching velocity from the track residual path [*Kashkarov et al., 2008*]. But due to fragmentation of GCR nuclei, mainly superheavy ones, in pallacite (Fe, Ni)-matrix the number of GCR nuclei registered in olivine is underestimated, while the flux of the secondary light fragments increases.

In the publication the simulation results of high energy (400 and 1000 MeV/nucleon) uranium nuclei fragmentation in their interactions with iron and nickel nuclei from pallacite matrix are presented.

Calculation methods

Numerical calculations of the yield of different fragment nuclei from uranium fragmentation in uranium-iron and uranium-nickel interactions were held with a help of Monte-Carlo simulations on base of GEANT4 program [*Agostinelli et al., 2003*]. GEANT4 energy loss algorithm takes into account all possible mechanisms of ion passing through the matter. In particular, the stopping power values are determined with Bethe-Bloch relation and the data are extrapolated numerically on base of ICRU (International Commission on Radiological Units and Measurements) tables.

In the calculations there was used the Hadr01 program, an official component of GEANT4 which was worked out with participation of LPI colleagues. The program allows to simulate different nucleus beams passing through the matter. The results are presented as different distributions of primary and secondary nuclei available for analysis. The most informative parameters are those which characterize the energy loss of primary beam nuclei along their stopping tracks, and besides, the secondary particle energy and charge values. Test calculations of different energy ^{131}Xe, ^{207}Pb and ^{238}U nuclei passing through the various materials are already held. The results show good agreement in error limits with table data [*Hubert et al., 1990*] containing the stopping power and path values for ions with $2 \leq Z \leq 103$ in the energy region from 2.5 to 500 MeV/nucleon for different materials.

Results and discussions

The following plots and tables present the numerical results of the yield of fragments from uranium interactions with $Fe_{0.9}$ and $Ni_{0.1}$ target nuclei.

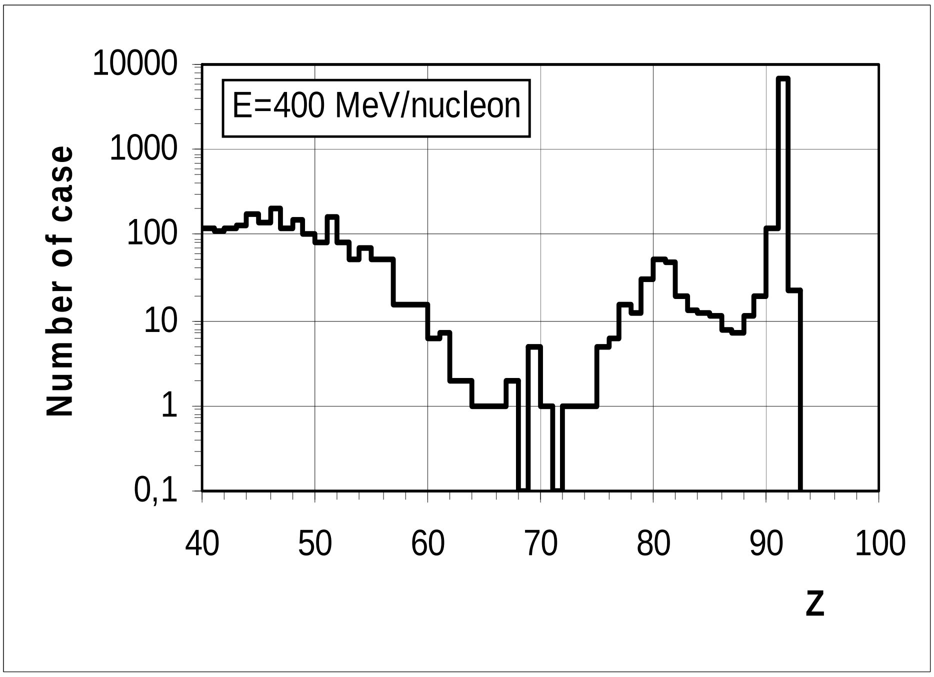

Fig. 1. Nuclear composition of fragments from accelerated uranium nuclei (E = 400 MeV/nucleon) interactions with $Fe_{0.9}Ni_{0.1}$ 10 mm target

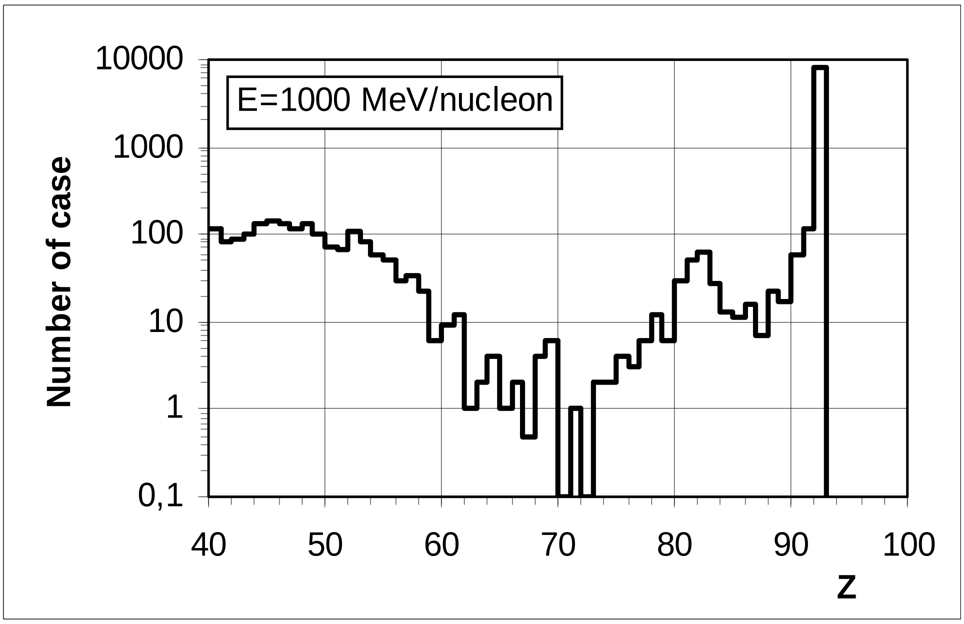

Fig. 2. Nulear composition of fragments from accelerated uranium nuclei (E = 1000 MeV/nucleon) interactions with $Fe_{0.9}Ni_{0.1}$ 10 mm target.

Fragmentation of uranium nuclei with E_o = 95 GeV

Depending on the energy the fragment nuclei range in the olivine crystals, contacted with $Fe_{0.9}Ni_{0.1}$-matrix, can be equal from tenths up to some millimeters due to energy from ~ 10 MeV/nucleon up to ~ 1000 MeV/nucleon, correspondingly.

Energy and residual range (RR_{ol}) distributions for the particles in olivine crystals of pallasite $Fe_{0.9}Ni_{0.1}$- matrix are presented in Table 1.

Table 1. Energy and residual range (RR_{ol}) distributions for the uranium nuclei in olivine crystals 10 mm from $Fe_{0.9}Ni_{0.1}$-target

Nuclear group	E, GeV	RR_{ol}, мм	ΣN_U	$\Sigma N_U/N_{U,o}$ (*)
I	30.5–22.5	1.7–1.0	683	~ 0.07
II	22.5–13.5	1.0–0.5	2124	~ 0.2
III	13.5–5.0	0.5–0.15	3108	~ 0.3
IV	≤ 5.0	≤ 0.15	4085	~ 0.4

(*) Initial beam contents $N_{U,o}$ = 10000 uranium nuclei.

Special attention was paid to the II and III groups of nuclei with RR_{ol} values in interval from ~ 1.0 to ~ 0.15 mm, corresponding to "cylindrical" zone of the etched part of track. Flux of these nuclei makes ~ 50% of $N_{U,o}$. Making ~7% of $N_{U,o}$ the I group nuclei get into olivine and form tracks in their "needle" extended zone. The IV group nuclei make rather short path track background ($RR_{ol} \leq 0.15$ mm) with a density ~ 40% of $N_{U,o}$.

Fragmentation of uranium nuclei with E_o = 238 GeV

The energy distribution of the uranium nuclei behind the target (10 mm of $Fe_{0.9}Ni_{0.1}$ - matrix) shows a peak at E = (180 ± 10) GeV formed by ~1100 nuclei, what makes 10% of $N_{U,o}$. The peak is formed by the initial beam uranium nuclei which have lost ~60 Gev from their energy after passing the target. Their RR_{ol} is about 25 mm. The number of uranium nuclei with RR_{ol}=0.5-1.0 mm (at $E_U = 20 \pm 2$ GeV) equals 520 (~ 0.5% of $N_{U,o}$). Uranium nuclei with RR_{ol} from ~ 1 to ~ 20 mm, which tracks are formed in the "needle" zone, make the major (~ 90%) group of nuclei.

The fragment nuclei yield

In Table 2 there are presented the numerical results of the yield for different nuclei conventionally separated in six groups. The data were prepared for the initial uranium beam energy E_0=95 GeV.

Table 2. Relative yield of the fragment nuclei from interactions of uranium nuclei with E_o = 95 GeV and 10 mm $Fe_{0.9}Ni_{0.1}$ - target

Nuclear group		ΣN_Z (*)	$\Sigma N_Z/N_{U,o}$
№	Z		
I	40–49	1253	0.13
II	50–59	585	0.059
III	60–69	27	0.0023
IV	70–79	72	0.007
V	80–89	192	0.019
VI	90–92	7142	0.71

(*) Initial beam contents $N_{U,o}$ = 10000 uranium nuclei.

Total yield of fragment nuclei with Z≥40 makes about 50% of $N_{U,o}$. About 7% of this number are formed by II, III and IV groups. Fragment nuclei with Z in the interval 80–89 are observed about 20%. Maximum contribution about 70% is made by nuclei with Z in the interval 90–92.

Results for primary uranium beam with E_0=238 GeV are presented in Table 3.

Table 3. Relative yield of the fragment nuclei from interactions of uranium nuclei with E_o = 238 GeV and 10 mm $Fe_{0.9}Ni_{0.1}$ - target

Nuclear group		ΣN_Z (*)	$\Sigma N_Z/N_{U,o}$
№	Z		
I	40–49	1145	~ 0.11
II	50–59	529	~ 0.053
III	60–69	35	~ 0.0035
IV	70–79	36	~ 0.0036
V	80–89	258	~ 0.026
VI	90–92	8180	~ 0.82

(*) Initial beam contents $N_{U,o}$ = 10000 uranium nuclei.

In the fragment-nuclei charge distribution, across of 8180 slowed-down uranium nuclei (~ 82% of initial uranium flux $N_{U,o}$), superhigh nuclei fraction (Z = 80–89) exclusive of 258 that is near of 2.5%.

The fragment-nuclei with charge in interval 60–79 consist only ~ 0.7%. Approximately of 10% and 5% fall on the nuclei of I-st and II-nd groups, accordingly.

Conclusions

Numerical estimation of fragment nuclei yield after uranium interactions in 10 mm $Fe_{0.9}Ni_{0.1}$ – target shows:

Output of secondary nuclei with charge in intervals of $40 < Z < 49$ and $50 < Z < 59$ make up ~ (11–13) % и ~ (5-6) %, relatively to initial uranium flux.

Nuclei with charge in intervals of $60 < Z < 79$ make up smaller of ~ 1% from the total number of formed fragment-nuclei.

About (2-2.5)% of fragment nuclei yield with Z = 80–89.

Part of the actinide group (Th-U) nucleus with Z = 90-92 and energy 400-1000 MeV·nucleon^{-1} do not underwent to fragmentation process in $Fe_{0.9}Ni_{0.1}$ – target of 10 mm thickness make up ~ (70–80)%.

Preliminary estimation of superposition of the fragment nuclei over GCR nucleus flux in the region 50<Z<89 gives not higher ~ 10 percents which are to be taken into account in track experiments on GCR charge composition.

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