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Results of investigations associated with the search for tracks of relict galaxy nuclei in olivine crystals from meteorites.

Aleksandrov A. B. [1], Bagulya A. V. [1], Vladimirov M.S. [1], Goncharova L. A. [1], Ivliev A. I. [2],
Kalinina G.V. [2], Kashkarov L. L. [2], Konovalova N. S. [1], Okateva N.M.[1], Polukhina N. G. [1],
Roussetski A. S. [1], Starkov N. I. [1]
[1] *Lebedev Physical Institute of RAS. poluhina@sci.lebedev.ru; starkov@sci.lebedev.ru.*
[2] *Vernadsky Institute of Geochemistry and Analytical Chemistry of RAS. leokash@mail.ru*

Abstract: *A group of researches from Elementary Particles Laboratory of Lebedev Physical Institute successfully operates the completely automated PAVICOM setup designed for processing the solid-state detectors of different types, such as nuclear photoemulsions, X-ray films, plastic and minerals. Since 2005 PAVICOM is used for processing tracks of relict heavy galaxy nuclei in olivine crystals from Marjalahti and Eagle Station meteorites. To make the more effective using of the crystal volume for the nucleus track search a new procedure of stepwise cutting and etching was developed. As a result, even the longest tracks corresponding to heavy nuclei are being successfully followed. The nucleus charge value is determined by using its connection with geometrical (residual range RR) and dynamic (etch rate V_{etch}) characteristics of the etched channel. The function $Z(RR,V_{etch})$ is specified by experimental data and by calibration measurements.*

By now, 133 crystals from Marjalahti meteorite and 37 crystals from Eagle Station meteorite were processed and 4900 and 1839 tracks correspondingly were found. About 40 tracks of them were associated with nuclear charge $Z>88$ and 5 tracks with nuclear charge $Z>92$.

Moreover, there were found three tracks with extremely high etch rate (more than 40 μm per hour). In particular, the charge of one of these nuclei was preliminary estimated as $Z\sim110$.

Keyword*: super-heavy nuclei, galactic cosmic rays, tracks, olivine*

PAVICOM – the Russian high-tech facility satisfying the current world standards – has been designed and is successfully operated at the Lebedev Physical Institute of the Russian Academy of Sciences. (PAVICOM is the Russian abbreviation for *Completely Automated Measurement Complex.*) The facility includes three automated microscopes and is intended for processing nuclear emulsion and solid-state track detectors used in diverse physics research. The simplicity of track detectors offers them significant advantage over many other detector systems. They are broadly used in many fields of science and technology. These are high-energy physics, cosmic-ray physics, reactor physics, metallurgy, geology, archaeology, medicine, biology, meteorite and lunar sample studies.

The PAVICOM facility was initially developed for processing nucleus–nucleus interactions registered by means of nuclear photoemulsioins irradiated with a lead nucleus beam of a 158 A GeV energy at the SPS accelerator (CERN) within the framework of the EMU-15 experiment. However, to date, PAVICOM's technical potential – its versatility, high-speed performance and constantly updated software – enable it not only to cover the requirements of LPI research but also to be efficiently used by other Russian laboratories and institutes. The main distinction of this facility is its versatility – PAVICOM's automated units process both nuclear photoemulsions and plastic detectors, as well as olivine crystals from meteorites [1].

In 2005, the project OLIMPIYA (the Russian abbreviation for *Olivines from Meteorites: Search for Heavy and Superheavy Nuclei*) was started to be implemented at the PAVICOM facility. This project aims at the studies of heavy and superheavy nuclei in cosmic rays and the search among them for trans-Fermi nuclei with $Z \geq 110$ in olivine crystals from Marjalahti and Eagle Station pallasites [2].

The issue of the existence of superheavy nuclei is of utmost importance for understanding the properties of nuclear matter. First and foremost, of interest is to verify the prediction of a significantly increasing stability of nuclei in the vicinity of the magic numbers $Z = 114$ and $N = 184$ (N, the number of neutrons), which could lead to the existence of "stability islands" of stable superheavy nuclei [3]. Confirmations of this prediction have been obtained in experiments under the leadership of Yu.Ts. Oganesyan at the JINR accelerator, where recently the nuclei of Elements 114 and 116 were discovered and the discovery of Element 117 was claimed [4]. The lifetimes of some isotopes of these nuclei are several seconds and even minutes, which exceeds tens of thousands of times the lifetimes of nuclei with smaller charges. However, it is impossible in these experiments to realize the above mentioned optimal ratios ($Z = 114$ and $N = 184$) due to a large number of neutrons.

At the same time, measurements of the fluxes and spectra of heavy and superheavy nuclei in cosmic rays is a sensitive method to study the composition of cosmic ray sources as well as the processes, occurring both in the sources themselves and in interstellar medium through which cosmic rays propagate, and the models of cosmic-ray retention in the Galaxy. The currently available experimental data on the abundance of heavy nuclei (with $Z > 50$) in the Universe, as well as on the spectra and fluxes of these nuclei in cosmic rays are rather scarce, and for trans-Fermi nuclei no sufficiently reliable data are available at all. Similarly, there are no data on the possible existence of exotic superheavy nuclei, either.

The use of the factor of long-time exposure of meteorites in space (hundreds of millions of years) leads to an enormous advantage of this method over the methods based on the use of various satellite and balloon-borne detectors. By measuring the parameters of tracks, it is possible not only to identify particles but in particular cases also to estimate their energy. Pallasite-class meteorites used in this experiment consist of an iron–nickel "matrix", in the bulk of which there are inclusions of crystalline olivine – a semi-transparent yellow mineral up to 1–2 cm in size. The preatmospheric depth of occurrence of olivine crystals in meteorites is 4–5 cm (Marjalahti) and 1.5–2 cm (Eagle Station); their size, 0.5–2 mm. Within the framework of the project OLIMPIYA, a technique for the automatic identification of tracks of nuclei in olivines has been created, a technique for scanning the bulk of the crystal has been worked out, and a database of images for the storage of information about tracks in the crystal has been developed.

For more efficient use of the crystal volume in search for nucleus tracks, a new procedure of stepwise cutting and etching has been developed [5]. According to this procedure, after the crystal surface is initially etched and the track parameters are measured, a 50–100 μm subsurface layer is removed and the cycle starts again. Each stage of measurements includes the search for track continuation at a new level. As a result, even the longest tracks corresponding to heavy nuclei could be successfully followed. Their length measurement errors are summed up from the measurement errors of the track angle to the surface of observation at each stage of surface polish, errors of removed layer thickness determination and errors of track residual length measurement after all polishes. The value of a relative error of the lengths of track segments at each stage is no more than 10–15%.

The nucleus charge value is determined from its relation to the geometric (residual range RR) and dynamic (etch rate V_{etch}) characteristics of the etched channel. The function $Z(RR,V_{etch})$ is specified by experimental data [4] and calibration measurements [5].

To date, 133 crystals from Marjalahti meteorite and 37 crystals from Eagle Station meteorite have been processed; respectively, 4900 and 1839 tracks have been found. Of them, about 40 tracks have been assigned to nuclear charge $Z > 88$; among them, 5 events with $Z > 92$ have been found. The ratio of the abundance of nuclei with $Z > 88$ to that with $74 \leq Z \leq 87$ is 0.045±0.015 (Marjalahti) and 0.025±0.02 (Eagle Station). These quantities are somewhat greater than those in UHCRE experiment (0.0147±0.0032) [9], but agree well with data from TREK, HEAO and Ariel experiments [10]. Figure 1 shows the charge distribution of nucleus tracks we obtained in the implementation of the project OLIMPIYA, as compared with the abundance of galactic nuclei obtained in HEAO and Ariel experiments [10]. It is seen that our method works at $Z>55$.

We have found three superlong tracks ($L_{tr} > 700$ μm) whose etching rate $V_{etch} > 35$ μm/h. If we take into account that the experimentally measured maximum etching rate of tracks in olivine for uranium nuclei before they are stopped is $V_{etch,U} = 26 \pm 1$ μm/h, it becomes clear that charges of these nuclei exceed $Z = 92$. As in this range of charges the function $Z(RR, V_{etch})$ is not known, to assess the charge of transuranic nuclei in the first approximation we extrapolated the function $Z(RR \approx 50\ \mu m, V_{etch})$ at the nuclei residual range $RR \approx 50$ μm, for which experimental data of the calibration measurements are available (figure 2). In this case, we obtain the value of the lower boundary of the charge, which, as is seen in the figure 2, is $Z = 105$. Earlier on in [11] the observation of five nuclei Z 110 was reported.

Thus, in the progress of the project OLIMPIYA, data have been obtained on the charge composition of approximately 6000 nuclei with charge greater than 55, whose distribution is consistent with the data of other experiments. Besides, tracks of three ultraheavy nuclei of galactic cosmic rays have been found and identified in meteoritic olivine crystals studied. In the first approximation, the charge of these nuclei is within the range of $105 < Z < 130$. Undoubtedly, the results obtained in this work confirm the hypothesis of the existence of “stability islands” for natural trans-Fermi nuclei.

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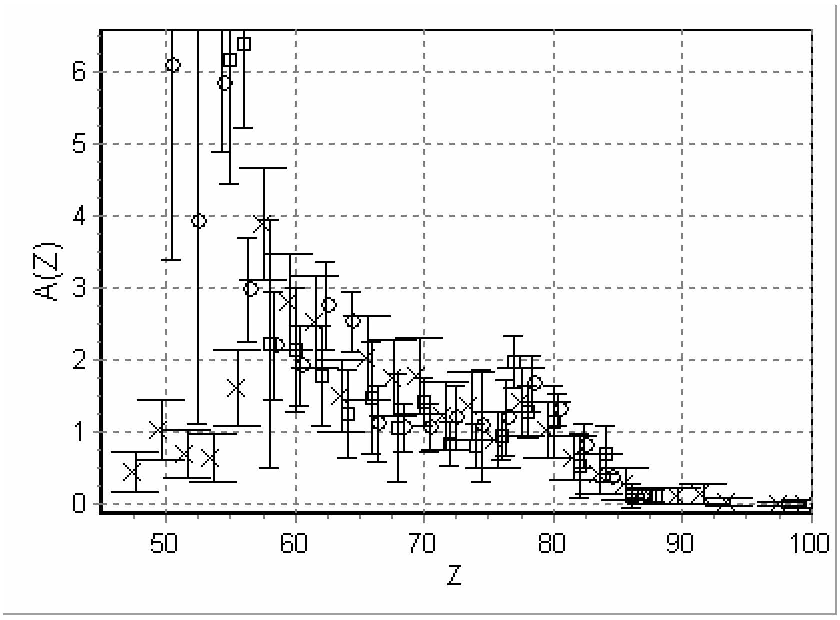

Figure 1. Abundance of superheavy nuclei A(Z) (A_{Fe}=10^6). Squares - HEAO [10], circles - Ariel [10], crosses - our results.

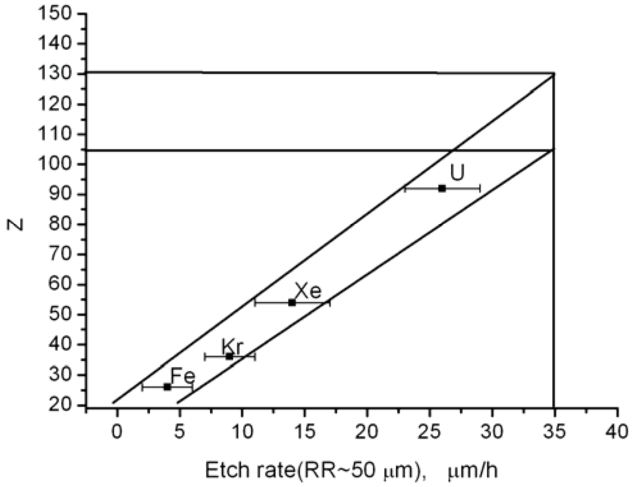

Figure 2. Extrapolation of Z(RR,V_{etch}) to the superheavy nuclei area. At V_{etch} = 35 μm/h the interval 105<Z<130 is derived.