Discovery of the tracks due to transuranic galactic cosmic ray nuclei in the olivine crystals from meteorites

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Abstract. Results of the experimental research, performed within the framework of the OLIMPIYA project on investigation of the relict galactic cosmic ray nucleus tracks in olivine crystals from the Marjalahti and the Eagle Station meteorites, are presented. Up to now, there were processed 170 crystals, and about 6000 tracks with nuclear charge \( Z > 55 \) were registered. About 45 tracks are identified as nuclei with charge of \( 88 < Z < 92 \). Charges of three nuclei, associated with super long tracks, exceed \( Z = 92 \). In the first approximation the charge value of two of these nuclei lies in the range of \( 105 < Z < 130 \). The charge of one of them is estimated as \( Z = 119 \pm 6 \). We believe that confirm the hypothesis of the existence of “stability islands” for natural trans-Fermi nuclei.

1. Introduction

The issue of the existence of super heavy 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 the relatively stable super heavy nuclei [1]. 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 [2]. 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 super heavy 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. 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 the galactic cosmic rays are rather scarce, and for trans-Fermi nuclei no sufficiently reliable data are available at all.
2. Experimental
The use of the factor of long-time exposure of meteorites in space (~ 200, and ~ 300 millions of years for the Marjalahti and the Eagle Station, correspondingly) 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 determine 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, but of the very crumbling structure, that gives the middle size of the olivine grains under investigation only of 0.5–2 mm. The least pre atmospheric depth of occurrence of the searched olivine crystals in meteorites is 4–5 cm in the Marjalahti and 1.5–2 cm in the Eagle Station.

Within the framework of the project OLIMPIYA [3], a technique for the automatic identification of tracks of nuclei in olivine crystals 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 individual crystals has been developed [4].

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 sum 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 polishing procedure. The value of a relative error of the lengths and corresponding track etch rate of the observed track segments at each stage of measuring is no more than 10–15%.

![Image](image.png)

**Figure 1.** The curves of the etching rate ($V_{etch}$, in units of µm/h) depending on residual range RR (in µm) for the high energy nuclei from Pb ($Z=82$) up to U ($Z=92$).

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 track-channel. The functions of $Z(RR, V_{etch})$ (see figure 1) are specified by experimental data [6] and calibration measurements [7].
Experimental calibration data, obtained for Au and U nuclei [7], are a basis for the intermediate nuclei the function of \((V_{\text{etch}})_{Z\text{-vs}}(RR)\) calculation.

3. Results
To date, 133 crystals from the Marjalahti meteorite and 37 crystals from the Eagle Station meteorite have been processed; respectively, 4900 and 1839 tracks due to nuclei with \(Z > 55\) have been found. Of them, about 200 detected tracks are related to the GCR nuclei of \(Z > 70\) and among them, six are related to the Th-U–actinide group (90 < \(Z < 92\)). The flux value of the last nuclei relatively to the GCR nuclei of the Fe group is \(\sim 6 \times 10^{-7}\). About 40 tracks have been assigned to nuclear charge \(Z > 88\). The ratio of the abundance of nuclei with \(Z > 88\) to that with \(74 \leq Z \leq 87\) is \(0.045 \pm 0.015\) in the Marjalahti and \(0.025 \pm 0.02\) in the Eagle Station. These quantities are somewhat greater than those in UHCRE experiment \((0.0147 \pm 0.0032)\) [8], but agree well with data from TREK, HEAO and Ariel experiments [9, 10]. Figure 2 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. It is seen that our method works at \(Z > 55\).

![Figure 2](image.png)

**Figure 2.** Abundance of super heavy nuclei \(A(Z)\) \((A_{\text{Fe}} = 10^6)\). Squares - HEAO [9], circles – Ariel [10], crosses – our results.

We have found three superlong tracks \((L_{\text{tr}} > 700 \, \mu\text{m})\) whose etching rate \(V_{\text{etch}} > 30 \, \mu\text{m/h}\). If we take into account that the experimentally measured maximum etching rate of tracks in olivine for uranium nuclei before they are stopped is \(V_{\text{etch}, \text{U}} = 26 \pm 1 \, \mu\text{m/h}\), it becomes clear that charges of these nuclei exceed \(Z = 92\). As in this range of charges the function \(Z(RR, V_{\text{etch}})\) is not known, we extrapolated the function \(Z(RR \approx 50, V_{\text{etch}})\) at the residual length of the run \(RR \approx 50\) nuclei, for which experimental data of the calibration measurements are available. As a result we have got estimation \(Z=105 \pm 130\). For one track we have more exact the value \(V_{\text{etch}} = 35 \, \mu\text{m/h}\) and corresponding more exact \(Z=119 \pm 6\) at the 95% level of confidence (see figure 3).

Besides taking into account the frequency of supernova explosion, the Galaxy size, the time exposition of meteorite and the depth of a olivine crystal in a meteorite we estimate the minimal lifetime of the found nuclei as 3000 years.
4. Conclusion
Thus in the progress of the project OLIMPIYA, the pallasite olivine track data have been obtained on
the charge composition of approximately 6000 nuclei with charge greater than 55. Charge
distribution of these nuclei is consistent with the data, obtained in a number of other apparatus
experiments. As the most distinguished result, the tracks of three transuranic nuclei of galactic
cosmic rays have been found and identified in meteoritic olivine crystals studied. In the first
approximation, the charge of two of these nuclei is within the range of 105 < Z < 130. The charge of
one of them is estimated as Z = 119±6. We believe the results obtained in this work confirm the
hypothesis of the existence of “stability islands” for natural trans-Fermi nuclei.

Figure 3. Extrapolation of Z(RR,V_{etch}) to the superheavy nucleus area. At V_{etch} = 35 µm/h the interval
Z=119±6 is derived. The straight is the approximation of the experimental points; the thin lines are the
errors corridor at 95% level of confidence.

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References
[1] Strutinsky V M 1967 Nucl. Phys. A 95 420
[2] Oganesyan Yu. Ts 2001 Vestnik RAS 71 590
[3] Ginzburg V L, Polukhina N G, Feinberg E L, Starkov N I and Tsarev V A 2005 Doklady
Physics 50 283–285
[4] Aleksandrov A et al. 2009 Instruments and Experimental Techniques 2 38–42
[5] http://www.scgis.ru/russian/cp1251/h_dggcms/1-2006/informbul-1_2006/plante-6.pdf
[6] Perron P and Maury M 1986 Nucl Tracks Radiat. Measur. 11 73–80
[7] Fleischer R L, Price P B and Walker R M 1975 Nuclear Tracks in Solids. Principles and
Applications (University of California press)
[8] Donnelly J, O'Sullivan D O, Keane A J, Drury L O'C and Wenzel K-P 1999 Proc. of the 26th
Int. Cosmic Ray Conf. OG1.1.30
[9] Westphal A J, Price P B, Weaver B A, and Afanasiev V G 1998 Nature 396 50–52
[10] Binns W R, Garrard T L, Gibner P S, Israel M H, Kretchman M P, Klarmann J, Newport B J,
Stone E C and Waddington C J 1989 ApJ 346 997–1009
[11] Perelygin V P, Bondar Yu V, Brandt R, Ensinger W, Fleischer R L, Kravets L I, Rebetez M,
Spohr R, Vater P and Stetsenko S G 2003 Yadernaya Fizika 66 1612–16