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Cosmic-Ray Induced V-Shaped Fission Tracks in Silicate Minerals: to a Problem of SH-Elements Search in the Meteoritic Phosphates

L. L. Kashkarov.
Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow 119991 Russia
Presenter: L. L. Kashkarov (ugeochem@geochem.home.chg.ru), rus-kashkarov-L-abs1-og12-poster

One of the possible experimental path of detecting the traces of SH-elements (Z≥110) in extraterrestrial material is observation of three-prong fission-track events in meteoritic and lunar silicate minerals. The first experimental observation [1] of ternary fission of heavy elements Au, Bi, Th and U induced by Ar ions efforts this opportunity. The base starting point at that is a big difference in three-fragmental spantaneous fission of ^{238}U and ^{244}Pu nuclei as compared with SH-elements: for the first probability of ternary fission by a factor of ~10^4 is smaller. At that time under action of the primary (protons) and secondary (n, π-mesons etc.) cosmic-ray nuclear-active particles V-shaped induced fission of Th-U target elements, consistings searched crystals, can be realized. Experimental observation of V-shaped proton-induced (E_P = 660 MeV) fission events [2,3] indicate a certain possibility to form of the pseudo three-prong track images. Occurrence probability of these events in any cases can amount to the level of the estimated three-prong track events due to spontaneous fission of the SH-elements. In present work on the base of known up to day experimental results estimate of the detection possibility of three-fragment fission of SH-elements in meteoritic and lunar phosphates are reported.

1. Introduction

It was theoretical prediction [4], that super heavy (SH) double ″magic″ closed shells nuclei in the region of Z = 110-114 and N = 184 can possess the life times up to 10^9 years. Nuclei of SHE are supposed to be the products of nucleosynthesis in explosive processes in our Galaxy (Supernova r-process nucleosynthesis, and especially neutron star formation process, etc.) [5]. Accelerated up to relativistic energies in the Galaxy, these nuclei can produce extended traces of the high damaged material in exposed silicate crystals that can be revealed by chemical etching as the visual tracks. To be registered in extraterrestrial crystals the lifetime of such SHE nuclei in the galactic cosmic rays (GCR) shall exceed ~10^3 years. Besides such a nuclei of SHE can survive in the extraterrestrial silicate crystals and produce the tracks due to their spontaneous fission if life time is more than 5×10^7 years.

In general results of search and identify of the SH nuclei in the galactic cosmic rays obtained up to this time [6,7] are: (1) Observation and identification by calibrations of more than 1600 of Th-U nuclei tracks in the searched olivine crystals from pallasite meteorites; and (2) Revelation of the 11 anomalously long tracks [8,9], detailed analysis of which shows that 5 out of them could not be produced by Th-U cosmic ray nuclei and identified as the tracks due to SH nuclei (Z ≥ 110). Thus it was obtained the evidence of the existence of SHE nuclei in the composition of galactic cosmic rays, and their abundance relative to the actinide elements accounted as of value ~ $(3\text{-}10)\times10^{-3}$.

Principally new approach to a SHE problem is based on search and registration of ternary spontaneous fission cases [10]. The experimental researches of three-prong fission fragment tracks of SH nuclei were performed by V.P. Perelygin et al. [11]. At these experiments were observed the unique events of ternary spontaneous fissions of the compound SHE nuclei $^{278}C_{110}$, formed at capture by $^{238}U_{92}$ nuclei of accelerated up to ~10 MeV/nucleon of $^{40}Ar_{18}$ ions. From obtained results it was determined probability of SHE ternary fission in relation to fission on two fragments: $\leq3\times10^{-4}$. This value appears on three-four order of magnitude higher of probability of ternary fission for ^{238}U nuclei [11,12]. The lunar and meteoritic phosphate crystals – whitlocites, apatites and stanfilldites - can be used in these studies. It can be indicated three main preferential possibilities:(1).The annealing characteristics of the spontaneous fission fragment tracks differs drastically in phosphates for actinides and SHE. It was established that annealing at 450°C during 32h for Marjalahti whitlockite provide the separation of fission fragment tracks due to ^{238}U-^{244}Pu spontaneous fission and due to spontaneous fission of to Z≥110 nuclei in volume etchable track length by a factor of 2. Thus, the comparison of the fossil and thermal neutron induced fission of ^{235}U track spectra in the same crystals annealed at the same conditions can provide some proofs of spontaneous fission of Z≥110 nuclei existence. (2). The probability of ternary spontaneous fission of Z=110-114 nuclei as compared with binary fission estimated to be 10^{-3}-10^{-4}. For actinide nuclei thit ratio is $N_{3f}/N_{2f} \leq 10^{-7}$. (3). These 3-prong tracks also shall have the mean length about 20% greater than binary tracks due to spontaneous fission of actinide nuclei. In such a way, the observation and measurement of such 3-prong spontaneous fission tracks in the volume of the meteoritic or lunar phosphate crystals shall provide the unambiguous proofs of SHE nuclei existence in Solar system.

In our report a number of issue concerning to probability of registration of three-prong fission fragment tracks in meteorite phosphate crystals are considered.

2. Track sources in meteoritic silicate crystals.

Tracks, observed in silicate crystals of meteoritic matter are formed mainly by: (a) Spontaneous fission of ^{238}U and extinct ^{244}Pu in phosphates; (b) Nuclei of VH-group (23≤Z≤28) in GCR; and (c) Induced V-shaped fission tracks of heavy elements (Pb, Bi, Th, U) under action of the high-energy (E>100 MeV/nuclon) primary and secondary nuclear-active cosmic-ray particles .

Table 1 gives the uranium concentrations and measured track densities in the two main silicate minerals from pallasite meteorites.

Table 1.

Mineral	U Content, ppb	Track density, cm^{-2} ∗				
		^{238}U (4.6 by)	§ Cosmic ray	Cosmic-ray induced fission ∇		
				Protons E>100 MeV	Neutrons E<1 MeV	Neutrons E~(1-100) MeV
Olivine	0.1-1	10^3-10^4	(1-10) ×10^5	(1-2)×10^{-1}	(0.5-1)×10^{-1}	(1.5-3) ×10^{-1}
Phosphate	50-100	(0.5-1)×10^6	(2-20) ×10^5	~10^3	~5×10^3	(1-2) ×10^4

Notes: ∗ - For a cosmic-ray exposure age of 100 Myr.
§ - Track production rate in depth of ~200 g/cm^2 [11].
∇- Accounted for the heavy target elements Pb, Bi, Th, U.

(1) Spontaneous fission of ^{238}U and ^{244}Pu in phosphates from pallasites.

At concentration of uranium ~ (50 - 100)×10^{-9} g/g in phosphates from pallasites track density of spontaneous two-prong fission equal to ~ 10^5 - 10^6 cm^{-2}. The estimation of values of the contribution in expected track density of three-prong track events from spontaneous fission of ^{238}U and ^{244}Pu in this case do not exceed ~ 10^{-2} – 10^{-1} cm^{-2}.

(2) Nuclei of VH-group (23≤Z≤28) in GCR

For the silicate crystals located at the depth of some centimeters from the meteorite preatmospheric surface track density searched during a cosmic-ray exposure age of ~100 Myr equal to 10^5-10^6 cm^{-2}. As it seen, these values are the same order of magnitde in comparison with track density of spontaneous fission in phosphates.

(3) Induced by cosmic-ray nuclear-active particles of heavy elements fission.

Three types of cosmic-ray induced fission possibilities must be considered; (a) ^{235}U by neutrons (E≤1 Mev); (b, c) ^{238}U and ^{232}Th by neutrons (E = 1–100 MeV) and (E ≥ 100 MeV). Experimentally determined proton-induced fission of U and Th as a function of a simulated lunar material depth [12] give possibility to derive corrections accounted with the depths, exposure ages, and heavy target elements (U, Th, Bi and Pb) contents in the searched samples.

The estimation of probability of background events of three-prong fission of heavy elements (Pb, Bi, Th and U), induced by primary (p, n) and secondary (n, p, π) nuclear-active components of GCR, is carried out on the base of following experimental data: (a) The fission rate of heavy elements on two fragments, induced by cosmic radiation, is received on the data of [11]. On depth up to ~100 g/cm^2 of the lunar soil matter the basic contribution is necessary on ^{232}Th. Since depth ~200 g/cm^2, the fission rate of ^{232}Th and ^{235}U become comparable, mainly at the expense of highly effective fission of ^{235}U under action of thermal neutrons. (b) The induced fission rates of others (mainly Pb, Bi) heavy elements appear on 3-4 orders of magnitude by lower. (c) The deep variation of total induced fission rate under action of GCR on nuclei of heavy elements in comparison with the constant on depth of spontaneous fission rates of an isotope ^{238}U, principally allows us to estimate the rate of formation of three-prong track events of fission in volume of silicate crystals: these crystals simultaneously are the targets at GCR irradiation in cosmic space and the nuclear track detectors of fission fragments formed during the whole meteorite history.

In estimations also was taken into account theoretically received [12] meanings of probability of three-prong fission events are depending significantly on value of a charge of the easiest fission fragment (Z_L). So at increase of Z_L from 6 up to 25 effective cross-section of three-prong fission in nuclear reaction (N + Au) decreases from 5 up to 0.08 mb, and for reaction (N + Th) from 15 up to 0.8 mb under nitrogen ions energy of E_N = 1.5-2.5 MeV/amu. The relation of fission probability on three and two fragments for the mentioned above nuclear reactions equal to 10^{-3}-10^{-4}.

3. Some methodological remarks.

It is need to indicate several methodological sources of errors: (1) thermally annealed VVH (Z≥30) cosmic-ray nuclei; (2) possible etching of track-like figures; (3) partial annealing temperature of fission fragments; (4) tracks from the neutron-induced fission of U and Th isotopes; (5) formation of V-shape tracks due to nuclei fragments from cosmic-ray spallation reactions.

Psevdo three-prong track events in meteoritic phosphate crystals.

As a consequence of accidental imposition of the rectilinear (two fragmental spontaneous fission and VH-nuclei) and V-shaped (high-energy induced fission) tracks in the crystal volume can be formed apparent or psevdo three-prong track events. Rough estimation of these events formation probability give the value of these track-density equal to (0.01-1) cm^{-2}.

4. Conclusions

On the basis of the carried out estimation of the values of contribution from various sources of heavy element nuclei fission at an irradiation of meteorites in cosmic space, and also, starting from the received experimental meanings of track density three-prong (ρ_{3f}) and double-prong (ρ_{2f}) of fission of compound-nuclei of SHE (Z = 110) [12], the value of the relation probability of three-prong track events was determined: in comparison with the probability of three-prong fission of SHE nuclei contribution of all possible background sources not higher ~ 10^{-3}.

Carried out quantitative estimation of expected volume track density of three-prong cases of SHE nuclei fission has shown, that in view of the probable contribution of all considered sources of a background at viewing not less ~0.1 cm^3 of total volume of phosphate crystals from meteorites, in them it can be revealed several cases of three-prong fission of SHE nuclei.

The results of estimated corrections show that proton-induced fission is negligible and it makes a minor contribution even at a maximum flux of ~5 protons/cm^2·sec.

Thus, detection of three-prong fission cases in phosphate crystals of meteorites, the formation age of which makes ~ (4.45 - 4.55) by, will testify to registration of traces of SHE nuclei fission in the early Solar system matter.

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