DOES HELIUM-3 ABUNDANCE DECREASE IN DEPENDENCE ON DEPTH AT MARE CRISIUM?

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Introduction: Strong dependence of helium-3 abundance on size and composition of regolith particles imposes significant restrictions on use of the measured and published data for an estimation of the isotope resources in lunar regolith. The estimations of the helium-3 abundance received for preliminary enriched samples, i.e. for different regolith fraction in size, and also for the separate components of regolith selected to mineral, chemical or other attribute do not reflect the average abundance of the isotope in bulk regolith and cannot be used for an estimation of the general resources of this element. The optimal are the estimations received for representative samples of bulk regolith without division into fractions and components.

Luna 16: Core sampling at «Luna-16» landing site was carried out to depth of 35 cm with core drilling. Mare basalts in the landing site belong to a spectral class with average Ti abundance (TiO_2 - 4.9 %) [2]. ^{3}He abundance is examined for different fractions of regolith particles (Table 1).

Table 1. ^{3}He abundance in regolith at "Luna 16" landing site

Sample	Size, μm	^{3}He, ppb	^{4}He/^{3}He	Ref.
L16-19	1-400	7.9±0,35	2550±80	[4]
7-1a	≤83	12.4	2670±100	[6]
G-7	≤125	14.3	2350	[13]
G-49	40-150	4.2	3360	[14]

Exception in G-49 sample fractions less than 40 μm which contains up to 80% of all helium in regolith, and makes up to 50 % of all volume of regolith [3], has resulted in significant decrease of helium abundance in the sample. The most representative investigated sample of regolith is L16-19 [4] which is least enriched and most full reflects a particles size of lunar regolith among the values submitted in Table 1. Thus, as average value of ^{3}He abundance in regolith of mare basalts of Mare Fecunditatis the value of 7.9 ppb can be used only.

Luna-20: ^{3}He abundance in lunar regolith in continental area of the Moon between the Mare Fecunditatis and the Mare Crisium is known with the samples, delivered by "Luna 20" automatic station (Table 2). Sample of lunar soil was returned in the form of core sample to a depth of 30 cm.

Table 2. ^{3}He abundance in the "Luna 20" landing site

Sample	Depth, cm	Size, μm	^{3}He, ppb	^{4}He/^{3}He	Ref.
L2010		<400	3,1	2630±50	[7]
2002-1	5-10	<83	4,0±0,36	2490±40	[6]
2004-1	15-20	<83	5,9±0,45	2550±60	[6]

Regolith on set of the chemical and mineralogical data consists predominantly of anorthositic rocks with low Ti abundance (TiO_2 - 0.52-0.54 % wt.) [5], that is characteristic for lunar highland rocks. The data on helium-3 abundance received by Vinogradov and Zadorozhny [6], were estimated for regolith fraction with particles less than 83 μm in size. The data received by Eugster [7], were estimated for regolith fraction of <400 μm. The sample with taken into account of dependence of ^{3}He concentration on regolith particle sizes is less enriched and, accordingly, is much close to bulk composition. Therefore the ^{3}He abundance, equal 3,1 ppb [7] may be taken as the element abundance in regolith at "Luna 20" landing site in lunar highland.

Luna-24: ^{3}He abundance in regolith of Mare Crisium has been received at research of samples delivered by "Luna 24" station. A deep-drill core stem was driven to a depth of 225 cm into the regolith in the landing site [8] and regolith sample was returned in the form of stratified core sample. Mare rocks in the landing site consist of low titan basalts (TiO_2 of about 1% wt.) [9]. The data on helium-3 abundance in an interval from 92 up to 218 cm of depth are shown in summary Table 3, where samples have been sieved on some fractions. There is distinct dependence of helium-3 abundance on the particle size. Dependence of ^{4}He/^{3}He ratio on the regolith fraction size is also distinctly observed. The data by Bogard [11] as against data by Zadorozhny and Ivanov [10] are less representative, because of fraction of 20-45 and 90-150 μm in size have been withdrawn. But that is the fullest data, allowing estimating the average abundance of helium-3 as on intervals, so on all depth up to 2.18 m. Weighted average of ^{3}He abundance in a sample was found relative to weight of each fraction. For an estimation of distribution of ^{3}He abundance on depth all samples at which there was a fraction <200 μm in size were selected only. The fraction more than 200 μm was rejected as it is present not in all samples. For samples of the same intervals, for example, 24109,13 and 24118,4, 24182,15 and 24184,4, for more correct estimation there was found a weighted average value of helium-3 abundance relative to length of an interval. It is obvious, that decreasing of helium-3 abundance with a factor of two within interval from 92 up to 218 cm is observed (Table 3). Whether similar distribution of helium-3 abundance is characteristic for all regolith thickness in the landing site, or it is a local heterogeneity and what is the reason of such dependence - this question remains while open. The weighted average ^{3}He abundance relative to length of the intervals up to 218 cm in depth for regolith of low titan basalts in Mare Crisium is 3.3 ppb. It is curious to compare the data considered (Table 3) with estimations, received by Galimov and Anufriev [12] through 30 years after delivery of lunar soil from the landing site of "Luna-24" (Table 4).

Table 4. ^{3}He abundance in lunar soil [12]

Depth, cm	^{3}He, ppb	^{3}He/^{4}He ×10^{-4}
72	1.3	3.03
92	1.2	3.03
130	1.4	3.11
160	1.6	2.89
192	0.8	2.84

The isotope abundance turned out less by a factor of 2-3 than in comparison with earlier estimations. If to take into account, that the ^{3}He abundance was defined only for fraction of <83 μm the abundance of one for not enriched fraction of <200 μm will be even less. Probably, it may be explained by diffusion and loss of helium from regolith particles for past 30 years.

Table 3. ^{3}He abundance at "Luna 24" landing site

Sample	Depth, cm	Particle size, μm	Wt., mg	^{3}He, ppb	^{4}He/^{3}He	Sample weight, mg	Average sample abundance, ppb	Average abundance in depth range, ppb	Ref.
24092,4	92-95	<74	5,20	7.5	2480±50	7,35	5,8	**5,8**	[10]
		74-95	1,23	2.2	2120±50				
		95-200	0,92	1.2	1680±70				
24109,13	109-121	<20	1,04	12.6	2649	10,24	3,3	**3,8**	[11]
		45-90	6,04	2.6	2322				
		150-200	3,16	1.5	2002				
24118,4	118-121	<74	5,90	6.8	2410±50	8,46	5,3		[10]
		74-95	1,52	2.1	1990±50				
		95-200	1,04	1.6	1860±60				
24143,4	143-146	<74	4,75	5.8	2560±50	8,22	4,1	**4,1**	[10]
		74-95	1,57	2.1	2120±50				
		95-200	1,90	1.5	2010±60				
24149,15	149-163	<20	1,33	9.3	2696	9,74	3,1	**3,1**	[11]
		45-90	4,91	2.2	2244				
		150-200	3,50	1.9	2047				
24174,10	174-183	<20	1,46	13.7	2669	9,89	3,7	**3,7**	[11]
		45-90	6,45	2.3	2386				
		150-200	1,98	1.1	1974				
24182,15	182-196	<20	1,38	7.6	2671	8,36	2,2	**2,4**	[11]
		45-90	4,63	1.4	1903				
		150-200	2,35	0.6	1579				
24184,4	184-187	<74	5,05	4.6	2490±50	7,71	3,4		[10]
		74-95	1,19	1.3	1980±50				
		95-200	1,47	0.9	1840±60				
24210,9	210-218	<20	1,38	7.8	2683	9,42	2,6	**2,6**	[11]
		45-90	4,71	2.0	2252				
		150-200	3,33	1.2	2185				

Summary: The estimations of helium-3 abundance received for preliminary enriched samples, i.e. for different regolith fraction in size, and also for the separate components of regolith selected to mineral, chemical or other attribute do not reflect the average abundance of the isotope in bulk regolith and cannot be used for an estimation of the general resources of the element. The most optimal are the estimations received for representative samples of bulk regolith without selection into fractions and components. The optimum average ^{3}He abundances for bulk regolith at the Mare Fecunditatis, lunar highland and in the Mare Crisium are shown in Table 5.

Table 5. ^{3}He average abundance

Station	Depth, cm	^{3}He, ppb	Region
Luna-16	35	7.9	Mare Fecunditatis
Luna-20	35	3.1	Lunar Highlands
Luna-24	218	3.3	Mare Crisium

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