

**THE ESTIMATION OF HELIUM-3 PROBABLE RESERVES IN LUNAR REGOLITH.** E. N. Slyuta<sup>1</sup> and A. M. Abdrakhimov<sup>1</sup>, and E. M. Galimov<sup>1</sup> V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry (Russia, Moscow, 119991, Kosygina, 19, albertabd@mail.ru).

An abundance ratio of solar wind elements in regolith does not correspond to those in a solar wind. Most part of captured helium escapes regolith. The left insignificant part of helium depends on ability of lunar regolith to keep helium, so abundance of helium captured in regolith first of all depends on composition and properties and almost does not depend on helium supply. Depending on the mechanism of the capture two basic types of trapped <sup>3</sup>He are distinguished. The first is weakly bound, intergrained helium and the second is strong bound, implanted in particles of regolith [9].

The weak bound helium abundance is controlled by two key parameters: the solar wind supply, which depends on a longitude and latitude, and degassing, which depends on surface temperature and saturation of regolith. Direct measurements of weak bound helium-3 abundance in the regolith at Moon landing sites are absent, because weak bound helium is very unstable at mechanical influences on lunar regolith [9].

The abundance of implanted <sup>3</sup>He substantially is defined by quantity of an electroconductive minerals and a degree of radiation imperfection of a mineral crystal lattice, i.e. a degree of a maturity of the regolith. High electroconductive metallic minerals, e.g. ilmenite (FeTiO<sub>3</sub>), under surface solar wind radiation, keep own crystal structure as against nonelectroconductive main rock minerals, which superficial layer loses the crystal structure and becomes amorphous. That explains high enough mechanical and temperature stability of implanted helium which essentially exceeds heats in lunar midday at equatorial area of the Moon [9].

Direct measurements of the implanted <sup>3</sup>He abundance in the regolith samples demonstrated the distinct dependence of isotope concentration on the size of fraction: the less size of particles of regolith, the more concentration of <sup>3</sup>He. It is explained by concentration of gases in the superficial layer of separate grains, i.e. the less particle size, the more the particle surface relative to total volumetric regolith weight. As a whole there are 80 % of all trapped helium are contained in regolith particles in the size <50 microns, which make about 50 % of all regolith. 90 % of the trapped <sup>3</sup>He are contained in fraction of regolith in the size <100 microns. 10 % of the <sup>3</sup>He abundance accounts for 0.1- 1 mm regolith particles.

Observable strong dependence of the <sup>3</sup>He abundance on the regolith particles sizes and structure imposes significant restrictions on use of the measured and published data for an estimation of this isotope

probable reserves in the lunar regolith. So estimations of the abundance received for preliminary enriched fractions, and also for the separate components of regolith allocated to mineral, chemical or other attribute, are of little use or unsuitable, because lead to significant reassessment of reserves. The most unbiased estimations are received for representative regolith samples without division into fractions and components, as for example the data on station " Luna - 24 " which allow to estimate the average weighted abundance in the regolith layer of thickness of 218 cm, i.e. on all depth of drilling.

In the table 1 it is shown <sup>3</sup>He abundance in lunar regolith for different areas of landing sites. The specified values are the most representative and are recommended for use in helium probable reserves calculation.

Using assessments of regolith thickness at the landing sites (Table 1), regolith thickness map [8] for the Near Side, and global geologic map [11] it was calculated the approximating regolith volume for each geologic complex. Using Clementine data [10] mare basalts were divided into three categories by TiO<sub>2</sub> abundance: high-Ti (5-10%), moderate-Ti (3-5%), and low-Ti (1-3%) (Table 2).

For the calculation it was used the direct measurements of <sup>3</sup>He abundance of landing site regolith as representative for each category (Table 1).

The probable reserves of implanted <sup>3</sup>He in lunar regolith in the area of high titanium basalt occurrence concern to the highest category I and are estimated as 53000 tons on the Moon Near Side. As a whole on all Moon surface the probable reserves of this category are estimated as 61000 tons.

The probable <sup>3</sup>He reserves of category II concern to areas of occurrence of sea basalts with moderate TiO<sub>2</sub> abundance (3-5 %) and are estimated as 109000 tons on the Near Side. It is twice more on reserves, than in category I, but it is almost in 4 times more on the occupied area.

The areas with probable reserves of a category III are characterized by low titanium mare basalts occurrences with the lowered abundance of <sup>3</sup>He in regolith.

The probable reserves of this category are estimated as 143000 tons on the Moon Near Side. Reserves of this category settle down approximately on the same areas, as well as stocks categories II, but are characterized almost by the twice greater thickness of regolith. In the sum probable reserves of first three categories are estimated in 306000 tons on Moon Near Side and occur on the 12 % of all area of a hemi-

sphere. Practically the reserves of first three categories occur in the lunar mares territory. The area of mare geological complexes is estimated approximately as 13 % of all Near Side area.

The fourth category of probable reserves is characterized by low values of  $^3\text{He}$  abundance and the raised average thickness of regolith. The probable reserves of this category occur in highland areas of the Moon and are estimated on all lunar area in 2150000 tons.

The general probable reserves of strong bound  $^3\text{He}$  in lunar regolith on all surface of the Moon are estimated in 2469000 tons (Table 2). On the Near Side the general reserves are estimated as 1276000 tons. For comparison, probable reserves of  $^3\text{He}$  on the Near Side on the basis of independent radiolocating -optical model [8] are estimated as 1034000 tons. It is quite in accord with the received estimation of reserves on the basis of the complex analysis of the geological, geochemical and geophysical data.

The general probable reserves of weak bound  $^3\text{He}$ , for the lack of the abundance and distribution data, were not estimated. Theoretical estimations show, that the abundance of weak bound  $^3\text{He}$  in regolith in high latitudes on the Moon can exceed the abundance of strong bound  $^3\text{He}$  in high titanium basaltic regolith twice and more and to reach 44 ppb. Hence, the estimation in 2469000 tons can be considered confidently

enough as the minimal bottom value of the general reserves of  $^3\text{He}$  on the Moon

The obtained reserves are rough, due to the limited data which besides frequently do not correspond to the representative requirements for the estimation. But the available data already allow define some categories of helium reserves surely. The most perspective sites will be considered for certain as prime landing sites, and further and as potential sites for creation and construction of lunar bases, such as the Tranquility Mare, the central part of the Mare Imbrium, a significant part of territory of Oceanus Procellarum and partly the Mare Humorum, the Mare Nubium and the Mare Crisium, and in view of potential reserves of weak bound  $^3\text{He}$  areas of Northern and Southern poles.

**References:** [1] Bogard D. D. et al. (1978) *Mare Crisium*, 105-116. [2] Eberhardt P. et al. (1970) *Proc. Apollo 11 Lunar Sci. Conf.*, 1037-1070. [3] Eberhardt P. et al. (1972) *LPS III*, 1821-1856. [4] Eberhardt P. et al. (1974) *LPS V*, 197-199. [5] Eberhardt P. et al. (1976) *LPS VII*, 563-585. [6] Eugster O. et al. (1975) *LPS VI*, 1989-2007. [7] Zadorozhnyj i dr. (1980) *Lunny Grunt iz More Krizisov*, 289-299. [8] Shkuratov Y.G. and Bondarenko N.V. (2001) *Icarus*, 149, 329-338. [9] Taylor L. (1994) *Eng. Constr. Oper. in Space IV*, 678-686. [10] Lucey P.G. et al. (2000) *JGR*, 90, 20377-20387. [11] Wilhelms D.E. (1987) *USGS*, 1342, 205 p.

Table 1.  $^3\text{He}$  regolith abundance at different landing sites. [1-7].

Station	$^3\text{He}$ abundance, ppb	Estimated regolith thickness, m	Region, Category
"Apollo-11"	15.1	4.7; 4.6; 4.4	Mare region, Category I
"Apollo-12"	7.1	3.7; 4.6; 5.3	Mare region, Category II
"Apollo-14"	5.7	8.1; 8.5	Mare region, Category III
"Apollo-15"	4.4	6.0; 4.4	Mare region, Category III
"Apollo-16"	1.4	10.1; 12.2	Highland region, Category IV
"Apollo-17"	8.0	7.0; 7-12; 8.5; 6-8	Mare region, Category II
"Luna-16"	7.9	4.0; 4.0; 1.0-5.0	Mare region, Category II
"Luna-20"	3.1	9.2; 0.4; 11.6	Highland region, Category IV
"Luna-24"	3.4	2.0; 2.0-3.0; 3.9	Mare area, Category IV

Table 2. The estimation of  $^3\text{He}$  probable reserves in the lunar regolith.

Category	TiO <sub>2</sub> , wt. %	Area S <sub>TiO<sub>2</sub></sub> , km <sup>2</sup>	$^3\text{He}$ abundance, ppb	Regolith thickness, m	Density kg/m <sup>3</sup>	$^3\text{He}$ probable reserves, tons	$^3\text{He}$ , %, %
I	5-10	487114	15.1	4.4	1900	61491	2%
II	3-5	1518587	8	4.8	1900	110796	4%
III	1-3	1586312	5.7	8.1	2000	146480	6%
IV	0-1	34340315	3.1	10.1	2000	2150391	87%
Sum						2469158	100%