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THE RUSSIAN LUNAR PROJECT

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Abstract

The main objectives of the Russian Lunar Project are: (1) internal structure of the Moon; (2) volatile in the Polar region. Study of the internal structure of the Moon will be accomplished by use of two types of seismic experiments: (1) small aperture seismic array, (2) broad band seismometer. As an element of the small aperture seismic array it is suggested to use the improved version of the seismic receiver PM-6 designed for MARS-96 missions. 10 HSP will be deployed in Mare Fecunditatis on the area about 80 km². HSP will be thrown from approaching trajectory without deceleration. Two penetrator landers (PL1 and PL2) caring broad band seismometers will be semi-hard landed on equatorial region at the distance about 300 km. between them. Soft landing Polar station (PS) will carry payload consisting of TV-camera and instruments intending study of concentration and composition of volatile at the permanently shadowed lunar site.

After unsuccessful launching of the "MARS-96" spacecraft in November 1996 Russian Space Council requested to work out a new program of the planetary research. By the March 1997 the Planetary Division of the Council submitted new concept in which the first priority had been done to Lunar Mission and Phobos Sample Return Mission. Russian Space Agency in 1997 opened funding of the Russian Lunar project ("Luna-Glob") and the work was started. Unfortunately this year funding of the Project has been stopped again.

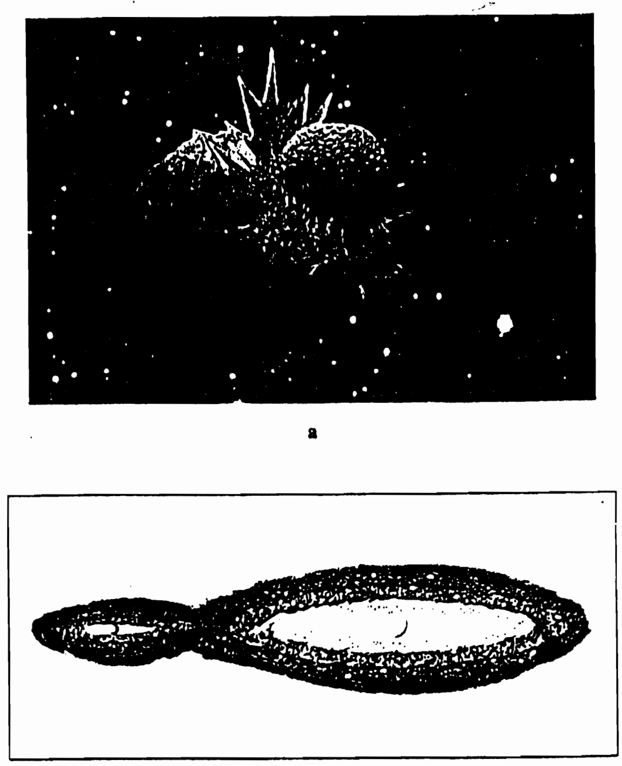
Rational

The Moon is a new continent waiting for its exploration and utilization by the mankind. For several reasons return to active exploration of the moon is particularly actual. Solution of fundamental aspects of the Earth geology is closely related to understanding of the origin and evolution of the Moon. Lunar resources including ^3He and solar power beaming feasibility may be decisive for the Earth energetic in the next century. The Moon is testbed for exploration of remote objects within the solar system and beyond it.

Objectives of the Project

The Russian Linar Program at its first step gives a priority to the problem of the Moon-Earth origin.

Today, the giant impact hypothesis of the Moon formation is a paradigm. In accordance with it the moon was created from the Earth mantle after the iron was extracted to the Earth core (ref. 1, 2). The alternative is that the Moon formed from the same primitive material as the Earth, and the iron was lost by the Moon during a high temperature process (ref. 3). This concept is quite different of the binary accretion model (ref. 4, 5). Fig. 1 illustrates both ideas.



a

b

Fig.1 Illustration for hypotetic mechanisms of the Moon formation: a) artist's view of giant impact; b) the Earth and Moon form as a twin system through collaps of preplanet accumulation of primary material (closed to CI composition)

Our purpose is to define the measurable parameters which allows solving the alternative. Geochemical analysis shows that such parameters do exist. One of the key one is concentration of the refractory elements including Al, Ca, Ti, U, Th, Sr an so on. Enrichment of the Moon in the refractory elements would mean existing of a high-temperature stage in its formation. The laboratory experiments show that enrichment of a melt in the refractory elements suggests inevitable loss of iron. Since the Moon is not depleted in iron compared to the Earth mantle its enrichment in the refractory elements would be in conflict with the concept of its origin from the Earth mantle. Opposite, this would be in agreement with origination of the Moon directly from primary material in some high temperature process. The loss of iron by volatilization in this case would solve the problem of iron deficient in the Moon relative to the bulk Earth.

At present there is no reliable appraisals of the concentration of refractory elements in the bulk Moon. However elastic properties of the mantle depend on its chemical and mineral composition, in particular, on Al_2O_3-content. Thus concentration of Al and hence other refractory elements may be estimated through the seismic data (Fig. 2).

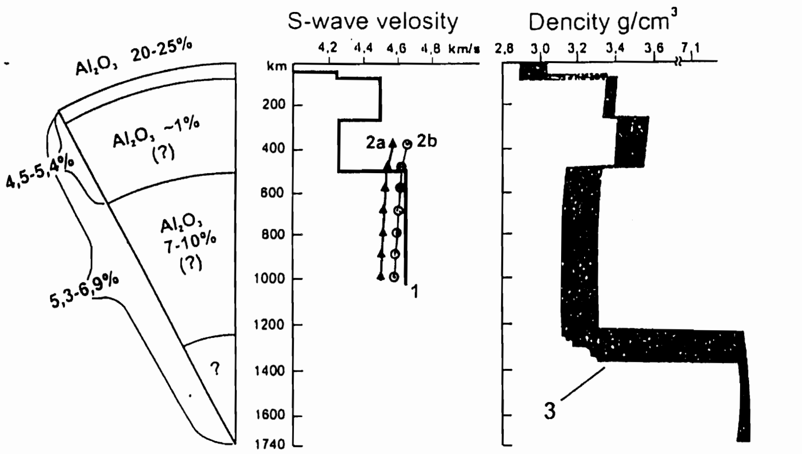


Fig.2 Suggestions on the internal structure of the Moon. 1- seismic profile based on "Apollo" missions data (ref.6); 2a and 2b - synthesized seismic profiles for lherzolite rock and 6%- Al_2O_3 -rock respectively (ref.7); 3- set of density profiles for Al_2O_3- riched lunar mantle (ref.8).

Moreover, there should be correlation between refractory elements content and size of the lunar core. This because Al-richer mantle has lower density and therefore should be balanced with more significant iron core (about 500km radius) to satisty the observed values of the moment of inertia of the Moon and its bulk density.

In contrast, the lower concentration of the refractory elements in the Moon, similar to Earth, is consistent with small core or lack the core at all.

The current interpretation of lunar seismic profile, based on the Apollo missions data (ref. 6) is rather consistent with the higher Al_2O_3-content. However the seismic data available are scarce and do not provide a basis for conclusive intrepretation.

Another geochemical test for mechanism of the Moon formation is related to distribution of siderophilic elements.

Siderophilic elements (Ni, Cd, W, P, Pt, Re, Te etc.) have affinity to iron and come down to the core during its formation. Both the Earth mantle and the Moon are depleted in siderophilic elements approximately in the same degree, with the Moon being depleted in a bit greater extent. Hence if the Moon originated from the Earth mantle a very small core is required: no more than 0.4% of the lunar mass.

On other hand, at the certain conditions, concordance between siderophilic elements distribution patterns of the Moon and the Earth may be achieved even if the Moon formed from the primary material. But in this case the Moon must have the core no less than 4.5-5.5% of the total lunar mass.

Thus the size of the lunar core is of crucial importance for the problem of the Moon origin. The giant impact hypothesis is consistent with small core (less than 1% of mass of the Moon), whereas the formation of the Moon from the primary material requires a significant core (about 5%).

As mentioned above, the Apollo seismic data do not allow to get seismic profile for the depths more than 1000 km. Elastic properties of the internal part of the Moon are unknown and question about presence and size of the core remain unanswered.

Hence, the first objective of the Russian Lunar Project is carriage of seismic experiment which would allow to get information on internal structure of the Moon.

The second objective of the Russian Lunar Project is testing of presence of volatiles in the Polar region of the Moon.

It is known that "Clementine" discovered permanently shadowed area at the South Pole, and "Lunar Prospector" traced presence of ice in the Polar regions from the lunar orbit.

It would be very important to collect and return to the Earth samples from those regions. this would allow to make detailed analysis of the condensed volatiles, including isotope analysis.

However at first stage *in situ* study of concentration and chemical composition of condensed volatiles also is valuable and it might be combined with the first objective of the suggested mission.

The Planned experiments

Seismic experiment

Study of internal structure of the Moon is suggested to be carried out through two types of seismic experiments: 1) small aperture seismic array, 2) broad band seismometery.

Experiment based on the concept of small aperture seismic array is proposed by seismologists of the Institute of the Earth Physic in Moscow (O.B.Khavroshkin).

Preliminary calculations show that satisfactory results can be obtained by deployment of network of 10 seismic sensors which should be employed on lunar surface by penetrators. The penetrator are expected to intrude into lunar surface with high speed on the area of about 80 km^2 (D ≅ 10 km) in 2-3 km of each other (Fig. 3).

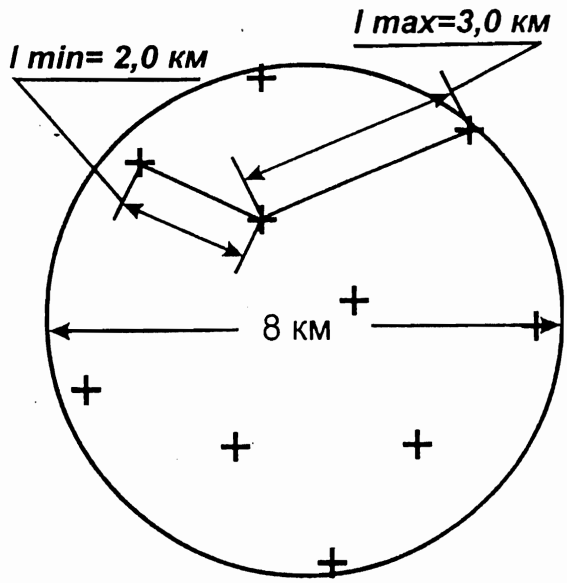


Fig.3 Schema of deployment of the small aperture seismic array

Information about the lunar interior may be obtained through several seismological approaches, including the method of modulation of high frequency seismic signal (ref. 9).

Peculiarity of the small aperture seismic array experiment is that the penetrators are thrown from approaching trajectory and intrude into the ground with high speed. In extreme case (without any decelerating impulse) the speed is 2.5 km/s. Given this the penetrators are expected to penetrate 10-15 m layer of regolith. The shape of the penetrator is designed so that to decrease an overload, and the scientific instrument is designed to support a hard impact (up to 10000G). The preliminary testing shows that the scientific instrument may survive under these conditions.

As an element of the small aperture seismic array it is suggested to use the improved version of the seismic receiver PM-96, designed for use in the MARS-96 mission. Its drawing with some characteristics is shown in Fig. 4.

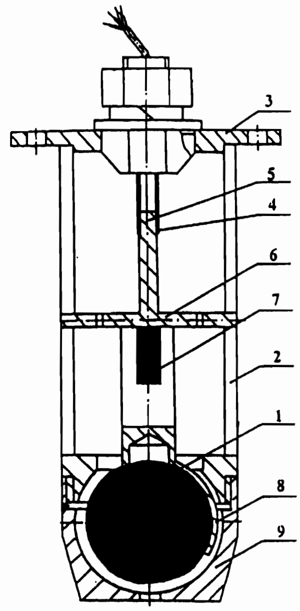


Fig.4 Two component seismic receiver

1- spherical mass
2- body
3- cover
4- piezotransformer
5- adapter
6- adapter
7- piezotransformer
8- spring clamp
9- bottom trap

Characteristics of the seismic receiver and the penetrator

- mass of the seismic receiver - 3kg
- sensitivity 10-10cm/Hz
- frequency band - 0.5-40 Hz
- overload - 10000g
- mass of the penetrator - 12 kg
- dimensions:
  - a) calibre -12 cm
  - b) length in different modifications - 1÷2m
- life time - 1 year
- battery - lithium (3 kg)
- radioblock -3 kg

The seismic array is best to be deployed on area of low seismicity and thick regolith layer. On the nearside of the Moon the eastern part of the south hemisphere has most quite seismicity (ref. 10). Experts (V.Shevchenko and group) have selected Mare Fecunditatis (18°S, 52°E) for emplacement of the seismic network (Fig. 5).

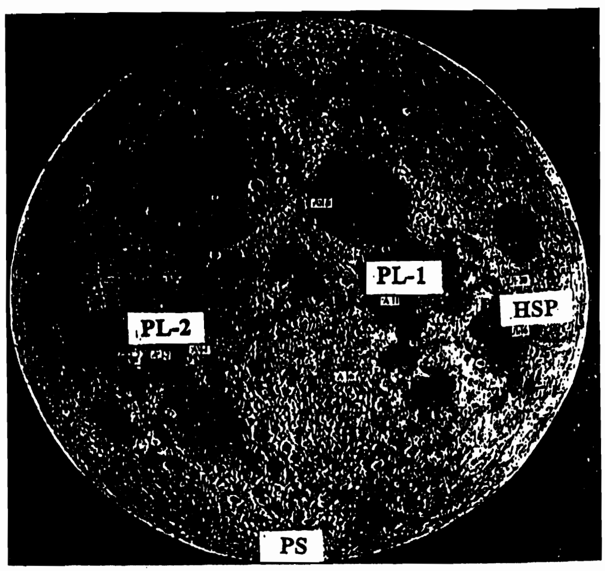


Fig.5 Landing sites in the Russian Lunar Project. HSP- high-speed penetrators of the small aperture seismic array (18°S, 38°E), PL-1 and PL-2 - penetrator-landers at 0.7°N, 23.5°E and 3°N, 23.4°W; PS- Polar Station (88°S, 38°E)

The second type of the seismic experiment suggests use of a broad band seismometer.

Obtaining information from internal part of the Moon is limited by attenuation of seismic waves in the Moon interior (ref. 11). There is substantial decrease of Q-factor with depth. Shear Q-values decrease from 1500 in the upper mantle to less than 500 at the depth 700km and even 300 at the depths 800-1100km. The higher frequency the greater is extent of attenuation. The 1 Hz amplitude of S-waves is reduced by 50, whereas at 0.5 Hz the reduction is 8 and at 0.125 is only 2.

Therefore it is essential to have an instrument with high sensitivity under low frequencies.

The appropriate example is Very Broad Band Seismometer worked out by P.Lognonne and his group for Mars-96 mission. According to the authors this seismometer cover the seismic band from 0.003 Hz to 10 Hz. Its resolution is 10 to 100 times better than that of Apollo below 1 Hz. The modified version of this seismometer is able to sustain the overload higher than 500G.

It is suggested to use such an instrument in the Russian Lunar Project.

Two landers carring broad band seismometers will be deployed on equatorial region at the distance about 300 km between them. The landers will have a shape of penetrator (Fig. 6). Unlike the high-speed penetrator the penetrator-lander will be supplied with decelerating engines, which provide semi-hard landing (80±20 m/c).

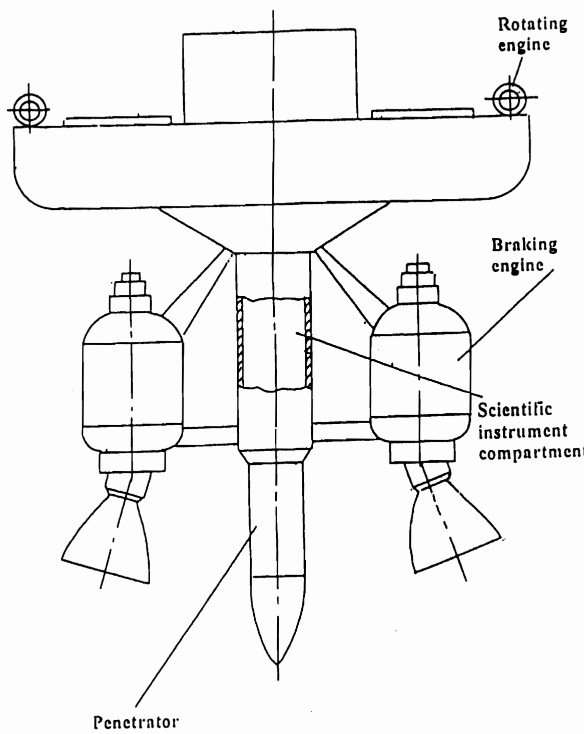


Fig. 6 The Lunar penetrator - lander

The sites with coordinates 0.7°N, 23.5°E and 3°N, 23.4°W are selected for the first and the second penetrators, which correspond to landing places of Apollo-11 and Apollo-12.

Lander at the permanently shadowed site

In order to study composition of the supposed concentration of volatiles at the permanently shadowed lunar site soft landing of the analytical station at the polar region is scheduled.

The scientific payload includes mass-spectrometer, TV-camera, thermometer and as option γ-spectrometer and neutron spectrometer provided that additional space in the spacecraft will be available.

As presence of organic compounds is likely among the volatiles a relevant type of chromato-mass-spectrometer will be worked out. Mass-spectrometric unit prepared for "MARS-96" mission will be used as mass-analyzer: resolution is better than 1 a.m.u., mass range from 1 to 50 sensitivity 10^{-2}-10^{-3} cm^3, mass of the instrument: 1.5-2 kg.

The lander will have TV-camera and equipment for illumination. The version of TV-camera proposed by "Institute of Space Device Engineering" (M.V.Novikov and group) may sustain overload exceeding 500G, able to work under low temperature, provide round -360°-image from 1 m. Mass of the instrument - 1 kg.

γ-spectrometer ensures recording more than 20 elements including main rock forming elements: Si, Ti, Al, Mg, Fe, Ca and others. Due to low temperature at the site of landing it is possible to use highly effective semi-conductor detectors working at temperature lower than 130°K and usually requiring equipment for permanent cooling.

Neutron spectrometer is most relevant for recording of hydrogen content. The version of the instrument designed for "MARS-96" mission is suggested to be used.

Masses of the γ-spectrometer and the neutron spectrometer are 20 and 10 kg respectively. Therefore their including into scientific complex is optional.

The polar station is suggested to be landed at the crater of 56 km size with coordinates of the center 88°S, 38°E (marked "X" in the Fig. 7).

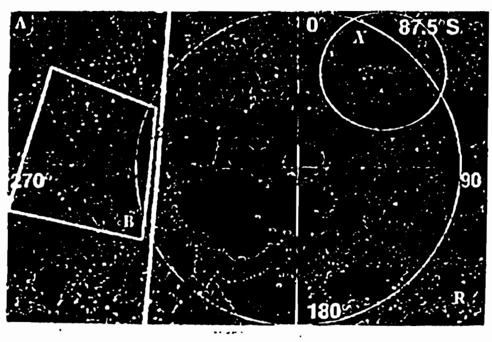
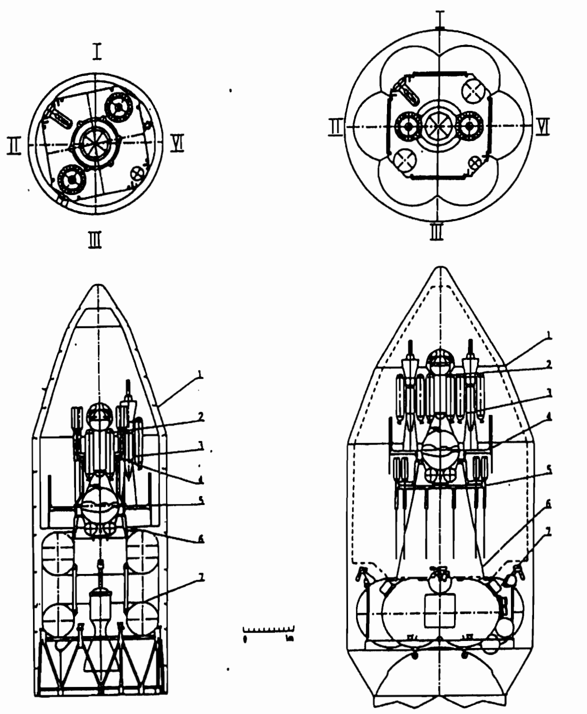


Fig.7 Landing place ("x") of the Polar Station

The lunar mission concept

In accordance to technical order of V.I.Vernadsky Institute "NPO Lavochkin Association" has carried out design of the mission providing achievement of the scientific objectives.

Two versions of spacecraft have been examined - one is adapted to the "Molnia" launch vehicle and the second one - to the "Souz-Fregat" (Fig. 8).



a   b

Fig 8. The Lunar spacecraft under head cover of the "Molnia" launch vehicle (a) and "Souz-2-Fregat" (b): 1- head cover, 2- polar station, 3- penetrator lander, 4-cassete with high speed penetrators, 5- transfer module, 6- spacer, 7- thruster of type 2BL ("Molnia") and "Fregat" ("Souz")

The spacecraft consists of 1) main frame, 2) cassette with high-speed penetrators, 3) polar station, 4) two penetrator-landers.

The High-speed penetrators (HSP) are disposed along perimeter of the cassette ring. The cassette is supplied by battery, solid-fuel engines and control unit.

The polar station (PS) consists of the landing module, braking engine and inflated shock-absorber. The braking engine makes first deceleration to leave the orbit and the second one-to decrease vertical speed. Overload at the moment of shock on the lunar surface does not exceed 200G.

The penetrator-landers (PL) are designed to deliver seismic instrument, containing broad band seismometer, to the selected sites. The braking engines provide deceleration velocity to 80±20m/s at the moment of contact with the surface. The overload has not to exceed 500G. In addition the penetrator contains radiotransmitter, antenna, energy system, control unit.

The spacecraft also contains systems of control and orientation, engines, solar panels and executive devices. Apart from the service equipment it may have scientific payload for exploration of the Moon from orbit.

The spacecraft will be launched by rockets "Molnia" or "Souz". The rocket "Molnia" consists of 4 stages. Its dimensions: the length is 43.4 m, maximal diameter 10 m. The initial mass 320t. The three stages send 7000kg on the 200km Earth round orbit. The thrust (4th stage) transfer the spacecraft from the Earth round orbit to the trajectory to the Moon.

The diagram of the mission are shown in Fig. 9.

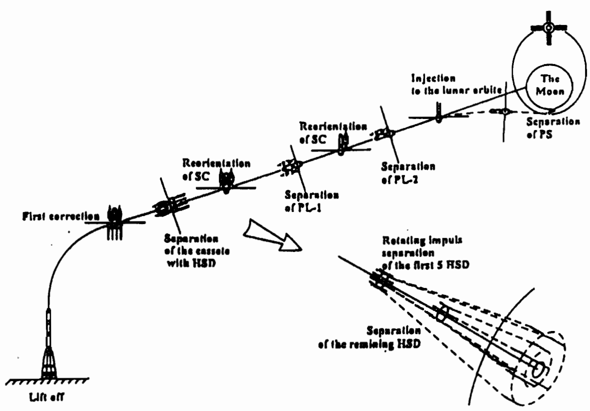


Fig.9 Shematic diagram of mission profile of the Russian Lunar Project

Duration of the flight to the Moon is 4.5 days. For 32-38 hours after starting (at the distance 210-260 thousand km of the Earth) the first correction is scheduled. Then, 29 hours before arriving to the Moon the 14 hours cyclorama is setup.

- during the 1-st hour reorientation of the spacecraft and separation of the cassette with penetrators is carried out

- during the next hour new reorientation of the spacecraft and 4 hours later parting of the 1-st penetrator-lander comes

- then again reorientation of the spacecraft is carried out and the 2nd penetrator-lander leaves the spacecraft.

After detachment from the spacecraft the cassette with high-speed penetrators moves along the hit trajectory rotating with 3 rad/s.

- at 700km rotation speed increases to 20 rad/s and the first set of the high-speed penetrators detached from the cassette. With side velocity of 20 m/s and vertical speed of 2.6km/s, the penetrators during their travel to the moon surface (about 250 sec) fly away around the circle of diameter ~10km.

- at the altitude 350km the remaining 5 penetrators leave the cassette and for the time of falling down to the lunar surface they fly away within the circle of 5 km-diameter.

The penetrator-landers after detachment of the spacecraft move along the hit trajectory. The braking engines are geared at the altitude 2km. The speed decreases to zero. Then, the braking engines are dropped out and the penetrator enter the surface with speed about 60-120m/s.

After releasing the penetrators spacecraft is injected onto a polar circular orbit. It is selected so that to pass over the site of landing of the Polar Station. The Polar Station is detached of the spacecraft and decelerated to zero orbital speed. It falls down to the altitude about 2km, where the braking engines decrease vertical speed to zero. The braking engines are dropped out and the station touches the lunar surface with the speed 5-25m/s.

The orbital module is necessary to translate to the Earth information from the Polar station. The Polar orbite of the lunar satellite allows mapping of the entire surface of the Moon. Gamma-spectrometer and neutron spectrometer will be installed in the orbital module, if enough space remains after installation of the instruments of the first priority and if the orbit will be sufficiently low.

The gamma-spectrometer and neutron spectrometer will be of the same type as in the polar station.

Conclusive remarks

Achievement of the objectives of the Project could result in significant breakthrough in geosciences and planetology. At the same time we consider it as a first step in the long-term program of exploration of the Moon. If the presence of the water in polar region of the Moon will be confirm this open new prospects in its exploration. The sample return mission becomes necessary. At the next century utilization of the Moon will undoubtly become actual, particularly, in connection with, energetic problem. This demands extensive research, exploration, and mining works on the Moon which would be timely to start now.

After unsuccessful launch of spacecraft "MARS-96" the whole strategy of the Russian planetary research should be reviewed. In this connection return to the Moon seems to be most reasonable in the current situation.

The Lunar projects besides their great scientific interest have other advantages:

- they are least expensive since can be realized with use of the middle class launch vehicles line "Molnia", "Souz" and even military conversion missiles

- they might be led up very soon as the Russia has unparalleled experience in exploration of the Moon by automatical instruments

- in contrast to missions to the remote objects of the solar system (i.e. Mars) the launch of spacecraft to the Moon is not related to a certain date, and hence implementation of the project is not jeopardized under bad and nonsystematic funding

- the lunar projects can be combined with other purposes, in particular, with engineering testing during preparation of the expensive missions designated to explore remote bodies of the solar system.

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