Pioneer geotechnical research in space – Moon soil investigation

Specially for Time Capsule project

The Moon is the first extraterrestrial space object, on which geotechnical studies were carried out, and where first geotechnical instruments were used, as well as the first data on the mechanical properties of regolith - the dispersed soil, which covers the surface of the Moon, were obtained.

Any activity on space objects closest to the Earth, such as construction of scientific stations, sites, shelters and structures, the design of engineering equipment, will always require a preliminary study of the natural and engineering (geotechnical) conditions of theses space objects. Thereby, the need to evaluate mechanical properties of their surface inevitably arises.

Soviet scientists were the first in the world to launch a research on the physical and mechanical properties of lunar soil (regolith) in the 1960s. This initiated a new direction in geotechnical engineering, named «Planetary Geotechnics». A.P. Vinogradov, I.I. Cherkasov, V.V. Shvarev, V.V. Gromov, V.V. Mikheev, M.I. Smorodinov, V.P. Petrukhin, Yu. M. Lychko, A. A. Morozov, E. A. Motovilov and others contributed a lot to its development. A number of research institutes of the USSR Academy of Sciences and other ministries and departments were involved in the design of unique instrumentation for the lunar soil analysis.

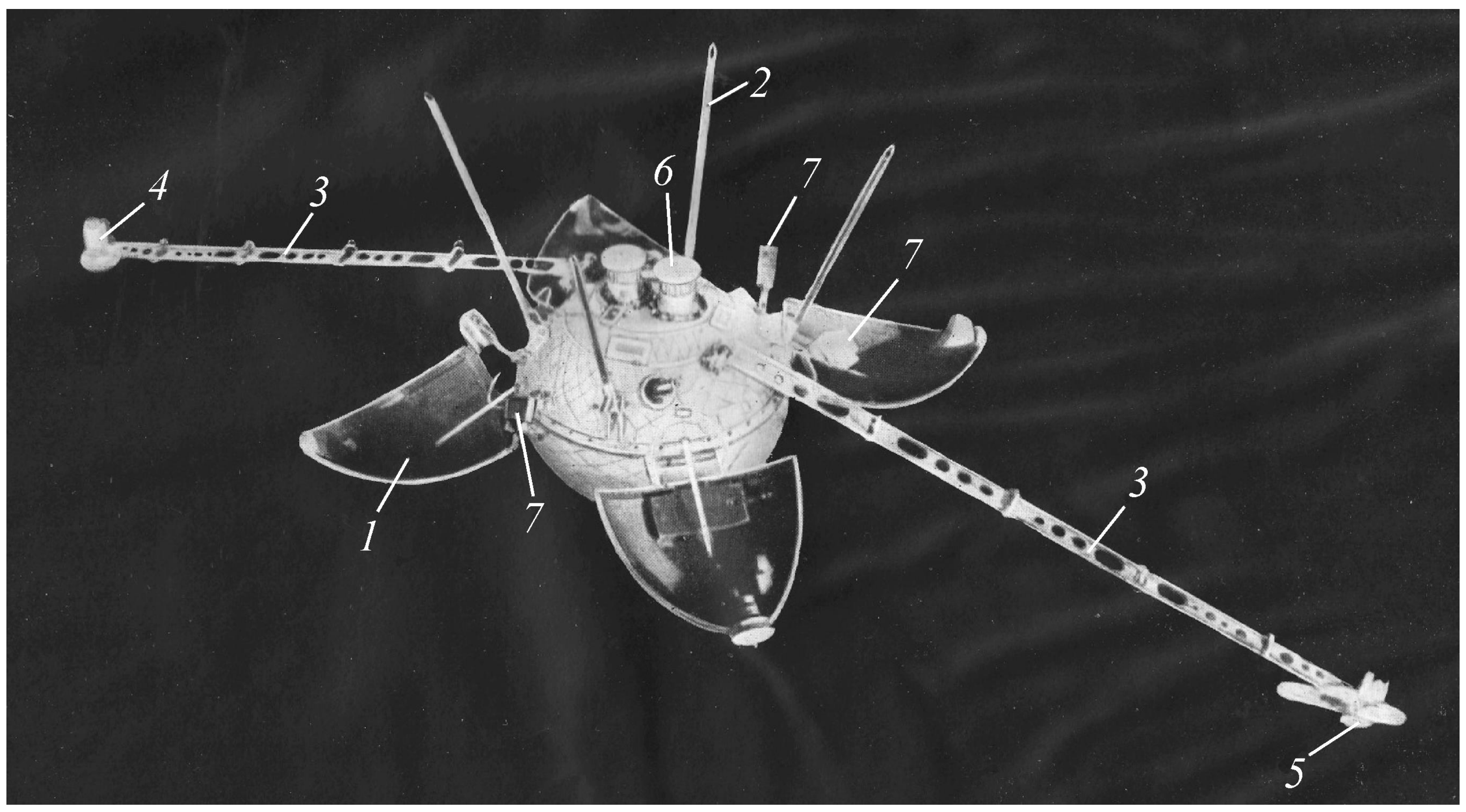
CHRONOLOGY OF EARLY RESEARCH

03.02.1966 – The Soviet automatic spacecraft "Luna-9" accomplished **the first in the history of space research soft landing on the Moon** in the area of the Ocean of Storms. The successful landing refuted the hypothesis of the existent thick layer of loose dust on the Moon and opened the opportunity to direct instrumental investigation of the mechanical characteristics of the lunar surface.

24.12.1966 – A robotic lunar probe "Luna-13" landed in the Ocean of Storms. The probe was equipped with instruments specially designed for lunar rock exploration. It carried RP-radiation densitometer and GR-1 mechanical penetrometer. These became the **first instrumentation for exploring soil properties of the extraterrestrial objects**.

17.11.1970-19.02.1971 and 16.01-22.04.1973 – "Lunokhod 1" and "Lunokhod 2" were the **first in the world roving remote-controlled robots** equipped with PROP odometer/penetrometer. The robots landed in the Sea of Rain and Lemontier Crater respectively.

20.09.1970, 21.02.1972 and 18.08.1976. The **robotic lunar probes** Luna-16 (Sea of Fertility), Luna-20 (Terra Apollonius) and Luna-24 (Sea of Crises) **equipped with drilling instrumentation** were launched to collect rock samples.

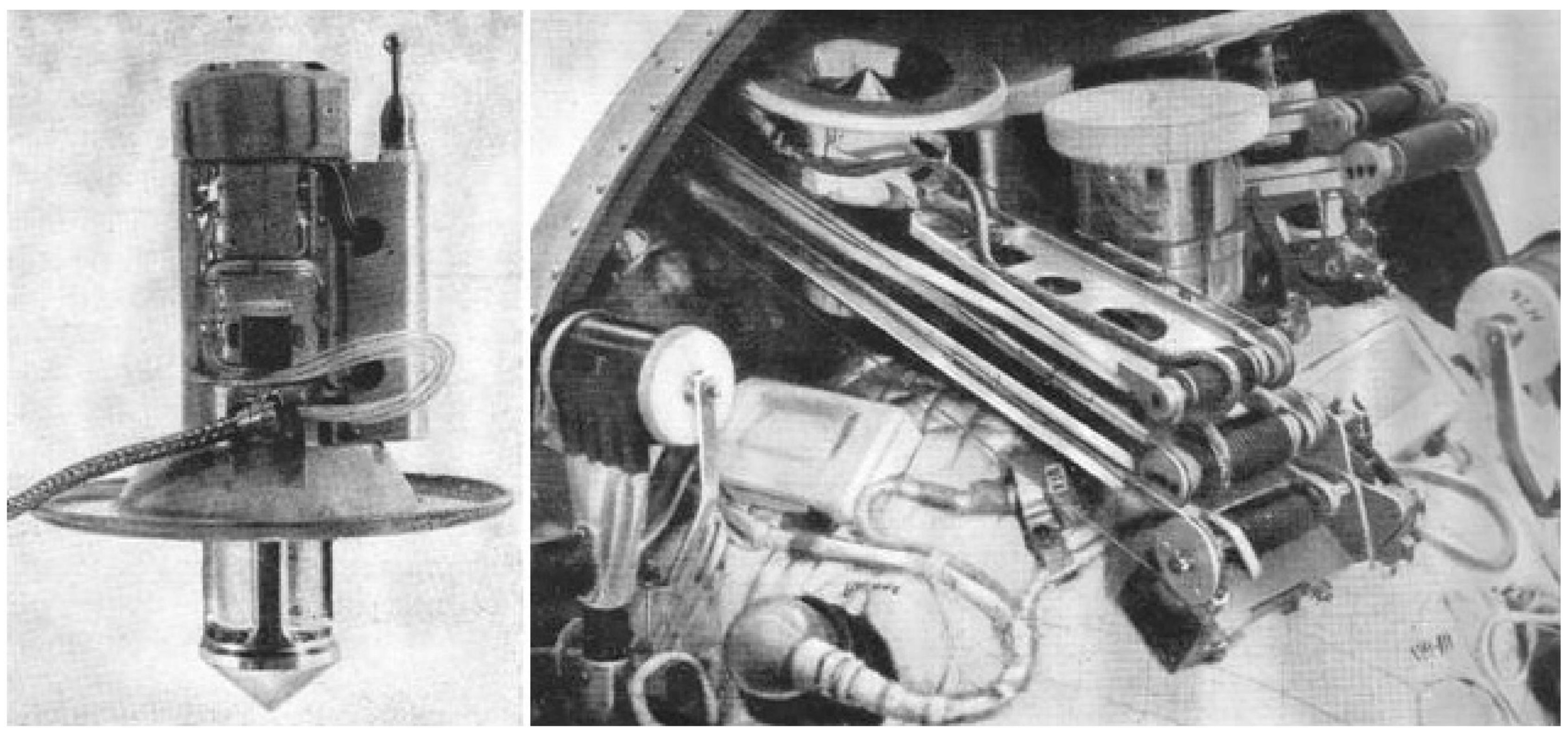


A robotic lunar probe "Luna-13": 1 - lobe antenna, 2 - antenna spike, 3 - instrument deployment boom, 4 - RP radiation densitometer, 5 - GR-1 mechanical penetrometer, 6 - TV camera, 7- radiometers.

The first robotic lunar rover «Lunokhod-1»

GR-1 MECHANICAL PENETROMETER

GR-1 Mechanical Penetrometer had a plastic case, the lower part of which formed an annular flat plate with an outer diameter of 12 cm and an inner diameter of 7.15 cm. In the upper cylindrical section, there was a movable titanium indenter, the working part of which was a cone with an apex angle of 103^0 and a base of 3.5 cm in diameter. Above mounted was a miniature solid-fuel engine with a nozzle facing up, designed to press the indenter into the ground. The thrust force of the engine in lunar conditions was 55 ... 75 kN, the duration of action was 0.6...1.0 s. The depth of penetration was measured with potentiometer with a wiper contact, mounted on the body of the penetrometer. Measurement accuracy was 0.3 mm.



GR-1 mechanical penetrometer (left) and folded instrument deployment boom (right) for regolith investigation

Mechanical properties of the regolith were evaluated after the device was deployed on the lunar surface. When zero-reading of the potentiometer was taken, a command to start the engine was given. There were two methods for interpreting test results.

According to the first method, a calibration of the device was performed. For that purpose, 14 various types of soil and materials had been laboratory tested with this device. Methods for defining material properties and density were those usually used for soil testing. The depth, to which the indenter and the body of the device penetrated into each of the studied materials, was tabulated. As a result, the received calibration table was afterwards used to decipher the data obtained from the Moon.

Special experiments were held to assess the acceleration effect on the depth of indenter penetration into granular soils. They were performed in the cockpit of an aircraft flying along a path, on which an acceleration was kept equal to the lunar gravity acceleration i.e., 1.62 m/sec^2. The indenter was pushed with a helical spring. A mechanical recorder registered the penetration depth. Comparison of the penetrated depth under these conditions with the depth obtained from the same method on the Earth revealed that six times decrease in the gravity acceleration led to an increase in the depth on average by 70%.

The second method for deciphering readings of the soil penetrometer used the solutions of soil mechanics related to the round plate soil test. Since there were no developed solutions for a plate of complex configuration, which had the penetrometer mounted on the Luna-13, V. Berezantsev's solution for a flat plate was used. The calculation showed a critical pressure of 66.7 kPa on the lunar soil.

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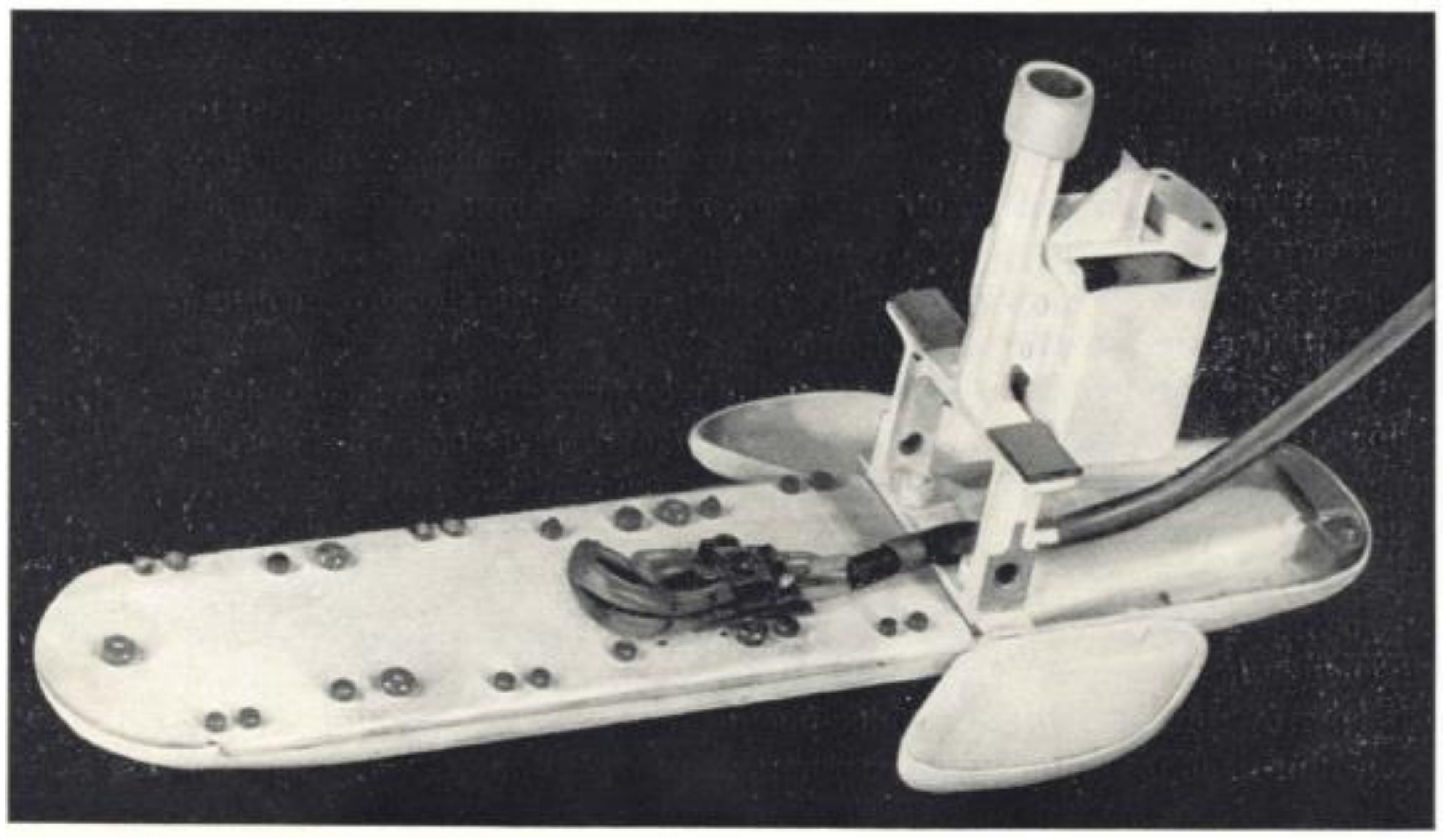
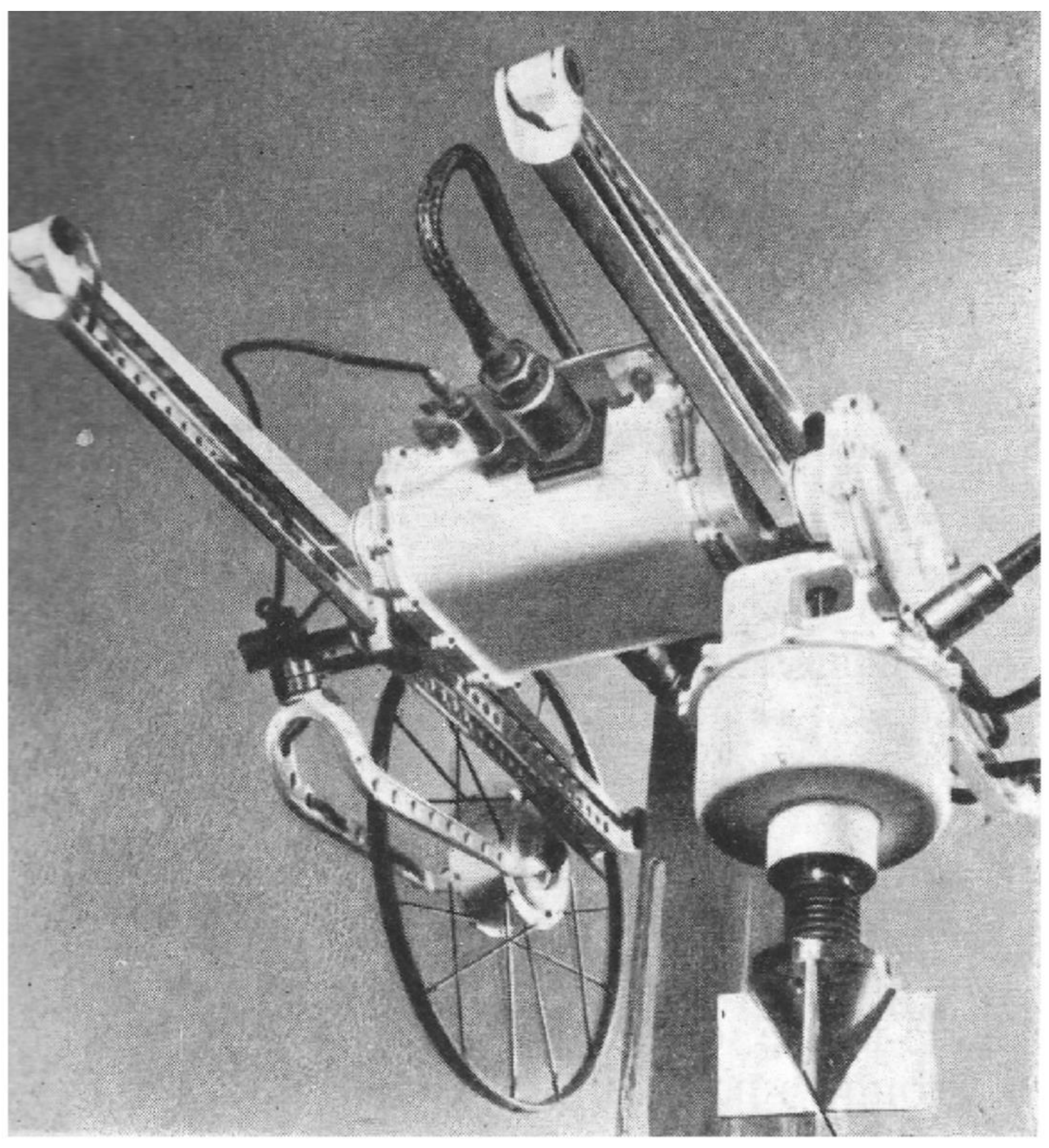
RP RADIATION DENSITOMETER



RP radiation densitometer

The RP radiation densitometer determined the density of the soil, scattering the gamma quanta emitted by the device. The sensor was mounted on a deployment boom, and the electronic unit and telemetry system were inside the station. Inside the sensor body measuring 25.8x4.8 cm, there was a radioactive isotope Cs^{137} and three groups of counter units for recording scattered radiation. A lead screen was placed between the isotope and the counters.

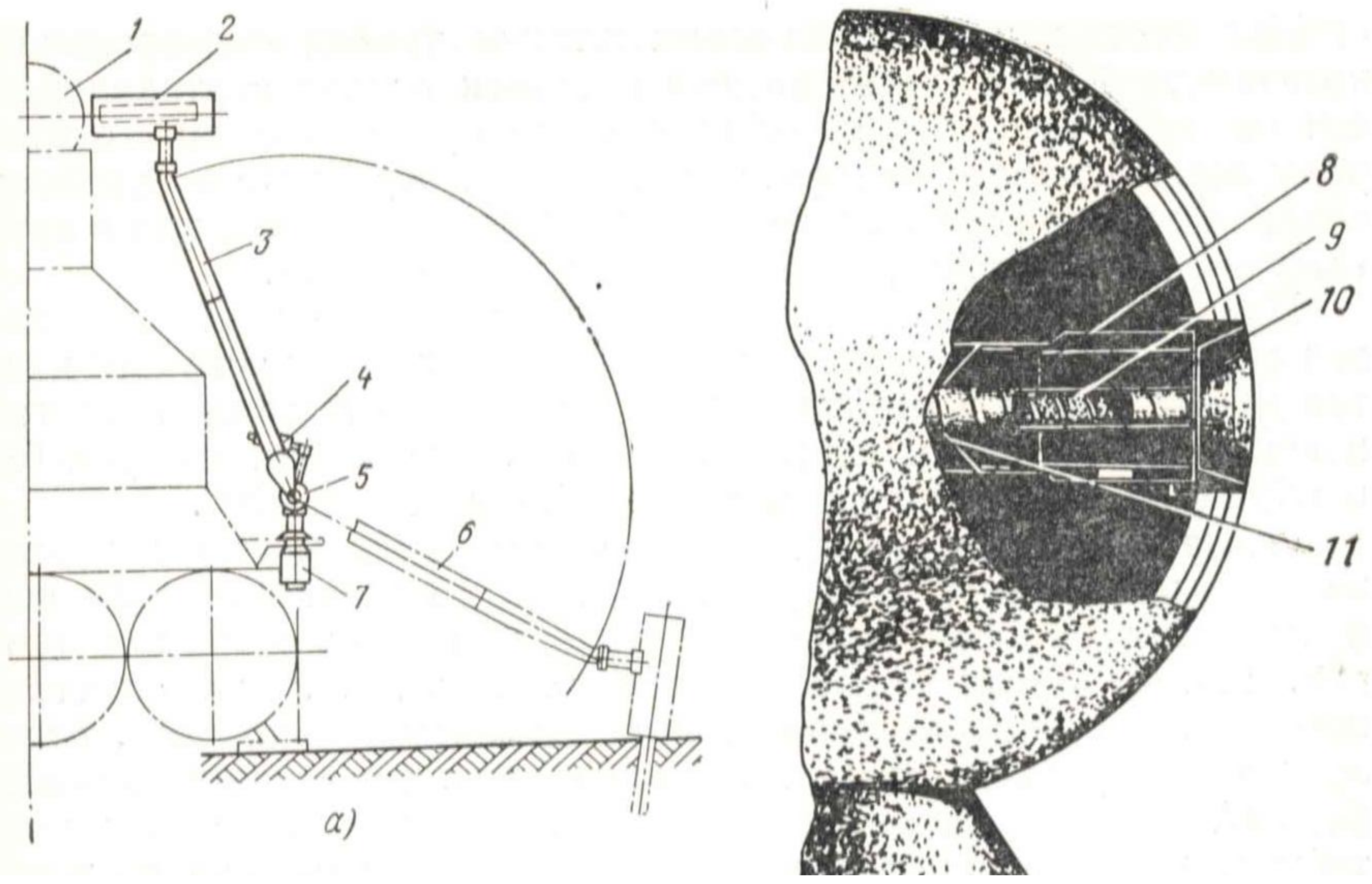
PROP DEVICE



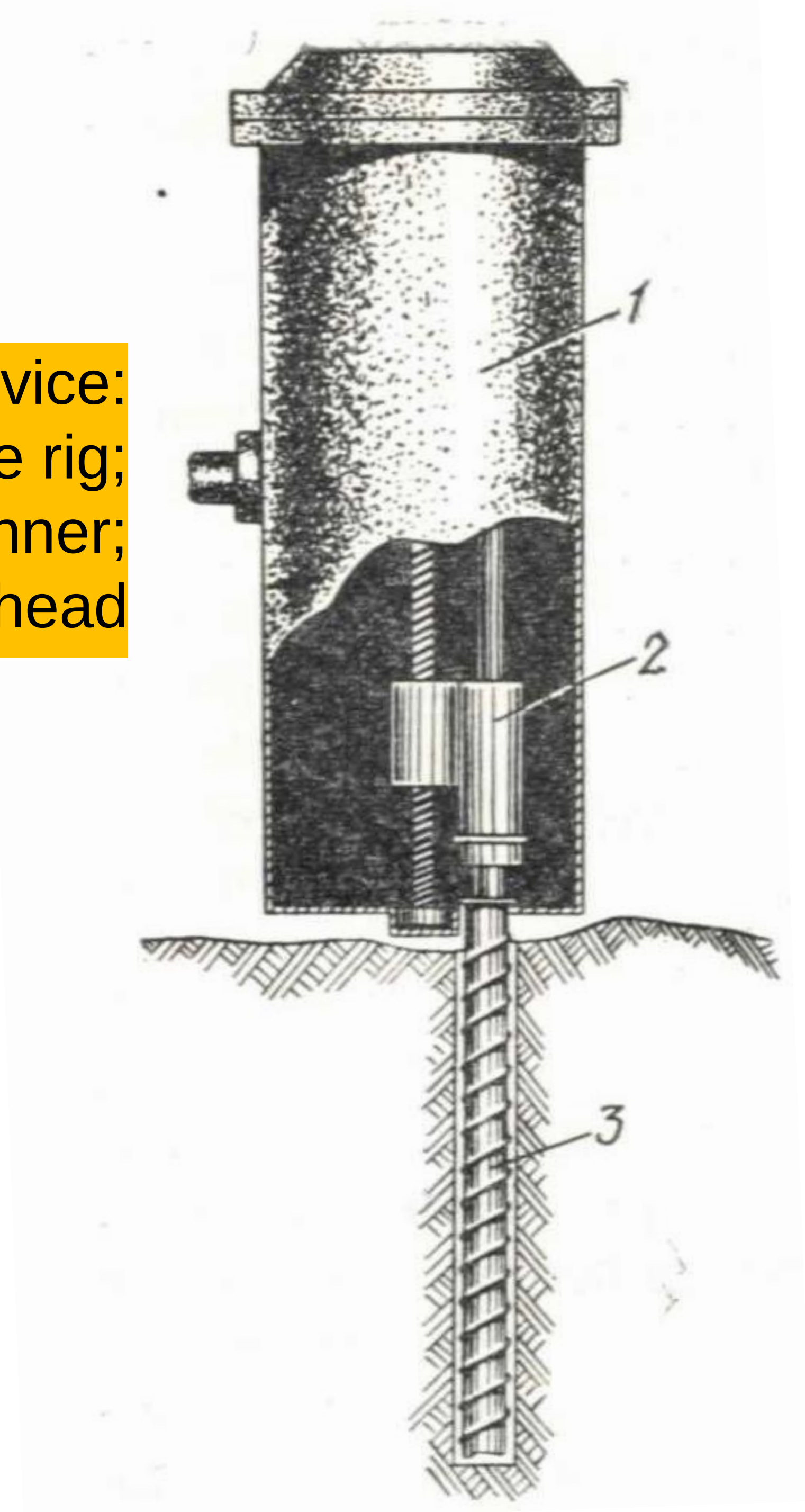
PROP device mounted on roving remote-controlled robots “Lunakhod-1” and “Lunakhod-2”

Mechanical properties of the regolith were identified with a PROP device installed on the lunar rovers. Its working body comprised a cone tip with an apex angle of 30^0 and a base of 5 cm in diameter and two vertical blades 7 cm wide and 4.4 cm high crossing it. The device combined elements of a penetrometer and a shear vane. The penetration force was 0.23 kN, penetration depth - 50-100 mm, angle of rotation - 90°, axial torque - up to 5 N*m. The device worked as follows. After the command was given, the cone with two vertical blades was lowered to the lunar surface level and pulled down to a maximum depth. Then the cone rotated through a limiting angle or torque. The following characteristics were continuously measured during the test: the cone movement, the puling force, the angle of cone rotation and the cone axial torque. As a result, regolith resistance to cone penetration and its shear resistance were defined.

DRILLING AND CORING DEVICE



Scheme of the coring device and core housing of the returnable spacecraft:
1 - a returnable spacecraft; 2 – a drill rig; 3 - an initial position of the remote rotary rod; 4 – a rod damper; 5 - an electric drive for turning the rod in a vertical plane; 6 - a working position of the rod; 7 - a drive rod scanning in azimuth; 8 - a container for a drilling tool with soil; 9 - a drilling tool with soil; 10 - a container cover; 11 - fixing springs



Drilling device:
1- a body of the rig;
2 – spinner;
3- rotary head

The device for extracting regolith consisted of a drilling device, a drill rod with a core extractor, and drives that moved the rod up and down. The working body was a tubular vibro-impact tool with cutters at the end, designed both for testing rocks and for testing silty-sand soil. The maximum drilling depth was 35 cm. The machine was driven by electric motors. At the end of the work, the drill with soil was removed from the well and driven into the container of the returned hermetically sealed apparatus. Then the spacecraft "Moon-Earth" took off to the Earth. Robotic lunar stations "Luna-16" and "Luna-20" delivered to Earth 100 and 50 grams of regolith, respectively.

A new type of rig was used on Luna-24, which provided coring from a depth of up to 2.6 m with minimal distortion of regolith properties. The drilling device was much more complicated. During the drilling process, the soil entered the internal cavity of the drill rod, where a flexible pipe, a soil carrier, and a mechanism that picked up the soil and held it in the form of a column throughout the entire drilling process were placed. Rotary drilling was used up to a depth of 120 cm, and then rotary percussion drilling was applied. Then the flexible soil carrier was removed from the rod and wound onto a drum placed in a special container, which was then enclosed in a sealed capsule and returned to the ground. Luna-24 delivered 170 g of lunar matter.