# Lunar Roving Vehicle

In the LM the astronauts will take with them to the surface a four-wheeled vehicle that can be used to transport themselves and equipment over the lunar surface. It is termed the Lunar Roving Vehicle (LRV) or Rover (figure 12). It is powered by two silver-zinc, 36-volt batteries and has an individual electric motor for each of the four wheels. A photograph of the Apollo 15 Rover, taken on the Moon's surface, is shown in figure 13. A photograph of the folded Rover taken just before it was placed in the LM is shown in figure 14. The Rover deployment scheme is shown in figure 15. There is a navigation system that contains a directional gyroscope and provides information as to total distance traversed as well as heading. The instrument panel is shown in figure 16. In addition to the astronaut's oral descriptions, television pictures are telemetered back to Mission Control in Houston from the Rover. These pictures will be shown over the regular TV networks.

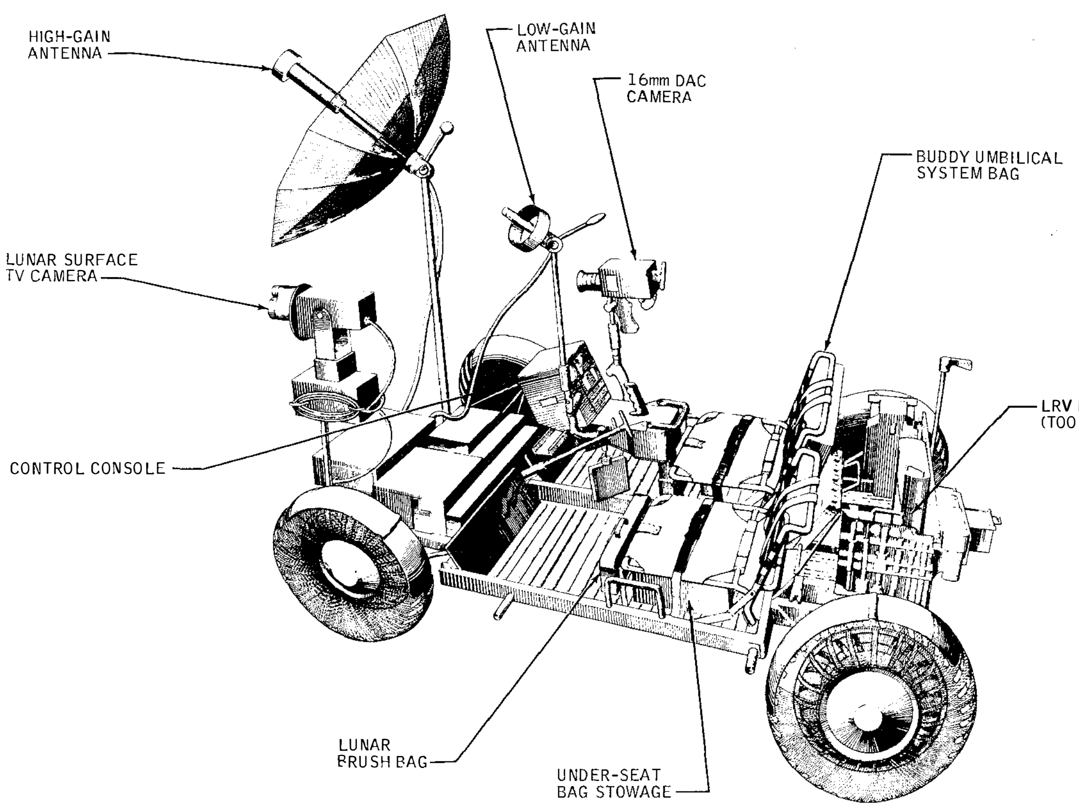



FIGURE 12.—The Lunar Rover. Both astronauts sit in seats with safety belts. About 7 minutes are required to fully deploy Rover. The capacity of the Rover is about 1000 pounds. The vehicle travels about 10 miles per hour on level ground. The steps necessary to remove it from the LM and to ready it for use are shown in Figure 15.

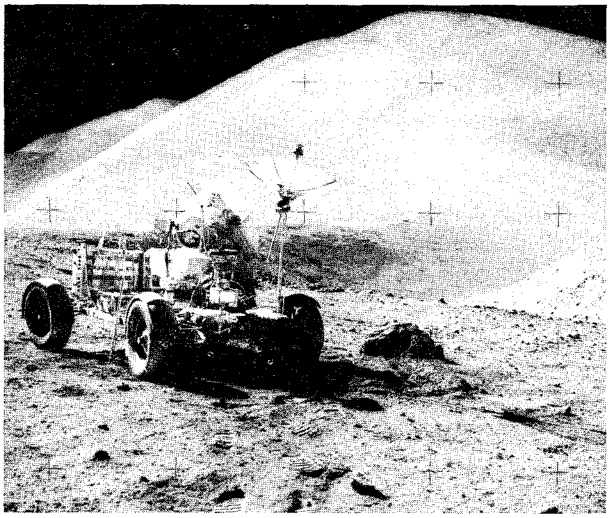


FIGURE 13.—The Apollo 15 Rover. Shown in the background is Mount Hadley delta, a 12,000 foot mountain. The valley on the right side of the photograph is about 1200 feet deep. On the Rover, note the high gain antenna and the television camera in the front and the tool carrier in the rear. The scale of the photograph varies greatly from the foreground to the horizon; it may be obtained from the footprints, the Rover, and the mountains in the distance, NASA PHOTO AS51–82–11121.

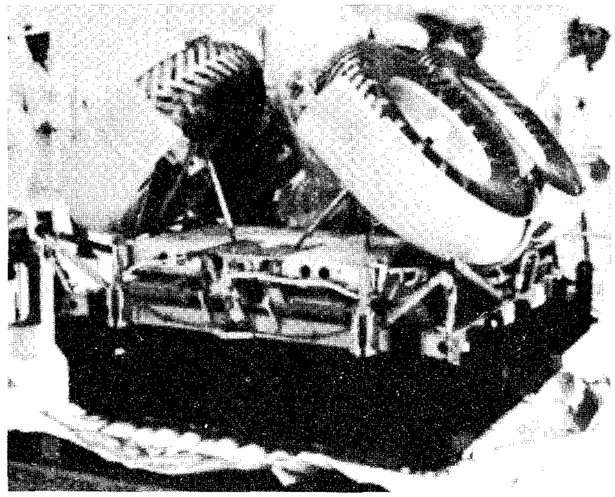


FIGURE 14.—Folded Rover. To save space in the LM, the Rover is carried to the Moon folded in this fashion. This photograph was taken at Cape Kennedy shortly before Rover was placed in the LM. NASA PHOTO 108–KSC–371C–171/4.

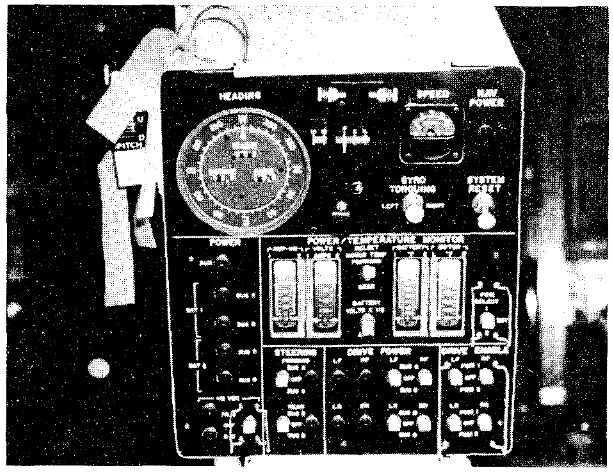


FIGURE 16.—Rover Instrument Panel. This panel contains all of the power switches for the Rover, an indication of the direction in which the Rover is heading, the speed at which it is traveling and the information (direction and distance) necessary to return safely to the LM. Also shown are the power and temperature of various motors. The small box below the instrument panel contains the gyroscope. NASA PHOTO S–72–16181.

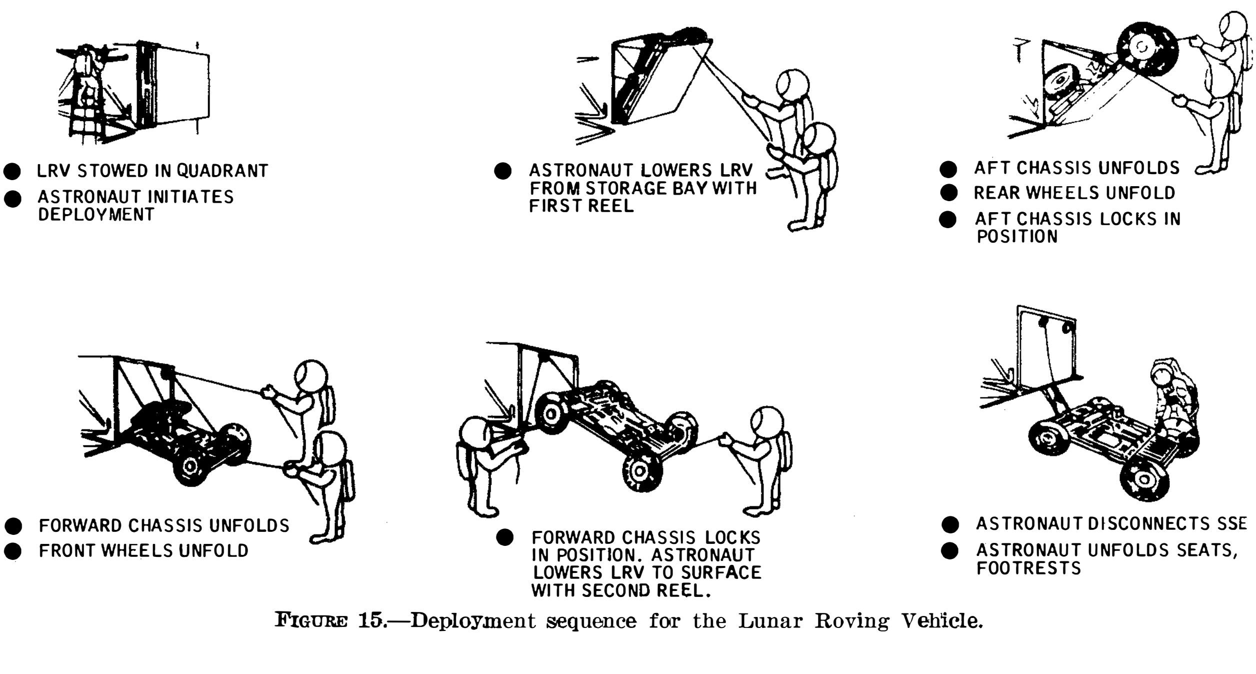



FIGURE 15.—Deployment sequence for the Lunar Roving Vehicle.

# Surface Science Activities

Each of the two astronauts that descend to the lunar surface in the LM will spend about 21 hours in three periods of 7 hours outside the LM working on the lunar surface. Most of that time will be used to study geological features, collect and document samples of rocks and soil, and set up several experiments that will be left behind on the lunar surface when the astronauts return to Earth.

The surface traverses described in this guidebook, which was written about $3\frac{1}{2}$ months before launch, should be considered as general guides for the astronauts to follow. From previous Apollo missions, we have learned that although some minor changes in plans are likely to occur, major changes are unlikely. On each mission a few changes were made by the crew because of unforeseen conditions. Instructions to the astronauts have always been "to use their heads" in following the detailed plans and the Apollo 16 mission is no exception. In addition, the astronauts may consult over the radio with a group of scientists located in Mission Control at Houston and decide during the mission to make some changes. Undoubtedly, some details of the traverses will change. Equipment changes, on the other hand, are very unlikely to occur because all of the equipment has been built and was being stowed in the spacecraft at the time of writing.

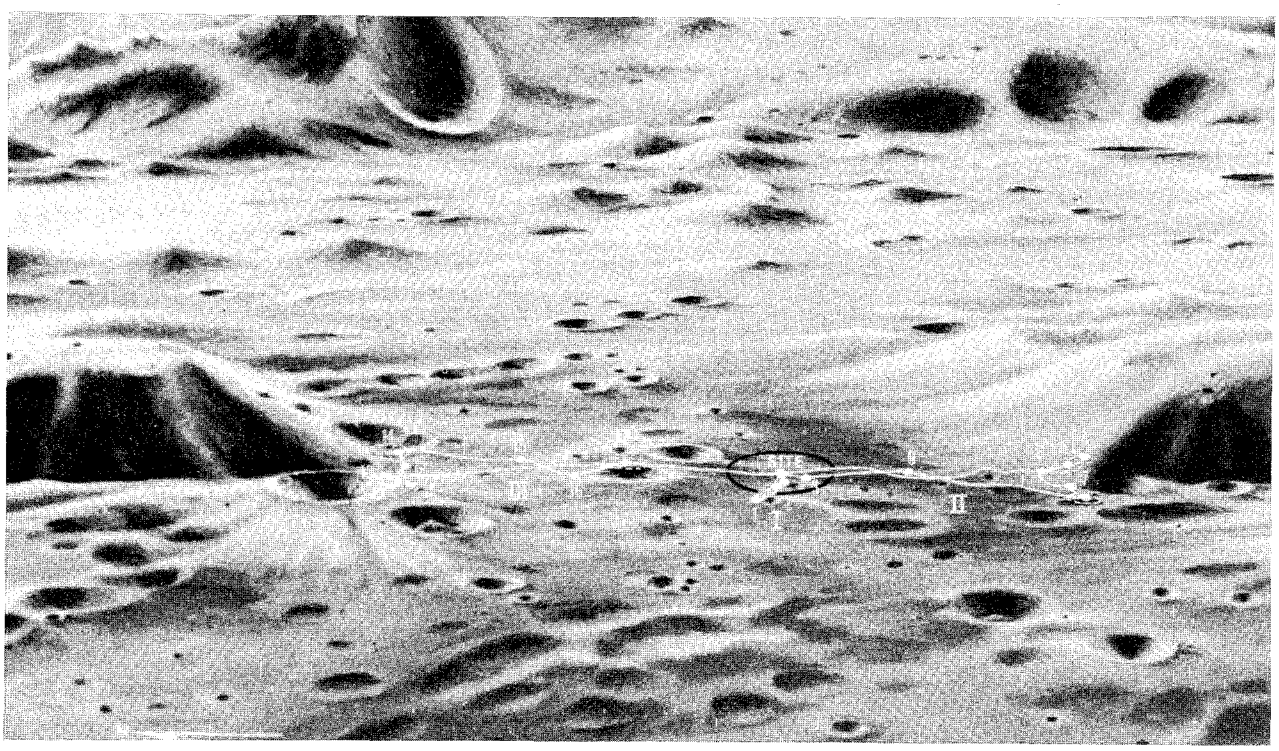


FIGURE 17.—The traverses planned for use with the Lunar Roving Vehicle. The Roman numerals indicate the three EVA's. The numbers are station stops. The station stops are keyed to the information given in Table 2. These same traverses are shown in figure 18, an overhead view of the landing site. *Drawn by Jerry Elmore.* NASA PHOTO S-72-16940.

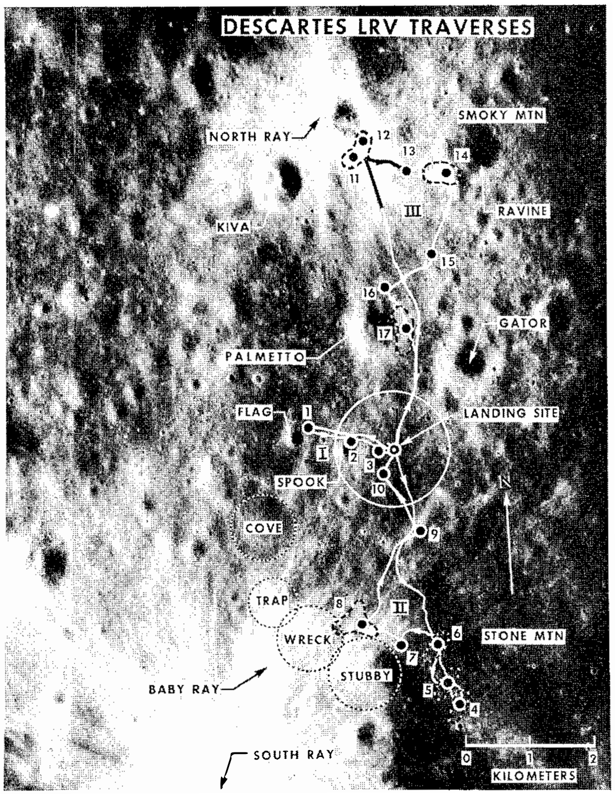



FIGURE 18.—The traverse routes are shown on the *photograph* of the site. This photograph obtained on Apollo 14, has been used extensively in planning the surface activities. Shown also are the geographic names of various features that will be used by the astronauts during the mission. NASA PHOTO S–72–017–V.

## TRAVERSE DESCRIPTIONS

The planned Rover traverses are shown in figures 17 and 18. The activities at each of the stops on all three traverses and along each traverse between stops are shown in Table 2. In order to use Table 2 effectively, the reader must have scanned most of the next section, "Surface Scientific Experiments and Hardware", and to have read the section "Lunar Geology Experiment".

The numbers assigned to each of the traverse stations shown in the figures and tables of this guidebook are current at press time (January 15, 1972) and are not expected to change. However, extra stations may be added before, as well as during, the mission. These extra stations will be given a special designation to avoid confusing them with the existing stations.

In the event that the Rover becomes inoperative sometime during the mission, a series of walking traverses has been planned. Because the maximum distance that an astronaut can walk safely on the Moon is set by the amount of oxygen and other supplies that he carries, the walking traverses extend to 3–3½ km from the LM. One walking EVA extends from the LM to the vicinity of Flag crater; another from the LM towards Stone Mountain; and a third towards Palmetto Crater.

## LUNAR SURFACE SCIENTIFIC EXPERIMENTS AND HARDWARE

In addition to the observations made by the astronauts and the collection of samples of lunar material to be returned to Earth, several scientific experiments will be set out by the astronauts on the lunar surface. The equipment for these experiments will remain behind on the Moon after the astronauts return to Earth. Data from these experiments will be sent to Earth over microwave radio links, similar to the ones used extensively for communications on Earth.

### Apollo Lunar Surface Experiments Package (ALSEP)

Several of the lunar surface experiments are a part of the Apollo Lunar Surface Experiments Package (ALSEP). General layout of the equipment on the lunar surface is shown in figure 19. A photograph of the Apollo 14 ALSEP, which is similar but not identical to the Apollo 16 ALSEP, is shown in figure 20. The ALSEP central station, figure 21, although obviously not an experiment, provides radio communications with the Earth and a means for control of the various experiments. After the ALSEP is set up, it is quickly checked out from Earth. After the astronauts leave the Moon, commands continue to be sent from Earth for control of the various experiments during the lifetime of the ALSEP. The experiments connected electrically to the central station are the Passive Seismic Experiment, the Active Seismic Experiment, the Lunar Surface Magnetometer, and the Heat Flow Experiment. I discuss briefly each of these experiments.

Electrical power for the experiments on the lunar surface is provided by the decay of radioactive plutonium in a device termed Radioisotope Thermoelectric Generator (RTG), shown in figure 22. A total of roughly 70 watts is delivered. Let me draw special attention to this power of 70 watts. It is truly incredible that all of the experi-

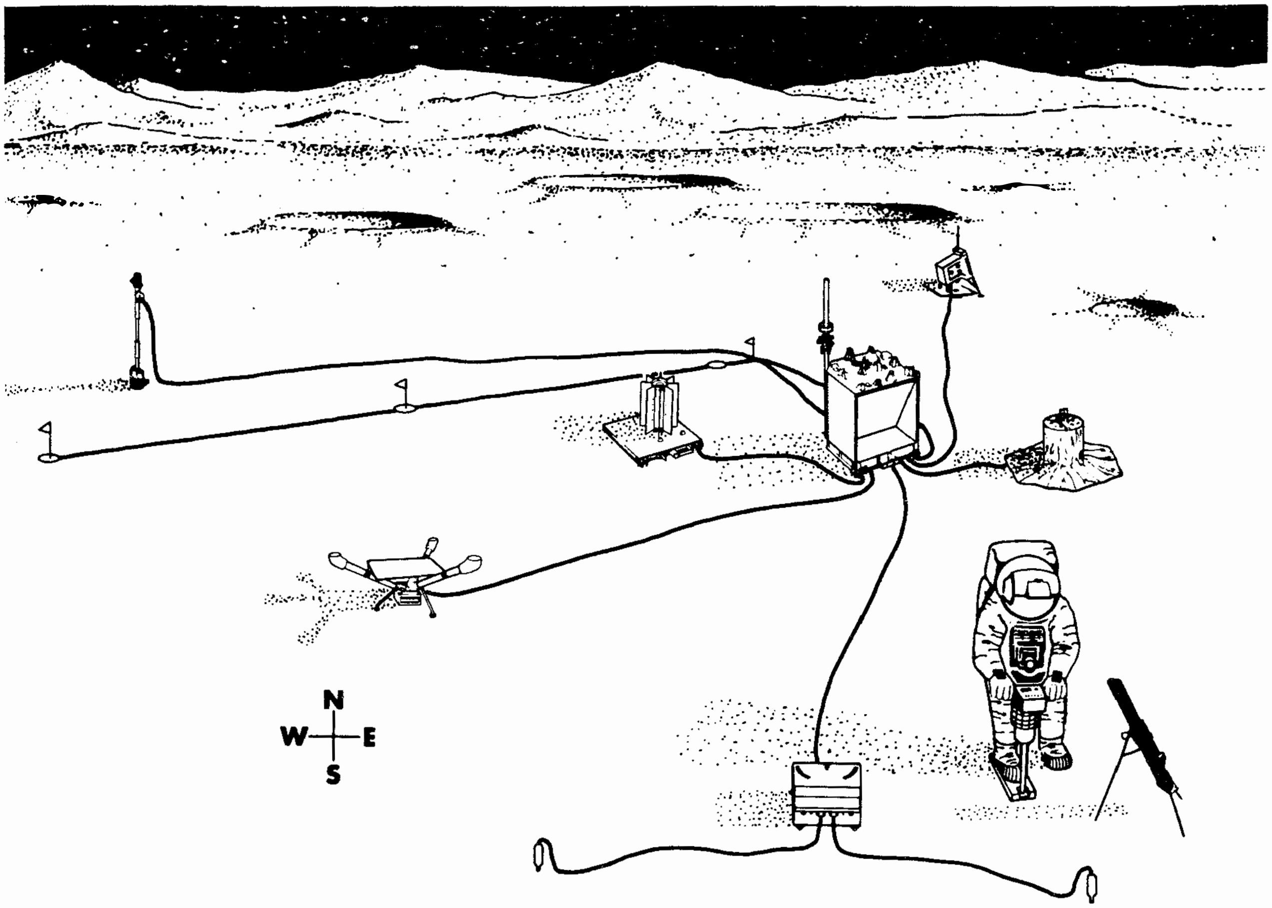
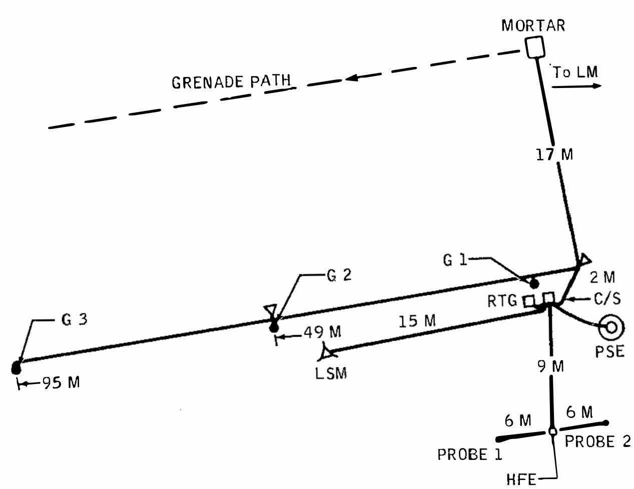



FIGURE 19.—General layout of the ALSEP. (Above) Although the astronaut, equipment, and lunar features are drawn to different scales, their locations are shown in true relation to each other. Shown here are the relative positions of the four experiments that are a part of the Apollo 16 ALSEP. This site is at least 300 feet west of the LH. North is towards top of figure. (Right) The correct distances (in meters) are shown on a map view of the site.




ments together, and including the radio that sends the scientific information over a quarter million miles of space to us, use no more power than is consumed by an ordinary 75 watt light bulb! The electrical wires are flat, ribbonlike cables that may be seen in figure 20. The RTG is filed with nuclear fuel after the astronauts place it on the lunar surface. The fuel is caried to the Moon in a cask mounted on the side of the LM. The cask is sketched in figure 23 and can be seen in figure 3.

During EVA 1, the astronauts remove the ALSEP equipment from the LM, carry it to a site at least 300 feet from the LM, and place it on the lunar surface. In figure 24, we see astronaut Al Bean carrying the Apollo 12 ALSEP. The 16-ALSEP is carried in a similar way. In figure 25, a sketch of the ALSEP pallet, you can see the packing of the individual items of the ALSEP. A summary of these ALSEP operations is given in Table 3. A layout of the various ALSEP experiments on the Moon is shown in figure 19.



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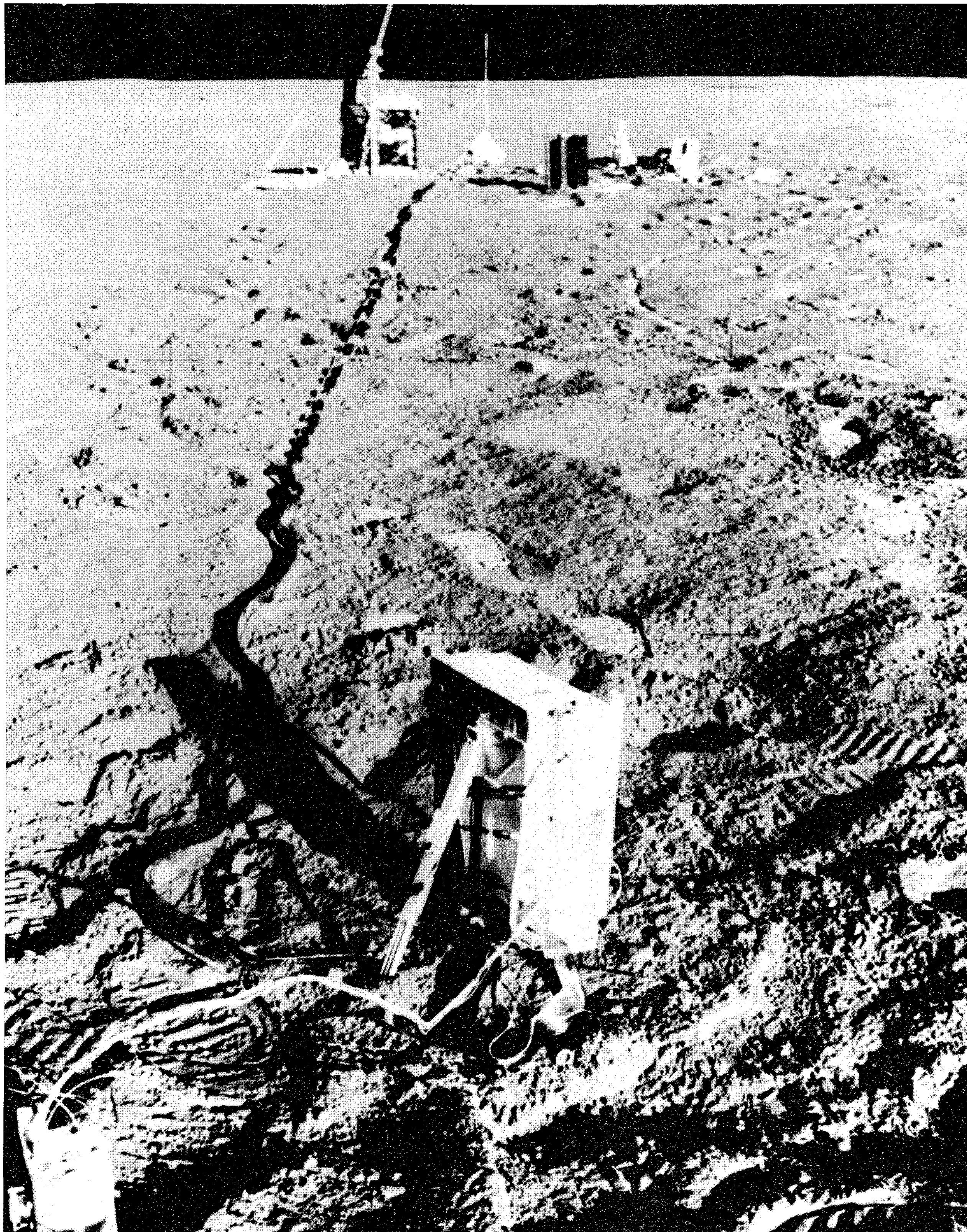

FIGURE 20.—Apollo 14 ALSEP. Note the changes in experiments between 14 and 16, NASA PHOTO A-71-31079.

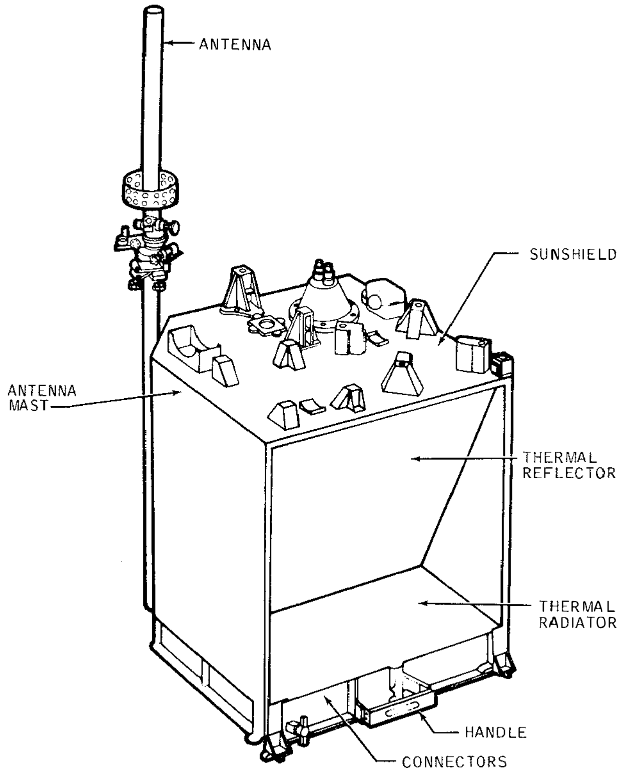


FIGURE 21.—The ALSEP central station. This equipment is connected electrically to each of the other ALSEP experiments. It is a maze of electronics that accepts the electrical signals from various experiments and converts them into a form suitable for transmission by radio back to Earth. The pole-like feature on top of the central station is a high-gain antenna. It is pointed towards the Earth. Commands may be sent from the Earth to the central station to accomplish various electronic tasks.

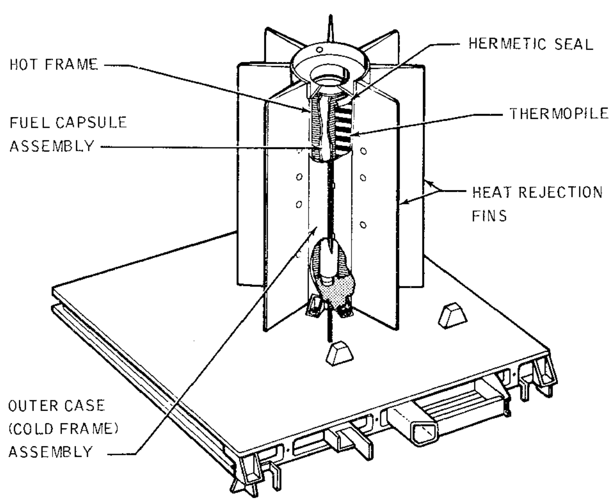


FIGURE 22.—Radioisotope Thermal Generator. This equipment provides all of the power used by the ALSEP. It furnishes continuously about 70 watts.

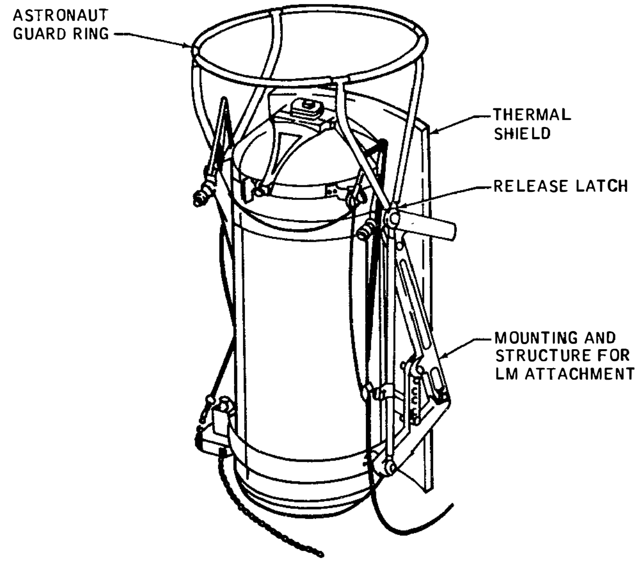


FIGURE 23.—Fuel Cask. The fuel, radioactive plutonium, for the RTG is carried to the Moon in this cask, which is mounted outside the LM.

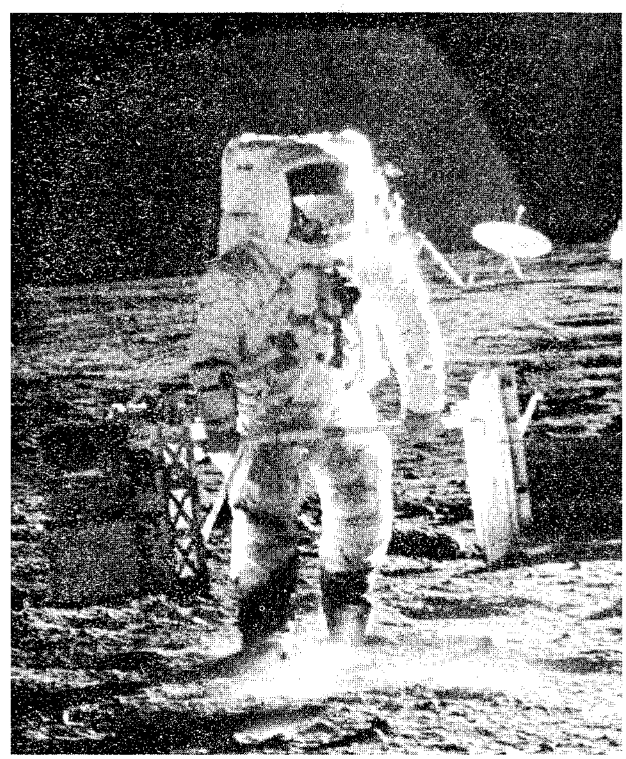

FIGURE 24.—Astronaut Al Bean carrying the ALSEP to its Apollo 12 location. There was no Rover on that mission and the ALSEP location was roughly 100 yards from the LM. The edge of the LM and the S-band antenna are shown in the background. The halo is caused by reflections in the camera lens systems; the halo was not present on the Moon. On Apollo 16 the same technique will be used to carry the ALSEP. NASA PHOTOGRAPH AS12–46–6807.

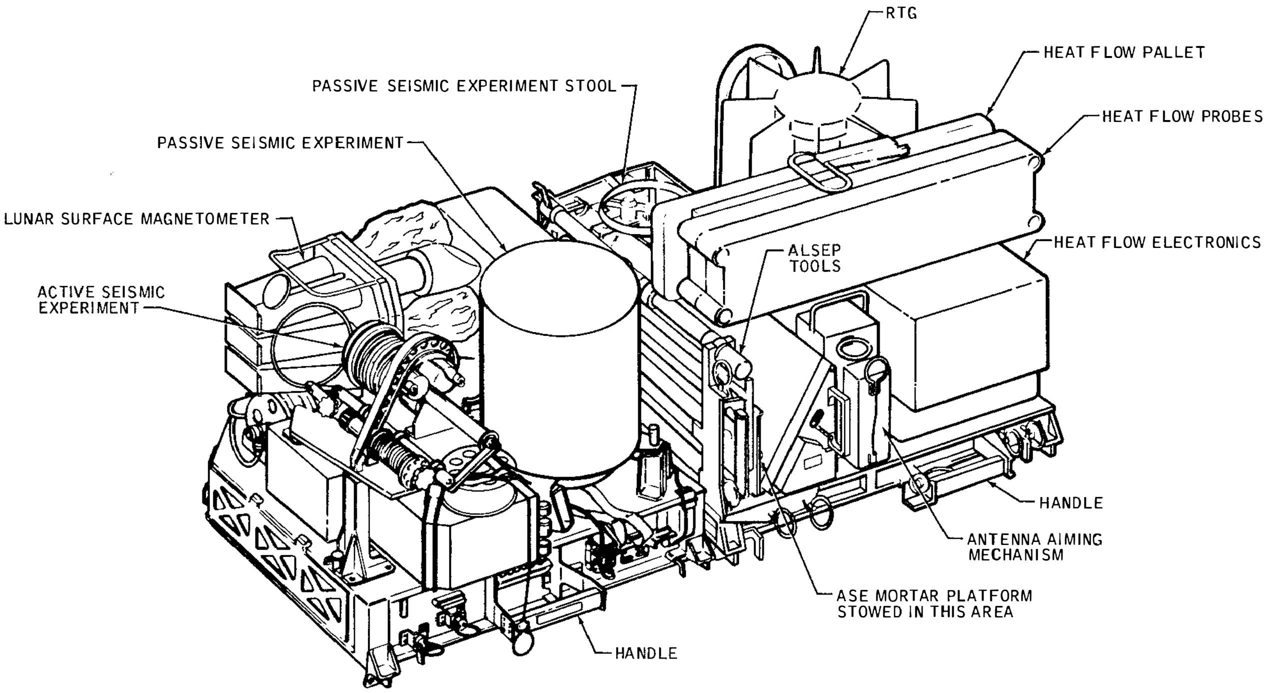


FIGURE 25.—ALSEP pallet, The ALSEP is carried to the Moon in the LM on this pallet. Note how tightly the individual items are packed in order to save space. NASA PHOTO S–72–16330.

A list of *all* science experiments of the Apollo Program, including those of this mission, is given in Table 4. A list of the principal investigators and their institutions is included in Table 5. Finally, you will find in Table 6 a list of the companies that have contributed significantly towards the design, building, and testing of the scientific equipment of the Apollo Program.

## Heat Flow Experiment (HFE)

Heat flows from hot regions to cold regions. There is no known exception to this most general law of nature. We are certain that the interior of the Moon is warm. It may be hot. Therefore heat flows from the interior of the Moon to the surface where it is then lost into cold space by radiation. The Heat Flow Experiment (HFE) will measure the amount of heat flowing to the surface at the Descartes site.

A similar measurement is now in progress at the Apollo 15 site, the magnificent Hadley-Apennine region. Some of the details were seen over television by millions of viewers. You may recall the problem of drilling the hole into which the astronauts inserted the temperature sensors. That problem was caused by the failure of the drill to expel the cuttings from the hole. The drill has been redesigned. It should now drill the Apollo 16 holes to full depth in 15 minutes, perhaps less. I am sure that many viewers will want to watch particularly this aspect of our mission.

But let me continue with the main story of heat flow. It will be at least several months before we have obtained our best estimate of the amount of heat flow at the Apollo 15 site. The preliminary value is about ¾ unit.* Let me explain this unit in the following way. If we were able to store the heat that flows to the surface of the Moon through a square foot from the interior during an *entire year*, it would just be enough to melt a layer of ice $\frac{1}{10}$ inch thick. Not very much heat, is it? Perhaps. Yet on Earth, the average heat flow is only about 3 times that value and it has produced our mountains, it causes the earthquakes so familiar in California and other regions of the U.S. as well as many parts of the Earth, it produces the volcanoes, and so on. I have always been awed by how much nature can do with so little per year! Of course I must add, for so long a time, and that is the key.

But by comparison with the Earth, the Moon

*The "unit" here is micro calories/square centimeter/second.

is rather quiet. Earthquakes on the Earth exceed one million per year. On the Moon, there may be 300 to 400. And they are much smaller than the ones on Earth. We are not yet sure why.

At the present time, the heat flowing to the surface of the Moon from the interior has been produced mostly by slow decay of the natural radioactive elements thorium, uranium, and potassium. Measurements made directly on the lunar samples returned to Earth by Apollo 11, 12, 14, and 15 have revealed the presence of significant amounts of these elements. The normal spontaneous change of these elements into other elements slowly releases energy. The process is similar to that used in nuclear reactors on Earth to generate electrical power from uranium. In the Moon, most of the energy appears in the form of heat which raises the temperature of the interior of the Moon.

In addition to the amount of radioactive material present, the internal temperature of the Moon depends on other things. The properties of lunar rocks and soil are equally important. The thermal conductivity of a material is a measure of the relative ease with which thermal energy flows through it. Rather well-known is the fact that metals are good conductors and that fiberglass, asbestos, and bricks are poor conductors. Most of us would never build a refrigerator with copper as the insulation. Values of the thermal properties of rocks are closer to those of fiberglass than those of copper and other metals. Rocks are fairly good insulators.

The HFE has been designed to measure the rate of heat loss from the interior of the Moon. To obtain this measurement at the 16-site, two holes are to be drilled into the surface of the Moon by one of the astronauts to a depth of about 8 feet by means of the drill sketched in figure 26. After each hole is drilled, temperature sensors (platinum resistance thermometers) are placed at several points in the lower parts of the holes and several thermocouples (which also measure temperatures but with lower precision) are placed in the upper portions of the holes. See figure 27. The thermal properties of the rocks will be measured by the equipment that is placed in the hole, they will also be measured on samples that are returned to the Earth.

Because the temperature of the rock is disturbed by the drilling process, the various measurements for heat flow will be taken at regular intervals over several months. As the residual heat left around the hole from the drilling dissipates with time, the temperatures measured in the experiment will approach the undisturbed temperatures of the Moon.

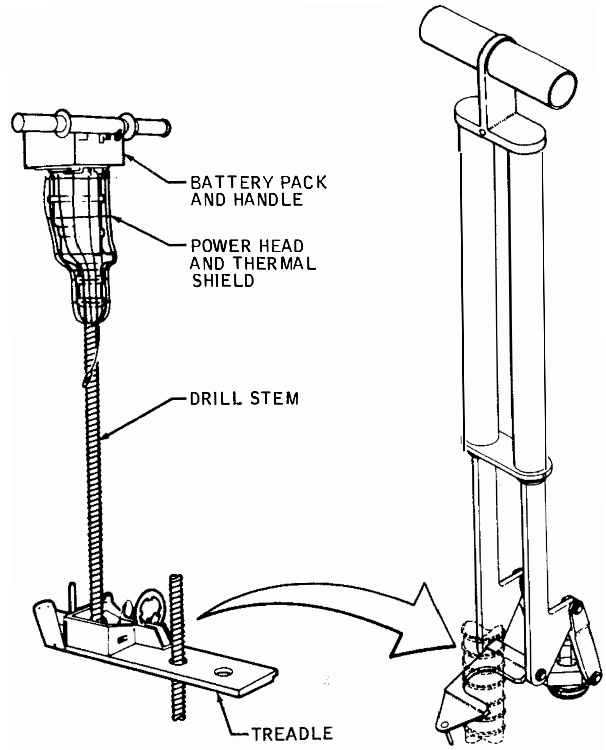


FIGURE 26.—Lunar Surface Drill. This drill will be used to drill holes on the Moon to a depth of about 10 feet. It is electrically powered and operates from batteries. The treadle is used to steady the drill stem and to deflect cuttings from striking the astronaut. Two holes are used for the heat flow experiment and a third one is used to obtain samples for study back on Earth. The tool sketched on the right is used to extract the core from the hole and operates somewhat like an automobile bumper jack. A rack, used for holding the drill stem, is sketched in figure 19.

The great importance of the HFE is due to the limits that it allows us to set. The heat now reaching the surface of the Moon has been produced by radioactive decay. Knowledge of the amount of heat flowing from the interior of the Moon will be used to set limits on the amount of radioactivity *now present* in the Moon. You see, the amount of such radioactive material already measured in the lunar samples on Earth is embarrassingly high! We know that such samples cannot be representative of the whole Moon because if they were, then the Moon's interior would be molten throughout. And we are sure that it is mostly solid throughout. By establishing limits on the radioactivity, we will come closer to a correct understanding of the thermal history of the Moon.

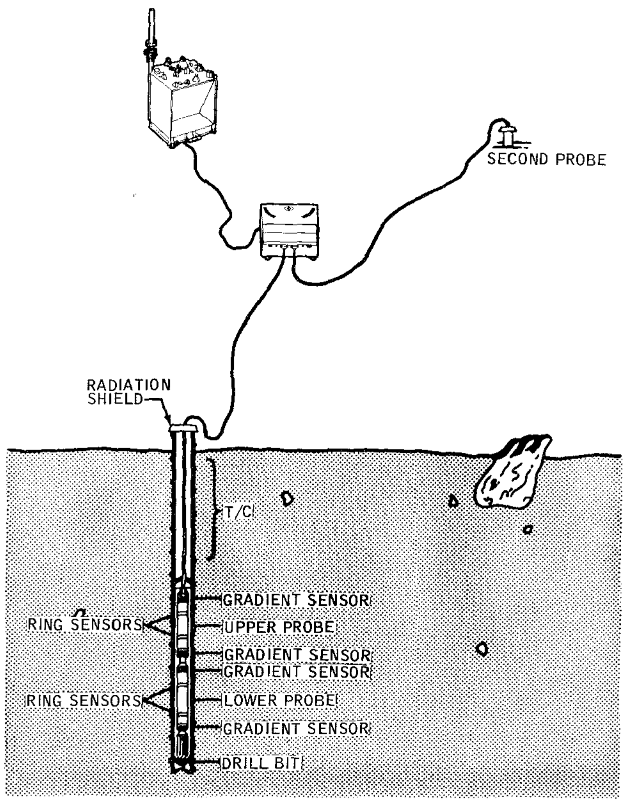


FIGURE 27.—Heat Flow Experiment. Probes are placed in two holes drilled in the lunar surface with the drill shown in figure 26. One hole is shown in the figure as a section to show the various parts. The gradient is the difference of temperature at two points divided by the distance between the points. Heat flow is determined by measuring both the gradient and the thermal conductivity; heat flow is the product of gradient and thermal conductivity. The symbol T/C indicates thermocouples that are present in the upper part of the holes.

Incidentally, the value of heat flow measured at the 15-site was completely unexpected. It was at least twice the value that most scientists had anticipated. So I think you can understand why we are particularly anxious to see if the Apollo 16 measurements confirm this surprising result.

### Passive Seismic Experiment (PSE)

The Passive Seismic Experiment (PSE) is used to measure extremely small vibrations of the Moon's surface. It is similar to instruments used on the Earth to study the vibrations caused by earthquakes and by man-made explosions. The PSE equipment is shown schematically in figure 28. The principle of operation is indicated in figure 29. As the instrument is shaken, the inertia of

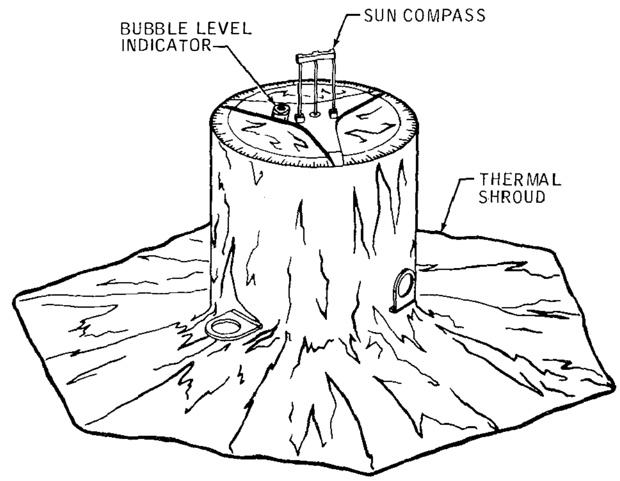


FIGURE 28.—Passive Seismometer. The instrument is covered with a blanket of superinsulation to protect it from the extreme variations of temperature on the Moon (−400° to +200°F). The principle of operation is shown in figure 29. The level, used on the Moon in exactly the same way as on the Earth, indicates whether the instrument is level. The Sun compass indicates direction.

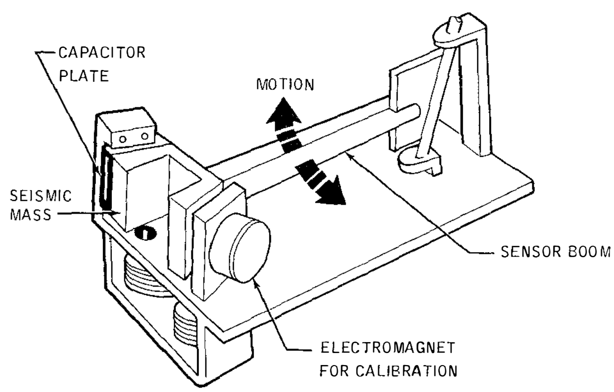


FIGURE 29.—Principle of operation of passive seismometer. See text for details.

the mass causes the boom to move relative to the case. This relative motion is detected electrically by the capacitor and the electrical signal is sent by radio to the Earth.

These instruments are really just very fancy electronic stethoscopes and are similar in some ways to the familiar ones used by doctors to listen to your heartbeat. With them, we can listen back on Earth to the vibrations of the Moon. Some of these vibrations are caused by naturally occurring events, others by impacts on the Moon of parts of the spacecraft, still others by meteorites.

Typical seismic signals for the Moon are seen in

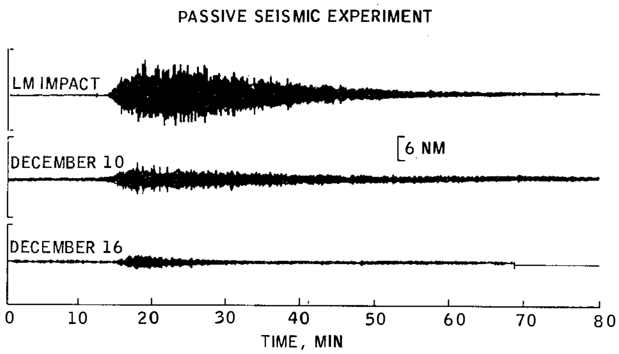


FIGURE 30.—Typical seismic signals for the Moon. These events were sensed at the Apollo 12 seismometer. To produce the largest signals shown here, the Moon's surface moved about 2 ten-thousandths of an inch.

figure 30. Such signals are detected at the Apollo 12, 14, and 15 sites at the rate of about one per day. There is usually increased activity when the Moon is farthest from the Earth and also when it is nearest the Earth, though we don't yet know why!

The spacecraft impacts have been very valuable to our understanding of the Moon's interior. Their locations are shown in figure 1. Two more are planned for this mission. The S–IVB will hit the Moon near 2°18′ South latitude, 31°42′ West longitude before the astronauts land. The LM ascent stage will hit the Moon after they leave. The sound waves produced by these impacts travel through the Moon and are detected by the seismometers. Signals like the ones shown in the top of figure 30 are sent to the Earth.

A very recent study of the results of previous spacecraft impacts has revealed the existence of a lunar crust that may be roughly 40 miles thick. It is now believed by some of us that the Moon may be shrouded with material that differs greatly from the material in the interior of the Moon. Perhaps the additional data that will be obtained from the Apollo 16 impacts will strengthen the hypothesis of a lunar crust.

The data from the PSE, in conjunction with similar data from Apollo 12, 14, and 15 sites, are especially valuable in understanding the natural events that occur on the Moon. They will be used to study the nature of the interior of the Moon, to determine the location of moonquakes and to detect the number and size of meteorites that strike the lunar surface. The Moon is still being bombarded by small objects; most of them are microscopic in size. The Earth is also being bombarded but most small objects completely disintegrate in the Earth's atmosphere; they are the familiar shooting stars.

### Active Seismic Experiment

The Active Seismic Experiment (ASE) is complementary to the Passive Seismic Experiment (PSE) in two ways, scale and source of energy. The PSE was designed to study the whole Moon; the ASE to study the local landing site. Rather than wait passively for natural events to occur on the Moon to produce sound waves, the ASE provides its own sources. The sound waves are produced by explosions on the lunar surface. Two different kinds are used, small ones made while the astronauts are on the surface and large ones after they leave the site and return to the Earth. The principle upon which this experiment is based is indicated in figure 31. The sound waves pro-

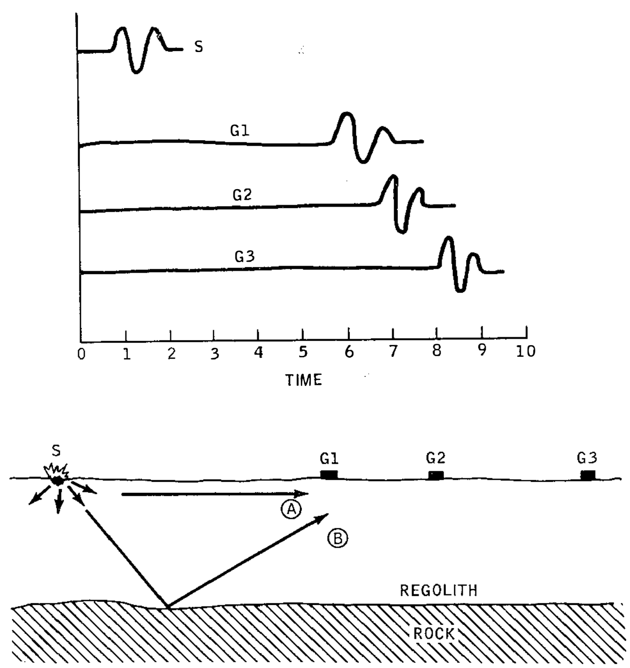


FIGURE 31.—Principle of the active seismic experiment. The geometry of the experiment is shown in the lower figure. At the source, which resembles the explosion of a shot gun or a grenade, elastic waves are sent in all directions. Some of these waves (marked A) travel in the direction of the three geophones, G1, G2, and G3. The relative times of the source and the arrivals at the three geophones are shown in the upper figure. In the actual case, the signals continue ringing longer than is shown in this figure; the signals have been abbreviated for clarity. If there is a layer of rock beneath the lunar soil, and the depth to it is not too great, then some of the elastic energy is returned to the surface. Such waves arrive at the geophones later than the direct waves.

duced by the source travel through the lunar soil and rock to the geophones. The geophones are similar to the stethoscope used by doctors to listen to our heartbeat. They "hear" the sound waves and transmit them over the ALSEP telemetry link to Earth. The time of the source explosion and the times at which the waves arrive at each of the three geophones are measured precisely. The velocity of the waves in the lunar soil is obtained by dividing the distance from the source to each geophone by the time required for the waves to travel. If the depth to solid rock at the ALSEP site is not too great, then a part of the energy in the sound waves is reflected towards the surface. The reflected waves travel farther than the direct waves, arrive at each geophone later, and their electrical signals are sent to Earth also. From the amount of time required for the reflected waves to arrive at the geophones, the depth to the reflecting surface can be obtained.

The different kinds of sources for the ASE to be used at the Descartes site are interesting. Let me describe them in somewhat more detail. In the first, a thumper is used by the astronaut to explode "shotgun-like" charges. The thumper contains 19 such charges. It is fired at evenly spaced intervals along the geophone line. The results from this part of the experiment should be available while the astronauts are still on the surface of the Moon and will probably be announced at a press conference before lunar liftoff.

The second kind of charge is similar to that of a mortar. In fact the unit that fires these charges is referred to as a mortar package assembly. It contains four grenades that will be launched sometime in the future with self-contained rockets. The astronauts align the mortar launcher and arm it for firing. The command to fire will be sent from the Earth sometime (probably several months) after the astronauts have returned to Earth. This unit contains provisions for measuring the velocity of each grenade on launch and the exact time of launch. The grenades themselves are also interesting. Each contains a rocket motor, a high explosive charge, provisions for igniting the rocket and a device to detonate the charge, a battery, a transmitter that provides information as to the length of time of the flight and the moment of impact on the Moon, and a thread with which to measure the distance of the impact from the launcher. Because there is (almost) no atmosphere on the Moon, the thin thread trailing the grenade remains taut and

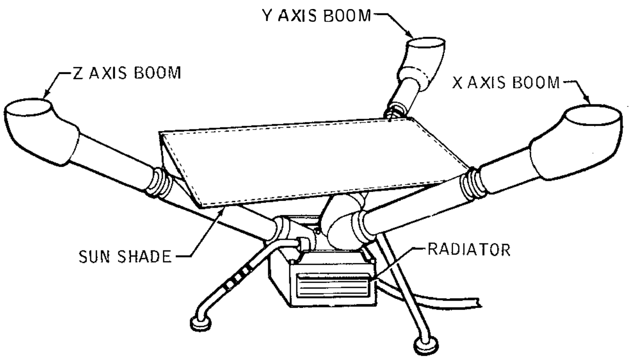


FIGURE 32.—Lunar Surface Magnetometer. Measurements are obtained as a function of time of the magnetic field at the surface of the Moon by the Lunar Surface Magnetometer. The actual sensors are located in the enlarged parts at the end of the three booms. The plate located in the center of the instrument is a Sun shade to protect the electronics in the box at the junction of the three booms from direct sunlight. The radiator cools the electronics box.

measures accurately the horizontal distance from the point of launch to the point of impact.

Within three months after the mission, we expect to launch the grenades by sending a command to the ALSEP central station. They have been designed to impact the Moon at distances of 450, 925, 2800, and 4500 feet from the launcher. The size of the explosive charge increases with distance. Any layering in the Moon at the Descartes site that is present in the first thousand feet beneath the surface will be seen with the ASE.

This technique is a standard one for the study of geology on the Earth. It is the chief way in which new oil and gas fields are looked for. This experiment is repeated on Earth millions of times each year by the oil industry. The principles are well understood.

## Lunar Surface Magnetometer Experiment (LSM)

Two magnetometers will be used on Apollo 16. One, the Lunar Portable Magnetometer (LPM), is used to measure changes with distance of the Moon's magnetic field. It is discussed below. The other, the Lunar Surface Magnetometer (LSM), is used to measure the variations with time of the magnetic field at the surface of the Moon. A similar instrument was left at the Apollo 12 and 15 sites. They are still sending data to Earth. None was left at the Apollo 14 site although two measurements of the magnetic field were made there with the smaller, portable magnetometer. The LSM equipment is shown in figure 32. Because the magnetic field at the surface of the Moon can change in amplitude, frequency, and direction, the LSM is used to measure the magnetic field in three directions. The sensors are located at the ends of three booms. The direction of each sensor is 90° to that of each of the other two sensors.

The magnetic field of the Moon (and also the Earth) has two parts, one that changes with time and one that is steady and does not change rapidly with time. The part that changes with time is caused by traveling electromagnetic waves.

The *steady* part of the Earth's magnetic field is about 50,000 gamma (the usual unit of magnetic field employed by Earth scientists). It causes compasses to point approximately north-south. The steady part of the lunar magnetic field, measured at the Apollo 12 site, was about 35 gamma, somewhat more than 1,000 times smaller than the Earth's field. Yet the 35 gamma field was several times larger than we had expected. The two measurements obtained at the Apollo 14 site with the smaller portable magnetometer revealed magnetic fields of about 43 gamma and 103 gamma in two different spots. The steady part of the lunar magnetic field is undoubtedly due to the presence of natural magnetism in lunar rocks. The natural magnetism was probably inherited early in the Moon's history (perhaps several billion years ago) when the magnetic field was many times larger than today. It is now too small to affect the usual compass. Neither is its direction such that a compass would point toward the north even if the friction were made vanishingly small.

The LSM is used to measure the variation with time of the magnetic field at the surface of the Moon. The variations are caused by electromagnetic waves that emanate from the Sun and travel through space. The largest change with time in the magnetic field ever measured in space, about 100 gamma, was detected by the Apollo 12 LSM.

Variations with time in the magnetic field at the surface of the Moon are influenced greatly by the electrical properties of the interior of the Moon. Therefore, a study of these variations with time of the magnetic field will reveal the electrical properties of the Moon as a function of depth. Because the electrical properties of rocks are influenced by the temperature, we hope to use the data from the LSM to measure indirectly temperatures in the interior of the Moon. Incidentally, there is now occurring an interesting debate in lunar science. One interpretation of the existing LSM data is that deep inside, the Moon is relatively cool. It may be only 600 to 800°C. Such temperatures may seem high but in comparison with the Earth's temperature which may be five times as high, they are relatively cool. This conclusion of low temperature is not certain but *if* substantiated by later work, will be most profound because it means that the lunar material is much lower in radioactivity than the Earth. Another interpretation is that some assumption in the data reduction method is incorrect and that the Moon is really hotter in the interior. It will be most interesting to watch the outcome of this debate which should be settled within a few years. Perhaps the data from the Apollo 16 LSM will help us understand better the conditions of the interior of the Moon.

## Lunar Portable Magnetometer Experiment (LPM)

In addition to the LSM, we are carrying another magnetometer to the surface of the Moon on this mission. Its purpose is different. It is a portable instrument named the Lunar Portable Magnetometer (LPM). It will be carried with the astronauts on the traverses and used to measure the Moon's magnetic field at several different spots. We expect to measure different values at each stop. This technique of measuring the magnetic field as a function of distance is also a standard one on Earth and is used extensively in prospecting. Many ore bodies cause *anomalies* in the Earth's magnetic field. In our jargon, the word anomaly really means anything that is different from what is normally expected. Thus if at a particular place we expect the magnetic field to be 40,000 gamma and it is 36,000 gamma, then the anomaly is 4,000 gamma. On the Earth, anomalies of several thousand gamma are common. Not so on the Moon. As we mentioned earlier in this booklet, the total magnetic field of the Earth is about 50,000 gamma. Because the Moon's magnetic field is only about one-thousandth that of the Earth's field, the magnetic anomalies are much smaller.

An LPM was carried previously on the Apollo 14 mission. Unfortunately only two measurements were obtained then. Both were startling. The first, taken near the landing point (but out of the LM's magnetic field) was about 43 gamma. The second was taken on Cone Crater. It was 103 gamma. These values were startling for two reasons. First, they were much larger than we expected before-



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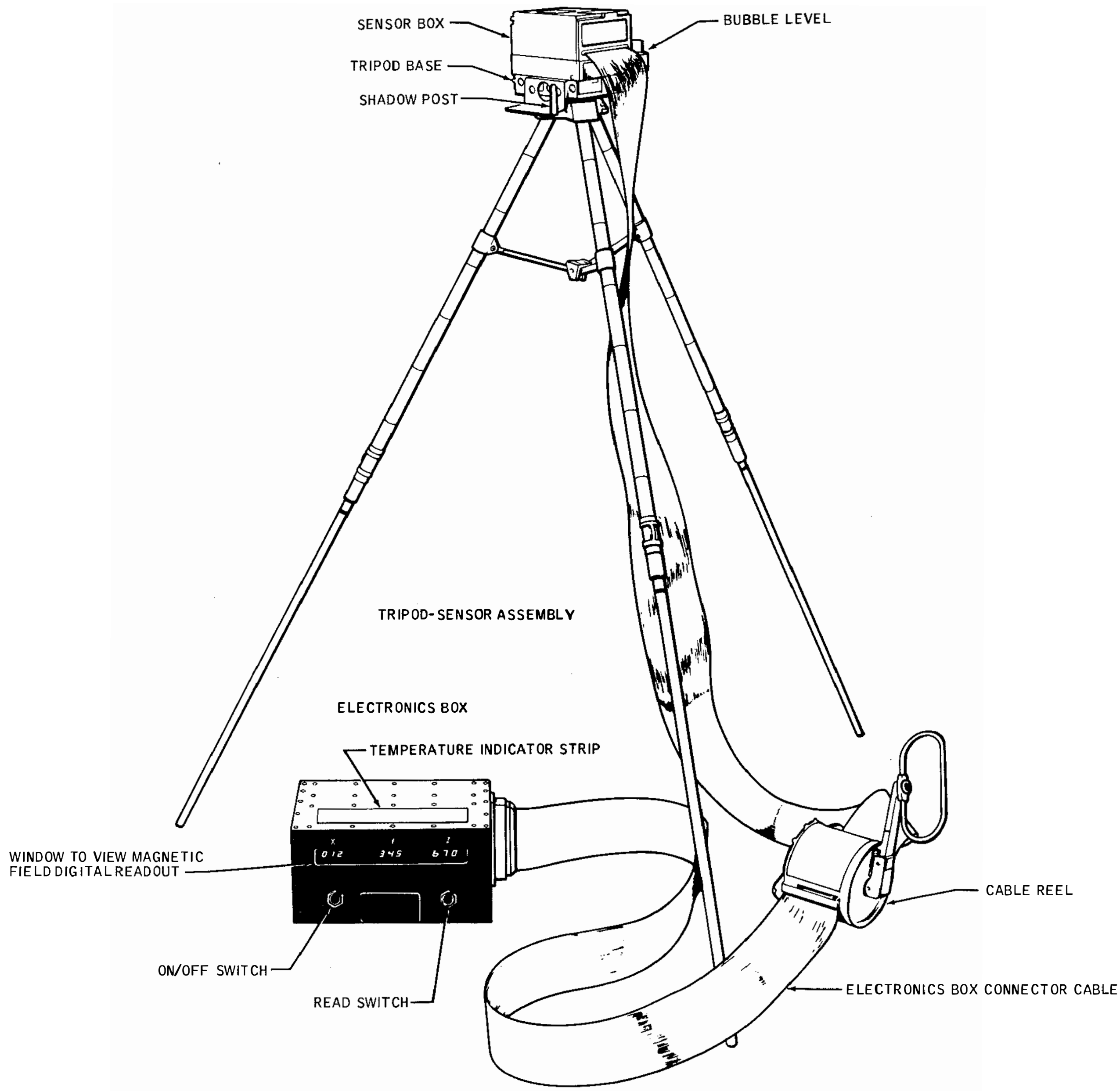



FIGURE 33.—Lunar Portable Magnetometer. This instrument is used to measure the magnetic field of the Moon at several different locations along the traverses. In use the electronics box will be mounted on the Rover. The tripod will be set about 50 feet away from the Rover. The astronaut orients the sensor box by the shadow cast by the shadow post. It is leveled by the astronaut as he watches a bubble level on the sensor box. The electric cable that connects the two boxes is a flat ribbon containing many electrical wires.

hand. We had obtained previously from satellite measurements an unequivocal indication that the *average* value for the magnetic field at the surface of the Moon could not be larger than 10 to 12 gamma. Yet these values were much larger. The difference in the two values, 60 gamma, was equally startling. We had not expected such a large change to occur over a short distance. In order to help understand the rapid change with distance, we are most anxious to obtain several measurements on Apollo 16. These changes with distance are almost surely caused by the natural magnetization of the lunar rocks.

Natural magnetization has been known in terrestrial rocks for many years. You are likely already familiar with the term lodestone which is the name used for a naturally occurring magnet. The material of lodestone is magnetite, a strongly magnetic mineral. There are, of course, other magnetic minerals but magnetite is the most common. It occurs in lunar rocks also.

The equipment used in the LPM experiment is shown schematically in figure 33. The sensors are contained in a box mounted on a tripod. They are connected to an electronics box on the LRV by a flat ribbon-type electrical cable. In use, the tripod is set about 50 feet from the Rover. It must be oriented with the shadow of the Sun and leveled. The astronaut then returns to the Rover and reads the instrument. There are three digital panel meters. They resemble digital clocks. These three meters indicate the size of the three components of the Moon's magnetic field. The astronaut reports the readings over the voice communications link with Earth. (Unfortunately, the numbers that you will hear reported by the astronaut are *not* the values of the magnetic field. A calibration chart must be used to convert them. I hope though that the results will be announced over television before the mission is over.)

You may wonder why we use a tripod that must be carried away from the Rover. Also, why not combine the sensor and the electronics box to save astronaut time? The answers are simple. The Rover is magnetic. So are the astronauts. Even though the human body is essentially nonmagnetic, the astronaut carries many pieces of metal and electronic equipment that *are* magnetic. So for the actual measurement, we move the sensors away from both the astronaut and the Rover.

### Solar Wind Composition Experiment (SWC)

Matter is ejected, more or less continuously, by the Sun and spreads throughout the solar system It is called the solar wind. It is very tenuous. It moves with a speed of a few hundred miles per second. The composition of the solar wind that strikes the surface of the Moon will be measured by the SWC experiment. This equipment is shown in figure 34. It is extremely simple.

The SWC flight equipment is essentially a sheet of aluminum foil like the familiar household item used to wrap food. The foil, exposed on the lunar surface to the solar wind, actually traps within it individual particles of the solar wind. The foil when returned to Earth is examined in the laboratory. The particles include atoms of many chemical elements, such as hydrogen, helium, neon, argon, and so on. Sponsored by the Swiss government, this experiment is international in scope.

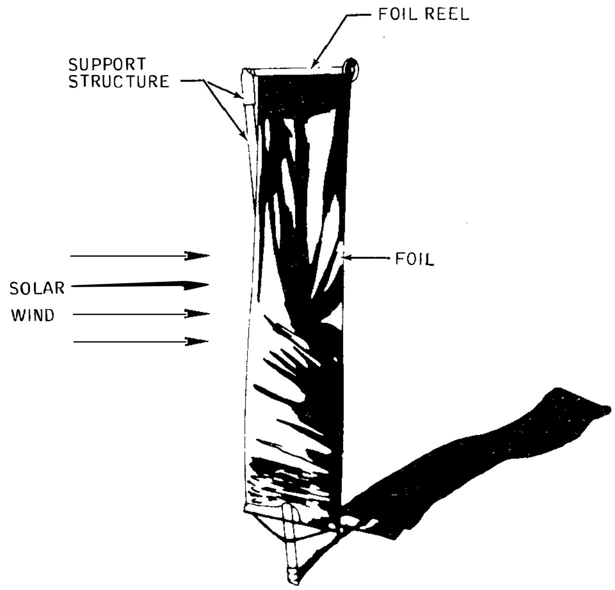



FIGURE 34.—Solar Wind Composition Experiment. Particles in the solar wind strike the aluminum foil, are trapped in it, and finally brought back to Earth by the astronauts for examination. The experiment is sponsored by the Swiss government.

### Cosmic Ray Detector Experiment (CRD)

Cosmic rays are just particles that have extremely large energies and very high velocities. Their velocity is almost, but not quite, the speed of light. They are mostly protons and alpha particles (see section "Alpha Particle Spectrometer" for discussion). But 1 to 2% of the cosmic rays consist of the nuclei (that is, atoms with one or more electrons removed) of heavier elements. The cosmic rays seem to arrive from all directions and, although their origin is not yet known with certainty, they come from outside our solar system.

In addition to cosmic rays, the CRD equipment will detect low energy solar wind particles. The solar wind is discussed further in the sections "Solar Wind Composition" and Subsatellite Experiments." The range of energy of the particles is very great but some have very low energy. One purpose of the CRD experiment is to investigate the low energy particles. Another purpose is to investigate neutrons from the lunar surface.

In the CRD experiment, we obtain actual records of the particles. Plates of several special materials (some resemble plexiglass) are carried on the outside of the LM to the Moon and then brought back to Earth. The passage of particles through the material is recorded in the form of tiny tracks. The characteristics of these tracks, seen through a microscope, tell us the kind of particle and, of course, its direction of travel. Some of the great interest in this experiment is due to the possibility that new elements may be discovered!

### Lunar Geology Experiment (LGE)

Most of the time spent by the *surface* astronauts during the three EVA's will be devoted to investigation of various geologic features at the landing site and to collecting samples of rocks. Many detailed photographs will be obtained to supplement the verbal descriptions by the astronauts. Samples of the rocks present at the site will be bagged and brought back to Earth. The astronauts will use several individual pieces of equipment to help them with their tasks. In this section, I describe briefly the goals of the experiment as well as the individual items used to study the geology of the Descartes region and to collect samples for return to Earth.

Lunar geologists have as their goal the reading of the historical record of the Moon for the past 5 billion years. That record has been preserved in the lunar rocks. One part of it is seen in the shape of the outer surface of the Moon. Another part is present in the distribution of different kinds of rocks over the surface of the Moon. And still a third part is given by the nature of the lunar interior. At the Descartes site, we plan to study thoroughly two rock units, the Descartes formation (fm) and the Cayley fm. Both of these geologic formations are widespread on the front side of the Moon. The Descartes fm covers 4.3%, the Cayley about 7% of the front side. The Cayley is the most extensive of all geologic formations in the lunar highlands. The distribution at the landing site of these two units is shown in the geologic sketch map, figure 9.

Because these two formations are so extensive, their study should provide the information needed to read an important chapter in lunar history. Samples of both units will be collected at the Descartes landing site. After the samples reach Earth, they will be studied extensively by nearly seven hundred scientists all over the world. The minerals present in them will be identified. The ages of the rocks will be read from their built-in radioactive clocks. Such physical properties as thermal expansion, velocity of sound waves, electrical conductivity, and many others will be measured. The value of all these measurements is greatly increased by knowing the geologic setting of the rocks. To provide the details of that geologic setting is one function of the Lunar Geology Team led by Professor William Muehlberger. They use the observations made by the astronauts. They study the rocks brought back to Earth and relate them to the things on the Moon they can see through hi-powered telescopes. And they re-study the existing lunar photographs in relation to the rocks. Another function, of course, is to integrate the knowledge obtained from study of the Descartes site into the geological understanding of the whole Moon.

In the process of collecting rocks for the geologic experiment and for the investigations on Earth, several items of equipment are used. Let's discuss them.

On each previous mission, the astronauts, soon after they had first set foot on the Moon, collected a small (1–2 lbs.) sample of rock and soil. It was appropriately termed contingency sample. It was stowed on board the LM immediately so that at least some material would have been obtained if the mission had had to be ended abruptly. A special collecting tool was used. On Apollo 16 though, we do *not* plan to collect such a sample. We wish to save both time and weight. Instead we plan to collect this sample only if the mission is aborted early in the first EVA. One astronaut carries a regular sample bag in his pocket. If it becomes apparent that the mission is likely to be aborted, then he will quickly fill the bag and stow it in his pocket for return to the LM. Perhaps the contingency sample provides the best illustration of our desire to obtain the most "science" during the stay on the Moon. You might think that the 5 minutes and one-pound-tool needed to collect the sample are both very small. And they surely are. But we believe that our new "if-needed-procedure" will give us the same insurance against returning with no sample and also give us an additional 5 minutes to collect other, more valuable samples.

Observations made on the lunar surface of the various geological features are very important. The television camera allows us on Earth to follow the astronauts and to "see" some of the same fea-

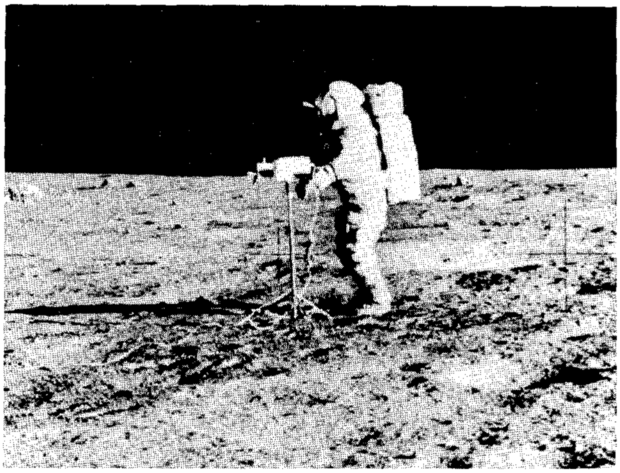


FIGURE 35.—Apollo 14 television camera. The astronaut is adjusting the TV camera to obtain the best possible viewing of activities around the LM during the Apollo 14 mission. A similar television camera will be carried aboard Apollo 16. After the Rover is placed in operation the TV camera will be mounted on it. The camera is controlled from Mission Control in Houston. Note the many craters in the foreground and the boulders in the distance. The distance scale of this photograph varies greatly. The small rocks seen in the foreground are a few inches across; the boulders near the horizon are several feet in diameter. NASA PHOTO S–71–31091.

tures, though not nearly so well as the astronauts see them. A photograph of the Apollo 15 TV camera, similar to the one on this mission, is shown in figure 35. The TV camera will be mounted on the Rover during the traverses. Its location can be seen in figure 12.

Other tools used by the astronauts, together with an aluminum frame for carrying them, are shown in figure 36. The hammer is used to drive core tubes into the soil, to break small pieces of rocks from larger ones, and in general for the same things that any hammer might be used on Earth. It will be used at one station to chip several small pieces of rock from a large boulder.

Because the astronaut cannot conveniently bend over and reach the lunar surface in his space suit, an extension handle is used with most tools. The scoop (figures 37A and 37B) is used to collect lunar soil and occasionally small rocks. The tongs, shown in figure 38, an Apollo 12 photograph, are used to collect small rocks while the astronaut stands erect.

The drive tubes (figure 39) are used to collect core material from the surface to depths of 1 to 4½ feet. The core remains in the tubes for return to Earth. Preservation of the relative depths of the core material is especially important. The drive

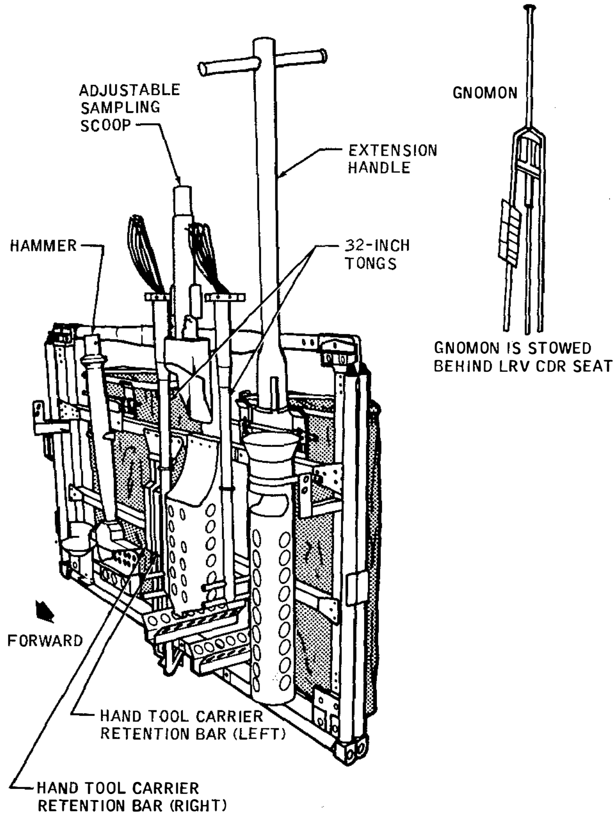



FIGURE 36.—Lunar Geological Hand Tools and Carrier. This equipment is used to collect samples of rock and soil on the Moon. The frame is mounted on the Rover. See text and subsequent figures for details.

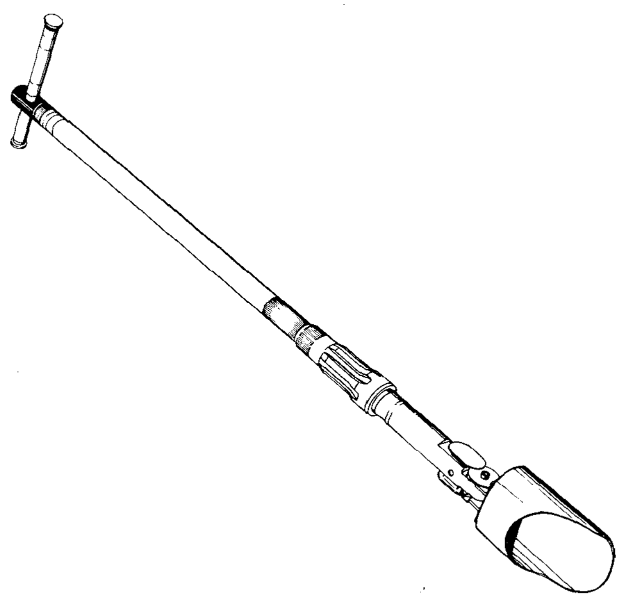


FIGURE 37A.—Scoop with extension handle. Its use in Apollo 12 is shown in Figure 37B. (Page 32.)

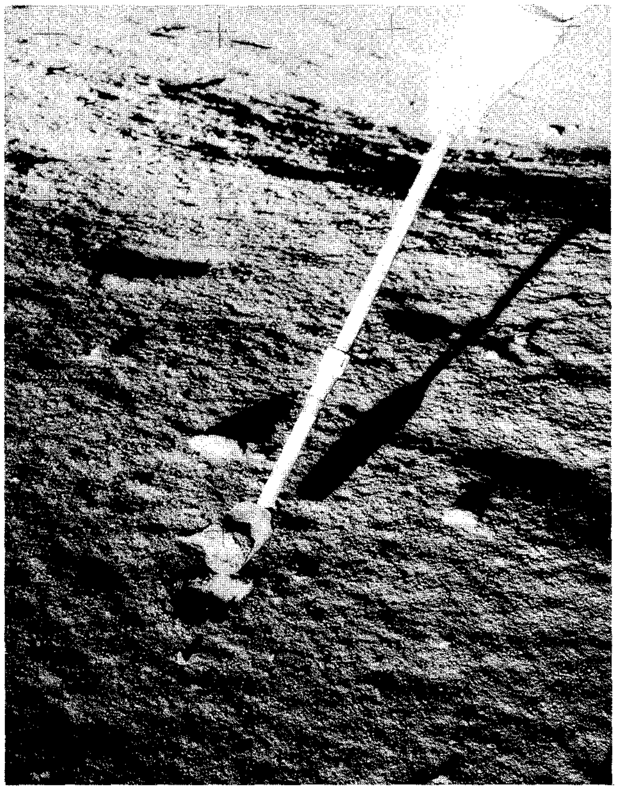


FIGURE 37B.—Note the small rock in the scoop. NASA PHOTO AS12–49–7312.

FIGURE 38.—Tongs shown in use on Apollo 12 to collect a small rock. NASA PHOTO S–71–31075.

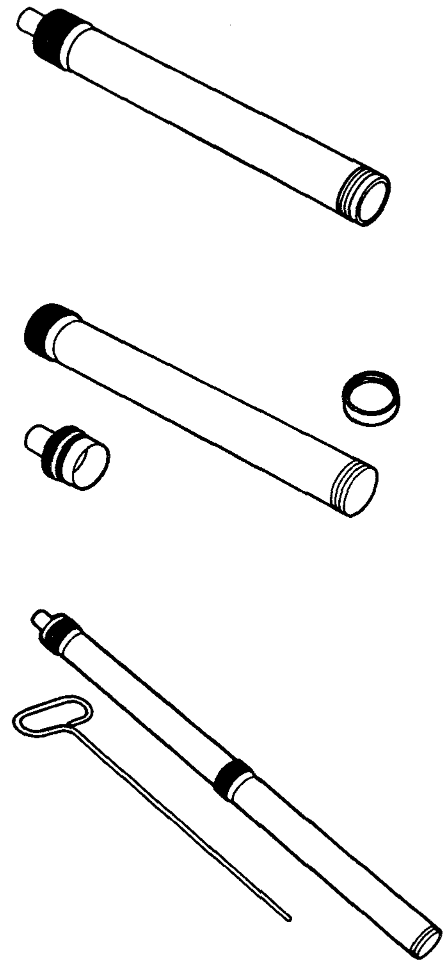


FIGURE 39.—Drive Tubes. These tubes, about 18 inches long, are pushed or driven into the lunar surface to collect samples as a function of depth. A single tube is shown in the top of the figure, a double tube at the bottom. Two, three, or even four of them may be joined together to obtain a longer core. Their use in Apollo 14 may be seen in Figure 40.

tubes were originally suggested about 7 years ago by the late Dr. Hoover Mackin, a geologist. Shown in figure 40 is a drive tube that was driven into the Moon's surface on Apollo 14. The individual tubes are about 18 inches long. As many as three tubes can be used together for a total length of about 4½ feet.

After the surface samples are collected, they are placed in numbered sample bags made of Teflon (figure 41). Most of us know Teflon as the "wonder material" that coats kitchen pots and pans to prevent sticking. It is used for our sample bags chiefly because it contains no objectionable foreign material (such as lead that would contaminate the samples), can be made readily into bags, and has

FIGURE 40.—Drive tube in lunar surface at Apollo 14 site. The relative difficulty of driving the tube into the surface is an indication of the strength of soil. Note in addition the footprints, rocks, and small craters, NASA PHOTO S–71–31082.

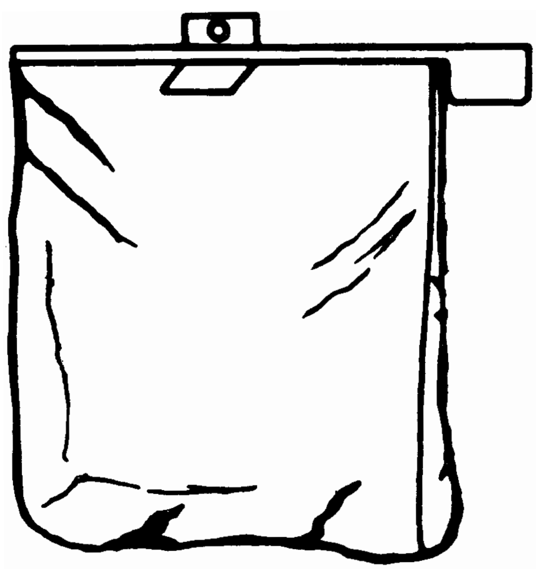


FIGURE 41.—Lunar sample bag. The bag resembles the familiar kitchen item "Baggies." It is made of Teflon. A strip of aluminum is used to close the bag.

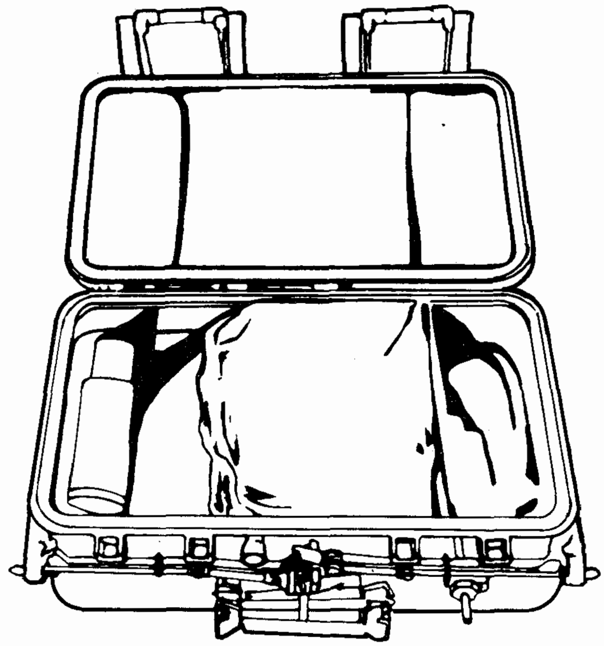


FIGURE 42.—Apollo Lunar Sample Return Container. Made of aluminum, this box is used to return lunar samples to Earth. It is about the size of a small suitcase but is many times stronger. The ALSRC has changed very little since it was first used on Apollo 11. NASA PHOTO S–71–33369.

certain desirable vacuum characteristics. These bags are about the size of the familiar kitchen storage bags. After a sample is bagged, the thin aluminum strip is folded to close the bag and prevent the samples from becoming mixed with others. The bags are finally placed in the sample return containers, sketched in figure 42, for return to Earth. The Apollo Lunar Sample Return Container (ALSRC) is about the size of a small suitcase. It is made of aluminum and holds 20 to 40 lbs. of samples. You will likely hear it called the rock box.

The teflon bags do not satisfy all our requirements though. For example, we are having some difficulty in unraveling the complete story of the permanent magnetism of the lunar rocks. One part of that permanent magnetism is very delicate. We are not sure just how, or when, the rocks obtain that part. It could be due to exposure to high magnetic fields in the spacecraft, though we don't think so. It could be due to exposure to the Earth's magnetic field, though we don't think so. To help us solve this problem, we expect to carry back to the Moon a small piece of lunar rock from an earlier mission. We will have removed the delicate part of the magnetism before the journey. Then, on return to Earth when we examine the permanent magnetism again, we can see whether the delicate part was originally present on the Moon or whether it was acquired later. If it was not originally present then we may wish to use some magnetically shielded containers on Apollo 17.

On each mission, the astronauts collect some rocks that are too large for the regular bags. You may remember the words of Apollo 12 astronaut Pete Conrad, "Oh boy I want that rock. There is a dandy extra grapefruit-sized-type goody. Man, have I got the grapefruit rock of all grapefruit rocks." That particular rock was not brought to Earth but rolled down a crater wall in another experiment. On Apollo 16, such large rocks will be placed in big bags that are made of Teflon also. For the journey to Earth, these big bags are to be stowed in various places in the LM cabin.

A new kind of sample bag, one that is specially padded, is being taken on Apollo 16. It is about the same size as the regular bag, but has padding built into the walls. We hope that these bags will protect the very thin, very fragile outer surface of the rocks. The outer one-hundredth-inch is valuable for the study of the radiation history of the rock. Such studies may eventually help us to read correctly recent chapters in the history of the Sun and our solar system. Better knowledge of such history may be useful in predicting more accurately the natural events of the next few hundred years.

We also hope that we will be able to collect some material from the very outer surface of the Moon on this mission. We need the outer few hundredths of an inch for the study of solar radiation, cosmic rays, and so on. To collect such a thin layer, we will carry a "surface sampler" if it is ready in time. In January 1972, we were still working feverishly on it. Many ways to collect the surface sample have been considered. Most of them were rejected. The technique finally adopted, though, is extremely simple. Any good seamstress could have told us how—use velvet cloth. Lay it gently on the surface. The grains will be trapped in the fabric pile. Bring back the velvet and the sample. In fact, we are using just such a simple technique after considering—and rejecting for very good engineering or scientific reasons—many, more sophisticated schemes.

A special container, termed Special Environmental Sample Container (SESC), is used to collect material on the surface of the Moon for specific purposes. (See figure 43.) This container has pressure seals to retain the extremely low pressures of the Moon. It is made of stainless steel. The Apollo 16 sample to be returned in this container will be collected in such a manner that it will have very little contamination with either organic or inorganic materials from Earth. The largest sources of biological contamination are the astronauts themselves; the suits leak many micro-organisms per minute and the lunar rocks collected on previous missions have all contained some organic material (a few parts per billion). I believe it unlikely that *any* of the organic material present on the Moon before the astronauts' landing was biologically formed but some researchers would disagree with me and this question is still being intensely investigated.

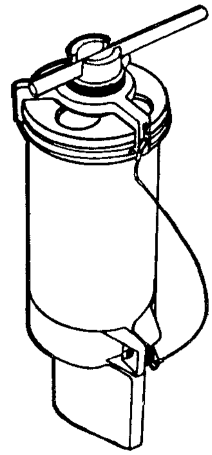


FIGURE 43.—Special Environmental Sample Container. This container has special vacuum seals to prevent gases and other materials from entering the container and being absorbed on the surfaces during the journey to the Moon. They also prevent contamination of the samples by rocket exhaust gases and the Earth's atmosphere during the return journey.

Another model, similar to the one shown here but about twice as long, will be used to store a drive core for return to Earth under vacuum conditions. This sample will be kept unopened, possibly as long as a decade, until ultra clean processing facilities are designed and built. It is our hope to preserve this sample completely uncontaminated.

The Hasselblad cameras used by the astronauts (figure 44), were made especially for this use. The film is 70 mm wide, exactly twice as wide as the familiar 35 mm film. The color film is similar in characteristics to Ektachrome-EF daylight-type. The black and white film has characteristics like Plus X. The primary purpose of the cameras is

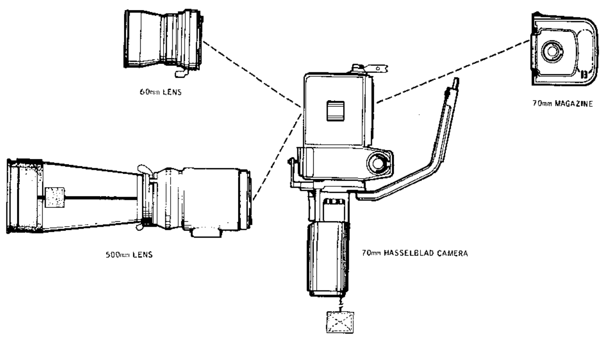
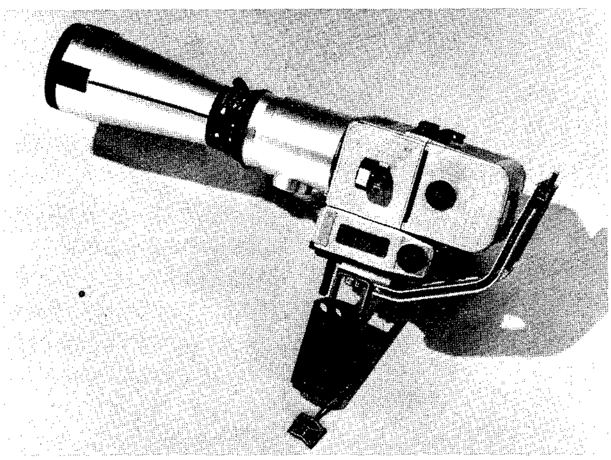



FIGURE 44.—Hasselblad camera. The film, which may be black and white or color, is 70 mm wide. Two separate lenses are used with this camera on the surface of the Moon. The 500 mm lens, a telephoto lens, shown attached to the camera in the photograph will be used to photograph distant features. NASA PHOTO S–71–32997.



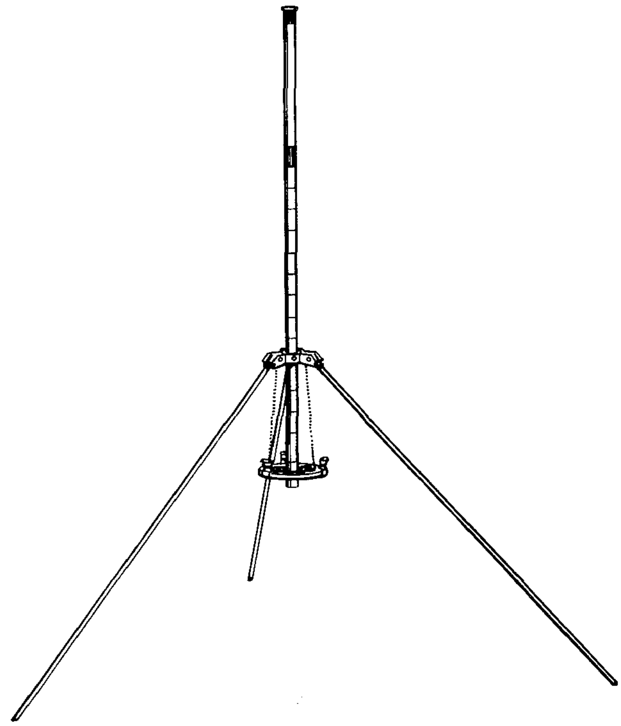
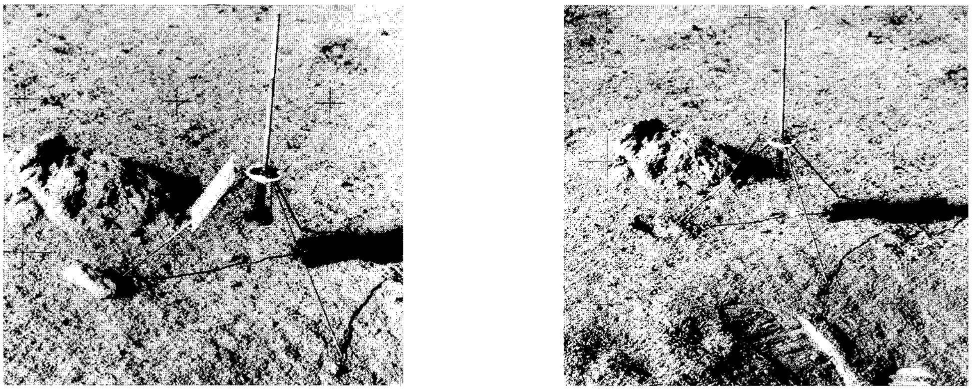


FIGURE 45.—Gnomon. This device is used to provide a physical scale and to calibrate the photometric properties of the samples on the Moon. It can also be seen in figure 46, an Apollo 14 photograph. The long central rod swings freely and indicates the vertical. Its shadow is used to determine direction from the known position of the Sun. The color scale, omitted from this sketch for simplicity, can be seen in other figures.

that of documenting observations made by the astronauts. Especially important is the careful documentation of rocks that are collected for study back on Earth. Ideally, several photographs are taken of each rock: (1) before collection with the Sun towards the astronaut's back, (2) before collection with the Sun to the side of the astronaut, (3) before collection a third photo to provide a stereo pair, and (4) after collection a single photo to permit us to see clearly which sample was collected. A device, termed gnomon, and illustrated in figure 45, is included with these pictures to provide a scale with which to measure size and a calibration of the photometric properties of the Moon's surface. In addition to these photographs, a fifth one is desirable to show the general location of the sample with respect to recognizable features of the lunar surface. An example from Apollo 14 is seen in figure 46. The photos taken before collection and after collection show clearly which rock was removed.

At some stations, still more documentation is desirable. Panoramic views are obtained by shooting many photographs of the horizon while turning a few degrees and sidestepping one or two paces between snapping each successive photo. The photos have considerable overlap. After return to Earth, the overlap is eliminated and the photos pieced together to yield a composite view of the Moon's surface as seen from a particular spot. The composite photo is usually called a pan, short for panoramic view. One example from Apollo 15 is shown in figure 47. Others from Apollo 14 may be seen in the July 1971 issue of National Geographic Magazine. In addition, the overlapped regions are used for stereoscopic viewing of the surface. Truly three-dimensional views are obtained in this way.

Marble-sized rocks from the Moon have proven to be especially valuable in lunar science. They are large enough to allow an extensive set of measurements to be made, yet small enough that many of them can be collected. Accordingly, we designed



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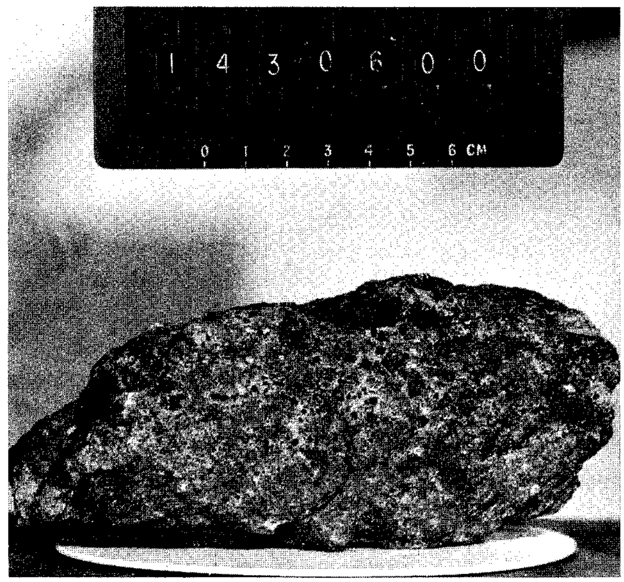


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FIGURE 46.—Photographic documentation of lunar samples. These three Apollo 14 photographs indicates clearly the method used to identify the rocks that were collected. The shadows in A, together with knowledge of the time that the photo was taken, have been used to orient the specimen. A location photograph (not shown) allows us to determine the relative location of this sample with respect to others collected during the mission. Photo A was taken before the rock was collected. Photo B was taken after collection. Photo C was taken in the laboratory after the Apollo 14 mission had returned to Earth. The Field Geology Team led by Dr. Gordon Swann, identified the rock in photos A and B as sample 14306 and deduced from Photo A the orientation on the lunar surface. NASA PHOTO S–71–31077, AS14–68–9462.

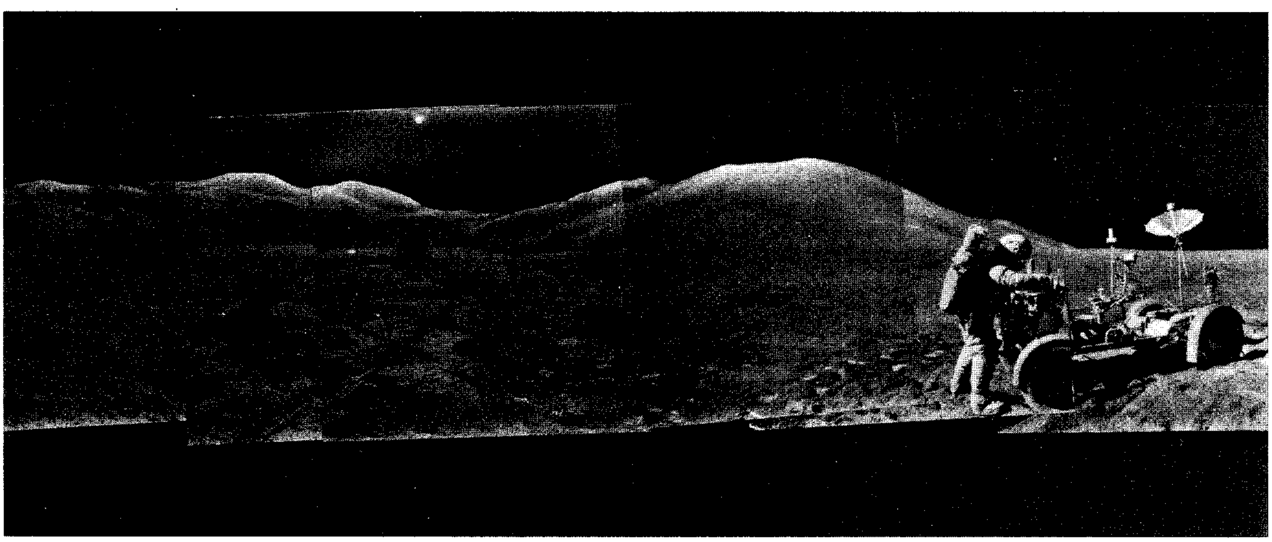

FIGURE 47.—Panoramic view obtained on Apollo 15. The method of piecing together several photos is clearly shown. Also, the difficulties of fitting the edges of the photos can be imagined from the mismatches evident here. Other panoramas from Apollo 14 may be seen in the July 1971 issue of National Geographic magazine. Note the tracks of Rover and the astronaut footsteps. Some people see a resemblance between this view and photos of Sun Valley, Idaho.

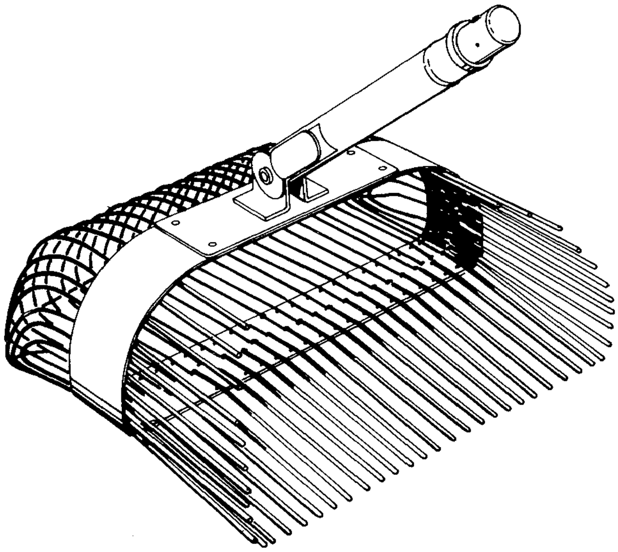

FIGURE 48.—Rake. This tool was used on Apollo 15 to collect marble-sized rocks. It will be used again on Apollo 16.

and built a tool and used it on Apollo 15 to collect many such samples. It is termed a rake, although the resemblance to the familiar garden tool is now slight. It is illustrated in figure 48. We expect to use it again on Apollo 16.

The Apollo Lunar Surface Drill (ALSD), used to drill the two holes for the Heat Flow Experiment and illustrated in figure 26, is used also to drill a third hole from which the samples are saved. The drill bit for this purpose is hollow and allows rock and soil to pass into the hollow drill stem. These samples, referred to as core, are about ¾ inch in diameter. Individual pieces of rock are likely to be button-shaped and ¼ inch thick. A few pieces may be larger. Most of the material will probably consist of lunar soil. These samples should not be confused with the samples obtained with the drive tubes which are also termed core. This equipment can drill and collect solid rock, if any is encountered, whereas the drive tubes can collect only material that is small enough to enter the tube.

## The Lunar Samples

In addition to the Lunar Geology Team, many other scientists study the lunar samples. In this section, I want to give you a brief glimpse of the many ways in which the samples are studied. No other material has ever held the attention of so many scientists so long.

I still vividly recall the intense excitement at the Lunar Receiving Laboratory in Houston almost 3 years ago when the Apollo 11 rock boxes were opened. The first samples of rocks and soil returned from the Moon. That was a moment some of us had worked toward for 5 to 10 years. But even so, most of us could hardly believe that we really had in our possession rocks from the Moon.

The study of those Apollo 11 samples opened up a whole new area in science, termed Lunar Science. It is still being intensively explored today. The lunar samples are helping us unravel some of the most important questions in lunar science and astronomy. They include: 1. How old is the Moon? 2. Where and how did the Moon originate? 3. What history and geologic features do the Moon and Earth have in common, and what are the differences? 4. What can the Moon tell us about the rest of the solar system, and of the rest of the universe? 5. Is there any evidence of life on the Moon?

To help solve these questions, we have used highly advanced and very sensitive scientific equipment, sometimes on samples almost too small to be seen by the naked eye. Some of the equipment was designed and built specifically to work on the lunar material.

One group, the mineralogists and petrologists, identified the individual minerals which formed the lunar rocks. Most of them were similar to the rocks and minerals found on Earth. A few new minerals were found. The lack of water and a significant atmosphere on the Moon has preserved the rocks and their accurate record of lunar history for several billion years. In figures 49, 50, and 51, I show photographs of three lunar rocks.

Another group, the geochemists, studied the radioactive elements thorium, uranium, and potassium in the rocks, using them as clocks to estimate the ages of the lunar samples. Most of the rocks studied so far are over 3 billion years old, much older than the rocks on Earth (with only a few exceptions). The processes of mountain formation and erosion have completely destroyed the first billion or so years of rock history on Earth. So, we study the Moon samples to learn the early history of the solar system.

The composition of the rocks tells us that the Moon has undergone differentiation—a word that means the rocks once molten have crystallized in such a way that some parts of the Moon have a

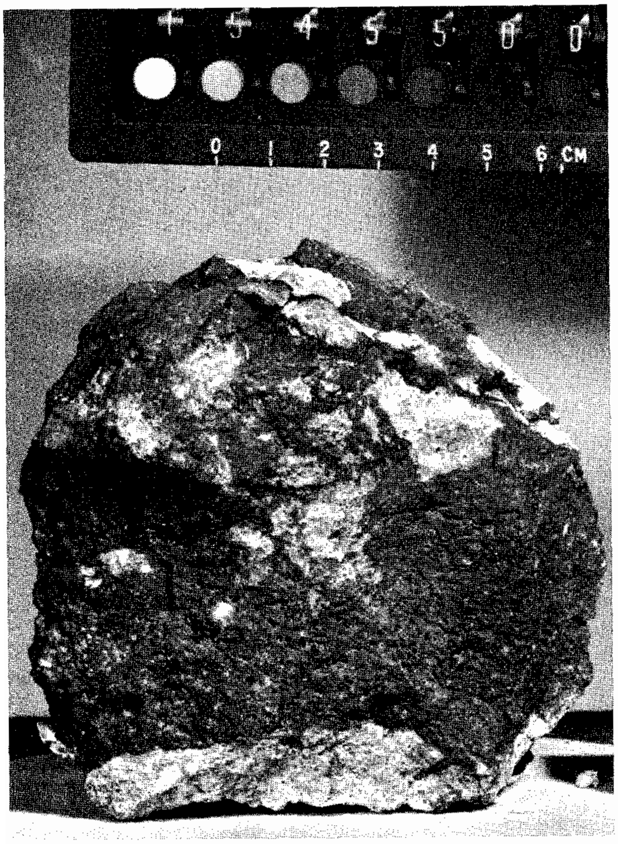


FIGURE 49.—The Black and White Rock. Sample 15455, collected on Apollo 15, is composed of two different kinds of rock and is termed a breccia. One kind shows as white, irregular spots within the second one. Note the gas holes or vugs in the dark rock. This sample weighs about ½ pound. Size of rock may be obtained with the scale shown in the figure. NASA PHOTO S-71-43889.

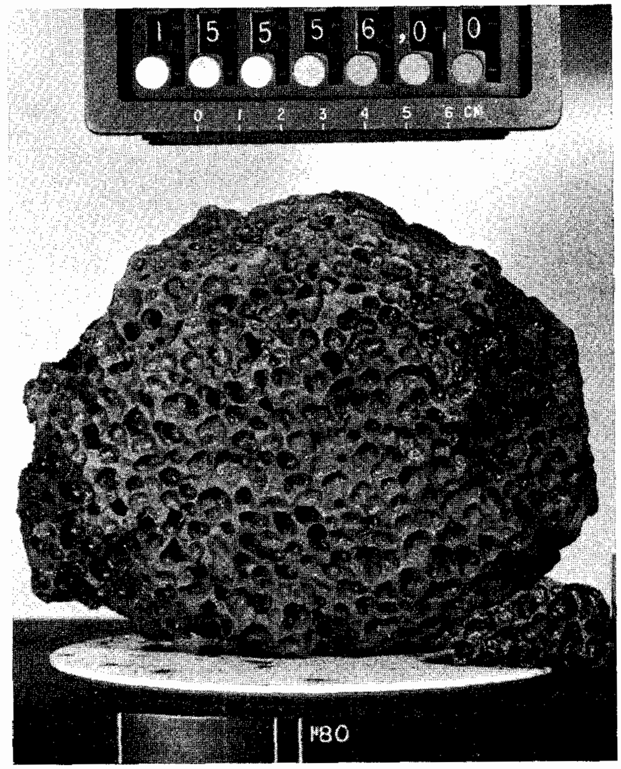


FIGURE 50.—Vesicular Basalt. The holes, termed vesicles, were caused by gas in the rock when it was molten. This appearance is typical of many basalts on Earth that were near the top of lava flows. Some cavities are lined with glass. NASA PHOTO S-71-43328.

different chemical composition than others. The process is similar, but not identical, to that used to separate crude oil into gasoline, kerosene, lubricating oil, and other products. This differentiation is an important clue for studying lunar history. Similar processes on Earth are responsible for the formation of ore deposits. These processes are continuing today on Earth. Our evidence so far indicates that although the Moon may have been very active in its early life, it has been very quiet ever since.

As I mentioned in the section on the Solar Wind Composition Experiment, a sheet of aluminum foil on the surface of the Moon can collect particles from the solar wind. Similar particles are also trapped in the mineral crystals and glasses of the lunar samples. We have found evidence for

FIGURE 51.—Big Bertha. This sample, collected on Apollo 14, is the largest one yet brought to Earth. NASA PHOTO S-71-56345.

nearly steady bombardment of the Moon going back for millions of years. In the samples, we have a special kind of recording of the Sun's activity that cannot be obtained in any other way. And a knowledge of the Sun's activity *is* essential, because nearly all life, weather, and human activity on the Earth ultimately depend on the Sun. Is our Sun always "benevolent"? Perhaps, but we are not yet sure. We may learn the facts necessary to answer this question from the lunar samples.

The rocks also show tiny impact pits or "zap craters." These are sometimes as large as ¼ inch in diameter. They were formed by the impact of tiny grains of cosmic dust that may have been traveling at speeds as high as 20 miles per second. Such impacts, over billions of years, have helped to wear away the rough outlines of the Moon to give the generally rounded and smoothed surfaces you can see on television from the Moon.

What about life on the Moon? We have found no chemical evidence that living things (except eight very lively astronauts!) have ever been on the Moon. No fossils. No microorganisms. No traces of biologically-formed chemicals. Nothing. Yet, there do appear to be extremely small amounts of amino acids and possibly other related organic compounds in some of the lunar soil. Recently, such molecules as formaldehyde, ammonia, and methyl alcohol have been detected as clouds in remote space. Such findings have led many to speculate that even though there is no evidence of life on the Moon, life, even intelligent life, must exist elsewhere in the universe. Undoubtedly, this question will remain a major one for future investigations.

Nearly 800 scientists in the United States and 17 foreign countries are studying the lunar samples today. Even though about 381 pounds of lunar samples have been brought to Earth so far, and we expect to get almost 200 pounds more from Apollo 16, we are still being very conservative in how much we use. Most of us who work on the samples actually receive a piece smaller than ¼ inch on a side; a very few receive larger pieces. All material is returned to NASA when our work is finished. Less than 10% of the total samples have been used so far for analysis; the other 90% will be carefully preserved for scientific studies in future years, probably using new and more powerful analytical tools not yet known today. These samples will be a priceless scientific heritage as well as a special kind of enduring monument to the memory of the astronauts and to the many scientists, engineers, taxpayers, and others who made the Apollo missions possible.

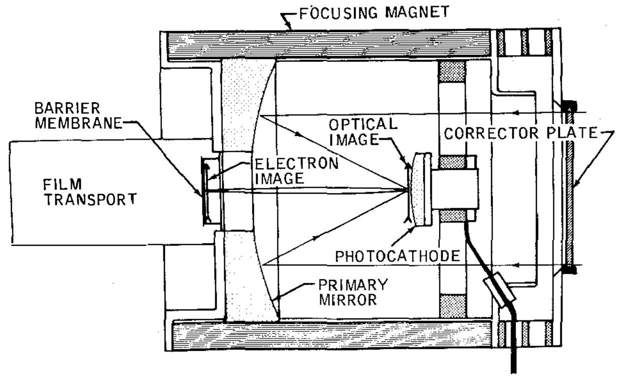


FIGURE 52.—Schematic diagram of the Lunar Surface Ultraviolet Camera/Spectrograph. See text for discussion.

### Lunar Surface Ultraviolet Camera-Spectrograph (UVC)

This camera-spectrograph, which I will call UVC, will provide the first astronomical observations made from the Moon. With it, we hope to study the Earth's upper atmosphere, magnetosphere (see section on "Subsatellite" and figures 52 and 53), and their interaction with the solar wind. The first object photographed with the UVC will be the Earth. We hope also to study the interstellar gas which is present throughout "empty" space and to study the uv haloes that appear around galaxies. By pointing the camera towards the lunar horizon we should detect the presence of any volcanic gas near the Descartes site. And finally, with the UVC, we will evaluate the Moon as a possible site for future astronomical observations. Because the terrestrial atmosphere limits the quality of such observations from Earth, astronomers have long wished for a telescope mounted on the Moon. Perhaps the Moon will be an ideal base for future astronomical observations.

The method of recording the images in the UVC is very interesting. Electrons, rather than light waves, are used. Why? Because greater sensitivities to the uv light can be obtained. Let's follow the paths of the light and the electrons in the camera. See figure 52. The light rays that enter the camera are focused by a spherical mirror onto a surface that is coated with a salt (potassium bromide) which emits electrons. These electrons are then moved by a high voltage (25,000 volts) toward a film and are focused by a magnet.

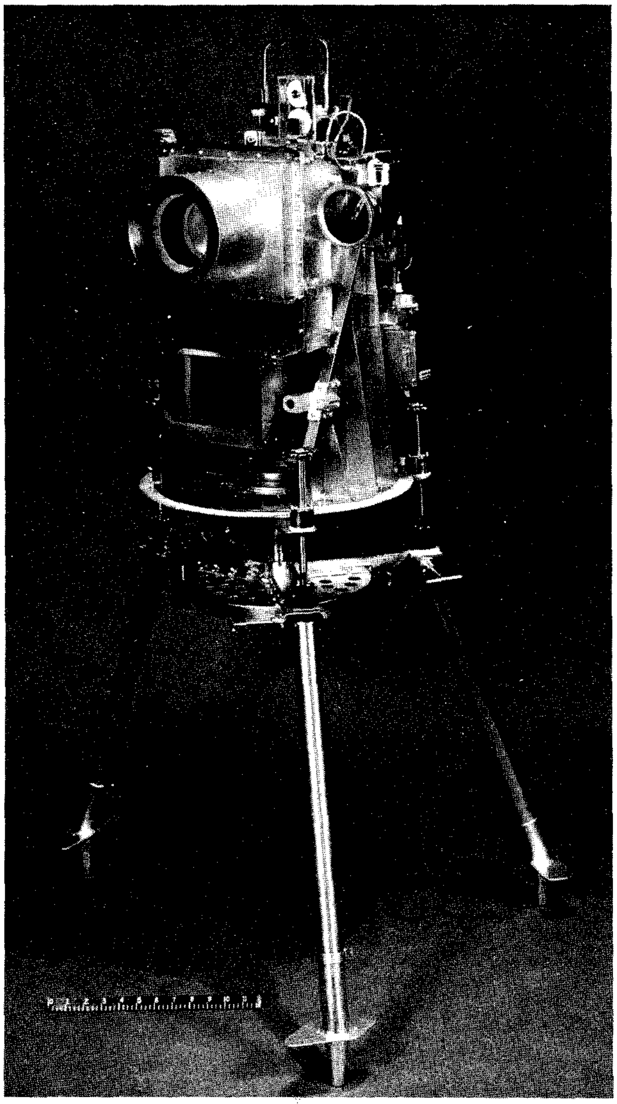

FIGURE 53.—Photograph of the lunar surface Ultraviolet Camera/Spectrograph. This equipment will provide the first astronomical observations taken from the Moon's surface. Photo courtesy Dr. Thornton Page.

The optical image is duplicated, faithfully, by the electron image which is formed on the film. The film differs from ordinary photographic film in that it is highly sensitive to electrons. The conversion of uv light to electrons may seem complicated to you. It isn't really very complicated though and does give very faithful images. Its main advantage is an increase in speed of 10 to 20 times that of a similar conventional photographic camera. In addition, the UVC is insensitive to visible light, a most important consideration because the Earth is a thousand times brighter when viewed with visible light than when viewed with uv.

A photograph of one model of the UVC, similar to the one on Apollo 16, is shown in figure 53. This camera is used in two different ways. In the first, direct images are obtained. These photographs are similar to regular photographic images with the very important difference that uv light is used rather than visible light. In the second, an optical device (technically termed grating) is used to break up the light into its individual frequency components. These individual components are then recorded on the film. Such data are extremely important. They allow us to determine the chemical elements present in the original light source. When the camera is used in the second way, it is termed a spectrograph. Spectrographic techniques have given us the chemical composition of the Sun and stars. In operation, the astronaut sets up the camera, levels it, and points it toward the target to be photographed. The sequence of operation is then automatic and the astronaut proceeds with other work. Sometime later he points the camera toward another target and so on. The final operation, of course, is to bring back the exposed film.

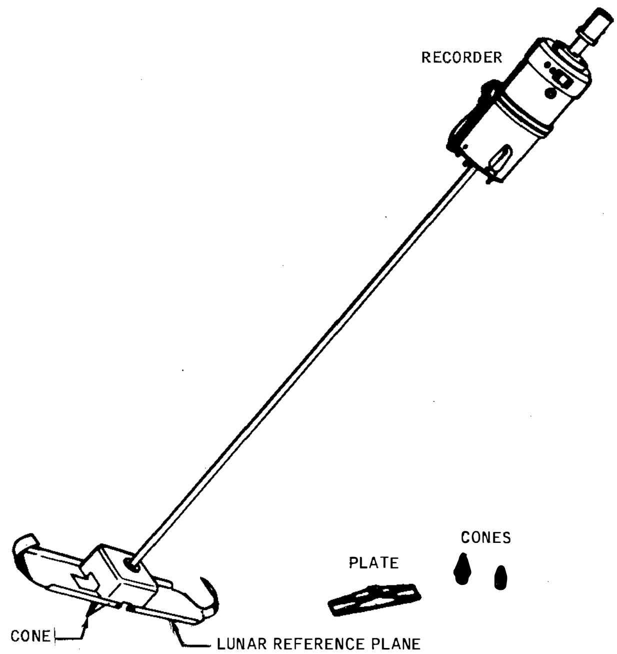


FIGURE 54.—Self-recording penetrometer.

## Soil Mechanics Experiment

The mechanical properties of the lunar soil are important for both engineering and scientific reasons. Future design of spacecraft, surface vehicles, and shelters for use on the Moon will be based, in part at least, on the data collected in the soil mechanics experiment of this mission. To obtain data, many observations will be made during the performance of the other experiments. Such items as the quantity of dust blown from the Moon by the exhaust from the descending LM, the amount of dust thrown up by the wheels on the Rover and the depth to which the astronauts sink while walking, are all important factors in estimating the properties of the lunar soil. Several figures in this booklet show these data. For example, see the drive tube and foot prints in figure 40 and the Rover tracks in figure 47. In addition to these qualitative observations, the astronauts will carry equipment with them with which to measure quantitatively the bearing strength of the soil, a recording penetrometer. It is illustrated in figure 54.