The Exploration of Outer Space

by L. A. DuBridge

Is outer space a resource? If so, one very positive thing can be said about it immediately: there is plenty of it!

Outer space is not only plentiful; it is also durable. It never gets used up. In fact, if you want to speak precisely, the quantity of outer space is rapidly increasing! Because of the expansion of the universe, the radius of space is increasing at a rate nearly equal to the velocity of light. This adds quite a lot to the volume of space every year!

A resident of New York, Chicago or Los Angeles must certainly regard space as a pretty transient resource, as he sees the space available to him dwindling each year at a rapid rate. Naturally, therefore, he looks to *outer* space in the hope that most of his neighbors may some day be transported out there. On this point we cannot offer our harassed city dweller much hope. After all, he or his neighbors could, if they chose, move at any time to Texas or Alaska, to the Mojave Desert, Death Valley, or many other places. If he does not like the desert because of the scarcity of water and food, why would he choose the moon where there is also not even any air?

The entire surface area of the moon is only $\frac{1}{16}$ of the surface area of the earth, or ¼ of the land area. The whole surface of Mars has an area about equal to the land area of the earth. Hence, if we are looking for extra space to which to transport an excess population, it would clearly be cheaper to build a colossal floating platform over the surface of all the earth's oceans. This would multiply our living area by four, whereas the moon and Mars combined would provide us less than a factor of two. Furthermore, I repeat, the earth has air — blessed air!

To tell the truth, it seems pretty likely that for the next few years the exploration of outer space will be one of our best methods of *using up* natural resources rather than conserving them or increasing them. A lot of steel, copper, oil, coal, many other valuable materials, and much human labor can be bought for the billion dollars a year or so we will be spending on space ventures, and it would be a good thing for the American people to try to understand what the investment is for and what returns it is likely to yield.

It is frequently suggested that on the moon or Mars, or some other planet, we may find huge stores of valuable minerals — gold, copper, uranium, or something else. (We won't find coal or oil, for these come from living things!) But I think it is very clear that it would be far cheaper to extract gold from sea water or uranium from granitic rocks than to haul them from the moon. We are really not running out of these minerals here on earth; we are only running out of cheap sources of them. The moon or Mars can hardly be regarded as cheap sources for anything.

Let me hasten to make it clear that I think a good sound program of space research, space exploration, and possibly space exploitation *is* worth a billion dollars a year to us — possibly very much more than that. I favor a bold, imaginative and extensive program of space activities covering both military and civilian

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and the problems we face in attaining those goals.

possibilities – including many research ventures whose potential value, whether military or civilian, cannot possibly be foreseen. My only hope is that this program can be based on realities rather than on fancies.

It is my purpose here to examine space activities from the point of view that the greatest resource to be gained from them is knowledge – new knowledge about our own earth, as well as about outer space; and new knowledge about the techniques of getting out there to gain more knowledge. After all, no human resource is more valuable than knowledge. And when we contemplate what a vast sea of ignorance we face in outer space, it is natural that we should be impatient to get on with the task of replacing ignorance by knowledge.

I shall discuss, first, certain matters related to the nature of the space environment; second, some of the goals to be sought in space exploration; and third, certain of the technological problems we face in attaining those goals.

I. THE SPACE ENVIRONMENT

At first thought it might seem that "empty space" is something about which there is not very much to say except that it is empty and big. Closer examination, however, shows that while space is certainly big it is *not* empty, and it will be instructive to review some of the things we know about it.

Of course, it is really meaningless to talk about the size of space itself, but it is not meaningless to talk about the distances between the various tangible objects in space. In fact, some of these distances are so enormous that it pays to take a look at them before we talk too blithely about the journeys we are going to take out to this object or that. It is not very useful to express these vast distances in miles, because the numbers are too huge to carry meaning. We could follow the lead of the astronomer and express them in light years—that is, the distance traversed by a beam of light in a year at the speed of 186,000 miles per second. This, however, gives an inadequate impression of the distances because light travels at a speed thousands of times greater than that which we can hope to give any material object in the foreseeable future.

I shall, therefore, express these distances in terms of the time required for a possible space vehicle to traverse them. I shall arbitrarily assume that we have a space vehicle which can travel at a constant speed of 25 miles per second, or 90,000 miles per hour. This is 3½ times the speed of escape from the earth; it is just about equal to the speed required to escape the sun's pull when in an earth-like orbit; it is also 50 percent greater than the earth's orbital speed around the sun. How long would it take this vehicle to travel from the earth to various points in space? Here are a few sample items:

To go to	*The time required is*
The Moon	2.9 hours
Mars (nearest approach)	16.0 days
The Sun	43.0 days
Uranus	780.0 days
Pluto	4.5 years
Alpha Centauri (the nearest star)	30,000 years
The center of the Milky Way	560,000,000 years
Andromeda Nebula (the nearest spiral galaxy)	15,000,000,000 years

The conclusion is obvious: All points *within* the solar system (the first five items above) are well within reach of our imaginary vehicle in times reasonable compared to a human lifetime. However, no known object *outside* our solar system comes within a factor of a thousand of being accessible. It is true we can someday probably exceed my assumed speed of 25 miles per second. But the 25,000 miles per second required to bring the nearest star within reach is not in sight. In brief terms: interplanetary but not interstellar space is now open to conquest.

Gravitational fields

Probably the most conspicuous property of interplanetary space is the existence of the all-pervasive gravitational field. The intensity of the field fluctuates greatly, depending on one's position relative to the sun or one of the planets. For example, a body which weighs 100 pounds on the earth would weigh only 25 pounds at 4,000 miles from the earth's surface, and 1 pound at 36,000 miles (40,000 miles from the earth's center). It will weigh 16 pounds on the moon, 38 pounds on Mars. If we recede farther from the earth, but still remain at the same distance from the sun, the latter's attraction with a force of 1/10 of a pound will eventually predominate. This force, in turn, will vary inversely as the square of the distance from the center of the sun and will have appreciable values out to distances of billions of miles.

A gravitational force inevitably means an acceleration and hence *no object in the solar system can remain at rest.* In other words, any object projected from the earth, if it does not return to earth, will go into some sort of orbit about the earth – or, if it escapes the earth's pull, into an orbit around the sun. It would not, without a further "push," orbit about any other object. These closed orbits about the earth or sun are always ellipses (a circle being a special and rather improbable form of an ellipse). In a case where the velocity of an object is high enough for it to escape from the earth, it will still have the velocity of the earth about the sun and will automatically go into a solar orbit.

Furthermore, once the propulsive force has ceased to act on the object (e.g., the rocket has burned out) then the precise path of that object in the gravitational field in space is determined (and its velocity determined too) for all time to come, unless another propulsive force is applied (such as another rocket impulse) or unless the object encounters the retarding effect of friction as it enters an atmosphere. Thus, a satellite projected into an elliptical orbit around the earth, at an altitude sufficiently great to avoid atmospheric friction, will continue in a predictable orbit for years or centuries to come. The particular orbit to be followed will, furthermore, be determined solely by the position and the direction and magnitude of the velocity at the instant the propulsive force ceases. Two objects starting from different initial positions, or with different initial velocities, cannot attain the same orbit. Nor can two objects traverse the same orbit with different speeds; an orbit is not a race track in which one vehicle can overtake another. Nor can two objects in different nonintersecting orbits ever have the same speed; the object farther away from the attracting center must always be going more slowly.

"Perpetual motion"

I emphasize this point of the inevitability of motion and the predetermination of motion in a gravitational field because many discussions of space travel seem to assume that a platform can be established which can float lazily around in space like a boat on a quiet lake. The picture is quite different. A boat in a whirlpool is a more accurate analogy; it simply can't stop.

The rotational nature of this "perpetual motion" gives rise to some odd results. If an object in an orbit around the earth or the sun is suddenly given an acceleration (e.g., by a rocket) in the direction of motion, it will not thereby proceed faster in the same orbit. Instead, the larger centrifugal force will cause it to move off tangentially into a new orbit of larger radius. But, as it moves against the gravitational attraction, it will also slow down and traverse the new orbit at a slower average linear speed and, of course, a longer period of rotation. Conversely, a retro-rocket would cause the object to move inward and attain a higher speed. It is amusing to speculate on the many problems encountered in an environment where one must slow down in order to go faster!

Radiation

A third characteristic of space is the radiation one finds in it.

We know about some of the types of radiation traversing space because they can penetrate both the earth's atmosphere and the earth's magnetic field and reach our instruments. But there are other radiations which cannot reach the earth's surface and which we cannot know about until we begin serious space exploration.

There are, of course, two general types of radiation: (1) *electromagnetic waves* of widely varying length from the long radio waves on through the infrared, visible light, ultraviolet light, to x-rays and gamma rays; and (2) *charged particles* – electrons, protons, and the nuclei of other atoms – with a wide range of kinetic energies from a few electron-volts up to possibly a billion billion electron-volts. Of all these radiations only certain wavelengths in the radio and the visible portions of the electromagnetic spectrum can penetrate our blanket of air, and only the more energetic charged particles can get through the magnetic field and strike even the upper atmosphere. Yet, up to 1957, all of our knowledge of outer space had come through a study of the radiation which does get down to our instruments. Though some instruments have been sent to nearly the "top" of the atmosphere, a whole unknown universe may be revealed as we get clear above the atmosphere and away from the earth's magnetic field.

Indeed, our very first ventures into the regions a few hundred miles above the earth revealed a new belt of radiation – the Van Allen layer – whose existence had been previously unsuspected. It consists of a double cloud of high-energy electrons or protons whose origin is unknown but which appear to be trapped in the earth's magnetic field at distances from a few hundred to 12,000 miles or so above the surface. The intensity is surprisingly great – more than a thousand times the intensity of the known cosmic rays which have been measured by balloon-borne instruments high in our atmosphere. The radiation is intense enough to be a potential hazard to human beings who might like to travel in manned satellites above the earth. And it could ruin photographic plates sent aloft to take pictures of the earth. Many a dream about space exploration has already been abandoned or modified by this discovery — and what additional unsuspected radiation streams are yet to be found no one can tell. Radio, infrared, and ultraviolet telescopes, as well as Geiger counters and other detectors should certainly be sent aloft as soon as possible to begin this fascinating era of discovery, which may well last for many decades before adequate knowledge is obtained.

What will be the results of all this? I do not know. New knowledge? Certainly. Many surprises? Probably. Revolutionary new discoveries? Possibly. But in these vast unknown radiation fields of space there certainly lie hidden many secrets about the nature and size and composition of the universe. The cosmic rays which manage to penetrate to the earth's surface have also told us many things about the structure of atoms and nuclei. The rays which cannot reach us may teach us even more.

Electric and magnetic fields

Around every sizable body in space we are likely to find both electric and magnetic fields. We know a little about the magnetic field about the earth, but very little about any electrostatic field. We know — from rather recent observations — a little about the magnetic field of the sun. It is quite weak and quite variable. Some stars are surrounded by very large fields. Very weak but very pervasive fields may spread throughout interplanetary space and throughout our entire galaxy. They might have profound importance in the acceleration and trapping of charged particles — cosmic rays — and even in the large-scale transfer of momentum between the planets and between stars. Only an extended series of properly instrumented flights far into interplanetary space will reveal the nature and extent of such fields.

II. GOALS OF SPACE RESEARCH

A major task of space research programs will be to learn more about the nature of the space environment itself, the radiation streams which traverse it, and the electric, magnetic and gravitational fields which pervade it. Certain other types of space ventures must indeed await the results of the initial explorations of space itself.

However, there are many more things to be done — so many that it is difficult even to classify them. First, however, we may consider the tasks which may be performed by vehicles placed in various orbits around the earth, and then the additional tasks for probes which are projected farther out into the solar system.

Earth satellites

For some time to come, the most important (though not necessarily the most spectacular) scientific missions will be performed by instrument-carrying vehicles projected into orbits at distances from a few hundred miles out to 20 or 30 thousand miles from the earth's surface. In addition to examining the nature and contents of space itself, they may be used to make observations of the earth or of other bodies. In addition to their information-gathering function, they may also perform certain service functions — as radio relay stations, as refueling stations or service platforms, or possibly as carriers for military weapons. I will confine myself to the information-gathering function here, because it is new knowledge that is the great resource we are now interested in.

However much we may love to learn about the moon and the planets and the sun, the earth will always be the object of primary interest to human beings. So what we can learn about the earth from observation stations circling far above its surface is of prime importance.

Even a "dead" or noninstrumented satellite, if it is large enough to be visible from the surface of the earth (e.g., 100 to 300 feet in diameter), could provide us with quite a lot of information. By observing carefully the nature, shape and perturbations of its orbit, one may learn much about the earth's gravitational field and hence about the exact shape of the earth itself and the distribution of mass within it. It should be remarked that the whole science of precise orbital calculations will need much further development. Astronomers have been working for generations to evolve an exact equation for the orbit of the moon. But every new satellite presents a new and difficult orbital calculation. Computing machines now make the task much easier — but the most suitable mathematical techniques must still be worked out, and much more information needs to be acquired about the exact form of the earth's gravitational field itself, and the small but important perturbations caused by the field of the moon, the sun and other planets.

As one looks down at the earth from a satellite, the most obvious phenomenon to be observed is, of course, the cloud pattern. A single good picture from a satellite which is, say, 300 miles high could — if it could be promptly transported or transmitted to the earth's surface — give a view of the entire storm pattern over an area some 2,000 miles in diameter, i.e., over much of the United States. A few dozen such pictures taken almost simultaneously from properly chosen points in the Northern Hemisphere could give for the first time a complete weather picture of the whole hemisphere. It would take a good deal of research to interpret such pictures and to use them for predictive purposes —

but, clearly, enormous contributions to the science of meteorology are in sight. The difficulties and cost of obtaining such collections of pictures continually and reliably, and getting them back to earth stations without losing too much resolution, are of course enormous. But useful information will be obtained even before such ideally complete observations can be made.

The charged layers of the earth's upper atmosphere, which play such an important role in the transmission and reflection of radio waves, will also constitute an area of intense interest. The charge density and thickness of these layers, the influences which cause the molecules to become ionized, and how these change with time and how they depend on events in the sun or other places, will cast important light on radio, television and radar transmission problems.

The strength, shape and variations in the earth's magnetic field out to distances of 100,000 miles could occupy the attention of dozens of properly instrumented satellites. The origin of this magnetism is still a puzzle and, though the solution to the mystery may not be found in space, pertinent information certainly will be.

If we turn our attention from the earth to other objects in space, we find a bewildering wealth of opportunities for making observations which are forever impossible under our blanket of air. However much we can bless this blanket for its life-giving properties, it is still a curse to the astronomer. As has already been suggested, observatories in space which can measure radio, infrared, visible, ultraviolet, and x-rays will undoubtedly reveal wholly unsuspected things about the sun, the planets and the stars. There is every reason to suppose that the radiations which cannot penetrate our atmosphere may carry just as great a wealth of information as those that do, and a new era in astronomy will dawn when space observatories become possible. Unfortunately again, complete space observatories will be very expensive — but even simple ones may be most useful.

These few examples will serve to prove what a gold mine of valuable knowledge may be revealed by instrumented earth satellites.

Manned satellites

I have said nothing about manned satellites. The first man-carrying satellite will be a tremendous achievement and the first passengers will experience a tremendous thrill. The first look that human eyes have of the earth and the heavens from a space vehicle will mark a new epoch in the annals of human experience.

But adventure and prestige are not the only considerations. One must examine carefully what functions men can perform that instruments cannot perform as well or better, and which functions are worth the very great extra cost of carrying a human being aloft, keeping him alive and alert, and getting him back alive. Certainly a vast amount of data can be collected by automatic instruments without human intervention, and space research should not be delayed until the perfection of passenger-carrying vehicles. Nevertheless, the human being — though he is a costly and delicate instrument to carry aloft — does have many attributes which electronic equipment does not yet possess. If intelligently used, man can be a great asset to space research, but if he just goes along for the ride he will be a costly liability. For the next few years the human being can just as well be left at home until we really need him to do the things that instruments cannot do.

Deep-space probes

While earth-satellite vehicles are being used to explore the earth's vicinity, probes to reach the moon, Venus, Mars, and eventually other planets, will soon be launched. Whole new mines of knowledge will be opened up as we get into a position to make visual, photographic, magnetic, and gravitational measurements in the vicinity of these bodies.

We face here, however, some deep difficulties. From the rocket point of view there are no serious problems in projecting deep-space probes into suitable orbits which will pass *near* these bodies. One might even expect someday soon to cause an object to strike the moon. But for the most part, in the foreseeable future, our space probes will sail past their targets and out beyond their gravitational fields to become captured in an orbit about the sun. Such objects will be lost to view forever, and the only information which they will yield is that which they radio back before their batteries burn out, or before they get too far away for the radio transmissions to be detected. Whereas a satellite around the earth might continue in a closed orbit for years, and — when larger solar batteries are available — continue to provide useful information for a long time, our space probes will be one-shot affairs and, as they get millions of miles away, there will be serious difficulties in getting signals from them at all because of the very large amounts of power required.

A great step forward will be made when we succeed in navigating a vehicle into a permanent orbit about the moon — and equip it with solar cells large enough to keep its radio operating for a long time. A great wealth of information can be gleaned from such an experiment.

However, nothing short of a very elaborately equipped vehicle can hope to get into an orbit about Mars or Venus because of the delicate navigational and propulsion problems. And even if this is accomplished when the planet is at the distance of closest approach, it will be only a few days or weeks before the planet and its new satellite — as they increase their distance from the earth — will be hopelessly out of range of the most powerful radio. Thus, a rather sophisticated space technology will be required to begin to obtain continuous information from the vicinity of even these nearest planets. To land instruments on the planets, to explore the more distant planets, and to send manned expeditions to them will be even more difficult.

III. TECHNOLOGICAL PROBLEMS

The success of the first earth satellites and of the first moon probes has led many people to suppose that it is now only a step to the most distant and complex exploratory ventures. It is true that once the first step has been taken it is dangerous to predict that additional steps will not soon follow. It is, however, pertinent to examine the nature of some of the problems yet to be solved.

Consider first the field of rocketry and propulsion. Rockets of thrust of 300,000 pounds are now available and thrusts of a million pounds are in development. These, especially when used in clusters, will send substantial instrumented packages into earth or planetary orbits; i.e., space probes to the region of the moon, Mars, and even more distant planets. Even manned vehicles can be placed in earth orbits with sufficient equipment for a safe return – if the journey does not last too long. A package could also be landed safely on the moon.

However, when one begins to talk about sending even one man to the moon and getting him back alive, one quickly runs into thrust requirements of up to 10,000,000 pounds or more, calling for advances in technology which are far in the future. Space platforms to which the necessary equipment and fuel can be dispatched in smaller packages and then assembled are said to be the answer, but it is not clear whether the technology of such space stations will come more quickly than that of the large rockets. And it is yet to be decided whether a man can bring back enough more knowledge to make his journey profitable.

Some wholly new ideas appear to be called for. There is, in short, room for the development of some propulsion-energy source more useful than a mixture of kerosene and liquid oxygen.

The first thought in this field, of course, is nuclear power. In fact, the space amateur blandly dismisses all difficult propulsion problems by uttering the magic words "atomic energy." But a closer look is clearly called for.

It is certainly true that a fission reactor in a space vehicle could supply a large amount of heat for a very long time without refueling. Unfortunately, heat alone does not provide propulsion. The heat must be imparted to some substance whose molecules, thus speeded up, are then ejected from the vehicle. The simple physics of jet propulsion tells us that the momentum (mass times velocity) of the material ejected during a given time is precisely equal to the increase in the forward momentum of the propelled vehicle. Obviously, the mass of this propellent fluid must be carried along in the vehicle as it leaves the earth. So the limitation on the propulsive effect of a nuclear reactor comes, not when the reactor runs out of uranium fuel, but when the supply of propulsive fluid has been exhausted.

What shall we use for the propulsive fluid? Simple physics again tells us that, for a given total mass of such fluid, the maximum velocity, and hence the maximum momentum, will be imparted (for a given reactor temperature) to the fluid with the lightest molecules. This means that the best possible propellent is hydrogen. However, the problems of packaging many tons of liquid hydrogen (at -252° C.) for a space journey are imposing indeed. Furthermore, even in the liquid state hydrogen is not a very dense substance, so that some 100 tons of it will occupy a lot of precious space and the containing tanks may be pretty bulky. Other less ideal substances may offer more manageable engineering problems. But the point is that while a nuclear reactor for a submarine, for example, has the enormous advantage of carrying a lot of energy in a small mass of uranium fuel, a nuclear rocket must also carry a very large mass of propellent – and much of the apparent advantage of atomic energy is lost. Nuclear rockets *will* be needed someday in launching very large space vehicles, and research on such rockets should be energetically pushed. But nuclear power is not a simple magical answer to all problems.

Possible propulsion schemes

Other possibilities are being investigated, of course – ionic propulsion, photon propulsion, alpha-particle propulsion, etc. It is too early to evaluate their practical possibilities. One thing must be remembered – no propulsion scheme, no matter how exotic, can get away from the basic momentum and energy relations. If a space object is to acquire a large velocity and if it is to escape from a gravitational field, then energy is required – and indeed the energy given to the vehicle itself is very small compared to the energy which must be imparted to the high-velocity escaping propellent. Therefore, any practical propelling device must carry both large amounts of energy and large amounts of propellent mass.

The only scheme I know of which does not have to carry along its own energy source is one using sunlight. Though the sun's radiation pressure is extremely small, it will, over very long periods, provide appreciable momentum. A solar-pressure "sail" can cause an object in an orbit about the sun slowly to "accelerate" (i.e., circle outward into larger orbits) or "retard" (circle inward). Since the small pressure can be available for extremely long times, an orbit gradually spiraling out to very great distances from the sun becomes possible. The journey may take many years, however.

An instrumented satellite must also have energy to operate its instruments and especially must be able to transmit the accumulated information back to an earth station. All space vehicles so far, except the Vanguard satellite, have used dry cells as local power sources — and these have become exhausted in a few days or weeks — often long before the satellite itself has returned to earth. An invisible satellite whose "voice" has gone dead is a pretty useless object. (On the other hand, a great swarm of satellites that can't be turned off could someday be a nuisance too!)

Radio power requirements

Unfortunately, the power requirements for the radio transmitter which is to radio information back to earth get rather imposing as the distance from the earth increases. An earth satellite at a distance of 500 miles or so can be heard by special receivers when transmitting at only 1/100 of a watt. But, as one goes farther out, the inverse-square law begins to take its toll. At 5,000 miles the power for the same receiver and the same signal strength would have to be 100 times as much, or 1 watt; at 50,000 miles, 100 watts; and at the moon, 240,000 miles, one would need about 2½ kilowatts. At the distance of Mars, some 50 million miles, the power has risen to 50,000 kilowatts — 1,000 times the radiated power of a normal cleared-channel broadcasting station, and approaching the power of the very largest electric generating stations now operating on earth.

A part of this difficulty can be overcome by using a directional antenna on the satellite — with the obviously difficult problem of keeping it pointed toward the earth — and by using very large receiving antennas on the earth, 100 or more feet in diameter. But, even at best, the communication problem is one of extraordinary difficulty, and even in the simplest cases one needs some sort of power supply for a long time — and the possibilities of ordinary batteries are limited indeed.

Present zinc-silver batteries provide 20 watt-hours per pound of weight. It would take 440 pounds to operate a radio set consuming 1 watt continuously for one year; at 100 watts they would last only 4 days. Using intermittent operation — transmitting only on signal from the earth — correspondingly longer times can be obtained. Theoretically it should be possible to improve this performance by a factor of about 10. For orbits near the earth, where only a few watts of power will be sufficient, dry batteries will clearly be very useful. For distant ventures, however, the radio power required is so great that batteries become hopelessly inadequate.

Solar power at once suggests itself — and has indeed proved its potentialities in the Vanguard satellite whose solar-powered radio was still operating a year after launching. The power level was very small, however. Larger power requires larger area with corresponding engineering problems. The power available from the sun is, near the earth, of the order of 100 watts output per square meter of effective surface area, for solar cells of present types. Thus large arrays of cells, or else large concave reflectors to concentrate the energy, will be required. For satellites which are near the earth, and hence in its shadow about half the time, some storage battery may be required — and the weight and life requirements become immediately more difficult.

An ingenious but extremely expensive device has recently been constructed in which an intense radioactive source, activated in a nuclear reactor, is used as a source of heat to activate a thermoelectric couple. Available devices might provide a few watts of power, but the most suitable isotope (polonium) has a half life of only 138 days — which cannot be prolonged even though only occasionally used.

It would appear that unless a new invention is made, the outlook for having sizable energy sources which will supply considerable power for long periods of time and for distant journeys is very gloomy indeed. So we may expect to spend millions of dollars to launch a satellite, only to have its voice fail after only a few weeks of operation — or to have it quickly fade away at large distances. Here is a real problem worthy of the best developmental efforts.

It is clear, too, that power for operation of a radio transmitter is only one requirement for an instrumented satellite. The instruments themselves, the navigation and control equipment, the cameras, Geiger counters and other equipment for scientific observation all require energy also.

If the satellite carries human beings, additional requirements arise. Food, oxygen, and water will add up to substantial loads for long journeys. For orbits closer to the sun or farther from the sun than the earth, the temperature control problem will become serious — requiring additional energy.

A good investment

In summary it can be said that space exploration opens up fantastic new vistas for research and exploration. New knowledge of the earth, of space and of our neighboring planets, which has been hidden from human beings since the beginning of time, will soon be available. The new knowledge will be a resource of unimaginable and unpredictable value. It will, however, be acquired at very great cost. Space is large; travel times are immense; the energy requirements for some ventures may be colossal; the technological problems will constitute a challenge to man's ingenuity for generations to come. But new inventions, designed to aid space travel, will also aid many more earthly ventures and yield new dividends to technology. These combined with the new knowledge of unforeseeable uses will certainly make space research — like all other scientific research — an exceedingly good investment.