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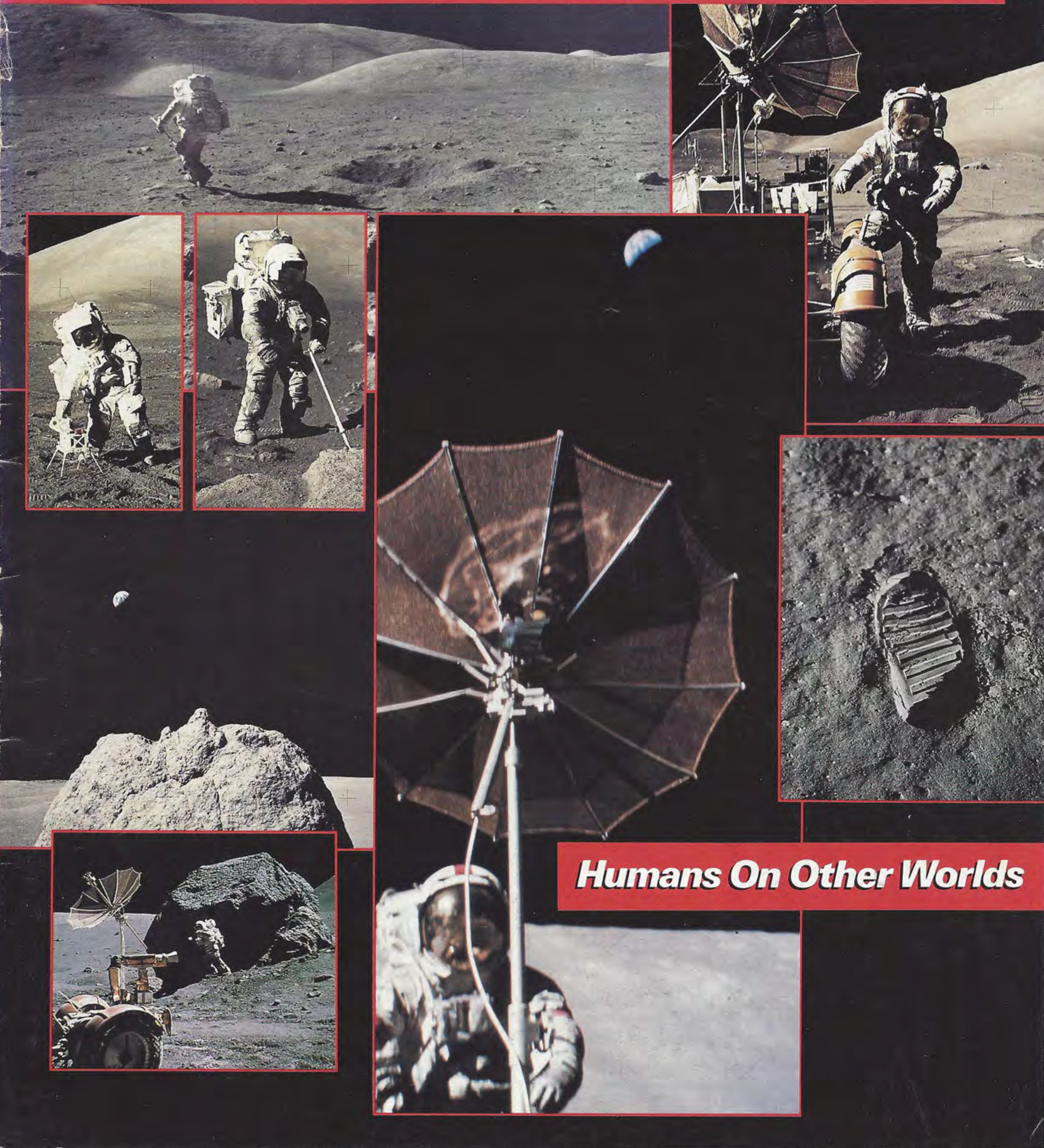

Humans On Other Worlds

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COVER: Humans have walked on the surface of only one world besides their own – the Moon. Someday we will return to the Moon, visit our neighboring world, Mars, and investigate asteroids that pass near Earth. In this issue we remember those first steps on the Moon and look forward to new journeys to other worlds. **Photos: Johnson Space Center/NASA**

PEOPLING OTHER WORLDS

Space is mostly empty; worlds are rare. Since humans grew up on one world, it seems natural to us to imagine visiting others. In the next few decades, there are only a few worlds that will be easily accessible to us: the Moon (the only world humans have already visited), asteroids (especially the kind whose orbits bring them close to Earth), and Mars (and its two small moons). But to send humans to other worlds is expensive. Generally speaking, an expedition by humans to another world is something like ten times more expensive than sending sophisticated robot explorers. *Apollos 11, 12, 14, 15, 16* and *17* brought back samples from the Moon, but so did the far less expensive *Lunas 16, 20* and *24*. There may be excellent reasons to send humans to other worlds. The reasons may be scientific and exploratory, the sorts of ventures that are central to the purpose of The Planetary Society. Missions may also have political and nationalistic, or even social and historical, justification. It is conceivable that missions might be proposed because they generate jobs or increase profits for aerospace corporations, or provide assurance of continuing employment for workers at NASA field centers. Perhaps we will even someday be told that some strategic advantage awaits the first nation to "take possession" of this or that world.

These justifications are not all mutually incompatible, and some mix of them might be proferred in any given case. Sometimes "spinoff" arguments are also proposed; but nobody really believes that the principal justification for a major space mission is that it will accidentally generate some useful domestic device. People understand that you can develop the household appliance directly for much less money than it costs to send people to the Moon, say. All such arguments should be examined very closely. With the costs so high, we should be quite clear what the reasons for going really are.

Recent work commissioned by The Planetary Society (see pages 4-6) indicates that missions to the Moon, or the asteroids, or Mars could probably be accomplished in another decade or two — assuming the appropriate sort of orbital "space station" is already in place — for less than the cost of the *Apollo* missions, or equivalently, for a few percent the estimated full deployment cost of the proposed Strategic Defense Initiative.

If we are not so foolish as to destroy ourselves, it seems likely that the technology of exploration will improve, costs will decline, justifications will be honed, and that, sometime in the lifetimes of most of us, humans will return to other worlds. The Planetary Society believes it can serve a useful function in examining those missions which are most meritorious on scientific and exploratory grounds, and those missions that hold the greatest promise for a benign human future.

Since The Planetary Society was founded almost five years ago, we have advocated and supported a variety of missions to other worlds. All of them have been with robot crews, because those were the only missions that were practical at the time. But we have consistently examined the merits of missions with human crews (see *The Planetary Report*, July/August 1983).

Today, the climate is changing. A palpable feeling that it is again feasible to muster human missions to other worlds — not to a mere few hundred kilometers altitude — is sweeping the technical community. There is evidence that The Planetary Society has played a role in creating this changing climate. This issue of *The Planetary Report*, therefore, is devoted to an examination of possible future missions of men and women to the Moon, the asteroids and Mars.

Speaking for myself, the most creditable goal in exploring up there is to make things significantly better down here. And the most interesting exemplar of such missions is a joint US/Soviet expedition to Mars — on behalf of the entire human species. This goal is explicitly mentioned by Senator Spark Matsunaga in language accompanying last year's Senate/House Joint Resolution 236 (see page 3). We hope to discuss such international missions, as well as more pedestrian national missions, in a future issue of *The Planetary Report*. It would be remarkable if the exploration of other worlds — an activity long (and dubiously) imagined to be of little practical benefit — played a role in resolving the most pressing and practical problem on Earth.

CARL SAGAN, *David Duncan Professor of Astronomy and Space Sciences,* Cornell University; *President*, The Planetary Society

MANNED SPACE EXPLORATION: Make It International

by Spark M. Matsunaga

The debate over whether humanity's advance into space should be led by humans or machines has always struck me as an unproductive expenditure of considerable intelligence and energy. The context is much too narrow. I ran up against its limitations nearly three years ago, after reading reports indicating that the arms race might go into orbit, literally. As one alternative, I proposed that the first permanently manned space facility be developed as an international project involving both the United States and the Soviet Union.

To my surprise, space scientists lined up against the proposal. Apparently, the threat of war held a secondary position to the threat of NASA. My proposal had been perceived as just more support for the dreaded space station which would squeeze space science dry. Subsequently, space-station advocates overwhelmed the opposition and the project emerged as a "free world" enterprise; then, despite previous assurances to the contrary, the head of our space weapons program raised the possibility of military applications that could only further narrow the space station's personality.

Of course, space scientists are as appalled at the prospect of space wars as is any other civilized segment of society. The villain in this instance is a policy context that fosters interest groups competing for slices of a space pie carved up each year in Washington. They invoke science, human destiny, private enterprise, the Communist menace — whatever works. Missing from it all is a practical vision of our future in space — an overarching space policy — that meets the unique requirements of the space environment.

To Know Space

Such a policy must recognize that we will never really begin to *know* space until humans move out into it. Assumptions that we can know it from Earth, using machines, rest upon earthbound conceits of a decidedly unscientific nature. The Copernican Revolution seems to have encountered a conservative reaction from unexpected quarters. The simple truth is that the human pursuit of knowledge isn't Earth-centered. It is human-centered. Its boundaries are determined by wherever humans are at any point in time and space. Human movement through space will generate requirements for knowledge inconceivable here on Earth. In that regard, the sooner we move out the better.

But by that same token, the move into space — if it is to bring a meaningful advance in civilization — must be based upon solidly reasoned scientific perception. That, to borrow a phrase, is a new idea. No matter how futuristic our costumes and our machines, civilization is doomed if its advance into space is to be guided, as it has been on Earth, by tribal drumbeats.

Cooperation in Space

For that reason, primary emphasis must be placed on international cooperation in space. Space is simply too *big* to be addressed according to timeworn, earthbound categories, with scientists battling NASA, NASA battling the Department of Defense, East battling West, in compulsive pursuit of an evanescent superiority of one kind or another or a scientific purity that also happens to serve the narrow interest of the puritans who preach it. We cannot expect to move through the cosmos planting tribal emblems and protecting trade routes with rocketships. That is strictly for the movies, Grade B variety. In a word, it is *irrational*. If we are serious about space, we must first overcome humanity's greatest failure and the seed of its self-destruction — the problem of getting our international act together as one human race.

We have heard the stock response: Space cooperation between the superpowers is "impractical, unrealistic." But the sober truth is that the extension of the cold war into space is even more impractical and unrealistic. At a certain point, anything other than a unified approach to the universe from our tiny microbe of a planet ceases to make any sense at all.

The challenge is to develop policies which guide us to the point where inevitabilities generated by space take over without first sealing off that saving prospect through pursuit of short-sighted policies aimed at preserving short-term advantages.

To that end, I have proposed that the US and the USSR renegotiate the space cooperation agreement which the US allowed to lapse in 1982, in response to imposition of martial law in Poland. In the process, we should establish an East-West Mars Working Group, to coordinate the already-scheduled 1988 USSR scientific mission to Mars' moon Phobos and the 1990 US Mars Geoscience/Climatology Observer. The Working Group should also plan joint follow-on missions, including a Mars sample return in the 1990's, leading to an international manned mission to Mars near the turn of the century — the most stirring undertaking in human history.

A Core Program

In arguing for special initial emphasis on Mars, I am not arguing against the Moon, or asteroids, astrophysics, plasma physics, solar-terrestrial physics, or any other physics or chemistry or geology. My proposal is a core program, one into which other objectives could be smoothly incorporated. Mars is clearly the primary target of Soviet space planners, no matter what we do.

The popular appeal of Mars is a proven reality that our space policymakers would be foolish to ignore. A Mars mission would be of first importance for science and for the essential objective of human settlement beyond our planet. An international Mars program could be initiated at once by coordinating US and Soviet activities already underway, thus making maximum use of important complementarities. The resulting building block process might include an unmanned sample return from Mars and a negotiated, step-by-step internationalization of US and Soviet space station activites, in association with other spacefaring nations.

The exploration of Mars could evolve into a major foreign policy objective, the first to recognize the new realities of a dawning era. As we approached the awesome goal, the superpowers would find themselves pulled toward a common destiny. It would be wholly irrational to not even try.

Senator Matsunaga (D. – HI) introduced last year a resolution calling for renewal of the US-USSR Space Cooperation Agreement that passed both Houses of Congress and was signed into law by President Reagan. This year, he has introduced a resolution calling for joint exploration of Mars.

VISIONS of 2010

Human Missions to Mars, the Moon and the Asteroids

by Louis D. Friedman

Foreword to the SAIC Report

With *Apollo 17*, a glorious but brief epoch of human exploration of other worlds ended. Soon, both the US and the USSR abandoned the Moon. Ambitious American plans for manned missions to Mars were shelved. By 1980, suggestions were being proferred by high administration officials that the historic NASA program of planetary exploration by robot spacecraft be further curtailed or even cancelled altogether. For several years, NASA programs were so reduced that the agency was prevented from funding any work on the future exploration of Mars (or even from analyzing much of the data from the spectacularly successful *Viking* missions). Persuasive arguments and careful re-evaluation have prevented the worst from happening, but even today NASA's future program of planetary exploration is, while of undoubted scientific merit, distinctly small in scale.

Believing that it was essential to bridge the chasm between past and future martian exploration, The Planetary Society initiated the Mars Institute — a university level series of courses, seminars and projects conducted nationwide in the US, and designed to prepare the way for future exploration of Mars. While missions to Mars with human crews cannot be justified on scientific grounds alone, they provide promising opportunities for international cooperation. They represent a readily grasped intent, especially if undertaken by the United States and the Soviet Union, to work on behalf of the entire human species. The exploration of the martian surface by human beings would constitute a hopeful and stirring long-term focus for the American — and for the world — space program.

But since *Apollo*, there have been, in the United States at least, almost no serious studies of human voyages to other worlds, despite the fact that enormous technological advances have been made since those early lunar landings. The Planetary Society therefore commissioned the Schaumburg, Illinois office of Science Applications International Corporation (SAIC) to examine what was possible with present and probable near-future space technology for missions with human crews to nearby worlds. SAIC has an outstanding record in performing advanced mission studies for NASA. This document presents a first analysis of concepts for advanced missions with human crews to the Moon, to a near-Earth asteroid, and to Mars. The Planetary Society has selected these objectives because they are the three most obvious near-term goals for human voyages beyond Earth orbit. For each objective, a baseline mission was specified which would provide a toehold for continuing missions, leading ultimately to permanent human outposts on other worlds. The chief objective of these studies was to provide a rough cost estimate; but such an estimate requires in turn a comparative system design and a technology requirements analysis.

The study is necessarily preliminary. It is intended to be the basis for further discussion of national missions, and especially of long-term goals for international cooperative exploration. Presented here are design concepts only; the very serious work of performing trade-offs among alternative mission designs remains to be done. But, apart from the innovative designs, the study is especially noteworthy in demonstrating that — with an Earth orbital infrastructure in place — missions to the Moon, to a near-Earth asteroid or to Mars could be accomplished (in real dollars) for less than the cost of the *Apollo* missions to the Moon.

The Planetary Society is happy to have sponsored this study, and is especially grateful to the staff of the Schaumburg office of SAIC. We hope this study will stimulate renewed interest in major international initiatives for the exploration of nearby worlds in space.

Carl Sagan, *President*; Louis Friedman, *Executive Director*
THE PLANETARY SOCIETY

For half the cost of the *Apollo* mission to the Moon, we can send humans to Mars. A manned mission to an asteroid or a return to the Moon could be done for half the cost of a Mars mission.

Those are bold and intriguing statements, but they were not pulled from the flighty musings of some dreamer's private inner world. Rather, they represent the cautious findings of a level-headed mission study group that NASA has used extensively in the past. Recently this group, the Space Sciences Department of Science Applications International Corporation (SAIC) of Schaumburg, Illinois, was retained by The Planetary Society to study possible manned missions to other worlds.

Before going into details about the missions, perhaps a little background would be useful in seeing how the Society became involved in planning missions to other planets.

The year 2010 is only 25 years away, and it's pretty clear that we won't be sending human crews off to Europa to the strains of Strauss waltzes. In fact, in these pressing times of global economic uncertainty and strained diplomatic ties between countries, perhaps the question for 1985 ought to be: "Will humans travel to *any* world beyond Earth?

The SAIC report grew out of our uneasy feeling about the future of missions to other planets with human crews. NASA and other space agencies were ignoring this subject and the Society felt it was time to start meaningful investigations on whether or not such missions are feasible and sensible for the beginning of the new millennium.

Sputnik's first step off Earth in 1957, the use of commercial satellites in Earth orbit, the exploration of other worlds with a fleet of semi-autonomous interplanetary spacecraft, all coupled with rapid advances in our understanding of the universe, are signposts marking our path to the planets. The *Apollo* landing on the Moon was one major milestone; the first manned flight to Mars will be another.

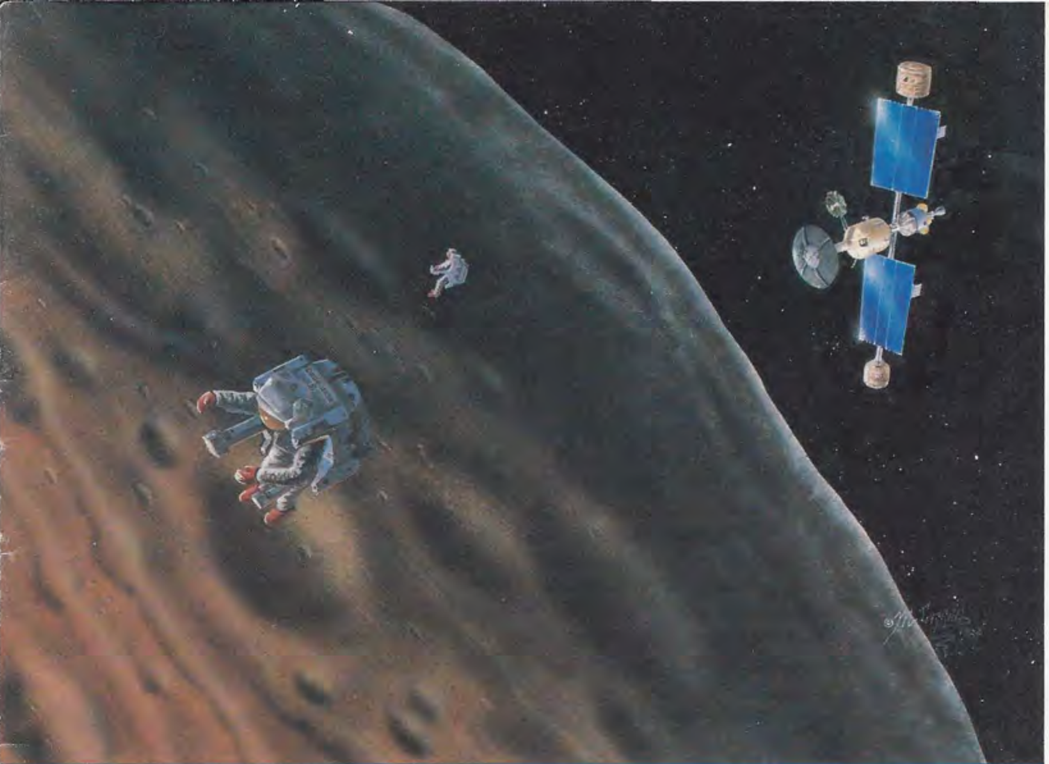
We began to explore space chauvinistically, with the United States and the Soviet Union racing for the Moon. Now, those days of intense rivalry are gradually fading as space travel becomes international. More than half of current space missions involve more than one nation.

The advantages of international cooperation become greater and more obvious with the growing realization that, if the US and USSR worked together on an ambitious space project, both countries could redirect some of their most advanced capabilities and energies from military competitiveness to peaceful cooperation. Economic, technical and scientific advantages also compel consideration of joint participation in manned space missions.

"Manned" exploration is expensive and technically difficult. It can't be justified for scientific reasons alone. Yet it ought to be done. And it would best be done as a truly planetary endeavor involving all spacefaring nations. Done this way, manned exploration of our solar system would be a stirring focus for scientific and technical progress around the world.

Paintings: Michael Carroll

Some day international expeditions may explore near-Earth asteroids and Mars. Here are an artist's conceptions of those missions, based on the SAIC report.



The Study

But, although sending humans to other planets is a great goal, can it be done?

The answer to that question brings us back to the SAIC report: the first serious — if preliminary — post-shuttle-era work on manned deep-space mission analysis and design. We funded it because it is important to have solid technical evidence to back us in our advocacy of new goals for the space program.

The SAIC report presents only design concepts. The very serious work of performing trade-offs between alternative mission designs remains to be done.

Perhaps there are not that many. Many areas overlap among the innovative mission designs found in the SAIC report. For instance, whether the goal is the Moon, an asteroid or Mars, each mission concept envisions some type of Earth-orbiting space station or platform as a major component of a successful mission although not necessarily the present NASA design.

The guideline we gave SAIC was simple: Don't design an *Apollo*-type mission with no goal beyond its own accomplishment. Each mission was to be considered as the first step in establishing continuing human activity on another planetary body.

Closest at hand, of course, is the Moon, which could be used as a base for scientific and technical development.

On Mars, the idea is to begin extensive exploration to determine the potential for self-sufficient human settlements there.

Asteroids with orbits that come close to Earth's would be explored and studied to determine the feasibility and value of mining them.

Despite the fact that all three missions are assembled in space, the three do have very different targets, and that sets very different requirements for each. For example, the Moon and asteroids are devoid of atmospheres, so aerobraking (using the friction of an atmosphere to "brake" a craft's descent) isn't feasible. But that also means we don't have to protect the spacecraft from heat build-up during entry as we do on bodies with atmospheres.

There are so many variables that just thinking about them produces a jumble of ideas, requirements and difficulties. Consider:

— As a class, asteroids are so small that they would exert little gravity during landing, unlike the Moon and Mars, which will demand retro-rockets for soft landings.

— The Moon, in orbit about Earth, can be reached in just a few days, so a lunar mission demands relatively little — compared with a Mars or asteroid mission, for example — in supplies.

— Missions to Mars and most near-Earth asteroids would require large amounts of fuel, compared to missions to the Moon and a few near-Earth asteroids.

—The return trip from Mars or an asteroid would generate very high arrival speeds, making it more difficult to return the crew to Earth.

But there are also many similarities among the mission concepts:

—All the missions require life support systems, although of differing levels of complexity, depending on their duration.

—The space shuttle will serve as the initial and final transfer vehicle, while chemical rockets will take the assembled spacecraft from low Earth orbit to their target trajectories.

—All three missions use aerobraking, slowing the returning vehicles into Earth orbit. (Those who saw the film *2010* will remember a dramatic representation of this maneuver as done at Jupiter.)

—Each mission scenario supposes that the crew will remain at the target world for 30 days, giving them time to explore and experiment before returning home.

WHAT TO CALL IT?

The customary way of describing a space vehicle with a human crew is to call it a "manned" mission. But four women have now flown in space — two Soviets and two Americans — and many more can be expected in the near future. We are proud to have one of them, Dr. Sally Ride, on our Board of Advisors. We cannot argue that the word "manned" covers both sexes. Manifestly it does not, and the word serves us poorly in encouraging the most capable individuals of both sexes to consider careers in space. "Manned and womanned" is unwieldy. "Crewed" is vulnerable to misinterpretation, at least in spoken language. "Humanned" or "peopled" are imperfect, but at least represent a step in the right direction. We have more than once used the phrase "with human crews" in *The Planetary Report*, to distinguish, properly, we think, from "with robot crews." But the subject needs an appropriate one-word encapsulation. This may be close to the last moment in which it is possible for an alternative to "manned" to carry the day.

Members of The Planetary Society are invited to submit suggestions to: The Planetary Society, "What to Call It," P.O. Box 91687, Pasadena, CA 91109. Entries considered the most promising by a committee appointed by the Board of Directors will receive prizes commensurate with the quality of their entries. — *C.S.*

Mission to the Moon

The purpose of this mission is to establish a base on the Moon. About two and one-half tons of equipment, including scientific instruments and computers, will be placed on the lunar surface. A shelter will be provided for shade, for protection against the Sun's ultraviolet rays and solar flares.

The mission requires 12 shuttle launches and two stages of an envisioned orbital transfer vehicle (OTV) that will be developed as the next step for the space transportation system (STS) of which the shuttle is only the first part. The OTV will heft spacecraft from the low Earth orbit of the shuttle to higher orbits or even outbound "escape" trajectories.

The four-member lunar expedition will require eight spacecraft: a lunar excursion module (LEM), an automated lander to deliver instruments, tools and sundries to the crew; two crew modules, one to take them down to the surface, the other to return them; and two rovers and trailers, each capable of supporting two crew members for surface exploration.

The Moon-bound spacecraft will fly on four launches from Earth orbit. The first will bring the rovers and trailers to the surface, the second the lunar excursion module. The third will take the crew to the LEM, while the fourth will return them from the surface. The LEM, the rovers and the trailers will remain on the surface for future use.

Mission to an Asteroid

The near-Earth asteroid selected for the example mission is 1982 DB (see the July/August 1982 *Planetary Report*). 1982 DB is the most accessible asteroid discovered so far, although handier targets may someday be found.

The mission to 1982 DB would take about two years, including 30 days of exploration. The cruise vehicle is a rotating "dumbbell" that will look a bit like the *Discovery* in the motion picture *2001*. The crew modules at each end of the vehicle will be adapted from ESA's Spacelab, which flew on the shuttle.

The vehicle will rotate at three revolutions per minute, using centrifugal force to create artificial gravity. At the center of the dumbbell there would be no gravity, so there the crew will exit and return to their spacecraft. After arriving at its destination, the spacecraft will hover above the asteroid rather than going into orbit, since the asteroid's gravity is too weak to "capture" it.

The three crew members will explore the asteroid during several four-hour stints. (An asteroid one kilometer in diameter has roughly the same surface area as New York City's Central Park, so four hours a day for 30 days should be enough to explore it.) They will conduct their outside activities in spacesuits similar to the maneuvering units used by shuttle astronauts. Over their stay, the crew will collect up to 150 kilograms of samples and deploy seven experiment packages.

This mission will require nine shuttle launches and five OTVs (one will go with the spacecraft as it leaves Earth). It will take two days to escape Earth's gravity.

As detailed in the SAIC report, the 1982 DB mission will begin with the crew leaving Earth on January 5, 2000. They will reach the asteroid on October 12, 2001, and return home on January 13, 2002, after a two-year mission. As the vehicle nears Earth, the three-person crew will transfer to a capsule which will enter Earth's atmosphere with an aerobraking maneuver and eventually rendezvous with a space station.

Mission to Mars

The expedition to Mars is the most complex of the missions studied. As an example, SAIC considered a mission for the first decade of the 21st century involving no exotic new technology, other than present capabilities extrapolated forward 20 years.

This scenario involves 18 shuttle flights with 10 OTV stages. The outbound cruise vehicles (similar to the one envisioned for the asteroid mission), a Mars orbiter and a lander will be launched first. The Earth return vehicle will be launched later.

The crew will leave Earth's environment in June, 2003 and arrive at Mars in December of the same year. At Mars, they will select a landing site from orbit; the major goal of the crew will be to find a site for a future permanent settlement. And in the example mission, 900 kilograms of scientific equipment will be carried to Mars.

One of the most exciting developments from this study is a hyperbolic orbit rendezvous for the astronauts at Mars. A spacecraft orbiting a planet flies in an ellipse if the orbit is closed, and follows a hyperbolic path if the orbit is open (above escape energy). A retromaneuver using a large amount of fuel would be needed to slow the spacecraft into a closed orbit about Mars. We can save fuel by letting the return vehicle fly by Mars on a hyperbolic orbit, aimed to return to Earth like a boomerang.

Because the orbit doesn't close about Mars, the crew has only a chance, at one precise time, to rendezvous with the return vehicle. Although this is risky, the SAIC analysis found it to be acceptable compared to other mission risks. (However, some of us at The Planetary

(continued on page 22)

Looking Spaceward:

Life, Work and Leisure...Out There

by Arnauld E. Nicogossian

The sky is the limit. We've heard this too-frequent quote from our parents, our teachers and, later, from our employers as a stimulus for achievement. Yet, in less than a generation, this familiar quote is becoming obsolete. Humans have explored the near space around Earth and walked on the Moon. Probes and satellites are busily visiting other planets and providing road maps through the solar system. Every night on our TV sets, we see pictures taken 23,000 miles above Earth that tell us what weather to expect and whether we should plan a picnic lunch or take an umbrella to work. Recently, we've seen TV films of astronauts at work in space, performing feats which, only twenty-five years ago, were sternly consigned to the realm of science fiction.

We're planning to live and work in space — *permanently.* The space program is now in an exciting phase of research and application, where frequent access to space and the ability to return experimental results and manufactured goods from orbit is becoming a reality. We are developing technologies to assemble large structures in space, and making tentative plans to visit the planets in person.

For humans to live safely and work productively in space, however, the spacecraft and its supporting equipment must be engineered to provide optimal living conditions for its occupants. Space is by no means a void. The interplanetary environment contains high-energy radiation particles, gas clouds, dust, various atoms and molecules, meteorites, and a variety of other known and yet-to-be-identified substances.

Radiation Exposure

The radiation exposure experienced by space travelers during long-term space flights has been a major concern for space medicine. The effects of radiation on living organisms depend on a number of variables, such as the type and sources of radiation encountered, and the intensity and duration of the exposure. The effects tend to be cumulative. However, the target area (whole body versus specific organs or tissues), the general health of the individual, and other stress factors such as weightlessness, are key variables, possibly affecting the extent of radiation damage.

Biomedical scientists are particularly concerned with ionizing radiation which, when absorbed by a living cell, excites or tears electrons off the atoms or molecules in the cell. If this occurs, the cells and tissues can die, or the cells can mutate, causing cancer and birth defects.

Ionizing radiation encountered during space flight comes from galactic cosmic radiation, radiation from the solar wind that is trapped in the magnetic fields surrounding planets, and radiation from solar flares. In addition, cosmic radiation can interact with the atoms of spacecraft materials to produce secondary radiation.

Cosmic radiation consists of particles that originate outside the solar system, probably resulting from early cataclysmic events such as supernovas. These particles are the nuclei of atoms. Some, such as hydrogen nuclei, are very light; others are quite heavy, such as tin nuclei. The individual particle energies are extremely high and virtually unshieldable by passive methods, such as lead shielding.

Trapped radiation, of the kind found in Earth's Van Allen belts, is comprised mainly of the electrons and protons of the solar wind. Upon encountering a planet's magnetic field, these electrons and protons become trapped, oscillating back and forth along the lines of magnetic force. The trapped particles follow the magnetic field surrounding the planet and can present considerable hazards to people working outside a spacecraft.

Solar flares are a major source of radiation concern, and are possibly the most potent of the radiation hazards. These storms release large quantities of high energy protons and x-rays into interplanetary space. The amount of radiation they produce requires that a specially designed, well-shielded "storm cellar" be provided aboard long-distance spacecraft.

The Skylab missions gave us an opportunity to evaluate another radiation hazard in space, the energetic neutron. Neutrons are of biomedical importance because, when they collide with a hydrogen nucleus, there is a high probability of energy exchange. Since humans contain an abundance of hydrogen-rich compounds, such as proteins, fats and especially water, neutron exposure can cause considerable damage.

Affecting the Body

It is characteristic of radiation exposures that all body organs and systems are not affected equally. Lymphoid tissue, crucial in maintaining the body's immune system, is the most sensitive of all body tissues to radiation. This is followed closely by the blood-producing components of the body, especially the bone marrow, and the cells lining the intestinal tract. The key characteristic of the most sensitive group is that the cells comprising these tissues are rapidly growing. Hence there is a greater chance of mutation in these cells compared with those that grow more slowly.

The skin and underlying tissues, and internal organs such as the lungs, kidneys and liver are moderately sensitive to radiation. The lens of the eye is particularly sensitive to neutron radiation, which can produce cataracts and other problems at relatively low levels of exposure. In general, however, by the time significant damage is done to any moderately sensitive tissue, severe damage has already occurred in the blood and lymph systems.

To date, the radiation exposure for any US or Soviet crew member during long-duration flights or multiple missions has been low — well under allowed career limits. The largest cumulative dose received over a 15-year period in space can be compared to the amount of radiation encountered if someone were to have 60 standard medical x-rays of the abdomen over the same period of time.

Protecting the Crew

The protection of spacecraft crews from radiation injury can follow any or all of four directions. First, passive physical protection, such as lead or other dense material, can be applied to the hull of the spacecraft, thickening its "skin." Equipment can be arranged inside the vehicle to provide an additional barrier against radiation.

While this type of shielding works quite well in protecting crews from solar flares and trapped radiation, it also produces some secondary problems. When the thickness of protection is increased to a certain limit, cosmic radiation will interact with the atoms in the shielding and produce secondary ionizing radiation, thereby defeating the purpose of the protection system.

A second approach is to use active protection. This method would require mechanically generated electric or magnetic fields around the spacecraft. These fields would repel or trap most charged particles in a manner similar to the way that Earth's magnetic field traps the radiation in the Van Allen belts. But this most promising approach will take considerable engineering development.

Local protection of critical organs and systems using special dense garments is a third possibility. However, the same problems exist for this method as for the

ABOVE: Cosmonauts Vladimir Dzhanibekov, Vladimir Solovyov and O. Atkov prepare to leave *Soyuz T-12* for a walk in open space. Photo: Tass from Sovfoto

RIGHT: Astronauts William Pogue and Gerald Carr demonstrate the possibilities of zero-g during the *Skylab 4* mission. Photo: NASA

ABOVE: Cosmonaut Svetlana Savitskaya tests a general purpose hand tool on her first spacewalk during the *Salyut-7/Soyuz T-11/Soyuz T-12* mission. Photo: Tass from Sovfoto

passive physical protection method. In addition, such garments would tend to be bulky, and would only be worn in the event of an anticipated increase in radiation, such as a solar storm.

Finally, we are working to develop chemical methods for the prevention and treatment of radiation damage. While some chemicals — such as vitamins, antibiotics, stimulants and anaesthetics — show promise, no chemical treatment has been totally successful to date in preventing or repairing radiation damage.

Dealing with Weightlessness

Although radiation is of medical concern, the most remarkable feature of space, and one that cannot be reproduced on Earth for more than a few seconds, is the absence of any discernable gravitational pull, or "weightlessness," a term coined about half a century ago.

To be more precise, gravitational forces are always present in the universe, but they are so low in space that we cannot detect them. Gravitational forces in space can range from 1/1000 to 1/1,000,000 that of Earth. The most accurate term, therefore, is "microgravity."

To reach space from Earth, space travelers experience a series of acceleration forces about equivalent to three times the force of gravity. This is approximately what we experience on a very fast roller coaster going up a steep incline. Understandably, space flight crews are pushed back against the seat during lift-off and ascent into orbit. They have difficultly moving their arms and legs, blood rushes to their feet, their pulse rates increase, and they get a feeling of emptiness in their stomachs.

After about fifteen to twenty minutes of acceleration forces, they suddenly emerge into weightlessness, which is similar to the sensation we have all experienced when an elevator descends very rapidly or an airplane hits a downdraft and drops a few hundred feet in altitude. In space, however, the feeling persists and results in some unusual physiological responses in lifeforms that evolved in a gravity field.

Coping with Gravity

The human body has learned to cope with gravity. When standing, an average-sized person is continuously subjected to an acceleration of about 9.8 meters per second squared — the acceleration of gravity. The resulting force creates a pressure gradient between the head and the feet roughly equivalent to the pressure difference between the surface and the bottom of 1.7 meters of water. This pressure gradient helps to pull fluids down toward the feet, while continuous muscle contractions in the legs, one-way check valves in the veins, and the pumping action of the heart prevent these fluids from pooling in the feet and assist fluid movement headward against the force of gravity.

In weightlessness, the pressure gradient is no longer apparent, and headward transport mechanisms operate unopposed. This experience can be duplicated on Earth by assuming a head-down position for a while. The leg veins empty and fluid migrates to the upper body. As a result, systems for regulating fluid volume are stimulated as approximately 1.5 liters of fluids are transported from the lower part of the body towards the head.

To compensate for what the body now interprets as a "volume overload," corrective action is taken: Blood volume is reduced, blood constituents are altered and hormone levels are changed. In this manner, the body is trying to adapt to space — that is, to make itself more physiologically suited to a weightless environment.

However, upon returning to Earth, gravity once again pulls fluids toward the feet, but the volume of fluids in the body is less than normal. Blood drains from the head and dizziness can result during critical landing maneuvers. The treatment for this problem includes drinking large quantities of fluids prior to landing to replace lost blood volume, and wearing "anti-g" suits that force fluids back towards the head.

Effects on the Body

The effect of prolonged weightlessness on the muscles and bones of the body is a potential problem for humans in extended

LEFT: Astronaut Sally Ride talks with ground controllers in Houston during the STS-7 mission of the space shuttle *Challenger*.

ABOVE: Astronauts Dale Gardner and Joseph Allen retrieve the *Westar VI* satellite during the shuttle *Discovery*'s 51-A mission. Photos: NASA

TOP: Astronaut and physician Joseph Kerwin examines astronaut Charles Conrad during the mission of *Skylab II*.

ABOVE: Cosmonauts V. Lebedev and Svetlana Savitskaya enjoy their free time during the mission of *Soyuz T-7/Salyut-7/Soyuz T-5*. Photo: Tass from Sovfoto

space flight. In fact, next to radiation, it may be the single critical factor determining how long humans may remain in space without extensive countermeasures.

The effect of microgravity on the bones and muscles is very similar to the effect of immobilizing a limb, or prolonged bedrest. If you have ever had your arm or leg in a cast for several weeks, you'll remember how weak and thin it was when the cast was removed.

In space, we can move massive objects around with ease, as was demonstrated on Skylab and, more recently, on space shuttle flight STS-51A, when astronauts wrestled a two-ton satellite into the shuttle cargo bay for return to Earth. In short-duration missions, crew members are physically unaware of their bones' and muscles' adaptation to space flight.

Bones and muscles were designed to support our weight, as well as the weight of any objects we choose to lift and manipulate, against a constant one-gravity acceleration. On Earth, the stress needed for maintaining muscle and bone strength is provided naturally by gravity. The mere presence of a one-gravity environment is enough to at least maintain a "normal" level of strength. When gravity is removed, the building blocks of bone and muscle slowly begin to leave these tissues. Muscle begins to shrink, bone begins to lose density, and the heart (which is also a muscle) reduces in size.

Return to Earth

Our primary concern is not directed toward what effect bone and muscle atrophy will have on space travelers while they are in orbit, but towards how they will be affected when they return to the relentless pull of gravity on Earth.

Calcium lost from the bones in weightlessness may be transported in the blood to the soft tissues of the body, causing such problems as kidney and bladder stones. Furthermore, some data suggest that once adults have lost a certain amount of bone material, it is never replaced. Long before they would be able to reach another planet, space travelers will completely de-adapt to gravity, so appropriate protective measures must be taken, such as exercise, simulated gravity and specific drugs.

Attending to the Crew

In long-term space flights, special attention must be given to forming crews with the proper mix of skills and personalities to do the tasks required while remaining compatible. Yet, there must be enough diversity in their personalities to provide the impetus that keeps people creative. The region between planets is vast, and those who travel to new worlds will experience an isolation known only to the *Apollo* astronauts, all of whom were profoundly affected by their experience.

It will take a minimum of three years to reach Mars and return home. The voyagers will travel that distance in enclosed, self-sustaining vehicles where it will be difficult to find an entirely private place away from the company and conversation of colleagues. The spacecraft will never be silent, the hum of machines providing life support will underlie every waking and sleeping hour.

The crews will have to provide their own medical and psychological care; the nearest hospital will be millions of miles away. They will have to plan three years worth of entertainment in advance so that the spacecraft can be supplied with the necessary games, tools and materials. Leisure could be a blessing or a curse in space, depending upon how well we understand the psychological "quirks" of individuality, and accomodate the creativity that makes life worth living.

Right now we are working on countermeasures to these and other potential problems of short- and long-term space flight. We have every confidence that we can devise methods whereby humans can live and work in space safely and productively to the benefit of all of us on Earth.

Arnauld Nicogossian is the director of NASA's Life Sciences Division. His research interests include health of space crews, increased space productivity and evolution of life in the universe.

LIVING ON THE MOON

by James D. Burke

On Earth today lives a cohort of humans, the first ever to have the option of living away from our planet. Dreamed of over centuries by those now dead and gone, this prospect has finally become real. But ironically, just as we were about to grasp it, our resolution failed. Instead of continuing after *Apollo* to explore the Moon and develop ways to inhabit it, we have fallen back to working in the space just above Earth's biosphere, where we now will slowly develop the skills of off-Earth living.

Today no one can say how many years may pass before humans again travel to the Moon. But when they do, it seems quite likely that they will go there intending to stay. In this article I will discuss some aspects of that adventure. Though we cannot tell when it will happen, or exactly why, we can predict some of its qualities because of what we already know about the Moon and about ourselves.

Reaching into the Cosmos

Jacques Monod wrote, "Man, like a gypsy, lives at the boundary of an alien world, a world that is deaf to his music and indifferent to his sufferings and his crimes." Yet we humans do often transcend our own petty quarrels, reaching out to each other and into the cosmos around us. The settlement of the Moon could be the next such milestone for our civilization.

Recognizing this possibility, and believing that now is the time to begin preparing for that next historic step, the American lunar community took action in 1984. In April a planning meeting convened at Los Alamos. One result was the plan for a nationwide symposium, which took place in Washington, DC at the end of October, on the subject of lunar bases and 21st century activities in space. Also, during the summer of 1984, NASA sponsored a study and a series of workshops on a closely related subject: the use of extraterrestrial resources.

Though these activities could not and did not lead to governmental acceptance of a new manned lunar program, they did re-energize the faith and commitment of those involved and they surely widened the base of public understanding. It is now broadly recognized that, early in the next century, humans may dwell on the Moon, and there is even support for some needed technical preparations. For example, NASA's deep-space exploration plan now includes an automated lunar geochemical survey from orbit — the first serious consideration of this often-proposed mission in almost a decade.

While corresponding — or, it is to be hoped, complementary — Soviet lunar initiatives have not been announced, it is clear that the USSR is building capabilities and operating experience that could provide a basis for manned lunar missions in the future. Indeed, in the USSR there has even been some public discussion recently of preparations for the manned exploration of Mars. Thus, though neither nation yet acknowledges an intent to establish bases on the Moon, both are capable of starting programs toward that end.

Lunar Resources

To sustain human settlements off Earth it will ultimately be essential to use local resources: materials, energy and the unique environments of the solar system. Humans have already begun to grapple with the problem of setting up a legal regime for the use of lunar resources. The large, nearby Moon is tempting but also forbidding as a site of human habitation. Though its origin is still unknown and hotly debated among scientists, some of the Moon's relevant characteristics are well established.

Forming some four and a half billion years ago, at about the same time as Earth, the Moon was apparently largely molten, at least in its outer layers. It cooled, but then about three billion years ago an episode of partial melting occurred (due probably to heat from radioactive elements in the interior) and gave rise to the great dark floods of lava in the maria. All the while, the Moon was being bombarded by the objects that made its thousands of impact craters, with the result that today the lunar surface is a mixture of rock fragments of all sizes.

Because of its small size (the lunar radius is 1738 kilometers; the surface area is about equal to that of Africa) and low density, the Moon's gravity is weak, only one-sixth that at the surface of Earth, so that it is unable to retain any significant atmosphere. Also, its interior heat has by now mostly leaked away; it still has some seismic activity but, by comparison to Earth's seething tectonic and volcanic activity, it is a very quiet planet.

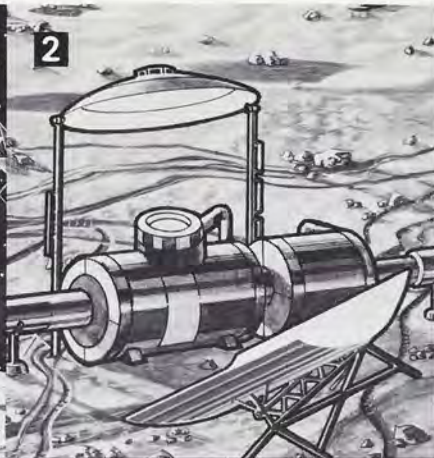
The Moon is a huge natural storehouse of rock, orbiting in the outer reaches of Earth's deep gravity well. Hauling materials up from Earth will always be costly. If lunar rock and soil can be converted into useful products, the rate of human progress into space may be greatly accelerated. Many analysts believe that the most important large-scale application of lunar material may be as oxygen for rocket propellant. Calculations show that, in a typical program scenario, more than three quarters of the total tonnage lifted from Earth must be propellants.

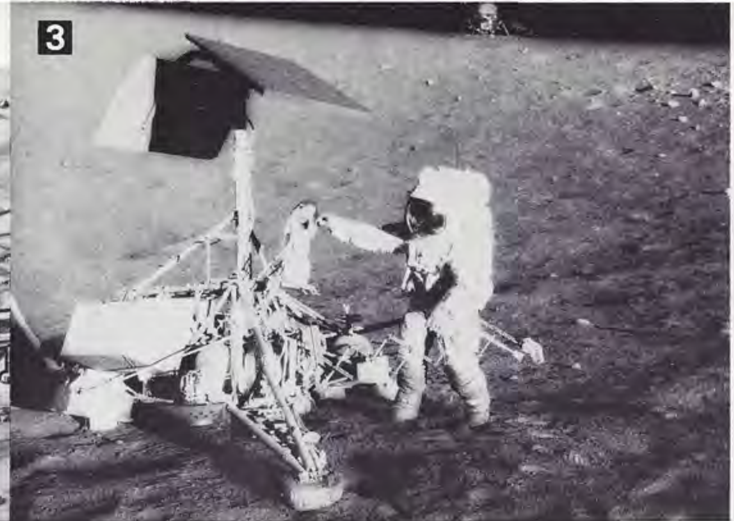
If some of this propellant mass could be launched from the Moon and delivered into Earth orbit via aerobraking in Earth's upper atmosphere, there could be a net economic gain — depending, of course, on the cost of recovering the oxygen from the Moon. Lunar minerals contain up to 40 percent oxygen, and methods are known in principle for extracting it with the aid of solar or nuclear energy. Some of these physiochemical processes could also yield useful metals, including ultrapure iron, titanium and aluminum.

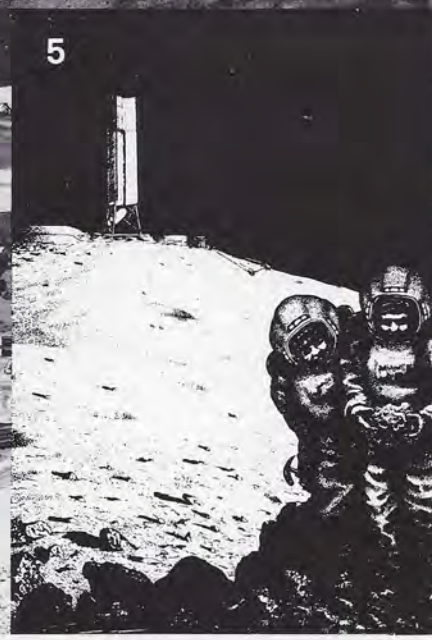
Lunar soil is also valuable just in its natural form. For prolonged inhabitation, all Earth-type life on the Moon must be shielded from ionizing radiation and micrometeorite bombardment, maintained in a proper temperature and pressure environment, and provided with energy and materials for metabolism. The obvious way to supply these needs is to provide living spaces underground, using lunar material as cover.

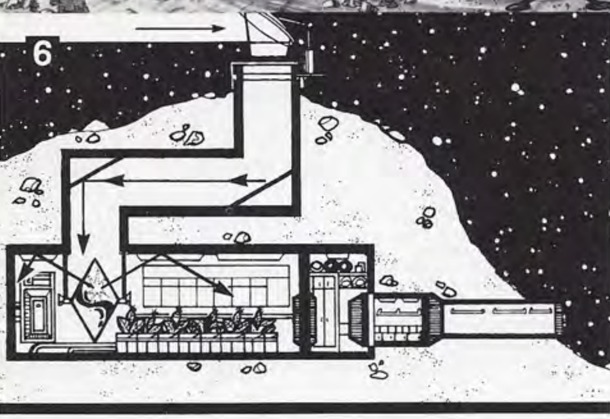
Essential Elements

Some of the chemical elements essential to off-Earth living appear to be nearly absent from the Moon. The most important of these are hydrogen and carbon. As the Moon went through a high-temperature phase in its evolution, volatile









1 A solar-powered electrostatic separator concentrates lunar ore. Drawing: Larry Ortiz, NASA/Calspace **2 A solar furnace conveys lunar soil for processing.** Drawing: Larry Ortiz, NASA/Calspace **3 *Apollo 12* astronauts visited one of their predecessors on the Moon, *Surveyor 3*, removed its camera and soil-sampler claw, and returned them to Earth.** Photo: NASA **4 Moon miners process lunar materials in the foreground; their habitat, power, communications, and transport systems are seen in the background.** Drawing: Larry Ortiz, NASA/Calspace **5 Lunar inhabitants investigate the polar region, while a tower collects solar power.** Drawing: Maralyn Vicary, NASA/Calspace **6 A heliostat mirror captures sunlight to warm, illuminate and power a polar lunar habitat.** Drawing: Larry Ortiz, NASA/Calspace

elements were baked out of its crust — or perhaps they were just never incorporated into the forming Moon. In any event, the currently known lunar rocks are absolutely dry and their minerals are those that form in the absence of water. How, then, are we to obtain this vital substance on the Moon? Hauling water up from Earth, perhaps as hydrogen to be combined with lunar oxygen on the Moon, may indeed be necessary in the starting phase of a program, but is probably a losing proposition in the long run.

An off-Earth source of hydrogen is essential, and three possible sources are known. First, a small amount of hydrogen is continually delivered to the Moon by the solar wind. Solar hydrogen and other atoms are implanted in a thin surface layer on the fine lunar soil particles, whence they can be easily recovered by heating the soil. But many tons of soil must be processed to obtain each kilogram of hydrogen, so use of this solar-wind resource will depend on the development of an economical mining method.

A second source of extraterrestrial volatiles can be the Earth-crossing asteroids. Some meteorites are rich in water and carbonaceous compounds. Even a small asteroid composed of these known meteorite materials would be an enormous space bonanza, especially if it were in an orbit easily reached from here. Some asteroid orbits do have this property. Indeed, because of the asteroids' small mass and negligible gravity, two-way trips to some Earth-crossers are possible at a small fraction of the propulsive energy needed to go to and from the Moon. Trip times are long, typically years as contrasted to days for lunar travel. But this need not be a barrier to voyages by automated spacecraft that could return asteroid materials for use in space or on the Moon.

(continued on page 14)

“Earth is the cradle of the mind, bu
live in the cradle forev

LOVERS IN SPACE

Someday humans will move out into space and open themselves to sensations and feelings far beyond our earthly experiences. Science fiction writers and artists have long imagined what humans will find and do in space. In the pages of *The Planetary Report* we have usually restricted ourselves to the work and speculations of the scientists and engineers who will someday put us there. But we felt that to illustrate the topic of humans in space, we needed to take a more personal approach. And so, we turned to the art of Pamela Lee.

Inspired by the quote from Konstantin Tsiolkovsky, often called the father of astronautics, artists William K. Hartmann, Ron Miller and Pamela Lee produced *Out of the Cradle*, a book describing humanity's possible travels in the solar system. For the book, Ms. Lee was assigned several paintings dealing with the day-to-day interactions and pursuits of humans in space. For this special issue of *The Planetary Report*, we asked her to share some thoughts about her work.

LUNAR GARDENS

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t one cannot er." — KONSTANTIN TSIOLKOVSKY

"More thinking goes into a painting than appears on the canvas. pend as much time speculating about at life would be like inside a colony's led environment as I do researching the ects of prolonged weightlessness, or the rect angular diameter of Earth as seen ough a space station window.

Each painting must strike a balance ween personal perspective, scientific accuracy and aesthetics. Once the parameters of the problem have been defined and the research is out of the way, I move vicariously through the environment or situation I'm painting, feel the surroundings and choose a viewpoint that has emotional significance for me.

"In 'Lovers in Space,' the blue and white expanse of Earth acts as a backdrop to the tenderness between lovers enjoying zero gravity. In 'Lunar Gardens,' I chose a perspective that shows Earth as it has never been seen before — through the fronds of a date palm. In 'Mother and Child Viewing Tranquility Base Monument,' the viewer sees the two faces while at the same time seeing what they are viewing — a monument to humanity's first step upon another world.

"If I'm successful as a visual communicator, the viewer will be able to experience some of what I felt while doing the paintings."

With these three paintings, Pamela Lee has certainly succeeded.

— CHARLENE ANDERSON

MOTHER AND CHILD VIEWING TRANQUILITY BASE MONUMENT

LIVING ON THE MOON *(continued from page 11)*

The third possible source of the needed hydrogen may be ices in the Moon. Because the Moon's polar axis is almost perpendicular to the plane of the ecliptic there are no lunar seasons. Thus in the polar regions some areas are never exposed to sunlight. From our position on Earth we cannot see into these dark places, and even from orbit nothing can be seen in the shadows.

Temperatures in the perennial darkness must be very low, perhaps more than two hundred degrees below zero Celsius. Here ice molecules could survive, even in vacuum, over geologic time. Are they in fact there? Nobody knows. Scientists' opinions differ, based on their assumptions as to plausible histories for the Moon.

For example, if the Moon's spin axis has been upset by impacts, allowing sunlight to reach all parts of its surface, all near-surface ices may have been baked out. Alternatively, volatiles may still exist in the deep interior, trapped there billions of years ago when the Moon's heat engine ran down and its volcanism died. The strange sinuous rilles in some volcanic regions of the Moon are most probably lava channels, but they might be the fossil traces of ancient rivers that ran briefly under a cover of mud and ice.

Icy El Dorado

Speculations about a possible icy El Dorado in the Moon are pointless; exploration is the only way to settle these questions. A lunar geochemical orbiter can detect near-surface ices, if they exist in useful quantity, by observing gamma rays at a particular energy resulting from the interaction of cosmic rays with deuterium in the ice.

The Moon's material resources, at least as we know them now, are thus a mixture of the familiar and the very strange. If we are to use them effectively, we must develop a whole new industry of mining and processing suited to lunar conditions. Technology can exploit the unlimited vacuum, and solar energy is abundant there.

Because of the absence of seasons, there may even be perpetual sunlight on mountaintops near the poles — an invitation by nature to the lunar base designer who, anywhere else on the Moon, will have to contend with two-week scorching days and two-week frigid nights. Even if no natural lunar ices are found, the polar cold traps can serve as sites for rejecting waste heat from solar or nuclear powerplants. Alternatively they can be used for storage of human-made volatile products which would otherwise have to be kept in heavy pressure tanks.

Other aspects of the lunar environment also constitute a resource: The polar cold traps may be good sites for cryogenic astronomical telescopes, and the Moon's far side, shielded from the radio noise of Earth, is the ideal location for an advanced radio observatory.

The Moon's gentle gravity will permit fantastic human gymnastics, leading perhaps to entirely new forms of recreation and of expression in the lively arts. Effects of this gravity level on the long-term health of animals and plants are presently unknown; perhaps it will prove sufficient to prevent the physiological deterioration that occurs during long exposure to "zero g." (See pages 7-9).

In these unearthly conditions we can expect new sciences, new arts and new forms of human living to flourish. Astronomy can reach into the cosmos, observing cool objects in studies of star formation and of planetary systems. Searches for evidence of extraterrestrial intelligence can reach unprecedented resolution and sensitivity in the Moon's quiet, protected environment. Most important of all in the long run, lunar agriculture may lead to the establishment of a new, spaceborne civilization that could then spread without limit.

These vistas can become real. There is no evident scientific or technical reason why they should not. But at present, humanity needs — but apparently does not have — a justification for making the large initial investment. Instead we spend our disposable resources in trying to obtain security here on Earth. If a lunar initiative could change this situation, it might be the most important collective human action since the coming of nuclear weapons. Let us now examine that prospect.

Should We Go?

If going to the Moon and living there were cheap, people would surely be there now. The adventure alone would be an adequate stimulus; never mind the beautiful science, the social experiments and the possible economic returns. But lunar travel is not cheap, and lunar living, at least at first, will demand devotion, ingenuity and bravery as well as continuous and costly Earthside support and resupply. Also, until some modest comforts and recreations are available there, crew rotation will have to be frequent.

The costs of realistic lunar settlement programs are, therefore, measured in tens of billions of dollars or rubles, with annual budgets reaching into the billions. While it is true that projects of this size have been fitted into NASA's budget in the past and could be fitted into it in the future, either the US or the USSR would have to have strong incentives to launch a lunar settlement program.

Ideally, they would do it together and share the costs and benefits. But even if that proved to be politically impossible, there are ways in which both nations could benefit. For example, scientific and cultural exchanges could occur within the framework of competing national programs, just as has occurred in the space enterprise up to now. And the competing national programs themselves could start a healthy trend.

During the *Apollo* era, the USSR carried on a major competing program whose achievements received relatively little attention because of *Apollo*'s overwhelming success. Soviet automated spacecraft did land on the Moon, orbit it, rove upon the lunar surface, and return soil samples to Earth. Soviet circumlunar manned-precursor test flights, made without human crews but on at least one occasion carrying live animals, photographed the Moon and the distant orb of Earth and returned safely home.

These and other lunar developments were a peaceful expression of Soviet skills in high technology, organization and management undoubtedly engaging talents, including military ones, in a manner presenting no threat to the world. Would it not be good if this could happen again? The American and Soviet military-industrial complexes are huge and powerful; efforts to simply shrink them will always meet internal resistance.

But suppose both nations decided to redirect a part of their military energies to this competitive but non-belligerent objective. The program would still demand high technology and human bravery, resourcefulness, discipline, strength and endurance; it would thus provide excellent training and personnel career prospects — but it would be a peaceable contest.

When considered in the context of defense budgets, even a multi-billion-dollar or -ruble lunar program looks small. Perhaps this is a way to assimilate the high initial costs and begin the investment that can someday lead to a confident stride by humanity — the stride that will plant an outpost of our civilization upon the waiting Moon.

James Burke, our Technical Editor, is a Member of the Technical Staff at Jet Propulsion Laboratory.

RETURNING TO THE **MOON**

by Harrison H. Schmitt

Only 12 humans — all Apollo *astronauts — have ever set foot on a planetary body other than Earth. Harrison (Jack) Schmitt is one of the lucky dozen. He visited the Moon aboard* Apollo 17 *in December 1972, the mission that marked humankind's last journey to another world. Here, Schmitt describes his impressions of the lunar valley of Taurus-Littrow, and tells us why we are going back to the Moon — and beyond the Moon, to Mars.*

I would like to tell you about a place I have seen in the solar system, and why we should return there. It is a valley on the Moon, now known as the valley of Taurus-Littrow. Taurus-Littrow is a name not chosen with poetry in mind: But, as with many names, the mind's poetry is created by events, events surrounding not only three days in the lives of three men, but also the close of an unparalleled era in human history.

Viewed from the unmarked paths in orbit, the valley's face slowly endures another week of changes from universal cold, to forbidding streaks of sunrise shadow and light, to the friendly morning contrasts for landing, to the harsh featureless glare of a desert's noon. The Sun's changing aspect on the Moon's surface gives a distinct personality to the meteor-rent craters Camelot and Cochise, the avalanche-covered Jefferson-Lincoln Ridge, and the waiting dust of Tortilla Flats in which we will leave our footprints in time.

Suddenly, we pitch over, as landing approaches, and the windows reveal the rocks and craters and looming mountain walls of our new home. A hurried glance shows that friends did not fail us as navigators, and we settle into the streaming, streaking dust rushing away from the soundless power of the rocket blazing beneath us. As the relentless clock goes on, we race to step out into this now familiar, yet still untouched, new world.

With our space suits on and checked, and the spacecraft open to the vacuum on Taurus-Littrow, we work our way through the yawning hatch of the lunar module *Challenger* and down its ladder to touch the gray valley dust made eons ago. Gene Cernan touches first and dedicates our visit to those who made it possible. I follow and issue a challenge to the next generation to leave their own footprints on distant worlds.

The valley of Taurus-Littrow is confined by one of the most majestic panoramas within the view and experience of mankind. The roll of dark hills across the valley floor blends with bright slopes that sweep evenly upwards, tracked like snow, to the rocky tops of the mountains seven thousand feet above. The valley does not have the jagged youthful majesty of the Himalayas, or of the valleys of our Rockies, or of the glacially symmetrical fjords of the north countries, or even of the now intriguing rifts of Mars. Rather, it has the subdued and ancient majesty of a valley whose origins appear as one with the Sun.

The walls of the valley rise to heights that compete well among the other valleys of the planets; but they rise and stand with a calmness that belies dimensions and speaks silently of continuity in the scheme of evolution. Still, the valley is not truly silent; its cliffs roll massive pages of history down dusty slopes; its bosom warms the valley floor and spreads new chapters of creation in glass and crystal; its craters act as the archives of their Sun.

Leaving the valley of Taurus-Littrow is not easy even though the friends and hills of Earth are waiting. Maybe it is the things left unseen and undone or the seven and one-half years of commitment now over. The liftoff from within the valley's mountain walls and subsequent rendezvous with Ron Evans over the still forbidding lunar farside seem routine and anticlimactic. The tears of farewell come as we jettison our friend, the *Challenger*, for its second and last journey to the valley and a crash for science near the sheltering South Massif.

The valley has watched the unfolding of thousands of millions of years of time. Now, it has dimly and impermanently noted man's homage and footprints. Man's return is not the concern of the valley, only the concern of man.

Being there in the middle of the vast, majestic valley of Taurus-Littrow, being at the foot of the towering lunar Apennine Mountains, or being in the historic plains around Tranquility Base are now among the uniquely meaningful experiences of a few men and of mankind.

It is "being there" that adds the human element to life's events. It is the desire to be there that will drive our young people away from the established paths of history on Earth and to the planets. Yes, they will probably follow our example and try other means to rationalize going "up into space in ships," but it still will be a rationalization for the basic human desire to "be there."

This desire has carried mankind from the caves to the Moon. Video pictures and data streams from Mars, no matter how good or how complete, will never be enough for the parents of the first Martians. For this generation of pioneers, some of whom are alive today, the Moon will become merely a way station as Independence, Missouri was for an earlier generation as they headed West.

The Third Millennium

The ultimate rationale for a return to the Moon, and the establishment of permanent settlements there, is to create the technical and institutional basis for the settlement of Mars by human beings. Steadily increasing philosophical and psychological momentum for this adventure is building among the young people of Earth.

* * *

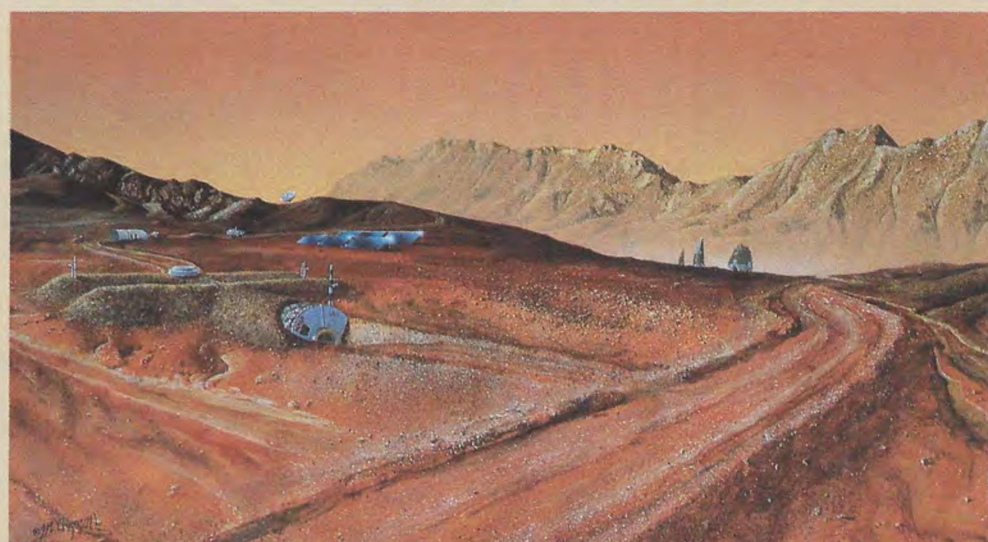
The importance, to the parents of the first inhabitants of Mars or of a self-sustaining settlement on the Moon, trading directly with our Earth orbital civilization, is that it gives us the technical and institutional basis to go to Mars with the purpose of establishing a permanent base on the first expedition. This expedition should be on its way by the end of the first decade of the third millennium. A permanent settlement will take longer, but a permanently occupied base, resupplied by regular interplanetary spaceflights, clearly will be possible, as well as desirable, soon after the establishment of a permanent lunar settlement and an Earth-orbit space station.

Why the hurry? Why a millennium project that stretches our reach to the limit? The answer is in the generations that will carry us into the third millennium. It is the generation now in school, now playing around our homes, now driving us to distraction as they struggle toward adulthood, who will settle the Moon and then Mars. They will do this because they want to do this. They want to "be there." Our role is merely one of staying out of their way while we preserve their opportunity.

Mars 2000 will be for our children what space stations were to their parents and what *Apollo* was to their grandparents: the total embodiment of the best in the human spirit. □

Excerpted with permission from The Space Station: An Idea Whose Time Has Come, *published by* The Institute of Electrical and Electronics Engineers, New York.

The Case for Mars



TOP: In this panorama that hangs in the National Air and Space Museum, pioneering space artist Chesley Bonestell imagined explorers setting up a temporary base on Mars. Painting: Chesley Bonestell

ABOVE: Working from studies presented at the Case for Mars II, Michael Carroll portrays a more recent concept of a Mars base. Painting: Michael Carroll

In the late 1960's and early 1970's, when humans stood on the surface of an alien world and looked back at their small, blue home planet, the surface of another nearby world, Mars, did not seem very far away. Our successful voyages to the Moon had proven our space technology, and the next step outward seemed to be Mars. But the political motivations for Apollo were satisfied, we withdrew from the Moon, and most people no longer contemplated Mars as the next stepping stone out into the solar system.

Then, in 1978, a group of graduate students at the University of Colorado in Boulder began to think once again about sending humans to Mars. Led by Chris McKay, they held an informal seminar on "The Habitability of Mars." Their study continued for years, gradually gaining the attention of people around the country — a sort of "Mars Underground," which still considered Mars to be within reach.

By 1981, this interest in sending humans to Mars culminated in the first "Case for Mars" conference, held in Boulder. Co-sponsored by The Planetary Society, this brainstorming session helped define some of the problems that must be solved before we send a human crew to Mars.

The first conference laid the groundwork for "The Case for Mars II", also co-sponsored by The Planetary Society and held in Boulder in 1984. The brainstorming has now given way to engineering studies and scientific research that may put humans on the Red Planet early in the next century.

This renewed interest in Mars has also led The Planetary Society to form the Mars Institute. The Institute supports classes, in colleges and universities around the world, which investigate the possibility of human settlement on Mars. It also sponsors a yearly contest in which students are asked to solve a problem crucial to supporting humans on Mars. Winners of the first contest described their water recovery system at the Case for Mars II.

The informal studies of a few graduate students have set the space community to once again think about Mars as a next step in human exploration of the solar system. In this article, Chris McKay, the original Mars underground leader, discusses some of the serious plans and possibilities for Mars as a future site of human habitation.

by Christopher P. McKay

Of all the planets and moons of the solar system, Mars is the most hospitable and similar to Earth. It has an accessible surface, a usable atmosphere and probably all of the chemical elements necessary to support life.

This makes Mars the most likely candidate for long-term human exploration, settlement and planetary ecosynthesis. If the human species can indeed form permanent, self-sufficient settlements off Earth, Mars will be the proving ground.

When humans venture out into the solar system for long periods, it will no longer be practical to transport from Earth all of the life-support necessities. Water will be the most needed compound.

Martian Resources

On Mars, water is available in several forms. The atmosphere, dry compared to Earth's, does contain substantial amounts of water — about one cubic kilometer, or 250 billion gallons. About one percent of the soil is water, and large quantities are trapped as ice in the polar caps.

In addition to sustaining life, water will be needed to produce rocket fuel, building materials and other useful compounds. Preliminary studies suggest that we can extract the water for human use from the martian environment.

We can also manufacture breathable air on Mars using indigenous resources. Oxygen can be easily obtained from the carbon dioxide in Mars' atmosphere. However, breathable air must contain suitable partial pressures of both oxygen and an inert buffer gas.

On Earth this buffer gas is nitrogen, which comprises 78 percent of our atmosphere. Carbon dioxide is the most abundant gas on Mars, but it is not a suitable buffer gas because it is toxic at high concentrations. Fortunately, the martian atmosphere also holds nitrogen and argon, and they can be used as buffer gases.

Mars' soil can also aid the development of a self-sufficient resource base. This soil contains at least 40 percent chemically bound oxygen, as well as salts (sulfates and chlorides), nitrogen and minerals containing metallic elements (iron, titanium, aluminum, magnesium and silicon).

Benton Clark of Martin Marietta Denver Aerospace has suggested that, from these raw materials, we can make many important construction materials: plaster-of-paris, portland cement, metals, ceramics and glass, blasting explosives, vehicle fuels, rocket propellants, fertilizers, organic compounds (including food) and chemical process reagents such as acids, bases, reductants and oxidizers.

Before We Go

Although the 1976 *Viking* missions returned a wealth of data about Mars, we still lack the detailed information necessary to plan a permanent base. Most important, we must know more about the yearly cycle of water and its distribution, and the mechanisms of water exchange among the atmosphere, soil and polar caps.

The Mars Geoscience/Climatology Orbiter (MGCO) will address exactly these questions. It will also survey the mineralogical state of the martian soil — information useful in selecting a base site. Although the reconnaissance of Mars' surface for human settlement is not a stated goal of MGCO, it will do the job without the slightest redirection of the program.

Many scientists and engineers feel a Mars Sample Return (MSR) mission could help them develop and prove methods for using martian resources. Samples brought back to Earth would yield not only scientific information about Mars, but also practical engineering data that we can use to design habitats and structures, and to test chemical production facilities.

The question of martian biology must also be resolved. The search for life on Mars must be carried far beyond the capabilities of *Viking*. Even if we find no signs of life, the search must be sufficiently thorough to give us confidence that any undetected lifeforms will be so well hidden in cryptic microenvironments that a localized human presence will not affect them.

If native martian life were found, we would have to reconsider the entire program of human exploration.

A Mission Profile

A settlement program would involve many trips to Mars to transport both cargo and crew. The size and complexity of the ships, and the desire to reuse them, suggest that assembling and refurbishing them must be done in Earth orbit. The space shuttle and a space station will be necessary tools for this extensive orbital construction, along with a heavy-lift launch vehicle still to be developed.

Jim French and Rob Staehle of NASA's Jet Propulsion Laboratory (JPL) have created the most detailed Mars mission scenarios. They describe two major innovations that will greatly increase the mass carried to Mars and so increase the payload delivered to the martian surface.

The first new technique, aerobraking, uses a planet's atmosphere to "brake" a spacecraft so it can enter orbit. Aerocapture requires specially designed, cone-shaped vehicles that can produce aerodynamic lift as they enter the atmosphere.

The second innovation also saves propellant, or more correctly, allows it to be produced on Mars. The JPL concept involves producing carbon monoxide and liquid oxygen (CO-LOX) as a propellant. While this combination is not as powerful as the fuels used, for example, to launch the shuttle, it can easily be manufactured from the carbon dioxide in Mars' atmosphere.

A plausible mission profile might be as follows: Three vehicles, each designed to house five people, have been constructed in Earth orbit. Derivatives of the space shuttle's main engines launch them onto Earth-to-Mars trajectories. Once enroute, the three ships connect into a pinwheel configuration and rotate to provide artificial gravity.

The cruise to Mars takes about six months. Upon arrival, conic-shaped shuttles separate from the main ship, use aerocapture to enter the atmosphere, and land on the planet. Meanwhile, returning explorers lift off from the surface using shuttles powered by propellant manufactured on Mars. They rendezvous with the main ship, which is traveling on an orbit that swings it around Mars and sends it home to Earth. [This scheme, one of many possibilities, is different from the SAIC mission design outlined on page 4.]

Learning to Live on Mars

The first crew to land on Mars will have to immediately set up equipment and structures to enable them to survive. They must protect themselves from the alien environment and produce the consumables they need to stay alive.

The first habitats could be constructed from the cargo vessels that traveled from Earth. Mars' thin atmosphere will not shield the crew from radiation, but one to two meters of soil covering the habitat should protect them.

Once the habitats are complete, the crew can begin work on a key element of the Mars base: the power plant. The amount of power available to the Mars base will determine the extent of operations, the speed of expansion and the type of resource utilization techniques. The crew's immediate needs include life support systems, fuel production, materials processing and scientific experiments.

These needs represent a power demand of about 100 kilowatts. The demand can be met with nuclear thermoelectric generators, used alone or in combination with solar panels. Solar cell arrays cannot be used alone because they will not work well during martian dust storms, which can last for several months. Both systems have expected lifetimes of ten years.

One of the crew's first uses of the power will be to run the compressors and cooling stages of the gas extractor. This is essentially a processing plant that uses the martian atmosphere as raw material to produce breathable air (oxygen mixed with argon and nitrogen) at pressures usable in the habitat. Tom Meyer, a consulting engineer, has calculated that breathable air could be produced for about ten kilowatt-hours per kilogram of air.

The gas extractor can also produce water from Mars' atmosphere. Last year, in a contest sponsored by The Planetary Society's Mars Institute, a team of University of Colorado students designed a Mars water system. Their calculations indicate that water can be taken from the atmosphere for about 100 kilowatt-hours per kilogram.

Producing fuel for the Mars ascent vehicles is also an essential task, so the crew will begin this early on. The fuel can be stored until needed. The fuel processing plant will also be a major power consumer.

As basic life support and survival technologies are set in place, the martian pioneers can turn their attention to self-sufficiency. An important step in this direction will be the construction of a greenhouse. Mars-grown plants will provide oxygen and food, and the crew can use the airy but protected space of the greenhouse for recreation.

Early in the mission, the crew must learn to accurately predict the martian weather in the vicinity of the base. Phenomena such as dust storms, winds and large pressure shifts can affect mission design and operations. They must forecast atmospheric moisture and frost point, and also predict and monitor the radiation environment so they can shield themselves from the effects of solar flares.

"Doing" Science

As the technologies ensuring survival are completed, the Mars settlement will be established as a scientific research base. Long-range and in-depth exploration will begin.

The Red Planet holds many clues to the origin and continuing evolution of the solar system. The abundance and distribution of volatiles (easily evaporated substances, such as water) on Mars is different from that on Earth or Venus. Yet these planets share many features and are quite unlike the planets of the outer solar system. Mars' surface geological features have preserved its volatile history. The apparent river valleys, tremendous volcanos and other features could help us unravel the mechanisms of planetary formation, outgassing and atmospheric loss.

One example can show how studying Mars may help us understand Earth. Mars' rotational period and orbital tilt are very similar to Earth's, giving the two planets comparable daily and seasonal climatic shifts. The martian climate appears to change periodically in response to changes in its orbital characteristics. (See the January/February 1985 *Planetary Report.*) Many scientists believe this same mechanism is responsible for ice ages on Earth. However, Mars' response to these orbital perturbations is ten times Earth's, and the record of change is neatly preserved in the laminated polar terrain.

Possibly the most profound goal of planetary science is to understand the relationship between the chemical and physical evolution of the solar system and the appearance of life. Mars presents a unique opportunity to study this problem.

In the first half-billion years after their formation, Earth, Venus and Mars may have been much more alike than they are today. Accumulating evidence suggests that, during this early epoch, life arose on Earth and advanced to a fair degree of biological complexity. It is entirely probable that similar events occurred on Venus and Mars.

Later planetary evolution appears to have favored only Earth. But on Earth active surface processes have obscured the record of this early epoch. On Mars huge areas of the planet are covered by ancient, heavily cratered terrain. So, although there may be no life there today, the best record of the chemical and biological events leading to the origin of life may be found on Mars.

An International Effort

Many people believe that a program of human settlement on Mars should be an international effort involving all space-faring nations. They strongly feel that the first human presence on another planet should represent the entirety of humanity.

While many feel the US could launch a Mars mission on its own, from the engineering and science point of view cooperation is attractive. While the US has had a more successful and vigorous program of robotic exploration of Mars, the USSR has had more experience with systems for supporting humans in space for the long periods required for Mars flight. The Soviets have also announced their intention to launch an automated mission to Phobos, one of the moons of Mars.

The US, on the other hand, can provide the aerocapture and resource utilization technology, as well as deep-space guidance and navigation. Jim Oberg, a noted observer of the Soviet space program, suggests that "a complementary melding of these capabilities could make such a mission even more attractive — and much more imminent — than it currently appears."

Christopher McKay is a planetary scientist at NASA Ames Research Center, Moffett Field, California. His major interests are planetary biology and Mars settlement.

Are the Soviets Planning to Send Humans to Mars?

One can answer this question both negatively and affirmatively by reading recent statements by distinguished members of the Soviet astronautics community. Anatoliy Alexandrov, president of the Soviet Academy of Sciences, said in a broadcast by Radio Moscow that a flight to Mars is feasible, but would require the solutions for a number of complex problems. The broadcast indicated that such an expedition was being studied in the Soviet Union, but Academician Alexandrov offered no schedule for it.

On the other hand, former cosmonaut Konstantin Feoktistov, a leading spacecraft designer, stated that he does not foresee such a trip in the next 10 to 15 years, for "there is no sign of the kind of goals that would make a flight to Mars necessary."

In an interview published in *US News and World Report*, Academician Roald Sagdeev, director of the Soviet Institute for Cosmic Research and an advisor to The Planetary Society, said, "We have no definite plans [to go to Mars], and even no intention of discussing long duration flights with men on board. I think that is not for this century. At the moment, we plan to explore the planets only with unmanned devices."

Others think differently on the subject. At the Lunar Base Conference held at the US National Academy of Sciences, former senator and astronaut Harrison H. Schmitt (also a Planetary Society advisor) said he believes that there will be cosmonauts "in the vicinity of Mars" by October 1992, the 75th anniversary of the 1917 revolution. Other reports suggest that the Soviets will not attempt a human Mars mission before the mid-to-late 1990's.

The *Salyut 6* and *7* missions have demonstrated that the Soviet Union is interested in extended human space flight. The missions have lasted for as long as 237 days — long enough to have traveled to Mars, but not long enough for a round trip. The Soviets have conducted in-depth biological and medical studies during the *Salyut* flights. The Soviets are also conducting experiments on the ground, in which people are confined to a restricted, sealed environment. There they grow vegetables and grains, which they harvest and convert to bread. They subsist, in part, on the products they grow themselves.

Two vehicles that could launch humans into Earth orbit as the first stage of a lunar or planetary mission are in advanced development in the Soviet Union: a shuttle, similar in shape and payload capacity to the US vehicle; and a very large booster, possibly capable of carrying payloads comparable to those of the extinct American *Saturn 5*. Both vehicles will probably fly within the next two years.

Every 15 years, Earth and Mars reach positions in their orbits where it would be relatively easy to send a spacecraft from Earth to Mars and back again. The next such "window" falls in 1986-87; it is unlikely anyone will try a trip to Mars at that time. The next opportunity is in 2001. By then we should know if any nation, or group of nations, is planning a trip to the Red Planet. — SAUNDERS B. KRAMER

News & Reviews

by Clark R. Chapman

I recently visited Hilo, Hawaii, gateway to Volcanos National Park and one of the rainiest cities in the United States. I was lucky to witness a couple of rare, cloudless mornings when the rising sun shone on Mauna Kea, towering in the distance beyond the palm-lined coastline of tropical Hilo Bay. Dawn's alpenglow gave way to the intense red-orange rays of the Sun. The pastel pinks, ochres and grays of the majestic mountain's cindery slopes were highlighted by the gleaming snow-fields and white telescope domes on top. Mauna Kea is not a craggy peak, but as viewed from Hilo it dwarfs the massive but gentle-sloped mound of its sibling, Mauna Loa, and the younger, still-steaming volcanos to the south. Rising higher from its base, further beneath the sea than any other mountain on Earth, Mauna Kea pokes through the cloud layer that normally enshrouds Hilo and penetrates 40 percent of Earth's dirty moisture-laden air up to a dry climate that is uniquely suited for groundbased astronomy.

World's Largest Telescope

Early in January, this mountain, which has already been a frequent dateline for news reports on fresh astronomical discoveries, achieved front-page status again with the announcement that construction of the world's largest telescope will commence on its summit late next year. The Keck Telescope will be built and operated jointly by the California Institute of Technology and the University of California. It will join a host of other telescopes already operating or under development, including facilities of NASA, the University of Hawaii, several European countries, Canada and Japan.

Mauna Kea's frequently cloudless, dry, dark and still skies foster the best opportunities on Earth for observing the stars and planets. So far, the mountain's marvels have been known only by astronomers, a few wild-pig hunters and some tropical skiing aficionados. But the Keck announcement inspired a Mauna Kea piece in the Travel Section of the January 20th *Los Angeles Times*, which heralds wider public interest in that mountain for the future.

Mauna Kea is not only the site of some of the best telescopes in the world; the lifeless landscape on its upper plateau, above 12,000 feet, resembles the surface of the Moon or the planet Mars. Backdropped by recently dormant cinder cones, the bouldery and sandy volcanic plains — in this case shaped by glaciers now vanished — provide the visitor with an uncanny extraterrestrial sensation. On occasion, Mauna Kea is the best vantage point from which to watch the spectacular eruptions from Mauna Loa, just across the Saddle, or from Kilauea on Mauna Loa's eastern flanks.

The Planets from Mauna Kea

Your columnist, having completed his sabbatical in Hawaii before returning to Tucson, embarked on a farewell visit to the summit, as much for contemplation as for obtaining spectroscopic data on several comets. It is no wonder to me why Rick Gore, a senior writer for *National Geographic*, also chose a Mauna Kea base to formulate his excellent account of modern planetary science in that magazine's January 1985 issue. From Dale Cruikshank's eerie photograph of telescopes silhouetted in front of Mauna Loa's volcanic glow, to Gore's final musings about the solar system while he basked in a tidal pool while watching the Sun set on Mauna Kea, *National Geographic* presents 50 pages of photographs, facts, concepts and reflections about the meaning of planetary exploration.

As is appropriate for a magazine noted for taking its readers on excursions around our own planet, Rick Gore returns again and again to unusual places on Earth that bear analogies to strange extraterrestrial environments. In poetic prose, Gore expresses in human terms the reality of these exotic places. Yet the emphasis on Earth-like worlds seems to displace some merited discussion of the smaller bodies in the solar system — planetary satellites, comets and asteroids. The excellent, well-illustrated account of the origin of the solar system pays scant attention to meteorites, those objects that contain most of our *real* data about primordial events.

Grasping the Big Picture

In preparing this masterpiece, Gore immersed himself in planetary science for several years, and it shows. He has clearly grasped the "big picture" concepts and articulates them well. As thoroughly integrated as the article is, I was amazed to discover how much of it is totally up-to-date, reflecting new discoveries, decisions and other "newsy" events into the winter of 1984/85. This article contains one of the first published radar maps from the Soviet *Venera* missions, a discussion of the *Galileo* spacecraft's now-probable encounter with the asteroid 29 Amphitrite, and a reflection of the increasingly catastrophist views of many planetary researchers — for example, the surge of interest in the hypothesis that the Moon was created from the splash of a Mars-sized body striking the young Earth.

The planet Mercury also gets short shrift from Gore, who quotes an anonymous astronomer as telling him that Mercury shows a face that "only a confirmed crater-counter could love." There is much more to Mercury, however, than the cratered terrains that are the most obvious features on that planet's surface. The less-prominent lobate escarpments are unique to Mercury, and testify to a global shrinkage of the planet not obvious on other planets.

Mysterious Mercury

Mercury is actually a mysterious world, with the suite of "accepted" ideas about its geology, composition, thermal history and magnetic field seemingly mutually inconsistent. These perplexing issues are highlighted in a recent article by Bruce Cordell about Mercury, in the September/October issue of a magazine of (coincidentally) the same name. *Mercury* is published by the Astronomical Society of the Pacific.

Cordell argues that the importance of planetary issues should not be measured simply by the flashy, spectacular items that hit the newspapers and can be so beautifully illustrated as in the multicolor *National Geographic* spread. "Mercury," writes Cordell, "poses some of the most challenging mysteries in the explored parts of the solar system." Some of these issues strike at the center of our fondest paradigms in planetary science, including the notion that the planets formed under conditions crudely approximating chemical equilibrium.

Other mysteries, of course, reflect the less advanced state of our investigation of this iron-rich world. But rather than challenging us to return to Mercury as soon as possible (at least two decades will have passed since the initial reconnaissance by *Mariner 10*), Cordell laments that "Mercury's outwardly dull appearance will continue to belie its enigmatic personality for quite some time."

Clark R. Chapman, having returned from his sabbatical in Hawaii, has resumed research at Science Applications International's Planetary Science Institute in Tucson, Arizona.

HERE COMES HALLEY

by John L. Wilhelm

WASHINGTON and TALLINN — The 1986 "Pathfinders" to Halley's Comet are on their way, in the most significant international cooperative efforts in space exploration since the *Apollo-Soyuz* manned project 10 years ago.

Both of the USSR's *Vega* spacecraft were successfully launched on schedule in December, 1984. They will first fly by Venus in June, dropping off atmospheric and surface probes, then use the planet's gravity to assist them to intercept Halley, flying by the comet in March, 1986.

For the first time, Soviet interplanetary missions will be tracked cooperatively by the US Deep Space Network (DSN). NASA has spent about $1 million modifying its receivers in California, Spain and Australia to allow them to tune in the *Vega* transmissions. The spacecraft will be tracked passively, by listening to their broadcasts, enabling DSN to determine their position in space with great precision.

The complex technique uses known quasar sources as benchmarks. The DSN antennas will measure the angles between the quasars and the spacecraft, enabling the Jet Propulsion Laboratory controllers to run off navigational "fixes" of the two *Vegas*. The method is somewhat reminiscent of the technique old-time, sextant-toting sailors used aboard their ships, by shooting sunlines and star sights to determine their positions on the ocean.

Tracking the Comet

Meanwhile, the *Vegas* will be using their onboard cameras — complex, charge-coupled devices which Bradford Smith of the University of Arizona helped to develop — to track the comet's movements against a background of known stars. The *Vega* team, headed by Academician Roald Sagdeev, will make these approach pictures (as well as the all-important camera pointing angles) available to NASA and the European Space Agency (ESA).

This effort takes advantage of the fact that the *Vegas* precede ESA's *Giotto* spacecraft to Halley by about one week. Because Halley and other comets skitter around in their trajectories due to unpredictable out-gassing of material from the nucleus — similar to reaction control jets aboard a manned spacecraft — not knowing Halley's exact position could lead to disaster for *Giotto*. Combining NASA's tracking information of the *Vegas* — to know precisely where they are when they take their pictures — with the *Vegas'* updates on the comet's latest position, will allow ESA to re-target *Giotto* about 48 hours before its encounter with the comet.

The goal is twofold: 1) to enable *Giotto* to pass by Halley's tiny nucleus within the spacecraft's 500-kilometer designed miss distance, obtaining the first, closeup pictures ever taken of a comet nucleus; and 2) to help *Giotto* avoid the dangerous jets of high density dust which shoot out from the comet's solar-heated nucleus. These jets — which recent studies by the University of Arizona's Stephen Larson have shown can be as much as 30 times denser than Halley's normal atmosphere — could destroy *Giotto* before it accomplishes its mission, or possibly obscure the nucleus from *Giotto*'s camera.

Planning Pathfinder

Plans for this unusual cooperation in space navigation were agreed upon last November in Tallinn, Estonian Soviet Socialist Republic, on the shores of the Gulf of Finland. There, representatives of the space agencies of the US, USSR, Europe and Japan culminated several years of negotiations by signing the "Pathfinder" agreement, which formally specifies how the complex, joint navigational effort to Halley is to be carried out.

The signing was the highlight of this fourth annual meeting of the so-called Inter-Agency Consultative Group (IACG). The IACG's purpose is to maximize the scientific information obtained from the various space flybys, orbital studies, and groundbased observations of Comet Halley during its 1985-86 apparition. Academician Sagdeev, director of the Institute for Cosmic Research in Moscow and member of The Planetary Society's advisory board, headed the Soviet host delegation. Other delegation heads were: Dr. Geoffrey Briggs, director of NASA's Solar System Exploration Division; Prof. R. M. Bonnet of ESA; and Prof. K. Hirao of Japan's Institute of Space and Astronautical Science (ISAS).

Also attending the meeting were the co-directors of the International Halley Watch (IHW), Dr. Ray Newburn of NASA's Jet Propulsion Laboratory and Prof. Jurgen Rahe of the Remeis Observatory, Bamberg, Federal Republic of Germany. They reported that the IHW network now has over 900 professional astronomers from 50 countries and several thousand amateurs signed up and ready to conduct groundbased observations of Halley in what will be the largest coordinated astronomical event in history.

Symbolic Site

One reason for holding the meeting in Tallinn was symbolic: Astronomers at an old Estonian observatory just outside the picturesque city made extensive observations of Halley's Comet during its 1835 apparition. The rare, leather-bound book of those observations and detailed drawings, compiled by F. G. W. Struve, a relative of the well-known 20th century physicist Otto Struve, was exhibited to the participants by the Vice Minister of the Estonian Academy of Sciences.

Previous IACG meetings have been held in Japan, Hungary and Padua, Italy, where the original Giotto fresco showing Halley's Comet as the Star of Bethlehem adorns a private chapel. ESA's *Giotto* mission was named after the Florentine master painter.

In addition to exchanging information about their current efforts to observe Halley cooperatively, the IACG leaders briefed the conference on each agency's future missions to explore the solar system. Ways are being sought to extend the IACG's cooperation beyond Halley, perhaps by joint missions in the 1990's to sample a comet using the backup *Giotto* spacecraft, or by jointly exploring Mars with the USSR's 1988 Phobos Rendezvous mission and NASA's upcoming Mars Geochemistry/Climatology Orbiter (MGCO), tentatively planned for launch in 1990.

At the signing of the formal "Red Book" document, which sets forth the technical agreements between the space agencies, conference chairman Sagdeev announced with prophetic emphasis, "I think we will remember all these meetings."

John Wilhelm, formerly national science correspondent for Time *magazine and managing editor of* Science 80 *magazine, is a producer and writer of public television science specials.*

SOCIETY-NOTES

THE UNIVERSE UNFOLDING

Attention Southern California educators! The Planetary Society is co-sponsoring "The Universe Unfolding," a special weekend on astronomy to be held at UCLA in memory of eminent astronomer Dr. George O. Abell. On Saturday, April 27, a workshop for teachers (grades 3-12), librarians, curriculum specialists and youth group leaders, will demonstrate many ways of teaching astronomy, and guide participants through astronomy activities that have been used successfully in classrooms. Resource materials and activities to use for the return of Halley's Comet will be featured.

On Sunday, April 28, a public lecture program will follow the educator's workshop. The Society's vice president, Dr. Bruce Murray, will be a featured speaker. Topics include: the latest information on Halley's Comet, black holes, expansion of the universe, ancient astronomy, infrared astronomy, and the exploration of Mars.

Co-sponsors with The Planetary Society are UCLA Extension/Department of Engineering and Science, UCLA Department of Astronomy, and the Astronomical Society of the Pacific. If you take the course for UCLA Extension credit (1.5 units), the fee will be $85 for both Saturday and Sunday; the noncredit fee for Saturday's program will be $25, and $29 for Sunday's program.

For more information write The Planetary Society, Abell Weekend, 110 S. Euclid Ave., Pasadena, CA 91101.

SCHOLARSHIPS NOW AVAILABLE

For students who are members of the Society, or children or nominees of a paid member, college scholarships are now available through The Planetary Society. We will award the scholarships on the basis of SAT or ACT scores, scholastic achievement, letters of recommendation, accomplishments that show leadership and creativity, a written essay, and plans for a career in space science. Write to The Planetary Society, Department ED, 110 S. Euclid Ave., Pasadena, CA 91101, or call (818) 793-5100 for an application form. Scholarship funds have been made available through the generosity of the Society's New Millennium Committee.

SOCIETY CONFERENCES SUCCEED

The Planetary Society sponsored two exciting conferences for members and the general public in January. In Pasadena, more than one thousand people attended a discussion, "To Halley and Beyond," featuring Society Advisors Roald Sagdeev of the USSR and Jacques Blamont of France. A day-long "Space Weapons Symposium" in Washington, DC, co-sponsored with the American Academy of Arts and Sciences, was attended by 500 people. Thanks go to volunteers who organized and coordinated these large programs: Jackie Delarue, Gail Abend and David Webb in Washington, DC; Joan Tuzzolino and David Hagie in Pasadena.

ADVOCATING AMPHITRITE

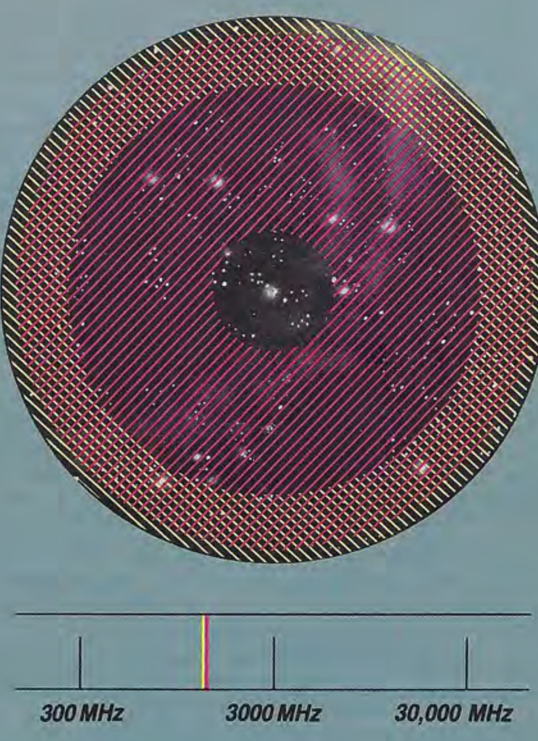
NASA's decision to modify the *Galileo* mission to allow a December 1986 flyby of the asteroid Amphitrite shows what can be accomplished when the science community and program officials work together. According to Harry Mannheimer, *Galileo* Program Manager at NASA Headquarters, "The continued advocacy by the science community, including The Planetary Society, was a significant factor in this process. As a result, NASA has seized this unique opportunity for major science return, at relatively modest cost, and incorporated the flyby option into the *Galileo* mission."

Project Sentinel Continues

Despite last winter's severe weather, the 84-foot radio antenna of The Planetary Society's Project Sentinel is continuing to scan the sky in search of radio signals from possible extraterrestrial civilizations. According to Professor Paul Horowitz of Harvard University, the project's originator, Sentinel is now searching the 1665 megahertz band, and has covered the sky from −40 degrees to +55 degrees.

From its location at the Oak Ridge Observatory in Harvard, Massachusetts, Project Sentinel is capable of covering the sky up to +60 degrees. But when the snow began to fall, Professor Horowitz decided to stop the scan at +55 degrees and to retrace the search at the 1665 megahertz band, beginning at −45 degrees. If he had continued on to +60 degrees, the antenna would have been pointed up, positioned to catch and hold the falling snow. "We didn't want to wake up in the morning with a snow bowl," he said. With the dish pointed toward the horizon, toward south declinations, the snow will slide off. As we went to press, Sentinel had again reached −15 degrees.

Meanwhile, work continues on Project META (Megachannel Extraterrestrial Assay), which will expand the Oak Ridge system from 131,000 radio channels to 8 million. Professor Horowitz has now completed 3 million channels and plans to have META ready to turn on by the end of summer.



VISIONS OF 2010 *(continued from pg 6)*

Society wonder if the crew will feel the same way!)

The return to Earth will take two and one-half years, so the life support needs will be greater than for the six month outbound trip. The great difference in travel time is due to orbital geometry and planetary alignments. We either have to wait for favorable alignments or fly on slower trajectories.

During this long flight, the crew will need radiation protection, artificial gravity, entertainment, exercise and intellectual stimulation. (See pages 7-9). Their air and water can be recycled, but all food will have to be brought along. Although SAIC estimated that each person will need a little over two kilograms of solid food per day, the design conservatively allowed for two and one-half kilograms.

After their lengthy trek back across interplanetary space, the crew will return to Earth orbit in January, 2004, three years after they left home.

Can We Afford to Go?

The principal purpose of this study was to provide a modern cost estimate for manned missions to solar system targets. No such estimates had ever been done based on post-*Apollo* and post-shuttle space systems. The *Apollo* program cost $75 billion in today's dollars, but it was done 20 years ago when the technology had to be built from scratch. With a technology base to build upon, the shuttle cost $17 billion.

Costs for future missions are estimated by analyzing the mass, technology and mission requirements, and comparing them with the actual costs of previous missions. Allowances are made for peculiar requirements and contingencies.

All estimates included the costs of shuttle launches and OTVs, but did not consider the development costs of the OTVs, a space station or other facilities which are being advocated on quite separate grounds.

Since these missions will push against the outer envelope of our knowledge, the cost estimates are actually educated guesses.

The lunar and asteroid missions, although very different in design, would cost between $15 and $20 billion in current US dollars, not taking into account inflation or differing economic systems if other nations joined in their implementation. The asteroid spacecraft are less expensive because of the negligible local gravity, and so will need less fuel. The lunar mission is shorter, but it will use more hardware.

SAIC estimated the cost of the Mars mission at about $40 billion; almost half that money will pay for mission control and ground support. Assuming the cost spread out over a ten-year period, it would average $4 billion per year (60 percent of the current NASA budget). If other countries or space agencies teamed together, the costs to any individual nation could be reduced.

The Next Steps

The SAIC study reinforced our conviction that manned missions into the solar system are affordable goals. Done as an international effort, they could open new opportunities for cooperation, and advance science and technology for all people. Combined with robotic exploration of other worlds, observations of the universe, and new services from Earth orbit, these missions could spearhead a space program that offers new frontiers to the human species.

The Planetary Society, through its Mars Institute and International Space Cooperation Fund, is now advocating the goal of human flight to Mars.

We will follow up the SAIC report with workshops to investigate how international cooperation might influence the mission design, and we will call a conference to discuss the human exploration of Mars.

Our members, by supporting these programs, will be initiating the long-dreamed of journey to Mars.

Louis Friedman is Executive Director of The Planetary Society.

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