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Future Space Development Scenarios: Environmental Considerations

Richard Tangum

Introduction

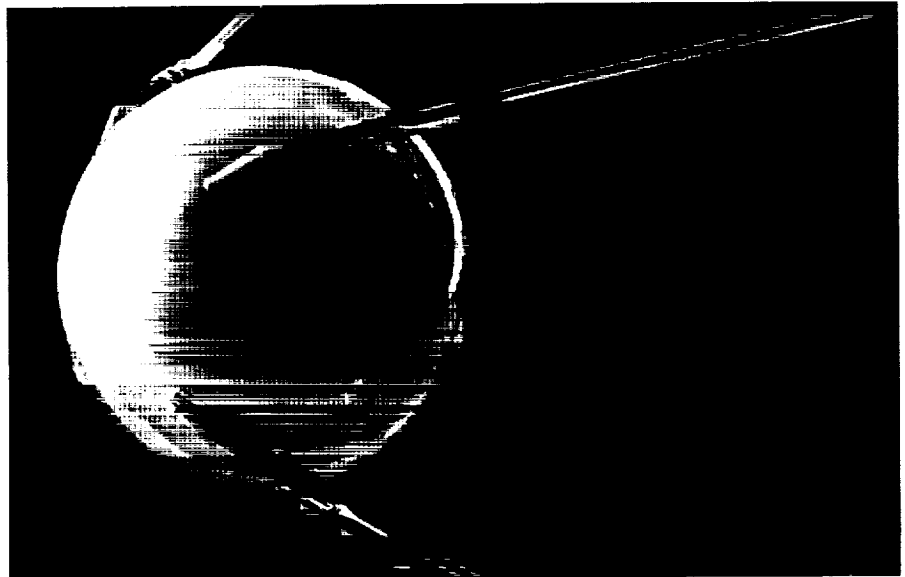
Human presence in space has expanded dramatically since the first Sputnik of October 1957. Between 1959 and 1976, 40 spacecraft were launched into lunar orbit or to the surface of the Moon.

Spaceflights That Provided Lunar Data

Apollo missions	(1968-1972)	9 manned flights
Luna series	(1959-1976)	13 Russian probes
Surveyor	(1966-1968)	5 unmanned landings
Ranger	(1964-1965)	3 preimpact photography flights
Zond	(1965-1970)	4 unmanned flybys
Lunar Orbiter	(1966-1967)	5 orbital photography flights
Explorer 35	(1967)	1 orbital flight

Sputnik I

The "beep beep" of Sputnik I in October of 1957 changed the world's perception of itself. This full-scale model of the basketball-size satellite was on display at the Soviet Pavilion at the Paris Air Show.



Likewise, the launching of satellites into low Earth orbit (LEO) and geosynchronous Earth orbit (GEO) has continued unabated. This presence in space—to include the lunar surface, asteroids, and Mars—will increase dramatically in scale and scope within the next quarter century. NASA's plans for a space station in LEO are already under way.

The National Commission on Space appointed by President Reagan calls for human outposts on the Moon by 2005 and on Mars by 2115. The Commission believes that an aggressive plan should be adopted

To lead the exploration and development of the space frontier, advancing science, technology, and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars.

The Commission further states that a major thrust should be exploring, prospecting, and settling the solar

system. Furthermore, space enterprises should be encouraged to benefit people on Earth. President George Bush, in his speech at the Air and Space Museum on the 20th anniversary of the Apollo 11 landing, both echoed an Apollo 11 astronaut and reinforced the Commission's goals by stating

Mike Collins said it best: "The Moon is not a destination; it's a direction." And space is the inescapable challenge to all the advanced nations of the Earth. And there's little question that, in the 21st century, humans will again leave their home planet for voyages of discovery and exploration. What was once improbable is now inevitable. The time has come to look beyond brief encounters. We must commit ourselves anew to a sustained program of manned exploration of the solar system, and, yes, the permanent settlement of space. We must commit ourselves to a future where Americans and citizens of all nations will live and work in space.



Lunar Colony, as Conceived In February 1969

This painting and its caption, published 5 months before the Eagle of Apollo 11 touched down on the Moon and brought back the first lunar samples, is remarkable not for its mistakes in detail, which analysis by hundreds of scientists of the nearly 400 kilograms (841 pounds) of lunar rocks collected by the Apollo astronauts has subsequently revealed, but rather for the accuracy of its general idea of facilities and activities that now, "a generation" later, we are planning to build and carry out on the Moon:

"Frontiersmen of the Space Age, engineers and technicians colonize the

moon. Drawing on the most advanced thinking of experts, artist Davis Meltzer portrays a lunar outpost that might be possible in a generation. A survey team drills core samples and maps the surface as an attendant monitors the oxygen supply. Aluminum habitation modules lie almost buried for protection against micrometeorites and temperatures that fluctuate 500°F. between noon and night. In a laboratory module, foreground, biologists observe animals and experiment with raising vegetables in fertilized water. A multi-level main module encloses dressing rooms for entering and leaving, medical dispensary, dormitory, kitchen, and dining and recreation areas. Pressurized tunnel leads to a smelter,

where lunar rock quarried on the surface is processed for the water chemically locked within it. The water not only fills the station's swimming pool, but also yields oxygen for breathing and hydrogen for fuel for a flying vehicle, far left. A fencelike radio telescope probes deep space, and an optical scope in a small observatory studies the heavens, undimmed by earth's atmosphere. Beside a hangar pit, a commuter rocket poises for return to the blue planet earth."

Artist: Davis Meltzer

Illustration and caption taken from Kenneth F. Weaver, 1969, "The Moon, Man's First Goal in Space," National Geographic 135 (2-Feb.): 206-230.

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Apollo 16 Lift-Off From the Moon

The confetti-colored sparkles of the lunar module lift-off for each of the last three Apollo missions were seen by millions of people, thanks to a TV camera mounted on the lunar rover. We were glad to see our astronauts lifted safely from that far-off surface to join their fellows in the orbiting command and service modules and come home to Earth. But, as we contemplate going back to the Moon, to establish a permanent base, we must be concerned about the effect that our built environment will have on the natural environment there.

Studies of the potential use of nonterrestrial materials could have far-reaching implications for the environments of low Earth orbit and the lunar surface, in terms of both use and the prevention of possible contamination. A need is clearly emerging for some form of environmental assessment and management to determine what to use space or planetary surfaces for and how to do it; what changes to tolerate and what standards to impose; and how to meet these standards.

The term *environment* in space can be used in three different senses: first, the natural environment of soils, gases, and organisms that may be present; second, the built environment, including manned satellites and the areas humans build to live and work in; third, the social environment—culture, law, and economics. Of immediate concern is the effect of the built environment on the natural environment in space.

Potential Research

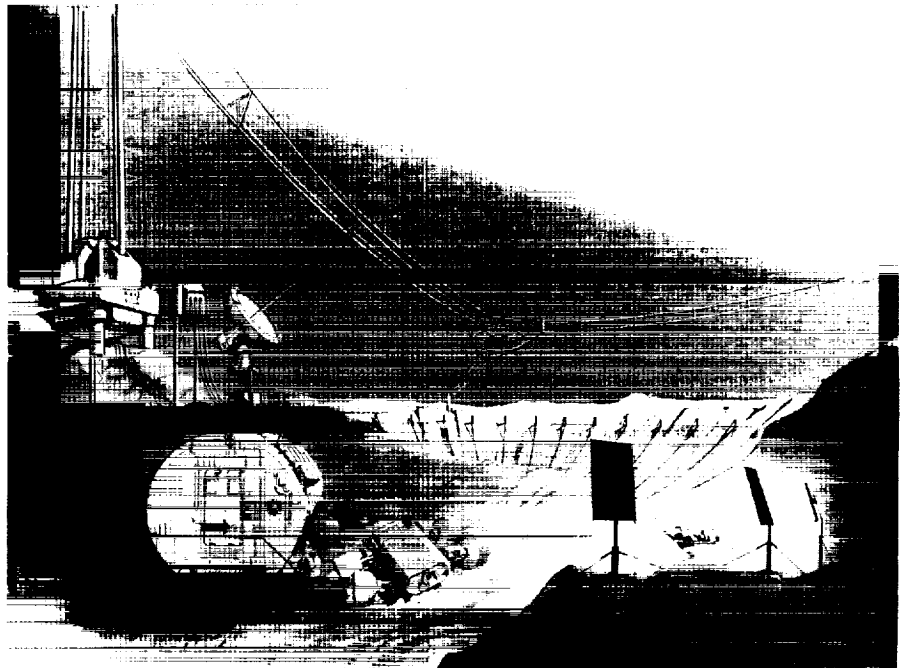
Many of the initial activities potentially associated with the establishment of a lunar base will involve research. A lunar base setting with low gravity and a vacuum environment makes it possible to conduct unique experiments that are not possible on Earth. These factors, plus added seismic stability, make the Moon a perfect observatory platform. The far side of the Moon is especially suited for radio astronomy because its pristine environment, shielded from radio

frequencies, allows measurements over a wide range of wavelengths (see fig. 15). Solar wind studies are easier on the Moon because of the lack of an atmosphere and also the lack of a large magnetic field. Furthermore, the Moon acts as an absorbing surface to the charged solar plasma. Geological studies can answer questions about the Moon's history, its evolution, structure, composition, and state. Practical resource development questions will arise about where large quantities of various ores can be found and how to mine them economically.

Figure 15

Radio Telescope on the Far Side of the Moon

In this artist's concept, a radio telescope has been placed in a meteorite crater on the far side of the Moon. The parabolic grid in the crater reflects the signal to the steerable collector suspended by cables. The lunar far side may prove to be an ideal location for radio telescopes because nearly all radio frequency noise generated by human activity on Earth will be blocked out by the Moon itself. In the concept shown here, the radio telescope is human-tended but is operated by remote control most of the time. Information from the telescope is beamed to a lunar communications satellite which relays the data back to Earth. Other radio telescope designs have also been proposed, including large-area phased arrays which do not require parabolic reflectors. While early lunar base installations will likely be on the near side of the Moon, far side sites for radio telescopes will likely follow because of the clear advantage of such a location.



An Illustration of the Problem

Mining of the lunar surface is an area of potential environmental concern. This issue was voiced by the Lunar Base Working Group, meeting at Los Alamos National Laboratory in 1984:

Most lunar scientific activities require that the unique lunar environment be preserved. Lunar base operations might affect this environment in *adverse* ways, especially if industrial operations expand.

Specific potential environmental impacts were cited: increased atmospheric pressure, which could change atmospheric composition and compromise astronomical observations, and increased very low radio frequency background through satellite communication networks, which could affect the use of the far side of the Moon for radio telescopes.

Unprotected by any atmosphere, the Moon will accumulate scars of impacts by humans at an increasing rate. In contrast, the Earth will exhibit a more youthful appearance, since it is constantly rejuvenated by geological processes such as erosion by wind and water. On the Moon,

micrometeoritic action turns over the top 3 mm of the lunar surface every 1 000 000 years (Gault et al. 1975). In this time span, the lunar surface is destroyed, recreated, and shaped.

Extensive mining efforts on the Moon, however, could scar its surface irreversibly. Numerous components of mining on the Moon must be environmentally assessed: the scale of the mining operation, its associated development, and its technological features. Factors affecting the scale of mining include

- Ore quality
- Size of ore body
- Availability of energy
- Cost of operation
- Type of operation

Strip mining would probably be the most efficient method for producing ore (see fig. 16). There could remain the desolation of steep piles of discarded regolith, alternating with the trenches from which the regolith is removed. The Moon, in time, could become a visual and scientific wasteland. Laws requiring backfilling of the trenches and recontouring of the ground surface to some semblance of its original state would be needed.

Development and technological features affecting the environmental impact include

- Size of mining installation (land required)
- Volume of spoil generated
- Nature of energy source used
- Nature of transportation system used
- Nature and volume of pollution released
- Use of explosives
- Drilling processes

Oxidic minerals will probably be the first resource mined on the Moon for life support and rocket propellant. Although projected ore volume for initial production of oxygen would be low (82 cubic meters of unconcentrated fines per day), eventual development of

larger settlements would require a vast mining operation to sustain them. Approximately 100 000 tons of regolith (10-percent usable ilmenite content) are needed to produce 1000 tons of oxygen in a carbothermal oxygen production plant (Cutler and Krag 1985). This translates into a mining operation that extracts 50 000 cubic meters of regolith for each 1000 tons of oxygen produced.

Selenopolis, a fully developed lunar settlement envisioned by Krafft Ehrlicke (1985), could require vast quantities of oxygen per year for its inhabitants' use for life support and rocket propellant. Annually to produce 500 000 tons of oxygen, an area 7.07 kilometers square and 5 meters deep would have to be mined.

Figure 16

Three-Drum Slusher

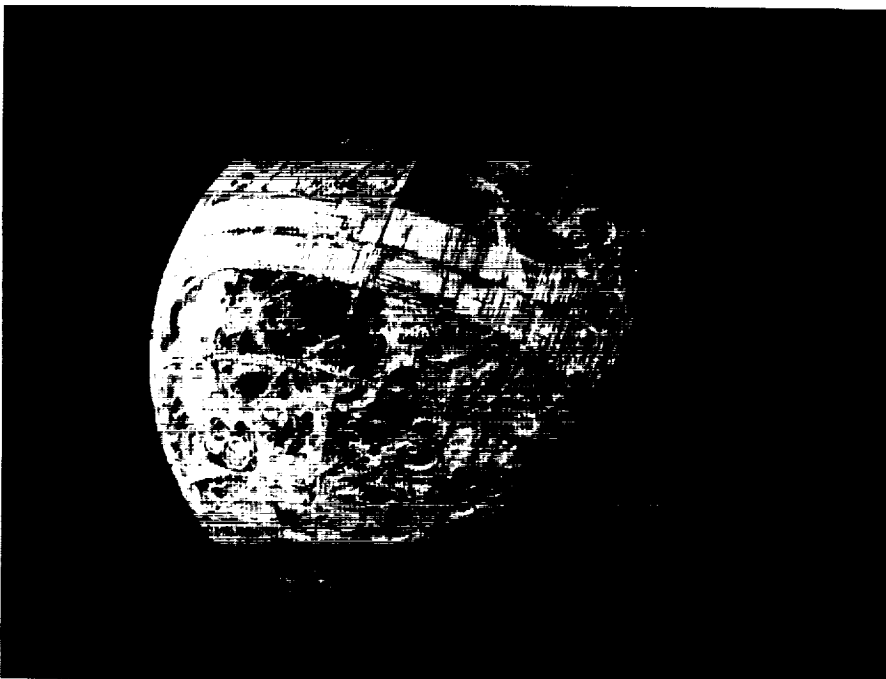
This lunar mining system is called a "three-drum slusher." It is similar to a simple two-drum dragline, in which a bucket is pulled by cables to scrape up surface material and dump it into a waiting truck. The third drum allows the bucket to be moved from side to side to enlarge the mining pit. Surface mining of unconsolidated lunar regolith, using versions of draglines or front-end loaders, will probably be done at a lunar base initially, although deeper "bedrock" mining is also a possibility and underground mining may even be attractive if appropriate resources are located.



Although the Moon does not have an atmosphere as such, it does have an exosphere in which individual particles are captured by its gravitational field. Each one of the Apollo missions between 1969 and 1972 added more than 10 tons of exhaust gases to the exosphere. Over the 3-year period, more than 60 tons of gases were released on the lunar surface. And the five Luna missions that returned samples from the Moon between 1970 and 1976 probably added a similar amount. Although subsequent measurements failed to detect their presence, these gases had a sufficiently high molecular weight that their dispersal from

the gravitational field of the Moon would occur only through a very slow process. What happened to these gases? A likely answer suggested by Zdenek Kopal (1979) is that the gases were rapidly absorbed by the lunar crust and bound in a solid state. The implications of the release of large quantities of gases of different types is unknown.

We must remember that the Moon, in its pristine condition, serves as an important, well-preserved fossil of the solar system. Much remains to be discovered about the evolution of the Earth and the solar system. Very little geological evidence has



"Moon, 2000"

Would-be developers may find this image of the Moon overly optimistic, at least by the year 2000. But environmentalists like Rick Tangum may view the image, by visual futurist Syd Mead, more pessimistically. Tangum is concerned about the scale of a mining operation necessary to support a large lunar settlement. Unmanaged development of the Moon could destroy its potential to reveal scientific information about the early history of the solar system.

Artist: Syd Mead

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been discovered about the first billion years of Earth's 4-1/2 billion year history. Geological discoveries on the Moon will

continue to clarify Moon-Earth and solar system history (see box). Unmanaged development of the Moon could destroy this potential.

What We've Learned About the Earth by Studying the Moon

- The Earth formed during the same planetary accretionary period as did the Moon—about 4.5 billion years ago. Much older rocks are found on the dry, airless, rapidly cooled Moon, whose crust has not been eroded and subducted like the Earth's has.
- The Earth, like the Moon, continued to be bombarded by planetesimals from its formation down to about 3.9 billion years ago. This record, too, is preserved on the relatively inactive Moon.
- The most likely story of the origin of the Moon explains why the Moon is less dense than the Earth: A planetesimal the size of Mars collided with the Earth and splashed some of the Earth's mantle, along with the silicate mantle of the impactor, into orbit around the Earth, where the debris accreted to form the Moon. The metallic core of the impactor, on the other hand, accreted to the Earth. This collision tilted the Earth 23° from the plane of the ecliptic and gave it its spin.
- The Earth was once completely molten, allowing its differentiation, the heavier elements sinking toward its still molten core, the lighter elements rising to eventually form its granitic continental crust. Traces of such chemical separations, occurring while the Moon was covered by a "magma ocean," are still preserved in its rocks.
- Even after the period of heaviest bombardment (4.5 to 3.8 billion years ago), impacts by asteroids, meteorites, and comets have continued to be significant, albeit random, events in geological history, though the evidence has been mostly erased on Earth. One such catastrophic impact has been found to be coincident with the extinction of the dinosaurs.
- The eruption of basalts, derived by the partial melting of the mantle, has been common on the solid planets and their satellites and on some asteroids. This igneous process is seen in the dark lava flows that filled the lunar basins we call "maria" (or "seas"), more of them on the near than on the far side of the Moon.

And an unanswered question:

Why does the Moon lack a magnetic field while the Earth has a relatively strong one? Is it because the Moon has only a small, if any metal core? If so, then why is a "fossil" magnetism preserved in lunar rocks?

Compiled from information provided by Michael B. Duke, S. Ross Taylor, John A. Wood, and the Solar System Exploration Division at NASA Headquarters.

Conclusion

The formation of positive attitudes and values concerning the environment of space, as the basis for assuming a wise stewardship role, is becoming increasingly important as many nations begin their journeys into space. A strong emphasis should be placed on fostering an international space environmental ethics.

The object of environmental assessment and management in space should be to define what interplanetary regulatory procedures are needed to avoid unnecessary environmental damage and to monitor the effectiveness of such avoidance. The first requirement for research is to narrow the field of concern to areas where there could be an increased scale of development in space in the immediate future. Research needs to be focused on methodologies for defining the environmental systems involved (e.g., the lunar surface) and then recognizing key variables in the system that are fragile and need to be respected. Criteria for environmental quality should emerge which identify, in the case of the lunar surface, how much

mining activity can be safely undertaken and what quantity of exhaust gases can be released over a given period of time. Only then will humans be most able to evaluate the likely consequences of ventures into space and be able to best preserve the newest frontier for posterity.

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