Maglev and fusion energy for lunar development

A September conference brought together experts in the fields of magnetically levitated trains, space development, and fusion power. Marsha Freeman reports.

"Krafft Ehricke gave a talk in October of 1984, and one of the things he said was, 'If God had wanted men to be space-faring, he would have given mankind a Moon.' That was a poetic way of saying without the Moon being there as a goal for us to consider, we might never have invented rockets and wanted to leave the Earth. We're in the process of establishing goals, and the one we're most interested in, is the lunar base."

That statement by Dr. Michael Duke, the chief of the Solar System Exploration Division of the NASA Johnson Space Center, opened the keynote presentation of the first Lunar Development Symposium, held on Sept. 22-23, 1986 in Atlantic City, N.J. The symposium was combined with the first U.S. Maglev Transportation Conference, to present one of the most unusual meetings on space development.

The sponsors of this Symposium '86 conference—which included the Engineering Club of Philadelphia, a number of other engineering societies, three state transportation commissions, the Young Astronaut Council, a division of the Johnson Space Center in Houston, and the American Mag-Lev company—were as varied as the topics on the agenda.

Scientists and engineers, from small high-technology companies and government laboratories, presented their work-in-progress on strategies and technologies for lunar development. Dr. Gerald Kulcinski, director of the Fusion Technology Institute in Wisconsin, captured everyone's imagination by demonstrating that mining a rare isotope of helium on the Moon, could provide fusion energy for the entire Earth, and the Moon, over the next century.

One of the goals of the meeting, was the formation of the Lunar Development Council, to engage private industry in planning non-government initiatives for the industrial development of the Moon. Current plans to have an operational space station by the mid-1990s, if kept on schedule, would create the possibility of a manned return to the Moon, just past the beginning of the next century.

In his conference presentation, Dr. Duke sought to explain why the development of the Moon is the next step for the exploration of space, and to answer the question most attendees were asking themselves as the Symposium '86 conference began: What does magnetically levitated train technology have to do with the industrial development of the Moon?

How will the Moon be developed?

"The lunar base can be important to us as a stepping stone outward from the Earth in the migration of people into the Solar System and eventually into the universe. . . . It opens the possibility of using materials, energy resources in space, to better our life here on Earth. It is a critical point in the development of our space capability. We know how to routinely fly back and forth to space, and we can envision a lot of ways to use that space environment," Dr. Duke stated.

"[But] we have not found the political motivation to provide urgency to the endeavor of exploring space. Right now, at least in the United States, there is not the urgency associated with the Apollo program. . . . If we are to maintain a strong civil space program in this country, we must find exciting goals where we can focus our energy, which motivate us, which can motivate the whole society. I believe the lunar base is such a goal.

"It's feasible, it is affordable, and it can return profits to those people who are wise enough to identify the potential and to make the right kinds of investment," Duke stated. "It can be helpful in maintaining U.S. leadership in technology. . . . An important part of choosing the right goals is to choose things that will motivate the young people in this country and around the world, to put the right emphasis on their education to develop in science, engineering, and technology.

"Although the Moon is a harsh environment to work in—we have a high vacuum, extreme temperatures, radiation, and less gravity—it's not so different from the Earth. . . . The challenge for a lunar base is to adapt to an environment that is more or less familiar, but has some different constraints.

"What we have to do on the Moon, is to learn how to use the Moon's materials and energy resources to establish a new place for humanity—homes, farms, transportation systems, power plants, mines, schools, and everything.

"There are several parallel themes that tie the technologies of lunar development to the technologies of maglev [magnetic levitation]," Duke explained. "The obvious one is that lunar surface transportation will be required. Magnetic levitation may in fact be the best choice for developing major transportation systems on the Moon, either on the surface or in tunnels. Maglev uses electrical energy directly, without the need for chemical fuels, which will be scarce for a long time on the Moon.

"In the short term, maglev systems to move materials from mines to mills efficiently; in the long term, maglev can provide transportation systems for moving people between lunar habitats, and perhaps, even for lunar tourism.

"Another parallel is the general technology for magnetic levitation, and electromagnetic accelerators. This is a field of technological growth." In addition to the need for low-cost transportation from the Earth to space, "low-cost Moon-to-space and space-to-Moon transportation is the key to the long-term viability to lunar economy and electromagnetic launch is of major interest. . . . Ultimately it should be possible to launch payloads from the Moon with maglev, at less cost than launching from here," Duke speculated.

"Another thread that ties maglev and space together is the general advancement of technologies; of materials, struc-

Magnetically levitated trains on Moon and Earth

On Earth, the major drawback to wheel-on-rail trains is the speed limit of about 200 miles per hour, due to problems of loss of traction, frictional heating, and the difficulty of transmitting electrical power through physical contact. On Earth, however, our atmosphere produces an aerodynamic drag on any vehicle above about 300 miles an hour, which once again ultimately limits its speed.

In the environment of the Moon, however, there is no atmospheric drag nor indigenous sources of fuel. In addition, it is important to keep the Moon's near-vacuum as clean as possible, for scientific experiments. All of these factors make all-electric magnetically levitated trains a good match for lunar transportation needs.

The fundamental principle involved in using the interaction of magnetic and electrical fields to levitate anything, is that bodies of like polarity repel, and those of opposite polarity attract. In the most advanced design for maglev systems, fields of opposite polarity are produced by a current flowing underneath the train vehicle in a guideway, and fields produced by magnets on the vehicle itself.

The use of a linear synchronous motor produces propulsion for the train by pulling the vehicle forward by the positive attraction of on-board magnets, and a second set of coils in the guideway, positioned on the sides. As the train passes by, the polarity or direction of current in the guideway is changed, and the vehicle is given an added push from behind, from the repulsive force of the two sets of magnetic and electrical fields.

On Earth, the real potential for maglev systems will be realized if the trains are placed underground in evacuated tubes. Without aerodynamic drag, the only limit to the speed of the train, at a constant comfortable rate of acceleration, is the distance and therefore amount of time, over which the train has to accelerate.

On the Moon, if radiation exposure can be limited, there will be no immediate need to place the trains underground. The noiseless, pollutionless, all-electric maglev transportation system can move equipment, materials, and colonizers around the surface quite easily.

Electromagnetic launchers, based on the same dynamic principles as maglev trains, are also being designed, to accelerate unmanned payloads to great speeds. These self-contained payloads could be "thrown" across the Moon's surface, or, if they attain high enough speeds, can reach orbital velocity and perhaps deliver material to a space station, or storage depot near the Moon.

Though the United States stopped its maglev development effort a decade ago, West Germany, England, and Japan are in the process of testing, building, and operating maglev systems. Some cities in the United States are now considering buying the technology from abroad.

tures, electronics, computers, that will support both ventures. Technology transfer opportunities exist between NASA and maglev.

"If we continue to focus on the near-term payoffs in projects that are motivated only on the basis of the near-term payoff, we will not be able to carry out such projects as lunar development."

Maglev on the Moon

A series of presentations at the conference, including a luncheon address by Henry Kolm, who is the father of magnetically levitated trains in the United States, summarized the state of maglev research. Using magnetic fields to levitate a train above a guideway, and to power the motors to move the train, offers noiseless, pollutionless, energy-efficient all-electric transportation, which is nearly limitless, in terms of speed (see box).

The program in the United States, which began in the mid-1960s at MIT, came to a halt a decade later, and this nation has no research ongoing, no system under development, and no manufacturing companies that could build such an advanced transportation system.

But in Japan, West Germany, and England, maglev systems are under development, and representatives of the General Electric Company of England at the conference, described their small operating system at Birmingham Airport, which went into service in 1984.

The Birmingham meters of track (less than half a mile), and can carry 397 passengers each way every 15 minutes. Each trip has a journey time of 100 seconds. The only moving parts on the trains are the doors, and the maximum speed of travel is 34 miles per hour, due to the short distance. Though this system is a kind of miniaturization of a full-scale train line, it is the only commercially operating maglev system in the world.

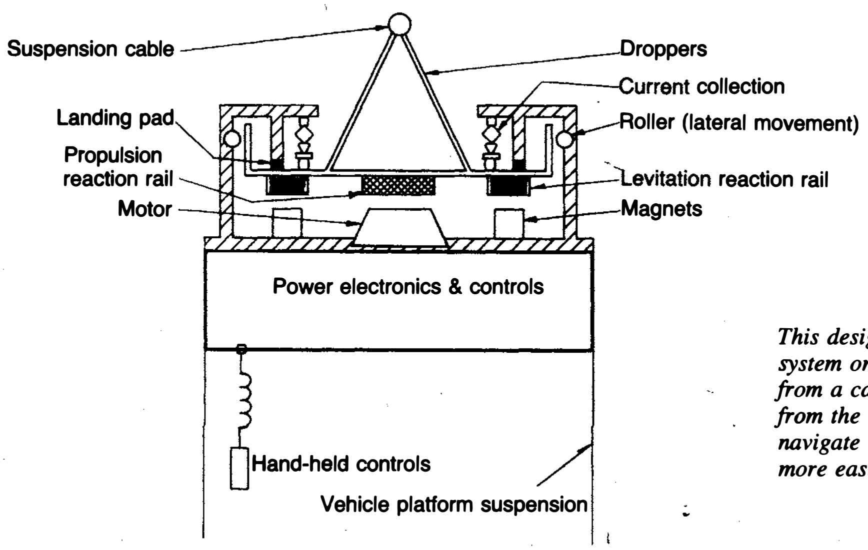
The GEC speakers speculated on how such a frictionless, all-electric transport system might operate under the gravity of the Moon, which is one-sixth that of Earth. Michael Atwell, from Rapid Transit Projects in England, which was formed recently to market maglev technology from the United Kingdom, stated that a lunar transport system will be needed to travel from the initial base to landing sites, to mining outposts, to exploration regions, and to the telescopes and other scientific instruments stationed on the Moon.

The early vehicles will be brought in pieces from Earth to be assembled on the Moon, but will be considerably lighter than the five-ton vehicles used in the Birmingham system. Power requirements to run the trains will be as little as 1/20 of those on Earth, though trains will need life support systems if they are enclosed, or, if the cars are open, the passengers will have to wear space suits.

Ron Sturland from GEC suggested that, rather than trying to perfectly level the highly cratered and irregular lunar surface, the trains be suspended from an overhead cable guideway, or catenary (**Figure 1**). Most of the payload would be equipment needed for the base, he said, and the astronauts could simply stand up during the short trips.

If the system is suspended in this way, it would have to be designed to protect the passengers and equipment electronics from lethal radiation. The alternative is to place the

FIGURE 1



This design for a magnetically levitated train system on the Moon, has the vehicle suspended from a cable. The all-electric train would hang from the elevated structure, which would navigate the craters and uneven lunar surface more easily than a conventional rail design.

Source: Ron Sturland, GEC.

trains undergound, which would require the use of new, highly efficient tunneling technologies.

Such a new technology, using a nuclear fission reactor for a heat source, was proposed at the conference by Joseph Neudecker, Jr., from the Los Alamos National Laboratory. Twelve years ago, a team at Los Alamos developed a system they called Subterrene, to use the heat of a nuclear reactor to melt rock and soil to build tunnels. The anti-nuclear sentiment of the 1970s, and the fact that there were not high power-level, compact nuclear reactors available at that time, left Subterrene in the experimental stage.

In his concept for use on the Moon, which Neudecker calls Subselene, a reactor provides 3 megawatts of thermal power at about 1,300 degrees centigrade, to each of 134 individual rock-melting heaters. This tunneler design would produce a 5-meter-diameter hole, using a total of 400 megawatts of thermal energy, which could advance at a very fast rate of 80 meters per day. The system could be entirely automated.

One of the most serious problems in lunar tunneling will be the fact that the surface is heavily cratered, and the soil very fragmented. Internal support for the tunnel using Subselene, however, would be straightforward, since the liquid melt from the boring heaters forms a glass lining, for tunnel support. The remainder of the melt could be extruded behind the Subselene machine, and further processed and used in a variety of structural shapes, such as bricks and cylindrical tubes.

Subselene does not require the use of volatiles such as water or gases, which will be very expensive on the Moon since they will have to be brought from Earth. Neudecker stated that all of the elements of the Subselene technology had already been worked out at previous projects at Los Alamos, and the current space nuclear reactor project being developed jointly by NASA, the Defense Department, and the Department of Energy, will make small, compact nuclear reactors available, by the time Subselene is ready to go to the Moon.

Transport for lunar science

One half of the Moon is never seen by us from the Earth, because its period of rotation on its axis is the same as its period of revolution around the Earth. This makes the far side of the Moon a perfect place to put radio telescopes and other observational equipment, to be able to look at the heavens from a stable platform, outside of the Earth's atmosphere, and facing away from the Earth's radio transmissions and other electromagnetic radiation.

Dr. G. Jeffrey Taylor, from the University of New Mexico, described the characteristics of the Moon's environment, from the standpoint of lunar astronomy, in his conference presentation. He stated that the Moon's geological environment makes it extremely well-suited for astronomical observation.

The Moon is a "seismically and tidally stable platform on which to build structures," he said, with the total amount of seismic energy released being one billion times less than on Earth. Most moonquakes are so slight they would be considered background noise on Earth, and there are about 500 quakes per year, compared to about 10,000 on Earth.

Our Moon has a tenuous atmosphere that does not cause wind-induced stresses and vibration on structures, nor does it blur images. The near-vacuum will be important for measurements of phenomena such as the solar wind. The tenuous atmosphere on the Moon will have to be carefully monitored in the vicinity of scientific experiments, when you consider that each Apollo mission temporarily doubled the nighttime mass of particles in the atmosphere.

According to Taylor, the micrometeorite fluxes on the Moon, where there is no atmosphere to slow down or break up small bodies from space, mean that "sensitive surfaces, such as mirrors on optical telescopes, will have to be protected," and the high-radiation environment will require protection for people working on the lunar surface, and for electronic devices that are deployed there.

Dr. Taylor showed the fanciful design for an array of radio telescopes on the far side of the Moon (see illustration).

Stewart Johnson, from the BDM Corporation in New Mexico, added other possible scientific missions on the Moon. "Lunar-based astronomy," he said, "will utilize optical telescopes, radio interferometers and possibly high-energy photon detectors, cosmic-ray detectors and neutrino astronomy instruments." Johnson stressed that any transportation system on the Moon will have to be benign in terms of dust, chemical pollutants, electromagnetic radiation, and any other disturbances.

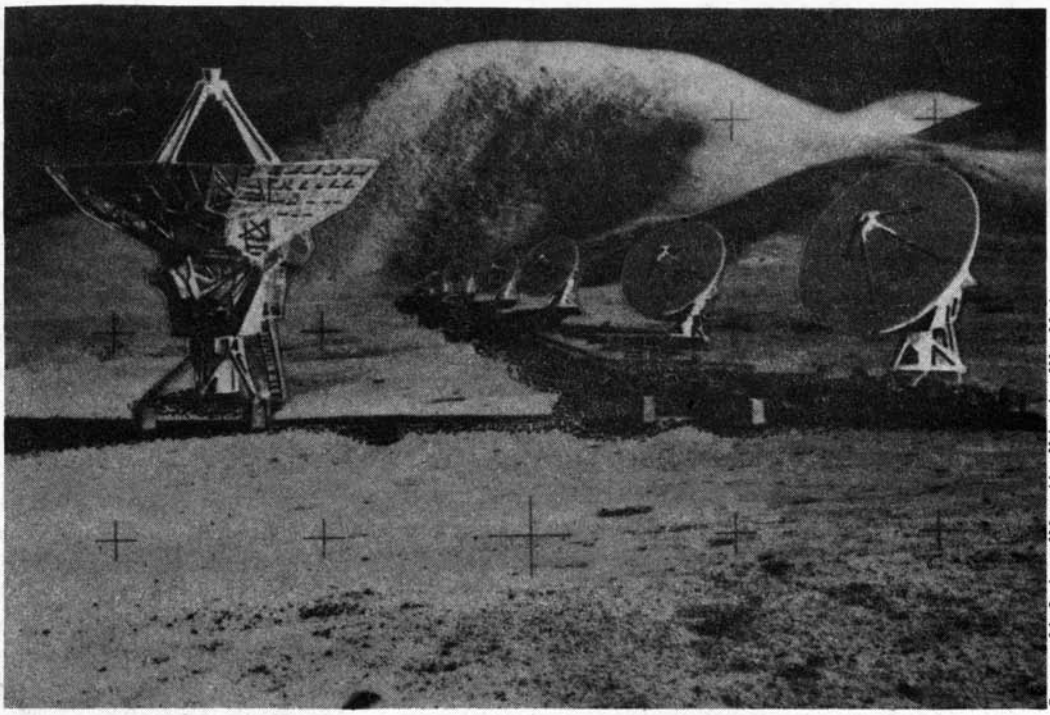
He described one possible astronomy concept for the Moon, which is based on the very large Arecibo-type telescope. This radio telescope is engineered into a natural depression in Puerto Rico, and a like design could protect a telescope and antenna arrays at the bottom of a crater on the Moon.

Mining and materials

One of the major activities on the Moon that will start soon after astronauts return there, will be the movement of large amounts of soil, or regolith, to provide radiation shielding. Wallace Roepke, from the U.S. Bureau of Mines in Minneapolis, presented a challenging picture for the conference participants of what mining on the Moon will require.

A few weeks before the September meeting, Roepke had provided this author with a paper that was presented at the Working Group on Extraterrestrial Resources, in 1968, eight months before the first manned landing on the Moon. The earliest source on lunar mining cited in this paper, was a 1956 article from the *Journal of the British Interplanetary Society*.

NASA began funding research by the Bureau of Mines (BOM) in 1965, as everyone in the space program assumed



This fanciful superimposition of a radio telescope array on the Moon was used by Jeff Taylor as one example of the opportunity for science on the Moon.

Courtesy of the Institute of Meteoritics, University of New Mexico.

that the establishment of lunar bases would follow within a decade of the initial manned exploration. In the 1968 BOM paper, it is pointed out that space logistics and economics "emphasize the need for simplicity, reliability, and automation" for mining and materials-processing systems.

Work was under way, at that time, using simulated lunar materials to determine a broad range of physical properties of the soil. The work done by the BOM contributed to the design of the drilling and other equipment Apollo astronauts took with them, between 1969 and 1972.

At the lunar-maglev conference, Roepke presented a picture of the mining technology requirements to develop lunar resources. During Apollo missions, astronauts found that no core samples deeper than 2.9 meters could be obtained, using the drills they had with them. Extracting the rotary drills from the soil proved to be more difficult than expected from Earth experience, and almost had to be abandoned at the Apollo 15 site.

Roepke stressed that in most of the "strategies currently being proposed . . . the assumption is being made that terrestrial mining technology can be readily adapted to the lunar environment." The friction, temperature variation, chemical composition, and other characteristics of lunar rock and soil are so different from those of Earth, that entirely new mining and materials-processing technologies will have to be developed, rather than simply modified from existing techniques, he stated.

At the end of his presentation, Roepke demonstrated the only mining equipment that he could be sure would work on the Moon (see photograph).

In his paper on astronomy on the Moon, Stewart Johnson mentioned that telescopes and other equipment will have their foundations buried in the lunar soil, to prevent them from being subjected to wide variations in temperature on the surface. Larger-scale mining, however, will be required, to provide approximately 10 feet of shielding material for living quarters, and also the raw material for new materials-processing industries.

Materials scientists have already started to experiment with simulated lunar soil, and the real thing, to examine what can be fabricated on the Moon.

What you can make from lunar soil

The small amount of exploration done by the dozen astronauts who traversed the Moon during the Apollo program, has not indicated that there are Earth-like veins of minerals there. But the soil has recently proven to be a potentially excellent raw material for the structures that a lunar base will require, assuming the Bureau of Mines solves the problem of digging up lunar rock and soil, and provision is made for transporting them to processing facilities.

Over the past year, an impressive amount of actual hands-on experimental work has been done, to examine the properties and fabrication techniques needed to use lunar soil. A paper by Tom Meek, from Los Alamos National Laboratory, presented to the conference by Dave Vandeman, discussed the possibility of using microwave energy to process lunar material. Experiments were done using 2.45-gigahertz microwaves, produced by a magnetron, for 25 minues in an oven.

The material was melted and sintered, and the reseachers found that the heating rate increased as the temperature increased. They were able to generate different phases in the material that are transparent to the microwave energy, and created a ceramic which they posit could be used to "pave" lunar roads, reinforce sides of craters to hold structures, and cover over places where a low dust level is desired.

Bill Agosto, head of Lunar Industries, discussed the production of cement and concrete from lunar soil, and pointed out that the strength integrity must be maintained in the lunar vacuum.

T.D. Lin, from Construction Technology Laboratories, described the experiments he had done with the 40 grams of real lunar soil he had been given last March, by the Johnson Space Center. The sample was from Apollo 16.

Lin stated that the goal of his work was to evaluate lunar concrete for the construction of a lunar base, and that his preliminary finding was that the strength in the lunar concrete was two times the pounds per square inch construction code requirement for concrete used here on Earth.

This is quite significant in two respects. First, this result was not found using lunar simulant, and it has been hypothesized that, though you can simulate the chemical composition of lunar soil, the real soil, which has been created from micrometeorite bombardment of rock, has suffered thermal and other shocks, which are not recreated in the simulant.

Second, if you produce a building material with more strength than is needed on Earth, in the one-sixth lunar gravity, structures built from this material can be enormously larger than on Earth.

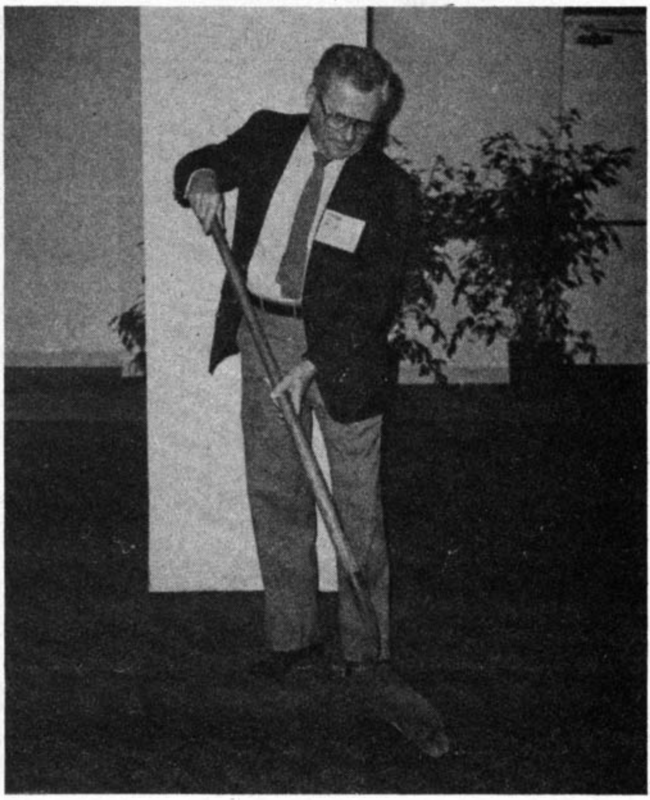
Lunar composite materials were discussed in a paper by William Lewis and Theodore Taylor, based on experimental work being done at Clemson University. They have been examining the use of lunar-derived glass for construction, by producing glass fibers. The lunar regolith simulant was melted, formed into fibers, given a metal coating, pressed together, and welded into structures.

The material produced has properties similar to fiberglass, which does not crack, because the fibers are held together by a matrix. In Earth-made fiberglass, the matrix is made of resin, and in the lunar simulant experiments, it was supplied by the metal coating. The tensile strength of the lunar glass composite is comparable to certain kinds of wooden building beams.

How people might live on the Moon

One of the most interesting conference presentations was given by architect Joseph Mangan from New York, who has taken the regular Platonic solids and formed them into basic building elements and living structures, for Earth and Moon.

Based on the tetrahedron, made up of equilateral triangles for its four faces, Mangan has created an expandable platform which can be added to with identical modular faces and connecting joints, and clustered in either a convex or concave configuration. The open and light structural frame can be used to form a multilevel platform with a variety of activities possible for each level.

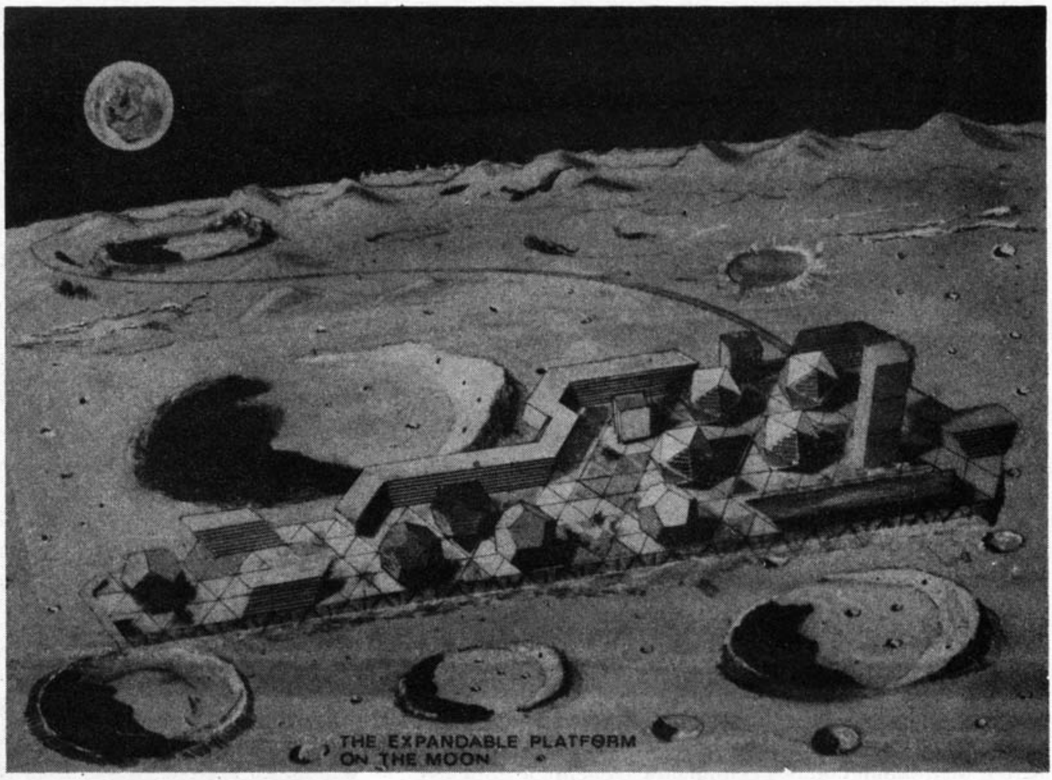

Marsha Freeman

Wallace Roepke from the Bureau of Mines demonstrates the operation of the only proven technology for mining on the Moon.

Mangan has made use of all of the Platonic solids (the tetrahedron with four sides, the cube with six sides, the eight-sided octahedron, the 12-sided dodecahedron, and the 20-sided icosahedron) for buildings which can be living quarters, laboratory space, and office space. On the Moon, the platform supported by the tetrahedral frame could be covered with the necessary lunar soil or regolith, for radiation protection.

With its truncated base, the tetrahedral frame is ideal for stepping around craters and other irregularities on the lunar surface, the same way any elevated structures do on Earth (**Figure 2**). Portions of the base inside a crater, for instance, would simply have extra levels, compared to the areas under the flatter parts of the surface.

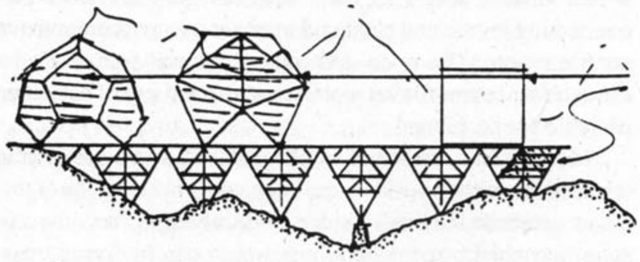
Mangan remarked that the icosahedron and dodecahedron forms, when sitting on the platform, as pictured in the illustration, look like geodesic spheres, but they are not. They are structures that can be highly pressurized due to their inherent structural strength, and fit exactly into the support frame of the platform, because of its geometric shape.



Joseph J. Mangan

The expandable platform on the Moon would have levels underneath the soil, which would house the transportation, energy production, and other lunar base infrastructure. Here, Platonic-solid structures are on top of the platform, though they would either be shielded for housing, or they would be used for unmanned operations.

FIGURE 2



The structural pieces for the expandable platform holding the Platonic solids are made of tetrahedral shapes. As can be seen here, they can form a flat top platform, and also be the structural support anchor for buildings above.

Source: Joseph J. Mangan.

The tetrahedral frame uses 35% less steel or other building material than a conventional structure, and the preformed sections give the dwellers on the Moon the flexibility to create different-shaped structures for various purposes.

The key is fusion energy

A provocative and exciting concept was presented at the lunar-maglev conference by Gerald Kulcinski, director of the Fusion Technology Institute at the University of Wisconsin. Most of the research that has been done over the past 20 years, with the notable exception of Krafft Ehricke's work, has assumed that only today's energy technologies will be used in lunar industrial development.

Scientists and engineers have spent years trying to figure out how mankind will produce the life-support, food, industrial equipment, processing technologies, and other needs for lunar bases and cities, using conventional chemical and fission energy. They have also performed most calculations on getting from here to Mars, using the same energy sources for propulsion.

Thermonuclear fusion, with energy densities orders of magnitude greater even than fission, will open up the age of direct plasma processing, without the use of chemicals, intermediate gases, or precious water, none of which is indigenous to the Moon. Energy for electricity, heat, artificial sunlight, materials processing, scientific experimentation, and propulsion to more distant places, can be provided by fusion.

But as we are developing the Moon, the real energy deficit on Earth, as fossil and uranium supplies dwindle, will become more acute. Kulcinski pointed out that there is fusion fuel sitting on the Moon, which could provide enough energy for the Earth for thousands of years.

Fusion, the combining of the lightest elements into heavier elements which is the process that fuels the stars, has been under scientific investigation for about 30 years. Research

Marsha Freeman

Dr. Gerald Kulcinski, director of the Fusion Technology Institute at the University of Wisconsin.

TABLE 1

Comparison of Nuclear Energy Options

	Fission		Fusion		
	LWR	Breeder	DT	DD	DHe^3
Terrestrial world fuel resource	~10y	500-1000y	500-1000y	>10,000,000,000y	<1y
Rel. biological hazard potential	1000	1000	10-100	5-50	0.01-0.1
Thermal conv. efficiency, %	33	40	35-45	35-50	50-70

Source: Clean Thermonuclear Power from the Moon, G.L. Kulcinski, J.F. Santarius, L.J. Wittenberg, September 1986

has focused on combining two isotopes of hydrogen—deuterium and tritium—to release energy, mostly in the form of highly energetic neutrons. Electrical energy is produced, using D-T fusion, through the same process that is used with fossil fuel and fission plants today.

But on the Moon, where there is no water, using today's steam turbines with an overall efficiency of 33% to produce power, will not be desirable. More advanced fusion fuels, such as deuterium combined with ^{3}He, will produce nearly all of its energy in charged particles, rather than neutrons. In this form, the energetic particles can be used directly to produce electricity, without any moving turbines, or steam.

Unlike the tritium isotope of hydrogen, helium is not radioactive, and there will be no radioactive byproducts, or difficulties in handling the fusion fuel. Although the conditions for producing fusion using these more advanced fuels are more severe, recent progress in fusion experiments, according to Kulcinski, provide optimism in meeting the conditions for using ^{3}He.

The major reason that there have not been fusion experiments using ^{3}He until now, is that it is not a naturally occurring isotope of helium on Earth, and there is so little of it, that "the lack of a long-range supply of ^{3}He has limited serious consideration of this fuel cycle for the past 20 years," according to Kulcinski (**Table 1**).

Kulcinski and other scientists recently "began a search for this isotope elsewhere in the Solar System." They found that over billions of years, the solar wind has been depositing ^{3}He on the surface of the Moon. He estimated that there are probably one million tons of ^{3}He sitting on the lunar surface.

According to Kulcinski, modest heating, at about 600 degrees centigrade, would liberate most of the ^{3}He from the fine-grained particles on the Moon. The heat could be provided initially from the 14-day-long lunar day. The total energy content of the ^{3}He on the Moon is estimated to be 19,000 terrawatts per year.

This amount would satisfy approximately 1,900 years of present world energy demand.

At improved standards of living, and greater population, the lunar supply could at least provide a one-century bridge to the "extremely large reserves" of ^{3}He in the atmosphere of Jupiter.

Kulcinski notes that 20 tons per year of ^{3}He from the Moon, would provide the fuel for today's entire U.S. electrical utility industry. This ^{3}He, if liquefied, could be brought back to Earth in one spaceship, the size of the Space Shuttle, and the energy payback on returning ^{3}He to the Earth is about 250 times more than would be invested. Mining only 1% of the Moon's surface could provide all of the Earth's energy needs for a century.

Between now and the turn of the century, when we could expect lunar mining to be providing the Moon and the Earth with ^{3}He, Kulcinski explained that the decay of tritium from nuclear weapons production, nuclear fission byproducts, and the byproduct of natural gas production, could provide enough advanced fusion fuel for the experiments and testing of deuterium-^{3}He fusion reactors, and operation of a commercial prototype reactor.

His team at the University of Wisconsin is now investigating how experiments could be done, using existing devices, to demonstrate the production of fusion energy using ^{3}He. For the economic development of the Moon, and the like development of large sections of the Earth, producing fusion energy with advanced fuels will open up a new era of virtually limitless, high-quality energy.

In the two years between the Lunar Bases meeting in Washington, D.C., in October 1984, and the lunar development conference in Atlantic City this past September, impressive progress has been made in the hands-on experimental research that will produce the technologies for industrializing the Moon.

The new possibility that advanced fusion energy suited for orbital use, propulsion, and lunar base requirements can be ready when we set out to permanently settle the rest of the Solar System, means that mankind will start a genuinely new era of the age of exploration, past the turn of the century.