REPORT

of the

SECOND ANNUAL MEETING

of the

WORKING GROUP ON EXTRATERRESTRIAL RESOURCES

on

October 23 - 25, 1963

at the

Air Force Missile Development Center
Holloman Air Force Base
Alamogordo, N.M.

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FOREWORD

The Working Group on Extraterrestrial Resources is composed of people from the National Aeronautics and Space Administration (NASA), the U.S. Air Force, Office of Engineers of the U.S. Army, the Jet Propulsion Laboratory, and the Rand Corporation. It was organized for the following function:

> "To evaluate the feasibility and usefulness of the employment of extraterrestrial resources with the objective of reducing dependence of lunar and planetary exploration on terrestrial supplies; to advise cognizant agencies on requirements pertinent to these objectives, and to point out the implications affecting these goals."

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MINUTES OF THE SECOND ANNUAL MEETING

The second annual meeting of the Working Group on Extraterrestrial Resources was held October 23-25, 1963, at the Air Force Missile Development Center, Holloman Air Force Base, Alamogordo, New Mexico.

The first day's session (closed to industrial participants) was attended by about 25 members and invited guests. After a welcoming address by Colonel R. S. Garman, Commander of AFMDC, Dr. E. A. Steinhoff, RAND, Chairman of the Working Group made some introductory remarks on the objectives of research in the utilization of extraterrestrial resources, (Paper 1). Dr. Steinhoff's address was followed by the presentation of reports on the activities of the four subgroups by: Lt. Colonel G. W. S. Johnson (USAF-Ret.), chairman of the subgroup on Facilities Construction, operation and Maintenance; Bruce Hall, U.S. Army, who was substituting for R. C. Speed, JPL, chairman of the subgroup on Environments and Resources; Dr. J. W. Salisbury, AFCRL, chairman of the subgroup on Mining and Processing; and Dr. M. G. Del Duca, NASA, who substituted for Dr. E. B. Konecci, NASA, chairman of the subgroup on Biotechnology. These reports have been published in Recommendations for Utilization of Lunar Sources, Jet Propulsion Laboratory, June 28, 1963. Briefings on Air Force areas of interest and related research activities were given by: Colonel C. E. Lutman, AFSC (representing Major General O. J. Ritland, Deputy to the Commander for Manned Spaceflight) who described Project Super (Support Program for Extraterrestrial Research): and Colonel J. R. Fowler, AFOAR (representing Major General Don R. Ostrander, Commander, Officer of Aerospace Research).

Dr. J. B. Edson, NASA Headquarters, OART, chairman of the Steering and Planning Committee, spoke about future programs and objectives of the group. The names of the officers and subgroup chairmen, selected by the committee for the coming year were submitted.

The new subgroup chairmen and their addresses are:

Subgroup on Environments and Resources:

Dr. John W. Salisbury, (formerly chairman of Subgroup on Mining and Processing) Air Force Cambridge Research Laboratory, Headquarters, AFCRL, OAR (CRZEL). L. G. Hanscom Field, Bedford, Massachusetts.

Subgroup on Facilities Construction, Operation and Maintenance

Mr. C. W. Henderson, NASA, Chief of Lunar Basing Studies (Code MGL), Office of Manned Space Flight, Washington 25, D.C.

Subgroup on Biotechnology

Col. Charles W. Craven, Manned Environmental Systems Directorate, Air Force Space Systems Division, Los Angeles 45, California

Subgroup on Mining and Processing

Mr. Bruce Hall, Office of Chief of Engineers, U.S. Army, Gravelly Point, Virginia.

Dr. E. A. Steinhoff will continue as chairman of the Working Group and Dr. J. B. Edson will continue as vice-chairman of the Working Group and chairman of the Steering and Planning Committee. Major Roger E. Bracken, Acting Chief of Plans Division, DCS/Plans and Operations, AFMDC, (MOOP), Holloman AFB, will serve as the new secretary of the Working Group. William H. Allen, NASA, Headquarters, OART, will serve as the new secretary of publications.

Following the business session, attendees were joined by industrial participants for the evening session. The featured speaker of the evening was Dr. Raymond L. Bisplinghoff, Director, Office of Advanced Research and Technology, NASA (paper 2).

The second day's session was open to industrial participants. The papers presented at the open sessions are included (papers 3-12).

1- INTRODUCTORY REMARKS

Dr. E. A. Steinhoff, RAND Corporation*

Colonel Garman, Dr. Bisplinghoff,
Gentlemen, Representatives of Government and Industry:

It is a great honor to welcome you today to the Second Annual Meeting of the Working Group on Extraterrestrial Resources. For these of you who are with us for the first time, I should like to reiterate how this Group was founded, what its objectives are, and what we are planning to do during the coming year.

Nearly two years ago, I discussed with several staff members of the Marshall Space Flight Center, some of them here today as for instance Mr. John Bensko of the Future Projects Office of that Center, that my studies as well as those of others do indicate that the area of space logistics and use of natural resources believed to be existing on destination planets as for instance on Mars, appears to have a much greater effect on feasibility and economy of interplanetary space flight than is generally recognized. We came to an agreement that in order to spread this gospel, it would be necessary to combine in one study group those scientific workers in the field, who are contributing to the subject by own studies or by performing supporting experimental work. This was done, and in an organizing meeting early in 1962 at Rand, the Working Group on Extraterrestrial Resources was formed. Many have contributed time and effort to accomplish what we have today, but I would like to single out from these Dr. James B. Edson, our Deputy Chairman, who through his untiring personal effort, particularly at NASA Headquarters, has provided leadership and encouragement to many initially doubtful of the chances of such a venture. The history of the Working Group's past two years confirms this.

Figure 1-1 shows, from work of Herman Koelle and his colleagues at NASA - MSFC, the impact on the economy of lunar projects for cases in which locally produced fuel is used to refuel commuting space vehicles. The potential reduction of the commuting cost by a factor from 50 to 80 as compared to the estimated cost of Apollo missions should show unequivocally the possible pay-off of utilization of extraterrestrial resources, if vigorously pursued concurrently with the vehicle and technology development in support of this national effort. However, fuel is not the only supply needed to maintain an exploratory base on the Moon or Mars. Many items, if not produced or regenerated locally, will have to be supplied from Earth. Using Mars as an example, this will be a much more difficult task. Many of us are sure that the exploration of space will not stop with one manned landing on the moon only. If this becomes a national objective, its cost to the nation will be vitally affected by the work this Working Group set out to perform.

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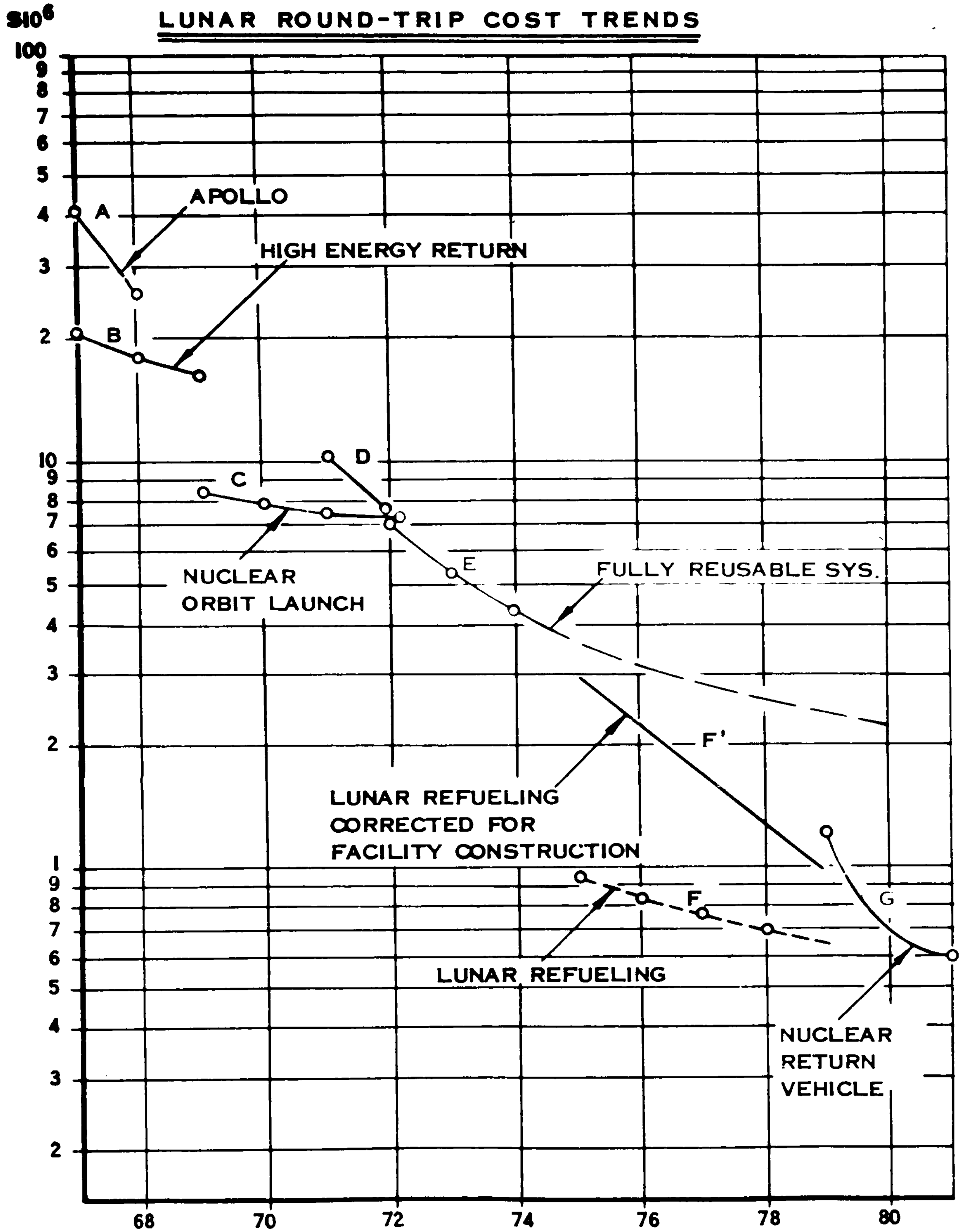
*The RAND Corporation, Santa Monica, California. Any views expressed in this paper are those of the author. They should not be interpreted as reflecting the views of The RAND Corporation or the official opinion or policy of any of its governmental or private research sponsors.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NUCLEAR
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FULLY REUSABLE SYS.
F'
LUNAR REFUELING
CORRECTED FOR
FACILITY CONSTRUCTION
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G
LUNAR REFUELING
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FIGURE 1-1

Figure 1-2 shows the history and composition of the Working Group.

WORKING GROUP ON EXTRATERRESTRIAL RESOURCES

HISTORY: WAS FOUNDED 18 MONTHS AGO BY WORKERS IN:

* NASA
* AIR FORCE
* ARMY
* JPL
* RAND
* UNIVERSITIES
* INDUSTRY

Figure 1-3 lists what we consider extraterrestrial resources.

USE OF EXTRATERRESTRIAL RESOURCES

WHAT ARE EXTRATERRESTRIAL RESOURCES?

* WATER FOUND ON MOON, MARS OR OTHER PLANETS
* RAW MATERIALS SUITABLE FOR FUEL PRODUCTION AND REPLENISHMENT OF LEAKAGE LOSSES
* BUILDING MATERIALS FOR BASING UNITS
* RARE MATERIAL RESOURCES

Figure 1-4 states the general objectives of the Group.

OBJECTIVES

* REDUCE SPACE LOGISTICS REQUIREMENTS TO REMOTE EXTRATERRESTRIAL BASES
* TO GENERALLY REDUCE COST AND INCREASE SAFETY OF SPACE FLIGHT TO EXTRA-TERRESTRIAL TARGETS
* TO STUDY PREREQUISITES FOR USE, PREVAILING ENVIRONMENTAL CONDITIONS . . . AND DETERMINE PROBABLE RAW MATERIAL RESOURCES.
* TO PROVIDE INPUTS TO PLANETARY EXPLORATION PROGRAMS FOR THE ACQUISITION OF SUPPORTING DATA
* TO MAKE RECOMMENDATIONS BASED ON FINDINGS TO FEDERAL AGENCIES

Figure 1-5 indicates that in order to be more effective we have subdivided the Group into a number of subgroups.

SUBGROUPS

* ARE ACTIVELY CARRYING OUT RESEARCH IN THEIR SPECIFIC FIELDS
* CONSIST OF ACTIVE SCIENTIFIC WORKERS OF FEDERAL UNIVERSITY AND INDUSTRIAL LABORATORIES
* CHAIRMAN AND DEPUTIES MEMBERS OF FEDERAL AGENCIES
* DISSEMINATE RESEARCH DATA AND INFORMATION IN FIELD

Before we go into more details of our goals, I would like to acquaint you first with the history, composition, organization and general objectives as well as the physical reference frame the Working Group intends to work in.

Figure 1-6 gives detailed organization and missions of the Working Group, the Steering Committee and the names and chairmen of the sub-groups as well as their current status.

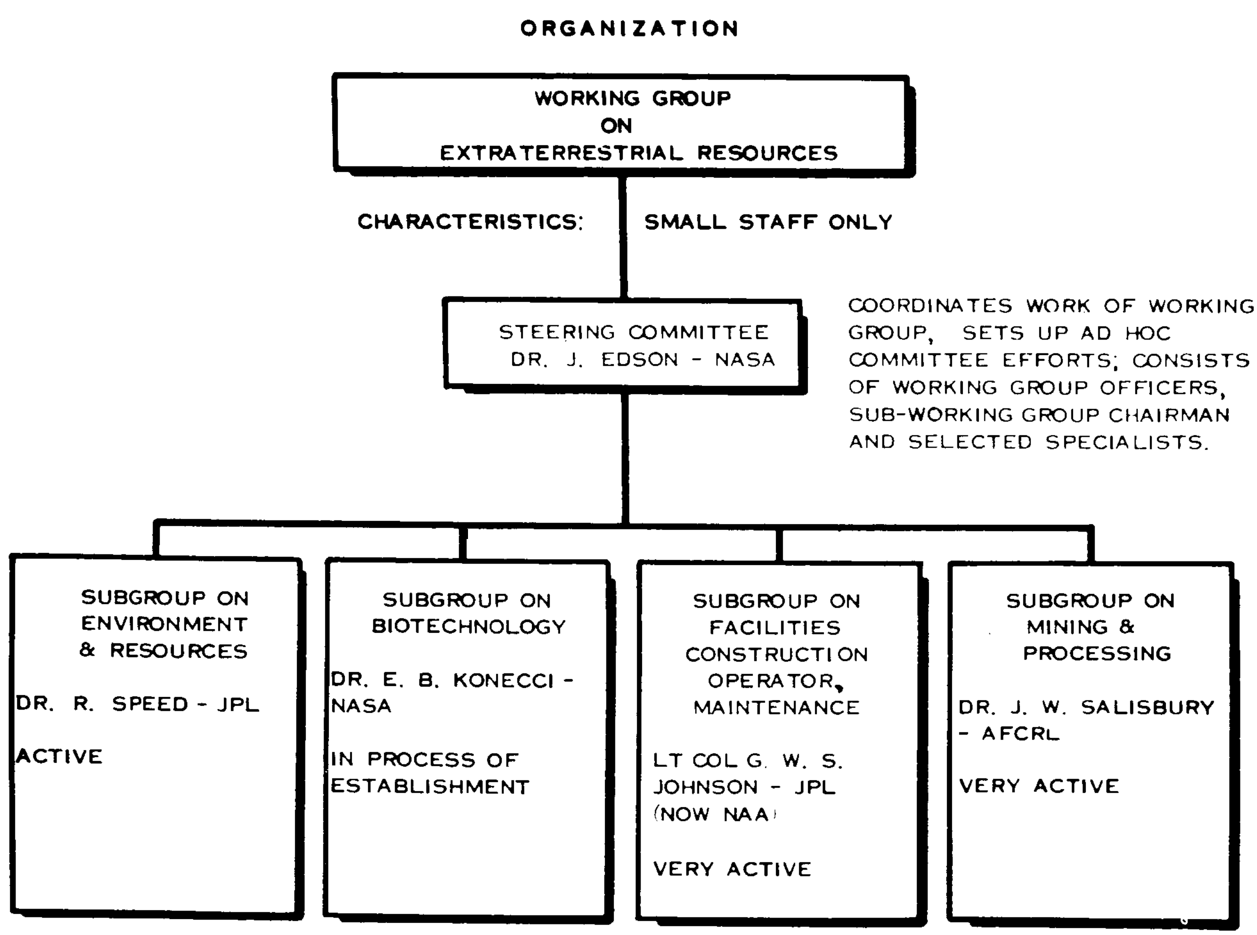

FIGURE 1-6

Figure 1-7 gives us an outline of the tasks of general space logistics. From it we can determine the areas of potential pay-off for work of the Working Group.

SPACE LOGISTICS

CONSISTS OF:

* FUELS FOR SPACE VEHICLE PROPULSION
* FUELS FOR SECONDARY POWER
* WATER AS RAW MATERIAL
* FOOD SUPPLIES AND CONSUMABLES
* SPARE PARTS
* NEW OPERATIONAL AND SCIENTIFIC EQUIPMENT; MODIFICATION KITS
* BASE UNITS FOR EXTRATERRESTRIAL BASES
* EXTRATERRESTRIAL TRANSPORTATION EQUIPMENT

According to figure 1-8, space logistics can be subdivided into three potential operational modes which all, to a greater or lesser degree, will affect economy of logistics.

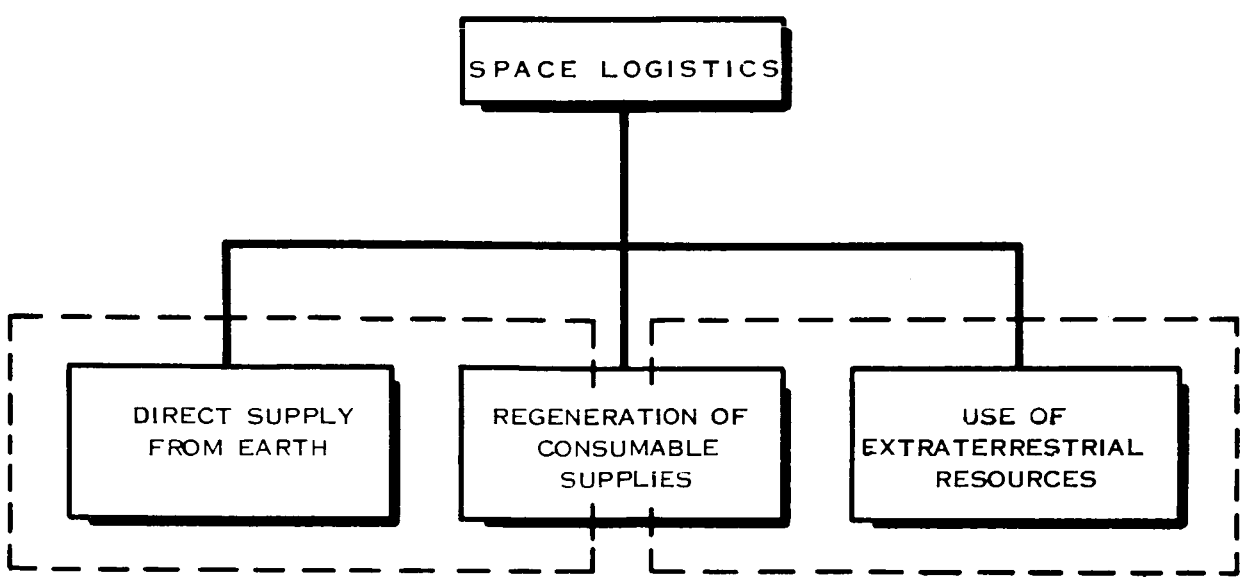

FIGURE 1-8

In looking into efforts under way, we find that two major areas of needed effort are not covered sufficiently and could delay utilization of potential developments. The two areas are; a) secondary power plants for stationary operation in extraterrestrial environments and b) regeneration techniques for life support in extraterrestrial environments.

The Working Group and its sub-groups communicate among themselves, with the scientific community, and with its sponsors by a) internal reports of sub-groups, b) recommendations for utilization of lunar resources, c) personal correspondence, and d) briefings on projects in progress and on the state of the art of technology.

Recommendations have been made for the utilization of lunar resources and published in the "Report of the Working Group on Extraterrestrial Resources," prepared for the National Aeronautics and Space Administration Office of Advanced Research and Technology, submitted on 28 June 1963.

Since these are available in subject report, they are not repeated here. However, certain aspects of these recommendations will have to be dealt with further.

In order to obtain a more specific picture in which way utilization of extraterrestrial resources can affect economy, safety and effectiveness of space research, models of extraterrestrial bases have to be developed. The problem areas encountered in the establishment, operation and logistics of these bases have to be studied in more detail, comparing support and logistics requirements of bases wholly supported from earth as compared to those either making partly or maximum use of extraterrestrial resources. In examining these cases, one finds that the first case requires a considerably different mission layout for chemically propelled space systems than the latter approach. Maximum utilization of the possible savings can only be made if the design of the mission and of the space vehicles reflects this observation. While in the first case, for instance, staged vehicles of the size of Saturn C-5 will have to be used to perform a lunar roundtrip involving refueling in either Lunar or Earth orbit, with fuel brought from Earth, in the second case one would use non-staged, re-usable vehicles which are refueled at both ends of their journey from Earth orbit to Lunar orbit or Mars orbit. These vehicles would commute between both terminal orbits and would be supplied from both celestial bodies by special surface-to-orbit shuttle vehicles. Size of the commuter vehicle, its payload capacity, number of crew members and duration of stay at the extraterrestrial base, among other functions, will determine the number of flights necessary to support such a mission. Henceforth, it determines the capacity of equipment necessary to utilize extraterrestrial resources to produce fuel, food and life support, if this equipment is intended to replace terrestrial logistics in support of lunar and planetary space missions.

In analyzing support requirements and substituting terrestrial logistics by progressive utilization of natural resources from the destination body, one finds that each particular case shows a trade-off between terrestrial logistics and required payload to support a mission, as against payload requirement for equipment needed to utilize extraterrestrial resources. This will result in a time span after which the utilization of extraterrestrial resources becomes superior to the direct supply from Earth. For each item of need for an extraterrestrial base or its occupants, be it return fuel, food, life support requirements, etc., this time will be different. There will be some critical items which never will be produced at extraterrestrial bases, since the demand never reaches the threshold at which, transport and cost of required equipment considered, it will be cheaper to produce these items at the extraterrestrial base. For other items, this time span can be counted in days, months or a few years before the local utilization of resources becomes competitive. It may be noted that the type of mission approach to some extend effects these time periods of crossover, but does not invalidate this conclusion. These numbers are naturally different, if one considers the Moon or planet Mars as a target, particularly if crew safety requirements are considered. It is quite obvious that utilization of natural resources is more important for missions to planet Mars than to the Moon, since Mars is farther away and it may take many months before even the most efficient space vehicles of 1975 vintage can reach Mars for an emergency rescue mission. An intermediate between terrestrial and extraterrestrial logistics is the regeneration of waste products, which is applicable to life support supplies only and does not cover the return fuel requirement. (Figure 1-9).

Figure 1-9 compares advantages and disadvantages of direct logistics from Earth.

DIRECT SUPPLY FROM EARTH

ADVANTAGES	DISADVANTAGES
* CONVENTIONAL MANUFACTURING METHODS USABLE	* COSTLY, WHEN SUPPLIES HAVE TO BE MOVED BEYOND EARTH ORBITS
* PLENTIFUL SUPPLIES	* EXPENDABLE VEHICLES REQUIRED IF Δv-REQUIREMENTS > 30,000 FPS
* NO TECHNOLOGICAL STRAIN	* HIGH MASS RATIO REQUIREMENTS
	* RETURN FUELS HAVE TO BE BROUGHT FROM EARTH

Water is the most prominent logistics requirement, since it can be used to cover weight-wise more than 90% of all supply requirements, including fuels if oxygen and hydrogen are used as fuel compounds. The use of regenerative systems is the next important item down the line in reducing water demand, except for fuels of rocket power plants, down to a reasonable minimum. (Figure 1-10). Therefore it is a most urgent requirement to fill in by direct observations from the Earth, by use of astronomic orbiting observatories by fly-by space probe missions and all other means available to modern science, to assess the chances of finding water in anyone of the many forms it can be found in nature, in the crust of the moon, and even more important from the above considerations, on Mars or his two natural satellites. While attempting to do

Figure 1-10 outlines the merits of regeneration of consumable supplies. To reduce logistic supply from Earth, regeneration of consumable supplies is under consideration and has become part of the design objectives of space vehicles. It becomes even more important, if we think of the establishment of permanent lunar and planetary bases.

REGENERATION OF CONSUMABLE SUPPLIES

ADVANTAGES

* REDUCES RE-SUPPLY REQUIREMENTS TO LEAKAGE LOSSES
* PERMIT LONG TERM OPERATION
* REDUCES OPERATING COST
* EQUIPMENT CAN BE DEVELOPED AND TESTED ON EARTH
* FOOD CAN BE PRODUCED IN EXTRA-TERRESTRIAL ENVIRONMENTS

DISADVANTAGES

* REQUIRES COMPLICATED EQUIPMENT AND HUMAN SKILLS IN SPACE VEHICLES OR ON EXTRATERRESTRIAL BASE
* DOES NOT REMOVE NEED FOR EXPENDABLE VEHICLES RETURN FUELS MUST STILL BE BROUGHT FROM EARTH
* GENERAL OPERATING COST STILL HIGH

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this, we can be busy on Earth itself determining the possible upper and lower limits of water content in rock formations most likely to be found at these two prime destinations, and studying the effect on equipment size, power requirements, trade-off time as a function of water concentration, etc., to be gained with mission crew size, mission mode, and space vehicle payload capacity and such other factors entering the picture and affecting trade-off parameters.

From these considerations, the following steps appear to be logical objectives of the next year's activities of the Working Group and its subgroups:

I. Establishing:

a. A lunar base mission model, possibly for a 21-man permanent crew and a crew-size variation of between 9 and 30 crew members and 5 years duration of occupancy. Individual tours of duty 150 and 300 days.

b. A Mars base mission model, with 5 years occupancy and a crew size between 15 and 36 crew members. The Mars model should be based on minimum one-way trip times of 100 days, and maximum trip times of 250 days. Individual tours of duty 500 and 1000 days.

All considerations should be based on use of chemical fuels as LH_2 and LO_2 only. Vehicle types for space boosters should include Saturn C-5 as minimum size vehicle, and the $1x10^6$ lbs Post Nova vehicle as the maximum vehicle size to be considered in the 1970-1975 period, and the use of air-breathing logistic supply vehicles as lower stages.

Figure 1-11 summarizes the relative merits and the technological hurdles.

USE OF EXTRATERRESTRIAL RESOURCES

ADVANTAGES	DISADVANTAGES
* REDUCE LOGISTIC REQUIREMENT OVER LONG DISTANCES (50 EARTH RATIO)	* TECHNOLOGY YET NOT HAND
* REDUCES VULNERABILITY OF SUPPLY SYSTEM	* EQUIPMENT REQUIRES DEVELOPMENT TO OPERATIONAL RELIABILITY UNDER EXTREME ENVIRONMENT
* PERMITS REUSABLE SPACE SHIP UNITS WITHOUT STAGING REQUIREMENT	* EXTREME WEIGHT REDUCTION OF PRESENTLY USED EQUIPMENT NEEDED
* RETURN FUELS CAN BE PRODUCED AT EXTRATERRESTRIAL TARGET BASE	* MINING, EXTRACTION AND GENERATION METHODS TO BE DEVELOPED
* REDUCTION OF OPERATING COSTS BY FACTOR 5 TO 80, CONSIDERABLE RETURN PAYLOAD CAPABILITY	* HIGH DEGREE OF AUTOMATION REQUIRED

II. Establishing of alternate logistic models for both destinations for use of terrestrial resources, regeneration and extraterrestrial resources based on a reasonable mean value of water concentration in most probable rock raw materials, and determination of the time threshold after which the use of extraterrestrial resources becomes competitive. Consider effect of probable upper and lower concentration limits on this time value.

The tasks under I and II should be compiled from existing study material of NASA Centers and possibly the Armed Services, and evaluated by a special task force of mainly government and non-profit corporation personnel in a similar fashion as the Golovin Committee on large booster and the NASA-Air Force Committee on Hypersonic Research Aircraft under support of NASA Centers and Air Force organizations. Some industrial personnel with recognized background in this area as for example: George Johnson, Rudy Buschman, Kraft-Ehricke, Robert Hindebrand (Boeing), Dandrigde Cole (GE), should participate. Best estimates rather than detailed mathematical analysis should be used to arrive at first approximations. These first approximations should be later refined by more detailed studies.

The findings should be reviewed by the Working Group Steering Committee, which should arrive at an official (a) Basing Model, and (b) Logistics Model, to support it. Both models should be updated yearly as new information becomes available either through improved observations or refined computational data.

The sub-groups in turn should then develop corresponding operating concepts for their particular areas and arrive at first at best estimates of performances, equipment weights, support requirements, etc., and then feed results back to the Steering Group for the purpose of updating its models.

From each of these activities, it is expected that improved recommendations will result for the conduct of exploratory space research and the priority of particular research areas in support of improved space logistics. The models of Moon and Mars should be considered separately but consideration should be given to similarity of operation and equipment specifications based on dissimilarity should be identified

III. From the results of these sub-group activities, the #2 and #3 logistics items should be determined and considered for specific study in the 1964/1965 time period in a similar way as the #1 item, raw material "water" and its effect on logistics volume and modes of space operation defined.

Conclusions

1. The number of sub-groups should be increased by two to include secondary stationary power and regeneration techniques.

2. The Steering Committee should prepare a task assignment for each subgroup and review administration of task force as suggested above.

3. A more official status should be given to Working Group activities in the national interest of space research.

SOME NASA VIEWS ON FUTURE SPACE ACTIVITIES

Raymond L. Bisplinghoff

[redacted]

Ladies and gentlemen, I'm very pleased to spend this day with you and to learn first hand of the activities of the Working Group on Extraterrestrial Resources. This work has been familiar to me for some time through Jim Edson and Jim Gangler and earlier reports to the NASA. There's a story attributed to General Maxwell Taylor who asked a young paratrooper if he joined the Paratroops because he liked to jump. The young paratrooper said, no, he didn't really like to jump, but he liked to be with people who did.

I am not here today because I like to make speeches but because I'm very much interested in the topic of this meeting. The roster of Dr. Steinhoff's working group is very impressive and so were the papers that I heard today. They indicate a very wide range of interest in the matter of extraterrestrial resources and I was, of course, very much interested to observe the extent of NASA participation.

As you are all very much aware, activities in space are responsible for more than half of the 9 billion dollar increase in federal research and development outlays since 1956. The total space budget in fiscal year 1963 amounted to about 5.4 billion dollars of which just under 3.7 billion was obligated by the NASA. The Department of Defense budget was about 1.5 billion and the remainder was expended by the AEC, the Weather Bureau and the National Science Foundation. During 1964 we have asked the Congress for 5.72 billion dollars and of course the fate of this request is still unresolved. The House of Representatives appropriated 5.1 billion and the Senate authorized 5.35 billion. I suspect that it will be less than that, perhaps something between 5.35 and 5.1 billion. How we will be able to discharge our commitments with this sum of money of course is unclear; we've still got to resolve that question.

The point I want to make is that the rate at which we can realize some of the planning objectives of your group is not just a matter of technical progress, it's a matter also of economic support, by the Congress and of course by the People. The support required to achieve a manned lunar landing and return has been spelled out by the NASA. It's difficult for me to imagine that Congress would endorse other major space undertaking during this period of the 60's, except for the possibility of a manned orbital research laboratory. Certainly such laboratories will come on the heels of our lunar landing if not before. There's a great ground swell that I perceive for the starting of a manned orbital research laboratory program.

But what can we expect beyond this? Lunar exploration could be a next logical step during the 1970's but it is difficult for me to envision a manned assault on Mars before the mid-1980's. Just the mere size of the total space budget up until this time would be one good reason for saying this. If one adds up what it's going to cost us to go to the moon, what it might cost us to mount a lunar exploration after this, what it might cost us to have a manned orbital research laboratory in addition to all of this, the budget is extremely large.

Of course there are other reasons for this. In order to make a manned expedition to Mars, we need a reliable nuclear rocket. This is going to take a while. As you know, the energy requirements for a Mars mission improve again after 1979. Such a mission would involve colossal expenditures; it's really difficult to guess what it would cost. It certainly would cost something in the order of 3 times or greater than that of the manned lunar mission. Such activities as this in the future I think must be truly national activities in which the country's total resources are mobilized in the most efficient manner. DOD and NASA resources, for example, must be used in close concert because the task would simply be so overwhelmingly large that every dollar and every person, from whatever agency he comes would have to work shoulder to shoulder for the common end. I'm pleased to see that this process is already taking place in the activities of the Working Group on Extraterrestrial Resources. What I'm trying to say is that manned flight, certainly manned flight to the planets, is going to be so complicated and expensive that it must be national effort.

As I listened to your papers today, I naturally gave some thought to the resources that my agency is investing in preparation for the exploration of. the planets. Of course Apollo, which demands the largest slice of our budget, is the first step toward extraterrestrial exploration. To go beyond Apollo, however, requires truly major advances in most of the underlying technologies. The NASA now invests about 10 per cent of its resources in improving those technologies that will carry us beyond Apollo. I was especially impressed by Dr. Steinhoff's first slide this morning, which gave projections of the cost of a round trip to the moon. And then there were many later references to power requirements for planetary exploration. I couldn't help being impressed by the tremendous demands that are going to be made in the whole field of energy conversion and propulsion. Man's efforts to propel himself along the surface and above the earth have always involved some kind of conversion cycle to convert the energy supplied by nature into thrust or torque or electrical energy. In the space program we are interested in two types of energy converters, the propulsion device, which supplies thrust, and an on-board power supply or a power supply for an extraterrestrial base. In our advanced research program in NASA, we are, of course, looking at both of these, and we are considering all three of the sources of energy; chemical, solar and nuclear.

As you are all aware, existing space boosters make use of the energy contained in the combination of liquid oxygen and hydrocarbon fuel. We have spent a good deal of effort in attempting to improve on this with higher energy combinations such as oxygen and hydrogen, fluorine and hydrogen, fluorine and hydrazine, oxygen diflouride and diborane and a number of other such combinations. Of course there is a point of diminishing returns here. With oxygen and hydrogen we can get specific impulses of say 420 sec by adding beryllium, and by doing other things, we may be able to bring this up to 450. If we change to combinations such as fluorine and hydrogen we may be able to improve this a bit more, but it's very hard work to extend this figure of merit, specific impulse, very much further with these kinds of propellant combinations. For example with oxygen difluoride and diborane, we're dealing with flame temperatures of some 8000^{0}F. We just do not have combustion chambers and nozzles that can handle this. We have other fundamental difficulties with these very powerful chemical engines; such things as combustion oscillations are extremely troublesome.

What can we do to improve this? The answer is to go to nuclear energy. We believe that we can almost double the specific impulse if we go to a solid core nuclear rocket. And this, of course, is the basis for the substantial expenditures that we are now making in project ROVER. During 1964, the NASA and the AEC will invest about 200 million dollars in the ROVER program. As you know the NERVA engine is a device that employs solid fuel elements containing uranium 235. We pump liquid hydrogen past these fuel elements and are able to heat the hydrogen up to rather high temperatures, and the heated propellant is expanded as a gas through the nozzle. The reactor has been under development for some time at the Los Alamos Scientific Lab and the Nuclear Rocket Development Station in Nevada. Last November 30th we had a reasonable successful test of this device. We're confident that the control system will work properly and we're confident that we can pass liquid hydrogen through the reactor as we expect to.

We did run into a very troublesome vibration problem due to flow-induced oscillations of the fuel elements. We were able to diagnose this in a rather interesting way. During the hot test of the reactor, portions of fuel elements were ejected out through the nozzle of the engine and this was quite a mystery for some time until we decided that we might try passing the liquid hydrogen through without have fission processes taking place; in other words by making a cold test. We found that we got the same kinds of oscillations even with the cold experiment. We passed nitrogen through and helium through, and found with helium we got similar oscillations. In the case of nitrogen we didn't get any oscillations. This allowed us to move toward the solution of this problem since it was simply a type of oscillation similar in nature to wing flutter or galloping transmission lines.

At any rate the ROVER nuclear rocket is something in which this country is investing a very large amount of money. What is the real use for such a rocket? Actually with the boosters that we have available it's pretty hard to justify nuclear rocket unless you're talking about a manned mission to the planets. In the case of the NERVA engine, we can hypothesize a number of missions in concert with the Saturn V; for example we can make a manned fly-by of Venus with the NERVA and Saturn V, a mission that would last about a year. We could put about 25,000 lb in a Martian orbit with a RIFT stage on Saturn V. This would be something like a 100 day mission. We could fly about 15,000 lb by Jupiter with this combination. This would require some 18 months to get there.

How can we improve this situation? One possible improvement is the application of a gaseous core reactor, a nuclear rocket with a gaseous core. We believe that we can get specific impulses of perhaps something of the order of 2400 sec with a gaseous core reactor nuclear rocket. However, we've got to have some invention before we can do this. The NASA is investing something like 2 million dollars in 1964 in research for gaseous core reactors. What is needed here is to obtain a stable gaseous system where the fissionable material can be put in a gaseous phase and retained there and not be pushed out through the nozzle. We've had some degree of success in doing this but we're a long ways from having anything that could be regarded as a basis for development.

This is about the extent of what we can say about the development or the early research for upper stage propulsion--except for electric propulsion. The field of electric propulsion has been given rather strong support in our space program not only by NASA but also by the Air Force. The ion rocket is perhaps the most advanced of these systems. One type of ion engine we are working with is known as the contact ionization type. In this particular system, cesium propellant is passed through a porous hot tungsten plate which extracts an electron from each cesium atom producing positive cesium ions and these ions are accelerated by field electrodes. Here specific impulses up to some 10,000 sec are possible. The thrust to weight ratio is very low perhaps something of the order of 10^{-5} to 10^{-2}.

In order to use engines of this kind, we need on-board electrical power. This fact was referred to several times today in terms of power devices that might be used on the planets for stationary power. Of course if you want long-time low-level power, solar sources are the best, or isotope sources. If you want short-time power, even though it might be at rather high power levels, the chemical sources are the best; but if you want long-time high power, we have to go to nuclear sources. And for these high powers, the systems such as our SNAP-8 system are indicative of the directions that need be pursued. This presents a very difficult problem in early development. The SNAP-8 system, which was referred to several times in papers today, is a 35 kilowatt system; it employs sodium-potassium liquid metals in the power loops. We still do not have full knowledge of how to use these kinds of liquid metals for converting energy. We don't understand their corrosive properties and since we need such long lifetimes, we are presented with a very difficult problem in reliability. The design goal for SNAP-8 is some 10,000 hours, at a specific weight of 200-300 #/kw. Of course we want to get the weight down. Our design goals are some 20 lb per kilowatt, although right at this moment the state of the art will allow us to build the system at about 100 lb per kilowatt.

For other types of energy conversion in space, we have almost limitless opportunities. The fuel cell is an example of a concept that is very old and which is being put to work in APOLLO and GEMINI. The problem here is not so much the problem of getting something that works as it is a problem of reliability. I've always been impressed by the possibilities in solar cell research of the thin film voltaics. As you know our present silicon solar cells are made in very small units. The NIMBUS space craft in fact uses about 10,500 of these little units, each one-inch square. These NIMBUS cells are about 20 thousandths of an inch thick. The very thin film solar cells can be made in much larger sizes and much thinner, perhaps on the order of 3 thousandths of an inch thick. These thin cells are made of cadmium sulphide or gallium arsenide, and the thinner cells are much more resistant to radiation. They have the advantage also that they can be rolled up like a flexible surface or perhaps can even be folded up or furled.

Several times during today's papers mention has been made of the need for an additional and better understanding of the space environment and assessing the effects of this environment on all the physical and biological systems. This forms a very large part of the 10 per cent expenditure which I mentioned to you earlier. One example that comes to mind is the question of the meteorite content of the near-earth space. I have felt for some time that we have come a long way in the space program with very little knowledge of the meteorite content of space. There's been a very wide uncertainty in our knowledge of the meteorite content of the near-earth space environment. If you looked at the earlier predictions of Whipple and Watson you got very large variations, something on the order of 20 or 30, in the skin thicknesses required to yield a given probability of penetration.

In the NASA we have a rather broad program aimed at learning about near-earth environment. This includes work using satellites as well as radar and photographic observations of meteorites entering the atmosphere. Last December 16th, we launched a satellite called Explorer XVI, with about 25 sq ft of area, in the near-earth environment. In fact it had an apogee of about 700 mi and a perigee of about 300. This satellite has since passed through its active life and during this time we got about 60 punctures of skin which ranged from 1 to 3 mils in thickness. Our conclusions from Explorer XVI have been that there's a very large quantity of fine dust particles near the earth but the incidence of particles that are capable of penetrating spacecraft skins is much smaller than the upper limits previously estimated. And in fact although this is a small sample, only 60 punctures, the data that one derives from this small sample falls much closer to the Watson distribution than the original Whipple distribution. We have also obtained microphone data from a rather large number of satellites and space probes. You will recall that microphone data on Mariner II indicated a very low incidence of detectable particles in deep space. We plan to launch another small satellite, 25 sq ft in area, early next year and then later on in the year, a much larger meteorite satellite of about 2,000 sq ft in area from a Saturn I vehicle. On the whole I'm very much encouraged by these data since they indicate that the micro-meteoroid protection problem may not be nearly as serious as we had once thought it would be.

There are other aspects of the space environment. There is, for example, the continuing problem of re-entry. Re-entry from earth orbit has been essentially solved. This involves re-entry speeds of some 20,000 mph. Even at the lunar return speed of some 25,000 mph I think our position is a good one. Phenolic charring ablaters do a good job here. We can still use a blunt object similar to the Mercury capsule. If we go up to planetary return speeds, some 40,000 mph, we find heat loads that are orders of magnitude larger than those of orbital return speeds of 20,000 mph and of course there's a change in the physics of the process. Whereas with the lower return speeds the mechanism of heating is largely conductive, at the very high return speeds, there is a hot gas cap attached to the nose of this blunt body. Most of the heating comes from radiation from this hot gas cap. The convective heating component is a relatively small fraction of the total.

The interesting thing about this is that it would be better to go back to slender bodies again to handle this kind of re-entry situation. Whereas we've been using blunt bodies for re-entry from earth orbit, it would now make sense to go back to slender bodies again for the higher re-entry speeds. One of my colleagues pointed out to me that this oscillation from slender to blunt bodies has been going on for many years, in fact for centuries. He mentions the fact that we started throwing rocks, which were rather blunt, and then we used arrows which were rather slender and we oscillated back and forth in our aerodynamics shapes of vehicles and finally we're going through another such oscillation here.

Along with research on reentry into the earth's atmosphere, we have been doing similar research on entry into the atmospheres of other planets, particularly the nitrogen-CO_2 atmosphere that's thought to exist on Mars and Venus. In order to obtain an understanding of the radiative heating in these kinds of environments, we've made preliminary measurements of the thermal radiation emitted from the hot gas cap of blunt bodies flying in a nitrogen-CO_2 mixture. These measurements were done on a very small model, about 1/25 inch across, which was fired from a light gas gun launcher. We find here that, at a given speed, the radiative heat transfer problem is considerably more severe during entry into the expected Martian or Venusian atmosphere than in the earth's atmosphere. In fact, since we believe that Venus has a higher CO_2 fraction than the Mars atmosphere, we would find a higher heating rate in the Venus atmosphere. We are now, in the Ames Lab, in the process of trying to define what the optimum body shapes would be for such entries.

These are just a few examples of the kinds of things in which we are investing our money in the NASA. In looking toward missions beyond those that are currently approved, I think we can envision many concepts and devise many means of achieving the goals of interplanetary exploration. But there is one spectre that really haunts me as I look ahead at this vista and this is the spectre of unreliability. We have simply not yet found the answer to the achievement of high reliability in our machines of space. In fact our record is really quite a dismal one. The long journeys to the planets will require us to improve reliability by several orders or magnitude. How can this be done. We can get a lot of advice on this question. Reliability experts are triumphant if they can predict by statistics that the satellite quits in two months instead of a year, or they advise us to make special reliability offices in our organization or to build redundancy into the system. But I'm not so sure what all this has got to do with reliability. Reliability of the kind that we need must be built into the product and will require the most unremitting effort of every person in the entire process. It will represent one of mankind's greatest achievements when it is attained.

Before stopping I'd like to make a few very general observations about our space program. It's been rather soundly criticized in the last few months. I'm sure that we will end up with a budget that is below what we had hoped to have in 1964, but I think that whatever happens to this budget or even the next budget, we can't turn back the march of time. The space age is clearly here to stay. Earth orbiting devices have proven useful and will continue to be useful for communications, meteorological data gathering and reconnaissance. I'm convinced that the military will use space just as surely as they use the airplane. Eventual exploration of the moon and planets is inevitable. Surely because of the inate stubbornness of the human race, if for no other reason.

Sir Bernard Lovell, a British astronomer, has been a rather severe critic of American foibles. I was interested to read not long ago a statement that he made. He said that "the challenge of space exploration, and particularly of landing men on the moon, represents the greatest challenge that has ever faced the human race. Even if there were no clear scientific or other arguments for proceeding with this task, the whole history of civilization would still impell men toward the goal. In fact the assembly of the scientific and military together with these human arguments creates such an overwhelming case that it can be ignored only by those who are blind to the teachings of history or wish to suspend the development of civilization at its moment of greatest opportunity." My principal concern is that we recognize the importance of striving always for an early and thorough understanding of the physical phenomena with which we are dealing prior to the initiation of major projects, and in this way build a sound basis for reliable space operations.

3- PROPOSAL FOR A LUNAR GEOLOGICAL OBSERVATORY

Dr. Eugene M. Shoemaker
U.S. Geological Survey

(Dr. Shoemaker's talk was primarily a lantern-slide talk in which a great many photographs of the Moon, of the new observatory site, and of the Arizona Meteorite Crater were presented and discussed. It would be impractical to reproduce his slides here or to give a complete transcript of his running comments--but a few selected excerpts from his verbal presentation are given below.)

First let me say that the Branch of Astrogeology of the Geological Survey is not defunct; it's very much alive, and still kicking. It occurred to me this morning that quite a few might think this is a proposal for an observatory that we should set up on the moon. Quite the contrary; I want to talk about an observatory in the process of being built right now on the earth, although we certainly are very much interested in the ultimate geological observatory on the moon. Specifically I want to tell you about the program of the Branch of Astrogeology of which this observatory will be the principal data-gathering arm.

The principal activity in terms of manpower in the entire branch comes under the heading of lunar planetary investigations. One of the prime objectives of our whole program is to work out increasing details of lunar stratigraphy and structure and thereby to reconstruct lunar history. Lunar photometry is one of the tools we use very intensively in working out stratigraphy and structure. The program on infrared investigations is just beginning this year. Dr. Kenneth Watson has joined our staff at Flagstaff, we'll be using a 24-inch reflector there to study the moon primarily in the 8 to 14 micron region. We have reason to expect that we may be able to identify minerals on the moon through use of differential spectrophotometry in this region. There are, however, many problems to overcome. Polarimetry is another tool that we are just getting into full use as part of our stratigraphic studies. The earth-moon libration region study has been curiously, an outgrowth of our investigations of hypervelocity impact in rock. We came to the conclusion that there should be particles from the moon temporarily trapped in the triangular or Lagrangian points L-4 and L-5, and we have had an active program observation trying to find these particles. Finally we have been intensely interested in comets and asteroids as objects that have been involved in sculpturing the moon's surface.

We are at the present time located at the Museum of Northern Arizona in Flagstaff, a very fine private research institution, which has built on a new wing to house our staff until our own facilities become available. We hope that we can begin the contracting procedures very early next year so we'll be in our new home on Switzer Mesa by a year from now. Our telescope facilities will be located, at least those that are under construction now, on Anderson Mesa, which is about 15 miles southeast of the center of Flagstaff. The instrument is a rather modest one as telescopes go nowadays. We have the basic tube and mount drive under construction by an outfit in Austin, Texas. It's essentially a 30-inch Cassegrain telescope. We hope to make this a very fine tool for lunar and planetary work. In the meantime, we have been using some of the very fine refractors available in the country which can be used successfully for lunar geological mapping.

Another tool of major importance to us is the digitally recording microphotometer which we use for a variety of programs, specifically for the photometric work on stratigraphic units, but we are also now getting into an extensive program of photometric determination on slopes and slope frequency distributions. This information can be synthesized into the form of a map, a geological map which shows deposits or units, rock units actually, classified primarily according to age. Each one of these units is characterized a variety of features: a very distinctive slope frequency distribution, for example, and a very distinctive pattern and statistical distribution of albedo. I'm sure as we go further into them, we'll probably find important differences in the composition. From this point of view we will be interested in studying and comparing them at some stage when we have more information on the mineralogical content for extraterrestrial resources.

4- EVIDENCE OF FAULTING IN THE CRUST OF MARS

Clyde W. Tombaugh
Research Center
New Mexico State University
University Park, New Mexico

(The following is a brief summary of Dr. Tombaugh's remarks. During his presentation he used a large number of slides to illustrate various features of the Martian surface.)

I. Preface

Gentlemen---I thought I would try to give you some of the results of my thinking of Mars. It is admittedly a more difficult planet to study than the Moon, because of its distance. However, I think it would be of interest to consider the geography of another world, if it is anything like our own, just to study the contrast.

I have been interested in this subject from a very early age, and am still interested in it. I had quite a lot of trouble getting much support for this kind of research prior to the Sputnik days. And so, if I had my wish about it, this work on the Moon and on Mars would have been going on a long time ago. It is a rather late start.

Some of the interesting features of another planet are its terrain relief and its geography. The methods of measurements of relief applied to studies of the Moon are not practical for Mars, because Mars is 300 times farther away when the terminator angle is a maximum. Therefore, an indirect approach was sought.

The seasonal changes in color and shade observed in the maria, their persistence in spite of occasional dust storms, Dr. Sinton's detection of organic absorption bands at 3.4 microns, and the presence of radiometric warmer temperatures on the maria compared to those on the deserts, all favor the theory of the vegetational nature of the maria.

I have used the vegetation idea in my studies in trying to map the topography of Mars, by assuming that the darker the maria, the deeper they are. Mars is a planet that is cold and has a thin atmosphere, and the vegetation would have to be hardy, even in the best of places, to grow or exist. I think that the maria in general are the basins of Mars. I do not agree with the idea that Mars is level. Far from it. I see no reason why Mars wouldn't have basins like the earth. If we could drain the water out of our ocean basins, we would find some pretty impressive escarpments around them. The atmosphere would drain into the basins and leave our continents bare and cold. I think nothing would grow on them because most of the air would then be below the continental shelf.

II. Climatic Conditions and Appearances

On Earth the cause of greatest variations in vegetation is in the amount of rainfall and its seasonal occurrence. Second in importance is temperature, and the least is type of soil. Altitude is important and involves precipitation and temperature together, generally.

On Mars, it is extremely dry everywhere except at the fringes of the polar caps and where there is possible volcanic degassing along fissures and places of eruption. There are good reasons for thinking that sedimentary rocks were never formed on Mars, and that all soils were derived from felsitic rhyolite. The atmosphere is so thin that pressure may be an important factor to plants, forcing them to favor lower altitudes.

Temperature is the only basic factor remaining that might explain the confinement of vegetation to certain areas. Thus, it is reasonable to assume that the intensity and persistence of vegetational darkening may be an indicator of altitude of the terrain.

The maria darken and canals on the deserts become more visible in a progressive wave from high latitudes to the tropics during the spring season. During the summer, a similar progressive wave of fading follows.

Most of the moisture in a given hemisphere is tied up in its polar cap during the winter part of the Martian year. The atmosphere is then tremendously dry, no humidity, and there is not enough moisture at the low temperatures to precipitate even a light frost. Only when the moisture wave, released from the polar region with the coming of summer, has progressed toward the equator do we have the development of the maria and the appearance of the canals. At the same time the high regions apparently get frosted.

One must study Mars over a period of 30 years or more in order to cover the seasonal changes throughout the equivalent of two or more complete Martian years. The appearances of the various maria at different seasons must then be reduced to a normalized basis.

III. CRITERIA OF RELIEF AND EXAMPLES

From the characteristics and behavior, there is some justification for differentiating the vegetational areas into six levels of altitude. The extreme northern sector of the Syrtis Major appears to be the lowest region on the planet, which I have provisionally designated as level "1".

Much of the time, the Syrtis Major is solidly dark blue-green. At other times, it exhibits color and shade differentiations such as to imply that there are at least four distinct levels, each sharply marked off from the others. This suggests the presence of cross-faults.

The borders of some maria are sharply defined in appearance and do not migrate in position. This indicates an abrupt vertical relief resulting from faulting. The borders of other maria are not sharply marked and migrate within limits. This characteristic would imply a more gentle change in level, as would be produced by monocline folding. The Mare Cimmerium appears to be an example of both, with a monocline on its northern border and a fault along its southern edge. Further evidence of the latter is the long, prominent canal seen marking its edge.

When the maria fade in their late summer season, they become riddled with canals and dark spots. Then the local areas of different levels manifest themselves. The "beak" of Mare Sirenum is a clear-cut case, where I have seen two divergent canals exactly marking its borders.

The maria on the moon offer little comparison to the maria on Mars. An outstanding difference is that the maria on the moon are round, while those on Mars are angular in shape, and this implies a different mode of origin.

A strong argument for the fracture nature of the canals is afforded by the many examples of triangular maria whose borders are exactly aligned with canals continuing on the desert to their points of origin, the oases. These maria appear to be crustal blocks lying between fracture-bounded sectors that later sank in altitude by thousands of meters in response to subcrustal readjustments in the long course of geologic history. Examples are: The Syrtis Major, Sinus Meridianii, and Trivium Charontis.

Margaritifer Sinus shows a progressive amount of darkening toward its apex at the Oxia Palus, implying a progressive deepening as would be produced by a tilted block sheared free from the adjacent desert. This type of crustal operation is further indicated by the presence of a corridor of lighter shading at the Pyrrhae Regio and Eos, which separates Margaritifer Sinus from Mare Erythraeum. During the late Martian summer, this narrow streak fades to desert lightness, implying high ground and is exactly the place one would expect to find a diastrophic hinge.

The round, dark dots known as "oases" very probably are impact craters, formed by the collision of asteroids. Fortunately, they are rendered visible under "full-phase" illumination by some kind of vegetation deriving the benefit of warmth and denser air within the craters.

There are many instances of sharply defined areas that are normally desert and darken slightly at times. The tracts of land between the components of double canals such as the Thoth, Euphrates, Square of Astaboras, Gehon, Ambrosia, etc, and triangular tracts such as Trivium Coprates, also that between the Gehon and Cantabras canals are examples of such occasional darkenings that indicate the presence of faults. It is most significant that they are exactly bounded by canals.

If our ocean basis could be drained of the water, the steep escarpments of the continental shelves, amounting to ten kilometers in places, would resemble the maria of Mars. The Earth's atmosphere would drain into these basins and cause the continents to be cold, barren plateaus. There are many major fracture zones on both the ocean basins and on our continents. On Mars such features would not be as mitigated because there is an absence of water erosion and turbidity currents.

Lastly, there is another class of features, known as "carets," which appear to be the product of faulting. These are the very dark and very sharply defined small triangles found along the northern edges of Mare Sirenum, Mare Cimmerium and Sabaeus Sinus. Their sides are exactly determined by the angles of two canals converging at the coastline. Where there are double canals with a common embouchure there are sometimes double carets, such as at the junction of the Phison-Euphrates canals. It is most curious that they are limited in distribution to the northern edges of these three subtropical maria of the southern hemisphere.

I would like to give you my ideas as to what I think we can find on Mars in the way of resources and in the way of minerals. I think it is a very poverty-stricken planet--that we do not have any sedimentary rocks there. This means that the minerals that have an origin peculiar to sedimentation would not exist. I have a long list of them here. I don't want to take the time to read them. I have another list of those that I think might be found on Mars. Of course there would be metamorphic minerals, but they would be buried since Mars has no water erosion to expose them. Whether there is subsurface ice or water I am a little doubtful; on a planet as dry as that I doubt whether there would be much of a permafrost below the surface. Of course there is plenty of water in the polar caps if you can scoop up the thin layer.

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LUNAR CONSTRUCTION RESEARCH

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[redacted]

I. INTRODUCTION

Before 1962, the requirement for a clear, decisive engineering approach to the problem of extraterrestrial construction had been recognized by few. Admittedly, the problem of merely placing man on the moon and successfully recovering him has occupied a major portion of space planning. Even so, prior to 1958, both the Air Force and the Army had engaged in preliminary investigations on moon-based facilities. These studies were general in character, covering shelter concepts, communication facilities and means of lunar mobility. The studies could have been expanded into acceptable engineering approaches to the problem, but with the establishment of NASA and its responsibility for space programs, the Army and Air Force projects died stillborn. Only recently has NASA accepted the baton and applied serious consideration to the engineering aspects of prolonged lunar habitation.

In November 1962, the Office of Manned Space Flight, NASA Headquarters, after reviewing the results of previous studies by the Corps of Engineers, asked them to undertake an analysis of the research and experimental effort required to develop a lunar construction capability and to present plans for program implementation. This study, conducted by our staff in the Office, Chief of Engineers, was completed by 30 April 1963 and a report was submitted to NASA. Subsequent to, and partially based on the Engineers' report, Marshall Space Flight Center, NASA completed an analysis of the engineering test requirements for an Apollo logistic support system. Although the objective of this analysis was Apollo support, results have direct application to any logistic system supporting the build-up and supply of a lunar base system. Overlapping this study in time is a current contract by NASA with the Boeing company, Aero-Space Division, for a study entitled "The Initial Concept for a Lunar Base". This study, commencing on 15 July, will be completed by 1 December 1963.

These three studies form the outstanding NASA studies to date on the subject of lunar basing. However, other minor and subsidiary study approaches are being made. These include, but are not limited to, a life-support investigation by the Manned Spacecraft Center, NASA, and several short-term studies assigned to OCE by OMSF. The OCE studies, currently being prepared or in progress, are subdivided into "Lunar Base Studies" and "Lunar Surface Operations Simulator Studies". The base studies are in the fields of:

(1) Lunar Energy Systems, Nuclear and Chemical
(2) Power Distribution and Conditioning Equipment
(3) Foundations and Structures
(4) Construction Procedures
(5) Construction and Materials Handling Equipment

The simulator studies involve:

(1) Solar Simulation
(2) Soil Simulants

The intent of this paper is to summarize the results of the three major studies cited and to analyze their directive influence on the character of lunar base design and construction. In doing so, it should be emphasized that this analysis and the opinions rendered represent solely the viewpoint of the writer.

II. THE OCE STUDY

A. PROCEDURE

The Corps of Engineers study was conducted in two phases. The first completed in January 1963, resulted in an interim report primarily concerned with identification of elements of the technical development program in order to facilitate early consideration of FY 64 program requirements. The second involved a much more comprehensive analysis of the technical program (particularly problem areas), refinement of schedules and fund estimates, and development of a detailed plan for executing the lunar construction training program.

In the study, current NASA planning and prior efforts by workers in this field were examined to develop the major areas of engineering application involved in attaining a lunar construction capability. Each was then analyzed in depth to determine requirements, evaluate these in terms of current state-of-the art, identify specific research and development tasks and prepare detailed statements of methodology, effort, cost and facilities needed to accomplish such tasks. Particular attention was given to the capability of existing or planned terrestrial facilities to serve program needs.

Findings concerning the individual technical areas were then synthesized into a comprehensive technical development program integrated in time with current NASA thinking regarding manned lunar operations and associated lunar facility requirements. Available resources, related programs, restraints, and past experience in comparable governmental research and development programs were related to the technical program and a plan for program implementation was drawn up representing the optimum combination of all factors involved.

B. LUNAR BASE CONCEPT

Fundamental to this study was a concept for a lunar base, to include a time-phased estimate of the types of facilities needed to support planned operations on the moon. Guidance provided by NASA Headquarters included a modular base concept, a lunar model detailing the applicable physical characteristics of the lunar environment, vehicle launch schedules and vehicle dimension and payload characteristics. As the study progressed, it was found necessary to make further assumptions within the framework of the planning data provided.

NASA's basic concept envisioned a family of modules of as few types as possible which could be combined in a variety of arrays to meet operational requirements. Both time and operational considerations dictate that only the most rudimentary construction capability be developed to support the Apollo landings. However, as stay times increase in the 1970-1972 period and lunar operations become more advanced, temporary bases with integrated life-support systems will be necessary. Depending on additional knowledge gained by Apollo operations, these temporary bases may be expandable into semipermanent bases or a new generation of facilities may be required. These semipermanent bases, needed in the period 1973-1975, could evolve into permanent bases with more sophisticated and centralized support facilities.

Present lunar construction concepts depend on limited hard data and extensive assumptions regarding the characteristics of the lunar environment and the lunar surface material, particularly the latter. Ranger and Surveyor probes will provide much valuable information on the composition of lunar surface materials but definitive data will not be available until man explores the moon. Notwithstanding this fact, most basic program requirements for developing a lunar construction capability can be foreseen now. It is entirely feasible at present to proceed with work in critical long lead-time areas and to develop a lunar construction capability in a timely manner. Such a program will clearly be subject to change in detail, but close control and built-in flexibility and responsiveness will minimize the adverse effects of such changes.

C. REQUIREMENTS

For purposes of the study, the following schedule for attainment of a lunar construction capability was provided by NASA:

Construction Capability	Time Period
Support for Apollo landings	1968 - 1969
Temporary bases, 6 man	1970 - 1971
Temporary bases, 8-12 man	1971 - 1973
Semipermanent bases, 12-18 man	1973 - 1975

To meet this schedule, two factors were considered critical. The first is a prompt start. The second is the timely acquisition of data on the characteristics of the lunar environment and lunar surface materials.

In addition to time schedules, lunar construction program requirements fall into several other general categories. These are performance requirements in terms of efficiency, simplicity, reliability and safety of systems and hardware items. The lunar environment imposes a multitude of restrictions and requirements on the development of suitable construction methods, techniques, and materials. Finally, the restraints imposed by the resources available to the program and by vehicle configurations and launch rates introduce requirements affecting program planning and execution.

This study considered requirements in those several contexts but its primary orientation, as an engineering study, was on the technical engineering development effort necessary to develop a capability to construct lunar facilities. Necessarily included in the scope of the program are tools, equipment, materials, systems, methods and techniques. Testing and demonstration of components, end items and man-systems on earth are likewise essential elements of the program, as is training of those who will perform the construction operations on the moon. In general terms, the required technical effort is as follows:

1. Identify in detail the types of engineering works that must be built on the moon in the period 1968-1975.

2. Develop design criteria and construction methods for these lunar facilities.

3. Determine performance requirements for engineering materials, methods, processes and man-systems in the lunar environment.

4. Develop and test new materials, methods and processes as required.

5. Design and test (on earth) prototype structures and man-systems to the extent required to demonstrate their adequacy, limitations, and degree of reliability.

6. Determine the need for, and develop equipment, methods and procedures to accomplish maintenance and repair of engineering works on the moon.

7. Identify training requirements, develop training procedures, and train men who will build, operate and maintain lunar bases.

As mentioned, the technical engineering development program was based on a series of studies in each of the major engineering areas involved in lunar construction. The results of these were arranged into a coherent development program, with special attention given to those specific tasks which should be started in FY 64 to achieve a lunar construction capability in an orderly and timely manner. These tasks were in the fields of selenology, construction materials, excavation and surface modification, equipment, electric power and life support.

D. PROGRAM EXECUTION

The study proposed a plan of action to implement the program requirements outlined above. The plan considered program management, research facilities required and funding. Facilities and estimated costs are discussed below:

1. Facilities

The study determined that a capability for integrated, real-time testing of man-systems in a simulated lunar environment, including the lunar surface materials, is essential to the lunar construction development program proposed. It was further determined that no facility, existing or presently planned, could achieve that capability. Performance specifications and preliminary plans for such a facility, called the Lunar Environmental Research and Test Facility (LERT), were developed during the study.

A number of ancilliary facilities, including one for low-order simulation of certain lunar phenomena under ambient earth atmospheric pressure (the Operations and Training Building), are also necessary. Preliminary criteria, plans and cost data were developed in the study for all such facilities.

2. Costs

The ultimate complete cost of developing a lunar construction capability was not estimated since the costs of suitable cargo and personnel delivery systems were beyond the scope of this study. In addition, the technical studies on which this report was based, while defining the planning, research, development and engineering effort required, did not attempt to make more than gross estimates of costs beyond FY 68. However, an order-of-magnitude estimate of total program costs, exclusive of purchase of operational hardware for use on the lunar surface, approaches $500 million.

Budget estimates through FY 68 were prepared during the study for major elements of the proposed program. These elements were:

a. Further study to refine and extend lunar base planning concepts.

b. The technical engineering development program. This program was broken down and costed by specific tasks, with particular attention to those which should be started in FY 64 as a base for later effort.

c. Facilities and Government furnished equipment (GFE) therefor.

d. Personnel and operating costs.

Program costs are summarized in the following tabulation:

	Years ($ millions)				
	1st	2nd	3rd	4th	5th
Lunar Base Study	0.5	-	-	-	-
Engineering Development	4.7	24.0	57.3	102.4	59.7
Facilities and GFE	3.9	29.5	3.0	2.5	.5
Personnel and Operations	1.3	1.8	4.0	8.0	12.0
TOTAL	10.4	55.3	64.3	112.9	72.2

III. STUDY BY MARSHALL SPACE FLIGHT CENTER

The MSFC study stems partially from their review of the prior OCE study, specifically that part dealing with recommended test facilities. Their suggested program attempts to define the test requirements of the Apollo Logistics Support Systems (LEM-Truck and LLV) and recognizes a future lunar base logistics follow-on. In this sense their report has meaningful application to lunar base concept studies. It should be emphasized that the testing concepts reported here are taken from a preliminary report. Elements may have been and probably are changed from that reported herein. In summary, then, the following:

The test program can be classified into the following types of testing: Parts testing, component testing, subsystem testing, thermal testing, system testing with and without astronauts, flight acceptance testing, simulated mission testing, qualification testing, and checkout. The environmental test program will follow this philosophy of thoroughly testing components, subsystems and major systems where deemed necessary.

All subsystems must be completely qualified and have undergone complete environmental testing prior to testing them in a major system. Major systems environmental tests will be performed to the greatest extent possible, considering the relative yield of information from the test with respect to the practicability of the test, its cost, and the cost of the required test facility. Actual operation by astronauts of major systems under simulated lunar environmental conditions should be done to the greatest extent possible. A major training program for astronauts should be performed under simulated environmental and mission operational conditions which come as close to reality as is technically and economically feasible. Facilities for meteoroid and particle radiation effects will not be an integral part of any major lunar environmental facility. These tests should be performed on scale models, prototypes, or test specimens at other existing or planned facilities.

The basic test philosophy and test programs for the two categories or payloads (LEM-truck and LLV payloads) will essentially be the same but the test duration for system and major subsystem testing required for the LLV payload will be longer and larger test facilities will be required as compared to those with for the LEM-truck payloads. Hence the facility planning for new facilities must take consideration the heavier test requirements for LLV payloads.

Consideration for major facilities for this testing program are essentially as follows:

1. Develop major systems for the LEM-truck payloads in existing large chambers, such as the Mark I and the GE Space Simulator. These facilities would require major modification.

2. Build a large lunar Environmental Mission Chamber with a working area of approximately 80 to 100 ft. dia. to be used primarily for mission testing. Mission testing for LEM-truck payloads including the initial payloads would be done in this chamber.

3. Build at a later date, which will depend on the scheduling of lunar base construction, a smaller Lunar Environmental Research Chamber with a working area of approximately 35 to 50 ft. dia. to be used primarily for research and development testing of major systems. This facility would be used for development testing of LLV payloads.

4. The sequence of building the above two chambers is predicated on the fact that no large chamber for research and development could be ready in

time for testing LEM-truck ,ˑ'loads and that these payloads would have to be developed in existing chambeı which will have to have considerable modifications for this purpose.

5. Existing other types of test facilities, both industry and government-owned, should be used to the greatest extent. The availability of such facilities, including those at MSFC, is being reviewed and studied.

IV. THE BOEING STUDY

The Boeing study constitutes another step toward developing a lunar base concept. It conceives of the actuality of the lunar logistics system. It is concerned immediately and directly with lunar base design. As Boeing states in their second interim report, "the basic objective of the study is to provide a conceptual design of the modular lunar base system within the criteria set forth by NASA". To meet this objective in the four-month study, Boeing plans to accomplish the following:

1. Define and analyze parametrically each major subsystem from the minimum function for the specified 90-day stay, two-man operation and limited transportation, to the two year system with an 18-man population.

2. The subsystems requirements will then be applied to an analysis of modules that might be designed to meet the requirements. Logical modules will be derived to fulfill the needs of varying base sizes and deployment up to 18-man base complexes. The function of each will be defined and the limits of its desired functional capability will be established.

3. A conceptual design of each module will be prepared. Dimensions, configuration and weight estimates, as well as operating characteristics and limits will be provided.

4. The interfaces between modules and subsystems will be defined. The effect of these interfaces on base design, weight, operating man hours, and performance will be investigated to determine the impact on selected base complexes. This will include an estimate of the flow of communications, materials, energy, and personnel to uncover interface problem areas.

5. Concepts for installation, operation, and maintenance of several base systems of various degrees of complexity and lifetime will be delineated.

6. A parametric analysis will be made to determine quantities of materials (other than modules) required for installation, operation, and maintenance. The analysis will consider base sizes, lifetime, degree of logistics independence, and activity level. The resulting data will be summarized in the form of logistics plans for the several typical base systems.

The basic modular concept, together with the stated ground rules and implied mission objectives have been the starting point for systems analyses aimed at guiding the subsystems investigations and contributing to the overall concept definition. Subsystems guidance is in the form of requirements definition, functional at first, but becoming more quantitative as the concept is developed. Additionally, as the subsystem aspects of the base concept are developed, meaningful concepts for base installation, operation, maintenance, and logistics support can be developed and described.

Boeing finds the following major trends developing thus far in the study:

1. Design of a basic lunar shelter with integrated meteoroid and radiation shielding adequate for a 1-year storage and subsequent 3-month occupancy appears feasible. This shelter requires no lunar soil cover for this period of operation but is structurally capable of withstanding a 2-foot thick cover of soil for protection in extended operations.

2. For longer operations beyond 3-months, these shelters should be emplaced on the lunar surface with a protective cover of lunar soil. A 2-foot thick layer of soil should provide the necessary shielding (with safety factor of 2) for up to two years operations. Underground emplacement does not appear necessary for the range of assumptions considered in this study. Burying the shelter increases the difficulties, and reduces the flexibility inherent in the modular concept.

3. All support elements for a three-man, 90 day lunar base operation may be carried in one Saturn V logistics payload of 25,000 pounds. These elements include the shelter with its integral life support, power, communications and fuel modules, and a lunar roving vehicle with its fuel.

4. This basic shelter module provides the flexibility of (a) accommodating up to six men in normal operations (or twelve in special situations), and (b) of operating without emplacement for about 3 months, or (c) emplaced on the lunar surface under a 2-foot thick soil cover for up to two years.

5. Plans for the larger bases would use this 6-man basic shelter module to accommodate 12 and 18 man crews with two and three interconnected shelter modules respectively. Each shelter-module payload would carry expandable supplies to fit the 25,000 pound Saturn V capability. Other essential base components, like vehicles, power plants, supplies, and unusual instruments would ride in the flexible cargo-payload modules.

6. The basic six-man shelter module has multiple utility: to be clustered into larger bases of whatever size, to serve as an optimum outpost, and to grow without waste from the simplest base to the most complex.

7. Nuclear power supply appears desirable to support lunar base operations extending to six months and beyond.

8. Hydrogen storage on the Moon for one year before use is a major problem and requires special design of tankage including:

Improved insulation
Delivery of hydrogen to the lunar base as a solid in tanks.

V. ANALYSIS

Lunar construction research, literally and figuratively, is barely off the ground. Studies in progress or concluded do little more than point the way. However, they do constitute the necessary first steps of deciding where you are going to go, with what equipment and training and how soon.

The OCE study took a sharp look at the technical effort requisite to obtaining an engineering capability for lunar design and construction. Marshall Space Flight Center has been and is engaged in a conceptual approach to the problem of how does one prepare a capability for an Earth-lunar logistics system. These two studies are complementary. Boeing is going a step further. Their study constitutes the first NASA effort to develop a lunar base concept. Now the following steps seem obvious, i.e., the establishment of new facilities the primary aim of which is to obtain a lunar construction capability in fact.

REFERENCES

Boeing - "Initial Concept for a Lunar Base", First and Second Monthly Progress Reports, 15 August 1963, and 15 September 1963.

MSFC - "Preliminary Test Program for Apollo Logistic Support Systems Payloads", August 1963.

OCE - "Special Study of the Research and Development Effort Required to Provide a U.S. Lunar Construction Capability," April 1963.

TIME-PHASING OF LUNAR EVENTS

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Division of Sperry Rand Corporation

[redacted]

N 67-20415

INTRODUCTION

The Working Group's first task of making basic research recommendations to NASA has been completed. What next? Of the many new tasks that can now be performed, the most outstanding is the task of developing a plan for the time-phasing of extraterrestrial resources into extraterrestrial systems.

The next goal of the Working Group should be to provide NASA and the Armed Services with a master plan that shows when the equipment to process extra-terrestrial resources will be operational. This master plan can be broken down into its basic research elements to define a logical sequence of R & D events. This presentation describes an approach for preparing this master plan. Three steps are necessary. The Working Group must show that (1) there will be a logistic savings, e.g., Mars missions will be cheaper; (2) that the facility is realistic and not just a result of academic speculations; and (3) that an investment in a lunar facility will produce a substantial return.

LOGISTIC SAVINGS

Papers have already been presented on the subject of logistic savings. In a report entitled "A Possible Approach to Scientific Exploration of the Planet Mars," Dr. Steinhoff of the Rand Corporation presented some very fundamental information. During the May 1962 meeting of the National Aerospace Electronics Conference, Colonel Athas of the Air Force Office of Aerospace Research presented a paper entitled, "Design Considerations for a Lunar Industrial Complex." These papers represent original work done early in the game. Two Sperry Utah papers have already been released. One is entitled "Propellant Production on the Moon," and appears in the September 1963 issue of Space/Aeronautics magazine; the other, "Advantages of a Lunar Base for Interplanetary Missions," was presented at a meeting of the Facility Construction, Operation, and Maintenance Subgroup in Houston, Texas, on 17 January 1963.

Information from the two Sperry Utah papers will be presented to describe one approach the Working Group can use in preparing the master plan. A master plan itself will not be presented, only suggestions for inputs to this master plan.

What are we trying to save? Material. But there are two types of material - consumable and nonconsumable. On which one should we concentrate? Figure 6-1 shows that we should concentrate on the consumable materials. During the average lifetime of an automobile, 9 times its weight in fuel is used. Using a power plant as another example, the plant, which is nonconsumable, may weigh

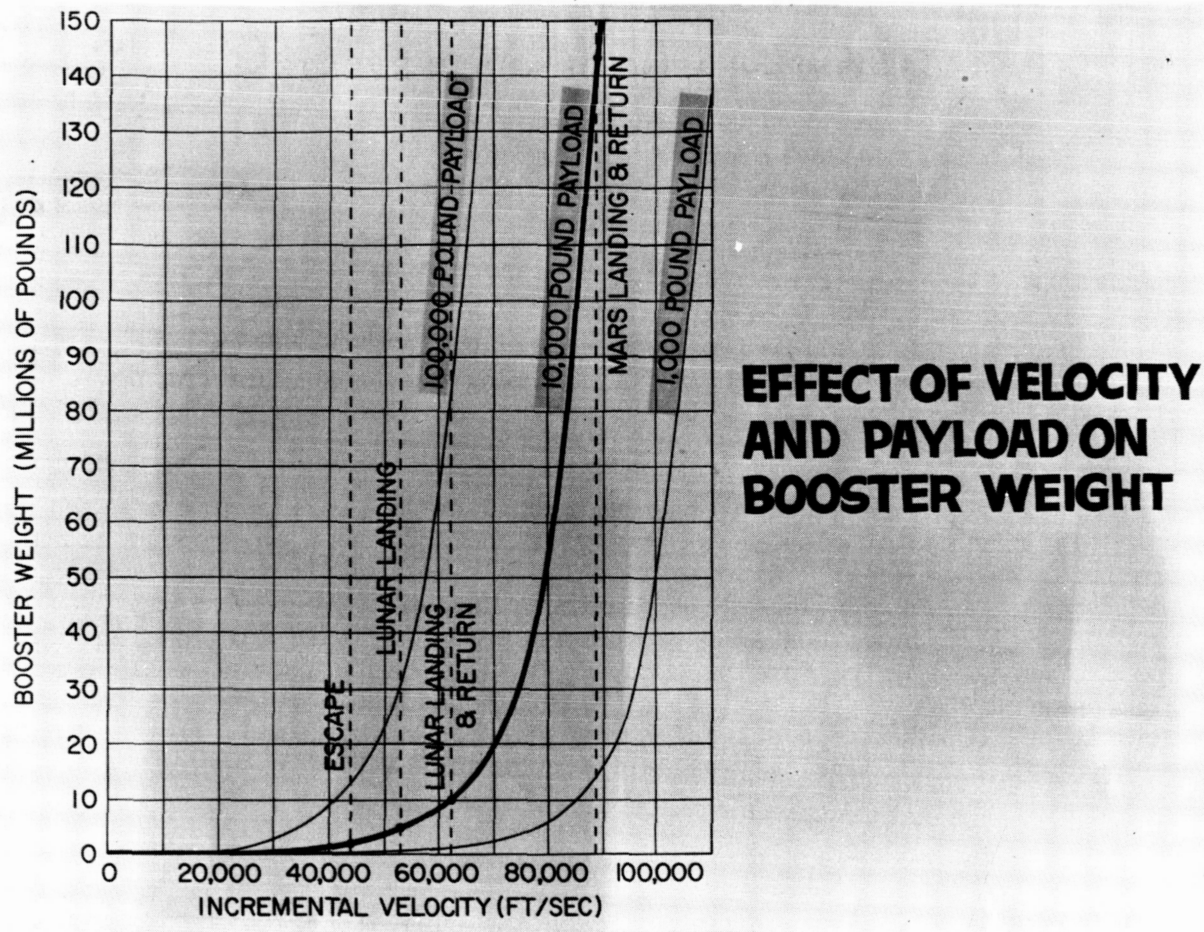


FIGURE 6-3

a million pounds, but during its lifetime of 50 or 100 years, it may consume a billion pounds of fuel. If we are concerned with developing resources in space, it is to our obvious advantage to concentrate on consumable materials.

Propellant appears to be a consumable material of significant interest to space travel. Logistic savings can be demonstrated by analyzing the propellant savings in lunar and Mars missions which are resupplied with indigenous resources. How much propellant can be saved in Mars and lunar missions if extraterrestrial resources are used for resupply? Figure 6-2 shows that if we fly an earth-to-Mars-to-earth mission requiring a Delta V of 88,000 feet per second, approximately 144,000,000 pounds must be boosted from earth. This weight can either be boosted in one large vehicle or broken up into segments and reassembled in orbit. The same mission can be performed with two 3-1/2-million-pound vehicles if lunar refueling material is used. The assumptions for this comparison are explaned in reference 1 and also in the velocity payload relationship shown in figure 6-3. These curves are based upon a specific impulse of 350 and a propellant-to-stage-weight ratio of 0.9. A chemical systems analysis was made because specific impulse, mass fraction, and availability of system are fairly well established. Extrapolations to more exotic systems can thus be made from a firm base. Nuclear systems, by comparison, are quite undefined at this time. However, irrespective of the type of system with which we are

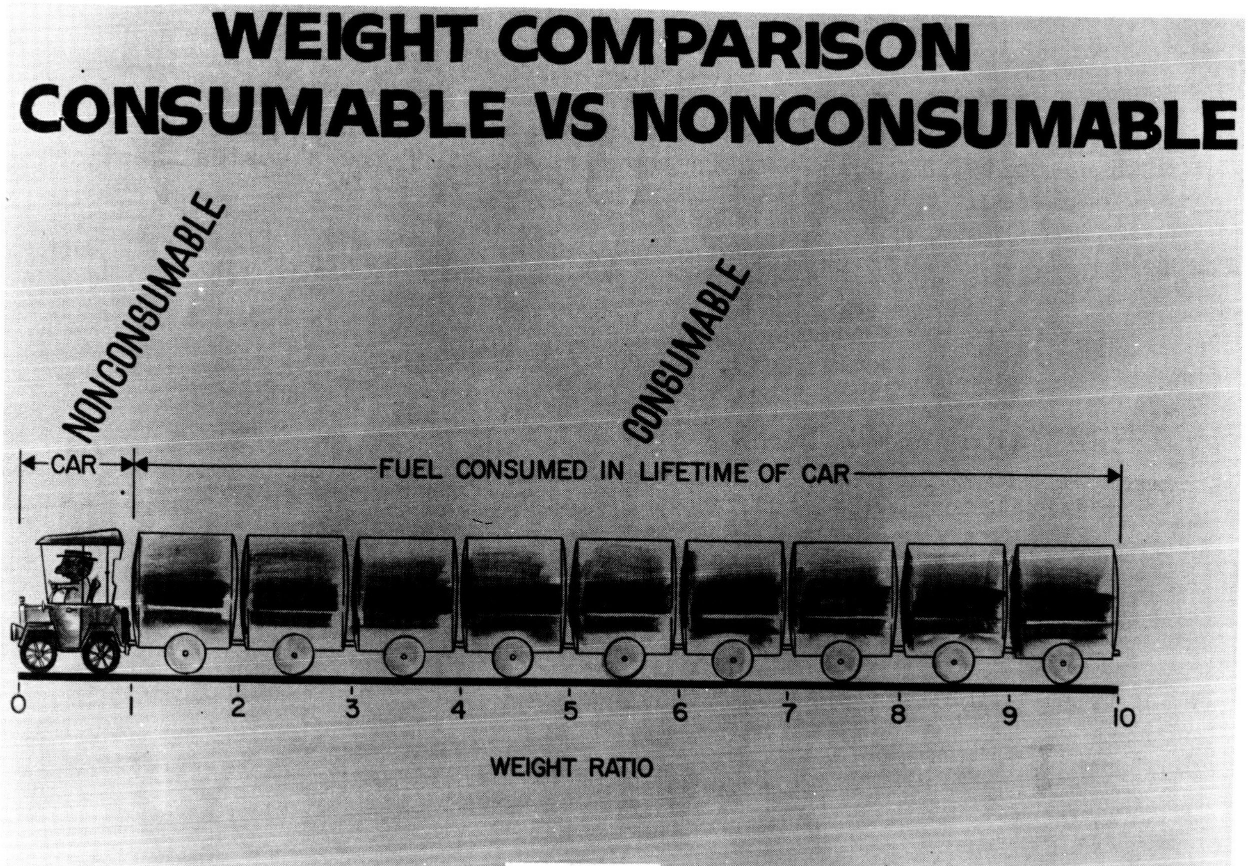


FIGURE 6-1

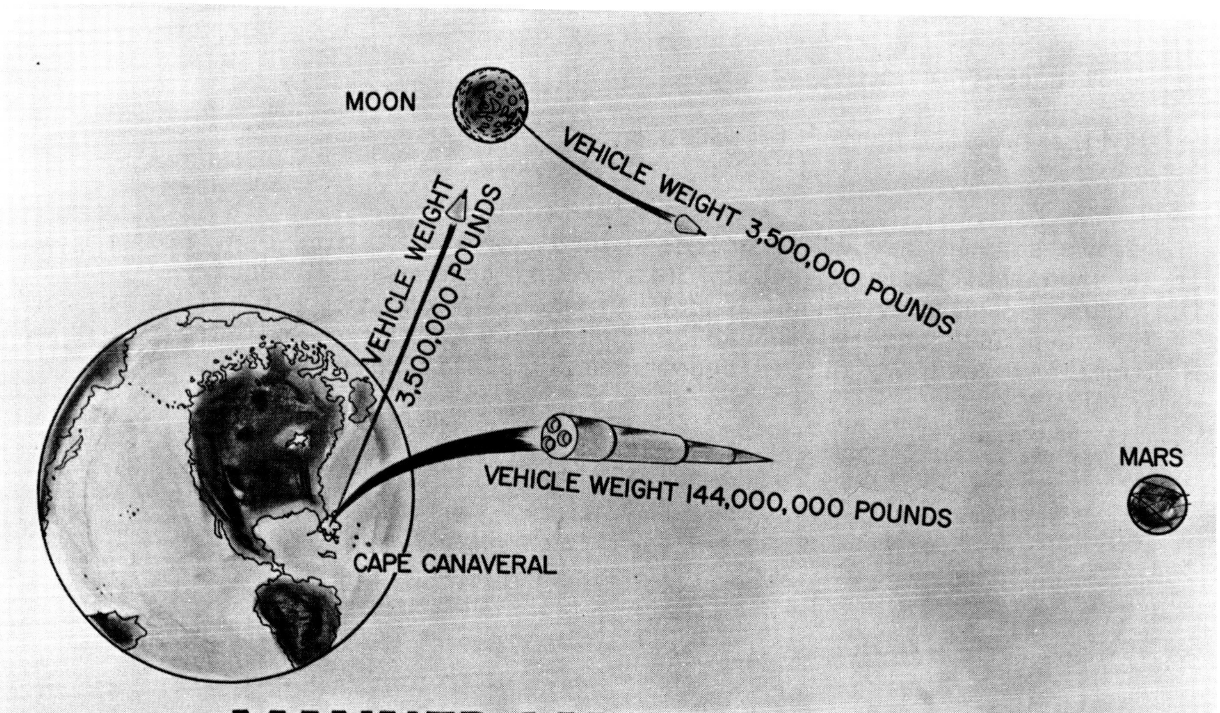


FIGURE 6-2

dealing, the savings ratio is a function of the logarithmic variation of vehicle weight with velocity. This is seen in the first term of the classical vertical trajectory equation:

$$V_B = g_o I_s \ln \frac{W_t}{W_e} - \bar{g} t_p - \frac{B_1 C_d A}{W_t} + V_o$$

Where

V_B = velocity at end of burning

g_o = gravitational acceleration at sea level

I_s = specific impulse

$\bar{g}$ = average grativational attraction

W_t = total weight

W_e = empty weight

A = area

B_1 = numerical values of drag integrals

V_o = initial velocity

C_d = drag coefficient

t_p = time from launching to power cutoff

Logistic savings are also realized for lunar return missions. From figure 6-4 it is seen that an Earth-supply lunar round-trip mission requires a 10-million-pound vehicle. A lunar resupply mission, by contrast, requires only a 3-1/2-million-pound vehicle. We can conclude that for lunar and Mars missions, lunar propellant resupply offers substantial logistic savings.

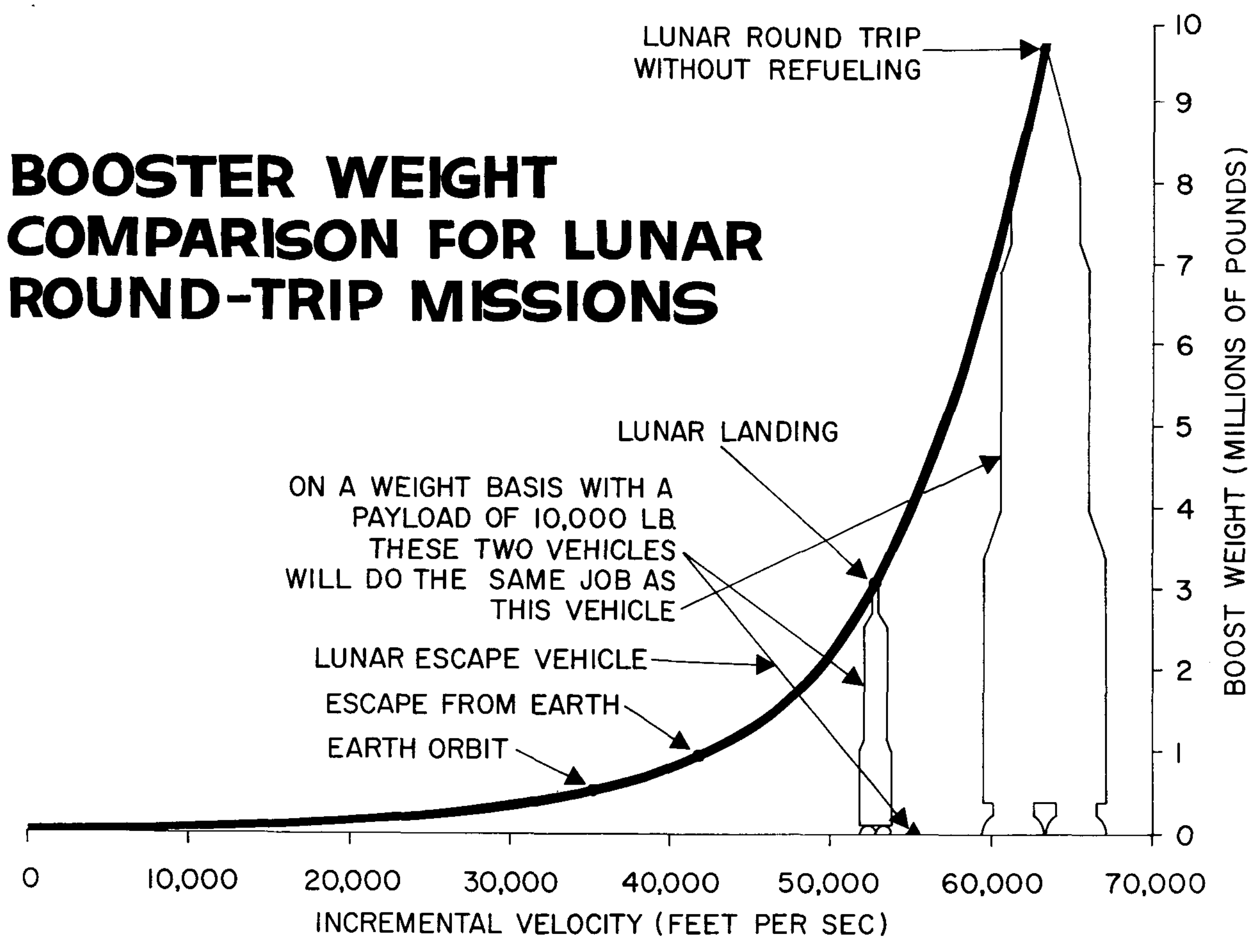


FIGURE 6-4

FACILITY

Is the lunar propellant manufacturing facility realistic? To help answer this question, it is necessary to assign numbers to the equipment we have been analyzing. It is imperative that a quantitative analysis be started because high equipment weight and large power requirements will rule out most systems for quite some time. Very little of our Saturn C-5 payload can be used for anything other than payload to support the man. The following explains why payload and power are so critical.

Most of our space booster payload will be needed to support the man. As is seen in figure 6-5, very little of this payload will be available for mission support. The way in which man and payload might be supported is shown in figure 6-6. While this description is based upon assumptions, it does help us understand space systems problems. Food supplies from earth would be later replenished with lunar-grown foodstuffs. We would start hydroponic gardening and obtain the water supply from lunar materials. Water and oxygen also would

ESTIMATED PAYLOAD ALLOCATION

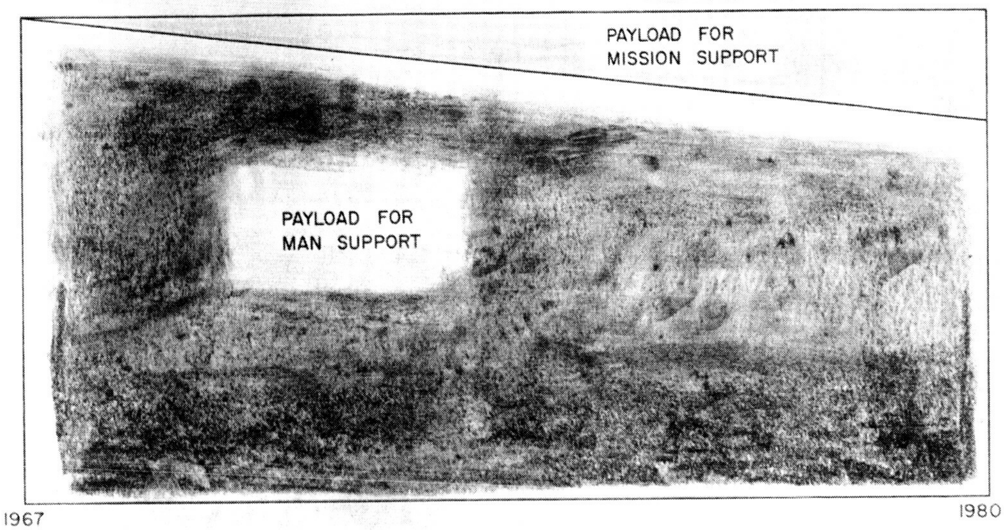


FIGURE 6-5

LUNAR EVENTS

	SUPPORT OF MAN 1967-? ITEM				SUPPORT OF MARS MISSION 1970-? ITEM
	FOOD	LIFE SUPPORT	SHELTER	TRANSPORTATION	MATERIAL FOR SPACE MISSION
SUPPLY FROM EARTH MTL	YES	H_2O TO O_2 DIRECT TRANSPORTS RECYCLING	SPENT MOTOR CASE	WALKING BICYCLE VEHICLE	
SUPPLY FROM LUNAR MTL	HYDRO-PONIC GARDEN-ING	H_2O TO O_2 FROM ROCK	CAVE BRICK MFG GLASS STRUCTURE	LUNAR FUEL FOR VEHICLE	PROPELLANT MFG MOTOR CASE MFG REENTRY SHIELD MFG

FIGURE 6-6

first be directly supplied from earth. However, as recycling techniques develop, earth logistic demands would decrease. Recycling, however, is not expected to be 100% efficient. The difference between water and oxygen requirements and the water and oxygen lost during recycling would be made up with water and oxygen obtained from lunar materials.

Shelter may initially be provided with a surplus motor case. Later, we would start using lunar resources. A cave may be used or we may start manufacturing bricks and structural materials from silicates. The advantage of using structural glass manufactured from lunar silicates rather than lunar rock is essentially one of material strength. Glass materials can be manufactured with unidirectional strengths as high as 700,000 pounds per square inch.

The transportation column in figure 6-6 shows the effect of power limitations on lunar operations. Walking and bicycle locomotion are shown. The elaborate crawlers and dozers shown in many lunar illustrations will not be operational until we land a large nuclear power unit.

The first effective machine on the moon would be man with his high mean-time-to-failure (he can perform tasks, such as brushing his teeth, with very high reliability for decades). Because of the tremendous capability and versatility of man, it is felt that a high-priority item is the development of a reliable, mobile, environmental-control system (spacesuit) so that the "man machine" can be used to maximum efficiency. Once a good power source is available, vehicular travel would be possible. Vehicles would become more independent of the central power source when lunar materials could be manufactured into storable fuels.

When man becomes self-sufficient, payload would be available to support other missions such as the Mars mission shown in this chart. We could then start allocating payload to equipment for the processing of lunar resources. A typical process might be the manufacture of propellant, motor cases, and reentry shields. Analysis of figure 6 indicates that the slow accomplishment of space missions support is caused by the nonavailability of earth-launch payload for missions other than those to support the man. Support of man will use up most of the anticipated payload for some time to come.

Why does the man use so much payload? Analysis of Mars-return and lunar-return missions will help answer this question. As is seen in figure 6-7, the requirements to land 10,000 pounds on Mars can be performed with a 13-million-pound chemical vehicle. However, if part of this 10,000 pound payload consists of a man, provisions must be made for bringing him back. Logistic requirements now increase over 20 times, requiring an earth-launch weight of 144,000,000 pounds, which is twice the weight of an "America"-class ocean liner. Man increases logistic requirements in three ways. He must have an elaborate environmental control system, a heavy reentry shield, and a source of energy to increase his velocity by the lunar or Mars escape velocity increment.

In designing most space systems, two questions must be answered. (1) How much payload must be allocated to the system, and (2) how much power does it require. The payload question has just been discussed. Why is power a critical item? To help find an answer, a lunar propellant plant sized at Sperry Utah

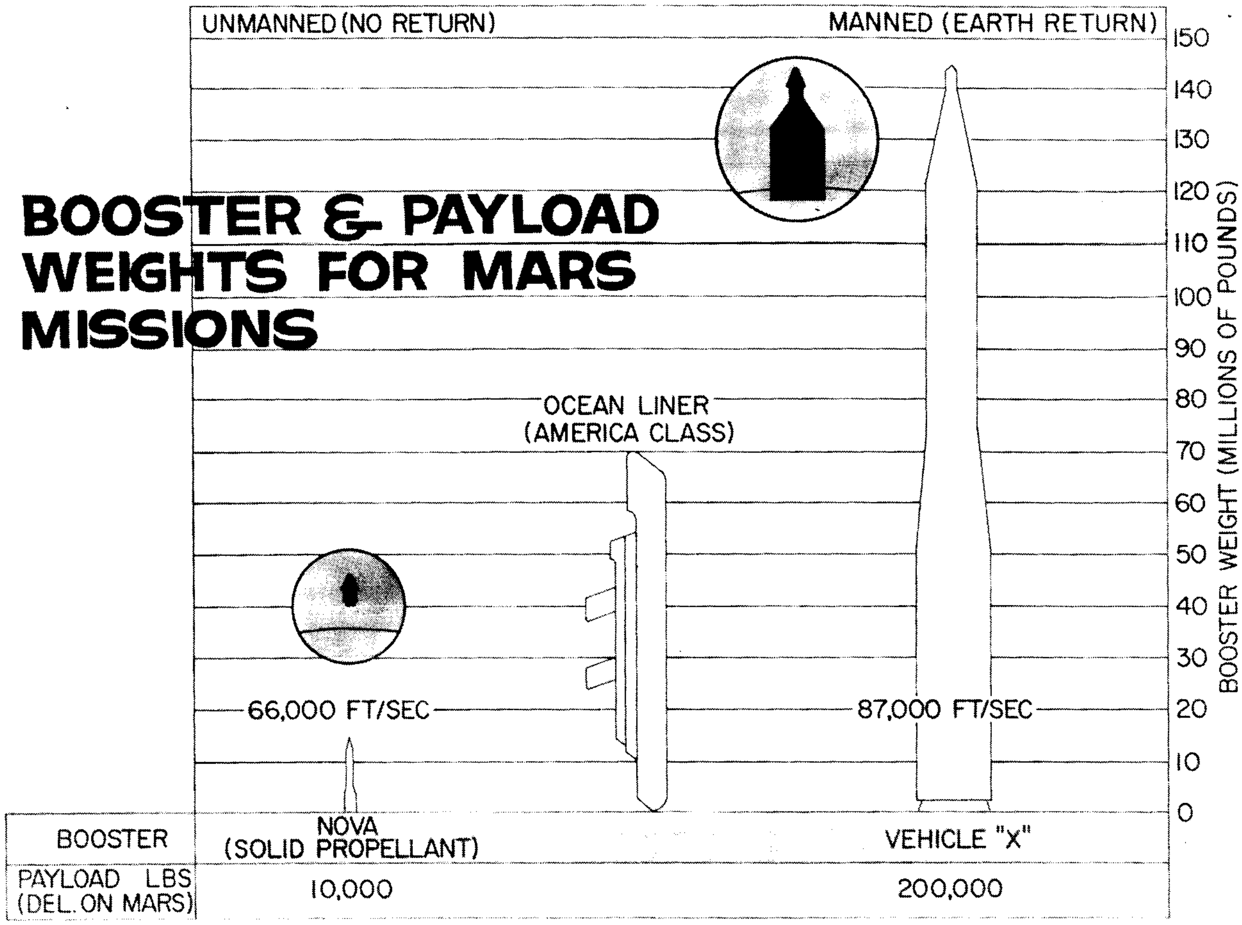


FIGURE 6-7

approximately 2 years ago will be used. This hydrogen-and oxygen-producing plant (figure 6-8) extracts water from lunar water-bearing materials and then dissociates it into hydrogen and oxygen which is then liquefied into cryogenic fuels for lunar use. A description of this plant is given in reference 1. Power requirements to extract water from indigenous materials may very well rule the plant feasible or merely the object of academic speculation. Figure 6-9 shows the power requirements to extract water from lunar rock containing 10, 1 or 0.01 percent water. Data from the 10 and 1 percent values were obtained from inputs in reference 2. Sperry Utah has added a value of 0.1 percent which is based on an extrapolation from the 1 percent figure, and use of the equation:

$$k(Q)/_{HR} = W\,C_p\,\Delta t/_{HR} + \text{Heat required to vaporize 16 lb. of water per hour} + \text{kiln heat loss per hour}$$

k(Q) is power input, W is material weight, C_p is specific heat of the material and Δt is the temperature change.

It might be added that the solar concentrator power source could be replaced with nuclear, fuel cell, or solar cell power systems. However, the

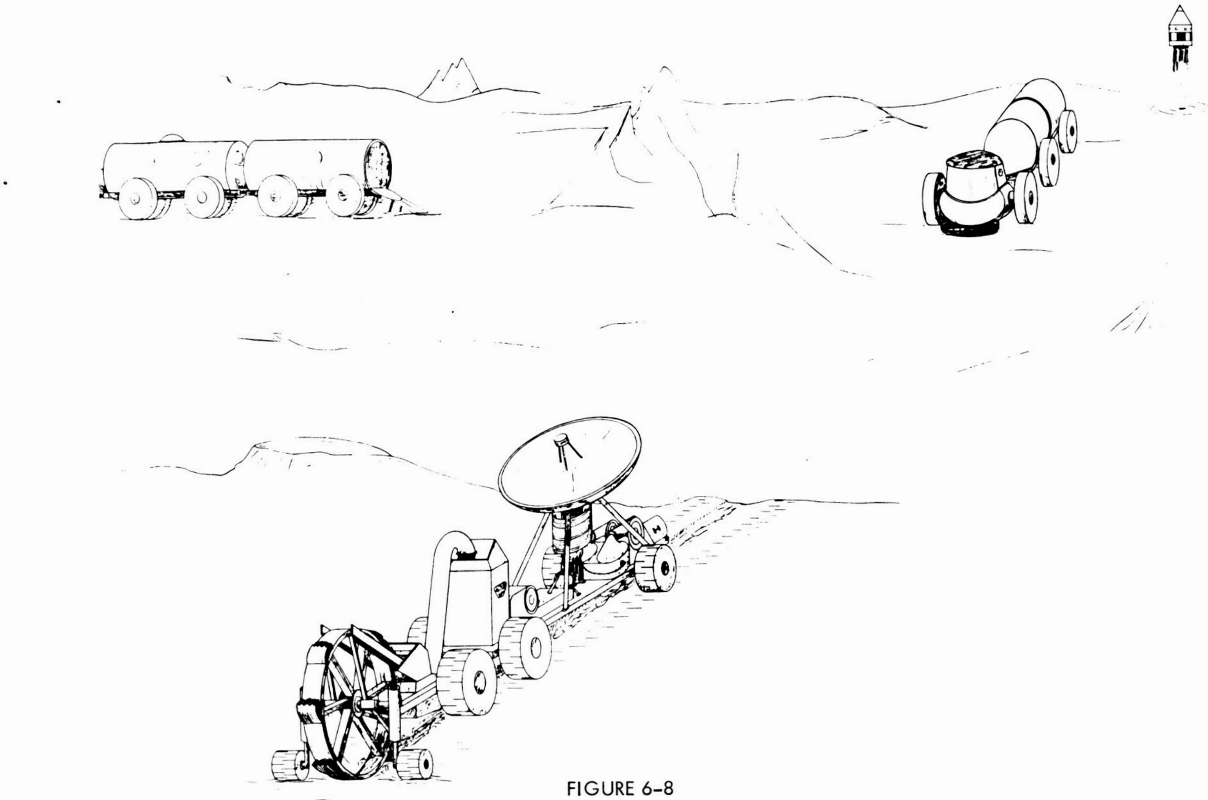


FIGURE 6-8

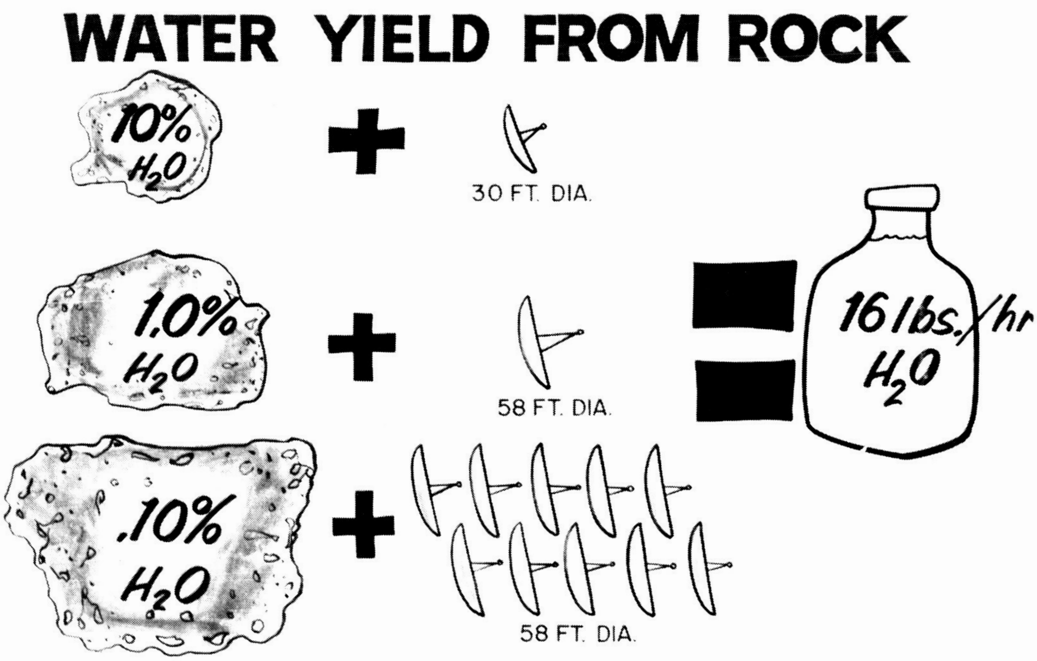
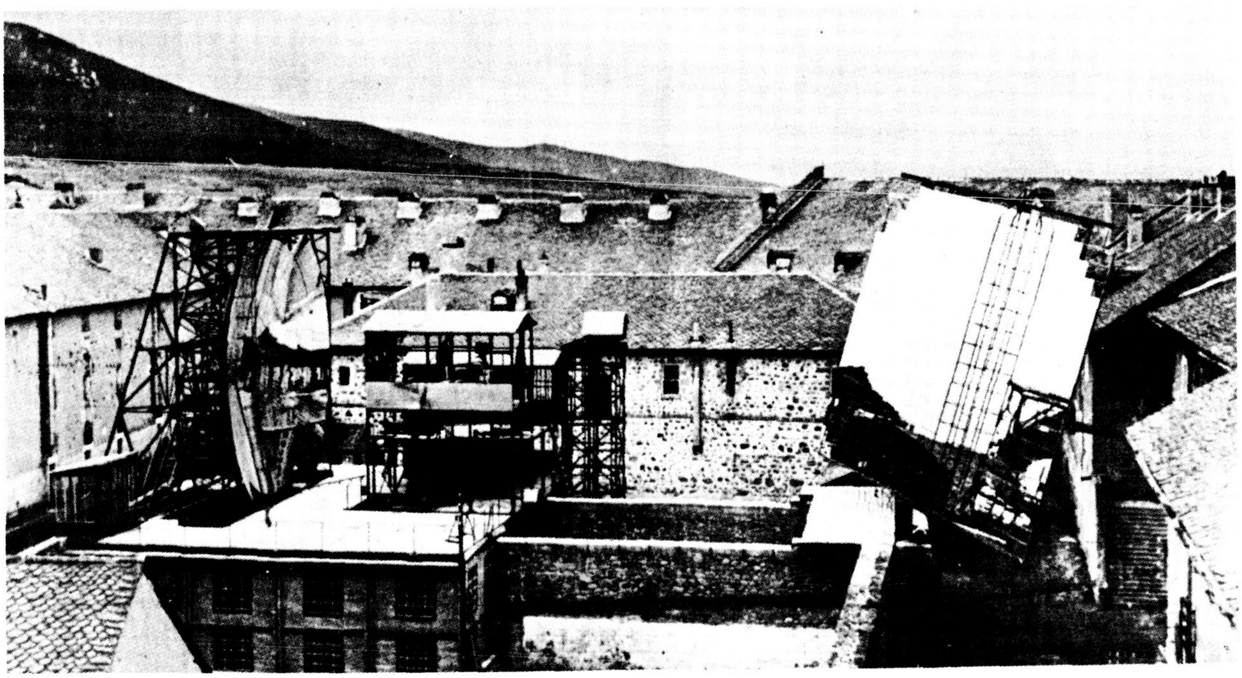


FIGURE 6-9

main purpose of this portion of this paper is to describe comparisons for order-of-magnitude power differences.

If 16 pounds per hour of hydrogen and oxygen are required, as is shown for the plant in figure 6-8, and if the rock contains 10 percent water, the water could be extracted with the power output of a 30-foot-diameter solar concentrator. If this water content value drops to 1 percent, the concentrator size would increase to 58 feet, and finally, if the water content dropped to 0.1 percent, the size would increase to one 167-foot-diameter concentrator or ten* 58-foot-diameter concentrators. The last system is prohibitive, not only from a power magnitude standpoint, but also from a size standpoint. Figure 6-10 shows the size of the 35-foot-diameter solar furnace in Mont Louis, France. Note the size of this concentrator in relation to the size of the windows in the building. This concentrator is only 35 feet in diameter, and yet we have been considering using ten 58-foot-diameter concentrators. Although more efficient systems might be devised to reduce the large power requirements, even if efficiency were increased 5 times, an extreme amount, we still would require two 58-foot-diameter concentrators.

Selection of the 0.1 percent figure was based on experiments at Sperry Utah on various igneous rocks which indicate that lunar rock will contain much less water than some authorities are extrapolating from earth igneous rock data. We have found that the H_2O plus figure of approximately 1 percent for earth rocks does not refer to combined water content, but rather to surface



*Two of the ten 58-foot-diameter systems are required to compensate for the additional kilns required.

D.T.A.

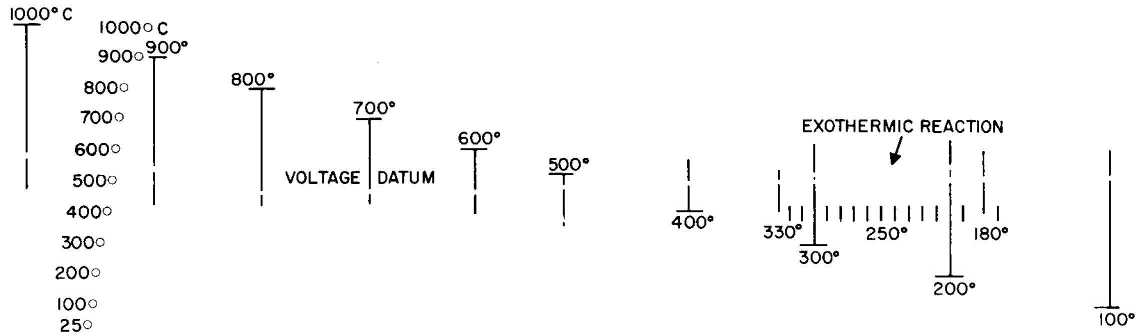


FIGURE 6-11

water content which is held by strong capillary forces. Figure 6-11 shows a differential thermal analysis for a Part City andesite. The low temperature at which water is evolved, along with a thin section analysis, provides conclusive evidence that the water being evolved at the low temperature is not combined water but surface water. Estimates of the combined water content for this type rock is 0.2 percent. This is to be compared with the experimental value of 1.6 percent at which one would arrive under conventional H_2O plus designations. Numerous additional tests on basalts and andesites have checked out the results of this DTA.

The simple problem of determining water content in rock is belabored in this paper merely to emphasize that, unless we become quantitative in our systems evaluation, we may be wasting our time considering a system that might require a power source as large as the one at Hoover Dam.

FINANCIAL REWARD

Will an investment in extraterrestrial resources equipment produce a financial reward? If 200,000 pounds of propellant are required on the moon over a two-year period and earth logistics are used, eight Saturn vehicles could boost this payload to the moon. However, if a plant such as the one described in figure 8 is used, the payload can be boosted to the moon with only one Saturn vehicle; and upon arrival on the moon the plant could proceed to convert lunar material into 200,000 pounds of propellant over a two-year span. The savings realized, therefore, is represented in seven Saturn vehicles.

SUMMARY

If the next function of the Working Group is to provide NASA and the Armed Services with a master plan of the time phasing of extraterrestrial events, then we must produce the numbers to back up our master plan recommendations. We must show that (1) developing extraterrestrial resources will first of all produce logistic savings, (2) there will be an investment return, and (3) the facility is realistic and not just the result of academic speculation. We must start to assign numbers to the equipment we have been analyzing. To implement these three items, it is recommended that systems analysis be performed somewhere in the Working Group.

It is hoped that the approach outlined in this presentation will help the Working Group present to the NASA and the Armed Services a plan to utilize extraterrestrial resources. Once this plan is accepted, an organized R & D program can be started and we shall be well on our way to realizing the utilization of extraterrestrial resources.

REFERENCES

Reference 1 - "Propellant Production on the Moon," H. M. Segal, Space/Aeronautics, September 1963.

Reference 2 - "Recommendations for the Utilization of Lunar Resources," George W. S. Johnson, Jet Propulsion Laboratory, March 8, 1963, pp. 52, 53, 54.

REMOTE DETECTION OF LUNAR WATER DEPOSITS

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INTRODUCTION

The use of the Moon as a refueling station depends upon the successful detection of lunar water deposits and subsequent extraction of the water. Both operations must be accomplished at less cost than would be involved in transporting fuel through the earth's gravitational field to a terrestrial satellite fuel depot.

This paper is concerned with the first step in establishing the Moon as a refueling station, the detection of water deposits. In view of the hostility of the lunar environment and the large surface area to be explored, it would seem that, in order to be economical, detection must be done by scanning the surface remotely from a lunar satellite, or even from the Earth, instead of taking many point measurements on the surface. If possible, the detection system should be made a part of the general scientific exploration program.

REVIEW OF POSSIBLE REMOTE TECHNIQUES TO AID WATER DETECTION

A single remote sensing technique on the Moon as on the Earth is generally both indirect in nature and ambiguous in result. Compensating for the physical difficulties of making measurements provided by the lunar environment, however, are both the wide range of the electromagnetic spectrum and the undistorted magnetic and gravitational force fields which are available for use.

The portion of the electromagnetic spectrum which may be useful as a remote technique for the study of the lunar surface includes radio waves, infrared, visible, ultraviolet and x-radiation.

Radio emission from the Moon is used to measure temperature. Because radio waves penetrate silicate materials to a certain extent, depending upon both the wavelength of the radiation and the nature of the silicate, such temperatures are considered to be subsurface temperatures. Radio emission measurements of the Moon have been made from the Earth and, although they are necessarily integrated over a large area, they show that the lunar subsurface temperatures are low, somewhere between -20 and -50°C, and fairly constant.

On Earth, areas of enhanced heat flow from the interior have generally been subject to alteration, and frequently mineralization, by aqueous solutions which accompany this flow. Thus, if a lunar satellite could measure the detailed variation of lunar subsurface temperature over the surface, areas showing subsurface thermal anomalies might be likely areas in which to find hydrothermally altered and water-rich rocks. It is also possible, and even likely, however, that areas of ancient alteration might no longer retain enhanced heat flow and so would not show up by this method. On the other hand, a thermal anomaly is not always a sign of hydrothermal alteration. In addition, the variables involved in producing the apparent radio temperature and the depth from which this radiation is emitted are not well understood. Thus, radio emission measurements of subsurface temperature are ambiguous in interpretation, but could, nevertheless, be used as a confirmatory or complementary exploration technique.

Radio reflections (radar) from the Moon can also provide information on the nature of the surface and subsurface materials. The dielectric constant, which is a major factor in the reflection coefficient, is a function of their mineralogical composition as well as a function of surface roughness, the density or porosity of the materials, and the addition of small amounts of such common lunar contaminants as nickel-iron. Thus, the results of radar measurements are also ambiguous, but may be used in conjunction with other measurements when the other factors involved are better understood.

Infrared emission measurements of the lunar surface have long been used to measure the thermal characteristics of the surface material. The recent detection of surface thermal anomalies associated with the more recent craters (Shorthill, 1962; Murray and Wildey, 1963) shows that thermal mapping of the lunar surface materials is, however, a function of the thermal conductivity, the density, and specific heat of the surface materials, as well as the emissivity. Thus, surface thermal anomalies are difficult to interpret with any certainty.

Determination of the spectrum of the lunar infrared emission is one measurement that has not yet been made, and which cannot be made from the Earth's surface because of the absorption of the Earth's intervening atmosphere. It is known, however, that silicates have characteristic absorption and reflection spectra in the 8-15 micron region, which make possible the identification of mineralogical composition (Lyon, 1962). Characteristic peaks in the spectrum are expected to be found as far out as 250 microns. Although not strictly quantitative, and far inferior to other laboratory techniques for the determination of mineral composition, infrared emission spectroscopy may be useful in studying the lunar surface. Such measurements made from a high altitude balloon or lunar satellite may reveal the presence of hydrated minerals in areas of alteration.

Visible radiation is largely reflected by the Moon, although a small amount of emitted fluorescence in the visible has been detected from certain areas. For the most part, measurements of the polarization and photometric curve of visible radiation reveal something of the physical state of surface materials, but are not useful for the detection of changes in composition.

Gross reflectivity or albedo of lunar surface materials is one useful property which, recorded on photographs, permits the delineation of different formations and features. Such a delineation adds considerably to the geological understanding of the Moon in the same way that color variations commonly do on Earth. Unlike terrestrial rocks, however, the lunar surface materials have virtually no color (Sytinskaya, 1959).

· Fluorescence in the visible region of the spectrum has been detected from several regions on the moon (Grainger and Ring, 1962), but because the fluorescent phenomena are the result of electronic transitions, rather than molecular or lattice vibrations, they are not related to the mineralogy of the surface materials so much as to the presence of minor impurities in minerals. Thus, they cannot in themselves be diagnostic of a water deposit, although it might ultimately be found that fluorescent effects accompany some types of lunar hydrothermal alteration.

Ultraviolet fluorescent and reflected radiation have not so far been used in lunar measurements because of both the difficulties of making these measurements and of analyzing these properties in terms of the lunar environment.

X-ray measurements of fluorescent x-rays emitted by the lunar surface can reveal the atomic or chemical composition of the surface materials. This semi-quantitative method of compositional analysis is not as useful as a method which would reveal mineralogy, but could still be an effective tool aboard a lunar orbiter.

Magnetic measurements from an orbiting vehicle might at first sight appear useful for the detection of magnetite-rich serpentine deposits. The addition of large amounts of nickel-iron to the lunar surface by past meteorite impacts, however, destroys the effectiveness of this technique.

Gravity measurements could be obtained from satellite perturbations, but anomalies detected would be the result of such large lunar features that they would be of doubtful usefulness.

EXPERIMENTAL INVESTIGATION OF THE INFRARED TECHNIQUE

Of all the remote detection techniques outlined above, the infrared measurements are probably the most useful because they are the least ambiguous. The IR spectral transmission, reflection or emission properties of a material are caused by changes in vibrational and rotational energy states. Rotational transitions are forbidden in solids, so that the spectral properties are functions only of vibrational modes. These vibrational modes appear to be the most useful in the determination of a mineral species.

The study of the Moon by infrared techniques is limited at this time to emission measurements. Reflection methods require an infrared source strong enough so that the reflected energy is much more intense than the emitted radiation; the Sun does not satisfy this requirement. Transmission techniques require extensive powder preparation and must, therefore, be limited to laboratory samples. The infrared method, as planned for use here, would be suitable for use from either a lunar satellite or flyby, or from the vicinity of the Earth, but effectively above the Earth's atmosphere.

Our initial study of the infrared properties of probable lunar materials was to measure the spectral emission of several rock species ground to particle sizes comparable with the best estimates of the particle size of the lunar surface material. The materials chosen were representatives of the entire series of igneous rocks, as well as a chondritic meteorite. The size range was chosen to approximate the predicted range of the lunar surface material.

Considering the constant rain of micrometeorites striking the lunar surface, the grain size of the pulverized surface layer should be very small, which is consistent with both infrared (Jaeger and Harper, 1950) and microwave (Evans, 1962; Gibson, 1961) measurements. The size range of this material is probably similar to the size range of the particles in space surrounding the earth, most of which were apparently ejected from the moon by micrometeoroid impact (Whipple, 1962). These particles average only a few microns in diameter.

Study of the spectral response of such fine powders showed that the spectral detail which is present in the transmission spectrum of a powder and the reflection spectrum of a polished surface is obliterated in the emission spectrum. (Van Tassel, R.A., and Simon, I., 1963).

This result has lead to a study of some of the variables involved in the production of the emission spectrum. The first variable which has been subjected to study is particle size.

Both quartz and olivine were ground to two particle sizes, a coarse "sand" and a "fine" flour. The distribution of particle size of both the quartz and the olivine is shown in Figure 7-1 and microphotographs of the powders in Figure 7-2. As shown in Figure 7-2, olivine flour still contains some particles larger than 20 microns. Figure 7-3 shows the apparent spectral emissivity of the quartz in the two different particle sizes. The sand clearly shows the peak between 9-10 microns associated with quartz while the flour shows the peak greatly diminished. Figure 7-4 shows the same information for the olivine powders. Again the spectral detail for the flour is greatly diminished, even though, it is not obliterated. The spectral detail remaining is caused by the few large pieces remaining in this flour. These large pieces (greater than 16 microns) were removed and the resulting spectrum was indistinguishable from a grey body. The major peak for the olivine sand occurs between 10-11 microns (1000-900 cm^{-1}) or a shift of about 100 cm^{-1} from the quartz spectrum. The shift in the peak position from acidic to basic rocks is known to be present in the transmission spectrum (Lyon, 1962). This change is also to be found in the emission spectrum when the particle size is large enough to give the spectral detail.

Another variable which was subjected to study was alteration. Alteration, in the examples studied here, produced a marked change in the grain size of the rock.

A serpentine, produced by alteration of olivine, was ground to the same particle size as the olivine sand. The spectral emission for the olivine (Figure 7-4) has shown that spectral detail is present. The spectral emission of serpentine, however, even when the serpentine was ground to fairly large particle sizes, did not show any of the spectral detail which is known to be present from transmission measurements. This result is explained by the change

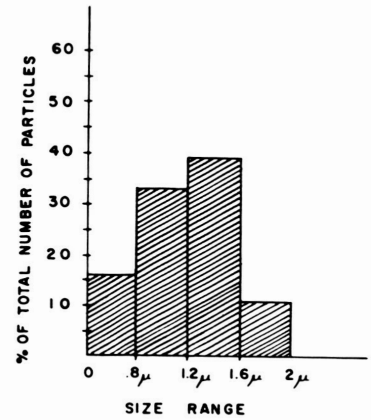

FIG. 1a SIZE DISTRIBUTION OF QUARTZ FLOUR

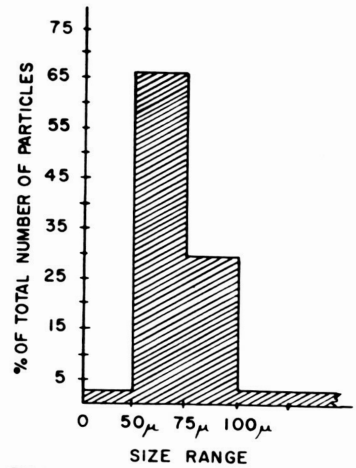

FIG. 1b SIZE DISTRIBUTION OF QUARTZ SAND

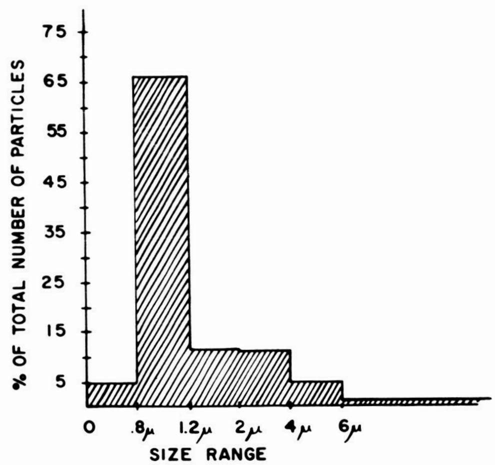

FIG. 1c SIZE DISTRIBUTION OF OLIVINE FLOUR

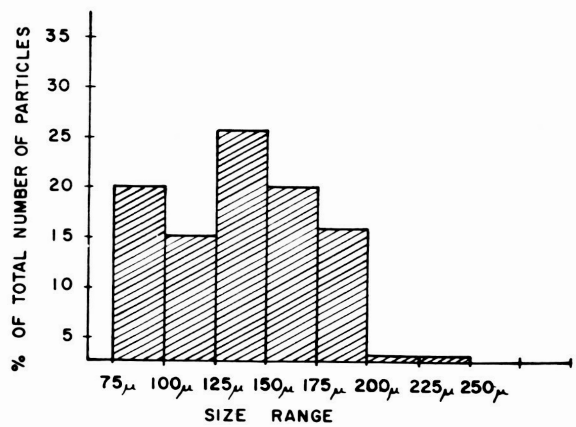

FIG. 1d SIZE DISTRIBUTION OF OLIVINE SAND

FIGURE 7-1

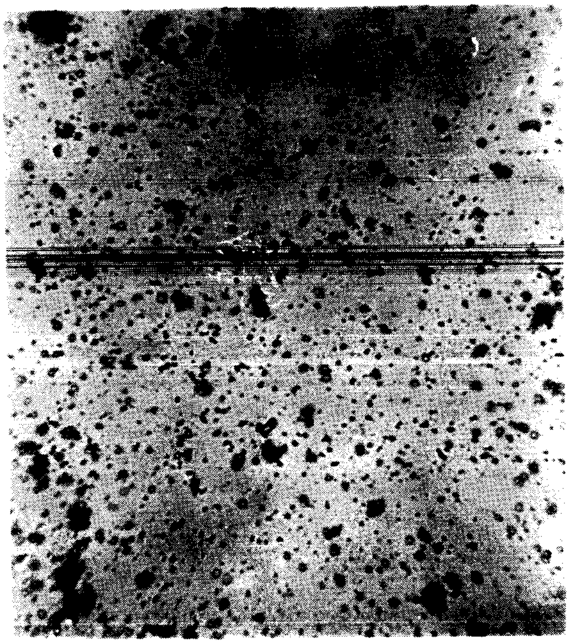

FIG. 2a MICROPHOTOGRAPH OF QUARTZ FLOUR 600X

FIG. 2b MICROPHOTOGRAPH OF QUARTZ SAND 150X

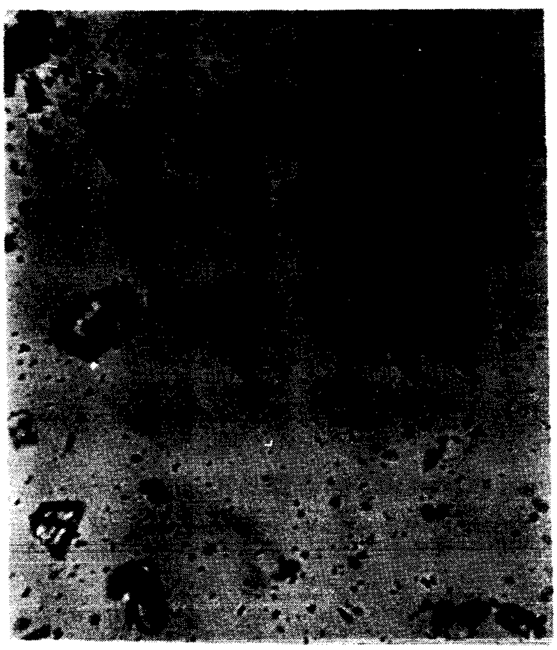

FIG 2c MICROPHOTOGRAPH OF OLIVINE FLOUR 600 X

FIG 2d MICROPHOTOGRAPH OF OLIVINE SAND 150 X

FIGURE 7-2

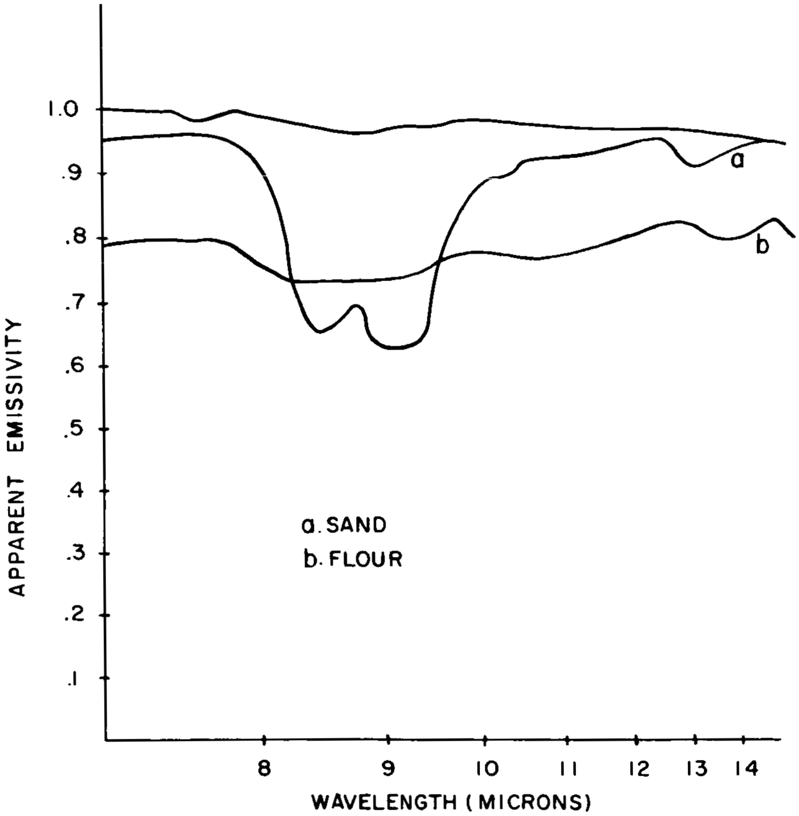

FIGURE 7-3

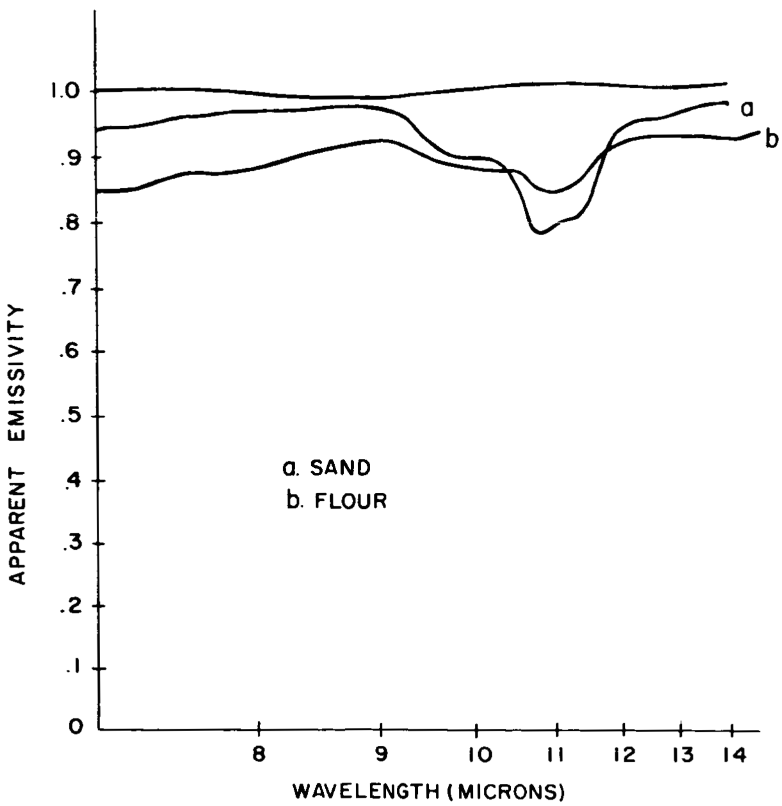

FIGURE 7-4

from the coarse grained condition present in the olivine to the very fine fibrous nature of the serpentine apparent in thin sections studied under the microscope.

Another rock studied was a sample of andesite* in three states of alteration. One sample (A), containing phenocrysts of feldspar in a fine-grained groundmass, was relatively unaltered, in another (B) the feldspars were largely altered to clay minerals, and in the third (C) large amounts of quartz crystals had been produced by hydrothermal silicification. Figure 7-5 shows the spectral response of the three differently altered samples, all ground to particle sizes from 75-200 microns. Curve A representing the response of the unaltered andesite shows structure that, although not marked, is consistent with the spectrum of feldspar (absorption maxima at 900 and 1100 cm^{-1}). Considering the loss of spectral response with decreasing grainsize, a weak spectrum was expected from a

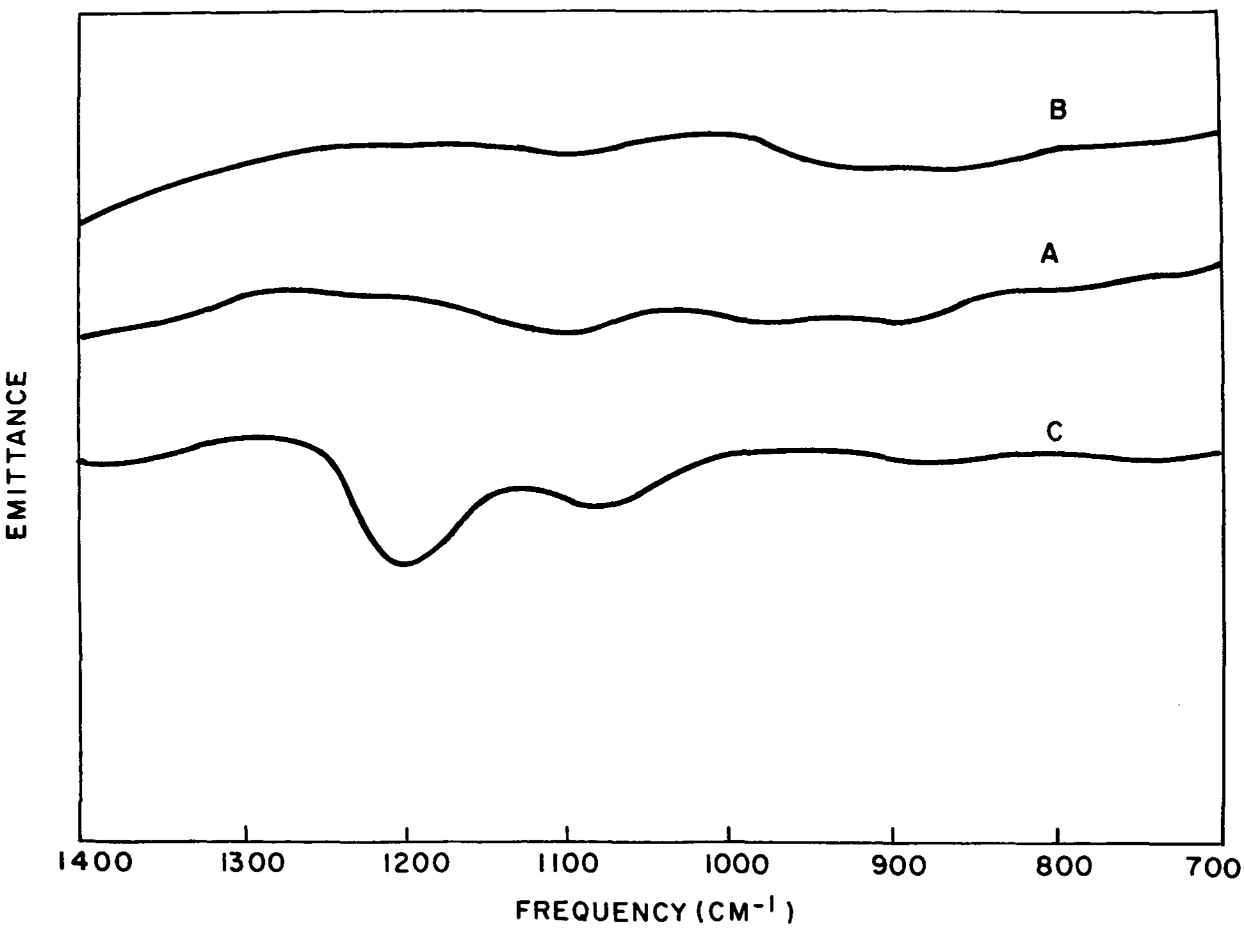

FIGURE 7-5

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*Obtained from Dr. J. Green.

rock such as the andesite measured, which was composed largely of a finegrained groundmass.

Curve B, representing the response of the andesite after argillization, shows much reduced structure consistent with partial destruction of the feldspar.

Curve C, representing the response of the silicified andesite, shows greatly increased structure clearly related to relatively large quartz crystals produced during silicification.

Thus, the two examples of alteration described above illustrate two ways in which infrared emission can be used to detect lunar water deposits, either through a change in grainsize, or a change in composition, or both. Anomalies so produced, especially when associated with geological features of probable internal origin such as the chain craters, can be used as strong indicators of water deposits. It is true that anomalies in composition and/or grainsize are not necessarily associated only with water deposits. The geology of the Moon is, however, much simpler than that of the Earth judging from the lack of folding or any but normal faulting. Thus, the interpretation of such anomalies should be possible, especially when this technique is allied with others.

CONCLUSION

Examination of different types of remote techniques for the detection of lunar water deposits suggests that measurement of infrared emission is the most promising, because it is the least ambiguous. Experimental work on rock and mineral powders has shown that the degree of spectral response is critically dependent on grainsize. Powder samples having a grainsize near the diagnostic wavelength of emitted radiation (8-15 microns) will show no structure in their spectrum. The addition of even a small proportion ($<1\%$) of coarser grains will, however, produce a spectrum that can be qualitatively diagnostic of the mineral species.

The spectral examination of two rocks, a dunite and an andesite, and their alteration products has shown that alteration characteristically produces a spectral anomaly, reflecting a reduction in grainsize in the case of serpentinization of the dunite and argillization of the andesite, or reflecting a change of composition associated with increased grainsize in the case of silicification of the andesite.

Although not completely unambiguous, the probable relatively simple lunar geology and use of complementary techniques should make infrared emission measurement a powerful tool for the remote detection of lunar water deposits.

FUTURE PLANS

The Lunar-Planetary Research Branch of the Air Force Cambridge Research Laboratories is currently conducting a program to measure the infrared spectral emission of the Moon.

Because a balloon vehicle at high float altitudes is above approximately 98% of the infrared absorbing constituents of the Earth's atmosphere, it is an ideal vehicle from which to make measurements in the infrared. Figure 7-6 shows the calculated transmission of the atmosphere at 100 K ft. Figure 7-7 shows the AFCRL 12-inch balloon-borne telescope capable of routine flights above 100 K ft. The stabilization and pointing system for this telescope was designed and built by Professor Alvin Howell of Tufts University.

Concurrent with making direct observations of the Moon, we are also making laboratory measurements of various silicate powders both before and after these powders have been exposed to the radiation environment of the Moon. These measurements will be used as a guide in the interpretation of results obtained from the Moon.

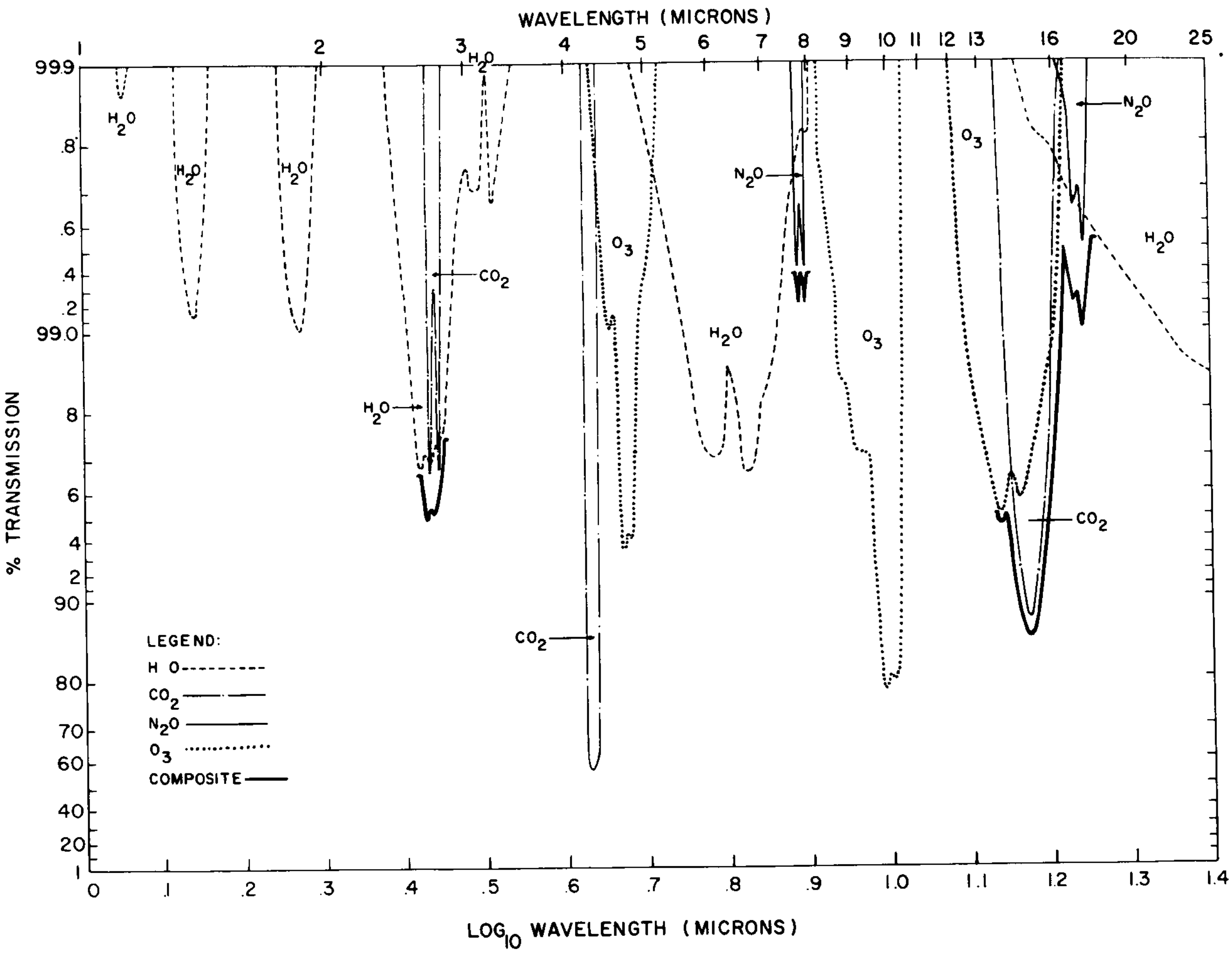

FIGURE 7-6

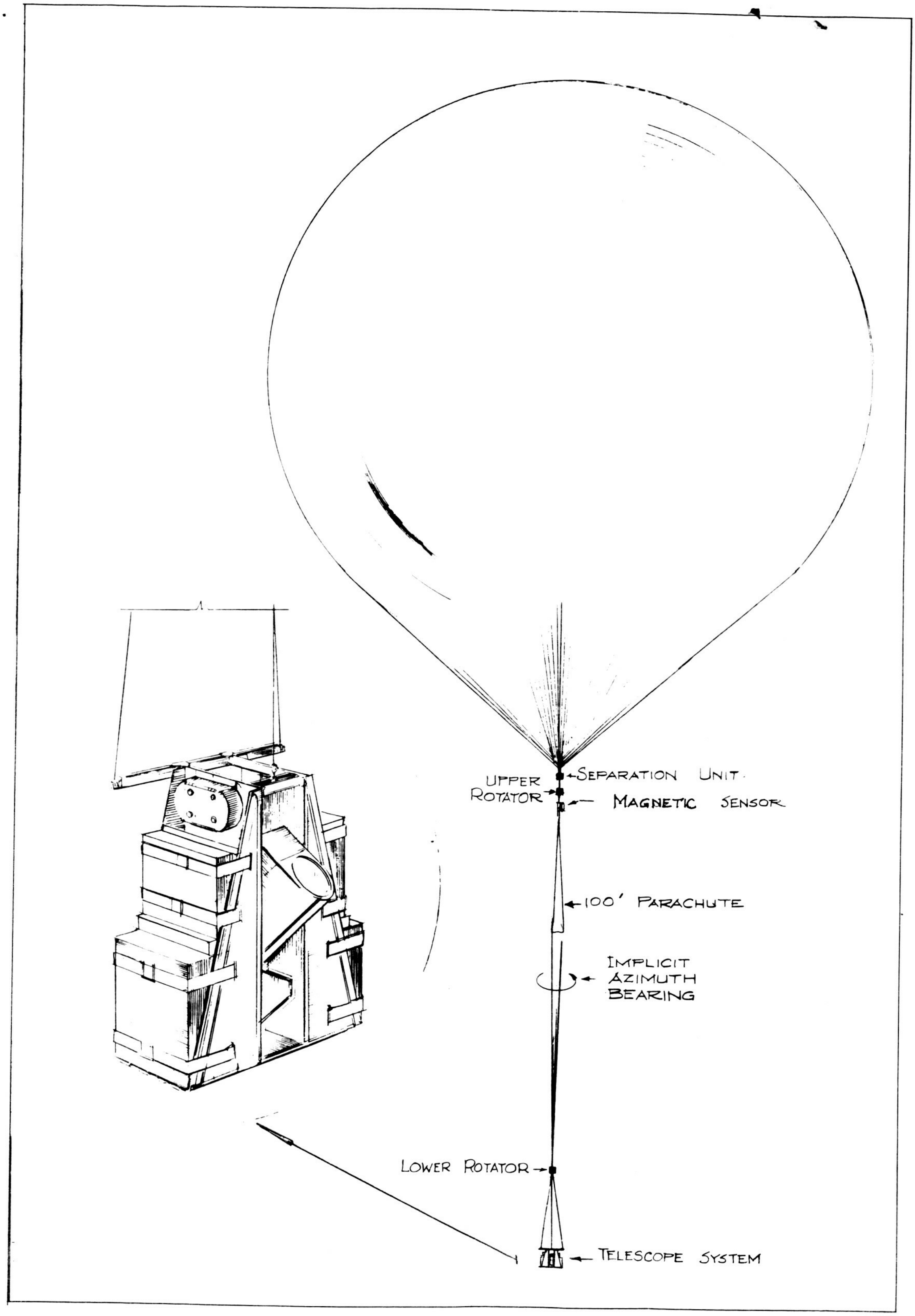
SEPARATION UNIT
UPPER ROTATOR
MAGNETIC SENSOR
100' PARACHUTE
IMPLICIT AZIMUTH BEARING
LOWER ROTATOR
TELESCOPE SYSTEM

FIGURE 7-7

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WATER EXTRACTION IN THE LUNAR ENVIRONMENT

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Introduction

The importance of a lunar source of water has been emphasized in several papers already presented at the Second Annual Meeting of the Working Group on Extraterrestrial Resources. The principal uses for water on the lunar surface will be for life support and as a fuel resource. In the initial stages of lunar exploration and lunar base utilization, water for life support will most probably be conserved in closed ecological cycles, and losses will be replenished from supplies transported from the earth. Similarly, chemical fuels will be conveyed from the earth and stored on the lunar surface. As lunar bases and expeditions increase in size and complexity, it will become practically and economically feasible to utilize lunar natural resources, particularly water. In subsequent space exploration, lunar water, as a raw material for fuel, will assume a most important role. The specific advantage of using hydrogen and oxygen, obtained from water, as a reaction mass or as chemical fuels have been described elsewhere (Salisbury, et al, 1963; Segal, 1963).

The objectives of this paper will be to present several processes suitable for water extraction in the lunar environment, to discuss their advantages and disadvantages from an engineering viewpoint, and to indicate the direction that our research and development effort should take to insure successful utilization of lunar water resources.

Types of Water Deposits

Before considering methods for lunar water extraction, we must consider the nature of the deposits. Evidence for the occurrence of water in the lunar environment is based upon observations of gas release (Kozyrev, 1959, and Green, 1962); surface features such as chain craters, lunar rilles, and maria domes (Salisbury, 1961); and indications of volcanism with terrestrial analogies of water volatilization. Surface or subsurface deposits may be possible; ice or ice-soil mixtures and water of hydration are the most likely forms of lunar water.

Ice or ice-soil mixtures may exist in permanently shadowed surface zones where the temperature does not rise above $120^{\circ}K$ (Watson, 1961). Surface water in the form of ice or physically adsorbed moisture will not exist in unshadowed areas. Observations of emission in the microwave region (Evans, 1962; Gibson, 1962) have indicated that the subsurface temperature remains relatively constant in the range of 220 to $250^{\circ}K$. The vapor pressure of ice at these temperatures is in the order of 10^{-1} torr, and rapid evaporation would be expected for exposed deposits.

If the ice-soil mixtures were covered with layers of fine particles, however, the evaporation rate would be substantially reduced. Estimates of the diffusion of water vapor from an ice bed at 230°K through layers of 10-micron particles indicate that weight losses of 6×10^{-2} and 6×10^{-4} gm/cm^2 - year would result for powder layers of 1 and 100 feet, respectively. (Physical adsorption should be small for the steady-state process considered.) These rates are sufficiently high to result in a rapid depletion (on a geologic time scale) of ice which is covered with dust alone. However, if the ice deposit were covered with an impermeable rock with a low diffusion coefficient (for example, diffusion coefficients of water through glass may be less than 10^{-24} of the values for diffusion through particulate mixtures) the ice may remain from its formation until the present.

The moisture content of hydrated minerals in a terrestrial environment varies from a small fraction of one percent up to 10 to 15 percent for serpentine. The moisture content of rocks (in the form of hydrated minerals) depends upon their mineralogical composition and the conditions during their formation. If volcanism is accepted as a contributing factor to the formation of the lunar surface, it is reasonable to assume that hydrated minerals will be present. The dehydration of rocks in the temperature and pressure environment of the lunar surface should be slow, and hydrated rocks should still remain; however, their mositure content may be as low as 0.01 percent. In addition, fluid inclusions in the rock, perhaps as much as 0.1 percent by volume, could exist if the diffusion rates are sufficiently low.

The feasibility of water extration processes will be based primarily upon finding hydrated minerals. The latter can be expected to be present either on the surface (perhaps covered with dust or meteoritic evolved material) or in subsurface vein or blanket structures.

Environmental Factors Influencing Water Extraction

On the earth, a process that extracted water from rocks containing hydrated minerals would involve relatively straightforward designs based on conventional chemical and mechanical engineering principles. The problem becomes much more complex in the lunar environment because of several factors:

1. Ambient Pressure: The extraction reactor must be pressurized to a reasonable level and must be free from leaks which would be unimportant under terrestrial conditions. The lunar vacuum will necessitate special techniques for lubrication of rotary seals and other moving parts and for transfer of raw materials and products.

2. Ambient Temperature: The large variation of the ambient temperature of the lunar surface will influence the heat transfer coefficients of the materials of construction (and thus affect the choice of these materials),

will necessitate modifications in techniques for condensing and storing water, and will provide unusual heat sources or heat sinks which must be taken into account.

3. Reduced Gravity: The reduced gravity field on the moon must be considered in the transport of solid materials and the flow of materials in fluidized or rotary reactors. Lower gravity will also have a pronounced effect on heat transfer rates in many systems that contain particulate material or boiling and condensing fluids.

4. Environmental Hazards: The effects of solar flares, ultraviolet and X-ray radiation, and meteoroid bombardment on the equipment and operating personnel must be considered. Adhesion of dust particles on equipment (which in some processes would reduce heat transfer coefficients) and deterioration of surfaces by secondary impacts will adversely affect most processes.

5. Lunar Logistics: The equipment to be used must be of minimum weight and easily transportable in the lunar environment. It may be desirable to transport the extraction system to the raw material. Spare parts and replaceable items must also be considered in the over-all logistical scheme.

6. Power Requirements: Electrical power or chemical fuels are terrestrially available in most locations at low cost. In a lunar extraction process, minimum power must be expended, waste heat recovery is essential, and utilization of available natural power resources should be considered.

7. Human Factors: Lunar water extraction equipment must be automated for minimum control and maintenance. Personnel and supplies available for repair, modification, and control will be limited.

Processes in Situ Versus Processes Using Mined Deposits

The choice of using deposits in situ or using mined materials for water extraction processes will of course depend primarily on the types and locations of the deposits of water-bearing rock or ice. An in situ extraction process can be defined as one in which water is extracted from a deposit in its original location; mining and/or transport of the deposit would not be required. An example of this type of process (in terrestrial use) is the Frasch process for sulphur recovery. In the Frasch process, steam or hot water is forced underground into a sulphur deposit; the sulphur is melted and flows to the surface with the water stream. Lunar in situ extraction of water from large deposits of hydrated minerals is attractive, because it would eliminate mining and reduce transportation costs. The complexity of mining and surface transport in the lunar environment would be formidable and would involve considerable expense. However, drilling, emplacement of heat sources, sealing formations to prevent adverse movement of gases, possible capping of rock formations to aid in pressurization, and other aspects of in situ extraction would be equally difficult. A detailed knowledge of the geology of the underground deposits will certainly be required for in situ processes. Considerable prospecting efforts would be involved.

In initial attempts toward water extraction, it is reasonable to expect that materials available on or close to the surface would be used. The first extraction processes might employ surface vehicles to transport surface rock to a processing plant or a portable processing plant that can be relocated on the surface to reach fresh deposits.

Naturally, if deposits are not found close to the surface, one must then consider mining or in situ extraction. Several in situ processes have already been described (Salisbury et al, 1963). However, as processes that use more readily available materials have greater immediate promise, we will confine the remaining remarks to extraction from water-bearing rocks that are found on the surface or as mineral deposits and not discuss the pros and cons of mining or in situ processes.

Energy Sources

All extraction processes will require energy to supply heat for vaporizing ice or breaking molecular bonds to free water of hydration. The two principal energy sources to be considered are solar and nuclear. Solar energy can be used directly as thermal energy, or it can be converted to electricity. Nuclear energy would most probably be converted to electricity for ultimate use in the processing of mined or surface deposits.

1. Solar

Several types of systems can be used for collection and concentration of solar radiation (Glaser, 1961; Francia, 1963). The effectiveness of solar systems is dependent upon the reflectivity of the surfaces of the concentrating and auxiliary mirrors, the losses due to nonreflecting portions, and the geometrical perfection of the lens systems. Techniques have been developed for forming mirrors from lightweight plastics which can be shaped and rigidized in place. (McCusker, 1963.) Collapsible lightweight structures have been designed to provide the proper curvature and the required support. The present state of the art permits mirrors up to 50 feet in diameter to be produced for solar energy applications on the lunar surface. In sufficient numbers, solar cells could provide electrical energy to operate water extraction processes; cells of thin film materials that can be rolled and packaged in small, lightweight units are now under development.

Solar energy systems may be adversely affected by the lunar environment. Meteoroid punctures, micrometeoroid erosion, coverage by dust, and deterioration of optical surfaces by solar flares and cosmic radiation are several influences on system performance which must be considered. Sufficient information is not yet available to determine the behavior of solar collection systems in the lunar environment.

2. Nuclear

Nuclear energy systems of various power levels are being developed for space vehicles. Modular units such as the SNAP series reactors will probably be available when lunar water extraction processes are necessary. These systems can be tested in the terrestrial environment and will not be as susceptible to adverse environmental effects as will solar systems. This feature, combined with minimum maintenance, ease of control, and applicability during lunar day and night, indicates that nuclear energy systems will be more versatile and more easily adaptable to water extraction processes. The final choice between nuclear or solar energy systems will, of course, be determined by advances in these fields in the next decade and our more complete understanding of the lunar environment.

Extraction Processes

Two relatively simple methods which deserve first consideration for water extraction are kiln or furnace processes and fluid bed processes. Each of these is now used in many commercial processes that are directly similar to dehydration of rock.

1. Kiln or Furnace Processes

The rotary kiln furnace is a versatile device for drying, calcining, and dehydrating. Several types of kilns can be considered for extracting water on the lunar surface.

Kilns can be heated directly with solar energy or electrical energy. In the kiln shown in Figure 8-1, solar energy is transmitted directly through a transparent window into the kiln. This system provides uniform heating of the rock being dehydrated and permits an efficient use of the solar energy. The design of this kiln presents some difficulties, such as protection of the window from erosion by micrometeorites, expansion of the window, and sealing problems due to pressurization of the kiln.

The rotary spherical kiln of Figure 8-2 is heated by an electrical radiant heater with energy obtained either from solar energy or a nuclear power source. This heating device will be less affected by dust adhesion or meteoroid impact; furthermore, shielding to prevent oxidation and chemical reaction is not required in the lunar atmosphere, and refractory metals could be used without a ceramic overcoating. The radiant energy must be transmitted through the shell of the kiln and its lining into the rock being dehydrated. An alternate system using direct solar heating is also shown.

Kiln efficiency will depend upon the properties of the material being dehydrated. Consideration must be given to heat losses by radiation to space, vacuum sealing in both the feed and product sections, and lubrication of the rotary joints. Kilns required for extracting limited amounts of water on the lunar surface would be small in comparison to commercial sized kilns. This resulting high surface-to-volume ratio may be used advantageously, since the kiln would be heated through its surface. Hot rock must be separated from the product steam before condensation. Special radiators may be required if the kiln is operated during the lunar day.

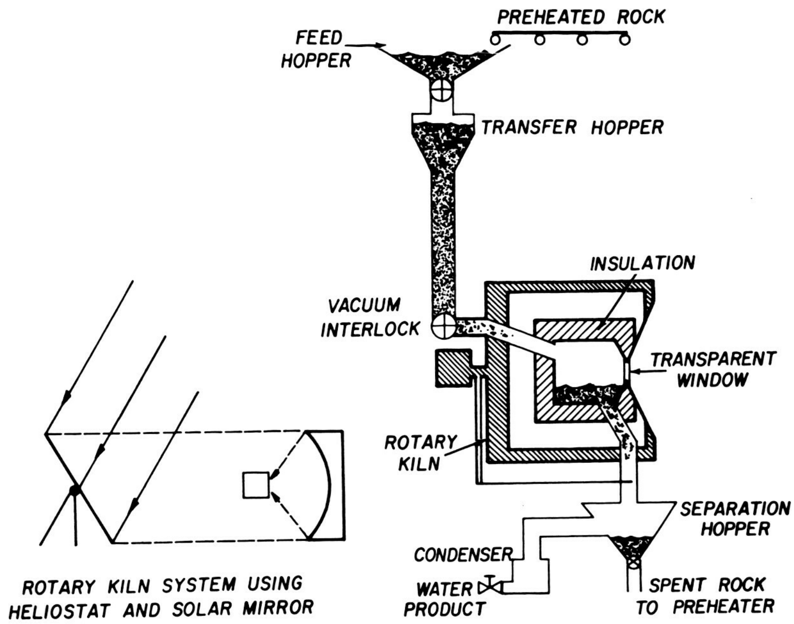

FIGURE 8-1 **ROTARY KILN USING SOLAR ENERGY DIRECT HEATING AND OPTICAL WINDOWS**

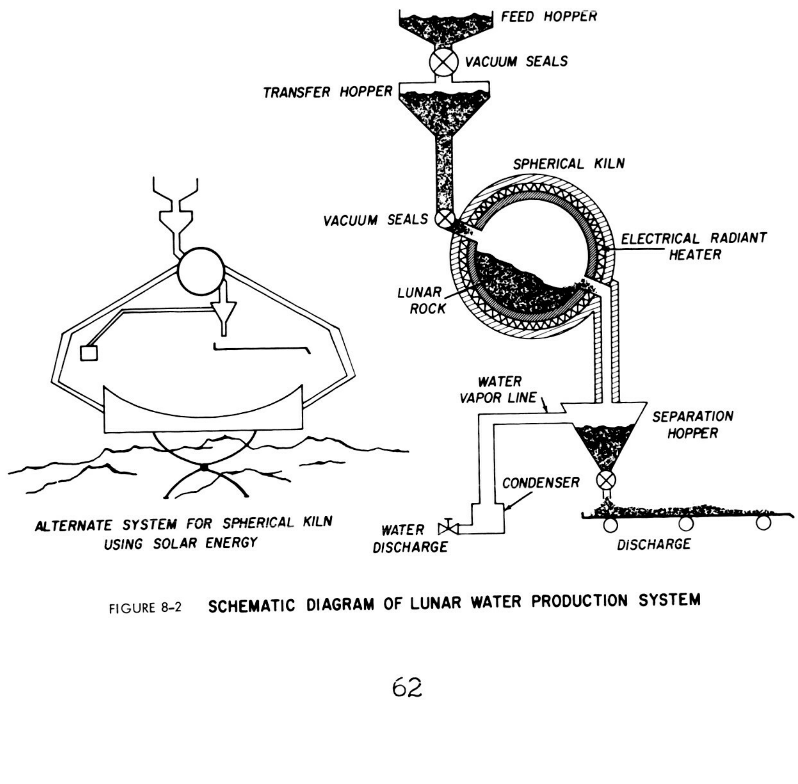

FIGURE 8-2 **SCHEMATIC DIAGRAM OF LUNAR WATER PRODUCTION SYSTEM**

Table 1 shows the results of some preliminary calculations of power requirements and typical reflector sizes for spherical kiln heated by solar radiation. The calculations were made assuming conditions of 1) no heat recovery and 2) 70% heat recovery from the hot rock. In practice, waste heat recovery--i.e., the use of dehydrated rock to preheat the incoming rock--would be necessary to make the process economically feasible. Kiln efficiency could be further increased by insulating the exterior surfaces of the kiln or providing controlled emissivity.

Other types of furnaces, such as an auger-type heated by solar or electrical energy, are also under consideration (Green, 1963) and present interesting modifications of kiln technology. It should be pointed out that the types of kilns considered here are within the state of the art; such problems as vacuum-sealing and lubrication are common to all lunar systems, vehicles, and processes and are being studied under a variety of programs.

2. Fluidized Bed Processes

Fluidized bed reactors, heated by electrical energy produced from solar energy or a nuclear reactor, can also be used to dehydrate rocks containing water of hydration. The fluidized bed process is similar to the rotary kiln process; however, higher heat transfer rates can be achieved, the size of the apparatus can be reduced, and more direct advantage can be taken of rock preheat.

Table 8-1.--TYPICAL REQUIREMENTS FOR LUNAR WATER RECOVERY SYSTEM

BASIS: 8 Pounds Per Hour Water Production - Cylindrical Kiln System

Water Content of Rock	NO HEAT RECOVERY			70% HEAT RECOVERY		
	Kiln Power	Total Power	Typical Reflector Diameter	Kiln Power	Total Power	Typical Reflector Diameter
(%)	(kw)	(kw)	(ft)	(kw)	(kw)	(ft)
10	12	19	19	7	14	16
1	78	90	42	27	39	28
0.1	735	785	123	225	275	74

Notes: Kiln Power includes heat required for heating rock from -40°C to +800°C and dehydrating the rock.

Heat of Dehydration was assumed to be 1110 cal/gm, the heat of vaporization from crysolite.

Heat losses were estimated from insulated kilns with 3" nominal insulation thickness.

Arc heating of a fluidized bed may result in rapid consumption of the electrodes, and replacement would be a serious problem. Advantage can be taken of the rarefied lunar atmosphere by using metallic resistance elements. Radiant furnaces can be constructed which will have small heat losses, provided there is adequate radiation shielding. In addition, the incandescent heating elements should have a long operating life.

Figures 8-3 and 8-4 show two designs for radiant-heated fluidized bed processes for extracting water. In Process A, a multiple-bed reactor is used. Crushed rock is ground to between 50 and 100 mesh and introduced into the upper bed, where it is preheated by steam rising from the calcining zone. From the upper bed, the rock overflows into the calcining zone, which is maintained at 700°C by a circulating stream that passes through tubes located

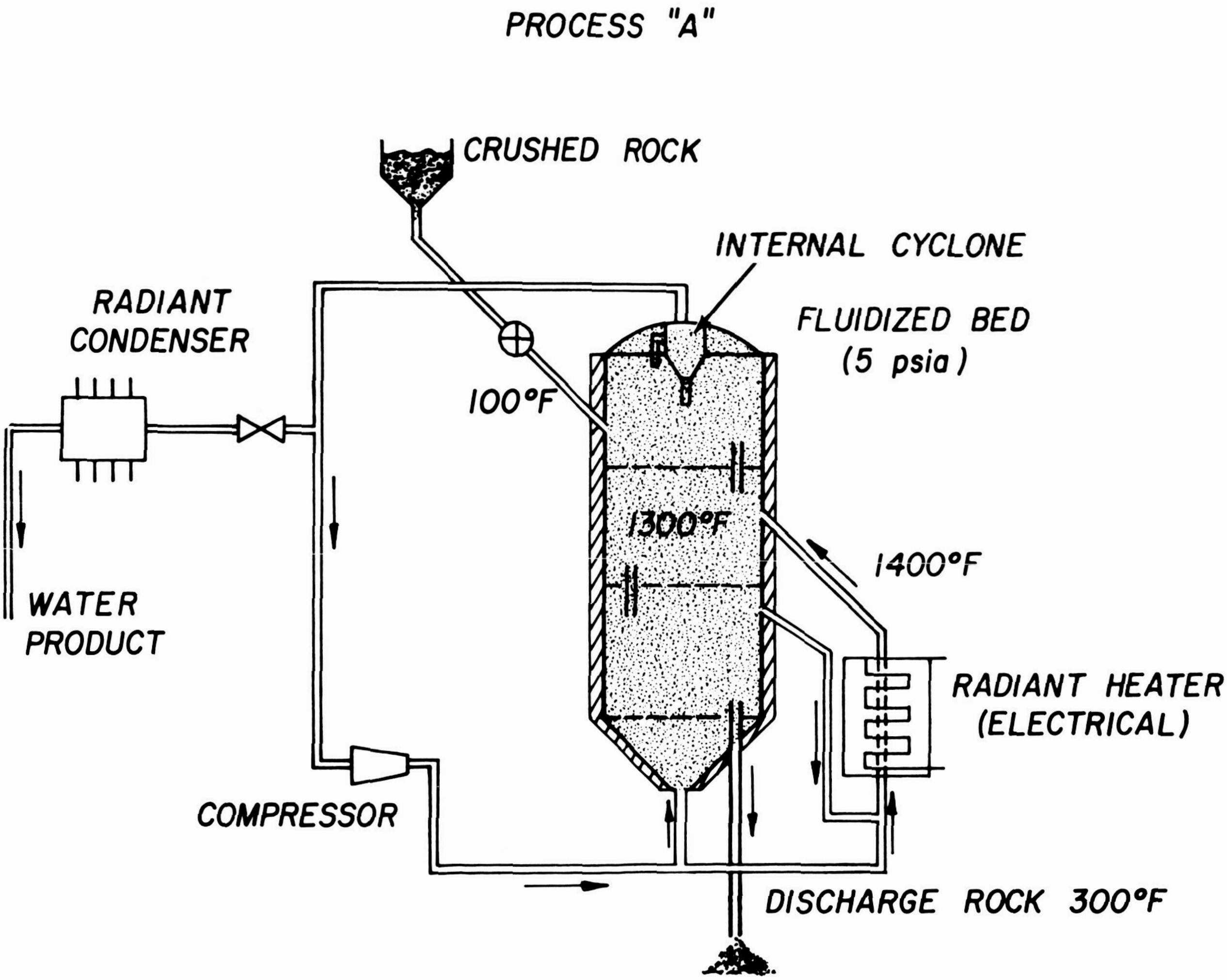

FIGURE 8-3 **FLUIDIZED BED PROCESS FOR WATER EXTRACTION**

PROCESS "B"

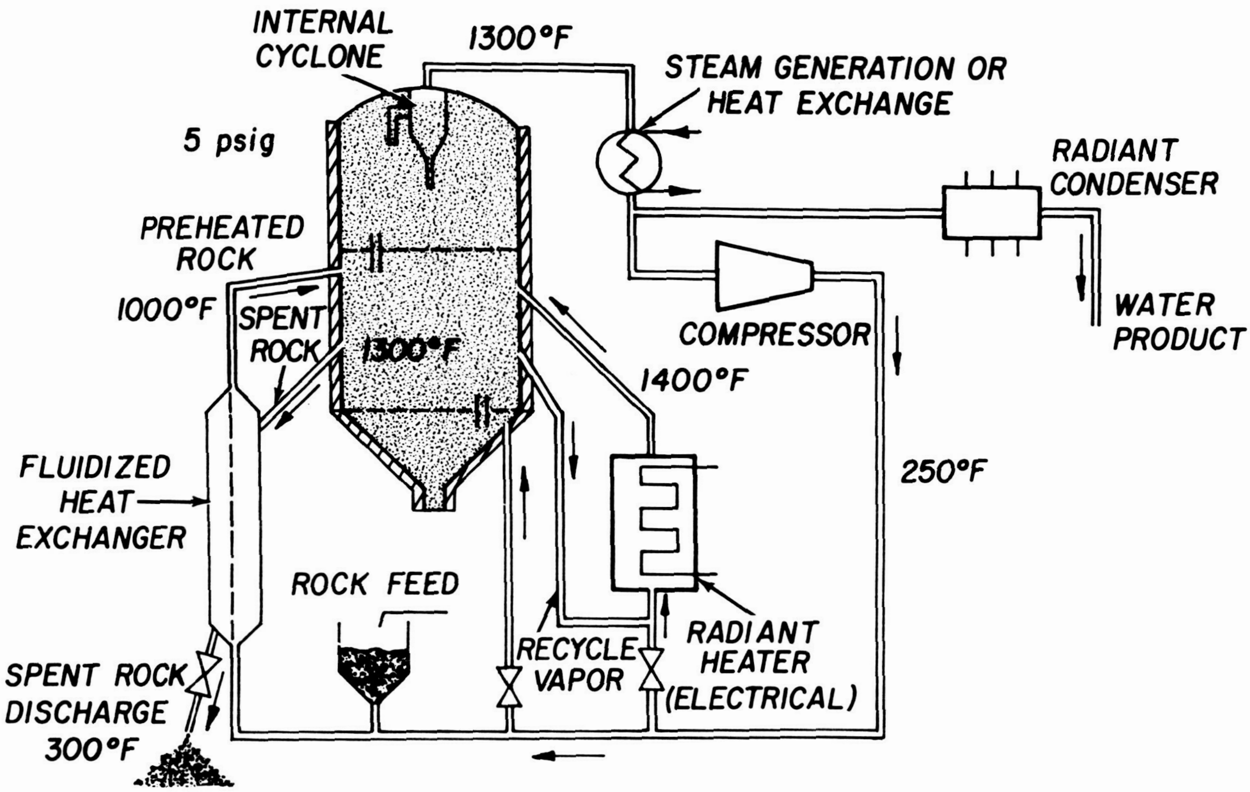

FIGURE 8-4 **FLUIDIZED BED PROCESS FOR WATER EXTRACTION**

within the radiant heater. Before it is discharged, the rock leaving the calcining zone is cooled by incoming steam. The steam produced must be condensed in a radiation cooler. It may be difficult to operate a radiation condenser during the lunar day, and a storage system for the steam may be necessary. It may also be of advantage to operate a fluid bed at a reduced pressure to simplify condensation.

The disadvantage of Process A is that a large amount of fluidizing gas is required to transfer the heat in the cooling and preheating zones. Process B avoids this by utilizing a fluidized indirect counter-current heat exchanger between the unheated rock and the rejected dry rock. The fluidizing gas requirements will be far less, and the simplification of the reactor may compensate for the additional complexity of a rock-to-rock heat exchanger. By expanding the superheated steam from the fluidized reactor to ambient conditions through a turbine or other work engine, it may be possible to obtain water as ice crystals and to recover work in the turbine.

Table 2 shows the results of preliminary calculations for dehydration of rock in fluid bed systems. The estimated power requirements are comparable with kiln systems using heat recovery. The power required for fluidization has not been included in the total power requirements. This should be small, however, compared to the power expended in heating and dehydrating the rock.

Table 8-2.--TYPICAL REQUIREMENTS FOR FLUID BED WATER RECOVERY SYSTEMS

BASIS: 8 Pounds Per Hour Water Recovery

Water Content of Rock	Heating and Dehydration Power	Total Power	Reactor Volume
(%)	(kw)	(kw)	(ft^3)
10	6	10	5.5
1	22	33	50
0.1	177	220	500

Notes: Heat of Dehydration assumed to be 1100 cal/gm.

Heat Losses based on 3" nominal insulation thickness.

Other Extraction Processes

In addition to furnace and fluid bed-type extraction processes, chemical and biological extraction techniques, nuclear "Frasch" processes, and underground in situ heating also deserve mention as alternate schemes (Salisbury, et al., 1963). The feasibility of these processes depends upon the exact nature of the deposits ultimately found on the moon and the degree of advancement of lunar technology in the next several decades.

Direction of Research Effort

The success of lunar water extraction processes will depend greatly on our knowledge of the lunar environment and the effects of this environment on man and materials. The information from many NASA and Air Force-sponsored programs can be utilized in the design of extraction systems. Problems such as vacuum-sealing lubrication, meteoroid protection, and thermal protection must be solved before man can explore the moon and determine whether or not he can use its natural resources. Information of a more specific nature on the behavior of hydrated minerals under various temperature and pressure environments, on diffusion rates through minerals, and on heat transfer and thermal properties of hydrated minerals and rocks is also required for successful design of extraction processes.

Several programs are being conducted by the Air Force Cambridge Research Laboratories and NASA to further our knowledge of the behavior and properties of possible water-bearing materials in a lunar environment. Methods of detection of water deposits are also being studied. Combined with the results of lunar reconnaissance programs, this information will help to establish the feasibility of extracting water from lunar materials.

Summary

The following points summarize our present thinking on lunar water extraction:

1. Successful extraction of water on the moon will greatly further space exploration.

2. Evidence from several sources indicates that water is present in the lunar environment in the form of ice or hydrated minerals.

3. Solar or nuclear energy sources should be available within the next decade to provide the energy required for lunar water extraction.

4. Surface and easily mined deposits will be more useful for water extraction processes in the initial stages of lunar recourse development.

5. Processes using kilns, furnaces, and fluid beds are easily adaptable for water extraction. These processes are well within the state of the art terrestrially and, with suitable modification, should be usable in the lunar environment.

6. The knowledge being gained from present programs on the nature of the lunar environment, space programs such as Mercury, Gemini, and Apollo, and the results of forthcoming programs using Ranger, Surveyor, and lunar orbiting vehicles will be of great help in assessing the feasibility of lunar water extraction processes. At the time when these processes are required for logistical reasons, sufficient technical information should be available to enable the design of simple, economical systems for utilization of the moon's natural resources.

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SYNTHESIS OF FOODSTUFFS FROM SIMPLE INORGANIC MATERIALS

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This paper outlines the initial research program for the development of nonanimate chemical methods for the conversion of carbon dioxide into foodstuffs. The specific syntheses recommended for study are (1) the preparation of alcohols by the catalytic reduction of carbon dioxide with hydrogen utilizing Fischer-Tropsch techniques, (2) the preparation of amino acids by the catalytic reduction of carbon dioxide with hydrogen and ammonia utilizing a modified Strecker synthesis, and (3) the preparation of carbohydrates from carbon dioxide and hydrogen utilizing formaldehyde as the key intermediate. The research is an outgrowth of the current NASA-OART Aerojet program on the synthesis of oxygen from lunar resources and is based, in part, on the excellent experimental results achieved to date.

At the present time the Mobile Systems Department of the Chemical Products Division of Aerojet-General, Azusa, is carrying out a research program for the Office of Advanced Research and Technology of the NASA which is devoted to research on processes for utilization of lunar resources, particularly the manufacture of oxygen from lunar minerals. A brief review of the results obtained to date is appropriate to the presentation of the main topic of this paper, the synthesis of foodstuffs from simple inorganic molecules.

Although the precise composition of the lunar surface and immediate subsurface is unknown at the present time, it is generally agreed that the lunar surface is composed of metallic silicates and that these silicates are widely distributed and readily available. We have designed a chemical process which will produce oxygen from silicate minerals, regardless of their precise composition and fine structure. We have avoided dependence on the presence of water or water precursors in the lunar materials. However, the process will produce water as byproduct if water, in any form, is present.

The Aerojet Carbothermal Process for the manufacture of oxygen from lunar minerals is exemplified by these reactions:

$$MgSiO_3 + 2\,CH_4 \xrightarrow{1800^0C} 2\,CO + 4\,H_2 + Si + MgO \qquad (1)$$

$$2\,CO + 6\,H_2 \xrightarrow[\text{Ni Catalyst}]{250^0C} 2\,CH_4 + 2\,H_2O \qquad (2)$$

$$2\,H_2O \xrightarrow[\text{Electrolysis}]{75^0C} 2\,H_2 + O_2 \qquad (3)$$

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At this time we are conducting laboratory research on the second reaction, the reduction of carbon monoxide with hydrogen to form methane and water by modification of the Fischer-Tropsch reaction. We have developed reaction conditions which result in the quantitative conversion of carbon monoxide to methane and water in a single pass, without formation of byproduct carbon or carbon dioxide.[1]

We expect to start research on Reactions 1 and 3 in the very near future. The continued development of the Carbothermal Process will lead to a practical solution for the on-site manufacture of oxygen based on the utilization of lunar minerals.

Along with our efforts to provide man with oxygen in extraterrestrial environments, we have given considerable thought to providing him with foodstuffs in closed ecological systems. The conversion of man's waste products into foodstuffs may be accomplished using biological systems, such as algae or pumpkin plants, or chemical systems, such as catalytic reactors. We believe that it is mandatory that each unit in the balanced environment, excepting man, be backed up by a redundant unit. As algae are sensitive, living organisms, their redundant unit should be nonanimate. Our work with carbon monoxide has encouraged us to believe that carbon dioxide can be converted into simple foodstuffs using nonanimate chemical processes.

1. Ethanol Synthesis

The conversion of carbon monoxide to alcohols by modification of the Fischer-Tropsch reaction has been studied extensively.[2] The synthesis of methanol and higher alcohols is complex and is quite sensitive to reaction conditions and catalyst composition. A wide range of products can be synthesized. This is exemplified by the results reported by Frolich and Cryder on the conversion of carbon monoxide to higher alcohols.[3] The reaction conditions were: temperature of $400^{0}C$, pressure of 3000 psia, H_2:CO mole ratio of 1.18 and a catalyst comprised of zinc carbonate, manganese carbonate, and potassium chromate, and they resulted in the preparation of methanol and high molecular weight alcohols as the major products. Ethanol, the product of greatest interest to us, was only a minor constituent of the reaction product.

More recently Winkler succeeded in preparing ethanol in rather good yields.[4] The reaction conditions were: $300^{0}C$, 2750 psia, mole ratio of 3.0 and a catalyst comprised of iron oxide, potassium carbonate and zirconium oxide.

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[1] S. D. Rosenberg, G. A. Guter, and F. E. Miller, Aerojet-General Quarterly Report 0765-01-1, Research and Processes for Utilization of Lunar Resources, NAS 7-225 (August 1963).

[2] H. H. Storch, N. Golumbie and R. B. Anderson, "The Fischer-Tropsch and Related Synthesis," John Wiley & Sons, New York (1951).

[3] P. K. Frolich and D. S. Cryder, Ind. Eng. Chem., 21, 867 (1929).

[4] L. Winkler, Ind. agr. aliment., 66, 159 (1949).

The alcohol product fraction contained 70% ethanol. Thus, by changing the reaction conditions and catalyst, it is possible to change the product distribution drastically.

We believe that the synthesis of ethanol from carbon dioxide and hydrogen holds considerable promise as a method to produce a nutrient material from waste carbon dioxide. Our research and that of others on the conversion of carbon monoxide to useful products indicates that carbon dioxide will be successfully converted to ethanol. The major difference is that in starting with carbon dioxide a lower energy material must be converted. Conversely, higher reaction activation energies must be provided. This will be accomplished by the use of higher pressures and temperatures and more active catalysts contained in longer catalyst chambers. The goal of this research would be the development of a practical method which will convert carbon dioxide to a single product, ethanol.

2. Amino Acid Synthesis

A number of investigations have been made on the random synthesis of simple metabolites from mixtures of gases containing hydrocarbons, ammonia, water, and hydrogen. These studies were all performed in a manner to duplicate primitive Earth conditions under which biological precursors might be formed. The metabolites are the building blocks of the large molecules associated with today's living organisms. Experiments reported by Miller[5], Oro'[6], and Groth and Weyssenhoff[7] demonstrate that a mixture of methane and/or ethane, ammonia, water, and hydrogen subjected to spark, silent discharge, or photoexcitation can form a mixture of compounds containing glycine, d,l-alanine, β-alanine, sarcosine, d,l-α-amino-n-butyric acid, α-aminoisobutyric acid, and substantial quantities of unidentified amino acids. The experiments demonstrate quite well that, in a random synthesis even under conditions of high energy inputs, sensitive molecules can be synthesized and exist long enough to permit isolation.

Other evidence that such random syntheses can occur is found by the examination of organic compounds found in stony meteorites. It has been speculated that the presence of such compounds in meteorites is evidence of extraterrestrial life processes. However, the most recent work reported by Kaplan, Degens, and Reuter indicates that the organic material has been synthesized by chemical rather than biochemical processes.[8] This conclusion was based upon the absence of optical activity, the type and distribution pattern of amino compounds and the lack of pigments, fatty acids, and nucleic acids. The formation of such compounds could certainly be catalyzed by high energy radiation or even by catalysis with some metal or oxide in the meteorite.

The yields of amino acids obtained by high energy discharges through gas mixtures are very small, of the order of micromoles. This method is not

[5] S. L. Miller, J. Am. Chem. Soc., 77, 2351 (1955).
[6] J. Oro', Nature, 197, 862 (1963).
[7] W. E. Groth and H. V. Weyssenhoff, Planet. Space Sci, 2, 79 (1960).
[8] I. R. Kaplan, E. T. Degens and J. H. Reuter, Geochim et Cosmochem Acta, 27, 805 (1963).

considered practical for synthesis because high energy is required and yields are vanishingly low. The method does serve to illustrate that under extremely harsh conditions, sensitive molecules can be formed in an absolutely random fashion. The results thus offer encouragement to experimental attempts using less vigorous conditions and catalytic directivity toward a desired product to obviate randomness. Research, therefore, is justified on a new method of amino acid synthesis from gas mixtures.

We recommend a dual approach to the synthesis of amino acids: (1) the direct combination of carbon dioxide, ammonia and hydrogen, and (2) modification of the Strecker synthesis.

The Strecker synthesis is an example of a standard method for the preparation of amino acids from starting materials other than the simple gases (CH_4, NH_3, H_2O, H_2). It is employed mainly for the preparation of alanine, glycine, and serine, and is exemplified by Equations (4) and (5).

$$CH_3CHO + NH_3 + HCN \xrightarrow{\text{aq. Sol.}} CH_3CH(NH_2)C{\equiv}N + H_2O \quad (4)$$

$$CH_3CH(NH_2)C{\equiv}N + 2\ H_2O \xrightarrow[\Delta]{\text{aq. OH}} CH_3CH(NH_2)CO_2H + NH_3 \quad (5)$$

The direct synthesis of amino acids is represented by Equation (6), where an amino acid containing k carbon atoms is the product.

$$k\ CO_2 + NH_3 + 3(k-1)\ H_2 \xrightarrow{\text{Catalyst}}$$

$$\text{Amino Acid with k Carbon Atoms} + 2(k+1)\ H_2O \quad (6)$$

A new approach to the synthesis of amino acids is offered by the direct reaction of carbon dioxide, ammonia, and hydrogen over effective catalyst in reactors of proper design. There are two distinct advantages in the successful synthesis of amino acids by this method. First, a highly toxic material, hydrogen cyanide, is not isolated but may have only a transient existence as a reactive intermediate. Secondly, a single reactor will have simplicity of operation over a multireactor process and consequently require less manpower for operation and maintenance.

The two-fold approach to the study of the preparation of amino acids is suggested because it is most reasonable to expect the reaction to proceed by a catalytic mechanism involving hydrogen cyanide and aldehydes as intermediates. We, therefore, propose to study the reactions of aldehydes, hydrogen cyanide, and ammonia over selected catalyst under various conditions in order to obtain good yields of amino acids. However, we are fully aware of the fact that the direct reaction may proceed by an entirely different and unknown reaction path as in the case of a random synthesis. Therefore, experiments should also be done to determine whether the direct reaction can proceed in a single catalytic reactor. The goal of the research is the development of a practical method which will convert carbon dioxide and ammonia to simple amino acids such as glycine and alanine.

3. <u>Carbohydrate Synthesis</u>

The formation of hydroxyaldehydes by the base catalyzed aldol condensation is characteristic of aldehydes having an α-hydrogen. Although the formaldehyde molecule does not posses an α-hydrogen, condensation can occur to form hydroxyaldehydes, hydroxyketones, and sugars as indicated in Equation (7).

$$CH_2O \xrightarrow[CaO]{\text{Ultraviolet Light}} \begin{array}{c} CHO \\ | \\ (CHOH)_2 \\ | \\ CH_2OH \end{array} + \begin{array}{c} CH_2OH \\ | \\ C{=}O \\ | \\ (CHOH)_3 \\ | \\ CH_2OH \end{array} \qquad (7)$$

hexose mixtures

In aqueous formaldehyde this reaction is catalyzed by alkaline reagents. In addition, it is induced by ultraviolet light.

The fact that sugar-like products can be produced by formaldehyde condensation was first observed in 1861 by Butlerov.[9] By careful handling of the crude product Loew succeeded in isolating a sweet syrup, which reduced Fehling's solution but was optically inactive. From the syrup, Loew obtained an approximately 75 per cent yield of a mixture of hexose sugars which was called formose.[10] Prudhomme has patented a photochemical process for the preparation of saccharose from formaldehyde in which calcium oxide is used as a catalyst.[11] More recently Akerlof and Mitchell, under NASA sponsorship, confirmed the results of the earlier researchers.[12] Their formose mixtures contained at least 13 different sugars. They found, however, that their synthetic mixtures were toxic to experimental animals.

Although sugars are the predominant product when the reaction is allowed to proceed to completion, glycolic aldehyde has been isolated from reaction mixtures. Euler believes glycolic aldehyde is the primary condensation product.[13] In addition, the presence of glyceraldehyde, dihydroxyacetone and erythrose has been demonstrated by Orthner and Gerish.[14] These simple sugars have the sweet tastes characteristic of the hexoses. Dihydroxyaceton is used specifically as a sweetener for diabetic foods.

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[9] A. M. Butlerov, <u>Ann.</u>, <u>120</u>, 296 (1861).
[10] O. Loew, <u>J. prakt. chem.</u>, <u>34</u>, 51 (1886).
[11] E. A. Prudhomme, U.S. Pat. 2,121,981 (1938).
[12] G. C. Akerlof and P. W. D. Mitchell, FMC Final Report, <u>A Study of the Feasibility of the Regeneration of Carbohydrates in a Closed Circuit Respiratory System</u>, NASr-88 (March 1963).
[13] H. Euler and E. Euler, <u>Ber.</u>, <u>39</u>, 50 (1906).
[14] L. Orthner and E. Gerisch, <u>Biochem. Z.</u>, <u>259</u>, 30 (1933).

Because most of the investigations on the carbohydrate mixtures were done prior to the perfection of paper chromatographic techniques,[15] little detailed data are available as to the exact composition of the sugar mixture and the manner in which the composition varies with the conditions of the synthesis. Only recently a method for the separation and identification of sugars by gas chromatography (via conversion to trimethylsilyl derivatives) has been described.[16] It is reported also that the latter method may be used in the production of pure carbohydrates.

We concur with Akerlof and Mitchell that a program designed to investigate the value of formose sugars as food, to determine the cause of toxicity in test animals, and to develop a synthesis for nontoxic sugars is required at this time. Such a synthesis will provide a chemical process for the production of carbohydrates from waste carbon dioxide. In such a process it would be first necessary to convert carbon dioxide to methanol. This step can be accomplished as described in the Ethanol Synthesis section. Formaldehyde is readily available from the oxidation of methanol by commercial methods.

In conclusion, we believe that chemical processing in space can economically provide many of the materials required for extraterrestrial missions. A start has been made on the development of such processes with the NASA's support of the development of the Aerojet Carbothermal Process. In reviewing the accomplishments achieved on this process we confidently believe that the required chemical technology can be developed to provide a variety of products and assume a major role in the Nation's future space efforts.

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[16] Chem. & Eng. News, p. 42, 9 Sept. 63.

10-EXTRATERRESTRIAL RESOURCES IN LIFE SUPPORT SYSTEMS

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The use of indigenous materials in life support systems is not unique to the space program. Explorers from the beginning of time depended upon the natural resources of new lands for survival. Even in apparently barren areas such as the arctic bases, the initial colonists utilized the ice formations for temperature control, protection from hazardous environments, and for water supply. The lunar program will require more intensive study in this respect if only to prevent costs from approaching astronomical figures. The logistic costs of supplying lunar colonists with all the materials needed for survival are so great in prospect that it behooves us to seriously investigate the possible uses of indigenous materials for life support systems.

In this discussion we shall be concerned primarily with food, water, a livable atmosphere, and waste management subsystems. For reasons of economy, it is the current belief that the subsystem requirements can best be satisfied by a semi-closed ecological system. A schematic diagram of such a system is shown in Figure 10-1.

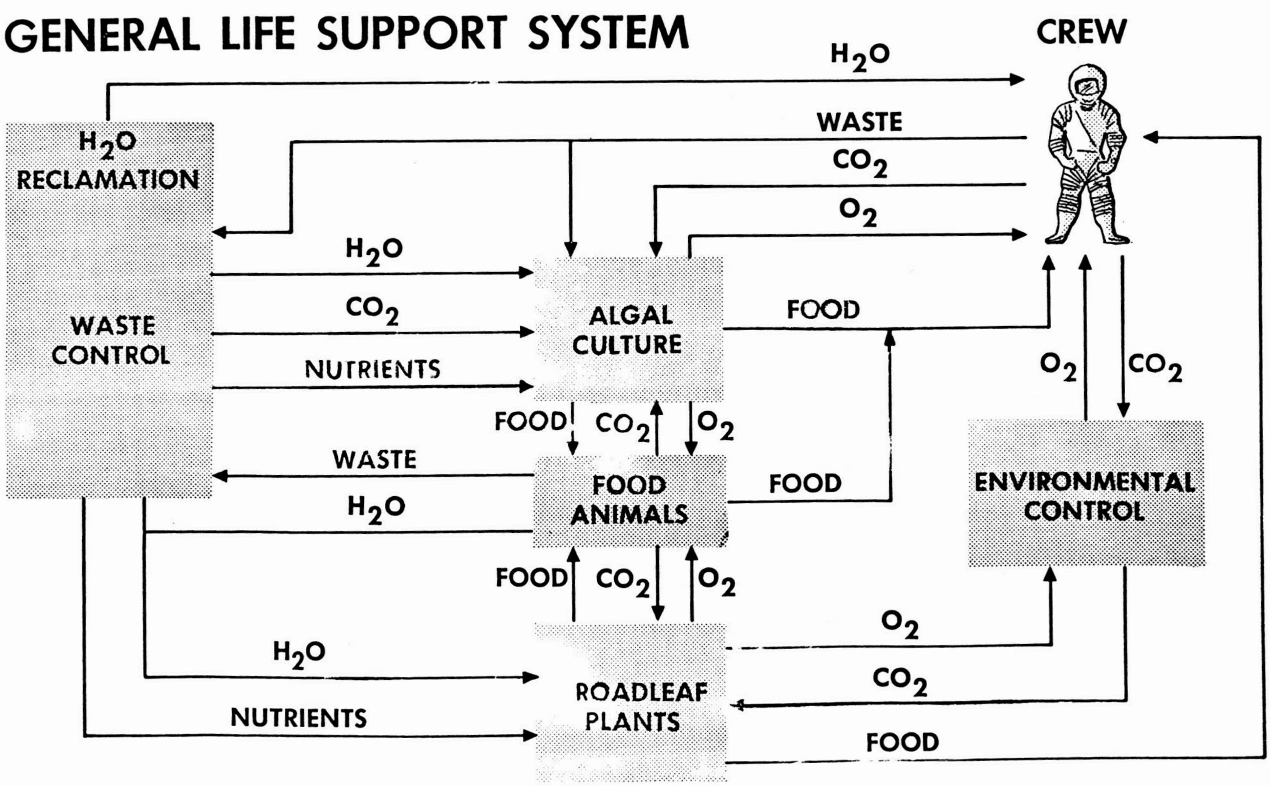

FIGURE 10-1

The semi-closed ecological system considered here comprises several integral subsystems including the crew, a water reclamation and purification unit, a waste disposal unit, an algal subsystem, a higher plant unit, a small animal colony for meat production, and a physico-chemical environmental control system.

Wastes of the crew members, as well as of animals, would be cycled through a waste converter which, in turn, would furnish a nutrient source for both the algal and the higher plant subsystems. These two subsystems would exchange atmospheric carbon dioxide for oxygen and would provide a food source for crew members and animals alike. Closely associated with this system would be a water reclamation unit to purify for immediate consumption and storage. Environmental controls include humidity regulation, temperature regulation, and maintenance of the required base atmospheric pressure.

Probably useful lunar materials in the semi-closed ecological life support system include: lunar rocks for water extraction, solid media for the growth of green plants, building supplies such as bricks and pipes for use as molecular sieves and as inert filter systems. The lunar base occupants must be considered as sources of potential life support materials, but for obvious reasons will not be included in this discussion.

An integrated extraction device employing a solar-nuclear-plasmatron train for the extraction of useful compounds from lunar rocks (Green, 1963), is illustrated in Figure 10-2. Gases, metallics, and other volatiles, as well as water, could be extracted in such a system. Liquid metal reactor coolants from SNAP-2 and SNAP-8 configurations could provide heat sources in water

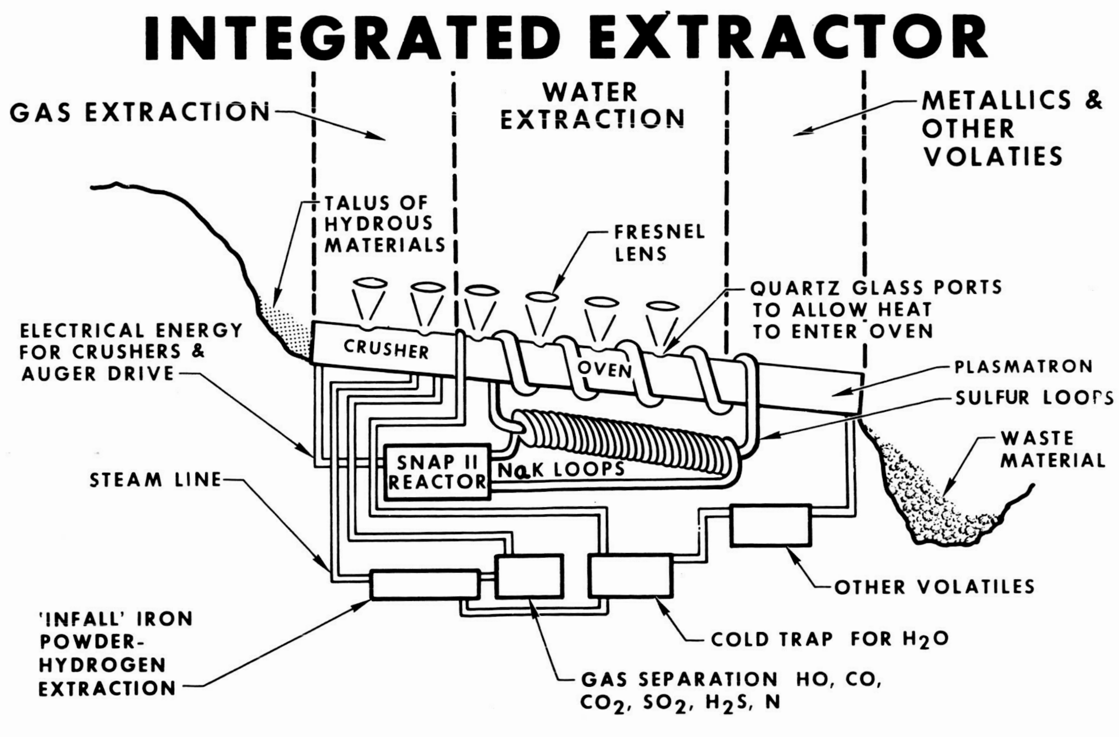

FIGURE 10-2

extraction. Zone refining and sublimate techniques could be applied to recover fluids and fractionated solids from vaporized rock dusts. For example, sulfur may be recoverable as a volcanic sublimate for use as a waterless cement and reactor coolant.

With a nuclear power unit as a source of heat, lunar rocks (particularly basalts) could be liquefied and molded for building materials. The use of lunar rocks would minimize the transportation of building materials from Earth. The variety of hardware items which can be made from basalts is illustrated in Figure 10-3.

LUNAR BASE APPLICATIONS OF PROCESSED BASALT

CAST BASALT

- PIPES & CONDUITS
- CONVEYOR MATERIELS (PNEUMATIC, HYDRAULIC SLIDING)
- TILES & BRICKS
- SIDINGS
- TRACK RAILS
- HEAVY DUTY CONTAINERS FOR HYDROPONICS
- MIRROR BASES
- THERMAL RODS

SINTERED BASALT

- NOZZLES
- TUBING
- WIRE-DRAWING DIES
- BALL BEARINGS
- WHEELS
- LOW TORQUE FASTENERS
- FURNITURE & TABLEWARE
- LOW LOAD AXLES
- LIGHT TOOLS
- LIGHT DUTY CONTAINERS & FLASKS FOR LAB USE
- PUMP HOUSINGS

SPUN BASALT (FIBERS)

- CLOTH & BEDDING
- RESILIENT SHOCK
- ABSORBING PADS
- THERMAL INSULATION
- FILLER IN SULFUR CEMENT
- FINE SPRINGS
- PACKING MATERIEL
- STRAINERS OR FILTERS FOR INDUSTRIAL OR AGRICULTURAL USE
- ACOUSTIC INSULATION

FIGURE 10-3

Current concepts for the modular development of the lunar base is illustrated in Figure 10-4. Initially, personnel shelters equipped with survival rations and atmospheric controls will be landed on the moon. These will be supported at a later date with communication, power, fuel, maintenance, and life support modules. For the purpose of this discussion, however, only the development of the life support modules will be considered.

The initial shelter modules will carry prepackaged food and cryogenic gas supplies from earth. The early life support modules will consist primarily of prepackaged food and physico-chemical systems for atmospheric regeneration. These will be augmented with later modules equipped with biological life

MODULAR LIFE SUPPORT CONCEPT FOR LUNAR BASE

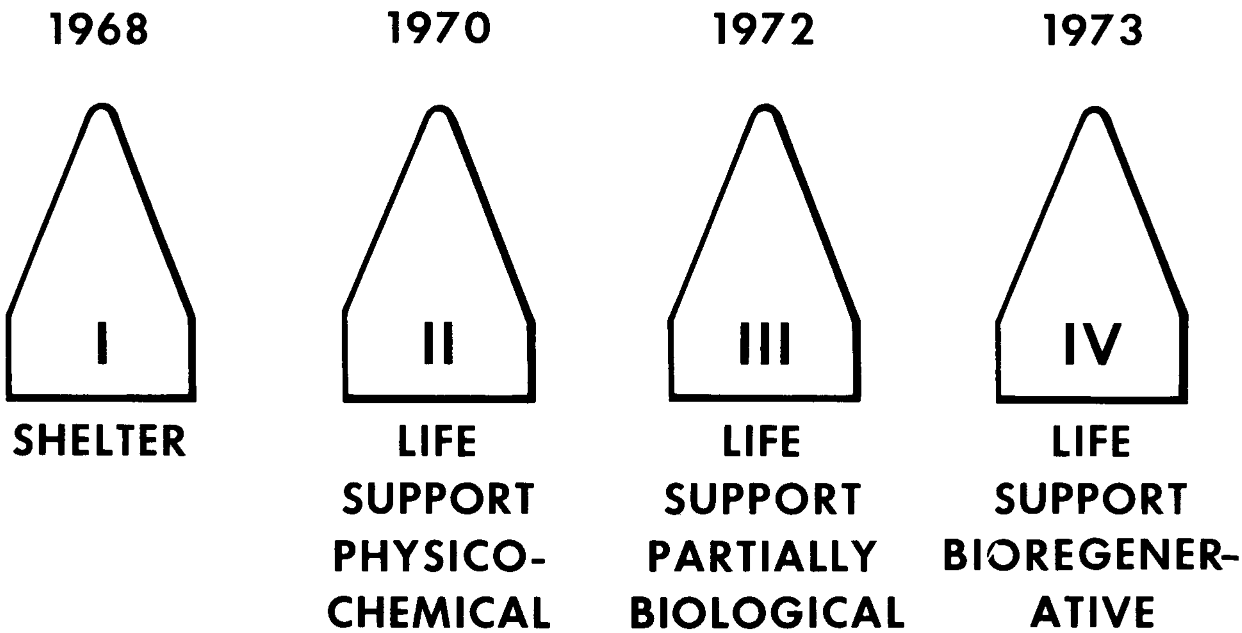

FIGURE 10-4

support systems such as aerobic waste digestors, algal photosynthetic gas exchangers, and other pertinent bioregenerative systems. The biological systems must be integrated with the earlier physico-chemical processes for maximum efficiency. The incorporation of lunar materials into the life support modules should be accomplished at the earliest possible phase of module development.

An example of an early incorporation of biological systems into the life support modules is illustrated in Figure 10-5. Waste materials and cabin air will be passed through an aerobic waste digestor, the effluent being treated by standard physico-chemical processes. Carbon dioxide may be converted to oxygen through the Sabatier reaction:

$$CO_2 + 2H_2O \xrightarrow{Ni} 2O_2 + CH_4$$

Molecular sieves also may be employed in the air purification system. Water purification will be accomplished by one of the physical methods currently under investigation. Lunar material will most likely be incorporated into one

BIOLOGICAL WASTE MANAGEMENT SYSTEM

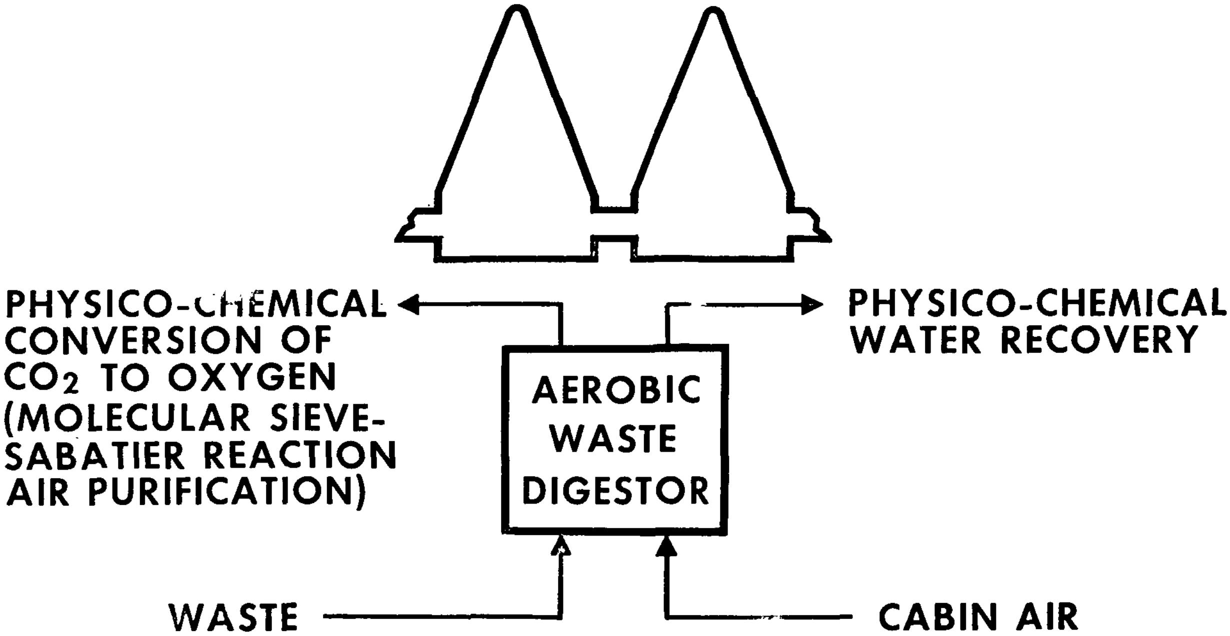

FIGURE 10-5

of the systems just mentioned. The probability is great that lunar dust will be used as an inert filter; possibly, also, it will be of value as a molecular sieve.

The algal system will be incorporated into the partial biological life support system illustrated in Figure 10-6. The algae will act as a photosynthetic gas exchanger and will also provide a portion of the diet. At this phase of development, lunar material can be utilized for containers, pipe lines, and provide, possibly, some of the inorganic nutrients required for optimum algal growth. The latter phases of development hopefully will provide life support modules almost completely bioregenerative in nature which would then provide for an almost self-sustaining base. Water recovery from rocks (Green 1962), and the furnishing of building materials and tools (Johnson and Finn 1962) will in all probability be operational processes by this date.

In order to utilize the lunar material properly, specific information is required. Of paramount importance is the knowledge gained from chemical and physical analyses. This information, of course, can only be learned from authentic samples of lunar rock brought to earth for study. If it were necessary to wait until specimens became available, the program concerned with the use of extraterrestrial resources would be delayed for several years. Assumptions based upon the previous studies pertaining to the origin of the lunar

PARTIAL BIOLOGICAL LIFE SUPPORT SYSTEM

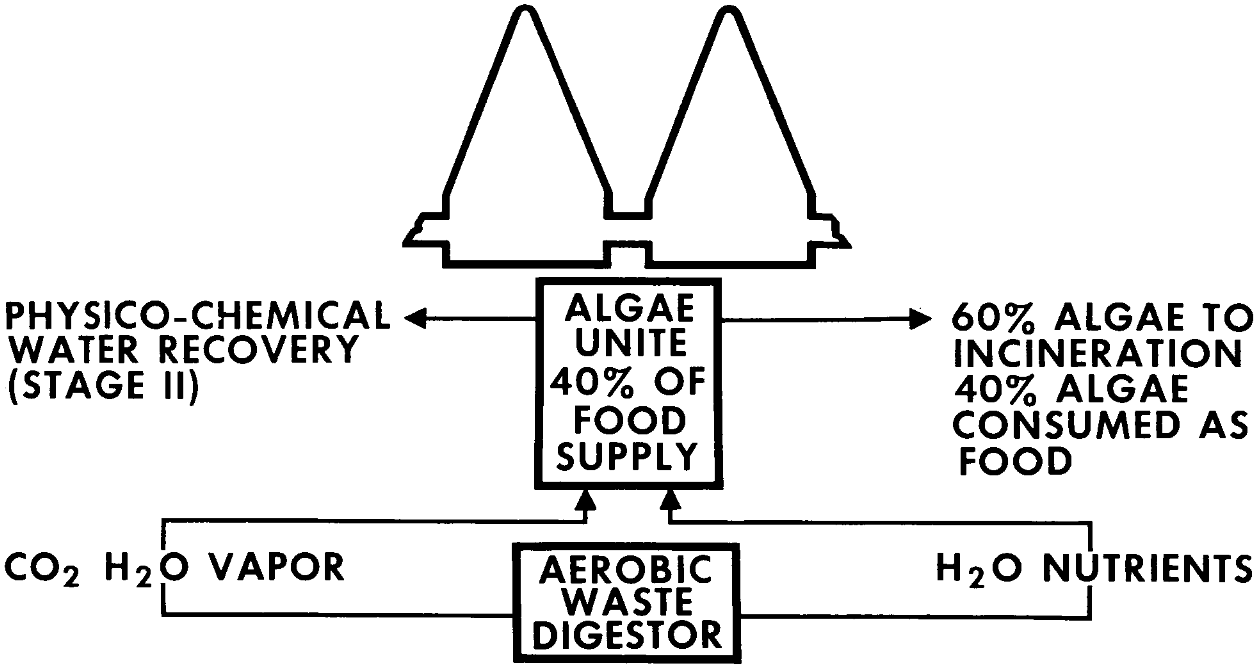

FIGURE 10-6

craters can reasonably be made. If one proceeds with the theory of the volcanic origin of the craters, basalt and pumice appear to be likely constituents (Green 1960). These rocks are presently available for study; if the premise proves to be correct, valuable time can be saved.

A chemical analysis of these rock types is presented in Table 10-1. The specimens analyzed were crushed Colombia River Tholeiitic Basalt and Rhyolitic Pumice from Monocraters, Oregon. The analyses indicate the presence of several cations required for the growth of green plants. The low level of nitrogen indicates the requirement of soil supplementation. Waste matter relatively high in nitrogenous compounds could be used to overcome this deficiency. It appears likely from these analyses that a small amount of water could be extracted from the rocks. Ignition would also release CO_2 from the carbonate, and the CO_2 could then be converted into oxygen through the Sabatier reaction mentioned earlier or through the use of photosynthetic gas exchangers.

The chemical analyses indicate that "synthetic lunar rocks" when properly enriched with a nitrogen source, would support the growth of green plants. These analyses were conducted using AOAC methods. The results of plant growth

SYNTHETIC LUNAR ROCK

CHEMICAL COMPOSITION OF CRUSHED COLUMBIA RIVER THOLEIITIC BASALT & RHYOLITIC PUMICE FROM MONOCRATERS

CONSTITUENT	SPECIES	BASALT	PUMICE
MOISTURE, 110°C		0.42%	<0.01%
HYDROSCOPIC MOISTURE		0.60	0.47
CARBON		0.69	0.01
CARBONATE		0.028	<0.01
NITROGEN		0.005	0.0008
(TOTAL OXIDES OF Fe, Al, P, & Ti)		33.37	15.73
PHOSPHORUS	P_2O_5	0.14	0.003
POTASSIUM	K_2O	2.66	6.59
SODIUM	Na_2O	5.58	5.21
SILICON	SiO_2	48.90	76.20
IRON	Fe_2O_3	4.43	0.34
ALUMINUM	Al_2O_3	28.24	15.34
TITANIUM	TiO_2	0.56	0.02
CALCIUM	CaO	8.40	0.62
MAGNESIUM	MgO	4.85	0.80
MANGANESE	MnO	0.19	0.002

TABLE 10-1

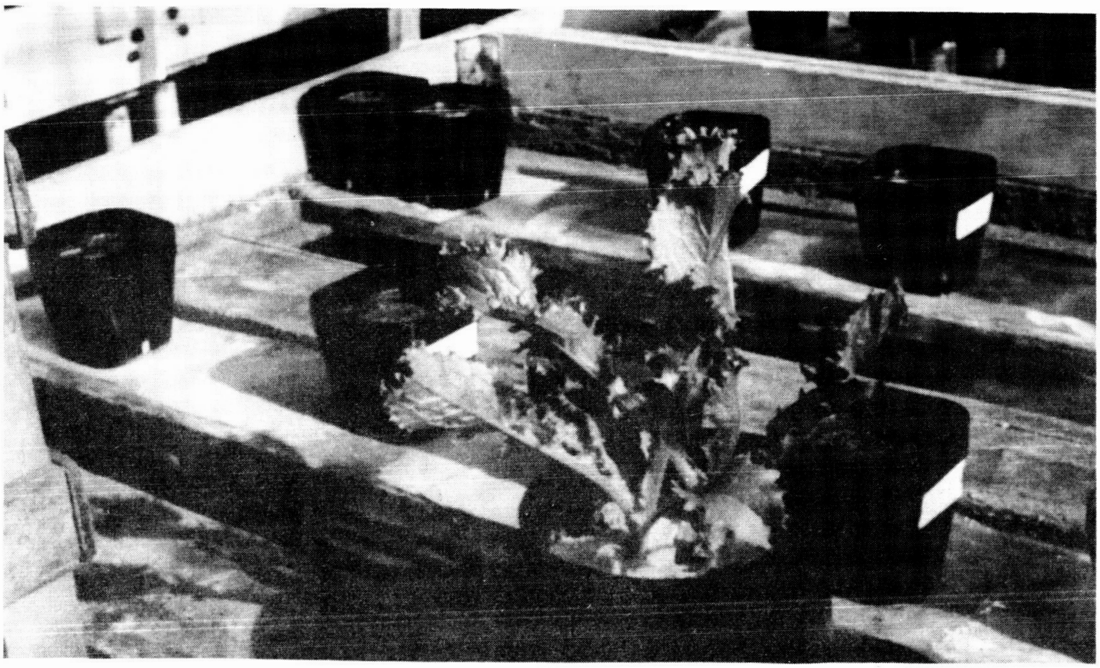

FIGURE 10-7

studies on the "synthetic lunar rocks" are illustrated in Figure 10-7. It is apparent that the results obtained differ from those obtained by standard geologic procedures. The plants used were Green Curled Green Rib Endive, seed batch #2181 obtained from Paul J. Howard's California Flowerland in Los Angeles, California. The seeds were sterilized in a 1% hypochlorite solution and grown in the green house at The University of California at Los Angeles (Coulter 1963) under high intensity natural light and with high humidity. Temperatures ranged between 18^0 and 35^0C for the duration of the two-month experiment.

The plant showing abundant growth received the complete supplement of trace metals required for growth as well as nitrogen enrichment. The plants on the rear bench (Figure 10-7) indicate the retarded growth symptoms caused by deficiencies in iron, phosphorus, potassium and magnesium. It is apparent, therefore, that although these particular cations were present in sufficient concentrations to support plant growth, they were in a form which is unavailable for use by the plants.

EXCHANGE CAPACIY IN mEQ/100 GM OF SOIL

TWO CHELATING AGENTS

CATION	BASALT-PUMICE	
	(NH4OAC)	(EDTA)
EXCHANGE CALCIUM	6.95	7.05
EXCHANGE IRON	LESS THAN 0.1	5.02
EXCHANGE MAGNESIUM	0.81	0.99
EXCHANGE MANGANESE	0.10	0.29

TABLE 10-2

It has been well documented that chelating agents such as ethylene diamine tetra-acetic acid (EDTA) convert the cations into a nutritionally available form. The figures in Table 10-2 demonstrate the increase in exchangeable cations obtained from two chelating agents, NH_4 OAc and E.D.T.A. It is reasonable to assume, therefore, that through the use of nitrogen and chelate supplementation, lunar rocks may provide an adequate base for plant growth.

Research in exploring the uses of extraterrestrial resources for life support systems must be continued. It has been shown that investigations based upon specific assumptions can be conducted without authentic lunar samples. It must be noted that many investigators disagree as to the origin of the lunar craters. This presentation has been made on the assumption that lunar craters are of volcanic origin and that similar rock types to those found on Earth exist on the Moon. Other assumptions must be made based upon the impact and other theories and similar use studies conducted. When confirmatory evidence becomes available, the issue can be resolved and achievement of a self-sustaining lunar base can be hastened.

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BIOLOGICAL EXPLOITATION OF A PLANET

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The events and processes to be described in this paper do not necessarily all have to occur in one place or in the designated sequence although this is not an unlikely possibility. We would like to stress also that microorganisms are a large and diverse group of species with capabilities of bringing about some very fundamental changes in their environment. They have much more potential for use in space than merely providing "cookies" for astronauts. Microorganisms in general and bacteria in particular are able to carry out very complicated chemical reactions and syntheses requiring only moderate temperatures (2-60^{o}C) and ordinary pressures. With this brief introduction, we would like now to consider various aspects of how extra terrestrial resources might be utilized.

A quotation from Oberth (1) on the purpose of space research appears to us to be timely: "This is the goal: To make available for life every place where life is possible. To make inhabitable all worlds as yet unhabitable, and all life purposeful." With this as a working hypothesis, we can set up a theoretical planet, and then proceed to adapt it to support life as we know it and ultimately to make it habitable for man.

Our planet will be one of similar size to the Earth, capable of retaining an atmosphere, and at a distance from the sun so as to be within a tolerable temperature range. Water will have to be available. The atmosphere will contain gases such as hydrogen, nitrogen, carbon dioxide and water as a vapor. The seas, or liquid water phases, will contain organic matter as living, or nonliving forms. Except for size, this planet is in many ways similar to Mars. The atmosphere is primarily reducing, the temperature is within human tolerances, water is present, and there is strong presumptive evidence for the existence of some forms of organic matter.

To convert this planet to one suitable for colonization by humans, we must bring about a change from a reducing environment to an oxidizing one. The simplest way, and one requiring the least input of energy, is to do this biologically. We have at our disposal a varied and diverse group of microorganisms that are able to thrive in a reducing milieu, and as a consequence of their metabolism to bring about some fundamental changes of a geochemical nature. By introducing these organisms in a given sequence, singly and in combination, we can control the changes brought about.

We have organisms available that can fix carbon dioxide, utilize hydrogen, hydrogen sulfide, ammonia, methane, and organic compounds. (2) Still others can be used to produce hydrogen sulfide, carbon dioxide, ammonia, hydrogen and oxygen. All of these processes are coupled oxidation-reduction reactions whence the organisms can derive metabolic energy. All of these changes can occur anaerobically and the only external energy source required is sunlight.

It is conceivable that we might encounter life already in possession of our theoretical planet. The ultimate fate of this life, once we invade it with our arsenal of microorganisms, will depend on several factors. Any established ecological unit is a delicately balanced system wherein the various groups that make up the community interact with and supplement each other. A completely foreign introduction that may actively compete with one or more of the residents of the group may have disastrous effect upon the ecological unit. Competition could be of various sorts ranging from limitations of a food supply to direct parasitism. The invading organism might conceivably utilize components of the environment for its food, resulting in changes that would make it completely uninhabitable for the indigenous population. The native biota would then be faced with extinction or relegated to isolated ecological niches wherein they might survive.

Earth organisms would have a good chance of competing effectively, especially if carefully selected. Since this would be an entirely new experience for the native population they will not have adequate defenses against the invading forms. By choosing organisms on the basis of generation time, antibiotic effects or changes they bring about in the oxidation-reduction potential and pH parameters of the environment, successful implantation would be achieved.

One of the first requirements for human colonization of the planet would be to provide a suitable atmosphere. If there is organic matter present, we could introduce any of several heterotrophic anaerobes to convert this into more familiar Earth forms. The tremendous adaptability of bacteria will insure that the appropriate enzyme systems will be available. Even organic compounds entirely foreign to us could be attacked. Bacteria have been known to degrade entirely synthetic substrates which have no counterparts in nature. This action could also release more carbon dioxide into the atmosphere for use by autotrophic forms. The next step may be to introduce the photosynthetic autotrophs. Species of <u>Athiorhodaceae</u> can link the oxidation of organic compounds to carbon dioxide fixation. The organic compound thus provides the reducing power needed for carbon dioxide incorporation.

The purple sulfur bacteria can, in the presence of light, utilize hydrogen sulfide, and even hydrogen gas, to carry out similar reactions fixing carbon dioxide into organic carbon and forming sulfate ion and/or water. (3) The net result will be to bring about the oxidation of the various elements of the environment. Hydrogen gas and sulfides would tend to be removed from the atmosphere and carbon dioxide would reach an equilibrium state between synthesis and respiration. The total energy pool will be increased as radiant energy from the sun is fixed in the newly synthesized organic compounds. There also might occur various temperature effects, as carbon dioxide is either added or removed from the atmosphere. Should the amount of carbon dioxide in the atmosphere be increased, the temperature of the planet will gradually rise because of the absorption characteristics of carbon dioxide; this in turn will have effects on the biota.

One need not feel that these changes will require unusually long periods of time. Most microorganisms, when placed in a suitable environment, develop at tremendous rates. It has been estimated that bacteria placed on a virgin planet similar to the Earth would distribute themselves over its surface in about eight days.

When conditions are considered propitious, we will be ready for the final step. Up to now, we have been working in an anaerobic environment. A hardy transitional organism is needed to initiate an oxidizing atmosphere. Selected strains of blue green algae appear to be appropriate. These algae are strong colonizers and can withstand a broad range of environmental conditions. Here on our planet they are found in the cold soil-less areas of the high mountains, in hot springs, or in arctic tundras. They are often the first species to make their appearance in barren or devastated areas and prepare the way for more advanced life forms - as for example, the island of Krakatoa after the volcanic eruption in 1883. The algae are highly adaptable and persist in environments over a wide pH - Eh range and also a wide temperature range. (4)

The algae would carry out a photosynthesis similar to the bacteria with one important variation. Rather than reducing power derived from oxidation of inorganic or organic compounds, the algae and the green plants utilize the photolysis of water. On this one reaction all of life on Earth is dependent - for an important by-product of this reaction is oxygen. Once the algae become established on the planet we are well on the way to being able to support human life. Green plant photosynthesis is the basic process for supplying oxygen to the atmosphere. Until the advent of green plants on the evolutionary scale our own Earth was endowed with a highly reducing environment.

Our hypothetical planet is now in a condition wherein a form of life entirely foreign to it is able to thrive and prosper. We have used bacteria, algae, and ultimately other organisms as something akin to chemical reagents to bring about certain reactions we have felt were desirable. It is conceivable that if a reducing planet could be converted to an oxidizing environment a similar course could be followed to bring about the opposite reaction ... to convert an oxidizing planet to a reducing one.

Since it is generally accepted that oxygen appears as a consequence of biological activity, it can be anticipated that any planet with oxygen in its atmosphere will probably have life upon it. As has already been indicated, the most important factor in maintaining oxygen in the atmosphere is green plant photosynthesis. Any factor that would alter the activities of the green plants would be of deep concern to the inhabitants of this planet, for the green plants are both the mainstay and Achilles heel of aerobic life.

The chloroplasts of green plants are the chief sites of photosynthetic activity. It is here that light energy is trapped by the chlorophyll pigments and water is split into a hydrogen and a hydroxyl ion. The hydroxyl ion eventually forms the oxygen that is released by the plant. The hydrogen ion provides the reducing power for fixing carbon dioxide. Radiant energy is also converted to chemical energy in the form of adenosine triphosphate which is used to drive the photosynthetic reaction. Carbon dioxide fixation per se is light independent and can occur in the dark under certain conditions. The chloroplasts can carry out both the energy yielding and carbon dioxide fixing reactions only if the structural integrity of the components are preserved. (5) This consists of layers of chlorophyll containing particles separated by lamellar membranes. This basic form appears to be constant for all living plants.

It thus appears that if we wished to modify the environment of an aerobic planet the simplest procedure is to alter or stop the production of oxygen by green plants. The use of a selective parasite such as a bacteria or virus is one possibility. Perhaps one could be selected or adapted to attack the porphyrin structure thus destroying or preventing the formation of chlorophylls. Possibly such organisms already exist on other planets and aid in maintaining reducing conditions. Whatever the mechanism used, it suffices to say that once green plant photosynthesis is blocked, further production of oxygen will cease. As the native population continues to respire the remaining oxygen would be used up. Organic matter would now be subjected to anaerobic decomposition. Gases such as hydrogen sulfide, carbon dioxide, and hydrogen would be formed and returned to the atmosphere. The atmosphere would now evolve towards the original state of our former theoretical planet. It is ready for colonizing by a form of life based on a reducing atmosphere or one that uses compounds other than oxygen for its energy metabolism.

As we send space ships out to encounter and land on other worlds, we make a strong case for sterilizing the vehicle. Our desire is to avoid contamination of a virgin land with Earth organisms. Two strong reasons are advanced - one, we do not wish to introduce Earth matter prior to a study of the native habitat on evolutionary grounds - two, Earth organisms may prove to be competitively more vigorous than the existing forms and destroy them before we can get a chance to study them.

Certain studies appear to be necessary before undertaking investigations on the planet's surface. The alien microorganisms should be examined before bringing them back to Earth to determine their pathogenicity, competitiveness and survivability to assure ourselves that potential contaminants are harmless. On the other hand, because our objective is to exploit the planet, we also need to study Earth microorganisms as potential inhabitants of the planet. This would amount to simulation experiments using our intimate knowledge of the planet's characteristics. Although such simulation could be done on earth there may be some value in studies being done in an orbiting base around the planet. A laboratory of this type would minimize contact with the planet and with Earth until sufficient information is gathered a more permanent operations base may be established on the planet.

One need only pause to think of the consequences if a form of life incompatible to our system was successfully introduced on Earth -- either accidentally or deliberately. The case of vehicle sterilization can be made even stronger when we consider the return trip from a world that may possess even a primitive form of pro-life. Our world is an aerobic one -- we know that anaerobic forms exist, that except for the use of the final hydrogen acceptor in the energy chain they posses an intermediary metabolism identical to the oxygen breathers. On our own planet the anaerobic form is less efficient as far as energy derived per unit of substrate oxidized and thus is relegated to a minor role. However, given different environments, coupled with the energy from photosynthesis, it is possible that an anaerobic form of life could become dominant. It might take only a small shift in the light spectrum reaching this other world to favor anaerobic photosynthesis.

Conceivably this life could evolve in a manner parallel to our own, differing only in the final hydrogen acceptor utilized in the energy cycle. This would still be life as we know it, but yet how completely different.

We can close by imagining one of these anaerobic forms paraphrasing Oberth "To make available for life every place where (our) life is possible. To make inhabitable all worlds as yet uninhabitable and all (our) life purposeful."

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12-RECENT OBSERVATIONS OF THE MARTIAN ATMOSPHERE BY SPINRAD, MÜNCH AND KAPLAN

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(Dr. Jaffe explained that the results discussed in his talk were obtained by Drs. Hyron Spinrad, Guido Münch and Lewis Kaplan, while making preparations for an experiment they planned to try during the 1965 opposition of Mars.)

They felt it was necessary to do some preliminary work on techniques, to try to get the right cameras, gratings, emulsions, exposures, etc. So, in the early part of 1963, which was shortly past the opposition of Mars they spent four nights at Mount Wilson trying to work out these techniques. This was on the 100-inch Coudé spectrograph. Of the four plates they took, only one came out reasonably well. The others were unsatisfactory because of the choice of emulsion and sensitization, exposure, local humidity, and so forth. One plate that they considered reasonably good, did come out even though it was somewhat overexposed. And on this night the seeing was only fair. This particular plate was taken with a 114-inch camera, a grating of 600 lines per millimeter and hypersensitized 4N emulsion. They got a spectrum that showed almost all of the known solar lines in this particular region, and they consider that it is a good high resolution photo. So all of the remaining data that I will report, as far as their work is concerned, is based upon this single plate. It is only one plate; this is obviously not what one would wish, but nevertheless in their opinion this is the highest resolution plate of Mars ever obtained.

First of all, they looked in the area of 8300 Angstroms where there are water absorption bands. They observed what appeared to be faint lines which were not attributable to the earth's atmosphere. There were eleven lines where this seemed to show up. These lines were measured independently by two of the authors, and they found that the wavelength shift from the terrestrial line was .42 Angstrom plus or minus .06 Angstrom. The calculated Doppler shift for the night of observation, which was April 12, was .41 Angstrom. They felt this was hardly coincidence. Of the 11 lines observed, they considered two of them might be overlapping or blending with faint lines of the solar Fraunhoffer spectrum; none of them with earth lines. Some of you may have seen the preliminary publication of this part of the work in the Astrophysical Journal, last May, which indicated there may be other blends, but a more careful analysis indicates that only two of the 11 lines are suspect on that ground. So they consider they have nine lines of Martian water, and this is the first direct observation of water vapor in the atmosphere of Mars.

From these data you can get an approximate idea of the strength of the line--the integrated area of that absorption. It came out to be about equivalent to a complete absorption of a line of 5 milliAngstroms wide plus or minus two. And this is equivalent to 1×10^{-3} grams per centimeter squared column, of water, plus or minus 50 per cent essentially. So, they believe that this is the best estimate that they can give now: 1 x 10^{-3} grams per centimeter, or an equivalent layer, if it were all precipitated, of 1 x 10^{-3} centimerers of water. These measurements are primarily for the third of the planet closest to the poles. Near the equatorial regions, the lines were somewhat weaker. This may have been due to overexposure, which was more severe there, but it may also be a real effect that there was somewhat less water vapor in the equatorial regions at the time of observation. It is really not possible to say from data available. These are certainly rough estimates but they are the only ones available yet, and it was felt desirable to publish them rather than wait until 1965 when another chance for observation would come along.

Next, what about CO_2. Well, separation of Martian and terrestrial lines is much less of a problem for CO_2 than for water. Apparently there is more CO_2 in the Martian atmosphere than there is in the terrestrial and quite a while ago, Kuiper observed at 1.6 micron band of CO_2 on Mars; other bands at 2 microns and 2.7 microns have also been observed. It is however, not really possible to get directly the amount of CO_2 on Mars from measurements of these bands. The reason is that these consist of strong lines which are completely saturated--that is the Martian atmosphere is completely opaque in the centers of these lines. It is therefore not possible to get an indication of the amount of CO_2 from the intensity measurement though you can get a lower limit. The integrated areas, the so-called intensities of these lines, are mostly measures of the collision broadening. In other words, how wide is the line rather than how deep is it, since it's completely opaque across the center.

Measurements in the region from 1.6 microns and longer, give only the product of the CO_2 content and the pressure. Therefore you have to put in the pressure from some independent measurement. This has been done; for example Granjean and Goody have used Dollfus' estimate of 85 millibars surface pressure to derive an estimated CO_2 content of 40 meter-atmospheres of CO_2. However, the authors' plate that I mentioned earlier did show a number of faint unsaturated lines corresponding to the CO_2band near 8700 Angstroms. The integrated intensity of these lines is primarily a measure of the total CO_2 content and is independent of the pressure. Measurements were made of the strength of these lines both from photodensitometer plots and from visual comparisons with some of the weak solar lines on the same plate. And these in turn were compared with laboratory measurements of CO_2 absorption in this region. The answer that came out was that the equivalent width of these lines was about 4 milliAngstroms plus or minus 1.5, and this corresponds, according to the comparison with the laboratory measurements, to something like 55 meter-atmospheres. There is obviously uncertainty in this, perhaps 50 per cent. The corresponding partial pressure on the Mars surface would be about 4 millibars. Now, this measurement gives the CO_2 content, and it is possible to combine these with previous measurements by other people which give essentially the product of the pressure and the CO_2 content. The best measurements of this, the authors felt, were measurements taken in the two micron region by Sinton and Kuiper. Combining these measurements of the product of CO_2 and pressure and working through the integral, the answer obtained by the authors for the surface pressure is 25 plus or minus 10 millibars. This is total pressure at the surface. Part of the uncertainty is of course due to errors in this work; part of it is due to uncertainties in the measurements of the two micron band, and part of it due to uncertainties in the method of analysis.

I might mention that the recent stratoscope balloon measurement of the two micron band gave quite different results, and these are not different from the present authors' since they were not in the same region. Calculations based on the authors' CO_2 measurements and the stratoscope observations of the 2 micron band give 130 millibars total pressure, and calculations based on the 2.7 micron band observed in the stratoscope give 290 millibars. The authors feel that either the experiments or the interpretation of the stratoscope results were unexplainable. It is not possible to get consistent data from them or to reconcile them with the earth measurements of Sinton and Kuiper. Therefore they consider that they will base their conclusions on the work of Sinton and Kuiper. It might be noted that the 25 plus or minue 10 millibars which I mentioned for the total pressure, is significantly lower than Dollphus' measurement of 85 millibars. Dollphus' estimate was based on several optical techniques but these primarily involve the assumption of Rayleigh scattering. Goody had earlier pointed out that if there is a haze layer on Mars, of which there is some evidence, Dollphus' estimate would be too high. Therefore they feel that their results are not really inconsistent with Dollphus' observations. In summary, the authors would give, as a best estimate now available for the total pressure on the surface of Mars, 25 plus or minus 10 millibars, of which 4 plus or minus 2 millibars is CO_2 and the remainder is presumably mostly nitrogen and perhaps argon. The water content, according to these measurements, is $1.0 \times 10^{-3} \pm 0.5 \times 10^{-3}$ grams per centimeter squared. I might mention in passing there is one other very rough piece of data that they got from the position of the maximum of the CO_2 line. This was for atmospheric temperature, which was of the order of 230° Kelvin or somewhat higher; but they warn this is an even rougher estimate than the others, so not too much reliance should be given to it. Actually of course, none of their results is very accurate, but to repeat, the authors feel these are the best we have at the moment and perhaps the best we are likely to get until the 1965 opposition.

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