

MOON PARK: A RESEARCH AND EDUCATIONAL FACILITY

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Moon Park has been proposed as an International Space Year (ISY) event for international cooperative efforts. Moon Park will serve as a terrestrial demonstration of a prototype lunar base and provide research and educational opportunities. The kind of data that can be obtained in the Moon Park facilities is examined taking the minimum number of lunar base residents as an example.

INTRODUCTION

As announced by President Reagan in his State of the Union Address to Congress in January 1988, mankind is expected to return to the Moon around the year 2000. The purpose of the return to the Moon is lunar base construction for permanent residence, which is required for lunar industrialization. In order to show the feasibility of lunar base construction, a ground-based demonstration is considered the most feasible approach in validating the lunar base design.

At the Pacific International Space Year (ISY) Conference held in Hawaii in August 1987, the present authors proposed the Moon Park concept as an ISY event to be achieved under international collaboration. Although 1992 is the year proposed for either operation or starting construction, the facilities constituting Moon Park are designed to be permanently operational.

The main facility of Moon Park is the training center simulating an outpost on the Moon, which is combined with the Controlled Ecological Life Support System (CELSS) as depicted by the diagram in Fig. 1. The CELSS is not only for the life support of the training center but is also studied as a key technology. Crew activities are observed by behavioral scientists and are even open to the public, as long as they are not significantly disturbed or degraded by doing so. If an open demonstration is supplemented by lectures and exhibits in the museum, the involvement of young students will be greatly promoted.

Basic technological development in the training center puts emphasis on CELSS demonstration and on studies in human behavior and psychological factors in a confined space. These technologies, together with others listed in Fig. 2, contribute to the lunar base. The CELSS in Moon Park is not a fully closed system, but is provided with several functions: water purification and recycling, management of human waste products, and cleaning and recycling of atmospheric gases.

Taking into account oxygen production from lunar soil, the first two items are regarded as urgent issues and discussed in the present paper in some depth. The objective of the present paper is to define the roles of the training center with its simulation of the crew habitat so as to derive conclusions for the design guidelines of the lunar base.

The major objectives of the studies on the CELSS and the human factors in the training center are to find the design guidelines for the minimum required number of crew for the proposed task, and the minimum dimensions of working and living space required for this crew, in conjunction with the life support needs and psychological factors affecting a small, isolated task group working in a confined space. These criteria will be necessary to design a manned outpost for lunar and planetary exploration. The

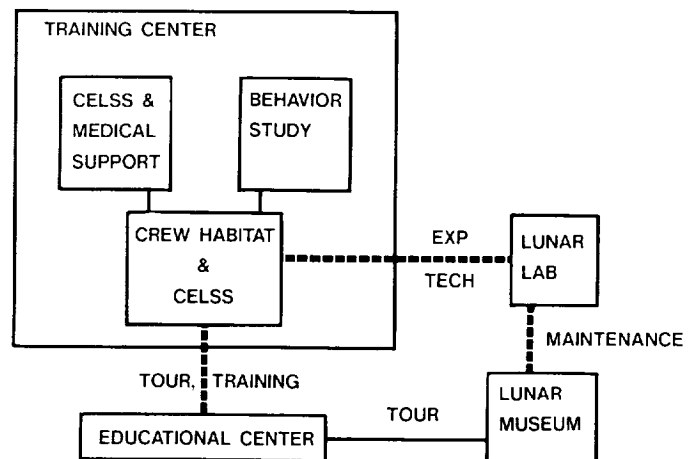


Fig. 1. Moon Park complex.

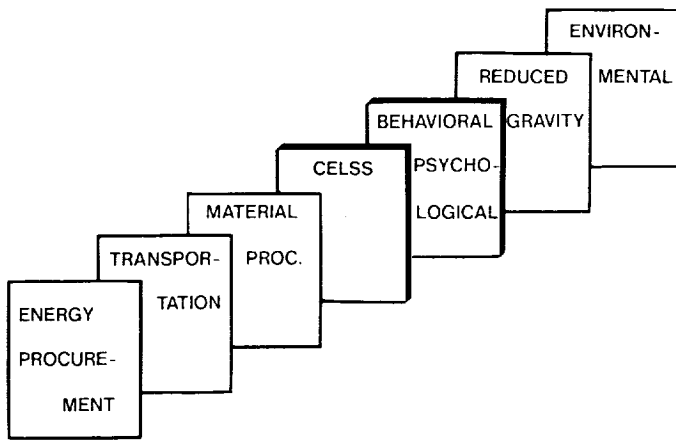


Fig. 2. The key issues of lunar industrialization.

present paper gives preliminary estimations for these values and points out influential factors that should be intensively studied in the Moon Park.

CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEM

The CELSS in the lunar base or Moon outpost will not be entirely closed but will be periodically replenished with protein food from Earth and provided with oxygen from the lunar factory. Vegetables, on the other hand, should be supplied from the hydroponic plant unit in the lunar base. The simulated CELSS of the training center in Moon Park is designed as shown in Fig. 3. The outside environment depicted in this diagram may correspond to the lunar regolith and landscape, and the oxygen factory outside the lunar base. Human waste and kitchen garbage are stored and processed in the biological reactor. The fertilizer generated in the reactor is transferred to the vegetable plant unit.

One of the problems related to the bioreactor is its conversion efficiency. If it is too low, vegetable supply will not satisfy the crew requirement and will have to be procured from outside. In

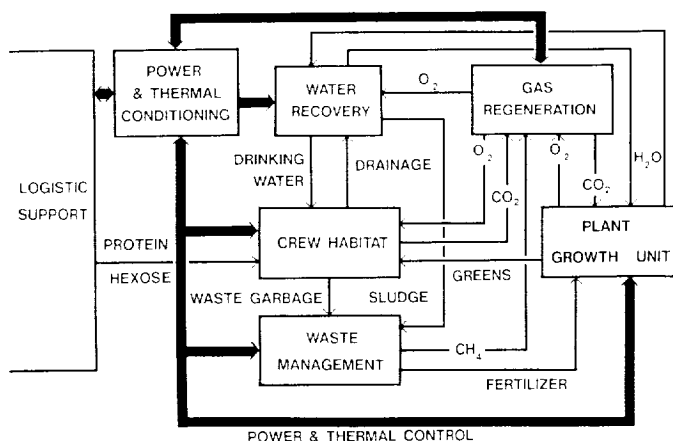


Fig. 3. Diagram of CELSS.

this case, the secondary waste in the reactor will have to be managed somehow. The second problem is the speed of the reactor. If it is slow, the size of the reactor or reservoir will become large. Large size, however, is advantageous from the viewpoint of system stability, as will be discussed later.

The stability issue is most crucial in determining the crew size of the lunar base. Disturbance may arise from both quality and quantity of the waste and there is a maximum level of fluctuation that the reactor system can tolerate. Suppose such a threshold value for instability is 25% and the type of disturbance is disease, which should be a minor problem, or the absence of a crew, the minimum crew number is estimated to be four, which corresponds to the shoulder of the CELSS curve in Fig. 4. In the following, the technological bases for the characteristic values of the reactor are introduced.

WATER RECLAMATION AND WASTE MANAGEMENT

Due to lack of hydrogen on the Moon, water will be a precious material and its use must be optimized. An ordinary Japanese citizen uses about 250 l of water a day for the purposes listed in Table 1. The amount of cooking may be reduced to about one-third of terrestrial use by avoiding the boiling method of cooking and using the microwave oven. Water required for toilet flushing is related to the scheme employed for waste management. The water in a conventional toilet is not used as a processing agent, but as a carrier to a processing facility. The water required for this purpose, therefore, may be reduced by directly transporting the waste to the bioreactor as had been done in Japanese farming in the past. Taking these modifications into account, the lunar base water requirements will be reduced by two-thirds, as shown in Table 1.

In manned spacecraft to date, a physicochemical system has been employed as the most reliable method of water reclamation. In the lunar base, however, physicochemical systems are not suitable because of their increased water requirements; thus, we should apply the water generation system with microbes, as is widely used on Earth.

There are two kinds of microbial water treatment: aerobic and anaerobic. With limited resources of energy and oxygen on the Moon outpost, the anaerobic system is preferred. The anaerobic

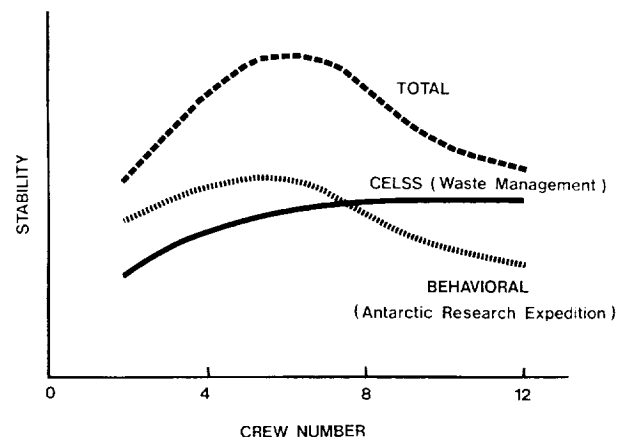


Fig. 4. Stability of closed ecosystem.

TABLE 1. Water consumption.

Purpose	Terrestrial (l/man/day)	Lunar Base (l/man/day)
Drinking	2	2
Shower	50	15
Cooking	50	15
Toilet flushing	50	15
Clothes washing	50	10
Cleaning (facility)	10	3
Others	38	33
Total	250	93

microbes, which are active in oxygen-free environments, decompose the organic waste in the used water, produce organic acids, and then convert them into methane and carbon dioxide. Because the extent of decomposition by the anaerobic system is limited, the assistance of an aerobic system is required for complete decomposition. In the further evolved lunar base where oxygen is available from a lunar factory, the aerobic system will be totally used, as it is more efficient and productive.

The water treated in the bioreactor is further processed physicochemically, as shown in Fig. 5, and is turned into drinking water. Methane, the by-product from the above system, is useful as an energy source, and the sludge is useful as fertilizer for the vegetable plant. The technologies of the water reclamation system discussed above have been terrestrially demonstrated in Tokyo in 1983 (Ogawa, 1985). A glass of water, about 100 ml, is obtained for a cost of less than one cent, only a few times as expensive as the city water in Tokyo.

The solid human waste will also be decomposed by the microbes in the compost tank. As discussed earlier, this may reduce the toilet water requirement. After releasing CH_4 and CO_2 , the processed solid waste will be sterilized with UV radiation, completely sanitized, and eventually applied as fertilizer for the vegetable plant.

When the microbial system is applied to the lunar base, as demonstrated on Earth, two problems may arise. One is the applicability of lunar soil or crushed rock for the filter. However, no hazard was observed in a terrestrial experiment at NASA Johnson Space Center where a simulated lunar soil was applied as a medium for plant growth. The prospects of the use of lunar soil for a filter also seem hopeful. The other problem is the bubble handling at $\frac{1}{6}g$ on the Moon. An artificial acceleration will be required for efficient operation of the liquid/gas system.

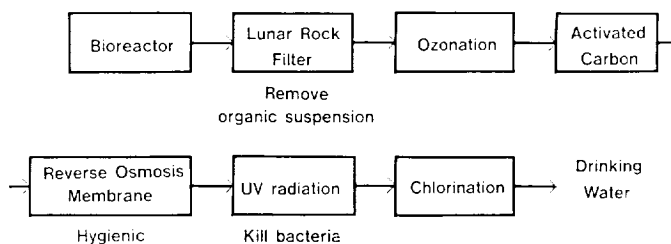


Fig. 5. Water regeneration process.

CREW BEHAVIOR AND ROLES

The minimum crew number for the Moon outpost is assessed from two factors. One is the stability of the crew's emotional behavior in confined habitat space. When the number of crew is extremely limited, fewer than four for example, the crew will find it hard to get along with one another. If the team size exceeds about 10, on the other hand, the crew will tend to lose frequent contact with each other. According to the summary report of the Japanese Antarctic Research Expedition, such loss of human communication will cause an unstable psychological state of the crew (Nishibori, 1958). This may result in a catastrophe for the team. An optimum number of crew members is suggested to be five or six so that they have frequent communication with each other and thereby make their community stable as described by the curve in Fig. 4. The bold dotted curve represents the product of the other two items.

The minimum number of crew is also discussed from the standpoint of the expertise required for lunar base operation. The type and minimum number of experts are listed in Table 2. The two electrical engineers are assumed to be specialists in power/electrical engineering and telemetry. One of the two mechanical engineers is an expert on CELSS, and the other is responsible for the O_2 generator. If a biological scientist supports the CELSS maintenance and a geologist supports the O_2 generator, the reliability of the lunar base community will be enhanced.

From the assessment given above, the most probable number of the Moon outpost crew is 8 to 10. An eight-person crew is assumed for the discussion in the next section.

TABLE 2. Crew composition.

Role	Number
Cook/Nutritionist	1
Medical Doctor	1
Mechanical Engineer (CELSS/ O_2)	2
Electrical Engineer	2
Scientist (CELSS/ O_2)	2
Total	8

BASE VOLUME REQUIREMENTS

Within the crew habitat with CELSS, the areas for water and gas treatments and waste management have to be taken into account. Based on the previous system design, about 120 m^3 is required as the volume of water and waste management facilities for eight people. If a compact O_2 generator is developed for production on the Moon, the CELSS operation with a bioreactor will be greatly improved. The volume required for the O_2 generator is assumed to be 100 m^3 , including the storage tanks.

The design of the crew's private compartments is of prime concern, since the crew must maintain sound psychological conditions while being confined in a closed area for a prolonged amount of time. The habitat volume required, as shown in Fig. 6, depends on the length of stay. Assuming the residence time of a crew in the lunar base to be about a year, 25 m^3 per person is proposed for their personal compartment to allow considerable comfort. The dining room, which is to be used as a reading and meeting room as well, is essential. This should be 100 m^3 in volume. In addition, the kitchen requires 25 m^3 , the workshop and

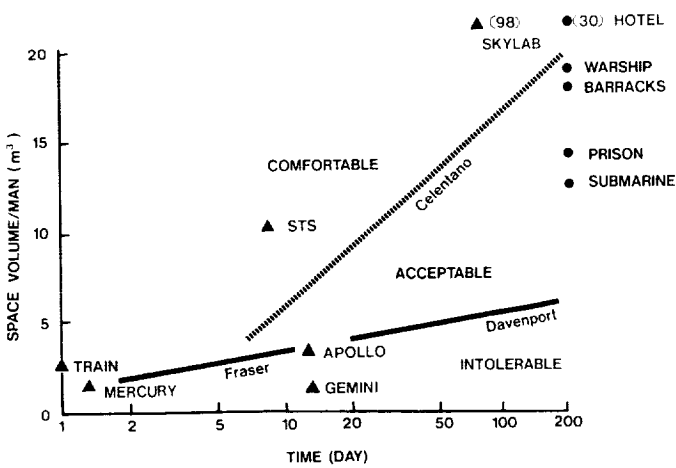


Fig. 6. Space volume for long-term habitation. Data from *Architectural Institute of Japan* (1980) and *Connors et al.* (1985).

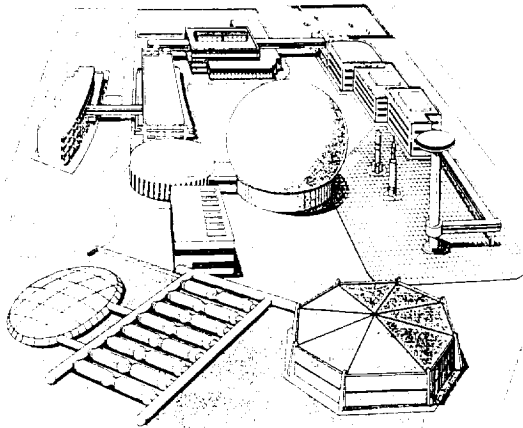


Fig. 7. Moon Park.

laboratories 350 m³, and the utility space 250 m³. These requirements, along with 360 m³ for miscellaneous purposes, constitute the total volume of the Moon outpost for eight people, 1500 m³.

SUMMARY AND REMARKS

From the preceding discussions, the following conclusions have been tentatively drawn. First, the water requirement in the Moon outpost is about (100 l per person) per day. Second, the crew should be as small as possible: the stability of the CELSS indicates a minimum of four, while good human relations are obtained with five or six people, and tasks on the Moon outpost require six technical experts and two scientists; therefore, the outpost crew should have eight members. Third, the outpost should have 1500 m³ space for eight people.

The data upon which the above results are based contain uncertainties and assumptions, as discussed earlier. It is not the intention of the present paper to calculate the minimum crew number but to suggest that the Moon Park facilities be used as a research center where the fundamental data are obtained for the design of a Moon outpost.

Sociological factors have not been discussed here, yet they are essential. Different designs may be considered depending on whether a single international lunar base will be constructed or whether each nation will have its own lunar base. Crews made up of individuals with different backgrounds and cultures may affect the design and development approach taken for the lunar base. For these reasons, Moon Park as shown in Fig. 7 should be of an international nature and open to international participants.

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