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既存の居住実験施設調査に基づいた月面基地実証施設の設計

Lunar Analog Habitat Design based on a Review of Existing Analog Habitats

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1. Introduction

The National Aeronautics and Space Administration (NASA) is pursuing the Artemis program to land two humans on the Moon in 2025, and in leading this program, NASA hopes that the private sector will establish a sustainable presence on the Moon and lay the foundation for a lunar economy. It also believes that international partnerships will play an important role toward the long-term goal of sending humans to Mars[1). Meanwhile, to study the human factors for life on the Moon and Mars, many analog experimental facilities have been constructed around the world, and a number of volunteer subjects have participated in the experiments. Various findings on the design of habitat facilities and lessons learned on habitat experiments have been reported[2).

In Japan, the government-led Strategic Project called " Development of an Advanced Resource Recycling Food Supply System to Support Long-Term Stay on the Moon" sponsored by the Ministry of Agriculture, Forestry and Fisheries (MAFF) selected SPACE FOODSPHERE as a contractor for the project in 2021[3). The proposal adopted by SPACE FOODSPHERE has three subprojects: (1) Development of an advanced resource-recycling food supply system, (2) Development of a quality-of-life management system, and (3) Design of an integrated demonstration platform of subproject (1) and (2). In this report, the author describes the results of the investigation on the existing analog habitation experiment facilities and experiments conducted during the preliminary investigation of Subproject (3).

2. Closed Life Support System Experimental Facilities

Heinicke et al. surveyed 30 analog experimental facilities around the world.[3) Table 1 shows the five closed life support system facilities from the list. The projects of BIOS3, Lunar-Mars Life-Support Test Project (LMLSTP), and Closed Ecological Experimental Facility (CEEF) have been terminated. China's Lunar Palace 1 (LP1)[4) and CELSS integrated test platform (CITP)[5) have continued to conduct habitation experiments since the 2010s. Table 1 shows the total volume, area, cultivated area, crop species, the self-sufficient rates, and three recycling rates for oxygen, water, and waste at the five experimental sites. In the case of a life support system with biomass production, it is possible to achieve close to 100% oxygen and water regeneration through photosynthesis. For food self-sufficiency, the CEEF's 92-95% is a high figure. Since high-pressure sodium lamps were used as the light source in biomass production in 1990s and LEDs are used after 2010s, it is possible to achieve the same self-sufficient rate with less power consumption. The still active facilities, LP1 and CITP in China, use LEDs for biomass production and have achieved self-sufficient rates of 70.8% for 25 species and 73% for 35 species; CITP reports using 310 kW on average, of which 100 kW comes from solar power generation[5]. For waste treatment, the CEEF used combustion and goats for ingestion of inedible parts. In China, LP 1 uses biological treatment for wastes.

Table 1. Biomass production and resource regeneration in closed life support systems

Facility, Place, Crewmember (CM), Duration	Total volume and area	Cultivated area, m^2	Crop species	Self-sufficient rate, %	Oxygen recycling rate, %	Water recycling rate, %	Waste recycling rate, %
BIOS3, Russia, 2-3CM, 90days	315 m^3 126 m^2	60 30	1 (Wheat) 12	48 max 80	100	100	
LMLSTP, US, 4CM, 91days	73 m^3 87 m^2	11.2 * 0.22	1 (Wheat) 1 (lettuce)	25	56	100 † (PC, PCBIO)	Urine(PC) Solid(PC)
CEEF, Japan, 2CM, 28days	1365 m^3 370 m^2	150	23	92-95 79(goat)	100 ‡	99.2 §	Inedible(to goat), Solid(PC), Urine(to outside)
LP1, China, 4CM, 365days	500 m^3 160 m^2	120	35	73 (FW83)	100	100 (BIO)	Urine(nitrogen) 99.7, Solid 67(BIO)
CITP, China, 4CM, 180days, Avg. 310 kW, SP100 kW	1340 m^3 370 m^2	Avg. 206.6 Max 260	25	Avg. 55, Max 70.8, 128.87kWh/kg	100	100 (BIO)	Solid 91(PCBIO)|| Solid 87.7

* Multi-stage cultivation, † Experiments with BIO (100%, SAE981708) and PC (combustion), ‡ Can be considered 100% because urine is treated outside the system (Miyajima), § Calculation by Miyajima, || High-temperature oxidation treatment

3. Summary

Focusing on the development of an advanced resource recycling food supply system, a design study of a ground experiment facility was started in FY2021 to conduct a demonstration experiment integrating each subsystem. In this study, closed life support system facilities were investigated in the U.S. and China. To achieve 100% food self-sufficiency, the minimum cultivation area (not floor space) per person was 80 m^2, and the maximum power when using LEDs was 20 kW. Assuming a living area of 10 m^2 per person and a resource recycling facility of 10 m^2, 400 m^2 would be required for four crewmembers, and assuming a margin of 30% to account for building code and fire code restrictions, the total would be 520 m^2. This project aims to design an experimental facility that can accommodate more highly efficient biomass production and resource regeneration through biological treatment, while using the results of long-term habitation experiments conducted in China using biological treatment as one benchmark.

References

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