JASMAC
Conference of the Japan Society of Microgravity Application

OS2-1

ECLSS に関連する全体概要
Outline of ECLSS in Japan

桜井 誠人 [1]
Masato Sakurai[1]
[1] 宇宙航空研究開発機構（日本語），JAXA,

1. Introduction

The Environmental Control Life Support System (ECLSS) provides a habitable environment for the crew of the International Space Station (ISS): 1 atm, a comfortable room temperature, potable water, and food. This report introduces the history of the ECLSS in Japan, such as temperature and humidity control in JEM and the closed ecosystem experimental facility (CEEF) in Rokkasho Village, Aomori Prefecture. It also discusses trade-offs in the design of the ECLSS ESM (Equivalent System of Mass).

2. Environmental Control Life Support System

An ECLSS is required to realize the living environment on the ground as it is in space. The ECLSS consists of four subsystems, an air system to maintain the air quality, a water system to supply potable water, a food system, and a waste disposal system

2.1 Resources provided by ECLSS

The primary role of ECLSS is to supply resources and to dispose of the generated waste:

-Air: O_2 is required at 840 g/person/day. N_2 is also required to maintain air pressure at 1 atm, but small N_2 leaks occasionally occur. Cabin air is temperature- and humidity-controlled to maintain a comfortable environment.

-Water: At least 2 to 3 L of water is required per person per day, but the amount needed to live comfortably is much larger than this—about 200 to 300 L/person/day. It is difficult to supply this amount in space.

-Food: The average person requires 1.1 kg of food per day. Food is processed and categorized into those of plant and animals' origin. Plant-derived foods, particularly grains, are necessary to human life. Grain production requires light, CO_2, and a large amount of water, about 1000 times as much as the dry component of the grain produced. Water is indispensable to food production.

2.2 Types of ECLSS

The stages in ECLSS development are classified as to type according to the degree of resource dependence on the Earth:

① **Consumption-oriented ECLSS:** This type of ECLSS provides disposable items brought from Earth, used, and then thrown away.

② **Regenerative ECLSS:** This ECLSS processes discharged waste. At this stage, food is still only supplied from the Earth.

③ **Self-supporting ECLSS:** At this stage of development, an ECLSS does not depend on the Earth for its air, water, or food. Ultimately, food production in space is essential, and food self-sufficiency in space is the goal of ECLSS research.

2.3 ISS air environment

The ISS sustains the same 1 atm O_2/N_2 air as at ground level, and the temperature and humidity are maintained at comfortable levels. The O_2 is replenished as the crew breathes it, and the exhaled CO_2 and trace contaminants (TC) are removed to acceptable concentrations. Since natural convection does not occur in a weightless environment, it is necessary to forcibly circulate the air with a fan so that the components of the air are mixed uniformly. Therefore, the wind speed requirement for air is set.

2.4 Configuration of air subsystem

The ISS ECLSS air system consists of the US ECLSS air module and the Russian ECLSS air module. The US system provides life support for three US crew members, as the Russian system does for three Russian crew members. In the event of an emergency, each function will be interchanged. Japanese astronauts are considered part of the US crew. The ECLSS function of the Japan module (JEM) refers only to the device responsible for air conditioning in the JEM; the US module provides all other ECLSS functions.

・ **Cabin pressure (total pressure)**

The total air pressure is maintained at 724 to 770 mmHg, a nominal 1 atm. Since the total pressure constantly decreases due to leaks, the air pressure is maintained to the nominal range by replenishing N_2 gas or air. The air leakage of the entire ISS is about 362 g/day. N_2 and air are discharged directly into the ISS from a tank on the supply ship (Russian progress, ESA ATV). In addition, N_2 gas for pressurizing the propellant tank of the supply ship is also used. Japanese HTV transport aircraft do not carry N_2 or air. The upper limit of the N_2 partial pressure is 600 mmHg due to the restriction of N_2 hours before wearing a spacesuit during Russian extravehicular activity (EVA). The minimum amount of stored N_2 is 106 kg because that is what is needed to repressurize the JEM after it is depressurized.

・ **Oxygen (O_2)**

The O_2 partial pressure is maintained and controlled between 146 and 178 mmHg because of physiological requirements. The minimum allowable O_2 partial pressure is 120 mmHg to prevent hypoxia; the maximum value is 24.1% of the O_2 to prevent fire hazards (24.1% is the test certification criteria for combustion of the materials used in the ISS). The following methods supply O2:

① **Oxygen production equipment**

Two devices produce oxygen, the US OGA (Oxygen Generator Assembly) and the Russian Elektron, both of which electrolyze water to generate O_2.

② **O_2 or air tank on the supply ship**

The O_2 and air stored in the tanks on the Russian progress transport ship, ESA's ATV transport ship, are released directly into the ship. The tanks must be completely discharged before the transport ship can undock.

③ **Candle**

O_2 can be generated by the thermal decomposition of solid fuel, such as potassium perchlorate ($KClO_4$), which is called a candle. The candle operates as an O_2 generator for backup and is used when the O_2 partial pressure drops below 120 mmHg.

④ **Airlock O_2 tank**

This tank repressurizes the airlock during EVA. A minimum reserve of 221 kg of O_2 is required. The breakdown of usage is crew metabolic consumption for 45 days (115 kg), an emergency medical inhaler for 72 hours (68 kg), an emergency EVA of four doses (45 kg), and JEM re-pressurization (38 kg)

・ **Carbon dioxide (CO_2)**

The maximum allowable CO_2 concentration on the ISS is 5.3 mmHg (7000 ppm). This is higher than the ground tolerance but lower than the allowance in submarines. Some years ago, the crew reported that the air sometimes seemed stuffy, so it was not identified to be caused by high CO_2. However, the CO_2 concentration (partial pressure) is typically maintained at 4.0 mmHg or less. Each person exhales 1000 g of CO_2 per day. The following methods remove CO_2:

① **Regenerative CO_2 removal device**

On the ISS, carbon dioxide removal assemblies (CDRAs) provide regenerative CO_2 removal devices for the US, and a Vozdukh operates for the Russian astronauts. These devices repeatedly adsorb and desorb CO_2 using Zeolite, a reproducible adsorbent. Since the adsorbent for CO_2 is decompressed and heated to desorb CO_2, it can be cycled repeatedly, significantly reducing the number of consumable adsorbents.

② **Adsorbent (non-regenerative)**

These adsorbents are a nonrenewable, disposable material that adsorbs CO_2 and is inside an adsorption canister. The entire adsorption canister, containing lithium hydroxide (LiOH), is replaced and discarded as necessary. Manned, short missions, including the Space Shuttle operations, have used this method to remove CO_2. LiOH is equipped in a 14-day LiOH canister for six crew members as a backup CO_2 removal capability on the ISS. Early Russian spacecraft have used potassium hydroxide (KOH) as an adsorbent. We can also use KOH as a CO_2 adsorbent, a by-product of the KO_2 used as an O_2 generator. At present, Russia also uses LiOH as an adsorbent.

- **Reuse of carbon dioxide (CO_2 reduction by the Sabatier reaction)**

The CO_2 removed by the regenerative CO_2 removal device is exhausted outside the ship. However, one practical use of CO_2 is that H_2 reduces it to produce water ($CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$). The ISS is equipped with a CO_2 reduction device that uses the Sabatier reaction. Since H_2 is generated during electrolysis, it is also waste. CO_2 reduction is an essential component of a regenerative ECLSS, indispensable for future long-term manned missions.

- **Trace toxic contaminant (TC) gas**

The allowable concentration of harmful trace gases is specified in the ISS-specific requirement document as the spacecraft maximum allowance concentrations (SMAC). The allowable SMAC depends on the exposure period; SMAC decreases with increasing exposure. The limits of the main components of SMAC are ammonia < 3 ppm, carbon monoxide < 15 ppm, methane < 5300 ppm, and $H_2 < 4000$ ppm

The ISS is equipped with a US trace contaminants control system (TCCS) and a Russian BMP to remove trace gases. The removal of trace gas is based on the adsorption of activated carbon. However, the components that cannot be adsorbed and removed by activated carbon are removed using functional activated carbon and a catalytic oxidation device.

- **Temperature and humidity (air conditioning)**

The inside of the ISS is air-conditioned, and the room temperature is maintained at 18.3 to 26.7 °C. The humidity is maintained at 25 to 75%RH. Wind speed requirements of 7.6 to 20.3 cm/s are set so that the components are evenly mixed even in weightlessness to prevent O_2 and CO_2 from becoming unevenly distributed locally, which could pose a danger to the crew. An air conditioner is installed in each of the main modules. However, to make the air between the modules uniform, a fan provides forced ventilation between them. The air conditioner takes air from the floor, cools, and dehumidifies it; then, a ceiling fan blows it out into the room. In the cooling and dehumidifying process, a large amount of water condenses due to unconscious human respiration. Originally, all the condensed water was discarded into space. However, when the ISS is equipped with a water processor assembly (WPA), it will be possible to generate clean, drinkable water from this condensate. This will make it possible to significantly reduce the amount of water supplied from the ground.

3. Closed Ecology Experiment Facilities (CEEF)

The Institute for Environmental Sciences (IES), researching the impact of vegetation on the environment and the public, was established in 1990. It is located in Rokkasho village, Aomori prefecture, Japan, where a spent nuclear fuel reprocessing plant was developed as a central part of the nuclear fuel cycle. The IES developed unique experimental facilities named (CEEF) between 1994 and 1999. The targets are radioactive carbon (^{14}C) and tritium (^{3}H), which are of essential concern concerning dose contribution in humans because they have migrated into the environment as gases cause internal exposure through the food chain. In this experimental facility, carbon-13 (^{13}C) and deuterium (^{2}H), stable isotopes with the same chemical behavior as their radioactive counterparts, were used instead of the radioisotopes.

Twenty-three crops, including rice, soybeans, peanuts, and sugar beets, were cultivated in the plant cultivation module (PCM). Two Shiba goats were bred in the animal breeding and habitation module (AHM). The residents consumed 82–95% of the food, and 79–100% of the feed for Shiba goats came from crops in the PCM. Waste treatment was carbonized without using wet oxidation.

4. Concept of ESM (Equivalent System of Mass)

Generally, the regenerative ECLSS offers more advantages than the consumption-type ECLSS for longer missions. However, there are variations of the ECLSS, and this is only a guideline for determining the optimum ECLSS system for each mission. The concept of the equivalent system of mass (ESM) is applied. To estimate the total system mass, we need to include the mass of the ECLSS system itself and the ancillary structures that make up the ECLSS system and require pressurized space, power, exhaust heat, and work time. In ESM, each system component's mass, volume, power consumption, exhaust heat, and working time are multiplied by coefficients to convert them into mass. Here, as shown in Table.1[1)], consider ESM on the moon as an example. When considering energy, the weight of the solar cell of a solar tracking device on the moon is estimated to be 54 kg/kW per kW. However, since solar cells alone cannot spend the night of the moon, the weight per kW is estimated to be 749 kg/kW, which is extremely heavy when providing electricity at night with a rechargeable fuel cell. The weight per kW can be as low as 77 kg/kW for a nuclear reactor because a charger pond is not required for nighttime. In pressurized spaces, an inflatable structure with a shield is 133.1 kg/m^3 per m^3. However, an inflatable structure without a shield is estimated to be 9.16 kg/m^3, less than 1/14 of the weight with a shield. Estimates show that 221 kg/kW is needed to exhaust 1 kW of heat. For reference, the existing technology of the ISS is 323.9 kg/kW when the radiator does not face the sun. By multiplying these coefficients by the volume, energy consumption, and exhaust heat of each component, such as a CO$_2$ removal device and an oxygen production device, the cost of each component can be compared in terms of weight.

The ECLSS includes such components and equipment combinations for water reclamation, CO$_2$ removal, oxygen production, the Sabatier reaction, and harmful trace gas removal. The weight, volume, power consumption, and exhaust heat of each component are shown in Ref[2)]. These values are multiplied by the coefficients shown in Table.1 and their weights compared. Figure 1 shows how the system weight changes during the mission period. For short missions, the single-use consumption-type ECLSS is best. With a more extended mission period, the ECLSS with a low regeneration rate becomes advantageous when the first break-even point is passed. The ECLSS with a medium reproduction rate becomes advantageous for a more extended period exceeding the second break-even point. ECLSS with a high regeneration rate becomes best for even longer missions.

Reference

1. Molly S. Anderson et al., “Life Support Baseline Values and Assumptions Document” NASA/TP-2015–218570
2. Anthony J. Hanford “Advanced Life Support Research and Technology Development Metric – The Fiscal Year 2005” NASA/CR-2006-213694

Table. 1 Equivalent system of mass

Mission	**Volume [kg/m3]** Inflatable Module		**Power [kg/kWe]**			**Cooling [kg/kWth]**
Lunar mission - surface	9.16 Unshielded	133.1 Shielded	54 Tracking PV no storage	749 PV + Regenerative Fuel Cell	77 nuclear refractory reactor	221 Current technology

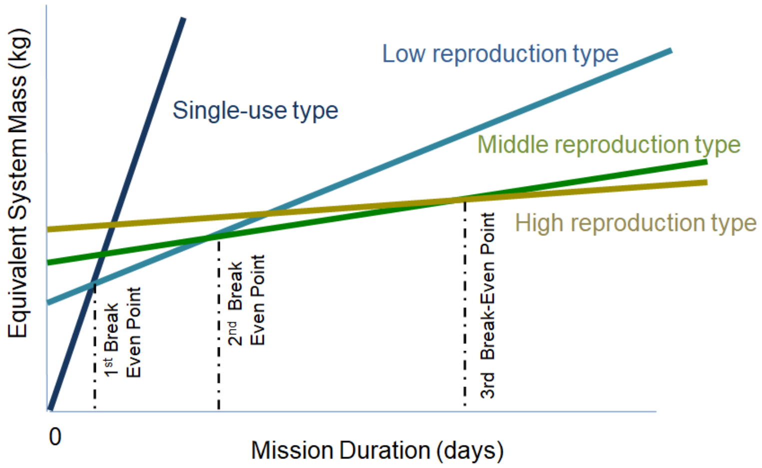

Fig. 1 Relationship between the mission period and the total system weight.