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Sustainability, Sanitation and Recycling for Long Duration Space Missions

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ABSTRACT

Long-term space missions produce a significant amount of waste, making it a difficult task to manage the waste through recycling, rejection, or reuse. The idea of simply sending the solid waste into space via an airlock was investigated for crewed Mars trips as well as Earth-moon libration point missions. The primary obstacles to be addressed as humanity aims to build a thriving and long-lasting colony on Mars include supplying settlers with a steady and wholesome supply of food, fuel, medications, and feedstock for 3D printing. Although there have been many suggestions for producing necessities on Mars, using microbes as the primary production units is gaining favor.In light of long-duration space missions, this review study looks at the crucial areas of sustainability, sanitation, and recycling. For space exploration projects to remain viable and for astronauts' safety to be guaranteed, these issues must be resolved. We investigate techniques including closed-loop systems, sophisticated life support technology, resource efficiency, and effective recycling. It has been determined that long-term planning, global cooperation, and behavioral changes are necessary for space exploration to meet its sustainability objectives. Space organizations can create self-sustaining habitats and spacecraft that can support longer missions while reducing their environmental impact by combining these technologies.

Keywords: Waste model, Water waste management, Recycling in Space

INTRODUCTION

We can gain a deeper understanding of the universe through space exploration, including its origins, evolution, and possibilities for extraterrestrial life. We can find answers to important concerns concerning our existence and our place in the cosmos with the use of this information. Establishing colonies on other planets and moons could serve as a fallback in the event of an extinction event or global disaster on Earth. By establishing human communities on other celestial bodies, we can preserve our cultural legacy and collective knowledge while also ensuring the survival of the human species. Numerous real-world applications of space exploration and colonization can be found in disciplines including environmental sustainability, materials science, and medicine [1, 2].Future generations may be motivated to seek scientific and technological advancements as a result of space travel and colonization. Space exploration has the power to advance society and open up new avenues for growth and discovery by pushing the boundaries of human knowledge and capacity.For a number of reasons, including scientific research, technological development, and the possibility of human settlement of other planets, humans are thinking of visiting Mars [3].

Because Mars' geology and potential for supporting life are comparable to those of Earth, scientists have been interested in the planet for a long time [4, 5]. Investigating Mars and learning about its geology and history may aid in our understanding of how the Solar System evolved and the possibility of extraterrestrial life. Furthermore, there could be a wide range of uses for the technological advancements made in creating the systems and infrastructure needed for a human voyage to Mars in industries including environmental sustainability, biotechnology, medicine, materials science, and food science. Investigating Mars and learning about its geology and history may aid in our understanding of how the Solar System evolved and the possibility of extraterrestrial life. Furthermore, there could be a wide range of uses for the technological advancements made in creating the systems and infrastructure needed for a human voyage to Mars in industries including environmental sustainability, biotechnology, medicine, materials science, and food science. For many years, people have been interested in the possibility of human colonization of Mars [6], [7-9]. Some see it as a means of establishing a permanent human presence beyond Earth and a contingency plan in the event of a planetary disaster.Long-duration space missions involve a lot of emphasis on making sure the crew has the supplies and tools they need to live and prosper, but managing the garbage generated is just as important. Crew biological products (carbon dioxide, water, human liquid and solid waste) and solid and liquid wastes (food scraps, clothing, packaging, etc.) are among the waste materials produced on a regular basis.The essential tasks performed by life support systems in space include regulating pressure, temperature, and humidity; providing oxygen and drinkable water; transporting food; and managing waste. Nevertheless, food and oxygen cannot be recycled from waste materials by space-qualified technology; as a result, trash must be stacked up or dumped before being returned to Earth. The primary driving force behind the development of advanced technologies capable of extracting resources from waste is the desire to lower resupply shipping costs, which are contingent on crew size and mission duration. Resupply operations on missions beyond low-Earth orbit (LEO), like as voyages to Mars, will be far more challenging and costly, if not impossible. Advanced life support (ALS) systems need to be less dependent on external resources and more dependable in order to preserve crew health and safety.

WASTE MODEL FOR CREWED MISSIONS

A thorough model of the garbage produced by crewed missions has been created using data from studies of waste products from the International Space Station and Space Shuttle as well as predictions for future exploration vehicles. Clothes, paper, foam packaging, wipes and other personal hygiene products, EVA supplies, and human wastes are among the things in the waste model. Apart from determining the daily quantity of garbage in every category, the constituent elements of every kind of waste have also been specified. Table below presents a breakdown of waste volumes by category and the overall amount produced during an Earth-to-Mars transit mission and a Gateway mission (Phase I and Phase II length).

Table 1. Mission Waste Summary

		Gateway Mission		Mars one-way Transit
Waste Description	**Waste Amount (kg/cm-d)**	**Phase I Total Mass (kg)**	**Phase II Total Mass (kg)**	**Mars DRA 5.0 Total Mass (kg)**
Clothing	0.160	15-58	58-115	173
Paper & Office Supplies	0.007	1-2	2-5	7
Wipes/ Tissues	0.137	13-49	49-99	148
Towels & Hygiene	0.098	9-35	35-71	106
Foam Packaging for Launch	0.040	4-14	14-29	43
Other Crew Supplies	0.037	4-13	13-27	40
Food & Packaging	0.352	24-127	127-253	380
EVA Supplies	0.010	1-4	4-7	11
Human Wastes	0.449	43-162	162-324	485
Waste Recovery/ Mgt System	0.162	16-58	58-116	174
Total	1.45	139-523	523-1046	1569

WATER WASTE MANAGEMENT & RECYCLING

NASA plans to use two technologies to manage waste from the Space Station. Subsystems for air and water are now being tested and studied by ECLSS (Environmental Control and Life Support System). Urine and water are two instances of these systems. Included are subsystems for oxygen production, carbon dioxide removal, and reclamation. In Huntsville, Alabama, at the Marshall Space Flight Center, the majority of this work is being conducted. Mars Systems is in charge of galley design, food management, rubbish management, and crew personal hygiene items. It is primarily situated at Johnson Space Centre in Houston, Texas [10].Trash management will be handled by six systems. Trash from solid sources will be handled by two systems, wastewater by three systems, and flying debris by one system.

Solid Waste Disposal Systems

There are two categories of solid trash: solid non-human waste and solid human garbage. Prior to being transported back to Earth, these two solid wastes will be compacted and kept in the logistics module. Plans for the future include the creation of technology that can turn these wastes into products that can be used. These two systems will not be recovered due to the current stage of progress in zero-g solid waste technology [11].

Wastewater Treatment Systems

Three different wastewater treatment systems and three different wastewater streams exist. Drinkable water is found in the first stream of water. Condensate from the cabin temperature and humidity control system will be collected, and potable water will come from the carbon dioxide reduction subsystem. The basic technique for polishing water free of metal ions and dissolved organic vapours is multi-filtration. Iodine is injected into the recovered water via a microbial check valve to prevent the growth of microorganisms. The second water waste source is washing water from hand washing, clothes washers, and crew showers. The fundamental technology for obtaining water from this stream is reverse osmosis (RO). Pretreatment with ultrafiltration is needed for this system to capture macromolecules and suspended particles.

The third cause of water waste is urine. Thermoelectric Integrated Membrane Evaporation Subsystem is the fundamental technology used in urine processing (TIMES). This subsystem has to be pretreated with sulfuric acid or ozone. Membrane permeation allows water to evaporate to a pressure equivalent to roughly one-sixth of ambient condenser pressure. Similar to the washing recovery system, this recovery system will only be used to supply hygiene water—not the potable water subsystem. This system will have various biological check valves and be continuously monitored to ensure that any contamination found does not propagate to the rest of the hygiene subsystem [12]. Since there is no connection between the potable subsystem and the hygiene subsystem, contamination crossing over is improbable. These systems are compliant with Voecks and Seshan's 1990 AIAA technical study.

Air Revitalization

The air rejuvenation system is still in the early stages of design. This system might use the water, hydrogen, and oxygen byproducts of the Bosch and Sabatier CO_2 removal procedures. In addition to this process, another system will operate to eliminate any particulates, moisture, or biological pollutants from the airstream.

Recycling of disused space crafts on the moon

In 2013, the "Sustainable Materials Concepts" investigation was initiated as part of ESA's "Clean Space" mission. Examining the possibility of materially reusing materials from abandoned spacecraft was the primary goal. This concept makes perfect sense with the above-described timeline, assuming that a number of unmanned moon trips would need to be completed before the fully manned station could begin operations. Thus, a landing structure that will never be utilized is left at the landing location by each mission. The overall mass of all spacecraft that have been disposed of has been determined in the first stage.

Twenty t of aluminum and seven t of CFRP structures were the results of the analysis. The major components of the Al are made up of 25% Al-2019 alloys and 50% Al-7075 alloys; the composition of the Al is not uniform. It was suggested that an Advanced Manufacturing (AM) technique be used to repurpose these aluminum resources once the disassembled aluminum components were shredded. The shredded material used as the AM's input would likewise contain the identified combination of the specified alloys. On the other hand, pure and well-qualified raw materials are used in terrestrial AM procedures with Al alloys [13].

Recycling in Space: Waste Handling in a Microgravity Environment Challenge

Solutions for handling trash and other waste produced by the crew are required for long-term human space exploration missions to the Moon and Mars. During a year-long trip, four astronauts can produce up to 2,500 kg of garbage. Trash takes up room and poses a physical and biological risk to the crew's safety. Currently, astronauts on the International Space Station handle waste by hand, gathering it into bags and transporting it into a special vehicle for short-term storage. Depending on the vessel, this vehicle either burns up in the atmosphere or returns the waste to Earth. Missions operating outside of low-Earth orbit will not be able to use this disposal technique.

One way to reduce these problems and possibly even turn garbage into a supply for the mission is to recycle rubbish. Small waste particles can be broken down into water, oxygen, and other gases by the astronauts in a high-temperature reactor. The crew can then use or vent the gases as needed. With the exception of the gases, the waste has substantially shrunk and is no longer biologically active [14].

Human Waste Processing and Reclamation

The management of human waste presents a barrier for human space travel, and solutions that have been put forth often concentrate on methods for compacting, sterilizing, and discarding human waste rather than recycling it [15]. Human excrement is currently stabilized, dried, and released from the International Space Station (ISS) to burn in the Earth's atmosphere [16]. This approach wastes potentially valuable resources; hence it is obviously unsustainable for long-term missions.

Alternatively, solid human waste could be utilized as fertilizer and/or nutrients for plant- or microbe-based Life Support System (LSS) components, as well as a feedstock for the manufacturing of food and edible supplements (Fig. 1). Numerous physicochemical methods, like incinerator or pyrolysis, are being proposed for solid waste management. On the other hand, by improving loop-closure, procedures aided by microbes could improve the recycling of human waste.

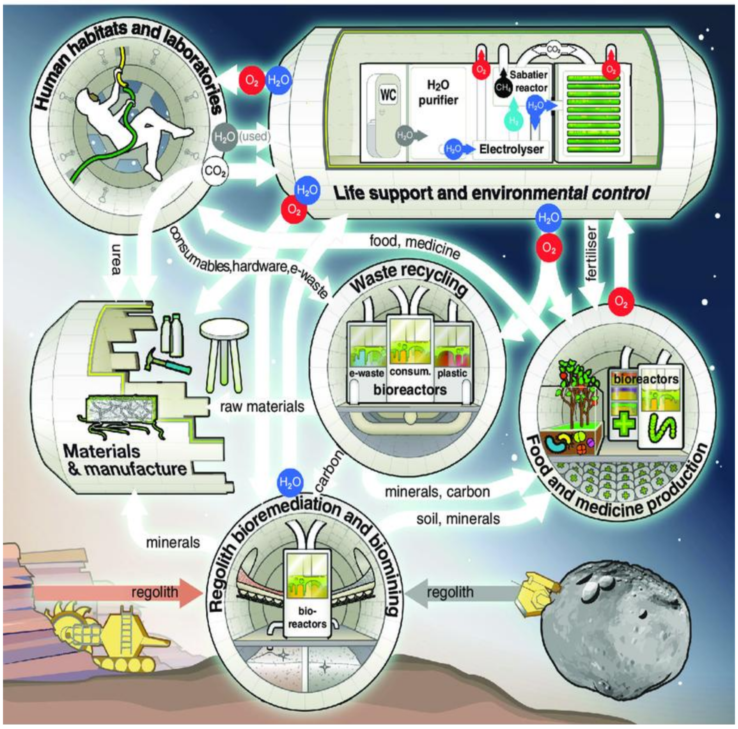

Fig1. Graphical rendering of a microbial biotechnology-based life-support system in an agnostic space environment [16]

Recycling of Electronics, Plastics and Other Waste Streams

The majority of current efforts to develop highly efficient systems for loop closure concentrate on the recycling and upcycling of biological waste (such as food waste and black, grey, or yellow water) [17]. In contrast, solutions for synthetic waste (such as plastics, consumables, and electronic waste) are largely unexplored and their current management is not sustainable for long-term missions. From metallic structures and electronic devices, valuable metals (Fe, Cu, rare earth elements, Al, Si, Zn), including precious metals (Au, Pt, and platinum group elements), as well as some non-metals (Cl, P, N, and even O), can be recovered via biology [18]. Recovering metals from electronic trash (such as solar panels, switchboards, and computer components) may lessen the need for resupply and/or more labour-intensive sourcing from in situ resources using techniques like biomining [19, 20].

Plastics are now a need in many aspects of our daily lives on Earth, including manufacturing, packaging, and building. Plastics, especially those with great strength and durability, are essential to sustaining human activities in space since they are used in spacecraft and spacesuits, among other frequent Earth-analog applications [21]. Organic polymers generated from non-renewable fossil fuels make up the majority of plastics [22].Recycling and upcycling plastics will be crucial in an environment like space, where fossil fuels are scarce, in order to: (i) obtain feedstock for manufacturing to produce new consumables; (ii) repurpose and recycle resources and thereby close the loop on carbon-based feedstocks; and (iii) reduce waste disposal. It has been demonstrated that microorganisms can degrade microplastics into metabolizable substances that promote growth. The process known as "biodegradation" presents intriguing avenues for the development of a circular bioeconomy. Scientists at the UK Centre for Astrobiology (University of Edinburgh, UK) are investigating the possibility of using these microbial processes to recycle garbage in space.

CONCLUSION

On extended expeditions beyond Earth, substantial volumes of garbage will be produced. It will no longer be possible to save this garbage to package and return to Earth or burn up in space; instead, new solutions must be created. Using a tiny airlock to release the garbage into space is one solution that has been proposed. A physical analysis of the waste's responses in a vacuum revealed that not much water flashes to vapor when it is first exposed to the vacuum. Before the garbage football is totally frozen, about 20% of the water in the waste will sublimate over time. To sum up, attaining sustainability, sanitation, and recycling in extended space missions is crucial to guaranteeing astronaut success and well-being while reducing environmental effect. Space agencies can build self-sustaining habitats and ships capable of supporting extended missions by putting closed-loop systems, cutting-edge life support technologies, resource utilization, and effective recycling procedures into practice. To achieve these aims, long-term planning, international cooperation, and behavioral measures are essential. By incorporating these tactics, mission success will increase and future space travel will be made possible.

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