

In-situ Resource Utilization Capabilities

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Question 1: Using the three provided resources, create a comparison of the available lunar in-situ resource utilization and describe the advantages and challenges of collecting these resources.

“Advancing in Situ Resources Utilization Capabilities to Achieve a New Paradigm in Space Exploration” defines In-Situ Resource Utilization (ISRU) as harnessing and utilizing in-situ resources by employing operations and using hardware. It is a practice of collecting materials found in outer space and then processing these resources into usable material. This practice helps eliminate the need to transport material from the Earth, which saves time. ISRU is seen as a sustainable practice that will aid in space exploration, allowing the astronauts to venture further into space for an extended time. These resources are then used in multiple ways, such as building structures, which include satellites, rovers, etc., and supplies that would aid human missions in space. During space explorations, some resources found cannot be brought back to the site and have to be collected, processed, stored and used at the site where these were found. For this reason, many different technologies are being developed to utilize these resources more efficiently.

ISRU presents many advantages, including propulsion optimization, reduction of landing mass, and a decrease in the number of health issues among the crew. The products manufactured using ISRU are sustainable and efficient and can be restocked easily. This ability will allow for long-duration missions without the concern of running out of supplies, and it will also make future human missions on Mars possible. Space exploration is very expensive, and from an economic standpoint, it is mostly a scientific investment; however, ISRU provides a huge advantage in this regard as it will help reduce the cost of space exploration. Resources found in the regolith of the moon can also be used to make repairs to satellites, rovers, etc., in real time without having to wait for the supplies. The five main advantages of ISRU include enhanced mission performance and increased sustainability, which will result in a decrease in life cycle costs, fewer crew required, reduced mission risk, and increased scientific development. These are the immediate benefits of the ISRU, and they will open doors to further opportunities.

Some challenges that need to be addressed for ISRU are the extreme environments, maintenance, operations, integration, infrastructure and return on investment. While the advantages are indeed going to elevate space exploration capabilities, these challenges also need to be addressed. To overcome these challenges, propulsion and power technologies need to be developed in such a way

that these can be integrated into life support and thermal management systems. This will ensure maximized benefits while reducing mass and production costs. Propulsion systems can be improved using ISRU as they can generate propellants using the material provided by the Earth's resources and even space resources. If 3D printing can be used on the moon, then the propellants and pressure vessels can be generated on-site. However, the greatest challenge of 3D printing is that it is highly flammable. In this case, it would be better to look for other safe methods so overheating the propellant can be avoided (Sanders).

"Lunar Prospecting: Searching for Volatiles at the South Pole" is the second article that talks about the Resource prospecting mission and the challenges that it will face during the lunar exploration. This operation is different from previous space exploration as its success will open a gateway for future human missions on Mars. Apart from that, the project will also include permanently shadowed regions (PSRs) of the moon to analyze the type of volatiles that may be present in these areas. PSRs have not been touched by sunlight for millions of years, and not only are the temperatures below freezing point but also the environmental factors are unknown. The data will be collected using real-time sciences, which will allow real-time scientists to make decisions accordingly.

The biggest challenge is going to be PSR exploration as the absence of light will only provide 6 hours of exploration, which is an estimate as the environmental factors may reduce this time. The regolith of the PSRs may collapse under the weight of the rover and may be too loose for the rover to drive on it properly. The texture of the regolith also needs to be taken into consideration, as it may damage the wheels of the rover. For rover egress, a minimum of 20 per cent battery must be left so that it may safely return. After its return, it will need 24 hours to recharge, meaning this time would be non-productive. For this reason, the PSR exploration will be carried out at the end so that the time is used efficiently.

Efficient time utilization is extremely important as time lost can increase the cost of the mission, and it should be utilized to maximize its success. To address this, parallel operations will be carried out, such as prospecting, collecting and processing. All the operations of the mission will be monitored in real-time, which will be highly beneficial when exploring PSRs. This will allow the scientist to select a safe path for the rover and change any plans or decisions in real time. Exploring the PSRs will be the biggest challenge for the RP mission as there will be time constraints as well as unknown environmental factors.

This mission requires a lot of formulations and simulations of real-time science, limited waypoint driving and basic science operations. This will allow for proper operation planning and improving the designs of the prospecting operations. While numerous challenges will be faced during the RP mission, the success of the mission will open up doors to future human missions on Mars that have not been possible yet. The Lunar South Pole is going to aid in this as it is suspected to be the site for abundant resources and water ice. The shadowed areas have cold traps that contain fossil records of numerous volatiles, hydrogen, and water ice. These resources will aid in longer explorations in the future (Trimble and Carvalho).

Article three, called “Ionic Liquid Facilitated Recovery of Metals and Oxygen from Regolith”, discusses the importance of the regolith in harvesting the resources. Regolith is the layer of consolidated solid material covering the bedrock of the planet; for instance, the soil is the regolith of the Planet Earth. Many useful resources, like aluminium, silicon, oxygen, iron, etc., can be extracted from the regolith and used to repair satellites and rovers. These elements are also necessary for ISRU utilization by recycling these metals using the electroplating process.

For instance, nickel-chromium alloy, a metal-like element found in iron meteorites, is utilized to heat other elements. It is a heat-resistant substance and can be used in building different structures. A sheet can be formed by recycling and electroplating the nickel-chromium alloy. This sheet can then be used as thermal protection against the sun and to avoid the corrosion of the material. Metal is recycled using electrolysis using the Bulk electroplating process. However, there is a disadvantage to this process. The disadvantage is that electroplating requires a constant flow of uninterrupted heat, which means that it cannot function properly in shadowed areas, and the metals depend on this process. The alternative to this method is the use of ionic liquids, which can help shape metals at room temperature. The regolith collection poses a challenge as it is found in highly stable oxides, so to process these elements, they must be recovered back to their original and pure form. This will be disadvantageous to the RP as they require a lot of chemicals to produce heat and energy to achieve this final pure substance.

The article represents the data collected using the ionic liquids process, which was used to recover metal from an acidic aqueous solution and demonstrated at room temperature. In addition to this, successful regeneration of the Ionic Liquid reagent was observed, proving that this process was well-suited for long-term explorations. This process will allow for the metals to be recovered and used on-site to fulfil the needs of the mission in time. The regolith is mainly composed of metal oxides, which can be a very beneficial resource for metals like iron, aluminium and nickel. Oxygen can also be separated from these metal oxides and utilized in life support systems. The metals obtained from the metal oxides can be used for repairs and infrastructure (Karr et al.).

Question 2: How does “real-time science” influence the path and the timing of the planned operation system of the lunar rover? Resource Prospector, to prospects, collect and process in-situ resources on the Moon?

“Real-time science” means the capability of decision-making at the exact moment as the operation is being carried out. It allows the scientists to make decisions and change plans as the mission is being carried out, minimizing the margin of error and maximizing the success of the mission. Real-time science provides real-time information regarding the environment, which allows the scientists to

analyze the data while managing the mission. This ability will allow the lunar exploration of the Resource Prospector to be more efficient than the other explorations done in the past. The rover will receive the data by communicating through X-band radio waves of the orbiters, while the information will be received on Earth through the Deep Space Network (DSN). The authors of the article explain in detail the procedure through which the RP mission will be carried out. The scope of this mission is much wider than the previous missions as the Permanently Shadowed Regions are also included in this mission.

The Resources Prospector (RP) mission is a technological demonstration that aims to explore and examine volatiles that are present at the Lunar South Pole. This mission presents many challenges as the region being explored includes an area that is permanently in the shadows. These shadowed regions will pose unseen challenges that would require real-time decisions and solutions. The regions will be explored using solar-powered rovers, and one of the challenges will be power and thermal management, as the temperature in this area will be frigidly cold. In this case, real-time decision-making will help in selecting the path for safe entry and exit (egress). This mission will require high efficiency and faster rover egress as the area being explored will be challenging and different from previous missions (Trimble and Carvalho).

The RP mission is designed to develop a deeper understanding and fill in the gaps in our knowledge that will allow for better planning for future space missions. These gaps are called Strategic Knowledge Gaps (SKGs), which will allow humans to design and plan for human missions on Mars. The technology is being tested on the moon as it is closer to the Earth and will decrease substantially while allowing us to prepare for the challenges ahead. The Lunar Exploration Analysis Group (LEAG) will work towards determining the following SKGs:

- The physical geography and accessibility of the cold traps
- The concentration of the volatiles across the surface is 1-2 meters.
- Water concentration variables
- The makeup of the volatiles
- Traffic-ability of the lunar surface

The most conclusive data collected regarding the lunar volatiles was done at the Lunar Crater Observation and Sensing Satellite (LCROSS) impact site. However, the distribution of lunar volatiles at permanently shadowed areas and their spatial distribution have yet to be determined. For this purpose, prospecting is necessary, which is the ability to move, sense volatiles and access them.

Exploration of permanently shadowed regions (PSR) is the primary mission of this exploration; however, as previously stated, the PSRs are one of the coldest regions in the entire solar system due to not being exposed to sunlight for millions of years. This means that the properties and the behaviour of the regolith are unknown. It may collapse under the weight of the rover or the surface, causing much damage to the rover and resulting in a driving hazard, and the wheels of the rover may also sink in if the regolith is loose. These are some of the anticipated behaviours that would need to

be tackled in real-time. The biggest issue will be the lack of solar energy, which will limit the operation time to six hours only. The environmental factors will slow down the progress of sample collection, so it is extremely important to have real-time management capabilities. Apart from that, the rover is required to have at least 20 per cent battery after its egress from the PSR, and it will take 24 hours to recharge it. The priority of the mission is a low-risk activity. For this reason, the PSR explorations will be conducted at the latest as this will allow the sample collection from less unpredictable areas without any unforeseen outcomes.

The mission is planned to maximize efficiency and minimize non-productive time, which means any time lost, not prospecting, collecting, or processing. This lost time also includes time spent charging the rovers. Parallel operations will be carried out to optimize the performance, and all the data will be analyzed in real-time. The operations are divided into three tiers, which include reactive, tactical, and strategic operations. Real-time science operations will be carried out during the calibration and checkout; this will maximize the productive time.

Egress means “the action of leaving a place”; it is one of the most challenging stages of the missions, as the history of previous explorations has provided evidence. The estimated time may vary greatly from the actual time spent during the exploration. For this reason, selecting a safe path is of prime importance and real-time surveillance will be very beneficial in this endeavour. To make the rover egress within six hours, a new system is being designed; this will make the egress faster than the egress of previous missions. This will require new designs for the lander and improved operational procedures.

Real-time science will be greatly beneficial as the prospecting, collecting, and processing will be controlled as these are being carried out. Prospecting using real-time science will be beneficial as it will allow the scientists to quickly search for the area that holds the most resources while ignoring the areas that are not as rich in resources. Similarly, the collection process will be aided by real-time science, allowing for efficient collection of resources from the regolith. The real-time quality control of the resources collected will allow for maximum resource gathering, which will allow for more material acquired during the processing phase. This real-time data collection will allow for maximum surface time and efficient solving of any unpredictable circumstances. Real-time surveillance will provide the flexibility of selecting a safe path and scientific responsiveness and reduce any stress to rover drivers. A command simulator will allow the rover to quickly respond to short commands, avoiding any hazardous situations. The real-time approach includes taking stereo images of the distance up to eight meters and finding the waypoint about halfway across the field of view. While the commander of the rover will guide the rover through the safe selected path, another pair of images will be captured, downloaded, and processed.

This project is still in the formulation phase as the team is trying to work out obvious concerns before the launch of the RP mission. They were able to simulate the project, which included real-time operations, path selection, and some basic science operations. The data collected from these simulations have helped in the designing of the prospecting operations. Further simulations and pre-

mission operations will allow us to work out any challenges that may arise during the actual mission. This lunar exploration is expected to bring in more data for the study and understanding of space regolith and volatiles, as the scope of this mission is much wider than the previous exploration. The success of this exploration will open a path towards human missions on Mars, which will be an achievement of a lifetime. It will open up new prospects for space explorations in the future.

Question 3: Stated in Ionic Liquid Facilitated Recovery of Metals and Oxygen from Regolith. “An ionic liquid-based process to recover metals and oxygen from regolith has been developed and demonstrated that could make resupply of chemical reagents negligible.” In your own words, describe this closed-loop ionic liquid reprotonization process, and explain the benefits of this process to future space exploration.

Oxygen reduction is the process of separating the materials using extreme heat. During this process, it is extremely important to keep the flow of the heat constant so as to prevent oxygen from reacting in a regolith. The process requires the oxygen to be oxidized while the metals are being reduced. This is beneficial as it allows the elements to be acquired and utilized on-site. Oxidization of metals changes them into a state called metal oxides during exposure to oxygen. Oxidization reduction can be used to liquidize the ionic liquids (apart from sand), allowing the metal to retain its pure quality. Organic salts that are molten at room temperature are known as ionic liquids (IL).

The process of constantly reusing the chemicals by recycling the purity of the substance is known as a closed-loop, and it is a three-step process. The first step involves the digestion of metal oxides using an acidic ionic liquid. Metal is dissolved using electrochemical plating, which reduces the IL to its acidic state. It is then used to dissolve the additional regolith. For operations like mining and refining in space, closed-loop ionic liquid deprotonation proves useful in the harvest and refinements of precious materials. It is also helpful in the reduction of waste material to minimize weight in space. This helps extend the life of satellites, procure materials like platinum, and bring the collected material back to Earth.

In the article, the authors mention regolith, which includes solar energy sources and the application of cement for life support and groundwork. The metal sourced is extremely important for building livable structures and providing supplies for deep space expeditions and maintenance. Refining the metal in

a closed space using the common methods of refinement can be severely hazardous for the ship and its crew. This will also be a very expensive process to perform on a ship, so preparing a boundless supply and autonomous method of preparing raw materials for 3D printers in space using this method will be very beneficial.

Shipping the supplies and spare parts for rovers from the Earth can be very expensive, so the ability to produce these materials outside of the Earth will not only be phenomenal but also cost-effective. Using the metals found in the regolith to manufacture parts for the rover will extend its life, and repairs will be made on time without waiting for the supplies to come from Earth. The elements that are not present or difficult to find in space's regolith, like Nickel Chromium Alloy, can be recycled completely. Rovers are ideal for gathering resources and delivering them for different operations and uses. Breathable oxygen is regularly needed in space by the astronauts, and timely supply is extremely important for their survival. However, the oxygen produced through the IL closed-loop process can ensure that the crew does not run out of their supply. ISRU is a step forward towards the goals of sustainability and resource utilization on Earth (Karr et al.).

Work Cited

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