Moon Exploration with the Deep Space Gateway: Lunar Exploration

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Abstract— **This report outlines scientific experiments and missions that will be conducted on the lunar surface, using the proposed Deep Space Gateway as a launching point. Data such as surface radiation and soil composition will be gathered at multiple sites on the moon in preparation to build a future lunar base. Seismic arrays will be installed to map the internal structure of the Moon by way of measuring moonquakes. The infrastructure required to maintain these experiments is also presented. Various other prototypes will also be tested in preparation for manned missions to Mars. These include a large rover, which can act as a living habitat, as well as a 3D printer using surface regolith to construct habitable structures.**

I. INTRODUCTION

Although mankind has planted its flag there, the Moon still hides many secrets to be uncovered. Direct access to the lunar surface ended with the Apollo missions in the early 1970s, but with the Deep Space Gateway it will once again be possible to conduct scientific research on our nearest heavenly body. To ensure permanent accessibility to the surface, the first missions from the DSG will be scouting for a suitable location for a lunar base. There are several unknown factors that need to be determined before a permanent settlement can be established. Among these is the radiation that astronauts will have to contend with. Without any atmosphere, the Moon will not protect humans on it in any way. To that end, the missions planned will also be testing out new technologies which can be used to settle on other worlds. One example is a 3D printer which will use the regolith on the Moon to construct usable buildings on the surface. A lunar base can also be seen as a test bed for potential bases on Mars. The science and missions enabled by the Deep Space Gateway will pave the way for a deeper understanding of our nearest neighbor, and serve as a springboard into the rest of our solar system.

II. PROPOSALS

A. Amenities

Living on the Moon surface: This section describes the living situation of the exploration crew on the lunar surface in the transport vehicle. The LSS will not be discussed in this paper, since it is part of the Transport system.

Time (UTC)	Activity
00:00 - 08:30	Free Time
08:30 - 12:30	Work
12:30 - 13:30	Break
13:30 - 17:30	Work
17:30 - 23:59	Free Time

TABLE I: Daily Schedule

Table I shows the schedule for the astronauts on the lunar surface with a workload of 8 hours/day like on the ISS.

Most of their free time, astronauts will spend with sleeping. The Transport System is therefore equipped with three beds, which is kind of a treat for the astronauts otherwise sleeping in weightlessness on the DSG. To pass the rest of the time the Transport System will be equipped with similar entertainment as the DSG. From experience some free time might also be used to prepare or finish tasks, but with improvements in the schedule it will be tried to reduce this time.

When their work schedule requires an EVA the astronauts leave the Transport system through the airlock. It is designed so that no moon dust finds it way into the vessel. The astronauts climb directly from the pressurized cabin through the hatch at the back into their EMU. The airlock is not big enough to hold three suits next to each other. This can be overcome by only attaching one suit to the hatch and store the remaining two on the sides of the airlock. The first astronaut to climb into his EMU then has to attach the next suit to the hatch. At the end of the day the procedure repeats just the other way around. The EMUs used for the lunar exploration will be described in the next section.

Spacesuits: The astronauts use two different space suits. During the transport phase the new Starliner Launch suit, pictured in figure 1, is used for safety reasons. It's a lightweight, 10 kg, pressurized suit, costume made for each astronaut.

Fig. 1: New Starliner suit [16]

For EVAs on the Moon astronauts use the Z-2 spacesuit, see figure 2. With its hatch at the back it is easy to put on, which will be used in the airlock, as described above. It's lighter than current EMUs only weighing 65 kg and should come with enough power to last for the full 8 hours of a work day, plus some spare time. This requirement is derived from current EMUs used on the ISS. Similar to these it should also host a rechargeable battery with 850 Wh. The batteries, oxygen and water tanks can be recharged "over night" in the airlock, CO_2 will be transferred to the vessels CO_2 tank and recycled on the DSG.

Rover: This section describes the rovers used for faster crew transport on the lunar surface.

- Lunar Rover (Apollo)

The Lunar Roving Vehicle (LRV) is a small 210 kg rover which allowed the crew of Apollo 15-16-17 to explore the lunar surface around their landing sites. It can carry a payload of 490 kg and can travel at least 36 kilometers (distance crossed by Gene Cernan and Harrison Schmitt, Apollo 17, in 1972) at 8 km/h. This easily transported rover is

Fig. 2: Z2 space suit [15]

brought for almost every mission described later. [10]

- Martian Rover

The program is an opportunity to test a new prototype developed by NASA: the Mars Rover Concept. It can be manned with 3 astronauts and is pressurized. It is powered by solar panels and can run at 10 mph [8]. It includes an on-board laboratory, and weighs 2500 kg.

Fig. 3: The Mars Rover Concept [9]

B. Experiments

Standard Mission Box: The Standard Mission Box (SMB) will contain a compact, self-sustaining platform for scientific experiments to be performed on the lunar surface. Apart from the actual experiments, the SMB also holds a communication system, to transmit the scientific data back to the Deep Space Gateway, and thermal control modules, to keep sensitive electronics alive during the cold lunar night. Finally, the SMB contains solar panels which will power all electronics in the package. The total mass of the SMB is 156 kg, and all components will require about 160 W of power. While on the lunar surface, the astronauts will unpack the SMB and set all of the experiments and infrastructure up. Once active, the platform will collect and transmit the data automatically, without any required input from the crew.

1) Scientific Experiments:

Radiation Detectors: Measuring the radiation at the lunar surface is a high-priority task since it is yet unknown what type of radiation dose astronauts would face if staying on the Moon for a longer period of time. The 3 types of radiation detectors included in the SMB are all tested technologies, and a couple have already been deployed on the ISS. The first instrument, the Compact Tissue Equivalent Proportional Counter (C-TEPC), will measure the total radiation dose that biological tissue will absorb at the lunar surface [23]. The Radiation Area Monitor (RAM) is a compact and lightweight next-generation personal dosimeter that astronauts will wear at all times to make sure they do not exceed the maximum allowed dose [24]. Finally, the Radiation Assessment Detector (RAD) will detect high energy particles incident on the lunar surface [25]. The power-mass budget for the radiation instruments can be found in the Appendix in Table III.

Seismic Arrays: Another important experiment that will be conducted is the mapping of the internal structure of the moon. By using regularly occurring "moonquakes", seismic arrays will be able to continue the research started by the Apollo missions, where they placed out individual seismic detectors. The seismic arrays will be able to gather a more complete picture of the Moon's interior. Each array will be made up of 9 cells, and each cell weighs 11.5 kg and requires 5.85 W of power [27].

Soil Sampling/Mass Spectrometer: The sampling of Moon soil is inspired by the Apollo missions, but will be executed on a slightly bigger scale, as those brought back less than 500 kg. Also astronauts will collect material from more different spots around the Moon. The composition of the soil can reveal

With an advanced version of the drill used in the Apollo program, see figure 4. It weighs 15 kg and with its 500 Wh rechargeable battery the drill can be operated for one to two hours, to reach depths of more than 10 m to investigate the Moons crust 4.

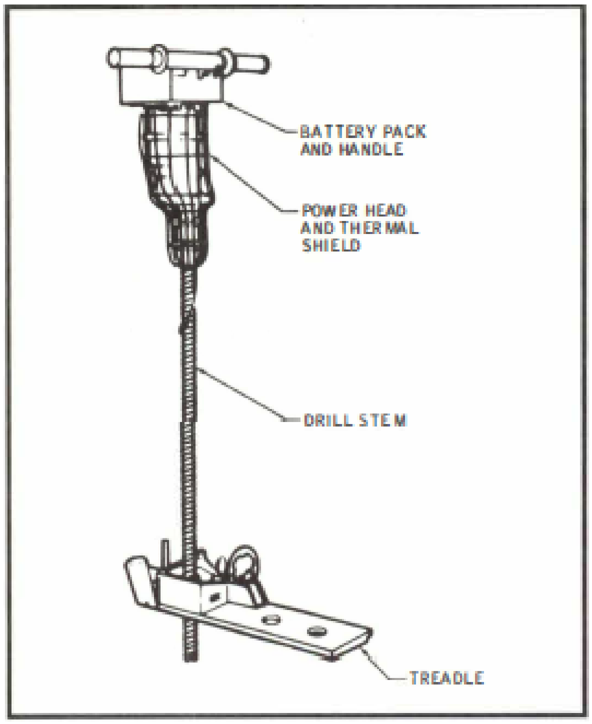

Fig. 4: Apollo Drill [17]

Living Box Experiment: The Living Box Experiment (LBE) is a self-contained incubator that attempts to grow various types of plants, especially of the edible kind. NASA already has one on the ISS to see how plants are affected by the micro gravity environment. The same tests should be performed on the lunar surface to gain a better understanding on how growing food on the Moon would work. The flight proven box on the ISS weighs 100 kg, and required 735 W of power [26]. The high power requirement means that it is not suitable for the SMB, but could be included in the Martian rover prototype, as it will be able to generate the required power. The environment inside the rover is also more suitable, since any potential lunar greenhouses would require a pressurized environment anyhow.

2) Infrastructure:

Communication: The communication system will be based on a system proposed by a team from Carnegie Mellon University [12]. It will provide a data rate of 7.5 Mbps to the DSG to transmit the scientific data gathered by the experiments in the SMB. The primary antenna is a phased array antenna dish 55 cm in diameter. The 683 individual radiating elements on the phased array will provide a natural redundancy since any individual element could fail and the array would still function normally. This antenna will transmit in the X-band at a frequency of 8.495 GHz, and will require 90 W for a 12 W transmit power. If the entire primary array should fail however, a couple of backups do exist. First, there will be a connection to the prototype Martian rover that will be landed on the first mission. The rover can act as a relay, beaming up the data from the SMBs around the planet. This system will use the UHF spectrum. Finally, if all else fails, there will be an omni-directional antenna in place to be able to receive instructions from the DSG and/or Earth in emergencies. This will only be used while the astronauts are still on the surface, and can not be used to transmit data back to the DSG.

A complete breakdown for the power-mass budget of the communication system can be found in the Appendix.

Thermal Control: The temperature can vary drastically between the lunar day and lunar night, so reliable thermal control will be required to make sure that the sensitive instruments and electronics are not ruined by the heat or cold. Lunar Mission Survival Modules (MSMs), developed by JAXA, will be used to maintain a temperature range of 0-40 C [13], which is the normal operating range for regular Commercial-off-the-Shelf (COTS) electronic circuits. A module is able to keep the internal volume within normal temperature range for the entire two week lunar night using only 0.4 W to power internal heaters. This means that just a few batteries will be required to keep the entire SMB platform alive during the lunar night, where instruments otherwise may have frozen and destroyed.

Power:

- Solar arrays To power all of the instruments and infrastructure, a total of about 160 W will be required. Upgraded X4/X5 flexible type solar panels are chosen to generate the necessary electricity. These triple-junction panels have a power/mass ratio of 136 W/kg, and an efficiency of 28% [14]. 2 kg of solar panels will be included in the SMB for a total capacity of 272 W. The extra capacity is necessary to recharge the batteries for the lunar night and for redundancy.
- Batteries: The energy coming from the solar panels is stored in batteries for a constant power and stable utilization. The chosen model is developed by Bixpower [21]. It is a 6 kg box which supplies 1044 Wh at 36 V. This box powers thermal heaters (requiring 0.4 W) during the lunar night, and supply all the required power for the SMB devices, during 6.5 continuous hours of idle solar panels (night).

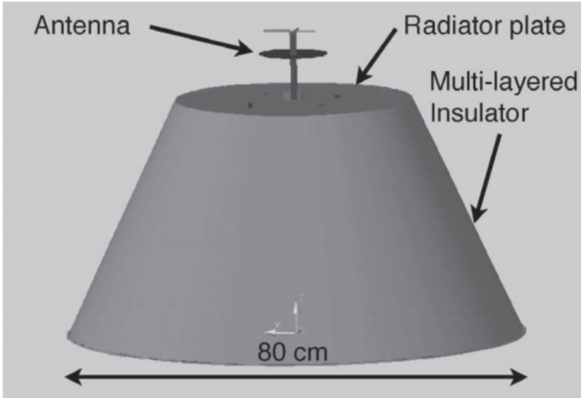

Fig. 5: Mission Survival Module [13]

C. *Missions*

Introduction

Mission 1: Apollo retrieval: The very first moon landing of the mission will have a significant symbolic impact. Visiting again the Apollo 11 landing site fulfill that objective. Moreover analyzing how the Apollo descent vehicle has aged will yield precious information on the long term effect of the Moon harsh environment. Studying the abrasive effect of Lunar dust and radiation on equipment is a prerequisite for future long lasting mission to Mars. To make sure that the Apollo 11 landing site will not be damaged, the landing will occur at a secure distance. The final approach will be performed using a small electric rover (Apollo type), carrying both scientific equipment and the astronauts. The first mission will also need to check the communication system based on a relay satellite.

Mission 2: The Search for Water: The second mission will take place at the Shackleton Crater (South Pole). The Shackleton Crater has a significant scientific interest. In fact the peaks along the crater rim are exposed to almost continual sunlight, while the interior is perpetually in shadow. The low-temperature interior of this crater make ice water presence possible. Measurements by the Lunar Prospector spacecraft showed higher than normal amounts of hydrogen within the crater, which may indicate the presence of water ice. The exploration mission will lend in a sunny part of the rim to be able to use solar panels. Further exploration of the crater to look for solid water and methane will use the Mars Rover Concept. The exploration trip will last maximum 8 hours before returning to the lunar lander. Parking the rover next to the LM in a sun exposed area allows battery refilling with solar panels. The large rover will be equipped with an autopilot so it can further continue the exploration after the Astronauts departure as well as being reused for the future landing at the Shackleton Crater.

Mission 3: Lunar Base Scouting: Alphonsus Crater is rated one of the most interesting locations for lunar scientific research and potential lunar base sites, this mission will simply consist on deploying the standard mission box. The main objective is to land radiation detectors to determine what radiation environment astronauts would face at a future lunar base at the site. Seismic arrays will be used to map the interior of the moon.

Mission 4: At the edge: The Mare Orientale is suspected to be the most recent impact basin. Therefore it has the thinnest basalt layer of all Mares. It also has a mass concentration, or gravitational high already confirmed by multiple spacecrafts. Therefore it's a geologically interesting spot for the composition of the Moon and its recent history.

Mission 5: The first lunar base: Advantages of building a proper and lasting infrastructure on the lunar surface are multiple : possibility to make longer missions, reduce fuel consumption, test technologies for a mars colony, add security in case of failure of the transport system.

The goal of this mission is to build a permanent outpost on the rim of the Shackleton crater, because of an almost constant exposure to sunlight and a possible presence of water.

This infrastructure must shelter both the astronaut and the scientific instrumentations from the lunar environment which is characterized by deep vacuum conditions, strong temperature gaps radiations and micrometeoroids. In order to achieve these requirements and based on the study made by ESA [2], a 3D printed outpost which exploits the dust covering the lunar surface, the so-called regolith, has been chosen. As a matter of fact, such a lunar base has :

- An efficient radiation shielding achievable thanks to a sufficient wall thickness (which also protects from micrometeoroids)
- No big infrastructure transported from Earth
- Maintenance and modifications relatively easily made compared to other construction methods

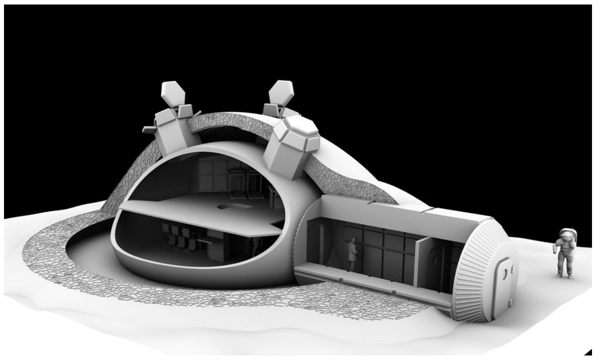

Fig. 6: Example of a lunar outpost [22]

The outpost is composed of two parts (Fig. 6):

- an inner inflatable module to provide a 40 m^3 pressurized and breathable environment. The structure have a height of 5 m and contains two levels.
- an outer part "printed" with Moon regolith using the D-shape technology, a three-dimensional printing system.

The lunar outpost will have a wall thickness between 1 and 2 m to keep the total radiation dose over one year within a reasonable level and to protect from micrometeoroid for at least 10 years. To make it, a binding ink is spread in the lunar soil and interacts with metallic oxides that compose it. It enables to start a crystallization process that links the small grains of regolith and thus creating a solid wall, an artificial double magnesium-carbonate sand stone. This liquid binding solution is composed of 23 % of dry salts (density of 1.6) and 77 % of water.

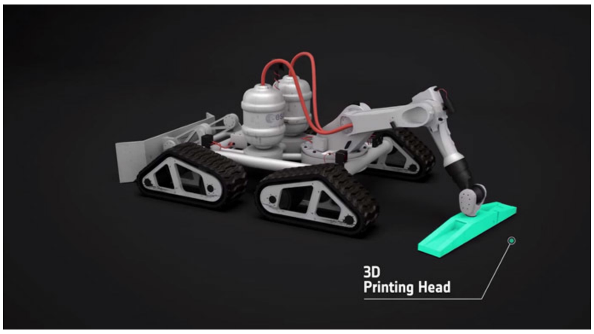

Fig. 7: Design of the 3D printer [22]

Because the regolith can be used without any additional milling or sieving, the printing system must only ensure that the powder is well packed and that the ink is directly put inside the regolith. For now, the D-shape technology is quite huge (6m $\times$ 6m $\times$ 3m) [3], but a more suitable and economical solution will consist in adopting a small 3D printer (around 2 m wide) equipped with wheels (Fig. 7). It will be supported by another small rover that will collect and pack the regolith. They will be powered by batteries of around 500 W that need to be charged thanks to solar panels.

All in all, the inflatable inner module (1.5 tons), the dry salts (3.8 tons), the water (12.7 tons but in future missions, water could be extracted from the moon or recycled from human waste) and the 3D printer (1.5 tons each rover) must be brought to the surface.

From these numbers, and if we compare to the capacity of the transportation system (4 tons and around 4 m^3), several missions are required. However, because the construction of the outpost will also take several months, water and dry salt can be brought in small quantities each time a mission is sent. In total, it's estimated that 7 missions are required (see Table II). The first step will consist in bringing the printer and the rover, that can be stored inside the transportation system. The next step will be to send the inflatable structure. Finally, 5 missions will send binding ink into small containers supposed to weight 1 % of transported mass. Rovers will be automatically driven, but a manned presence is needed to control the progress, refill the binding ink tanks of the rover, change the batteries and repair malfunctions.

Mission 6: Understanding of recent history of the Moon: Copernicus crater is supposed to be one of the most recent craters of the Moon, as it would have been created one billion years ago. Its age was estimated with analyses of some photos, especially by measuring the paths of "rays" coming from sand blast due to the collision with the meteoroid. Actually these rays fade with time. It was for instance concluded by Gene Shoemaker and Robert Hackman [6] that the Copernicus crater is younger than its most nearby (Erastothenes crater) because the rays of the former completely covered the ones of the latter.

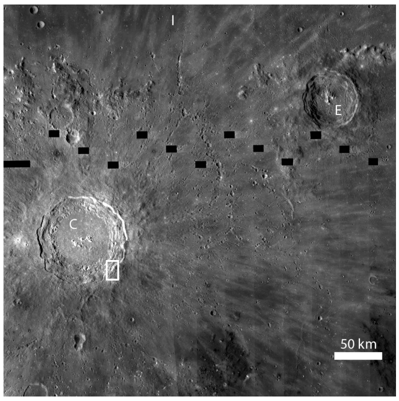

Fig. 8: Photography of Copernicus & Erastothenes craters [6]

Note: The Copernicus crater is on the left, the Erastothenes crater is on the right of the picture. The rays are clearly visible.

That is why it has been a reference location for lunar stratigraphy [6], which consists of the study of the different geological eras associated to a terrestrial or celestial body. The main difficulty, tackled in the NASA article, is that the scientists do not have at their disposal a set of geological samples to study the lunar stratigraphy. That is why planning a mission to Copernicus crater could be of great interest for geology: actually, understanding the geological history of the Moon could lead the scientists to understand better the history of the Earth!

The planned mission would be a "normal" exploration mission, which does not require particular equipment, apart from the Standard Mission

Box (SMB) containing tanks to bring back the samples, and seismic arrays to study the seismic activity of the region. A small 210-kg Apollo Rover would allow the crew to visit the crater [10].

Mission 7: Back to Shackleton, searching for Water: A crew is back to Shackleton crater, where the lunar base is. Their goal is to explore further the region, searching for water. They go around the rim of the crater, and use some optical devices (such as spectrometers) hopefully to detect a characteristic piece of evidence that there is water at the bottom. In that case, they either send a robot that could probe the bottom of the crater (4 km deep), or try to climb down at least a few dozens meters to enhance their sounding.

Mission 8: Understanding of the deep geological structure: On the Earth, we are thankfully very rarely confronted to asteroid collisions, and the collisions that could occur in the past did not leave scars on the Earth (erosion due to terrestrial weather). On the contrary, on the Moon, many craters resulting from a collision with an asteroid are clearly visible, even from the Earth. One of them, which is called Bullialdus crater, located in the Southern hemisphere of the Moon, is of particular interest [7].

In fact, many peaks are located at its center (it is called a complex crater), and could be testament of an excavation of material from the deep structures of the Moon, resulting from the collision. Some geologists could explore the central area of the crater and study the geological composition of these peaks. Some spectroscopic analyses of the crater have already been done, and showed that the surface of the crater is composed of different types of rocks, which makes a possible exploration even more essential and thrilling! It could allow the astronauts/geologists to understand the deep geological structure of the Moon, and from a more general perspective, understand the circumstances of planetary formation in the Solar system.

The explorers could take benefit from the relative proximity of this crater with the lunar South Pole and the Aitken Basin (2000 kilometers) where the lunar base is located, and make the Mars Rover Concept profitable. It could be programmed to get to Bullialdus crater, and the travel duration would be around 5 days [8], at an average speed of 10 mph. The astronauts could therefore benefit from the pressurized environment and the on-board laboratory.

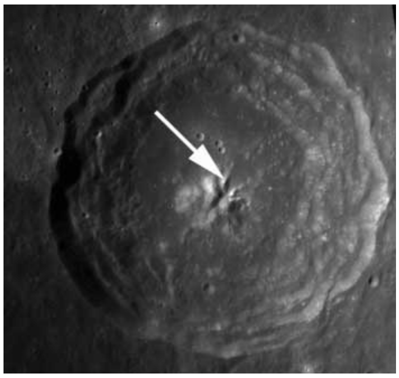

Fig. 9: Photography of Bullialdus crater [7]. Note: the arrow shows the central peaks.

Similarly to Mission 7, this mission is a "basic" exploratory mission, whose aim is basically to collect samples. The Standard Mission Box (SMB) is to be deployed, notably allowing the scientists to measure the seismic activity of the area.

Mission 9: Water extraction: Mc Govern et al. [4] determined that 17,698 km^2 of the lunar surface in the southern hemisphere is permanently shadowed. If the regolith contains as much water as measured by LCROSS in Cabeus (5.6 % in mass and the density of regolith is 1600 kg.m^{-3}), the theoretical water mass in the uppermost meter of this regolith would be 1.6×10^{12} kg. Extracting part of this tremendous water content could provide enough water for the lunar base (human consumption and perhaps for the 3D printing of other bases) but could also provide fuel through different processes. During the first phase of exploration, it is chosen to only focus on the water extraction, which is already a technological challenge. The water extraction will likely take place in the Shackleton crater, if water have been identified in mission 2 and 7. It will provide water for the lunar base built in mission 5.

To dry the icy soil, regolith must be heated and it will be done thanks to a Mobile In-Situ Water Extractor (MISWE) [5], an integrated mobile mining and water extraction system (Fig. 10).

It uses an auger based excavation and an integrated water-ice extraction plant. The MISWE is powered by a nuclear device that can be ei-

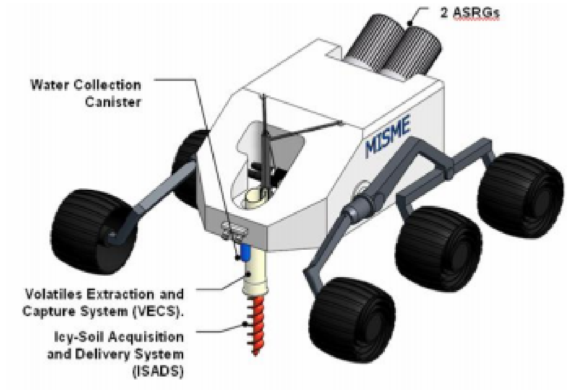

Fig. 10: Design of the MISWE [5]

ther an Advanced Stirling Radioisotope Generator (ASRG) or a Radioisotope Generator (RTG) which is used the MSL rover. MISWE has many advantages :

- It is automatically driven and is self heated thanks to its power generator : it can go on really cold shadowed surfaces such as Shackleton crater.
- Its conductive heating is simply implemented with resistive heaters
- It can work all day without any interruption (No recharge breaks)
- It does not need any requirements on the surrounding hardware (no need to be grounded)

ASRG power source generates around 350 W of heat and 140 W of electrical power during more than 14 years, with 1.2 kg of Plutonium, and weighs 32 kg. As designed, MISWE will use two of these power generators. They will also warm the electronics and power the communication, the data processing, the mobility system and the augers.

It is estimated that one MISWE can extract 5 kg of water each day [5]. Moreover, some studies show that the amount of water required - which includes water for consumption, hygiene, and everyday living in space - is 14.2 kg/man day [11]. If we consider a recycling system that recovers 90% of the water, like it is now on the ISS, extra water needed for a crew of 3 people each day is 4.26 kg. If we consider even more advanced technology, this recovering rate can rise up to 96%, which corresponds to only 1.7 kg of extra water needed per day. In either case, only one MISWE is sufficient but a second one can be sent later for more security and redundancy. Extra water can be used to make a binding ink for the 3D printing and/or fill a water container.

One MISWE can be sent at a time because it's around 2.5 m wide and weighs 2 tons. Moreover, because it contains nuclear power generator, the vehicle transporting it will be unmanned. During operation, ASRG are quite well protected (plutonium is stored in individual ceramic modular units, surrounded by a layer of iridium metal and encased in high-strength graphite blocks) and will represent a relatively low risk, even if some security rules must be adopted.

Mission 10: Observing deep space: Earthbound observation is limited by Earth atmosphere as well as man made light and radio pollution. That's why observatories on Earth are located in remote areas, such as ESO Very Large Telescope (VLT) in the Atacama desert in Chile, the Arecibo observatory in Puerto Rico or the Gemini observatory in Hawaii. Other famous telescopes as the Hubble Space Telescope and the Transiting Exoplanet Survey Satellite (TESS, launch in April 2018) are in orbit around Earth or in the case of the Kepler Space Observatory trailing Earth in a heliocentric orbit avoiding as much Earth and man made pollution as possible.

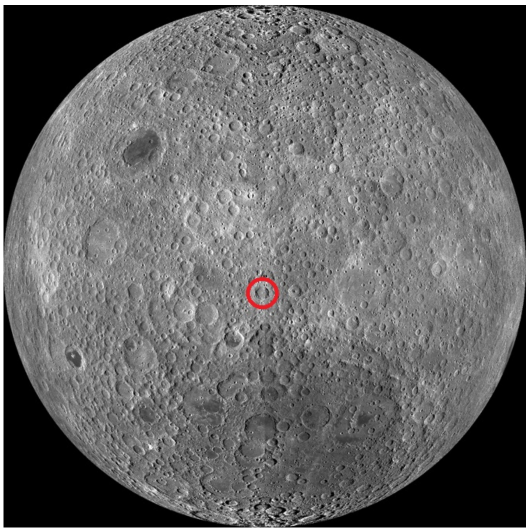

Fig. 11: Location of Daedalus crater on the far side of the Moon [20]

For more than two centuries some astronomers have envisioned an observatory on the far side of the Moon. This is where our tenth mission is set to go. The most promising location is said to be the Daedalus Crater. Due to its location on the very far side of the Moon and very close to the equator it is completely shielded from any radiation from Earth, satellites orbiting Earth and even satellites in the Lagrange Points 1,3,4 and 5 of the Earth-Moon-System. A satellite in L2 would be in direct sight of the crater. With a 3km high rim and a diameter of 100km the crater suits a telescope similar to the Arecibo observatory William E. Gordon-Telescope, see figure 13, only about 300 times bigger.

Fig. 12: Daedalus crater [19]

Fig. 13: Arecibo [18]

The second big advantage of this location is the absence of an atmosphere and thus its disturbance. But the missing atmosphere is not only an advantage. It also leaves the surface unprotected from solar radiation during the lunar day. These high radiation levels and moon dust are the biggest obstacles to overcome for the construction of a radio telescope in the Daedalus crater.

The mission for the astronauts here would be to explore the crater for the suitability of a radio telescope, take soil samples, measure radiation levels and maybe test materials and instruments under this kind of radiation exposure.

III. Results

A. Payload Mass Budget

Below are gathered the payload masses that are required for the different missions. The Transport Unit limited the amount to 4 tons. The value for each mission includes:

- 3 humans (roughly 200 kg)
- 6 spacesuits (3 EVA + 3 Starliner suits = 225 kg)
- the Standard Mission Box (156 kg) is only sent the first time the crew lands on a specific site
- a Small Apollo Rover (210 kg) [10], except for missions 5 & 9, because they already require a high payload. Mission 5 does not require any exploration of the area. The MRC is used for Mission 9.

The LSS is not included, as it has already been considered by the Transport Unit.

Mission	Payload Mass (kg)	Payload Power (W)
Mission 1	791	157
Mission 2	3341	100 000
Mission 3	791	157
Mission 4	791	157
Mission 5	3425+1925+5×3758	1000
Mission 6	791	157
Mission 7	425	-
Mission 8	791	157
Mission 9	2×2000	560
Mission 10	791	157

TABLE II: Payload Mass/Power Budget

A detailed version of the table is available in Appendix.

B. Power Budget

A detailed version of the table is available in Appendix.

IV. Conclusion

The opportunities that the Deep Space Gateway opens up are immense, and this report touches on some of possibilities on how the DSG can be utilized. In addition to the scientific advances, it can also be used to encourage more private investment into space and space-related technologies. If resources, such as water, are discovered on the lunar surface, it could be a boon to the budding asteroid mining industry, and a way to bring public and private groups together to build scientifically and economically profitable ventures in space.

APPENDIX

Instrument	**Mass** (kg)	**Power** (W)
C-TEPC [23]	0.25	0.5
RAM [24]	0.01	-
RAD [25]	1.5	4.2

TABLE III: Radiation Detectors Power-Mass Budget

Component	**Mass** (kg)	**Power** (W)
Primary Phased Array	12	90
Transponder	0.75	5
Martian Rover Link	0.75	1
Omni-Directional Antenna	1	10*
Total	14.50	96

TABLE IV: Communication Power-Mass Budget [12]
∗ not used unless primary array fails

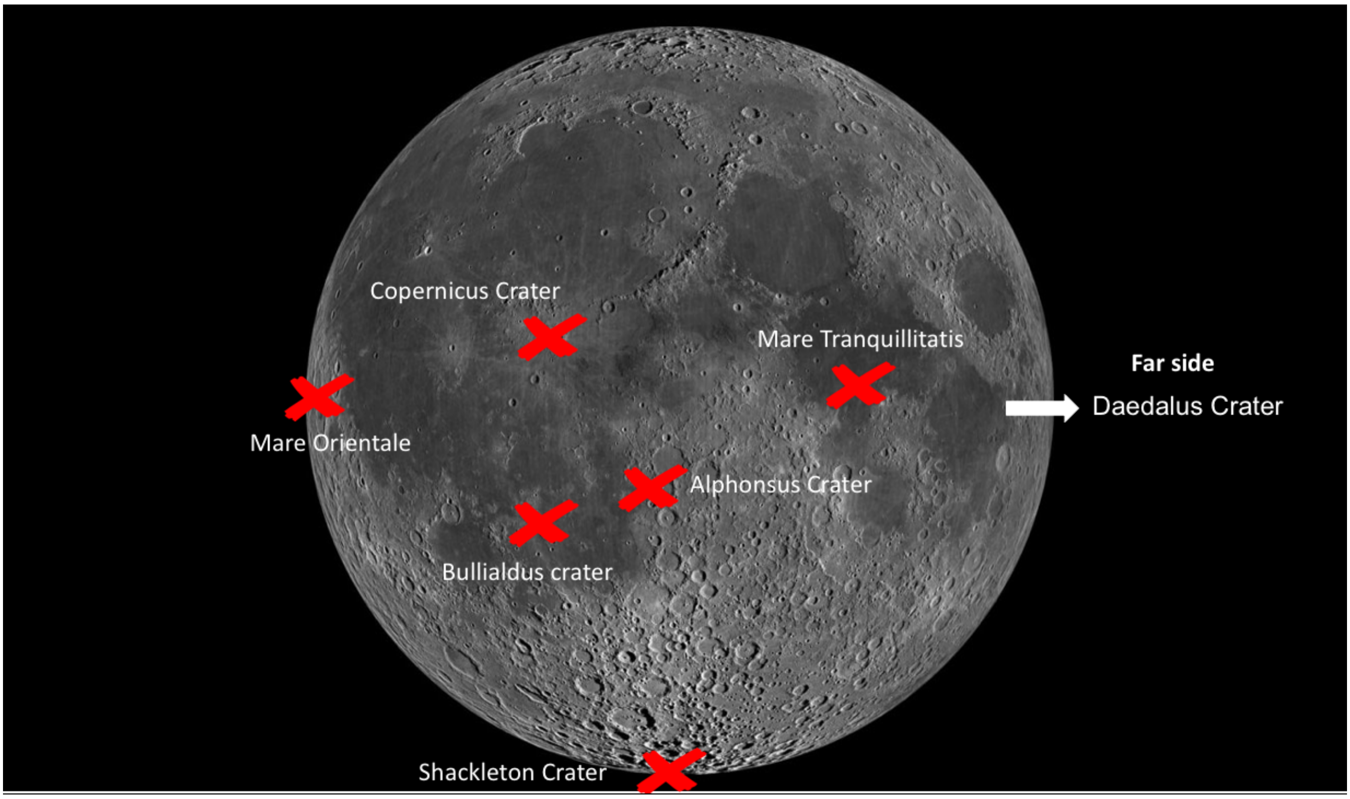

Fig. 14: Lunar landings map for the different missions on the near side

Mission	Paramater	Mass (kg)	Comment
Mission 1		**791**	
	Crew + Spacesuits	425	
	Standard Mission Box	156	
	Small rover	210	
Mission 2		**3341**	
	Crew + Spacesuits	425	
	Standard Mission Box	156	
	Small rover	210	
	Mars Rover Concept	2500	
	Advanced Plant Habitat	50	
Mission 3		**791**	
	Crew + Spacesuits	425	
	Standard Mission Box	156	
	Small rover	210	
Mission 4		**791**	
	Crew + Spacesuits	425	
	Standard Mission Box	156	
	Small rover	210	
	Gravitational Sensors	-	
Mission 5		**24140**	Mission box and rover already there
Mission 5.1		**3425**	
	Crew + Spacesuits	425	
	Printer + pack rover	3000	
Mission 5.2		**1925**	
	Crew + Spacesuits	425	
	Inflatable structure	1500	
Mission 5.3 to 5.7		**3758**	
	Crew + Spacesuits	425	
	Water	2540	2.5 m^3
	Dry salt	760	1.2 m^3
	Containers	33	
Mission 6		**791**	
	Crew + Spacesuits	425	
	Standard Mission Box	156	
	Small rover	210	
Mission 7		**425**	Mission box and rover already there
	Crew + Spacesuits	425	
Mission 8		**791**	
	Crew + Spacesuits	425	
	Standard Mission Box	156	
	Small rover	210	
Mission 9		**4000**	Mission box and rover already there
Mission 9.1 and 9.2		**2000**	
	MISWE	2000	Unmanned because of radioactive power generators
Mission 10		**791**	
	Crew + Spacesuits	425	
	Standard Mission Box	156	
	Small rover	210	

Fig. 15: Mass budget for the lunar exploration

Mission	Paramater	Power (W)	Comment
Mission 1		**157**	
	Intracommunication	Battery	
	Standard Mission Box	157	
	Small rover	Battery	
Mission 2		**~ 100 000**	
	Intracommunication	Battery	
	Standard Mission Box	157	
	Small rover	battery	
	Mars Rover Concept	~ 100 000	
	Advanced Plant Habitat	~ 1000	
Mission 3		**157**	
	Intracommunication	Battery	
	Standard Mission Box	157	
	Small rover	Battery	
Mission 4		**157**	
	Intracommunication	Battery	
	Standard Mission Box	157	
	Small rover	Battery	
	Gravitational Sensors	-	
Mission 5		**1000**	Mission box and rover already there
Mission 5.1		**1000**	
	Intracommunication	Battery	
	Printer + pack rover	1000	
Mission 5.2		**-**	
	Intracommunication	Battery	
Mission 5.3 to 5.7		**-**	
	Intracommunication	Battery	
Mission 6		**157**	
	Intracommunication	Battery	
	Standard Mission Box	157	
	Small rover	Battery	
Mission 7		**-**	Mission box and rover already there
	Intracommunication	Battery	
Mission 8		**157**	
	Intracommunication	Battery	
	Standard Mission Box	157	
	Small rover	Battery	
Mission 9		**560**	Mission box and rover already there
Mission 9.1 and 9.2		**280**	
	Intracommunication	Battery	
	MISWE	280	2 ASRG : 140 We / 350 Wt each
Mission 10		**157**	
	Intracommunication	Battery	
	Standard Mission Box	157	
	Small rover	Battery	

Fig. 16: Power budget for the lunar exploration

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