Eight Days in Inner Space:
My Experience at the Moon Desert Research Station

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Abstract—The author spent the week from February 28 through March 7, 2006, at the Mars Desert Research Station (a.k.a. "Moon Desert Research Station", or "MDRS", for the duration of the Moonbase simulation) near Hanksville, Utah, as a crewmember for the first Moonbase mission simulation (hereafter referred to as "Artemis Moonbase Sim 1" or "Moonbase Sim 1") conducted at that site.[1,2]

Figure 1: Mission patch for Artemis Moonbase Sim 1.

This paper reports selected crew activities and experiences during Moonbase Sim 1, summarizes data from the author's research projects on water reclamation, spacesuit biomechanics, and crew time allocation, and makes recommendations for future efforts in both simulation and actual mission preparation.

The author's primary research project on water reclamation involved installing flow meters and performing various water tests in order to evaluate usage rates and quality of the water used by the crew. Used (gray) water draining from the sinks and shower in the crew habitat module is routed through PVC pipes into the GreenHab, which consists of a series of aerobic and anaerobic water tanks, filters, and a UV treatment device, all housed in a greenhouse-like structure next to the MDRS habitat module. Flow meters measure gray water flow rates coming into and going out of the GreenHab. The water data collected during the Moonbase Sim 1 are summarized in the paper, along with recommendations for further developments in water reclamation systems.

Some of the projects undertaken by other crewmembers include a study on color differentiation within a substantially monochromatic environment, the development of a virtual reality tour of the MDRS and local environs, a crew psycho-social survey, and the development of an "Early Space Frontier Diet". Results of these projects can be reviewed at this website address: www.marssociety.org/MDRS/fs05/0311/sum.asp

Finally, this paper offers observations and recommendations in the areas of overall simulation design, system and equipment design, crew selection, personnel policies, and facilities requirements.

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1. INTRODUCTION

I recently had the opportunity to spend the week from February 28 through March 7, 2006, at the Mars Desert Research Station near Hanksville, Utah. The Moon Society had made arrangements with the MDRS directors to execute the first ever Moonbase mission simulation at that site (hence "MDRS" became "Moon Desert Research Station" for the duration of our stay), and I eagerly accepted the offer to participate as a crewmember.

Our Moonbase mission crew consisted of nine members with diverse areas of expertise including nutrition, software engineering, geology, land surveying, construction, journalism, nursing, human factors, and biology. The crewmembers are listed below in corresponding order (top to bottom and left to right) with each respective photograph in Figure 2:

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[1] 1-4244-0525-4/07/$20.00 ©2007 IEEE

[2] IEEEAC paper #1105, Version 10, Updated Feb. 13, 2007.

- William Fung-Schwarz – Human Factors/Health & Safety Officer
- Leslie Wickman – Crew Biologist
- Peter Kokh – Expedition Leader/Commander
- Laurel-Ruth Ladd – Executive Officer/Logistics
- Steven Winikoff – Chief Engineer
- Guido Meyer – Crew Journalist
- Chip Proser – Crew Videographer/Documentation
- Ben Huset – Crew Astronomer/Assistant Engineer
- Hugh S. Gregory – Crew Scientist/Project MAST Surveyor

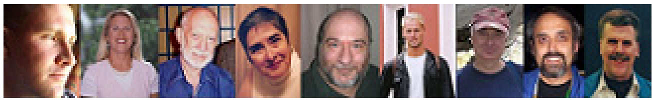

Figure 2: Artemis Moonbase Sim 1 crew photographs.

As anticipated in an actual mission, most crewmembers had expertise in more than one discipline. My role was to serve as the crew biologist, with the chief purpose of monitoring and adjusting the gray water recycling system. At the same time, I had the chance to pursue my various research interests in sustainable water reclamation methods, crew energy expenditure, and spacesuit technologies.

This paper describes selected crew activities and experiences during the Moonbase mission simulation, critiques the fidelity of the simulation, and makes recommendations for future efforts in both simulation and actual mission preparation. In addition, data from the GreenHab water reclamation project, the EVA suit range of motion study, and the crew activity study are also presented.

2. DISCUSSION

Excerpts from Moonbase Sim 1 Crew Biologist's Log

To give the reader a glimpse into some of the typical daily activities at the MDRS, I have included several entries from my daily log book:

2/27/06: Flew from Orange County, CA, to Salt Lake City, UT, to Grand Junction, CO. Stayed overnight at a hotel in Grand Junction for my last night on "Earth" prior to our Moonbase Simulation.

2/28/06: Traveled via rented SUV from Grand Junction, CO, to Hanksville, UT. As instructed by Mission Commander Peter Kokh, I checked in with the Mission Support Team Leader at the Whispering Sands Motel in Hanksville for a "pre-flight" briefing, before continuing on to the Artemis Moonbase at the MDRS.

3/2/06: Drove my SUV (aka, "shuttlecraft") to the Green River supply station for structural parts for Commander Kokh's tunnel project and plumbing supplies for the GreenHab project.

3/3/06: Crew Engineer Steven Winikoff and I tested the incoming GreenHab water meter, by disconnecting the line and drawing gray water directly from the settling tank into a calibrated bucket. The meter readings varied from one trial to the next, indicating that the meter is clearly inaccurate. The flow rate is probably too low for the design of the flow meter.

3/4/06: An extravehicular excursion with Health & Safety Officer William Fung-Schwarz and Crew Journalist Guido Meyer provided the perfect opportunity for me to spend the morning taking joint range of motion measurements for the Spacesuit Biomechanics Study. After lunch, we had a kind of "show and tell" session, in which we looked at lunar soil simulants and other potential lunar building materials. Later that afternoon we had a crew photo session. I was also able to collect more data in the GreenHab for the Water Reclamation Project. Great "fake lasagna" dinner tonight; hats off to our excellent chef, Laurel Ladd!

3/5/06: Today I analyzed water samples from the GreenHab. One thing that was immediately apparent is that the gray water treated in the GreenHab shows only slight improvements in quality compared with the gray water first entering the GreenHab.

3/6/06: On the road yet again! I needed more parts for the GreenHab project, and since Crew Astronomer/Assistant Engineer Ben Huset happened to be flying into Grand Junction today, I became the designated driver. We got back to the MDRS Hab just in time for dinner.

3/7/06: I finished up my work at the GreenHab today, then packed up my belongings to leave for Bozeman, MT, tomorrow morning for the 2006 IEEE Conference.

Water Reclamation Project

My primary research project at the Artemis Moonbase focused on evaluating the performance of the GreenHab water treatment system. This project is part of a larger research effort directed toward developing efficient, cost-effective, and environmentally friendly methods for reclaiming or regenerating used waste water to high standards of purity using low cost, low energy processes and locally available resources. The methodologies so developed are intended to help advance the goals of exploring the near-Earth solar system (i.e., the Moon and Mars, as well as Earth's extremes) by reducing the total amount of fresh water initially requiring transportation to the site. They are also intended to simultaneously minimize adverse impacts on the local environment (whether Earth, Moon, or Mars) by reducing the use of scarce resources, minimizing waste products, and recycling water along with other so-called waste products.

In addition to protecting and preserving the extraterrestrial environments of the Moon and Mars, these methodologies could be employed around the Earth within small remote communities (such as arctic bases, underwater research facilities, Earth-orbiting stations, or developing aboriginal societies) lacking adequate water purification technologies. These applications would certainly help in advancing existing and new technologies associated with human exploration, while at the same time improving upon the quality of life through the provision of safe and clean drinking and bathing water to space- and Earth-based peoples.


Figure 3: The author makes adjustments to the GreenHab water treatment system.

Research to date strongly indicates that by far the largest mass category of consumables for space exploration missions is water (and more specifically, wash water) [1]. If we fail to recycle water for space missions, large amounts of it will have to be launched from Earth on a regular basis, or possibly harvested from polar or ground ice to support the objectives of developing human bases first on the Moon and later on Mars. Either of these avenues would be pursued at great expense. A more cost-effective and environmentally friendly solution would be to reclaim and recycle both wash and drinking water to the greatest extent possible in a closed loop life support system cycle. This regenerative approach would help to preserve resources on both the extraterrestrial body as well as the Earth: consumables launch masses and frequencies would be reduced, with a concomitant reduction in the exploitation of natural extraterrestrial resources (such as water-ice and soil).

The elements of this study performed during Moonbase Sim 1 are as follows:

1. Observe the operation of the current GreenHab gray water recycling system.

2. Install flow meters and measure water usage rates.

3. Test water quality at input and output stages in the GreenHab system.

4. Recommend GreenHab upgrades.


Figure 4: Moonbase Sim 1 Commander Kokh displays his tunnel framework in front of the GreenHab entrance.

Gray water from the sinks and shower in the crew habitat module is routed through PVC pipes into the GreenHab water treatment system, which consists of a series of anaerobic and aerobic water tanks with aquatic plants, filters, and a UV treatment device, all housed in a greenhouse-like structure next to the MDRS habitat module. The system relies heavily on the activity of bacteria and other microorganisms in breaking down wastes into nitrates, ammonia, methane, and organic acids; on aerobic reactions which oxidize much of the remaining organic material; and on water plants housing protozoa and microinvertebrates that feed on bacteria and pathogens remaining in the wastewater. The filters, if properly maintained, reduce particulate matter, and the UV light treatment kills any pathogens remaining prior to returning the water to the habitat for re-use in the toilets.

Clean water usage in the sinks and shower is measured using a flow meter at the exit from the potable water supply tank. Water leaves the potable water supply tank on demand from the sinks and shower. As shown in Table 1, the average daily sink and shower water usage during Moonbase Sim 1 was about 11.7 gallons per crewmember. Crewmembers took an average of one shower every 5 to 6 days, with sponge baths in between.

Toilet water usage is determined using a flow meter measuring the flow of gray water leaving the GreenHab processing tanks on demand to the toilet water supply tank. The toilet was flushed an average of about 2 times per crew per day during Moonbase Sim 1, using an average of 5.8 gallons of gray water per crew per day.

WATER TYPE (source)	***water used per crew per day***
sink and shower (potable water)	***11.7 gallons***
toilet (recycled gray water; approx. 2.7gallons/flush)	***5.8 gallons***
COMBINED TOTAL AMT used per crew per day	***17.5 gallons***

Table 1: Summary of potable and gray water usage per crew per day for Artemis Moonbase Sim 1.

Figure 5: The author conducts tests on the GreenHab water treatment system.

Various tests of water quality were performed on the gray water draining from the sinks and showers in the habitat module into the GreenHab, first upon entering the series of GreenHab tanks, then again upon leaving the GreenHab system. These water quality tests include measures of pH, alkalinity, ammonia, nitrites, nitrates, dissolved oxygen, salinity, bromine, chlorine, copper, total hydrogen, CYA, odor, clarity, and particulate matter. The only significant changes between the pre-treated and treated water were qualitative improvements in odor (somewhat reduced), clarity (substantially increased), and particulate content (substantially reduced), with only barely detectable decreases in ammonia and increases in dissolved oxygen (a primary indicator of water quality). The GreenHab treated gray water at this point is only suitable for use in watering plants or as toilet water.

The slight decrease in ammonia indicates some microbial action, and the slight increase in dissolved oxygen indicates at least some photosynthesis is taking place. Nonetheless, the overall lack of efficacy in the GreenHab treatment system may be attributed at least in part to the consistently high alkalinity of the incoming gray water (in fact, the potable water source is itself quite alkaline). Alkalinity is an indicator of low carbon dioxide, which can adversely affect plant photosynthesis as well as microorganism activity in the processing tanks.

The functioning of the GreenHab water treatment system could be improved by addressing several major problems: high alkalinity, low dissolved oxygen, significant particulate matter, odor, and appearance. To that end, the following GreenHab recommendations are proposed:

1) Replace high-maintenance replaceable cartridge filter system with a wetlands/marshland style filtration system including stones, gravel, and sand

2) Add citric acid to potable water source to help neutralize alkalinity

3) Add acidic food waste (from fruits, vegetables, coffee, wine, etc.) to gray water through garbage disposal to neutralize alkalinity

4) Increase aeration of aerobic processing tanks to enhance oxidation of waste substances as well as growth of microorganisms

5) Ensure GreenHab trickling filter and bio-balls are fully functional to enhance aerobic processes

6) Introduce snails, algae, and fish to one or more of the open aerobic tanks to consume microbes and reduce biosolids

7) Substitute natural magnified sunlight UV exposure for higher maintenance UV shock treatment device

8) Add a solar still as the final step in the water treatment system to collect distilled condensate for drinking and cooking.

Spacesuit Biomechanics Study

A secondary research project, the EVA suit biomechanics study, involved taking range of motion measurements along with photographic documentation for a crew member first unsuited (in street clothes), then in the heavy canvas MDRS EVA Suit, and finally in a prototype tight-fitting neoprene "Mars-Skin" style suit (hereafter referred to as the Moonskin Suit). (Mars-Skin style suits now under development at MIT and other places around the world are based on physician Paul Webb's Space Activity Suit design from the 1960's. This type of suit applies mechanical counterpressure to the body via a tight fitting elastic garment, as opposed to the more traditional EVA spacesuits which provide a self-contained pressurized atmosphere, usually pure oxygen, within the suit.) These data are useful in comparing various spacesuit design strategies, and lead as well to recommendations for Moon and Mars spacesuit technologies.

Figures 6a and 6b show the author taking range of motion measurements with a test subject in first the canvas MDRS EVA Suit, and then in the neoprene Moonskin Suit. Fifty-four joint range of motion measurements were taken for each of the three attire options. These included movements in each rotational axis for the ankle, knee, hip, torso, head/neck, shoulder, elbow, wrist, and hand. Bending, kneeling, squatting, lifting, and climbing tasks were also evaluated. The range of motion measurements are displayed in Figure 9 below.

Figure 6a: The heavy canvas MDRS EVA Suit.

As was to be expected, for the vast majority of the 54 parameters, the unsuited joint ranges of motion were the least restricted, therefore the measured angular ranges were generally the greatest.

The Moonskin suit ranges of motion were superior to the MDRS canvas suit measurements in 30 of the measurements, and inferior in just 13 of the measurements. The Moonskin suit allowed greater ranges of motion than the MDRS canvas suit in the areas of shoulder flexibility, hand grip, and ankle flexion, as well as torso extension, rotation, and yaw.

The MDRS canvas suit offered greater ranges of motion than the Moonskin suit in 18 of the measurements, including head/neck rotation and flexion, as well as knee flexion. The MDRS canvas suit showed inferior flexibility to the Moonskin suit in 24 of the measurements.

The Moonskin suit generally showed greater promise of overall flexibility than the MDRS canvas suit, but since both the MDRS canvas suit and the Moonskin suit were generic "off-the-rack" sizes rather than being custom fitted to the crewmember, some of the differences in joint flexibility may be attributed to less-than-optimal anthropometric fit on the test subject's body.

Figure 6b: The prototype neoprene Moonskin Suit.

Qualitatively, as shown in Table 2 below, both the MDRS canvas suit and the Moonskin suit require improvements in the areas of radiation and micrometeorite protection, as well as the provision of pressure, oxygen, thermal and humidity control [2][3].

The most significant simulation related problem with the fidelity of these prototype spacesuits is that neither one applies enough pressure to the body – either atmospheric or mechanical – to be realistic for the low to essentially nonexistent pressure atmospheres of Mars or our Moon. This factor tends to give the test subjects a false impression of what their actual flexibility and mobility would be in real pressure suits designed for low pressure atmospheres.

Evaluation Criteria	MDRS Suit	Moonskin
radiation protection	little	none
micrometeorite protectn.	little	little
pressure provision	none	little
oxygen provision	not pres'rzd	not pres'rzd
thermal insulation	some	substantial
cooling	none	none
humidity control	none	none
overall mobility	good	excellent

Table 2: Qualitative evaluation of prototype MDRS canvas suit compared with prototype Moonskin suit.

On the other hand, these prototype suits set a high standard for flexibility which can be viewed as an ideal to strive for in the process of designing spacesuits to accommodate the wide variety of extravehicular activity needs of planetary explorers, such as extensive hiking, climbing, digging and building. Substantial reduced-gravity simulation research indicates that running appears to be more efficient than walking in lower gravity environments. (The "hopping" mode used by the American astronauts during the Apollo missions was simply an artifact of the limited lower body flexibility of the Apollo spacesuits.) Thus, planetary spacesuit designers should strive to eliminate restrictions on the wearer's normal range of motion for the entire body, to allow the body to move as naturally as possible. Since relatively high running speeds can be quite easily sustained in low gravity, spacesuit arm and leg section ranges of motion should not restrict extreme limb movements. Because stride length tends to be longer as gravity level decreases, hip flexion in the planetary spacesuit must also accommodate a larger range of motion than spacesuits designed for zero-gravity work. It should also be acknowledged that much larger masses of objects like life support equipment, tools, supplies, and samples can be easily carried for long distances on Mars (at 3/8ths of Earth's gravity) or the Moon (at 1/6th of Earth's gravity) than on the Earth itself [4].

Figure 7: Moonbase Sim 1 Health and Safety Officer William Fung-Schwarz demonstrates squatting and lifting tasks as a participant in the Spacesuit Biomechanics Study.

Figure 8: Moonbase Sim 1 Crew Journalist Guido Meyer demonstrates flexibility of prototype MDRS canvas suit.

Crew Activity Study

Another research project, the crew activity study, involved collecting (via individual logging and observation) data on time spent by Moonbase Sim 1 crewmembers performing various activities during each day of the mission simulation. The purpose of this project was to study how crewmembers allocated their time in the busy environment of a relatively unstructured moon mission simulation. This type of data could ultimately be used to assist in mission planning, work scheduling, energy expenditure forecasting, as well as for development of nutritional requirements. The data collected are shown in Figure 10 as representative percentages of individual crew time spent at various activities, since only two crewmembers participated in this study [5].

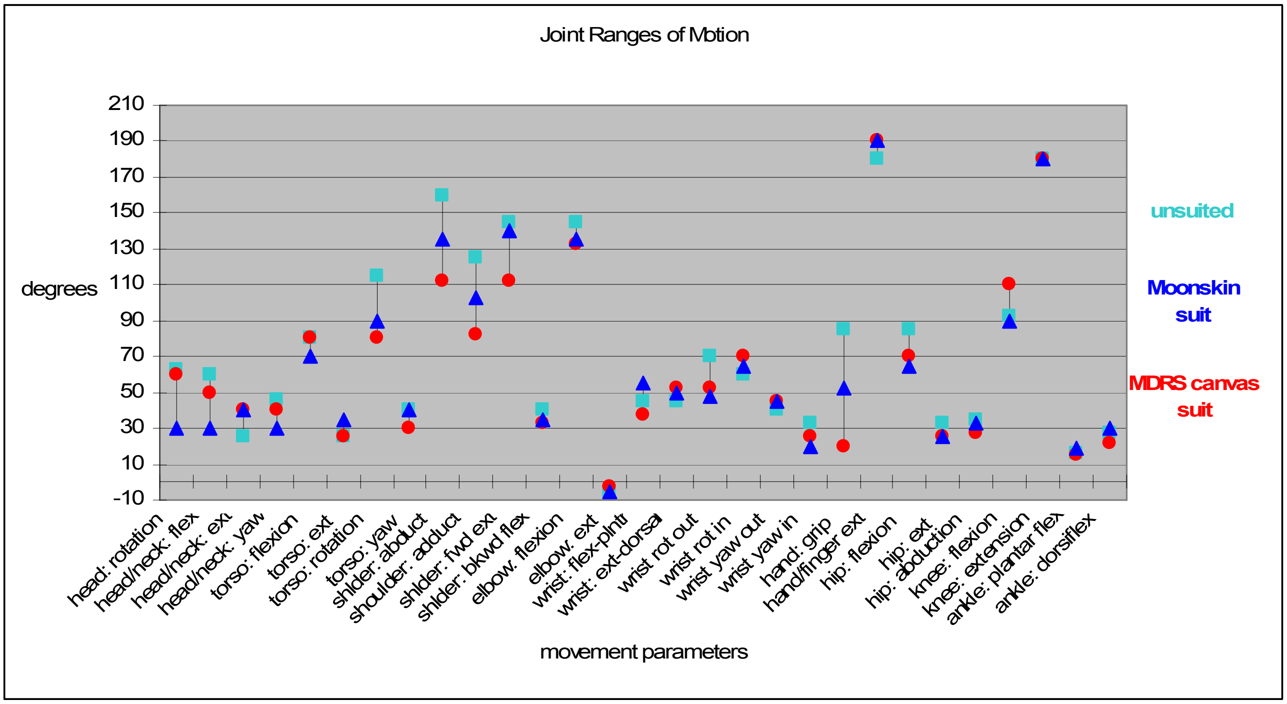

Figure 9: Joint ranges of motion for Unsuited, Moonskin Suit, and MDRS Canvas Suit trials.

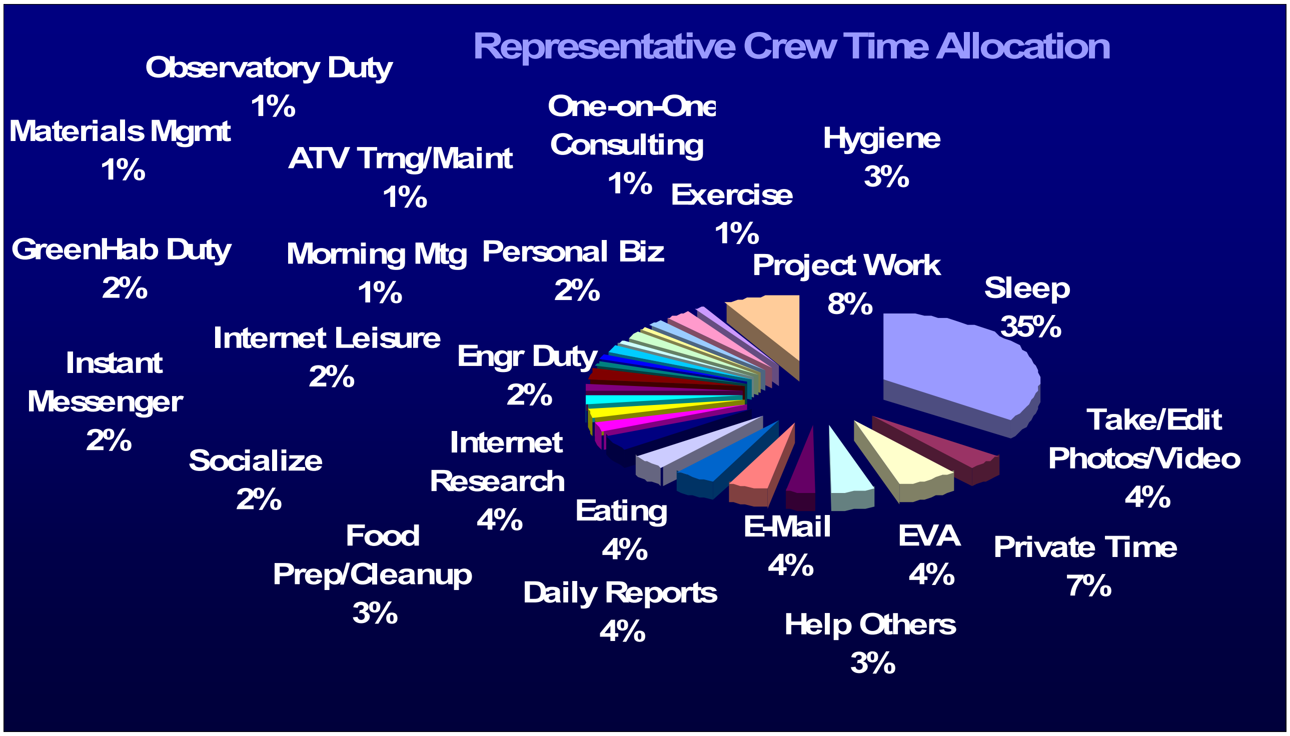

Figure 10: Representative crew time allocations from Moonbase Sim 1 Crew Activity Study.

Not surprisingly, the largest single block of time recorded was allocated to sleep (including a small amount of sleep related activities, such as changing into sleepwear, making up the bed, etc.) at an average of 8.4 hours per day. Private time alone accounted for an average of 1.6 hours per day. The largest amount of work time was allocated to project work at 1.9 hours per day. Approximately one hour per day on average was allocated to each of the following activities:

- EVA preparation and excursions
- reading and sending e-mail
- taking and editing photos and videos
- writing daily reports
- performing internet research
- eating
- assisting other crewmembers with their projects

As reflected by the "project work" time allocation average of 1.9 hours per day, relatively little time was available for each crewmember to work in his or her specific discipline. As a result, several of the proposed research projects did not get completed, and others did not even get started. Work duty time accounted for about 10.4 hours of each day, while non-sleep off-duty time only averaged about 5.3 hours per day.In a previous related study on crew energy expenditure levels (see "Lunar Life Support System Study: Metabolic Energy and Water Considerations", cited under references), we proposed that an astronaut working a typical lunar schedule might be expected to be on work duty an average of just 6.6 hours per day (including six off-duty rest days per month), expending an average of approximately 2938 kcalories per day [1]. Eight different daily work scenarios were developed and spread over what might be postulated as a typical lunar monthly work calendar. One of the possible daily scenarios is summarized below in Table 3.

If we use the crew time allocations from the Moonbase Sim 1 crew activity study in conjunction with the energy expenditure rates used in the Lunar Life Support System Study, we have crewmembers expending an average of 3418 kcalories per day. This figure is more than 16% higher than the average daily expenditure from the original Lunar Life Support System Study. This may be attributed to the relatively high ratio of daily work duty hours to non-sleep off-duty hours of 10.4:5.3, or 1.96 recorded by the Moonbase Sim 1 crewmembers. In contrast, the Lunar Life Support System Study allocated an average of 8.6 non-sleep off-duty hours per day, and just 6.6 work duty hours per day, giving a much lower ratio of 6.6:8.6, or 0.77 [1]. As another real world data point, NASA Space Shuttle and Space Station crews average 9.4 work duty hours and approximately 6.6 non-sleep off-duty hours per day [6], giving a more moderate ratio of 9.4:6.6, or 1.42. The higher figures from the Moonbase Sim 1 study (i.e., 10.4 work duty hours per day) are definitely worthy of further study as they may be more typical for the early days of a lunar mission when long work hours will be required to get new systems up and running, and crew enthusiasm is still in the early, euphoric phase before the novelty of the new environment wears off [7].

In any case, with further simulation crew participation, these kinds of data may be very useful for estimating crew energy expenditure levels and dietary requirements, as well as for mission planning purposes.

Daily Activity	Daily Time Spent	Energy Expenditure	Daily Activity Energy
Off-Duty			
Sleeping	9 hours	0.015 kcal/kg/min.	575 kcalories
Meals: prep/eat/clean	1.5 hours	0.04 kcal/kg/min.	256 kcalories
Personal Hygiene	1 hour	0.03 kcal/kg/min	128 kcalories
Reading/Sitting	4 hours	0.022 kcal/kg/min	375 kcalories
Housekeeping Chores	0.5 hour	0.06 kcal/kg/min	128 kcalories
Conditioning Exercise	0	0.115 kcal/kg/min.	0 kcalories
Total Off-Duty:	16 hours		1461 kcalories
Work-Duty			
Lab/Desk Work	2 hours	0.035 kcal/kg/min	298 kcalories
Walking	0.5 hours	0.07 kcal/kg/min.	149 kcalories
Standing	2 hours	0.03 kcal/kg/min.	256 kcalories
Kneeling	2.5 hours	0.025 kcal/kg/min.	266 kcalories
Crouching	0.5 hour	0.04 kcal/kg/min.	85 kcalories
Digging	0.5 hour	0.12 kcal/kg/min	256 kcalories
Total Work-Duty:	8 hours		1309 kcalories
Grand Totals:	24 hours		2771 kcalories

Table 3: Light Duty 6 EVA + 2 IVA hour Lunar work day energy expenditure for a typical 71-kg astronaut.

3. SUMMARY AND CONCLUSIONS

In summary, my experience at the MDRS as a part of the Artemis Moonbase Sim 1 team was very fruitful, as I was able to collect data for several research projects as described herein. I am grateful to both The Moon Society and the Mars Society for this opportunity, as well as to the Christian

Scholars' Foundation and Azusa Pacific University for their financial support.

The results of the Water Reclamation Project are as follows:

- Water usage was measured at 11.7 gallons of potable water and 5.8 gallons of toilet water per crew per day.
- The only significant improvements in water quality between the water entering and the water leaving the GreenHab water treatment system were qualitative improvements in odor, clarity, and particulate matter.
- The water entering and leaving the Greenhab is all highly alkaline.
- The Greenhab's major problems of high alkalinity, low dissolved oxygen, significant particulate matter, odor, and appearance could be improved through the following measures:

1. Replace cartridge filter system with a wetlands/marshland style filtration system
2. Add citric acid to potable water and gray water to neutralize alkalinity
3. Increase aeration of aerobic processing tanks
4. Ensure GreenHab trickling filter and bio-balls are fully functional
5. Introduce snails, algae, and fish to one or more of the open aerobic tanks
6. Substitute natural sunlight UV exposure for UV shock treatment device
7. Add a solar still as the final step in the water treatment system to collect condensate for drinking and cooking.

In the Spacesuit Biomechanics Study, the prototype Moonskin suit appears to be somewhat more flexible than the MDRS canvas suit for joint ranges of motion. However, both prototype suits need improvements in radiation and micrometeorite protection, as well as the provision of pressure, oxygen, thermal and humidity control. The most significant problem with the fidelity of these spacesuits is that neither one applies enough resistance to the body's movement to emulate a true pressure suit. In order to improve the fidelity of working in a simulation spacesuit at the MDRS facility, it is important to give the crewmembers a realistic impression of what their actual flexibility and mobility would be in real pressure suits. Therefore, some type of fabric stiffening techniques for the simulation suits should be implemented. Of course, the actual Moon and Mars exploration spacesuits should strive for optimal flexibility and mobility so that the explorers are as unencumbered as possible, and to that end the tight-fitting low-profile Moonskin type of suit design may offer the best solution.

The Crew Activity Study indicates that crewmembers were called on to perform many diverse tasks, with time being allocated in one- to two-hour blocks to a wide variety of tasks each day. Relatively little time was available for each crewmember to work in his or her area of expertise on a regular basis.

In conclusion, the Artemis Moonbase Sim 1 at the MDRS had strong aspects as well as aspects that could be improved upon. Some of the most beneficial features of the MDRS are as follows:

- The arid desert location of the MDRS makes it a good analogue for both the Moon and Mars.
- The low cost of participation makes it easily accessible to interested researchers.
- The absence of superfluous rules and regulations allows investigators the freedom to implement a variety of worthwhile research programs.
- The MDRS/Mars Society/Moon Society network includes a large number of diversely talented and enthusiastic people to consult with and resources to draw on.

As with any endeavor, improvements can be made to enhance operations. Here are some of my recommendations to improve the fidelity of the simulations conducted at the MDRS, as well as the effectiveness of the eventual missions:

- Develop screening methods to select teams of compatible crewmembers that are most psychologically and physiologically suited to long duration spaceflight missions.
- Make sure that each required skill and area of expertise are maintained by at least two crewmembers. Individual crewmembers should be a specialist in at least one discipline, but should also be a well-rounded "jack or jill of all trades" to ensure effective mission operations should one

crewmember become debilitated or incapacitated in some way.

- Quarantine crewmembers for one week prior to the mission, to make sure they are not exposed to infectious diseases that could decrease productivity or even debilitate the entire crew.
- Limit outside contacts to close friends, family, and necessary professional contacts for one month prior to mission (for the same reason as the previous recommendation).
- Allocate regular 8-hour sleep periods as an inviolable part of daily schedules.
- Implement more efficient water reclamation techniques to ensure an ample water supply.
- Provide a well-stocked parts room and well-equipped shop for dealing with contingencies and emergencies on site. On the Moon or Mars it will be very difficult to get to the nearest hardware store for supplies.
- Schedule regular time for exercise and recreation.
- Prioritize ample blocks of time on a regular basis for work in each crewmember's area of expertise.
- Consider implementing practical yet effective "creature comforts" to ease psychological and physiological stress.

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BIOGRAPHY

Leslie Wickman, Ph.D., *is currently director of the Center for Research in Science (CRIS) at Azusa Pacific University (APU). She is an internationally respected research scientist and engineering consultant. For more than a decade Wickman was an engineer for Lockheed Martin Missiles & Space in Sunnyvale, Calif., where she worked on NASA's Hubble Space Telescope and International Space Station Programs, receiving commendations from NASA for her contributions and being designated as Lockheed's Corporate Astronaut. For the last six years, she has worked as a research scientist with the RAND Corporation in Santa Monica on the technical and political aspects of various national defense issues. She also serves as a consulting scientist on fighter pilot training issues, future space launch vehicles, human factors problems for extreme environments, and runs a water reclamation research project. As director of CRIS at APU, Wickman's responsibilities include addressing the relationship between science and theology. She has lectured extensively around the world on satellite servicing, astronaut operations, mission planning, and space physiology issues. She is also a dedicated athlete who plays competitive beach volleyball and women's professional tackle football. Wickman holds a master's degree in aeronautical and astronautical engineering and a doctoral degree in human factors and biomechanics, both from Stanford University. She graduated magna cum laude from Willamette University with a bachelor's degree in political science.*