LUNAR LIFE SCIENCES PAYLOAD ASSESSMENT. S. C. Sun[1], F. Karouia[2], M. P. Lera[3], M. P. Parra[1], H. E. Ray[4], A. J. Ricco[1], S. M. Spremo[1]. [1]NASA Ames Research Center, [2]Blue Marble Space Institute of Science, [3]KBR, [4]ASRC Federal Space and Defense, Inc.

Introduction: The Moon provides a unique site to study living organisms. The fractional gravity and unique radiation environment have similarities to Mars and will help us understand how life will respond to conditions on the red planet. Martian and lunar environments can be simulated on the ground but not to high fidelity. Altered gravity and increased radiation are difficult to replicate simultaneously, which makes studying their combined effect difficult. The International Space Station, and previously, the Space Shuttle, provided a microgravity environment, and could simulate fractional-g only via an onboard centrifuge. Because the ISS and Space Shuttle orbits were within the Earth's magnetosphere, experiments on those platforms have not been exposed to the same level of galactic cosmic rays and solar radiation than what would be seen on missions to Mars.

The Space Life and Physical Sciences Research and Applications (SLPSRA) Division in the Human Exploration and Operations Mission Directorate commissioned this study to assess what systems are needed to study microbiology and cell biology utilizing Gateway, free flyers, and lunar landers. Even though SLPSRA focuses on Space Biology and the Human Research Program, this assessment looked at life sciences more as a cross-program discipline including astrobiology and planetary protection, as well as biotechnology applications. For this abstract, only the study results specific to lunar surface science are presented.

Study Methodology: The authors of the assessment scoped the study to be as broad and inclusive as possible, examining payload systems that have already flown in space as well as systems that are under development. The study encompassed US systems, including those developed by NASA centers and non-government institutions, as well as systems developed outside of the US.

Each of the systems was examined relative to 78 different criteria, grouped within categories including: science and technical capabilities; programmatic factors such as cost and technology readiness levels; logistics and operational requirements; and interface requirements. Assessments were based on publicly available information, in-house expertise, and in instances where information could not be found, direct contact with the payload developers.

Assessment: Over 60 payload systems supporting microbiology, cell biology, molecular biology, biotechnology, and astrobiology experiments were identified. Many were developed for experiments performed on the ISS, including systems that integrate into EXPRESS (EXpedite the PRocessing of ExperimentS for Space) Racks or are external space exposure research facilities. These same systems can be the basis for future payload systems for experiments to be performed beyond Low Earth Orbit. Such facilities would need to be adapted to be compatible with the new research platforms and function in the harsher radiation environment found outside the magnetosphere. If Gateway and a lunar based-lab could provide EXPRESS-compatible interfaces, leveraging hardware developed for ISS would be more feasible.

Gaps in Capabilities: Many of the payload systems that have been developed require human tending. Commercial Lunar Payload Services (CLPS) payloads will need to be completely autonomous. Human Landing System (HLS) payloads should also be highly automated, as crew time on the human lander missions will be extremely limited. Currently, only the smallsat biological payload systems can function without any human tending. Hence, more automated payload systems need to be developed. General robotic capabilities, such as robotic arms and free flying robots like Astrobee, are also needed to provide the ability to physically interact with and manipulate the experiments and payload systems.

CLPS payloads –CLPS provides a broad set of payload transport capabilities that will greatly enable life sciences research on the Moon. Early lunar life sciences experiments will last for the lunar day and will rely on telemetry to provide scientific data. Sample return will not be required. Organisms will need to stay in stasis for many months as a late-load integration process will not be afforded, and must be hardy enough to endure a range of harsh environmental conditions. To provide the proper thermal environment to sustain life, the payload would provide an internal heating capability. Lander location, shading of the payload, insulation, and multiple other parameters will need to be defined to provide the proper thermal conditions.

Through the development of a number of life science smallsats such as: GeneSat, PharmaSat, EcAMSat, O/OREOS-SESLO, EuCROPIS Powercell, and BioSentinel, NASA has multiple flight-qualified technologies to support biological research in 1-4U (U = cubesat unit, a 10-cm cube) system configurations. Many of the technologies were designed to function in an environment similar to what is expected on the Moon, and could support a range of microbiology experiments. Assuming the BioSentinel system meets its year-long interplanetary mission requirements, it is assessed to be the most capable system that could be adapted for CLPS to provide a near term research capability. BioSentinel experiments are already being developed to be performed on Earth, the ISS, and in heliocentric orbit, so adapting the system to function on the Moon should require only limited development.

Subsequent to BioSentinel-based experiments, future payloads could incorporate new and more powerful imaging systems that are in development. These instruments were originally designed to detect new life forms in our solar system; this study determined that they can be used in combination with other smallsat microfluidics systems to study life from Earth living in deep space.

As the CLPS payload capabilities grow, including greater payload mass and power, longer experiment durations, and the provision of a sample return capability, the complexity of the experiments will increase. Payloads up to 8U in size may be landed on the Moon. Samples returned could be in the configuration of sealed microwell plates, small sample vials., or a small self-contained sub-unit of the payload. Assuming there will not be any active thermal control of returned samples, biological organisms will need to be returned in stasis or fixed in a chemical preservative.

HLS payloads – Experiments utilizing the Human Landing System are expected to take advantage of larger power, mass, and volume envelopes for payloads; a small amount of crew time for manipulation and servicing of the experiment; and the possibility to return samples in a thermally controlled environment.

If there is a lunar base with a shirt-sleeve internal environment and a laboratory capability, a core life science research facility could comprise of multiple lockers similar to the EXPRESS lockers on ISS, including a small centrifuge, a refrigerator/freezer, imaging systems, molecular biology analytical instruments, and a small glovebox.

Cube payload interface: Because cube-size instruments are already onboard the ISS (e.g., Nanoracks and TangoLabs) and in smallsats, this study recommends that NASA develops a cube-payload interface to allow such systems to integrate easily with the different CLPS vehicles and to be more interchangeable with other space research platforms.

Regolith Radiation Shielding Experiment: Experiments on the lunar surface can help determine the shielding that will be needed to protect the astronauts living in a lunar habitat. Lunar regolith is one candidate shielding material. Experiments on Foton [1] and the ISS [2] have examined the effects of space radiation on bacteria, including bacteria shielded by simulated Martian regolith. Similar experiments should be performed on the Moon to evaluate the effectiveness of different shielding designs and materials, including lunar regolith.

Future Work: More detailed experiment requirements need to be defined in order to perform a more focused evaluation of payload systems and determine what new technologies need to be developed. As these requirements become more clear, the payload requirements on CLPS and HLS will be more precisely specified.

Summary: To perform life science experiments on the Moon, this study determined that CLPS and HLS should plan to support payloads with the general characteristics summarized in Table 1 below. These experiments will answer critical research questions for multiple NASA programs, alleviating risks associated with long duration human spaceflight, and understanding the fundamental nature of life in our solar system.

References:

[1] Rettberg P. et al (2004) *Advances in Space Research* Vol 33, Issue 8, 1294-1301 [2] Wassman M. et al. (2012) *Astrobiology*, Vol. 12, No. 5, 498-507.

Table 1: Summary of life science payload characteristics

Mission Type	Mass	Volume	Power	Description
Early CLPS mission	2.5 – 7 kg	1 - 4 liters	Nominal 6 watts; peak 12 watts	1- 4U cube-size instruments
Later CLPS mission	2.5 - 14 kg	1 - 8 liters	Nominal 12 watts; peak 24 watts	1- 8U cube-size instruments
Lunar Lab biospecimen facility (single locker)	$\leq$ 30 kg	71 liters	Nominal 80 watts; peak 300 watts	Project to need 4 - 8 lockers for experiment hardware
HLS Refrigerator/Freezer/Incubator	25 kg	71 liters	Steady state: 100 watts	Based on locker-size system developed for ISS