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Introduction: The NASA Life Sciences Research Capabilities Team (LSRCT) has been discussing deep space research needs for the last two years. NASA's programs conducting life sciences studies – the Human Research Program, Space Biology, Astrobiology, and Planetary Protection – see the Deep Space Gateway (DSG) as affording enormous opportunities to investigate biological organisms in a unique environment that cannot be replicated in Earth-based laboratories or on Low Earth Orbit science platforms. These investigations may provide in many cases the definitive answers to risks associated with exploration and living outside Earth's protective magnetic field. Unlike Low Earth Orbit or terrestrial locations, the Gateway location will be subjected to the true deep space spectrum and influence of both galactic cosmic and solar particle radiation and thus presents an opportunity to investigate their long-term exposure effects. The question of how a community of biological organisms change over time within the harsh environment of space flight outside of the magnetic field protection can be investigated. The biological response to the absence of Earth's geomagnetic field can be studied for the first time. Will organisms change in new and unique ways under these new conditions? This may be specifically true on investigations of microbial communities. The Gateway provides a platform for microbiology experiments both inside, to improve understanding of interactions between microbes and human habitats, and outside, to improve understanding of microbe-hardware interactions exposed to the space environment.

The current plan calls for the Gateway to be human-tended for up to 40 days per year which is ideal to investigate the island biology aspect of long duration space flight. Not having astronauts on the Gateway during most of the research period may even improve the quality of the test results. Their annual presence, however, will assure that the automated systems can be repaired, updated or even replaced and the biological species can be sampled, replaced or restocked as needed to assure continued productivity during the untended periods, in a manner analogous to Space Shuttle servicing missions to the Hubble Space Telescope.

What needs to be done: To enable meaningful biological research that can directly address key knowledge gaps and risk factors for long duration exploration missions, the technical capabilities and re-

sources have to be built into the Gateway facility and the operating conditions during periods of both crew occupancy and vacant free flight need to be established during the development of the Gateway and built into the flight system. The types of science to be conducted and the associated operating conditions will be an essential driver in DSG system design. Some of the operating conditions will be critical to the survival of the biological samples and other will have to be held to constant levels so LEO or ground based comparative studies can be conducted. Conducting research investigations on the Gateway enables continuous use of the Gateway during periods of crew occupancy and vacancy, which maximizes the return on investment of Gateway as a research platform.

What should be done: The DSG provides an opportunity to demonstrate and incrementally improve the capability to perform automated and remote life science investigations and production activities. As we move biological systems further away from earth, support system performance will be elevated to critical status. Within the habitat enclosures a stable system containing humans, animals, microbes, food producing systems, and human support systems must work in unison for long periods of time. The DSG, being in the deep space environment, will provide an opportunity to demonstrate and learn about the management of these complex integrated systems. The performance testing of bio-regenerative components in the deep space environment is an essential step in their acceptance for use in both transit systems and surface habitats. The understanding and management of the microbiome within habitats built for the deep space environment both during human occupancy and vacancy is critical to mission success.

How should Life Science be done during the Gateway era: The suite of equipment we currently have on ISS should be a point of departure for the suite recommended for inclusion on the Gateway. The triad of investigations performed at LEO, at the gateway, and within ground controls will reveal performance data on how animals, microbes and plants perform in unique environmental conditions. On the ground, we can tightly control the environmental conditions and mimic LEO and the Gateway but without the weightlessness, radiation, and magnetic field effects. At LEO, we can tightly control the environment and ex-

perience weightlessness but not the radiation and magnetic field effects. At the gateway, we will have a controlled environment, weightlessness, and the radiation and zero magnetic field effects. Together, data coming from these three research locations will reveal the important considerations for further exploration systems.

As a starting point the Gateway needs to be equipped with a comprehensive internal and external environmental monitoring system. It must have the ability to transmit environment and experiment conditions data to the ground monitoring station. The capability to perform petri dish science with real-time imaging to enable remote operations and data collection is needed. A capability to remotely initiate and control biological experiments will be a key Exploration capability and permit risk reduction studies in the radiation environment. Locations for the storage of prepackaged food so it can be returned for analysis after periods of one, two, three, four, and five years for degradation analysis are needed. Each mission to the Gateway will represent a consolidated campaign of life science questions covering the interests of Space Biology, the Human Research Program, Astrobiology, and Planetary Protection.

What is needed to perform Deep Space Gateway

Life Science: One EXPRESS rack (or equivalent) location for biological investigations, an external exposure facility, needed sample transfer equipment, and a consistent and stable internal environment is needed.

- Internal to the Gateway Habitat: The equipment being used on ISS has been developed for usage in the EXPRESS racks and a similar capability at the Gateway would enable common equipment usage. The power, fluid, instrumentation, and thermal capabilities would be common to both Gateway and ISS. To best support automated and remote operations, the computational, data storage, and data communication capabilities needs to be upgraded from ISS heritage hardware to the current state-of-the-art.
- External to the Gateway Facility: An external exposure location for microbes, spores, and seeds to assess the near and long-term to assess the effects of unshielded exposure to the deep space radiation environment.
- Biological samples delivered and returned from the Gateway need to be handled within a set of conditions that supports controlled science investigations at the Gateway and ensures valid post flight analyses.
- The internal environment at the Gateway would need to be maintained at the same conditions during periods of occupancy and vacancy to support biological studies. Those

atmospheric conditions should be kept nominally at 14.7 psi, 75° F, 60% humidity, and less than 2000 PPM CO₂.

Conclusion:

The proposed Deep Space Gateway, when used in a coordinated manner with ISS and ground-based facilities, presents an opportunity to acquire the needed understanding of life process to assure adequate mitigation of the risks to astronauts on deep space exploration missions while providing insights into basic biological processes in a rigorous manner. Appropriate attention to science requirements now can assure the maximum useful operational and scientific return during utilization.

Keys areas of scientific investigation will be on the biological effects of solar and galactic cosmic radiation, the integrated effects of microgravity and radiation on living systems, microbial development in the absence of a magnetic field, and generational development of microbial communities in an isolated and hostal environment.