AN INTEGRATED SCIENCE GLOVEBOX FOR THE GATEWAY HABITAT.

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Introduction: Next generation habitats for deep space exploration of cislunar space, the Moon, and ultimately Mars will benefit from on-board glovebox capability. Such a glovebox facility will maintain sample integrity for a variety of scientific endeavors whether for life science, materials science, or astromaterials. Glovebox lessons learned from decades of astromaterials curation, ISS on-board sample handling, and robust analog missions provide key design and operational factors for inclusion in on-going habitat development.

On Earth, NASA's astromaterial collections are stored in controlled environments – high purity positive pressure nitrogen atmosphere. Most sample handling and characterization of astromaterials are conducted in gloveboxes to prevent cross-contamination and preserve the scientific integrity of each sample. There are a variety of human spaceflight operational scenarios where such a glovebox facility could be used on a planetary surface, and on the Moon. However, a sample handling glovebox facility in cislunar orbit could also be used in a variety of ways to aid in receipt and preparation for transfer of samples collected from the lunar surface or other destinations. A Deep Space Gateway astromaterials glovebox facility could serve as a staging and storage area for later return to Earth of collected extraterrestrial materials.

From 2009-13, NASA Advanced Curation scientists built and integrated a high-fidelity analog sample handling glovebox called GeoLab inside NASA's Habitat Demonstration Unit (HDU) that deployed during Desert Research and Technology Studies (Desert RATS) expeditions in Flagstaff (2010 and 2011) and in Houston (2012) [fig. 1, 2][1-9]. We describe our earlier GeoLab concepts and discuss applicability of the hardware, various instruments, and operational concepts. The lessons learned from the GeoLab tests can be built upon to design the next generation of gloveboxes for human surface exploration as well as a cislunar orbit Deep Space Gateway astromaterials glovebox facility.

GeoLab Glovebox Integrated into HDU: GeoLab was NASA's first generation geoscience laboratory designed for a pressurized habitat to support human space exploration. GeoLab's goal was to foster the development of critical operational concepts and technologies for sample handling, preliminary examination, curation and prioritization of extraterrestrial samples for future sample return missions. GeoLab tested progressively more complex operations to determine the utility of such a facility inside a future planetary surface habitat, called the HDU-Pressurized Excursion Module Lunar surface configuration (2010), as well as the HDU-Deep Space Habitat configuration (2011 and 2012). Over the three years of field operations, GeoLab analog activities evaluated sample handling environments (field and lab), new technologies for sampling tools and analytical instruments, and a variety of operational concepts involving both robotic and human sample handling procedures.

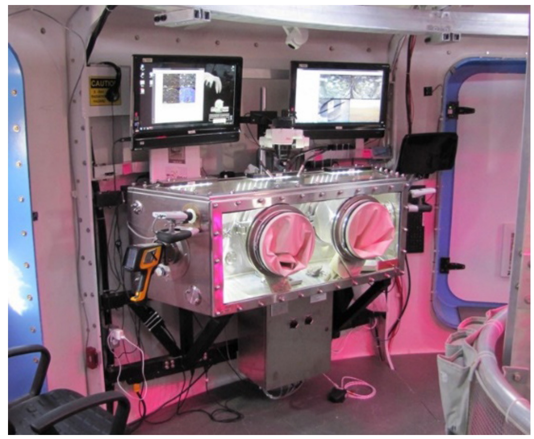

Fig. 1: GeoLab Glovebox integrated into the HDU during Desert RATS analog operations in 2010, 2011, and 2012.

Fig. 2: GeoLab Glovebox integrated into the HDU: Pressurized Excursion Module for Lunar surface operations (left); HDU: Deep Space Habitat for cislunar operations (right).

The GeoLab glovebox design supported evolving sample handling tests and configurations including:

- *Clean environment*: constructed with materials that have low off-gassing and particle shedding.
- *Sample preservation*: built to support positive pressure, enriched nitrogen atmosphere.
- *Direct Sample transfer*: three antechambers, or mini-airlocks, to the outside for sample transfers.
- *Analytical Instrument Ports*: configurable for instrument exchange within the habitat.
- *Rapid-Transfer Port*: transfer of samples and tools.
- *Environmental Monitoring*: Pressure, oxygen, temperature, and humidity/moisture sensors.

GeoLab also tested the following instruments for preliminary characterization and examination:

- *X-ray fluorescence analyzer* for geochemical analyses of Mg to U.
- *Multispectral microscopic imaging* for mineral identification.
- *Robotic Arm* for sample manipulation [fig. 3].
- *Stereomicroscope* for detailed characterization.
- *Digital balance* for mass measurements.
- *Video surveillance cameras* provided imagery of glovebox sample handling and astronaut activities; including a camera installed outside of the habitat for sample airlock activities.
- *Two HP Touchsmart computers* ran software to monitor the glovebox environment and provide interfaces for controlling cameras and analytical instruments.
- *Voice recognition* custom software for hands free control of GeoLab instrumentation and robotic arm.
- *RFID* for sample tracking and database management.

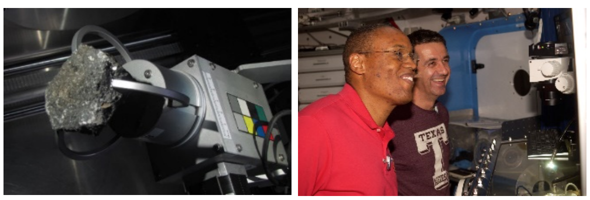

Fig. 3: GeoLab Glovebox Robotic Arm (left); Astronaut Alvin Drew and crew member (right) during Deep Space Habit GeoLab Ops.

After three years, GeoLab participated in 19 days of simulated mission testing in full analog settings, and monitored operations with 18 different test subjects. GeoLab also conducted stand-alone tests with nearly 20 other operators. GeoLab primary results reported [1, 3]:

1) The GeoLab design supports autonomous crew operations of the basic glovebox functions.
2) Good sample imagery is key for preliminary characterization.
3) Robotic assists for sample handling are critical in microgravity.
4) A combination of imaging tools and robotic tools provides significant flexibility for designing facilities and operations related to sample characterization and sample handling.
5) Preliminary sample characterization data leads to smart decisions during mission operations.

Flown Space-based Gloveboxes: Two notable rigid gloveboxes have flown in space that supported NASA human spaceflight missions: the Glovebox (GBX) and Microgravity Science Glovebox (MSG) [fig. 4]. In 1992, STS-50 flew the USML-1 Glovebox (GBX). This glovebox was a multi-user facility technology demonstration that supported 16 experiments in fluid dynamics, combustion sciences, and crystal growth. The GBX was again flown on USML-2 STS-73 in 1995. The GBX compact design not only allowed this glovebox to be adapted to the Space Shuttle's Spacelab module and the middeck area, but was also tested on the Priorda module of the Russian Space Station Mir.

After GBX, the MSG was developed by ESA/NASA for the International Space Station (ISS) Columbus laboratory module and flew to space in 2002. The MSG is a sealed glovebox enclosure for experiments conducted in microgravity. The MSG supports experiments in biotechnology, combustion science, fluid physics, fundamental physics, and materials science. The MSG is designed to provide any experiment with power, data acquisition, computer communications, vacuum, nitrogen, and specialized tools. In many cases, the design mimics working laboratory conditions on the ground.

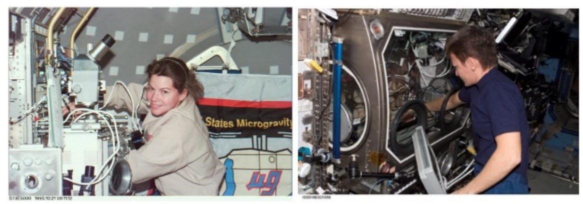

Fig. 4: Astronaut Catherine G. Coleman (left) working in the glovebox science module aboard the Space Shuttle Columbia in Earth-orbit during STS-73 (Oct. 23, 1995; NASA Photo: STS073-E-5000). Astronaut Peggy A. Whitson (right), Expedition 16 commander, uses the MSG in the Destiny laboratory onboard the International Space Station. (Jan. 5, 2008; NASA Photo: ISS016-E-021059)

Future Glovebox in Cis-Lunar Space: The GBX, MSG, and GeoLab provide a solid foundation and critical lessons learned for designing the next generation of gloveboxes for use in space. Before humans explore the Moon, Mars or elsewhere, scientists will define new protocols for the handling and return of unique extraterrestrial samples. NASA will implement innovative curation techniques aimed at preserving the pristine nature of the samples for study by earth-based scientists. A cislunar orbit Deep Space Gateway astromaterials glovebox facility could support a critical staging and storage area for later return to Earth of collected extraterrestrial materials.

References: [1] Evans, C.A., et al. (2013) *Acta Astronautica*, 90, 289-300; [2] Calaway, M.J., et al. (2011) *Enclosure Magazine, American Glovebox Society*, 24-1: 6-14; [3] Evans, C.A., et al. (2013) *LPSC XLIV, Abstract #1357*; [4] Bell, M.S., et al. (2013) *LPSC XLIV, Abstract #2134*; [5] Evans, C.A., et al. (2012) *LPSC XLIII, Abstract #1186*; [6] Evans, C.A., et al. (2011) *LPSC XLII, Abstract #1564*; [7] Calaway, M.J., et al. (2011) *LPSC XLII, Abstract #1473;* [8] Calaway, M.J., et al. (2010) *LPSC XLI, Abstract #1908;* [9] Evans, C.A., et al. (2010) *LPSC XLI, Abstract #1480.*