The Habitat Demonstration Unit Project: Test Operations

T. O. Tri[1], K. J. Kennedy[2], T.R.Gill[3], and A. S. Howe[4]

1 Engineer, NASA Johnson Space Center. Mail Code EA3, 2101 NASA Parkway, Houston, TX 77058; PH (281) 483 9234; email: Terry.O.Tri@nasa.gov
2 Architect, NASA Johnson Space Center. Mail Code EA3, 2101 NASA Parkway, Houston, TX 77058; PH (281) 483 6629; email: Kriss.J.Kennedy@nasa.gov
3 Engineer, NASA Kennedy Space Center. Mail Code LX-M, Kennedy Space Center, FL 32899; PH (321) 867 5824; email: Tracy.R.Gill@nasa.gov
4 Architect, NASA Jet Propulsion Laboratory. Mail Code EA3, 4800 Oak Grove Drive, Pasadena, CA 91109; PH (818) 354 4492; email: Alan.S.Howe@nasa.gov

Abstract

The Lunar Surface System (LSS) Habitat Demonstration Unit (HDU) will be required to support the readiness testing operations and the remote field testing operations planned for evaluating proposed LSS architectural scenarios. From the performance of the HDU's initial subsystem evaluations to its scheduled rollout in early July 2010 at NASA's Johnson Space Center (JSC) to its shipment to the field in mid-August 2010, the HDU will benefit from well-planned strategies to mitigate risks and ensure the various phases of field test operations are successfully executed. In cooperation with the activities associated with the overall integrated design and outfitting of the HDU systems, the project's team will incorporate design features which enable robust test operations capabilities both locally at JSC and at remote field test sites. Additionally, a suite of specialized equipment will be acquired or developed to meet the demanding needs of remote field testing. This will include long-haul transportation equipment, provisions for off-loading and reloading the sizable HDU, a robust portable power supply system, and remote site test operations team support facilities. Finally, a thorough, well-developed set of operational procedures will be utilized by the team to support the different HDU field testing configurations and to ensure smooth integrated operations with the other prototype lunar surface elements being evaluated during the field test.

Introduction

For over a decade, NASA has been conducting field tests of lunar/Mars surface system prototype hardware in various desert locations across the western regions of the United States. These tests, known as Desert Research and Technology Studies, or Desert RATS, have been held recently in such locations as Moses Lake, Washington, and Black Point Lava Flow, Arizona, near Flagstaff. The most recent field test was held in August/September 2009 at the Black Point Lava Flow site and included a fourteen-day excursion of the Lunar Electric Rover (LER) with a crew of two and demonstration of a half-scale All-Terrain Hex-Legged Extra-Terrestrial Explorer (ATHLETE). Plans are currently being made to define the test objectives and the scheduled sequence of events for the 2010 Desert RATS field test. The proposed major surface element prototypes for the 2010 test include two LERs, the half-scale ATHLETE, and the HDU configured as a Pressurized Excursion Module. The test will again be conducted at Black Point Lava Flow and the surrounding area, which has a variety of challenging terrain features and interesting geological formations. Similar to the 2009 test, the 2010 Desert RATS activities will run throughout the mid-August to mid-September time frame.

HDU Overview

Current proposed lunar architecture scenarios include a variety of surface elements designed to support extended duration crew habitation. These elements include the Pressurized Excursion Module (PEM), the Pressurized Core Module (PCM), and the Pressurized Logistics Module (PLM). Joined together with the LERs, these elements form the lunar outpost. The PEM provides laboratory and maintenance capabilities and can break away from the outpost to accompany the LERs on extended traverses by means of transportation provided by the ATHLETE. The PCM serves as the central core of the outpost, providing essential life support and habitation functions. Together, the PEM and PCM receive needed supplies, expendables, and experiment packages from the PLM, which can be detached from the outpost and replaced by a freshly stocked PLM to support continued operations of the outpost for further extension of the surface mission.

The HDU is designed as a testing platform for the candidate lunar surface habitation elements described above: the PEM, the PCM, and the PLM. The basic geometry of the HDU is a single-story, 5-meter-diameter vertical axis cylindrical enclosure with four equally spaced ports. Its basic construction consists of a fiberglass shell and a steel frame and support cradle. Figure 1 depicts a CAD image of the external view of the HDU shell positioned on its cradle. The HDU is fabricated in eight major wedge sections, then assembled and placed on the support cradle. Lower and upper floors are then installed, as is the lower and upper tunnel cylinders, and finally the ladder assembly.

For the 2010 Desert RATS field test, the HDU will be configured as a PEM. The PEM layout consists of four major internal areas: the geosciences laboratory, the EVA suit maintenance area, the medical operations area, and the general maintenance area. Figure 2 shows the proposed layout of the HDU in the PEM configuration. Note that only three of the four ports are shown; though the HDU shell has four ports, the PEM has only three, so one of the ports will be blocked off internally with a temporary wall structure for the 2010 test. The PEM also has an airlock. This airlock is planned to be provided via NASA's Centennial Challenges program through an organized competition involving parties external to NASA.

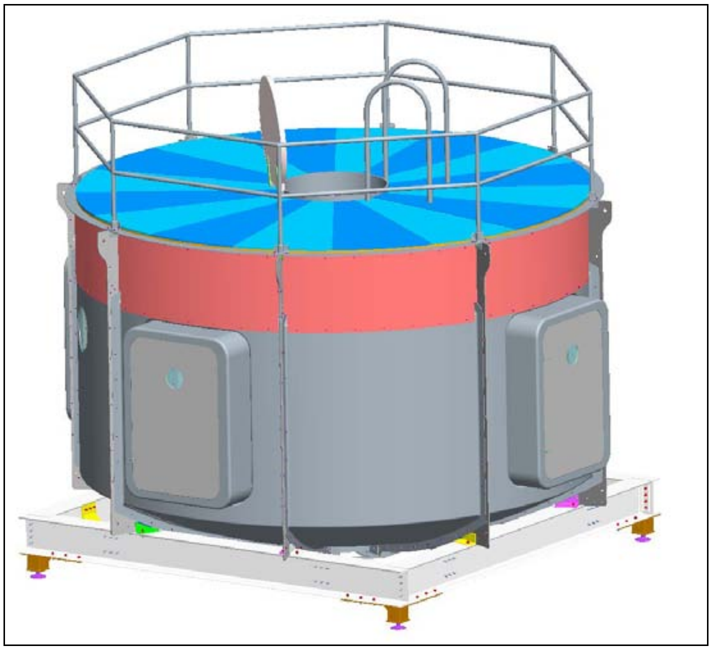

Figure 1 – External view of HDU shell on its support cradle.

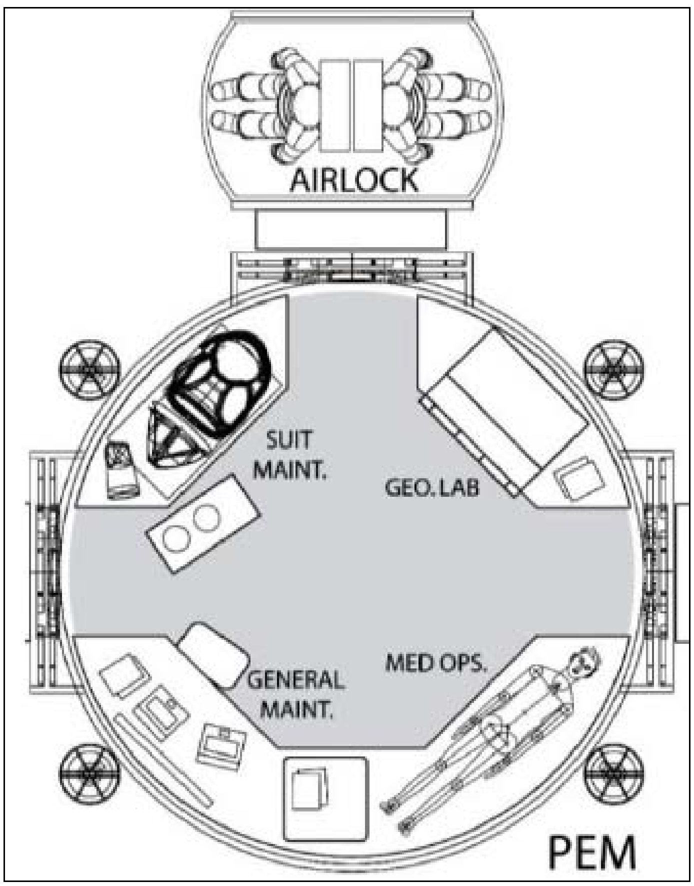

Figure 2 – Plan view of the HDU in the PEM configuration.

Reference Mission Operational Scenario

The current lunar reference mission targeted for use as the basis for the 2010 Desert RATS field test is a 28-day traverse from an outpost near Shackleton Crater to the vicinity of Malapert Crater, approximately 120 kilometers away. Figure 3 illustrates a convoy of two LERs and a PEM-laden ATHLETE leaving the lunar outpost on its way to Malapert.

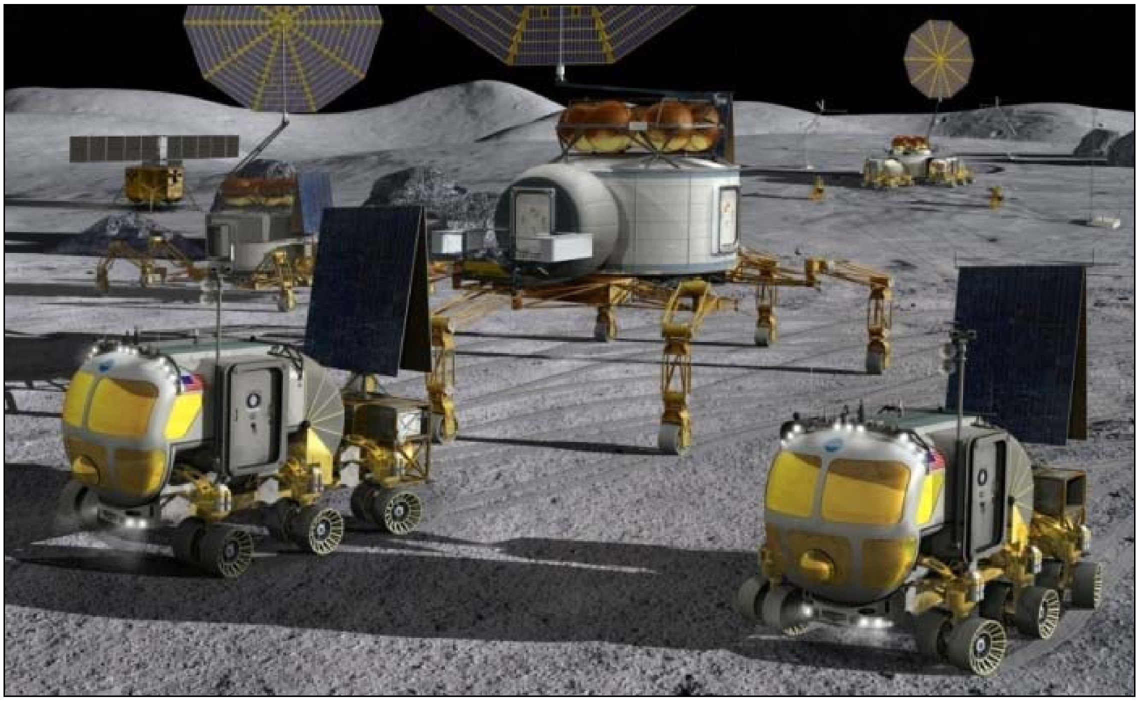

Figure 3 – Artist's concept of a convoy of two LERs, an ATHLETE, and a PEM making their way across the lunar surface.

During the Malapert excursion, each LER has a crew of two aboard, and the PEM is unmanned while being carried by the ATHLETE. During the traverse, stops at geologically significant sites will be made. After collecting samples, the LERs will dock to the PEM and make use of its onboard geosciences laboratory, its EVA servicing capabilities, and its medical operations facilities, if needed. Once Malapert Crater is reached, the PEM can be used as a mobile mini-outpost to which the LERs can dock after each day's traverse or as a more stationary mini-outpost to which the LERs can return after a more extended traverse of up to seven days. Details of the Malapert excursion are being reassessed and realigned at the time of the publication of this paper, so final mission definition may change, thus affecting the resulting adaptation of the mission to a 14-day field Desert RATS field test.

Field Test Operations Scenario

The reference mission targeted for the 2010 Desert RATS field test will consist of selected segments of the proposed lunar 28-day Malapert excursion. The Desert RATS mission is currently targeted to last 14 days and to traverse a path from the Black Point Lava Flow base camp to SP Mountain, approximately 20 kilometers away. Figure 4 shows the surrounding area around Black Point Lava Flow and the approximate traverse path to SP Mountain.

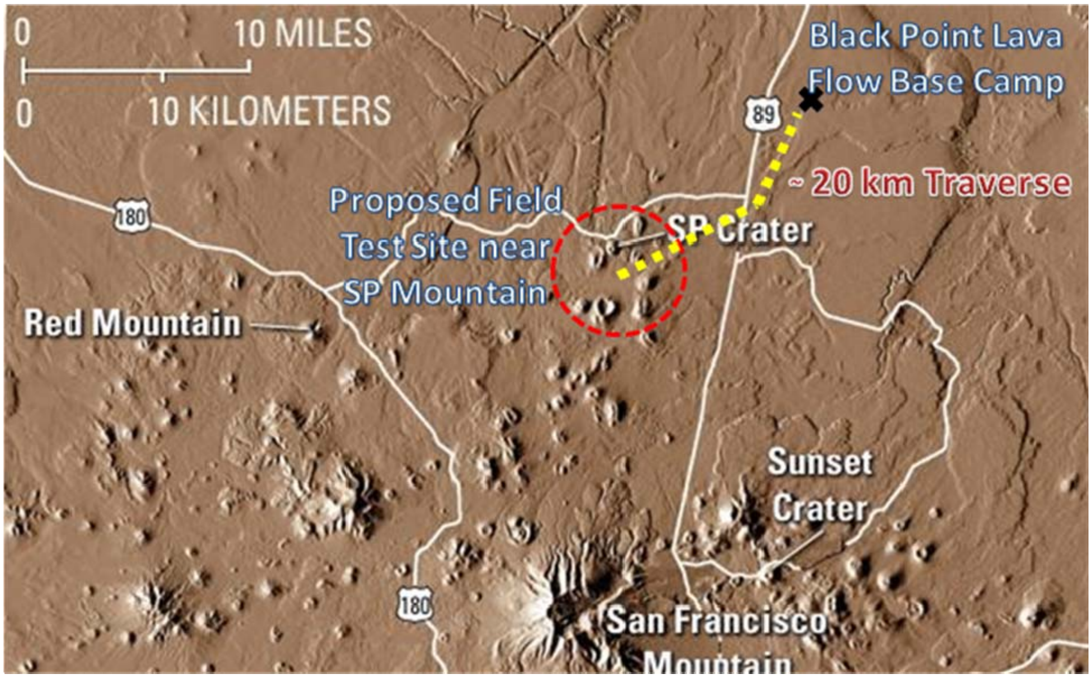

Figure 4 – Region north of Flagstaff, AZ—site of the 2010 Desert RATS campaign.

For the 14-day field test, it is currently planned to begin the traverse from the vicinity of the Desert RATS base camp, with the LERs, ATHLETE, and the HDU (configured as a PEM) all co-located for ease of initial deployment and integrated performance checkouts. Upon initiation of the test, the LERs—each with a crew of two—will set out on a multi-day 20 kilometer traverse to SP Mountain. The half-scale ATHLETE will also begin its trek to SP Mountain, likely carrying a scaled version of the PEM or the PLM. Figure 5 shows an aerial view of SP Mountain and its surrounding area.

While the LERs may take somewhat meandering paths to SP Mountain—stopping to investigate geological sites of interest along the way—the ATHLETE will take a much more direct path to minimize its traverse time. Unlike the LERs and the ATHLETE, the PEM will be transported via flatbed trailer over accessible roads to a pre-designated site near SP Mountain and then off-loaded. When the LERs arrive, they will have the ability to simultaneously dock to the PEM, and the crews can utilize the resources of the PEM to conduct geological laboratory operations and EVA maintenance, as required. Additionally, the medical operations capability can be used and evaluated, as can the general maintenance provisions. After several days of these kinds of integrated operations among the LERs and the PEM, the return traverse will commence, and the LERs and ATHLETE will set out on their independent traverse paths back to base camp. The PEM will be loaded for transport back to base camp and will be there waiting when the LERs return. This notional mission is still being discussed and formulated at the time of the publication of this paper, and the final mission may differ from that described above.

Figure 5 – SP Mountain, a cinder cone volcano near Black Point Lava Flow.

Test Operations

The test operations for the HDU in the PEM configuration will consist of four main categories of testing: integration testing, dry-run testing, field testing, and post-field test evaluations. Each of these categories has unique testing requirements, facilities, and test support equipment. Prior to any of these testing operations actually occurring, the assembly of the HDU shell must first be completed. Upon receiving the individual HDU shell segments from the manufacturing team at NASA's Langley Research Center, the JSC team will assemble the shell and cradle in the Exploration Mockups Development Facility onsite at JSC in Building 220 (see Figures 6 and 7). The overall process flow of the HDU buildup, outfitting, and testing activities is depicted in Figure 8.

Figure 6 – External view of the Building 220 facility at JSC.

Figure 7 – Exploration Mockups Development Facility in Building 220 at JSC.

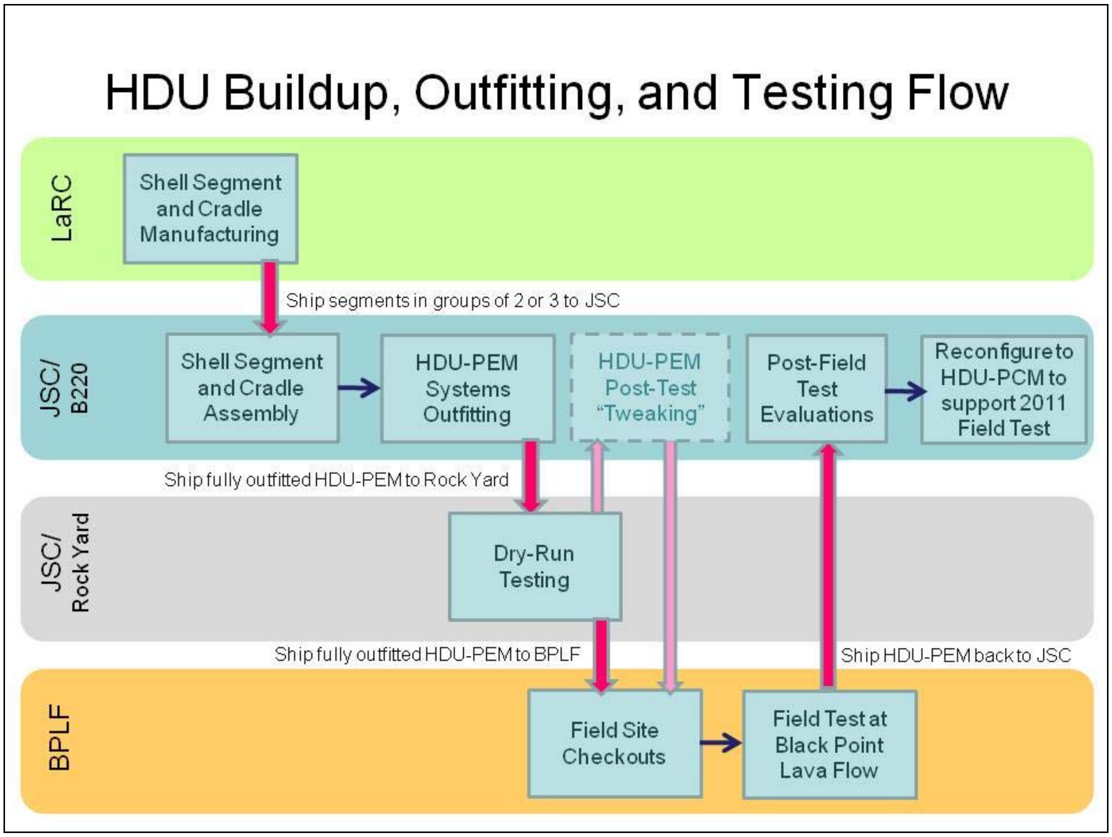

Figure 8 – Process flow for HDU buildup, outfitting, and testing.

Integration Testing

The first post-construction testing operations to occur will be those associated with integration of the utilities, hardware, and subsystems into the HDU to support the PEM configuration. These testing operations will focus on progressive performance and checkout evaluations of utility functions, individual subsystem functions, and finally integrated subsystem functions. Key to these test operations will be utilization of the existing Habitat Testbed facility in B220, shown below in Figure 9. The Habitat Testbed has been used to develop the command and control systems for habitation systems in general and specifically for the HDU. Using both hardware test articles and software simulations, the Habitat Testbed has been targeted to develop integrated control hardware and software systems to provide the command and control functions for the HDU in both the PEM and PCM configurations. In addition to the command and control systems functional testing, human factors issues with respect to both the interior and exterior outfitting of the HDU will also be assessed and addressed to ensure that crew interfaces are adequate to enable operational productivity and overall crew acceptability. Additionally, the functionality of the docking port interfaces will be evaluated utilizing an LER, which can access the HDU via the large door on the south end of Building 220. Finally, operation of the PEM's deployable airlock will be evaluated with suited test subjects to verify compatibility of the airlock systems with suited operations.

Figure 9 – The Habitat Testbed in Building 220 at JSC.

Dry Run Testing

Once the integrated utility and subsystem testing has been completed satisfactorily and all integrated test objectives have been met, the HDU will be ready for dry run testing. Dry run testing objectives will include establishing lift procedures for loading the HDU onto a flatbed trailer, tie-down procedures for securing the HDU to the trailer, transportation of the HDU a short distance across improved roadways to the JSC Rock Yard (see Figure 10), and lift procedures for unloading the HDU onto a preselected site in the Rock Yard with semi-flat terrain. Once in place, the HDU will be connected to a portable diesel generator to provide power to the subsystems outfitted for the PEM configuration. Each of the subsystems of the PEM will then be powered up and verified as operational. Communications systems will be checked out via the JSC Rock Yard communications network resources. The airlock will be deployed and its functions checked out. In conjunction with the LERs, docking port operations will be evaluated and verified. When the full suite of dry run testing operations have been completed, the results will determine whether the HDU can be prepped in-place for shipment to the field test site or if it instead must be moved back to the Building 220 facility for final modifications prior to shipment.

Figure 10 – JSC Rock Yard, showing the LER operating in the flat terrain between the hill on the right and the crater in the foreground.

Field Testing

The ultimate goal of the HDU Project is to create a flexible habitation system demonstration unit which can be transported to remote field sites for integrated testing of prototype surface system elements. Field tests offer unique opportunities to test hardware systems in a relevant environment. Current lunar surface architectural concepts have focused on use of LERs and habitation elements, such as the PEM, to conduct extensive lunar geology during extended traverses across the lunar terrain. A number of desert regions across the western United States can serve as good analog testing sites for lunar surface operations, exhibiting a minimum of vegetation and offering varied terrain features and interesting geological sites in which to conduct extended field test missions. The Black Point Lava Flow/SP Mountain region in Arizona has proven to be a very good location in which to conduct simulated lunar surface field tests and is the chosen site for the 2010 Desert RATS expedition.

Test Objectives

The first step involved in planning a field test is to define the primary test objectives and the secondary demonstration opportunities that are desired to be accomplished. The primary test objectives must be supported by sound rationale for performing the test at a remote field site, rather than simply in a sheltered facility—such as JSC's Building 220 facility—or in an easily accessible nearby exterior location—such as the JSC Rock Yard. The field test objectives for the HDU in the PEM configuration can be divided into architectural objectives, hardware objectives, and operational objectives. A listing of the PEM's objectives for the 2010 Desert RATS campaign and a listing of the accompanying technology demonstrations are shown in Figure 11.

Desert RATS 2010 Campaign: HDU-PEM Field Test Objectives

- **Test Objectives:**
  - Architectural Objectives:
    - Validate the use of the PEM as described in the LS-12.1 architecture
  - Hardware Objectives:
    - Evaluate use of PEM's geosciences laboratory in conjunction with LER sample collection
    - Evaluate use of EVA maintenance area in PEM
    - Perform "shake-down" assessment of integrity of HDU after long-haul transportation of the unit to the field site
  - Operational Objectives:
    - Evaluate logistics and waste management in conjunction with dual LER operations
    - Evaluate human factors associated with crew of four and docked LERs
    - Evaluate effectiveness of dust mitigation procedures
    - Determine PEM power duty cycle profile
- **Technology Demonstrations:**
  - Evaluate PEM medical operations capabilities
  - Evaluate PEM general maintenance support capabilities
  - Evaluate deployable airlock (Centennial Challenge)
  - Evaluate Logistics-to-Living concepts (Centennial Challenge)
  - Evaluate use of deployable loft (Centennial Challenge)

Figure 11 – Currently defined test objectives and technology demonstration candidates for HDU-PEM at Desert RATS 2010.

Field Test Scenario and Timeline

Once the field test objectives and demonstration opportunities have been defined, a field test scenario can be developed, with a corresponding timeline. For the 2010 Desert RATS campaign, these scenarios have not been firmly established at the time of publication of this paper, but a potential scenario and timeline are shown in Figure 12. This field test scenario includes a 14-day roundtrip traverse of two LERs (and a half-scale ATHLETE) from base camp at Black Point Lava Flow to SP Mountain and return. This scenario shows the rendezvous of the LERs with the PEM at the SP Mountain site during the middle third of the 14-day mission, with the long-distance LER traverses of approximately 20 kilometers each occurring during the first and last thirds of the mission. With only the middle third of the mission involving the PEM, this opens up the opportunity to use the PEM beforehand and afterwards to evaluate a variety of technology demonstrations while back at base camp. It should be noted that this 14-day mission is encompassed by a total 26-day campaign, with front-end and back-end activities which include site preparation, delivery of the prototype elements, checkout activities, a few "rest" days, a VIP day, a media day, and ultimately pack-up and loading activities for shipping the elements back to their home NASA Centers.

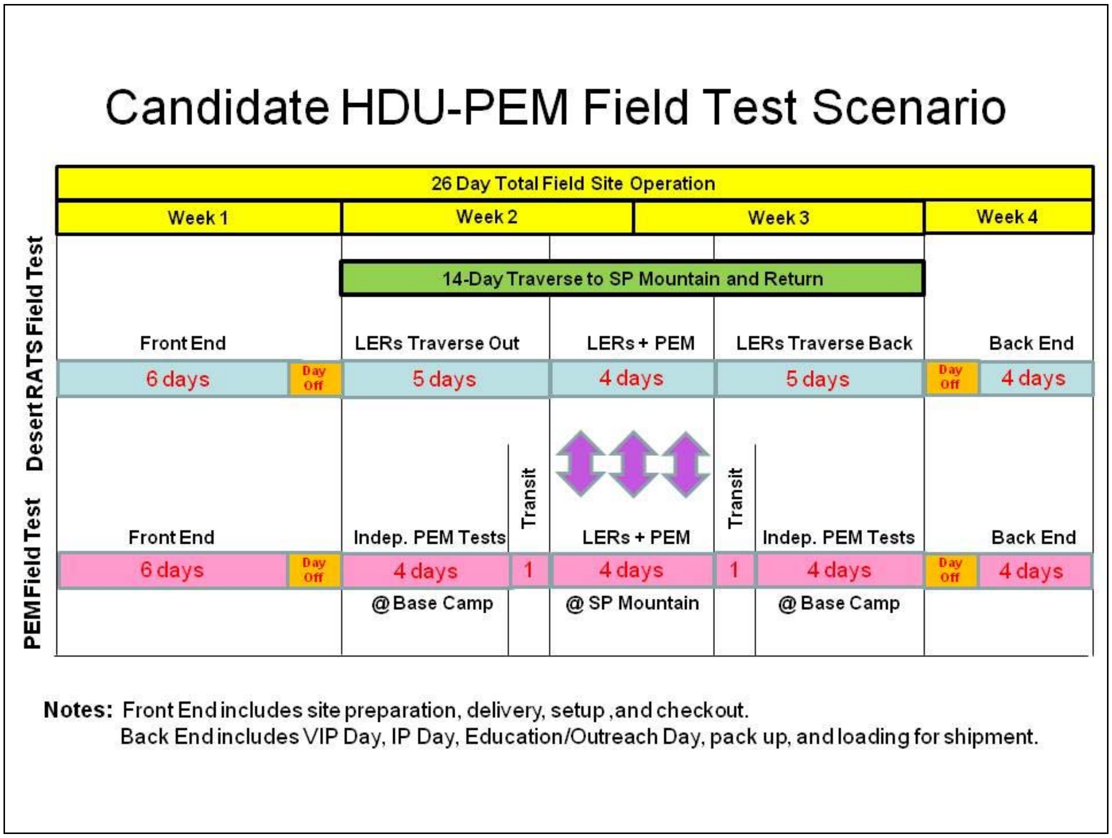

Figure 12 – Candidate 2010 Desert RATS field test scenario for the HDU in the PEM configuration, including interaction with the LERs.

Shipping

One of the major challenges inherent with the HDU is actual transportation of the unit to the field. With a maximum width dimension of over five meters, the HDU is considered a "super wide load" item, which necessitates development of a carefully planned route across America's highway system. Travel time from JSC to the test site north of Flagstaff, Arizona, is estimated to be upwards of two weeks, due to circuitous re-routing requirements and limitations on when the super wide load tractor trailer can be on the road, subject to differing state-by-state regulations. The shipping of super wide loads is also very expensive, costing up to ten times the cost of shipping a standard width item a similar distance.

Field Test Setup and Checkout Operations
Once the HDU is successfully shipped to the base camp at Black Point Lava Flow, it will be off-loaded via crane, set onto the desert terrain, and leveled. Similar to the Rock Yard operations, the HDU will be connected to a portable diesel generator to provide it with power, followed by power-up of the PEM subsystems, and subsequent verification of their operational state. Communications systems will be checked out via the communications network resources established at base camp. The airlock will be deployed and its functions checked out. When ready and available, the LERs will likely perform a docking maneuver to re-verify docking port functionality.

Field Test Operations
When all checkouts have successfully been performed, testing can commence in earnest, and both primary test objectives and secondary technology demonstrations will be performed via well-established test operations procedures, with resulting data collected, stored, and backed-up. Test control and management operations for the overall Desert RATS campaign will be conducted within the Mobile Mission Control Center (MMCC) that has been successfully used at past Desert RATS field tests. A representative from the HDU Field Test Team will occupy a seat in the MMCC during test operations.

Maintenance and Repair Operations
It is anticipated that during testing operations—both at base camp and at the more remote SP Mountain site—some subsystems may require maintenance or repair. At base camp, a rented portable office will provide an organized area to store tools and logistics items, conduct simple repairs and maintenance procedures, and provide a meeting area for the HDU Field Test Team to discuss the ongoing conduct of the test operations. At the more remote SP Mountain site, a recreational vehicle will be used to provide for a down-sized capability from that which is provided at base camp.

Field Test Shutdown and Packing Operations

Upon completion of all testing operations, all of the PEM subsystems will be shut down and safed per a pre-established checklist that was verified during dry-run testing operations. Trash will be removed and fluid tanks will be drained if needed. Generator power will be disconnected, and any deployed external hardware—such as the airlock, access stairways, cameras, or antennas—will be stowed and secured for shipping. The HDU will then be lifted via crane, placed on a tractor-trailer, and secured for transportation back to JSC.

Post-Field Test Evaluations

Invariably, there will be a subset of HDU tests and evaluations for which there is not enough time or not enough justification to conduct during the field test, but which can produce pertinent and valuable data. In these cases, there exist opportunities after the HDU has returned to its home base at JSC to conduct further testing. The ideal time to perform these evaluations is directly after the field test, when (historically) plans are still in the early formulation stage for the following year's field test. Reconfiguration to a new configuration, such as the PCM, will likely not be initiated immediately due to uncertainty of the following year's governing test objectives, so this "waiting period" is an opportune time to conduct the post-field test evaluations. Such testing can be conducted in the Building 220 facility or in the JSC Rock Yard, if warranted.

Summary

The HDU will require a well-planned series of test operations, including integration testing, dry-run testing, field testing, and post-field test evaluations, in order to successfully achieve the test objectives currently proposed. These test operations will require a well-trained team to conduct the widely varying test protocols across multiple testing locations at JSC and at remote sites. It is anticipated that lessons learned during this first field test of the HDU in the PEM configuration will greatly benefit the HDU Project in continuing to support NASA's exploration program with a flexible test demonstration capability that can be tailored as exploration goals evolve.

References

1. AS Howe; T Hong; B Hunkins; DS Hafermalz; K Kennedy; L Toups (2010). Mobile Field Analog for Lunar Habitat Integrated System Health Monitoring. Proceedings of the Twelfth Biennial ASCE Aerospace Division International Conference on Engineering, Science, Construction, and Operations in Challenging Environments (Earth & Space 2008); Honolulu, Hawaii, 14-17 March 2010. Reston, Virginia, USA: American Society of Civil Engineers.

2. AS Howe; G Spexarth; L Toups; R Howard; M Rudisill; J Dorsey; et al (2010). Constellation Architecture Team: Lunar Outpost Scenario 12.1 Habitation Concept. Proceedings of the Twelfth Biennial ASCE Aerospace Division International Conference on Engineering, Science, Construction, and Operations in Challenging Environments (Earth & Space 2008); Honolulu, Hawaii, 14-17 March 2010. Reston, Virginia, USA: American Society of Civil Engineers.

3. Gill, T., K. Kennedy, T. Tri, A.S. Howe (2010). The Habitat Demonstration Unit System Integration. Proceedings of the ASCE Earth & Space 2010 Conference, Honolulu, Hawaii, 14-17 March 2010. Reston, Virginia, USA: American Society of Civil Engineers.

4. Kennedy, K., T. Gill, T. Tri, A.S. Howe (2010). Habitat Demonstration Unit Project Overview. Proceedings of the ASCE Earth & Space 2010 Conference, Honolulu, Hawaii, 14-17 March 2010. Reston, Virginia, USA: American Society of Civil Engineers.