# The NEEMO Project: A Report on how NASA Utilizes the "*Aquarius*" Undersea Habitat as an Analog for Long- Duration Space Flight.

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**Abstract**

NEEMO is the NASA Extreme Environment Mission Operations, a cooperative project between NASA and the National Oceanic and Atmospheric Administration (NOAA). NEEMO was created and is managed by the Mission Operations Directorate at the Johnson Space Center in Houston, Texas. On the NOAA side, the National Undersea Research Center (NURC) in Key Largo, FL, with the help of the University of North Carolina at Wilmington, manages and operates the Aquarius Program.

NEEMO was developed by astronaut training specialists to utilize an undersea research habitat as a multi-objective mission analog for long-duration space flight. Each mission was designed to expose astronauts to extreme environments for training purposes and to research crew behavior, habitability, and space analog life sciences. All of this was done much in the model of a space mission utilizing specific crew procedures, mission rules and timelines. Objectives of the missions were very diverse and contained many of the typical space mission type activities such as EVAs (also known as extra vehicular activities), in-habitat science and research, and educational, public outreach, and media events. Five missions, dubbed NEEMO 1-5, were conducted between October 2001 and July 2003, the longest of which (NEEMO 5) lasted 14 days.

## History of NASA Undersea Research Participation

The concept of living and working in an undersea habitat as an analog for space flight is not a new one. This "inner" and "outer" space similarity has long been recognized but has only been demonstrated infrequently - the last time almost a generation of scientists, researchers and explorers ago.

The first real link from the space to sea environs came in 1965, as Commander Scott Carpenter jumped ship from the NASA astronaut corps and signed on as the Navy's commander of the SEALAB 2 program becoming the world's first astronaut/aquanaut. Then, in 1969, while millions watched the first lunar landing, NASA was simultaneously treading on the bottom of the ocean in Project Tektite. In this little known program operating off the US Virgin Island of Saint Thomas, NASA scientists with help from NOAA, the Department of the Interior, and General Electric researched space habitation concepts with scientists from many different agencies during multiple undersea missions. Interestingly, similar to the moon race, an *"inner"* space race was unfolding in July 1969, as the USSR deployed the Chernomoyr-2 Sealab for a two-week mission in the dark waters of the Black Sea. This was to be the last of the Russian undersea habitation programs. Much later, in the early 1990s, NASA scientists spent 30 days living undersea in the *La Chalupa* habitat in shallow waters to study crew psychology and behavior in isolated areas. In 1995 they even set up a communication link between the Space Shuttle during the STS- 69 mission, and the *La Chalupa* habitat.

During the four NEEMO missions, NASA has "saturated" 20 individuals, including 14 astronauts, 2 training leads, 3 Life Scientists and a Flight Director for a total of 30 days underwater. To date, 8 more astronauts have joined Scott Carpenter's elite club of having lived both in space and undersea.

**The Undersea Habitat "*Aquarius*"**

One does not have to look too deep to recognize the similarities between undersea and space habitation and exploration. In both of these environments, the threat of danger is real, the ability to sustain human life is difficult, and the rewards for exploring new areas have the potential to greatly benefit mankind. When making a direct comparison, no other isolated, extreme, harsh or otherwise in-hospitable environment better parallels the extreme isolation and confinement of space than living undersea.

As the only undersea research habitat in the world, *Aquarius* is a unique and valuable research tool. NASA recognized that since it was owned and operated by another U.S. Government Agency (NOAA), it would be both safe and effective as a research tool. *Aquarius* is also highly sophisticated in its logistical infrastructure and did not require major modifications to support unique NASA needs.

*Aquarius* was built in mid-1980s, and was previously located in Saint Croix (US Virgin Islands) before moving to the reef line 12 miles off of Key Largo, Florida in 1990. In these two locations, *Aquarius* has supported dozens of missions to study the undersea realm for several hundred marine research scientists from around the world.

*Aquarius* is similar in size to the U.S. Laboratory module on the International Space Station, or ISS (~ 15 m long X 4.5 m in diameter). It is firmly secured to a sand patch surrounded by large spur and groove coral reefs on three sides. The slope quickly becomes shallower to the west, deeper to the east and stays relatively constant to the north and south, which is the general direction of the reef. It sits in water 60 feet deep, but the entrance level is actually closer to 50 feet, which corresponds to an internal pressure of ~ 2.5 atmospheres. At this depth, aquanauts living and working in the habitat become exposed to excessive levels of nitrogen within the first few hours and must commit to staying in the habitat and undergoing "decompression" before returning to the surface. This type of diving is called "saturation" diving, referring to the complete saturation of the body tissues by nitrogen. A diver in this condition will quickly experience the onset of the "bends" if he returns to the surface without going through decompression, and would most likely experience injury and even death if not treated. The danger is real and the environment is truly extreme, which is one of the key reasons it makes such a good analog to living in space. Aquanauts participating in these missions must utilize their training, skills, knowledge and teamwork to ensure their safety and mission success.

*Aquarius* is very similar to a space vehicle in the interior. All of the on-board systems and switches are laid out in a systematic way, enabling the operators to safely monitor and maintain the vessel during the mission. It accommodates six aquanauts in relative comfort and has all of the basic amenities one might expect. One enters the habitat through the "wet porch," which is the air/sea interface. Since it is pressurized to the ambient water pressure, the experience of swimming up and into the habitat is much like coming back to the surface. Once in the wet porch, the aquanauts rinse and stow their equipment, shower, and enter the entry lock through a hydraulically operated door.

Inside the entry lock, one finds a shirtsleeve environment that is a bit humid (75–80% normally), but otherwise very comfortable. The lighting is good and ambient noise levels are low. There is a toilet, some work bench space with power, phone, and ISDN computer connections, a freshwater sink, and various system controls and circuit breakers. For NEEMO missions, this area was used for the crew laptop, a speaker phone, camera equipment, and basic toiletries (around the sink).

Through the next hatch, which is always kept open, one enters the main lock. The main lock serves as the main living area. On one side is a kitchen with a sink, hot water dispenser, microwave oven, and "coldbox" (not quite as cold as a refrigerator, but capable of storing fresh foods for a limited time). There is also a 4-person table adjacent to a large view port, which tends to be the gathering place for meals, conversation, fish watching and study. On the other side of the module are computers, phones, video teleconferencing equipment, and more habitat system controls.

Finally at the forward end of the main lock is the bunk area. There is a curtain separating the bunk area for privacy when changing clothes, but it is not a separate pressure volume, and there is no hatch. There are two sets of three vertical bunks on either side which allow for comfortable sleep and contain personal storage areas for necessary items. The interior of the habitat terminates in a large view port facing forward, which is a favorite spot for watching aquatic animals, especially at night under the eerie glow of the exterior lighting.

Permanently anchored above *Aquarius* is a 10 m "Life Support Buoy", or LSB. Onboard the LSB are redundant generators and compressors which provide electrical power and fresh air via umbilicals to the habitat. Separate umbilicals provide communications connectivity. From the LSB the signal is relayed via microwave to the NURC headquarters in Key Largo. This allows Aquarius to have real-time voice communication (radio and telephone) and internet connectivity. It also allows the "watchdesk" at NURC to monitor video and systems telemetry real-time, which they do 24/7 during a mission.

Excursion lines radiate in almost every direction from the habitat up to 800 feet away. These lines are hard-mounted to the seafloor and provide the aquanauts with a safe and dependable transit system while navigating about the reef. This system is a critical component to saturation diving because becoming lost or disoriented and returning to the surface for bearing is not a safe option. At the ends of the major excursion lines are air refill stations, also called "way stations." These small chambers provide an air space where two aquanauts can communicate with Aquarius or each other, refill their air tanks, drink or eat any snacks they brought, etc. One of these chambers is also located just outside the wet porch and is equipped to function as a "safe haven" in the event the aquanauts had to evacuate the habitat.

The diversity of the flora and fauna nearby is spectacular. Since Aquarius lies within the protected Florida Keys National Marine Sanctuary, the coral is healthier than in surrounding areas, and fish populations are stable. Also, due to the nature of the changing bathymetry, there is ample room for conducting exercises and science in a variety of shallow, deep, sand, coral and wall environments.

**Space Analog Missions in Aquarius**

Concept

The concept behind NEEMO was to make the undersea experience parallel a space mission in as many ways as possible. To that end, dozens of analog characteristics, from the types of foods being eaten to the "look" of the procedures, were evaluated. At JSC, a small cadre of scientists, instructors and astronauts put together an all-inclusive training and mission plan, which would begin several months before the mission. One of the biggest challenges before the team was the fact that astronauts typically have at least a year to train for a space mission yet NEEMO aquanauts only have a few months working part time to prepare for each NEEMO mission. Therefore, it was decided early on that the JSC participants would not be able to learn the systems operations of the habitat and would leave those operations to the NURC habitat technicians on each crew. This decision enabled the NASA aquanauts to concentrate their pre-mission time on the habitat science, underwater tasks, dive skills, and life sciences training. This model of operations seemed to work well throughout the course of the missions and was well accepted by the staff at NURC.

Since the two primary objectives of the project were to provide a unique mission training experience for the astronauts and to conduct valuable space analog sciences, the crews for the mission were selected from several different areas. These included astronauts, spaceflight training leads, a flight director, and space and life scientists. Thus representatives from multiple different areas were able to effectively capitalize on the unique opportunities afforded by experiencing a mission and conducting science in this environment. A side benefit was that a good symbiosis was seen as non-astronaut crewmembers came away with a better appreciation for the rigors a crew endures on a space mission, while the crewmembers got an early exposure to scientific tasks and equipment that might later show up on their space missions.

## Aquanaut Selection and Training

Aquanaut Candidates had to possess fairly high qualifications. The minimum requirements at NURC included open water dive certification, a minimum amount of dive experience, and successfully passing an extensive dive physical, written dive test, and swim test. In addition, NASA added a comprehensive list of requirements such as operations experience, medical (or EMT) experience, exposure to isolated and extreme environments, and ability to perform Space and Life Science research. There were many qualified candidates to choose from during the selection process. However, it quickly became clear that NASA candidates generally wouldn't have a very high level of dive experience, and that some additional dive training prior to their formal NURC training was desirable. Starting with NEEMO 3, each crew went on a short pre-mission training trip where they focused on basic dive skills, underwater tasks, and habitat orientation. This proved to be very beneficial.

Training for the missions took place at both the Johnson Space Center and at the National Undersea Research Center. Prior to the mission, aquanaut candidates were provided training and certification in First Aid, CPR, oxygen administration, life sciences experiments, habitability research, the EVA tasks, and data collecting tasks. During all training at both NASA and NURC, safety of all participants was always the top priority. The staff at NURC proved to be a very professional and qualified organization with a small but extremely diverse and capable staff.

## Mission Overview

A complete set of mission governing documents (e.g., timelines, procedures, mission rules, etc.), similar to those used in the ISS Program, was created for each mission. To a large extent, terminology and formatting were identical to those used on the ISS. As in space flight, a detailed timeline kept each crewmember busy every day. The crew was assigned specific timeslots for their daily activities, including EVAs, science tasks, educational outreach and media events. Even housekeeping, meals, hygiene, family conferences, and sleep were on the timeline. Throughout all of the missions, the crew did an exceptional job of staying "on the timeline."

In several instances, mission days had to be re-planned and new timelines were sent to the crew. They always responded positively and the new plans were completed successfully. In one particular instance, a crew finished a structure-building task a day early. Overnight, the topside team developed and re-planned the activity for the next day so that the crew would have to move the structure, rebuild some critical components and use the new structure as a camera platform. During this activity, the crew stepped up to the challenge and completed the task within the time available. The results were some high quality video that was taken from a camera on the platform that was used for national media coverage of the mission. Later, the crew stated that this type of re-planning activity ideally represented space flight and was a highlight of the mission.

In a later mission, the threat from a series of hurricanes caused the mission to be shortened by almost half of the available time. The topside team and crew had to scramble pre-mission to design a new timeline based upon a pre-determined list of prioritized objectives. Also, they had to adapt to major changes to the environment and dive capability as the excursion lines had to be pulled from the bottom prior to the mission. Again, the crew handled all of the changes well and re-scoped their tasks to be able to complete them near the habitat.

The scuba excursions (EVAs) from the habitat had a broad range of objectives and were designed to build teamwork, provide real mission data collecting experience, and challenge the crew's skills. The three primary EVA tasks for each of the missions included one structure-building task, one marine science task, and one communications equipment evaluation task.

The structure-building task seemed to be the most space-like and be the best task for practicing all of the teamwork skills. All of the crews developed their own individual plan for completing the structure and did so successfully.

The marine science task related to collecting data on the health and size of the coral on the local reef proved to be quite challenging. It required the crew to lay lines about the reef for sectioning off areas, and measure and photograph the corals in the boundaries. Often crews were subjected to high current, times of lowered visibility and surge. In one instance, the crew had to abort the dive due to the high current and return to the habitat as measuring the corals was impossible. All of their training was put to use as good judgment, dive skills, communication and teamwork all played active roles in their decision. This led to a re-plan activity and the crew made up for it in the following days.

For the communication system evaluation task, NASA teamed with a principle investigator outside NASA to evaluate a full face mask underwater communication system. This system was used by the aquanauts on their EVAs so that full two-way verbal communication would be available, as in space. While it was possible to talk and understand each other, the system had several limitations not found in the space environment. One was that there is a lot of ambient noise created while on scuba: the hiss of the regulator while inhaling, and the sound of the bubbles being exhaled. To clearly communicate with one another, each party had to essentially stop what they were doing, slow down (in order to quiet) their breathing, and focus on the conversation to some degree. Also, the systems tended to be very directional, and best results were obtained when the antennae were within line of sight of each other. Having one's body between the antennae could significantly degrade the conversation, even when in fairly close proximity to one another. Finally, it is not a duplex system: each person has to take their turn speaking. Therefore, most aquanauts only used the system when necessary and didn't use it very much for idle chatter. However, in spite of these limitations, the general crew consensus was that they were pleased at the additional level of safety that an underwater communications system provided, that they enjoyed using it while working on specific tasks, and that it did improve efficiency at times.

One aspect of the evaluation was to ship the communication signal from the aquanauts to the habitat and then route it via the telephone or internet back to a Mission Control Room in Houston. This test was successful on several occasions, showing that aquanauts in the water were able to communicate with the habitat from hundreds of feet away in the right conditions. Early on, equipment in the habitat to route the signal to the surface proved to be problematic. However, these problems since seem to be resolved, and the latest mission incorporated real-time communication with the Mission Control team during all of the EVA activities.

During each of the days the crew was in saturation, there were two separate, but connected, groups watching over their activities. Back at NURC base in Key Largo, the staff kept 24-hour watch over the habitat and its systems and were in constant communication with the habitat techs. They also made daily trips to the habitat area to perform such tasks as servicing the Life Support Buoy, re-provisioning food and water at the habitat, and performing maintenance in the habitat area. The NASA Topside staff also monitored the mission and focused on the science and EVA tasks. As stated before they communicated with the crew on a daily basis, re-planned crew activities, provided daily status reports to the crew and families, co-workers and friends in Houston and provided daily logistical support on the reef including photo and video documentation on the crew activities.

Daily Life

A typical day inside the habitat is much like a day in space. The crew tends to keep busy and focused on the tasks at hand, but the atmosphere is generally light-hearted. Although there are several windows available to watch the spectacular array of fish swimming just outside, the crew rarely has time to do so except during meals and those rare slices of free time.

Since the habitat is relatively small for occupation by 6 people, movement about it must be planned and deliberate. Typically this process becomes routine after a few days and begins to flow smoothly. While inside the habitat, the crews were busy completing all of the tasks on the timeline, which were quite diverse.

A typical mission day would start with the crew rising around 7:00 A.M. to perform morning activities and prepare breakfast. During this time they were also scheduled for a brief planning conference with the NASA Topside team. This conference focused on planning and activity updates to their schedule for the day, but also might include idle chit chat with the Topside team if the crew was in the mood. Shortly afterward, the crew would begin the daily in-water activities. The 4-person NASA team was usually divided into dive buddy teams of two and two. The first team would usually don their dive equipment and be headed out the door for a 3-hour EVA by about 8:30. They would soon be followed by the other dive buddy team about thirty minutes later (buddy teams were staged like that to avoid crowding the wet porch area.) While out on their excursions, the crew would perform a wide variety of in-water tasks as described earlier.

The crew ended each EVA with a short, hot shower (as fresh water is limited), followed by applying eardrops to counter the possibility of ear infections. After the morning EVA activity, the crews would spend a 4-hour time slot in the habitat resting, eating lunch, taking photos and video, working on the computer and working on interior habitat science.

Several times during each of the missions the crew would participate in a Public Affairs or Educational Outreach events. One buddy team would host the event from the habitat via a video conferencing system, while the other buddy team worked in the water (and on camera) nearby. Thus the people controlling the event back at JSC could cut the video to the aquanauts in the water at any time, which provided an excellent backdrop for the event. Audio quality from the aquanauts in the water was too poor to use during these events (partly due to the multiple connections, and partly due to antenna shadowing when very near the habitat), so the crew inside the habitat did all the talking. Millions of students and the general public saw these events over the course of the NEEMO missions.

The science performed in the habitat was highly varied. One of the main areas of focus for the crews was to capture and categorize the overall habitability of the vessel. Researchers at JSC had the crew collect record data such as ambient light and sound levels, along with other data related to life in the habitat. They will use this data to further their knowledge of the types of things that provide comfort to a crew in such a confined and isolated environment, such as a crew would experience on an ISS or Mars mission. Another set of science objectives dealt with physiological and medical aspects of long duration confinement. These were achieved through a series of questionnaires and by conducting a simulated medical emergency in the habitat. One ("Oto-Acoustic") experiment tested possible hearing changes due to the hyperbaric environment, and also due to the dives themselves. A viral shedding experiment, similar to those done on many Shuttle and Antarctic missions, required periodic blood, saliva and urine samples from each of the aquanauts. It is hoped that this research will help quantify why viruses duplicate (shed) more in extreme and stressful environments. Quantifying and understanding this phenomenon is essential before sending a crew off on long duration missions to Mars. Data collected from the missions showed that the habitat is a good analog, and further study on missions between 14 and 30 days long is desired.

In the afternoon, a second set of dives by the team was accomplished. The two teams would again depart the habitat for an in-water task and stay out for 2-3 hours. While the four NASA aquanauts were accomplishing these tasks, the NURC habitat technicians ("hab techs") performed their daily routine as well. This consisted of monitoring and maintenance of the systems aboard the habitat and performing routine maintenance outside the habitat. The hab techs did their diving outside without a buddy, as they had an air umbilical connected to the habitat (hookah) at all times, and carried a pony (emergency) bottle of air with them as well. Therefore, there was always one hab tech in the habitat while NASA divers were in the water. In this way someone was always inside the habitat to monitor systems or communicate with the NURC watch desk as needed. The hab techs were also responsible for monitoring the aquanauts and alerting topside in the event of an emergency situation. An example of such a situation occurred on one NEEMO mission when the habitat lost power due to a breaker tripping which carried power from the topside generators. The hab techs quickly alerted the watch desk which sent a crew from shore to fix the problem. The problem was quickly and safely resolved by the topside team. This event allowed NASA the opportunity to watch NURC staff respond to a contingency and demonstrate their professionalism and experience in this environment. In any event, the habitat has a backup battery supply and could have operated in a safe powered-down mode for about 5 days.

In the late afternoon the aquanauts would end their EVA activity and return to the habitat. The crew would typically gather for the second daily tag-up with the NASA topside team. During this conference, the activities from the day would be reviewed and changes to the plan for the following day would be discussed. This activity was usually a little more laid back than the morning conference and all of the aquanaut team would participate.

Soon after this, the crew would eat dinner. This is an important crew bonding time in the habitat and was usually an opportunity for everyone to sit down together to discuss the day's events. As the space is tight, one crewman would usually prepare the dinner and this task would be rotated throughout the mission. On each of the missions the menu consisted of a variety of foods including the pre-packaged "space" food. This provided an excellent opportunity for the crews to sample many types of space food. They also provided feedback to the JSC food nutritionists. To supplement the pre-packaged food, there was also an ample supply of fresh foods and snacks. There were no reported instances of aquanaut starvation!

After dinner, the crew was given time to complete activities for the day and perform general housekeeping chores. Typical activities during this off time were to write journals of their experiences that day, to correspond with family and friends via email, and to watch DVD movies.

At least once during each of the missions, the crew was given the opportunity to make a night dive. This dive was typically done without a list of accompanying objectives and allowed the crews to experience the different environmental conditions and witness the varied spectrum of animals going about their nightly routine. The reef is altogether a different place at night and this dive was always rated as a highlight by each of the crews.

## Feedback from the Participants

Feedback from the personnel involved in the mission was universally positive. So far they have unanimously thought the activity was a worthwhile experience and that they learned things they could take back to perform their jobs more effectively.

An ever recurring theme from all of the crews during the mission debriefs was that they felt like they were on a real mission and not just a simulation or training exercise. The ever present personal danger required constant vigilance in safety. Because of the high degree of mission complexity, with multiple competing priorities and objectives, there was always a flight-like sense of pressure to get the tasks done, as well as to work together effectively as a team. The fact that there were mission rules, prioritized objectives, and procedures made for a strong comparison to space flight. Even building basic structures with the handicap of being in a foreign environment and dependent on a life support system on one's back was a good exercise applicable to space-based EVAs. Learning to be a "proxy scientist," the eyes and hands of the PI, was directly applicable to spaceflight expectations of an astronaut. Generally, crewmembers showed a high degree of curiosity about the science, and were not content to just be data collectors. Finally, PAO /educational outreach events were a highlight for crews. These were greeted enthusiastically, as the crews were delighted to share their unique experience.

**Lessons learned**

Many lessons were learned during the missions, and the NEEMO team tried to incorporate crew suggestions in each succeeding mission. There were literally hundreds of suggestions for improvement and lessons learned. The most relevant of these were:

- Begin crew bonding prior to the mission. The crews really enjoyed living together as a team during training prior to the mission. Simple things, such as eating meals together strengthened the crew before the mission. They were much more cohesive by the time the mission was started than expected. One NEEMO crewman stated that he was closer to this crew than his previous space flight crew at the time of lift-off after a year of training together.
- Allow the crews to be involved in procedure development for the in-water (EVA) tasks when possible. This included both pre-mission and real-time mission changes to the procedures. Generally, they were happy to learn and follow the procedures developed for the in-habitat science objectives.
- Develop a means of taking a break from training in extreme environments and calling a "time out." This signal will let all parties know that they need a training time out.
- People that are troublesome during the training week as far as teamwork, promptness, etc. will bring those same attributes to the mission.
- Integrate all of the mission inhabitants to form a cohesive crew. The NASA aquanauts felt that the NURC hab techs were key to the mission success and safety and should be included in as many activities as possible.
- Tasks underwater take much longer and are more difficult even when practiced topside. Simple tasks became complex problems in some cases. It was best to have a low expectation on the quantity of science a data collection team could perform.
- Keep Topside communication to a minimum and pre-plan if possible. Give the crew a very detailed plan, the tools to do their work and then let them do it. Keep surface-based interference to a minimum.

- Provide daily status (e.g., via a daily status email). Families, management and friends feel better and are much more involved when they receive daily progress reports on the mission. This is especially true during the dynamic phases of the mission, such as decompression. Also, explain to them what is happening to the aquanauts (such as the fact that they are saturated after 24 hours.)
- Discourage visitors to the habitat. Visitation takes away from the effectiveness of the mission. The isolation factor is compromised when this occurs.
- Assume that the underwater communication during the EVA exercises and outreach events will be poor (often it is) and have a back-up plan. Don't let the communication system ruin the results.
- Simple things can lead to huge results. A line tagging exercise was a very simple task but ended up being a good analog that yielded new and relevant data that was used on a daily basis by the NEEMO team and also provided another level of safety.
- Ramp up the difficulty of the mission from the beginning to the end. Start the mission with simple dives: orientation, photo, and comm. gear familiarization dives, which are very important for the first couple of activities. Let the crews mature in their teamwork, adapt to the environment and equipment and increase their dive skills before the complex tasks are undertaken.
- Value crew input in the re-planning process when developing a plan from topside. They are the ones living in this extreme environment and understand their capabilities the best.
- Take care to eat a balanced diet each day. There are many unusual stresses on the body, and the temptation to eat high-energy junk foods is very high.
- Take care of any medical issues early. Small medical problems can become large ones if not treated expeditiously.

## Summary

The NEEMO 1 – 5 missions exceeded all expectations. The opportunity to live in the extreme environment afforded by Aquarius, along with careful mission planning, proved a tremendously good analog to a space mission. NEEMO missions are now used as the "graduate school" of exercises designed to prepare future ISS crewmembers for their ISS missions. Furthermore, NEEMO has proven itself to be an important test bed for a wide range of Life Sciences research. It will be used to a much greater extent in future missions to investigate problems on the "critical path roadmap" to Mars missions, as well as for operational and procedural checkouts of equipment and concepts that are slated for ISS missions in the near future.