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Lunar-Mars Life Support Test Project, Phase II: Human Factors and Crew Interactions

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ABSTRACT

Phase II of the Lunar-Mars Life Support Test Project was conducted in June and July of 1996 at the NASA Johnson Space Center. The primary objective of Phase II was to demonstrate and evaluate an integrated physicochemical air revitalization and regenerative water recovery system capable of sustaining a human crew of four for 30 days inside a closed chamber. The crew (3 males and 1 female) was continuously present inside a chamber throughout the 30-day test. The objective of this paper was to describe crew interactions and human factors for the test. Crew preparations for the test included training and familiarization of chamber systems and accommodations, and medical and psychological evaluations. During the test, crew members provided metabolic loads for the life support systems, performed maintenance on chamber systems, and evaluated human factors inside the chamber. Overall, the four crew members found the chamber to be comfortable for the 30-day test. The crew performed well together and this was attributed in part to team dynamics, skill mix (one commander, two system experts, and one logistics lead), and a complementary mix of personalities. Communication with and support by family, friends, and colleagues were identified as important contributors to the high morale of the crew during the test. Lessons learned and recommendations for future testing are presented by the crew in this paper.

INTRODUCTION

The National Aeronautics and Space Administration (NASA) has established as one of its major strategic goals to expand human presence beyond low Earth orbit as part of the Agency's Human Exploration and Development of Space (HEDS) Enterprise. The HEDS mission is to open the space frontier by exploring, using and enabling the development of space, and to expand the human experience into the far reaches of space [1]. One of the critical technologies necessary to achieve these goals is the development of regenerative life support systems to sustain human life on long duration missions (e.g., Mars outpost [2]). NASA has established the Advanced Life Support Program to develop critical life support technologies, and a series of human tests have been initiated at the NASA Johnson Space Center (JSC) to evaluate both physicochemical and biological systems [3,4]. These tests are associated with the Lunar-Mars Life Support Test Project, although the program was previously called the Early Human Testing Initiative (EHTI). Three tests (Phases I, II, and IIa) have been successfully completed in this program, as shown in Figure 1.

Phase II of the Lunar-Mars Life Support Test Project was conducted in June and July of 1996. The primary objective for Phase II was to develop and test an integrated human life support system capable of sustaining a crew of four for 30 days in a closed chamber. The life support system included physicochemical air revitalization and regenerative water recovery systems, and an active thermal control system to reject excess waste heat from the chamber. Other objectives for the test included cooperative research related to human factors and psychological aspects of the crew. This paper provides an overview of some human factors of the Phase II test, including a description of the human accommodations and pre-test, in-test and post-test crew activities. In addition, comments on the experience from the crew perspective are presented, along with lessons learned and recommendations in support of future long duration testing and space missions with humans.

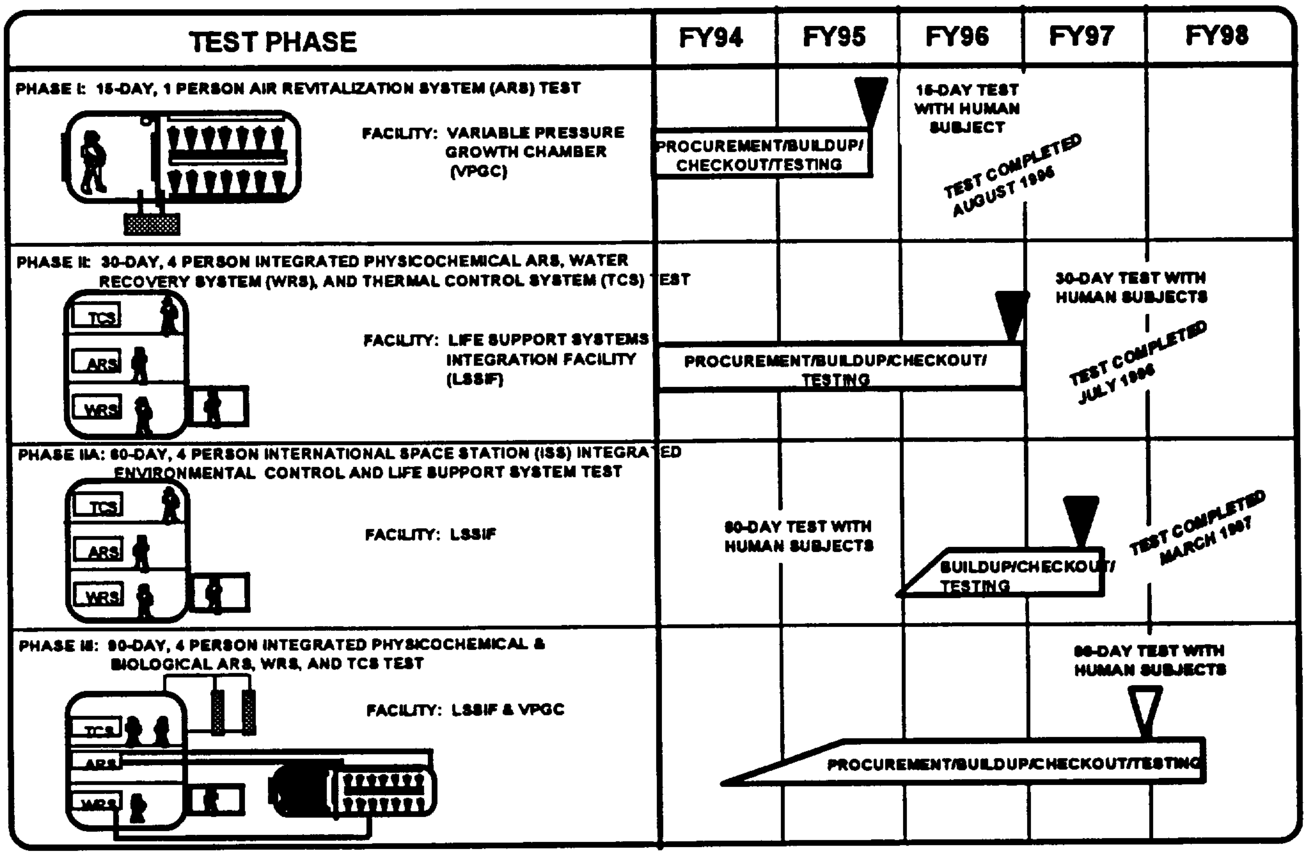

Figure 1. Schedule for the Lunar-Mars Life Support Test Project and International Space Station Testing.

HUMAN FACTORS

HUMAN ACCOMMODATIONS – The chamber used in the 30-day test was modified from an existing cylindrical vacuum chamber with a diameter of 6.1 meters and a height of 8.4 meters. This chamber, also known as the Life Support System Integration Facility (LLSIF), is separated into three working levels and it is outfitted with an innerlock to provide an access port. The innerlock is 3 meters in diameter by 1.5 meters in length. Figure 2 shows a functional schematic view of the chamber.

The first floor of the chamber provides the general living quarters for the crew, but also houses the water recovery system which is described in detail by Versotko et al. [5].

First floor crew facilities included a full bathroom (i.e., shower, urinal collection device, sink, mirror, storage shelves and fecal collection stool), dining and social area, and food storage and preparation area (Figure 3).

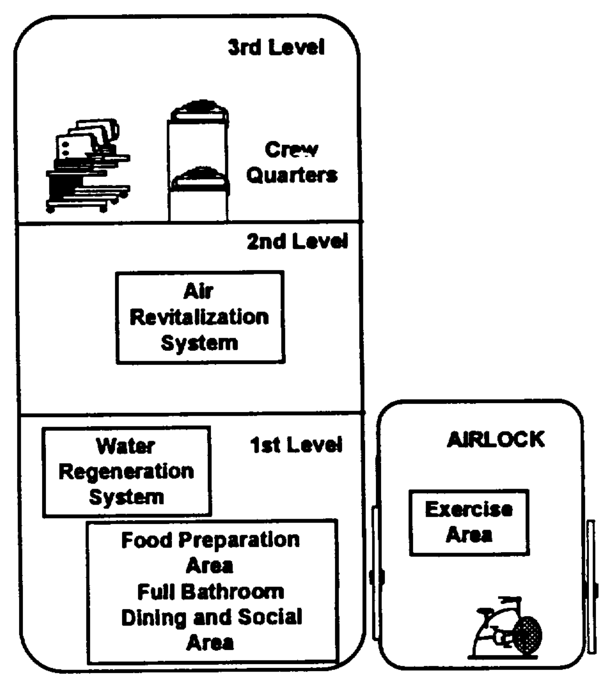

Figure 2. Functional Diagram of the chamber used for the 30-day test.

1st Level Layout

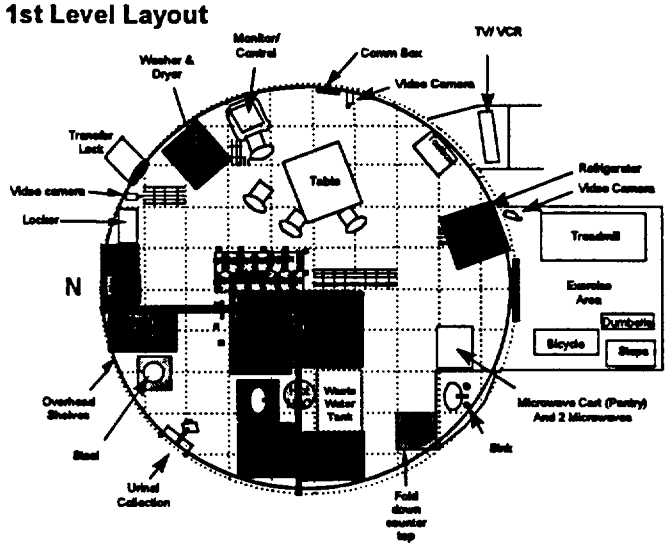

Figure 3. First Level of Chamber (VCD = Vapor Compression Distillation unit; UF/RO = Ultrafiltration/Reverse Osmosis; APCOS = Aqueous Phase Catalytic Oxidation Subsystem; WQM1 = Water Quality Monitor).

The dining, social, and food areas were outfitted with a table and four chairs, stacked washer/dryer, refrigerator, two microwave ovens, food pantry, counter and sink, television/VCR, and a storage locker. Additionally, a control/monitoring station and tool box were located on the first floor to support crew in-test activities as described in later sections. Video cameras and a communication box were provided to allow the crew to communicate round-the-clock with the control room test team. A transfer lock was also included on the first floor and allowed for transfers of food, equipment, sampling materials, and waste into or out of the chamber as necessary throughout the test. The innerlock attached to the chamber was used as the exercise area, and was equipped with a treadmill, stationary bicycle, hand weights, steps for aerobics, portable stereo, and 2 cassette players with headsets.

Air revitalization systems and thermal control system components were located on the second level of the chamber (Figure 4). The air revitalization system is described in detail by Brasseaux et al. [6]. With the exception of a video camera, communication box, and laser-jet computer printer, no human accommodations were placed on the second floor for the Phase II test.

The third level of the chamber provides the primary crew quarters, including four private offices/living areas (Figure 5).

Each quarters had approximately 50 sq. ft. of living area, and was equipped with a bunk and mattress, bookshelf, locker, desk, chair, telephone, reading lamp,

2nd Level Layout

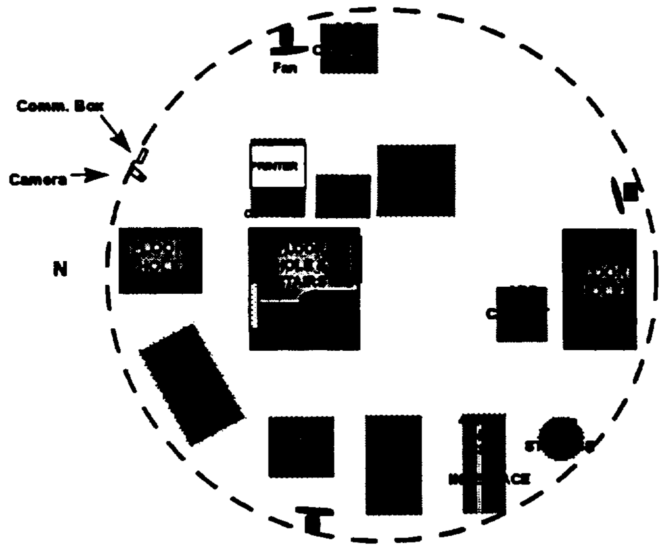

Figure 4. Second Level of Chamber (ITCS = Thermal Control System; 4BMS = Four Bed Molecular Sieve; CRS = Carbon Reduction System; OGS = Oxygen Generation System; ARS = Air Revitalization System).

wastebasket, clothes bag, electrical outlets, and an extension cord. Crew members were provided clothing and personal hygiene items (stored primarily in their private quarters), which were compatible with the life support systems; however, additional personal items (e.g., books, work-related documents, items for leisure activities, special hygiene requirements) were also evaluated and approved for crew usage by the test team.

PC workstations were located in each crew member's private living quarters. Workstations were Pentium 100

3rd Level Layout

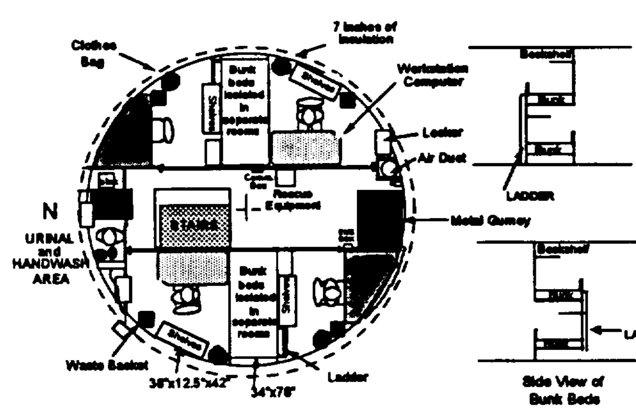

Figure 5. Third level of Chamber.

MHz machines with sound cards, data/fax modems, TV and network cards and provided video conferencing, phone/voicemail, Internet access, and e-mail. In addition, each workstation had a communication box similar to those on each chamber level. A hallway with a centralized communication box, video camera, and "half" bath was also located on the third level. The upstairs bathroom facility included a urinal collection device, sink, mirror, and cabinet. A rescue hatch was incorporated on the third level, with an opening on the second level as well, to allow for the extraction of an injured/incapacitated crew member should the need arise.

The Phase II Patch is shown in Figure 6 and symbolizes the chamber layout and primary objectives for the 30-day test, including the four crew members on the third level, the air revitalization (symbolically) on the second level, and the water regeneration (symbolically) on the first level.

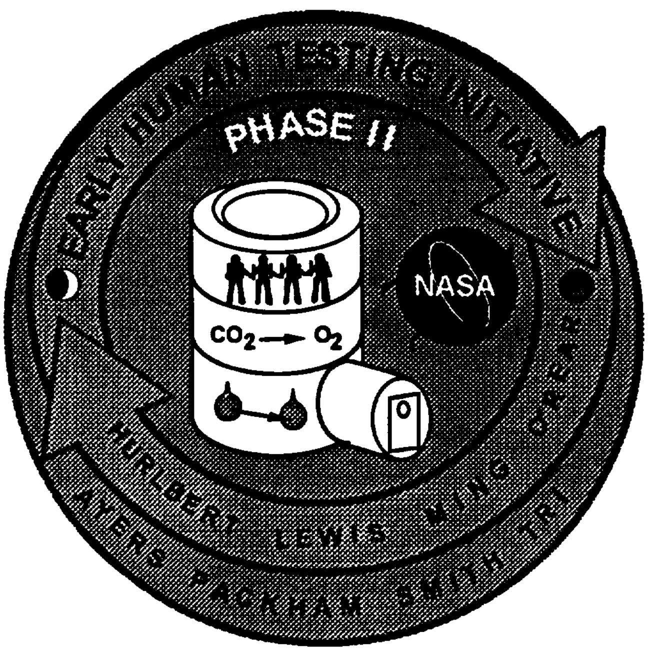

Figure 6. Phase II Crew Patch.

The names of the primary and backup Phase II crew members are also shown, and the small Moon and Mars symbols represent two potential future space missions that the life support technologies will support.

CREW ACTIVITIES

Pre-Test – Preparation activities prior to the test start primarily focused on training, familiarization with the chamber accommodations, and medical evaluations. Crew members were briefed and trained on the life support and chamber systems, including routine system maintenance expected during the testing. Two crew members had been extensively involved in the buildup of the chamber systems, and were therefore experts on the life support hardware. These crew members gathered appropriate tools, spare parts, and documentation to perform the planned maintenance inside the chamber during the 30-day test. Items with a limited life or those that could not be provided through the transfer lock were stored inside the chamber as required (e.g., filters).

To familiarize the crew with the human accommodations, 24 hour "sleep-over" tests were completed. These tests were used to identify any changes or enhancements to be implemented prior to the test start, and some minor changes were made to support the comfort of the crew. This time also allowed the crew members to evaluate items provided to conduct their normal duties, including their personal computer workstations and software. In addition, two food and regenerated water taste panels were conducted to identify personal tastes and preferences. The crew filled out food surveys, and menus were prepared by personnel from the JSC Food Systems Engineering Facility. The menu was designed to provide common meals for the four crew members, and was repeated every 10 days. Frozen, shelf stable, and fresh foods were provided and re-supplied throughout the test, along with dehydrated drink mixes and juice concentrates. The first floor pantry provided storage for "snack" items (e.g., granola bars, chips) and imported foods sent through the transfer lock were minimized (e.g., limited milk, 2 cans of soda per day per crew member).

Both physical and psychological evaluations were completed prior to the test start. All crew members passed a Class III Air Force Physical prior to their selection. Extensive blood work was performed immediately prior to the test, and microbiological analyses (saliva) were taken daily for 14 days pre-test. The day prior to the crew ingress, blood, urine, stool, nasal, and throat analyses were performed and each crew member was given a brief physical. In addition, all crew members were given psychological evaluations prior to their selection, and were further briefed by NASA JSC psychologists to prepare them for the expected environment. To support "team building," regular crew meetings and frequent scheduled social events (e.g., crew lunches) were held over several months prior to the test.

In-Test - During the 30 days inside the chamber, the crew performed numerous tasks. Figure 7 shows a typical daily schedule, with variations for each crew member based on their personal preferences and assigned responsibilities.

Generally, the crew maintained the schedules shown in Figure 7; however, deviations from the schedule were common due primarily to system maintenance, regular duty tasks, and public affairs opportunities. The crew did maintain one common mealtime (dinner) even if the overall daily schedule was shifted. Regular job duties were performed when possible, however, the crew

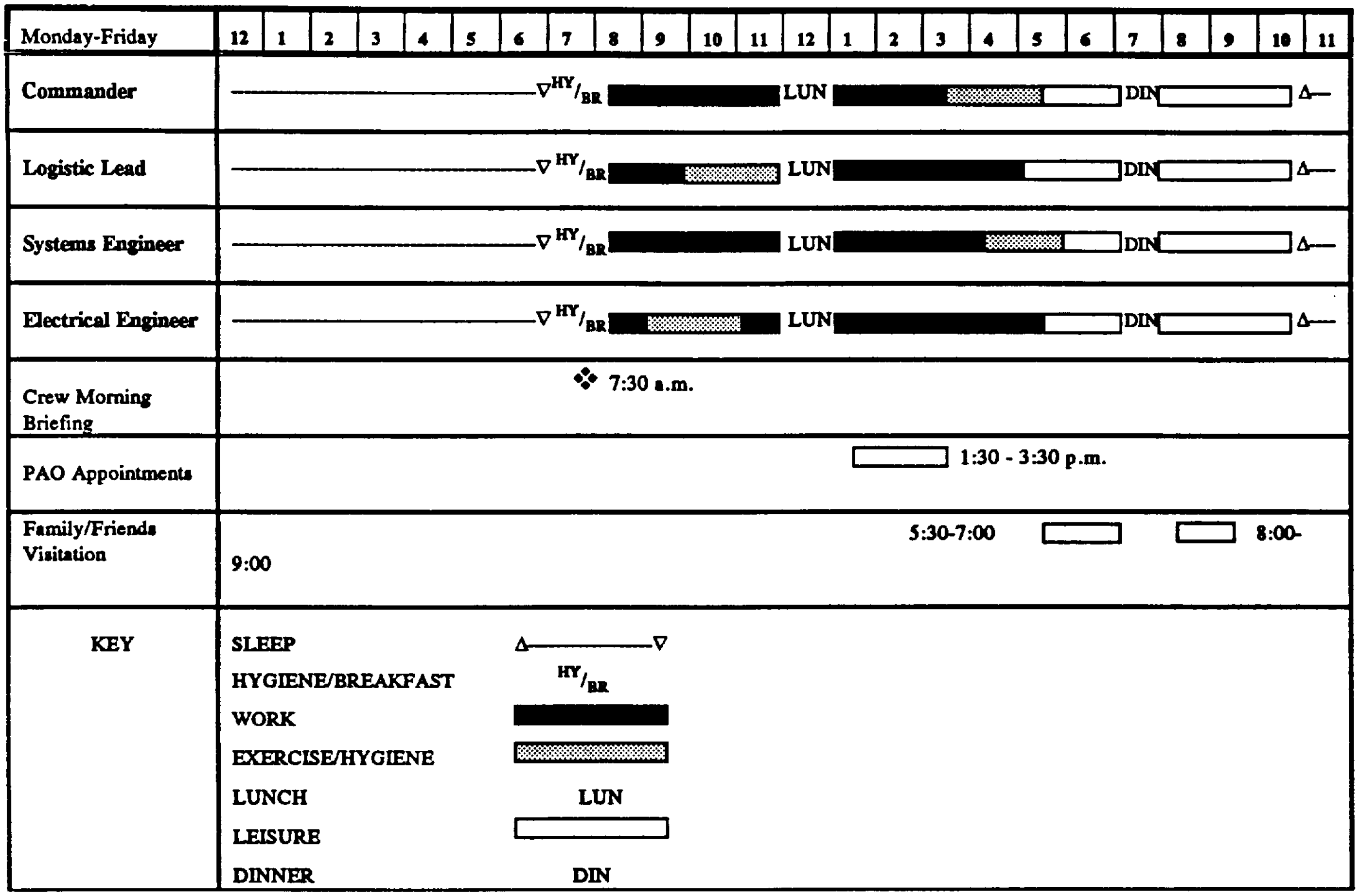

Figure 7. Typical schedule for all four crew members during weekdays (Monday through Friday).

consensus was that chamber activities did not allow for the same productivity level as a standard workday.

To challenge the air revitalization life support systems, the crew was required to exercise consistently throughout the test. Exercise periods were nominally one hour each day per crew member, for six consecutive days and then one day off (generally Sunday). Near the end of the 30-day test, each crew member conducted a CO_2 calibration using a CO_2/O_2 analyzer to provide data for post-test modeling for the Air Revitalization System.

Because of the limited water supply inside the chamber, daily hygiene activities required more time than normally encountered at home. Each crew member used their own "funnel" to interface with a system receptacle for urine collection, and bagged their own solid waste for storage and transport out of the chamber. All hygiene activities were logged and closely tracked to support the post-test mass balance modeling.

Systems inside the chamber frequently required crew interactions, with the support and concurrence of the control room test team. The importance of human interaction with systems was evident in the unplanned or unexpected tasks, including repairing or replacing components. During the first two weeks of the test, the crew worked nearly round-the-clock on several occasions to fix system problems, while the last two weeks of the test required less time for maintenance. The crew also routinely performed planned maintenance (e.g., filter changes, sampling). The first floor control/monitoring station provided the crew with a diagnostic tool to monitor the systems in the chamber, and also allowed dynamic modifications to the systems control code if necessary.

Communication with the "outside world" was a very important function of the crew's daily activities. Crew members contacted control room personnel via the audio communication boxes and video conferencing provided in the chamber. The crew was also able to view the control room through a stationary video camera mounted there, which could be displayed on a dedicated channel on the first level TV or on the PC workstations in the private quarters. Personal communications were also important on a frequent basis, and primary communication with family members and friends was through video conferencing, telephone, and e-mail.

Crew members participated in heath-related activities during the 30-day test as well. NASA psychologists, medical doctors, and microbiologists regularly visited the control room to check on the crew. Microbiological samples (saliva) were taken daily by the crew, and nasal and throat analyses were taken at days 11 and 22 after the test start. In addition, chamber surface and air microbiological samples were taken approximately every 6 days, and required between 2 to 3 hours from two crew members each time. An modified Antarctic psychological questionnaire was completed by each crew member twice weekly on a laptop computer. The questionnaire required about 15-20 minutes from each crew member for each session, and was used to evaluate the psychological aspects of the isolation experience.

Post-Test - The primary post-test activities for the crew were receiving medical evaluations to ensure their health and well-being after the experience, and to prepare a presentation to provide feedback to the entire test team. Each crew member received a brief physical immediately after egress from the chamber. Blood, urine, stool, nasal, and throat analyses were taken one hour after egress. In addition, microbiological analyses (saliva) were taken daily for 14 days after egress. A full post-test physical was performed 15 days after leaving the chamber, and each crew member also had a debrief with the Antarctic psychological questionnaire requesters and the NASA psychologists relative to their personal observations and experiences.

The crew did conduct a thorough post-test briefing shortly after the completion of the 30 day test for the test team, which emphasized the importance and success of the human factors team. Many of the details of this debriefing are included in the next section.

CREW PERSPECTIVES

GENERAL CONDITIONS – Overall, the four crew members (3 males, 1 female) found the chamber to be comfortable and the provisions to be adequate for the 30 day duration. The 3rd level living quarters allowed a place for privacy and quiet time. The environment provided by the life support systems was good, with the only noticeable air odors occurring during and immediately following exercise periods in and near the innerlock, and from biological waste from fecal materials and spent filters during transfer activities out of the chamber. The taste of iodine was noticeable in the recycled water at the test start, but the crew became accustomed to the taste shortly into the testing. The addition of drink mixes and juice concentrates to the recycled water also helped to alleviate the iodine taste. The food provided was generally enjoyable, and "surprise" foods passed through the transfer lock were a morale boost.

CREW INTERACTIONS - The four person crew performed well together for the 30-day test. The crew members attributed this in part to the team dynamics, and the skill mix (i.e., one commander, two systems experts, and one logistics lead) was believed to be an important aspect. The chamber systems demanded a considerable amount of the systems experts' time, while the other two crew were available to perform other duties (e.g., sampling, logistics). Also, it appeared important to have a complementary mix of personalities. Communication and support by family, friends, and colleagues was identified as one of the largest contributors to the morale of the crew and the success of the test. The morale was maintained at a high level throughout the 30 days, and no noticeable negative affects on any crew member from the confined environment were observed.

LESSONS LEARNED/RECOMMENDATIONS - After leaving the chamber, each crew member presented their viewpoints on lessons learned and recommendations. Below is a condensed list:

- Maintain hardware accessibility for maintenance
- Provide dual hygiene supplies on first and third level bathrooms to reduce trips on the stairs
- Maintain a public relations schedule
- Stress the team concept, both inside the chamber and in the control room
- Crew Communication Officer in the control room is an invaluable point of contact
- Keep the communication bandwidth, [i.e., keep a variety of communications pathways in and out of the chamber (e.g., phone, e-mail, video conferencing, communication boxes)]
- Allowances for the crew and/or team members should be made concerning their normal work duties
- Crew experienced less than anticipated leisure time during the test
- Team dynamics were ideal for this test
- Pre-test preparations were greatly hurried
- Plan for PAO activities (improve chamber remote camera capabilities)
- Consider only one crew for the upcoming 60- and 90-day tests
- Strong support by family, friends, and co-workers is essential and a direct contributor to the success of the test
- Management, co-workers and outside team should be briefed/sensitized to the psychological aspects of the test
- Because the human element is very important to the Lunar-Mars Life Support Test Project, human factors need to be a higher priority and strongly supported
- Early crew selection is encouraged (e.g., allows more planning/preparation, focuses the work and the team)
- Highest stress periods were encountered by the crew going in and coming out of the chamber, and the crew could use some "down time" right before and right after the testing
- Recommend PAO training/preparation activities for crew
- Place control room camera view on separate dedicated video channel

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