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The Lunar-Mars Life Support Test Project: the Crew Perspective

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Commander, 91-Day Test

SUMMARY

A series of four tests of advanced life support (ALS) systems were performed from 1995 to 1997 at the National Aeronautics and Space Administration's (NASA) Johnson Space Center. Human crews of up to four persons spent up to 91 days inside closed environmental chambers. Originally called the Early Human Testing Initiative (EHTI), the project was later renamed the Lunar-Mars Life Support Test Project (LMLSTP). A total of over two person-years of confined testing were performed during EHTI and the three phases of LMLSTP. The first test (EHTI Phase I) was designed to evaluate the performance of plants and their ability to provide the air revitalization function of an advanced life support system. In 1995, one crewmember spent 15 days in a small chamber (approximately 2.5 by 2.5 by 2.0 meters) breathing the oxygen produced by 22,000 wheat plants growing in an adjacent chamber. In later years, the three phases of LMLSTP were performed in a larger (6-meter diameter) chamber housing four crewmembers at a time. With each phase, the complexity of the systems under test was increased. Water recycling, air revitalization, and waste processing technologies were investigated, employing both biological and physicochemical approaches. As the duration of the tests increased, finally approaching projected mission durations for individual crews on board the International Space Station (ISS), the crewmembers also became a resource for investigators in the areas of human factors, medical sciences (both physiology and psychology), and crew training. Rather than going into detail about the life support or experiment approaches of each test, this report will focus on the unique aspect of the test from within the closed chambers from the crew's perspective.

General Background

Crewmember volunteers were solicited from within the ALS community, initially focusing on scientists and engineers within the Johnson Space Center. For later tests, the entire ALS community (the four prime NASA centers engaged in

ALS activities, academia, and industry) was seen as a source of viable crew members. Although not a primary objective of the series of tests, one of the benefits of using scientists and engineers rather than flight-certified astronauts was that it provided those selected individuals with valuable insight in how to design, build, and test better life support system components and subsystems. Science disciplines ranged from chemistry to food science, microbiology, and soil science. Several engineering disciplines were represented including mechanical, electrical, aerospace, and chemical.

Crews were of mixed gender (except the single crewmember in EHTI Phase I). In the LMLSTP, crews were made up of a commander, two life support systems technical experts, and an individual who coordinated science activities within the chamber. The commander's duties involved representing the crew with outside entities, including management, visitors, and education/outreach groups. One of the more challenging tasks for the commander was to relay the fact that the test was more than just four people stuck in a chamber. The science crewmember acted as the sole point of contact between principal investigators from the science disciplines and the crew, setting schedules for each experiment activity. The life support systems experts, together with the systems test control room personnel, maintained, repaired, and optimized/evaluated all aspects of the life support systems within the chamber.

Crew selection was loosely based around the astronaut selection process. A crew selection committee evaluated the individuals who applied based upon the skills mix anticipated for that particular test. Medical testing (equivalent to an Air Force Flying Class III medical), coupled with in-depth psychological testing, provided a short-list of qualified individuals from which to build a crew. Back-up crewmembers were always selected in case one of the prime crew could not participate further.

Crew training prior to the test depended upon the exact objectives of the specific test in question. For example, microbiological sampling was taught to the crewmember in EHTI Phase I so that plant, atmosphere, and surface sampling could be performed. By the time LMLSTP occurred, two crewmembers had been trained as phlebotomists and as crew medical officers, all crewmembers had undergone extensive isolation training at an underwater facility in Key Largo, and the entire test team had participated in a crew/control room resource management class to minimize the "us versus them" potential.

Crew Selection

From the crew selection viewpoint, it may be surprising to most to find that the potential crewmembers went through very similar experiences as potential flight crewmembers might. Having personally been through both processes, the emotions experienced throughout each of the waiting periods between interview and selection announcements were very similar. However, the same camaraderie that exists between astronaut candidate interview groups was also plainly evident during the chamber crew selection process.

One important factor that must be carefully considered is the effect of any change in selected crew configuration at any time after selection. Moreover, the closer to test start any change occurs will correspondingly increase the impact to crew cohesion during the test itself. Therefore, unless absolute necessity demands a crew change, all efforts should be focused around a way to include, rather than preclude, specific crewmembers from participation.

Test Preparation

Different crewmembers prepared for each of the tests in widely different ways, dependent mainly upon their role during the test. The life support specialist crewmembers spent the majority of their time prior to the start of the test getting the systems ready for test. Similarly, the science specialist crewmembers spent the majority of their time understanding the objectives and procedures necessary to successfully complete each of the science projects. The commander's role was primarily one of a support person during the pretest planning phase, spending as much time as possible with both fellow crewmembers and test management personnel.

A portion of pretest planning involved getting one's affairs in order both at home and at work. Obviously, this involved an increased dependence upon other people (family, friends, and co-workers). No attempt was made to make the chamber living quarters like a home, but the bare essentials for living were provided.

There is nothing that can be done to prepare the crewmember for the instantaneous change that occurs on the morning of the test start. Bidding farewell to family and friends seems an almost comical process since the crews are the ones going nowhere while friends and family are the ones departing for home.

The feeling that the test is actually a "mission" is an important concept to realize. Indeed, although the chamber and its inhabitants are going nowhere, most crews took on the test as a mission, especially as test durations approached the types of lengths of missions aboard the Mir or the ISS.

The First Few Days

Settling in to chamber life took several days. The stark contrast between the pretest preparations, specifically the chamber entry celebrations, and the relative quiet of the chamber took some getting used to. However, once a daily routine was established (a few days), the crew settled in for the long haul. Again, although pretest planning helped a great deal in terms of individual roles and responsibilities, the first few days were used to further refine these roles so that each crewmember knew exactly who was responsible for what. The benefit of starting the test on a Friday was also evident in that the weekend was available for arranging the chamber to prepare for the duration of the test. Several audiovisual system problems and procedures were also worked on during this time.

Life Support Systems Maintenance

The two life support systems specialists fell rapidly into their roles, responding to various problems with the life support systems and subsystems. It should be noted that failures of systems or components of systems were expected and in fact welcomed. Should the test have proceeded with completely nominal performance, its value would have been significantly less than it actually was. Only by experiencing hardware and software failures can the team learn how to avoid mistakes and build better systems.

Of course, the systems within the chamber experienced failures at all times of the day or night requiring both systems specialists and, on occasion, other crewmembers, to be awakened during sleep periods. Because of this, consideration must be given to allow crewmembers additional sleep periods during normal work time to ensure sufficient rest is obtained.

Finally, a word on schedules. It is an impossible task to timeline events surrounding the life support systems or any other tasks to any reasonable degree. It became obvious very quickly that a shopping list approach to tasks would provide the best solution. Using this approach, the crewmembers could allocate time themselves during the workday. Of course, if there was a time-critical task to be performed, this could be easily scheduled, but it is suggested that for tests and/or missions of this duration, scheduling to a timeline to the same degree as shuttle missions is both impractical and impossible.

Involvement With Science

In general, excellent compliance with all planned scientific experiments was obtained for all phases of the LMLSTP. Compliance with certain experiments such as the exercise protocol was near 100 percent since they represented a valuable tool to the crewmember for both psychological as well as physiological benefits. The involvement of all crewmembers pretest was invaluable, not only from the crew training perspective, but also in failure investigations during the test phase.

One of the main reasons that the science aspect of the test proceeded so smoothly was that the crewmembers themselves arranged the pretest, during test, and posttest schedules for all science activities with the principal investigators for each experiment. Hence, no surprises arose during the test phase. Of course, adjustments to the schedules were made to accommodate other activities, but once again, these were coordinated by the crewmembers and the principal investigators real-time.

One comment from all crews was that the science experiments should be designed so that the method of collection of data should not influence the data itself. The most obvious case here was the experiment designed to evaluate crew sleep patterns. The hardware involved in this experiment interfered with the normal sleep patterns of the crew, hence giving rise to spurious data in terms of actual crew sleep patterns when the hardware was not being used. This is not meant to single out this specific experiment, but rather to suggest that careful consideration be given to methods of data collection.

Time Shifting

Interestingly, had the crew been left to settle into their own time cycles, it is certain that they would have shifted towards a 28- to 30-hour day/night cycle. The major reason they didn't was the continuous contact with the control room. This, coupled with the fact that the crew was always aware of the time of day, kept them to a regular 24-hour day. However, it is interesting to note that most crews spent a considerable amount of time awake, compared to pre- or posttest times. On a personal note, my workday approached 20 hours, followed by 1 to 2 hours of personal time presleep. The two- to three-hour sleep period did not seem to affect my performance during the test phase. All crews have reported similar shifts in work/sleep cycles compared to pre- or posttest periods.

Environmental Effects of the Chamber on the Crew

One of the interesting phenomena of spending three months inside a 6-meter diameter chamber was the effect on the senses of the crew. Eyesight in particular was affected in several crewmembers. Since items in the chamber were no more than 6 meters away, it took a learning period of several hours posttest to acclimatize to focusing on objects further than 6-meters distant.

Hearing was another sense that was affected. Since the chamber provided a near constant, and relatively higher, ambient noise environment, upon exiting the chamber normal functions such as sleeping proved to be more difficult than previously expected. In general terms, the relative quiet of the external environment was a stark contrast to the constant noise within the chamber. Also, the constant nature of the noise inside the chamber afforded the crew an invaluable tool to assess problems with a variety of hardware. For example, when pumps or motors were experiencing problems, the crew often reported the problem long before any effect was noticed by the control systems.

Although as noted, the noise levels were generally higher than the external environment, the crew spent a considerable amount of time during the first few days of the test isolating particularly noisy areas and components. In most cases, the crew was successful in abating such noisy areas/components.

The acuteness of the sense of smell was evidenced by all crewmembers being instantly aware of new items transferred into the chamber through the transfer lock. This was additionally enhanced by the constant nature of the chamber odors, i.e., differences were very easily detected.

The lack of variable-intensity lighting inside the chamber also affected the crew. Normal circadian rhythms outside the chamber environment are influenced by a gradual darkening of the sky at night and a gradual lightening during the waking hours. Inside the chamber, conditions represent instant day or instant night, depending on whether lights are on or off. This manifested itself in a longer period of "waking up" in the morning, and a difficulty in falling asleep at night. Although the crew attempted to mitigate this effect by introducing lamps in their quarters that slowly increased in intensity in the early morning, the benefits were not obvious, and the use of the lamps in this manner was discontinued.

A Question of Confinement

One of the most common questions asked of any of the chamber crews is how they were able to cope with long periods of confinement in a small chamber. The answer from all of the crewmembers has been consistent. One very rapidly adapts to the surrounding environment. Therefore, as soon as the chamber door was closed (and remembering all of the pretest preparations), the limitations on the environment switched instantaneously. Indeed, perhaps the more challenging task was exiting the chamber after having become accustomed to the small volume.

If you couple the small volume of the chamber with the addition of three other crewmembers, the logical question now changes to "How did you cope with being around three other people in such a small space?" Apart from long-duration space flight, there really is no analogous situation that you could conceive whereby you would spend three months in the company of the same individuals for every waking hour.

The answer to the above question for all crews has been the same. There were no problems at all inside the chamber. There were perhaps some miscommunications between the inside crew and management which led to some issues in the early phases of the project. However, as lessons were learned, and as test durations increased, more emphasis was placed on an overall team-integration approach including resource management with all team members, including management.

One aspect of crew life that has to be accepted is the lack of privacy inside the chamber. Although each crewmember had his or her own crew quarters, the doors were rarely closed. Also, unless one was alone on the first floor of the chamber, there was absolutely no audible privacy, i.e., all conversations, whether work or family-related, were heard by all. What this drove was a complete requirement for trust within the chamber, which was complied with in every case. This respect of privacy needs to be continued to the outside crew. Communications by electronic or other means should not be forwarded, referenced, or communicated in any fashion to personnel who do not need to know, unless the release of such information is granted by the initiating crewmember.

Unexpected Happenings

Other than the expected problems with the life support system hardware and controls software, several unexpected events occurred during the 91-day test. The first was a complete power outage across the entire Johnson Space Center. Although back-up generators were supposed to automatically start-up, for some reason, the crew was left (literally) in the dark for a short period. The only lighting came from the glow of our laptop computer screens, running on battery power. Since all of the life support systems lost power, the quiet of the chamber became deafening, leading to the thought that perhaps the living breathing chamber had indeed taken its last breath. Of course, the crews both inside and outside set about the task of safing the system for the return of power. When power was reestablished, a quick survey of the systems and the chamber revealed no damage from the short outage.

Alarms were actually few and far between throughout the 91 days, and all were caused by faults in the alarm systems (i.e., false alarms). Whenever an alarm did go off, the crew (per test rules) immediately made their way to the airlock door in case evacuation was necessary.

One constant throughout the test series was the ability of the chamber to “know” when the last day of the test was. This may seem to be a strange comment, but in all four phases the last day proved to be one when alarms were rife. For example, on the ninety-first day of the final test, I happened to be taking a long shower, having been cleared to use as much as I wanted since all water recycling operations had ceased. In the middle of my glorious five-gallon shower, the alarm (false) sounded. During an alarm, all water supply to the chamber ceases. Therefore, still covered in soap, I managed to make my way out of the shower to the first floor waiting area. Power to the systems was eventually reestablished, but I can only guess what a sight I must have been with a towel wrapped around me trying desperately to reconfigure the tanks and valves using the computer mouse with soapy hands. Having finally managed to turn the water supply back on, I recommenced my shower. One minute later, it happened again.

The Absolute Need for Humor

One very important characteristic of long-duration crewmembers and the people who sit at the console day after day is to have a sense of humor. Without one, you may just as well shut your door and let three months pass you by. Humor provides a release of tension and is an invaluable tool to defuse critical situations. This is not to say that practical jokes need to be a part of everyday life inside, but to be able to laugh something off rather than let it fester was beneficial in every sense.

A variety of planned events maintained the level of humor both inside and outside the chamber. Movie nights were held each Wednesday evening with all of the test crew participating in a "Science Theatre 2000" show. Almost always, a theme was chosen for movie night such as science fiction, spaghetti westerns, or Elvis movies. The volume of singing during the Elvis night almost proved fatal to the communications system, and only through extended efforts by our audiovisual gurus did we manage to reconfigure the system just in time for our planned link-up with the STS-87 crew the next morning.

Other planned celebrations included a birthday for one crewmember (with a paper candle on her cake), Thanksgiving dinner (eaten at the same time as the control room crew), celebrations of the 15-, 30-, and 60-day marks, and the halfway point (over-the-hump day). Events such as these were beneficial in maintaining a healthy test team.

Posttest Blues

Different crewmembers have reacted to the end of the test in different ways. Some decide to leave for two weeks' vacation; some tend to stay around the chamber (some actually carried on their work after the test within the, now open, chamber). All crews were sorry to see the test end. Whether that is from the lack of being "in the limelight," or whether it is due to the loss of a feeling of camaraderie, it is difficult to say. From my personal point of view, I certainly experienced a mild form of depression in the weeks following test completion. Perhaps some of these feelings were related to not knowing the future of such tests. Whatever the true reason, it is important to provide a mechanism for discussions of feelings even after the test/mission has been completed.

Lessons Learned

Apart from the invaluable lessons learned regarding the operations and designs of the life support systems, other lessons were learned which should be examined closely for any planned long-duration testing. The first is to avoid crew changes late in the preparation phase. Although the 91-day test proceeded smoothly even with a change in crew at the test start minus 10-day mark, it was an unknown that should not have appeared that late in the flow. Crewmembers (both potential and selected), should be made aware ahead of time of specific items that could cause them to be deselected prior to the start of the test.

During this series of tests, significant medical data was collected on each crewmember. This data represents important scientific material and should therefore be used by the scientific community to help solve issues for long-duration space flight. Such data, however, can be extremely sensitive in nature. All scientific teams have been extremely conscientious in terms of maintaining the confidentiality of such data. Yet, a problem still exists. That is, the use of such data in the selection or deselection of a crewmember for future chamber tests or during application for astronaut candidacy. Unless definitive explanations about the use of collected data are provided to the crewmembers before experiments commence, what will inevitably happen is that crewmembers will either be noncompliant during the test, or will decide not to participate (an option that is always available to any test subject or flight crewmember). Of course, if the data shows there to be a life-threatening condition, then such data should obviously be included in any review for future selection.

An important aspect of communications from inside to outside was the direct contact between the system specialists on the outside with the crew on the inside, i.e., there was no single point of contact through which all communications were made (such as the "Capcom" during Shuttle/ISS missions). It was felt that the people who knew the systems should be the ones giving advice on how to maintain or fix problems with hardware or software within the chamber. Although a small amount of such contact is taking place on ISS (particularly on the Russian side), it is recommended that more leeway for one-on-one discussions be provided even for flight.

One of the disappointments during the test was the lack of public awareness. The press conference held at the halfway point was attended by one member of the local press. Ironically, since the test was completed, media from around the world have included the test series in programs in several different languages. The one common question asked by these media representatives is "Why didn't we know about this during the testing?"

The final lesson learned is that testing with humans in the loop is an absolute necessity to understand the intricacies of life support systems. Real metabolic profiles, real-time problem diagnoses, and instantaneous feedback are just some of the benefits of human crews.

So. What's Next?

It would be foolish of me to suggest that we are ready to take the big step of going outside low-Earth orbit (LEO) back to the Moon or on to Mars. We are, however, in a much better position to design, build, and test a life support system that will get us there and back safely. We are dependent upon the ISS to act as our proving ground for the Mars transit vehicle, since we have little to no understanding of how our systems will react to a long-duration microgravity environment. ISS will give us the benefit of a long-duration test bed, without the added risk of being a year away from home.

Although the advanced life support project has accumulated 195 days of closed-chamber testing, it is certainly insufficient to be able to design the final flight hardware.

The BIO-Plex will be our ultimate test bed before we commit to flight designs. This closed-loop test bed will provide scientists and engineers with a high-fidelity environment to develop the reliable and optimized system to keep our crews alive for long durations (up to one and a half years).

Whether or not the global community decides to venture beyond LEO and to take the next giant step, the LMLSTP series of tests has taken the first small step to make it possible to do so. I truly believe that the benefits that LMLSTP has given the agency will prove to be invaluable when and if the call is made.

FURTHER INFORMATION

Photographs of each of the crews follow. However, many more photographs, including ones taken by the crew, are available on the Advanced Life Support Project Web site: http://advlifesupport.jsc.nasa.gov.

If, after visiting this site, you still have questions, the Advanced Life Support Project at the Johnson Space Center would be happy to hear from you:

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Figure 1.3-1
This group portrait shows the EHTI Phase I team, with the in-chamber crewmember visible through the window

Figure 1.3-2
The entire EHTI Phase I team poses for a group portrait as the crewmember joins in the back row

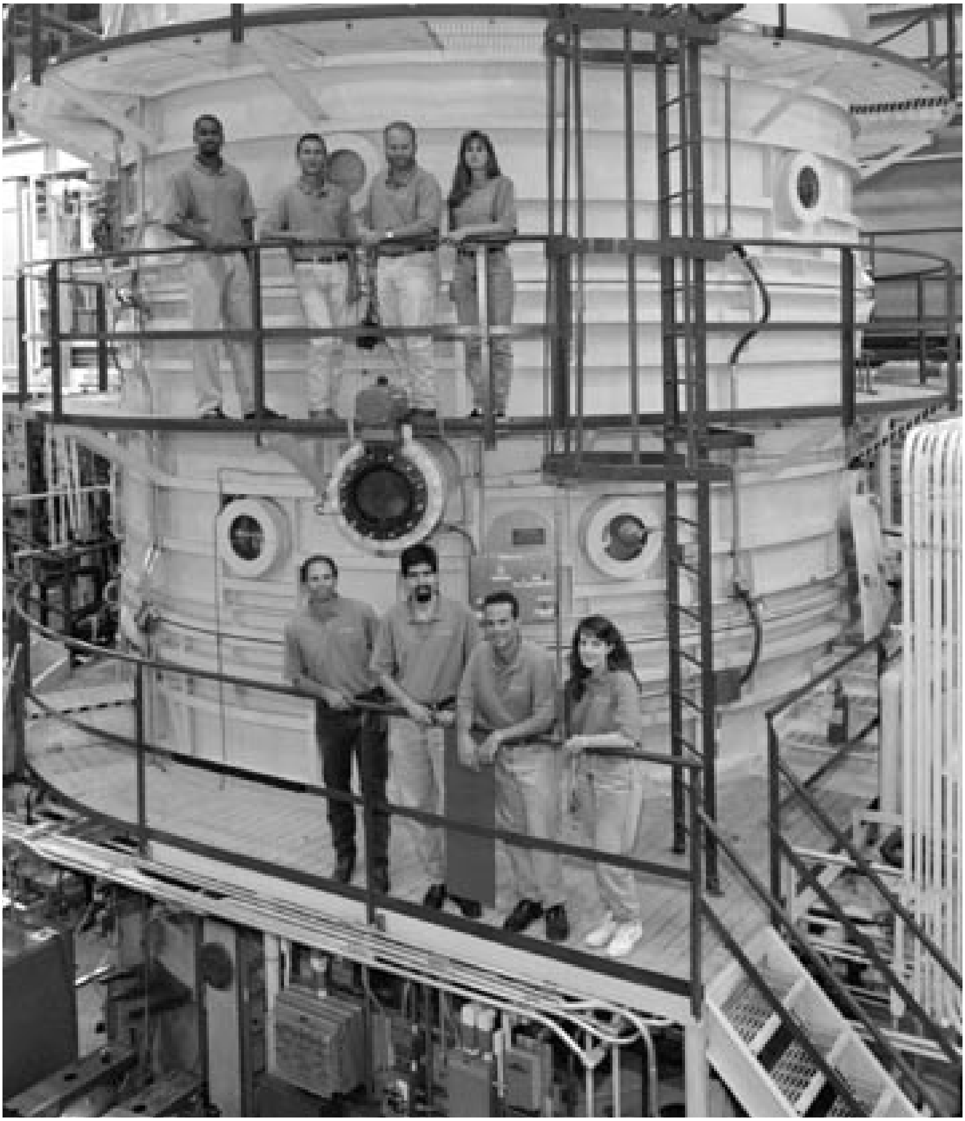

Figure 1.3-3
The LMLSTP Phase II crews stand outside of the testing chamber, including the primary crew (bottom row) as well as the back-up crew (top row)

Figure 1.3-4
The 20-foot test chamber is surrounded by the test team and crewmembers for LMLSTP Phase II

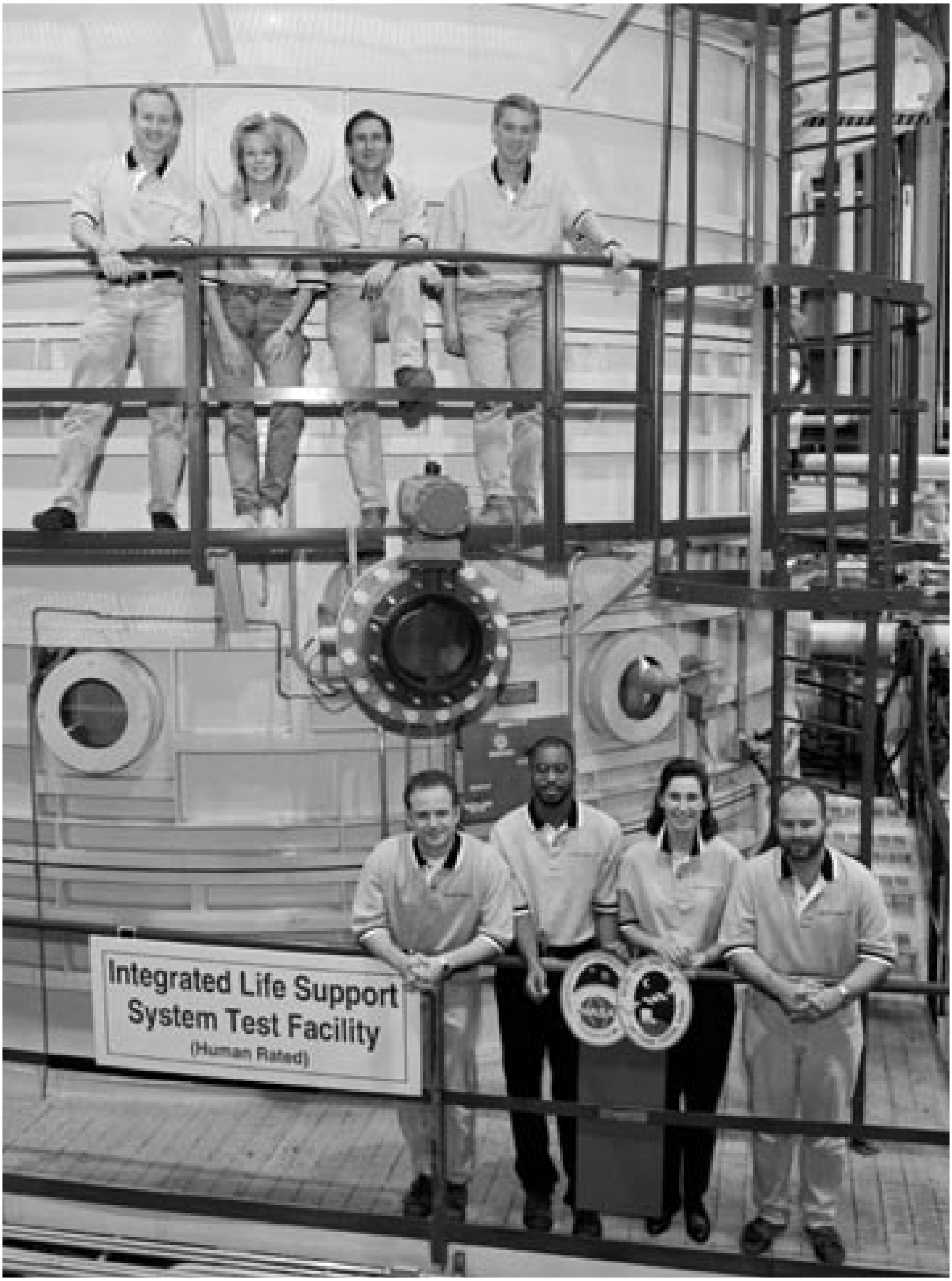

Figure 1.3-5
With the 20-foot chamber serving as the backdrop, the Phase IIa primary crewmembers stand on the lower balcony and the back-up crewmembers pose on the upper balcony

Figure 1.3-6
In this Phase IIa group photograph, the primary and back-up crewmembers gather on the lower balcony while surrounded by other Advanced Life Support personnel

Figure 1.3-7
The Phase III primary and back-up crews pose in front of the testing chamber

Figure 1.3-8

Before the start of the test, the entire LMLSTP Phase III staff poses for a group portrait