3.1

Architecture

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SUMMARY

For the Lunar-Mars Life Support Test Project (LMLSTP), the retrofit of an existing 6-meter (20-foot) vacuum chamber, renamed the Life Support Systems Integration Facility (LSSIF), was challenged to provide for a human's basic needs, in addition to those that would be required given the unique nature of the environment and test objectives. Located within a building at the Johnson Space Center, only a limited volume was available within the geometry of the chamber, which was already divided into three levels. Each floor provided approximately 29.1 square meters (314 square feet gross area) and 226.5 cubic meters (approximately 8000 cubic feet gross volume) for crew functions and equipment. Required was an overall plan to divide each of the levels into functional spaces, several serving as dual- or triple-use areas. The lower level was dedicated to most of the crew's public and group activities, the second level housed systems equipment, stowage, and occasional exercise equipment, and the upper level provided for crew privacy.

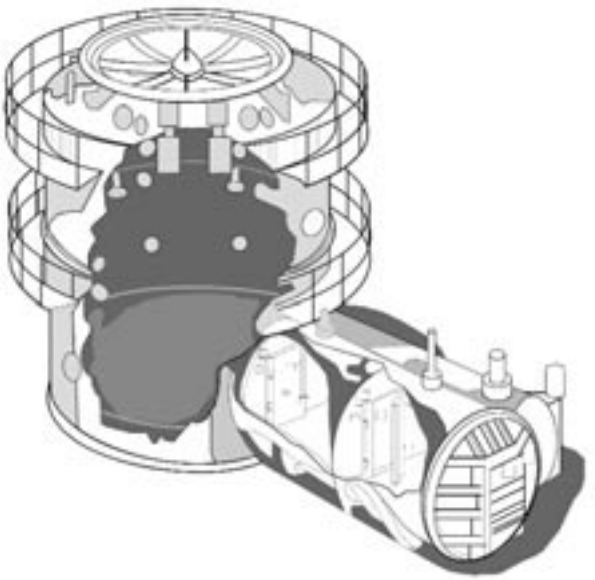


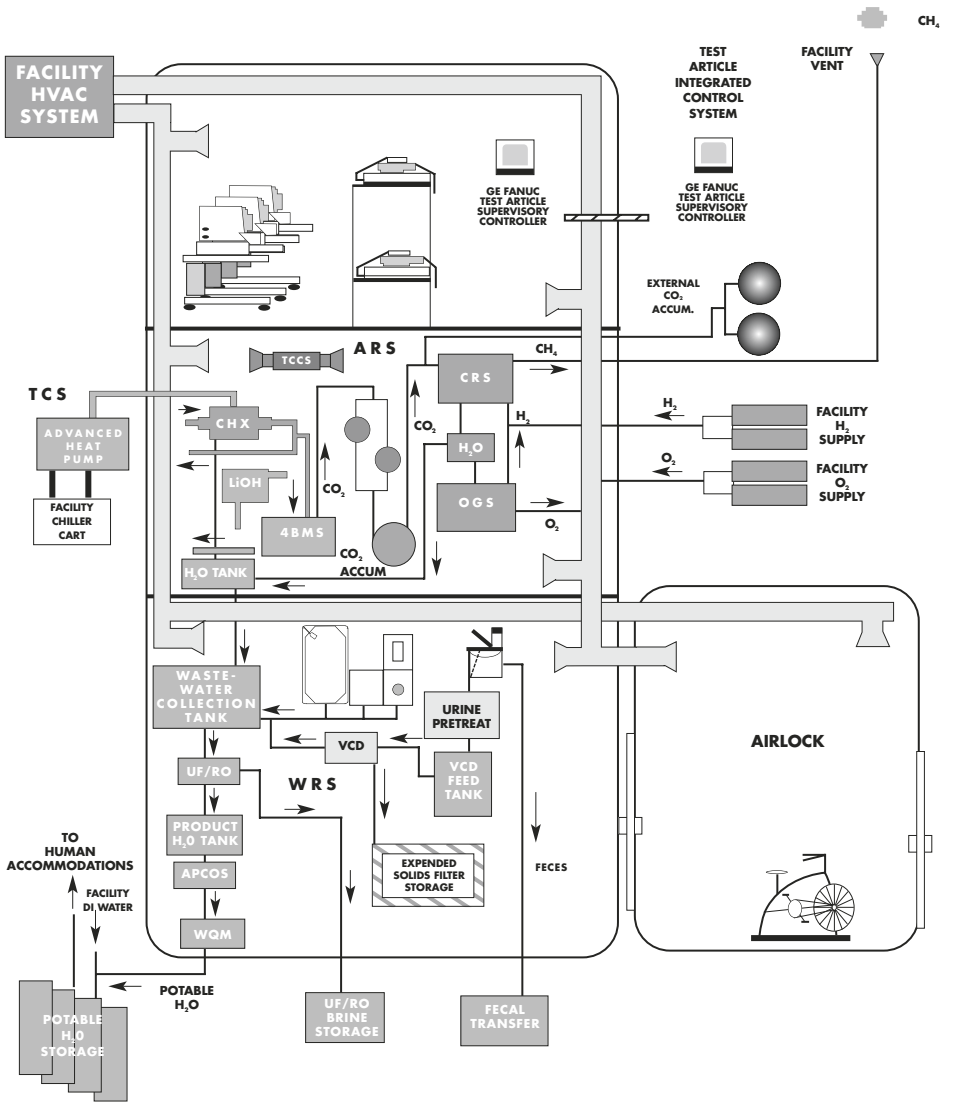
Figure 3.1-1 *Exterior rendering and cutaway of LSSIF complex with airlock*

Of importance was that the interior configuration and outfitting would need to address the safety of the crew. The design addressed potential mechanical and electrical hazards and endeavored to eliminate them. Fire safety and warning systems were employed. A lift was required on the upper level to allow for the safe exit of a crewmember in the event of an emergency. A considerable challenge confronting the team charged with the interior configuration was the materials from which the vacuum chamber had been constructed. Metal was the construction material of choice – an acoustics challenge to be sure. The selection of all interior surfaces and materials had several critical criteria that had to be met: they should be nonflammable, should produce minimal outgassing (within acceptable limits to the life support system), should be easy to maintain and clean using cleansers compatible with the recycling systems, depending upon use could not be porous, and would support acoustics abatement when possible.

The "20'-Chamber" design for the LMLSTP was to provide for basic needs and to allow the outfitting of a number of crew functions: external/internal communications, general meeting capability, personal hygiene, health care, food preparation and associated stowage, dining, exercise, sleep, crew privacy, general stowage, cleaning of clothing, recreation, trash management, and installation of equipment required to support the tests.

LMLSTP Phase II

The LSSIF (or commonly referred to as the "20 foot chamber") was retrofit for a series of three tests. Entitled Phase II, Phase IIa, and Phase III, each test had its own objectives yet needed to provide for the same crew functions. The schematic section below illustrates the divisions of the chamber by floor. The exterior image shows the mid and upper levels with support structure surrounding the chamber.



KEY

APCOS = aqueous phase catalytic oxidation subsystem
ARS = air revitalization subsystem
4BMS = four-bed molecular sieve
CHX = condensing heat exchanger
CRS = carbon dioxide reduction subsystem
DI = deionized
GE FANUC = programmable logic controller used for the LMLSTP
HVAC = heating, ventilation, and air conditioning
OGS = oxygen generation subsystem
TCCS = trace contamination control subsystem
TCS = thermal control subsystem
UF/RO = ultrafiltration/reverse osmosis
VCD = vapor compression distillation
WQM = water quality monitor
WRS = water recovery subsystem

Figure 3.1-2 *Architectural section of LSSIF during Phase II test*

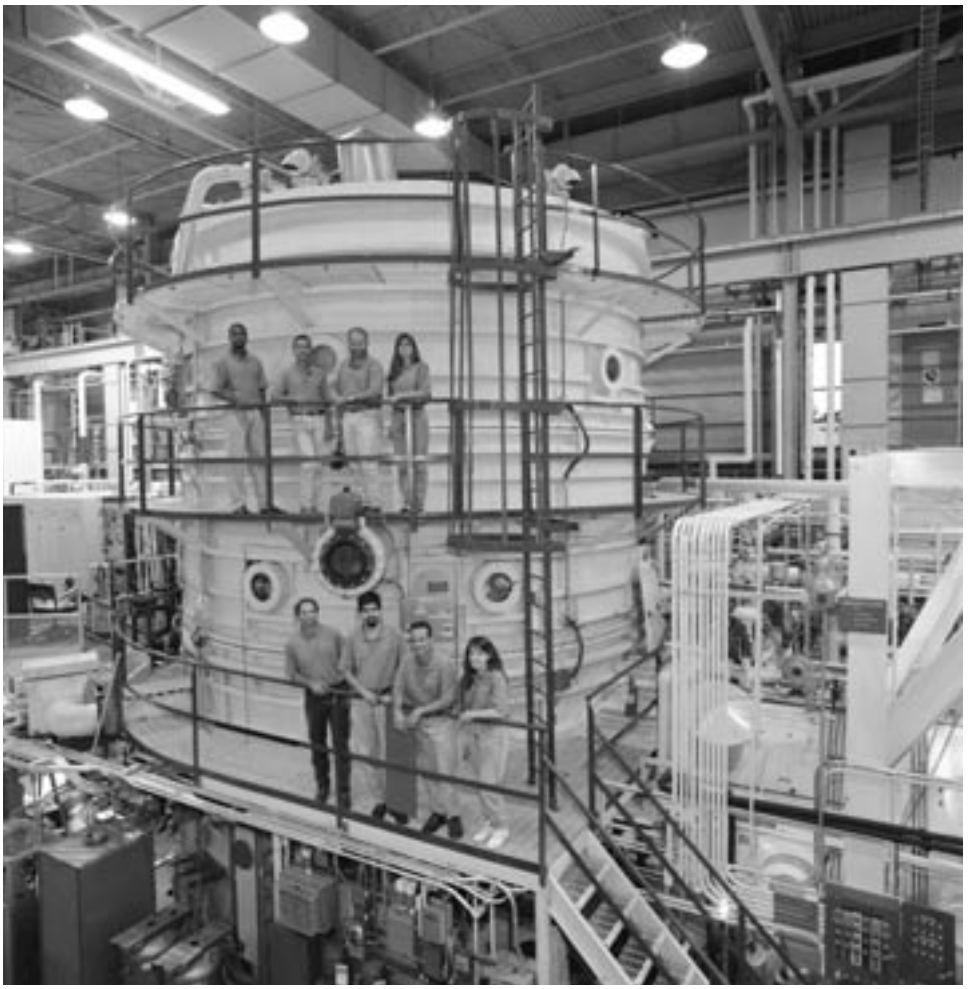


Figure 3.1-3 *Exterior of LSSIF for Phase II with prime and back-up crewmembers*

The entrance to the LSSIF is an airlock that is attached external to the cylindrical shell at the first level. Within the airlock, a volume separate from the living quarters was dedicated to crew exercise. The airlock housed the treadmill and exercise bicycle for Phase II. Other than carpet on the floor, no other material was attached to the airlock shell. General illumination was attached to the airlock wall. Electrical and audio outlets provided power for hardware and personal audio equipment used while exercising.

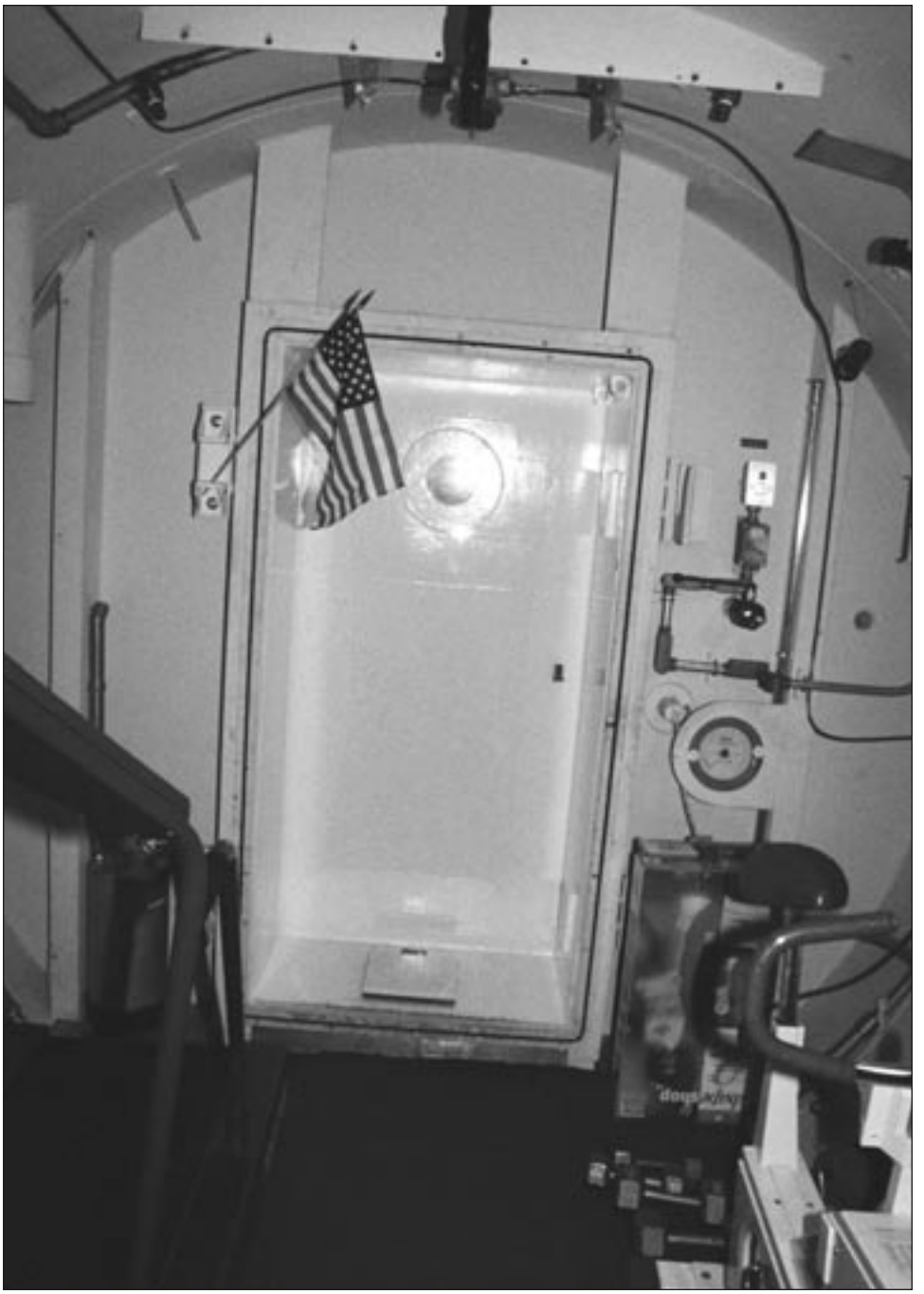


Figure 3.1-4 *View of airlock toward chamber exit, treadmill on left, exercise bicycle on right*

Figure 3.1-5 *View of Phase II crewmember Pat O'Rear during exercise on treadmill*

The lower level provided accommodations for food preparation and stowage in the galley. Also included on the lower level was the hygiene facility (for hand washing, showers, and fecal waste and urine collection), the wardroom (a table located centrally in one half of the level), the laundry facility, communications, and

translation staircase to the upper levels. In addition, a transfer lock was provided to allow for equipment, personal items, food, supplies, and samples to be imported into and exported from the chamber. In general, those functions that supported group or public types of activities were allocated space on the lower floor. Gathering for meals, holding group meetings, communications between the crew and the control room staff and guests, and videoconferences with a variety of remote sites were all held in the common space. This public versus private separation of space was created to allow for the greatest amount of privacy for individual crew functions on the upper level.

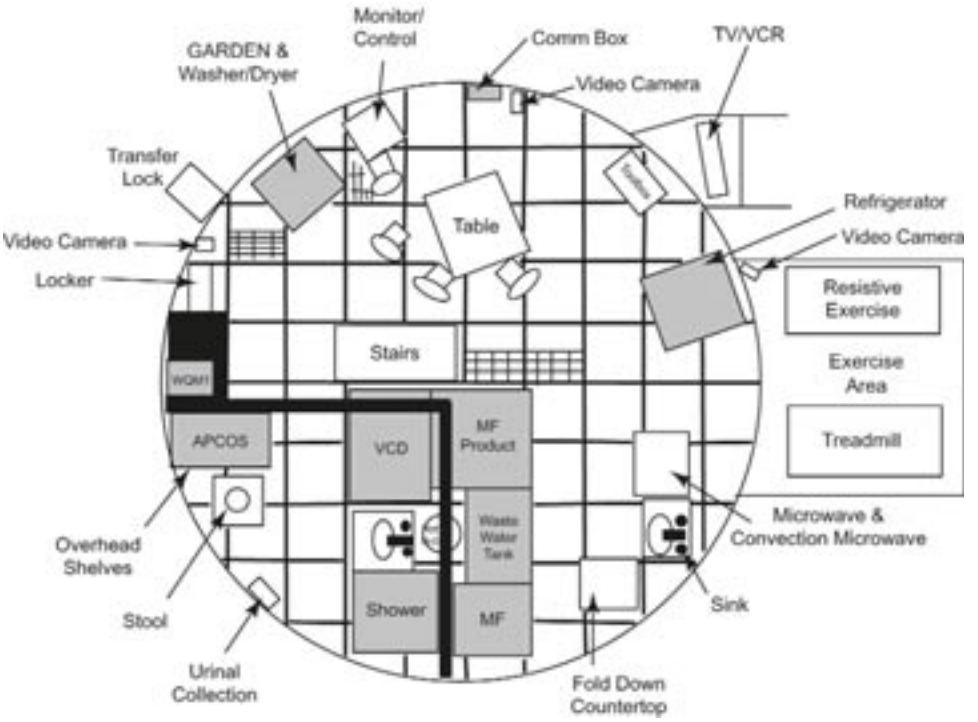


Figure 3.1-6 *LLSIF lower level floor plan*

Figure 3.1-7 *Lower-level galley*

Within the chamber, the metallic walls were covered with an insulation material to provide general acoustic abatement. General illumination was provided by fluorescent fixtures which were diffused to assist in light distribution. Carpeting was installed over the floor plates in such a fashion to allow for access to the volume directly beneath the floor level. The color of the materials was limited to commercial availability and only to materials with the properties necessary for the closed-loop life support environment. Special attention was paid to the use of adhesives that also possessed the properties compatible with the closed system to attach the materials.

The galley was equipped with a sink and stowage cabinetry of stainless steel. Two microwave ovens allowed for preparation of the food. Food preparation surfaces with nonporous characteristics provided a surface that was easy to maintain, minimizing the potential for microbial growth.

Adjacent to the galley was the wardroom area that served multiple functions. The most prominent use was for crew dining, although the table served as a workstation and location for the crew to gather for group communication, either for recreation or for more formal presentations or interviews, as mentioned above. Group messaging and logging of food consumption, daily activities and crew exercise, as well as water usage, were accomplished by manually recording these activities onto clipboards attached to the front face of the refrigerator.

Figure 3.1-8 *Crewmembers Vickie Kloeris, Laura Supra, and John Lewis at wardroom table; communications center visible behind John Lewis*

Figure 3.1-9 *Phase II crew, Katy Hurlbert and Doug Ming, preparing meal at wardroom table*

The compact washer/dryer unit was placed close to the table. Every fourth day, the crew was allowed to wash their clothing. The table could then serve as a place to fold the laundry prior to stowing it within the crew quarters. A computer workstation provided a means of monitoring various functions and systems within the chamber at a location on the lower level where cameras provided direct communication with the control room.

Figure 3.1-10 *Compact washer/dryer unit located near the wardroom table*

Figure 3.1-11 *Phase II crew, Patrick O'Rear, John Lewis, and Katy Hurlbert, gathered at wardroom table. Note locations of washer/dryer and workstation*

Various items were transferred several times per day through the small equipment lock. The items transferred included personal items for the crew, samples to be tested by investigators outside of the chamber, equipment supporting experiments, tools, and biological samples. Located adjacent to the washer/dryer, the transfers were accomplished by loading the transfer cart on either side of the equipment lock. To transfer, one hatch was opened, the transfer cart was placed into the equipment lock, and the hatch then closed. Communication was given to the crew, or to the control room, that the hatch on the opposite side could be opened. By securing the hatches on either side in the appropriate order, the integrity of the internal environment of the chamber was maintained.

Figure 3.1-12 *Phase II crewmember John Lewis performs transfer duties*

Figure 3.1-13 *Phase II materials being placed in the transfer cart by Katy Hurlbert and readied for placement within the transfer lock*

Personal hygiene was accommodated on both the lower and upper levels. On the lower level, full-body cleansing could be performed. This level included the shower stall, a one-piece premolded unit, hanging space for towels, stowage for personal belongings, a curtain for privacy, and a flow meter control to monitor water usage. One shower per day was allotted to each crewmember, occurring most often immediately after the conclusion of the exercise session.

Figure 3.1-14 *Solid fecal waste was collected in the toilet portion of the hygiene area. It was bagged and exported from the chamber. A curtain allowed for personal privacy during use*

Figure 3.1-15 *The urinal collection area provided for crew hygiene plus the hanging of towels and a posting area for checklists and logs*

Figure 3.1-16 *The premolded shower unit defined the majority of the hygiene area*

During the Phase II test, the second level of the chamber was utilized only for equipment and additional stowage. The crew did translate through the second level by staircase that led to the private quarters on the third floor. The stairs were quite steep, and translation had to be taken with care, especially if transferring equipment or supplies from one level to another.

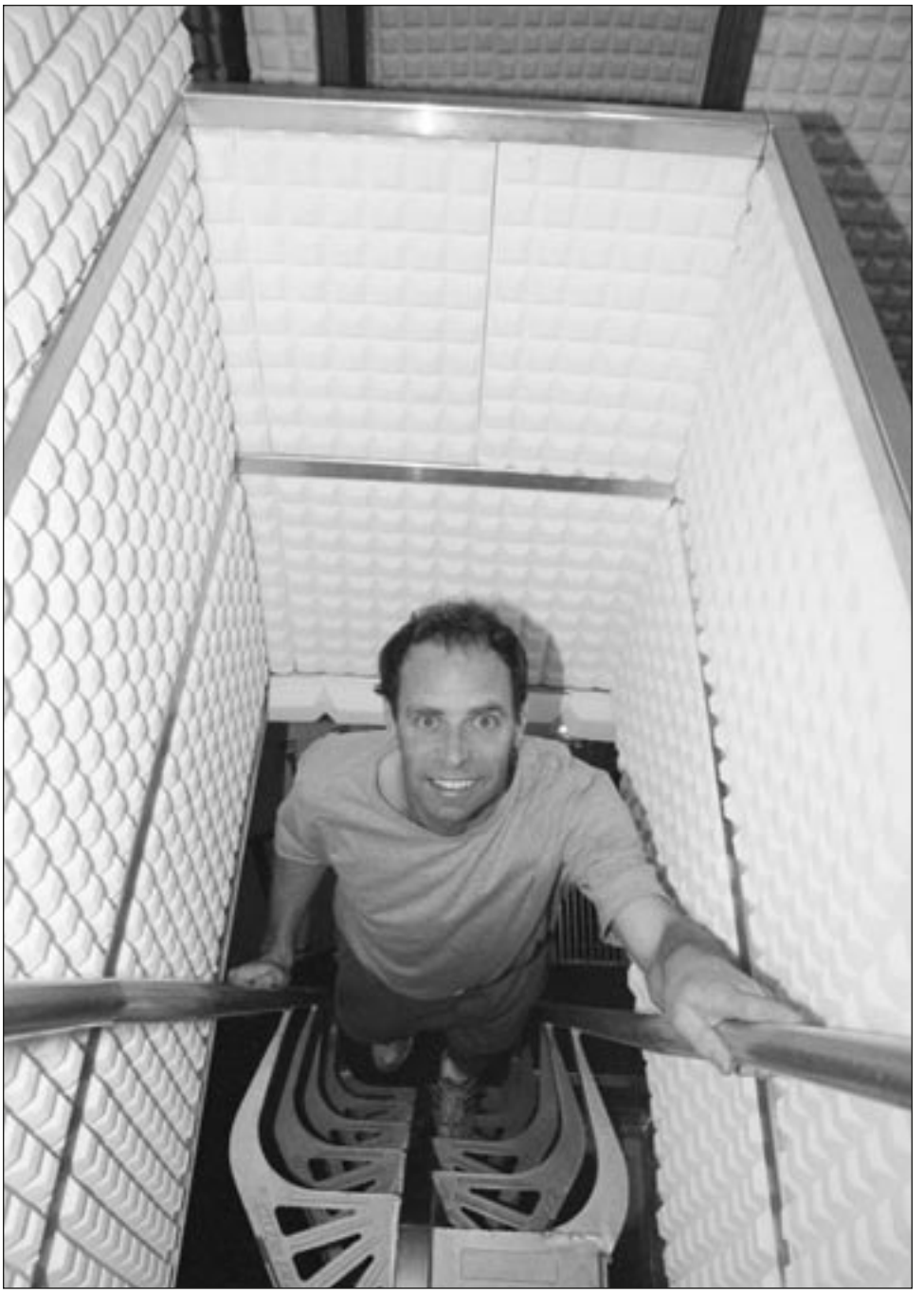


Figure 3.1-17 *Phase II crewmember Doug Ming climbs the stairs from the second to third level. Note the acoustic material surrounding the stairwell. Equipment on the second level emitted noise that the material helped abate*

Above the equipment level, the entire space was dedicated to the crew and their individual, private quarters. The layout of the floor was divided in half with two quarters on either side of a central hallway. The stairs terminated in the central portion.

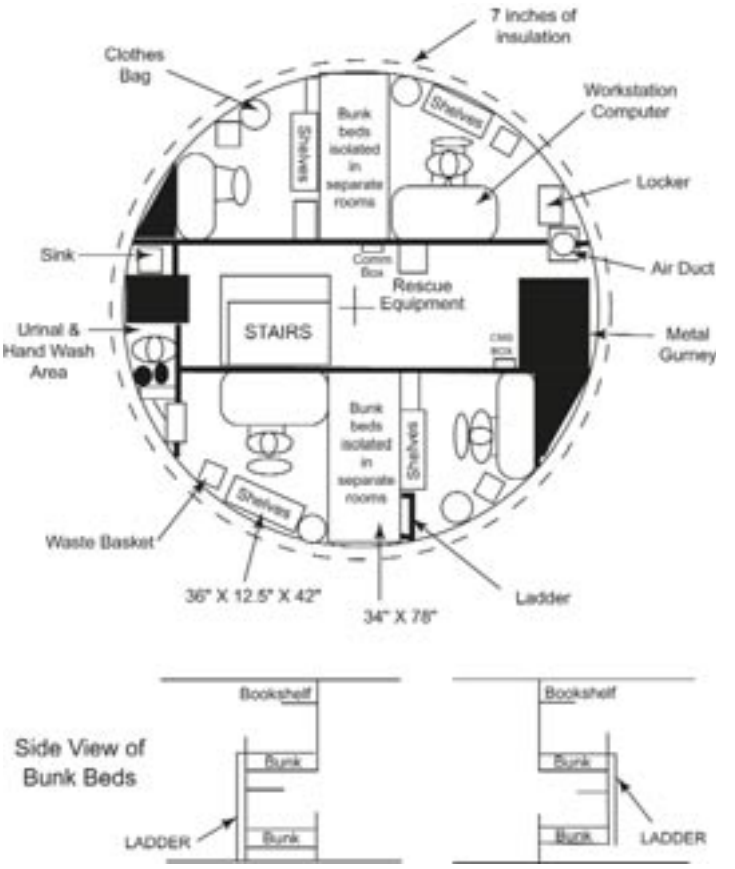


Figure 3.1-18 *Floor plan for third level of chamber. Detail of bunk area illustrates the utilization of the bed from each crew quarter*

For the sake of economy, each of the quarters was provided a twin-sized bed. By placing them in bunk fashion, one over the other, the crew quarters were provided additional floor space. In one quarter, the crew had a lower bunk, and in the adjacent quarter, the other crew was given an upper bunk. Acoustic material was installed to provide as much privacy as possible within the allowable limits imposed by the life support system. Each quarter was equipped with controllable lighting and ventilation, a computer workstation, stowage, and private communications capability. The individual quarters were also an area for the crew to display personal items.

Figure 3.1-19 *Crewmember Laura Supra at workstation within her personal quarters*

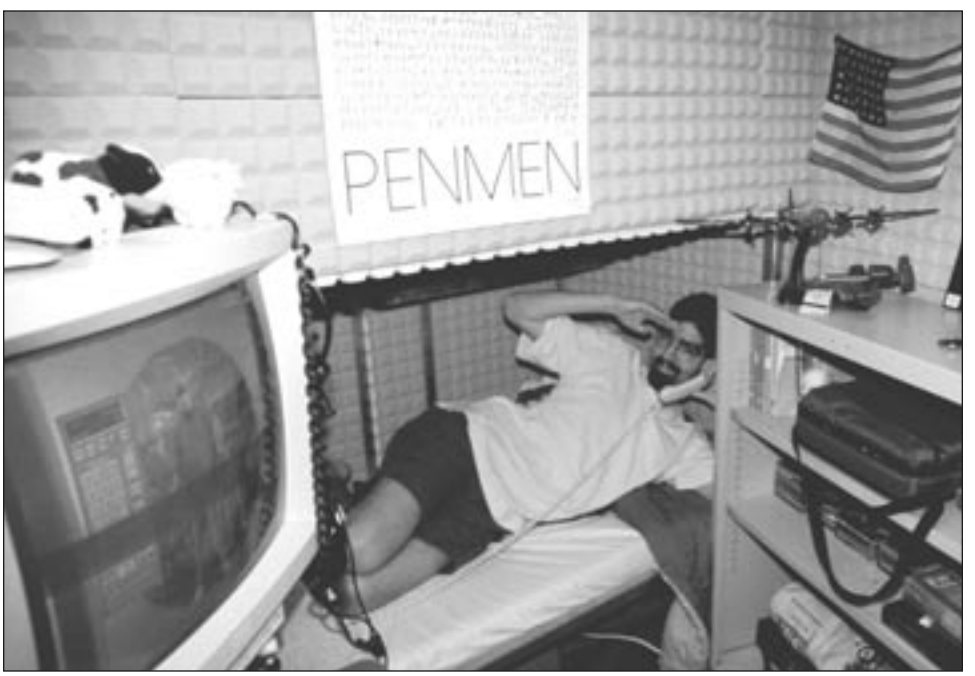


Figure 3.1-20 *Phase II crewmember John Lewis relaxes in lower bunk. Note acoustic lining of the bunk area to provide additional privacy*

A partial hygiene facility was installed on the upper level of the chamber, providing hand washing capability and urine collection. This volume was quite compact as it was located in a compartment at the top of the stair. A sliding door provided privacy.

LMLSTP Phase IIa

The second test conducted within the LSSIF provided accommodations for the crew of four similar to those provided during Phase II. In addition to those accommodations already constructed, the second level provided a laboratory workbench amidst the systems equipment. The work area was lined with the acoustic insulation, and the work surface was again of a stainless steel material that would allow for ease of maintainability and cleaning. Simple shelving on the lower level adjacent to the wardroom table area provided a location to store additional food and supplies for housekeeping of the chamber interior.

Figure 3.1-21 *First-floor pantry provides additional stowage for food and supplies*

In addition to the treadmill and bicycle ergometer, the airlock housed a resistive exercise machine for this particular test. Again the crew spent a portion of each day performing a series of exercises to maintain their health.

Figure 3.1-22 *Phase IIa crewmember Terry Tri works out on the resistive exercise equipment*

Phase IIa saw the inclusion of various cooperative research objectives to evaluate the habitability of the chamber, food system, sleep, training, and environmental assessments, to name but a few. The chamber proved an appropriate venue to study these issues, and the findings can be found elsewhere in this body of work.

LMLSTP Phase III

The final phase of the tests to be held within the LSSIF saw minimal changes in the interior configuration of the three levels. One of the more prominent changes, however, was the replacement of the acoustic insulation that lined the walls of the chamber. A concern had arisen over formaldehyde offgassing exposure from the

maroon-colored insulation used during Phase II and Phase IIa. In keeping with the priority of crew safety, the maroon-colored insulation was removed and replaced with an available nonhazardous golden-color material that met the life support system requirements.

The airlock remained the location for the majority of the exercise devices. Both the treadmill and the resistive exercise equipment dominated the volume attached to the chamber.

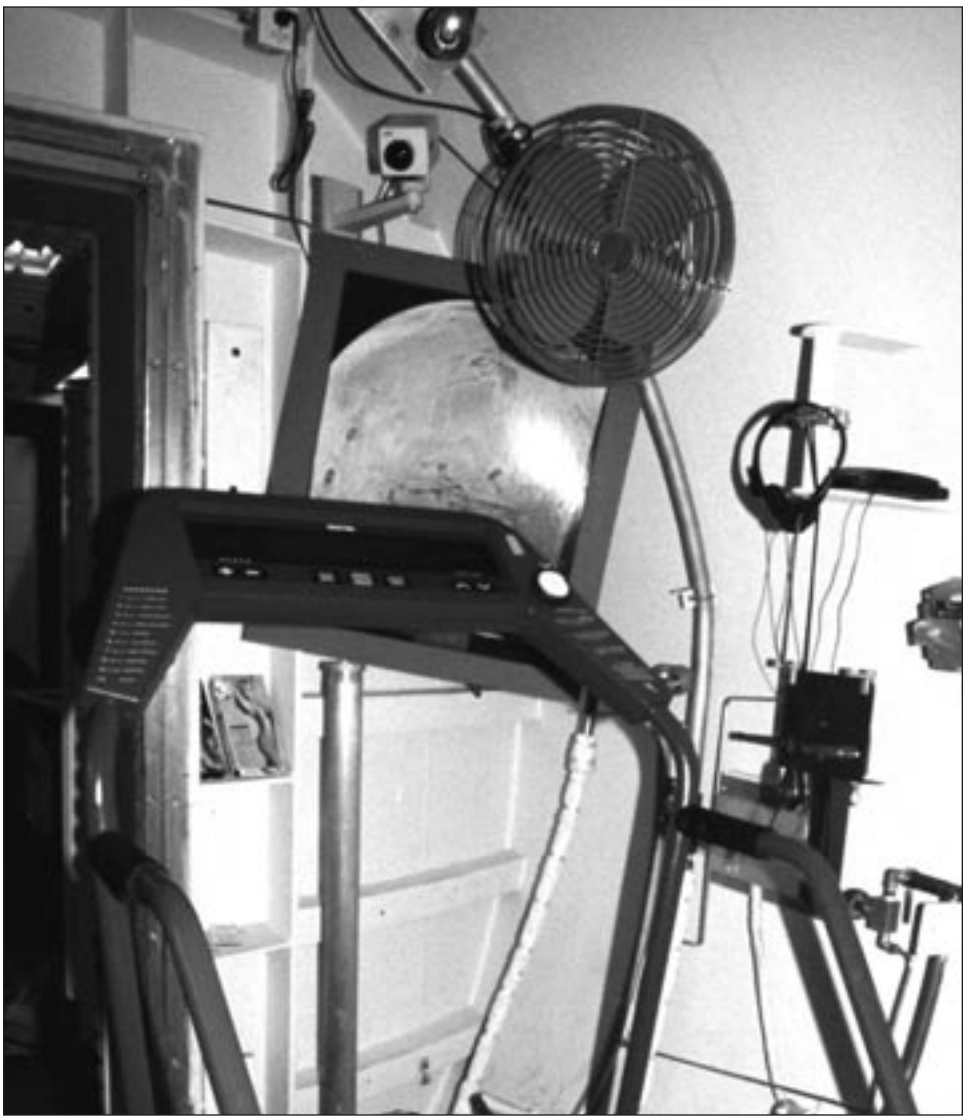


Figure 3.1-23 *Treadmill located within the airlock*

The same hardware for the wardroom and galley remained. Each area still provided a multipurpose work surface, communications capability, food preparation and serving capability, and provisions for record keeping, trash management, and cleaning (see Figure 3.1-7). General illumination using fluorescent lighting remained installed.

The lower level contained the personal hygiene area comprised of the urinal, fecal collection device, shower, and hand wash (see Figure 3.1-16). Each area provided stowage of hygiene supplies, test and monitoring equipment, and personal belongings.

Another change in equipment for the lower level was the washer and dryer unit. A unit was installed for Phase III that allowed the clothing to be laundered and dried within the same component. This allowed for a saving in volume that was then allotted to the "GARDEN"- Growth Apparatus for the Regenerative Development of Edible Nourishment. Not only did the GARDEN provide fresh produce, it also provided a change in the color scheme of the lower level. The prominent "purple" glow emitted from the "growth lights" was evident from all locations on that level.

Figure 3.1-24 *Lettuce grown in the GARDEN unit provided fresh produce during Phase III*

During Phase III, the second floor remained dominated by the systems equipment necessary to support chamber functions. In addition, a piece of exercise equipment, the bicycle, was relocated to that level, the maintenance/laboratory workbench was again used, and stowage volume was available for additional provisions.

The upper level of the LSSIF supported the crew of four by providing their personal quarters (including locker stowage, bookshelf, bunk bed, and computer workstation), a partial hygiene facility, and the lift necessary to allow the safe exit of a crewmember in the event of an emergency.

Figure 3.1-25 *View of personal quarters stowage and bunk*

Figure 3.1-26 *A bank of stowage lockers gives the crew additional volume for personal belongings*

Cameras were installed in various locations throughout the chamber, except for the private areas, providing views of chamber life to the community. Intercoms on each level gave the crew the ability to communicate with each other and the control room. A camera within the control room gave the chamber crew the ability to see what events were occurring within that area.

As experienced by previous crewmembers, the staircase, which allowed for movement between levels, challenged individuals with or without carrying supplies or equipment. The staircase was quite steep and very narrow and provided just enough tread to place only one foot, step by step.

Figure 3.1-27 *Phase III crewmembers tightly gathered on the staircase for a photo opportunity*

SUMMARY OF CHAMBER ARCHITECTURE

The retrofit of an existing vacuum chamber on site at the Johnson Space Center served to house humans involved in the development and test of life support systems equipment. The interior volume was preselected, the "shell" geometry defined and unchangeable, and movement between levels supported by a steep staircase. Given these initial conditions, a team of engineers, coupled with limited consultation from architectural designers, began the task of preparing the interior to support a crew of four humans each for three successive tests. There were assumptions made regarding the interior configuration, the most challenging being the use of existing equipment to outfit the chamber. Little custom design of crew accommodations was provided. This meant that the equipment and accommodations would have to be fit as best as reasonable within the given geometry.

The chamber was contained within a building and provided no direct viewing to the natural exterior environment. Camera views outside could be placed on the monitors if desired. No sunlight was available. Window viewing was limited to the airlock "porthole" where, on occasion, visitors could view the chamber crewmembers and communicate on a limited, infrequent basis.

Materials were chosen with properties that would not prove toxic to the humans in this closed environmental system. Unfortunately, one material, the maroon acoustic insulation used in Phase II and Phase IIa, outgassed formaldehyde and had to be replaced. Available colors for this type of material were limited, forcing a selection of a color that was considered least objectionable. A wall color was selected, and the ceilings of all three levels were covered with white insulation. Materials and color selections for any future advanced life support facility should be made based upon a scheme that incorporates the entirety of the chamber complex, considers material availability and appropriate use, and allows the crew a measure of control over the appearance of the interior by color changes.

Other materials were chosen based upon the need for ease of maintainability and clean-up – surfaces that were not porous, thereby limiting potential microbial growth – and allowing acoustic abatement whenever possible. Carpeting covered the metal grating floor plates but allowed for access to the volume below the plates. Materials needed to be compatible with all the life support systems within the chamber. The risk of outgassing had to be minimized, and the outgassing that did occur would need to be tolerated by the crew and the life support systems. These criteria will need to be applied once again when the construction of the new test facility is undertaken. One recommendation is that the limited "palette" of materials and colors be investigated more thoroughly and that additional tests be conducted on more materials to determine their viability for this type of use. This will allow for more flexibility on the selection of surface application, as well as for future selections of color and texture.

Lighting was limited to fluorescent fixtures located as required within the airlock and on all three levels of the chamber. Additional task lighting was made available in the private quarters. Future lighting will again need to address not only general illumination, but also both general and task lighting that the crew can control. This will allow for a full range of lighting levels to suit the functions supported within the test chambers.

Movement between levels was made possible with the use of a steep "ship's" staircase. Nearly vertical in nature, this provided a great challenge for the crew, with or without carrying equipment or supplies, yet was economical in volume utilized. Future trades would need to be conducted as to what type of translation can be provided and how each candidate solution would impact the interior configuration. In the LSSIF, the stair was at the central portion of the chamber. All interior outfitting had to address the location of that stair on all three levels. Economy is a significant consideration, but location will be a significant design driver to allow for maximization of the volume.

The lower level supported a number of functions in relatively close proximity. Given the defined shell and the equipment necessary to support test and chamber activity, those functions deemed group and public were assigned to the lower level.

This included the galley (food preparation, clean-up, and stowage) and wardroom functions (dining and general meeting), laundry, and overall chamber communications (audio and visual). The location of private functions, the shower and toilet, was placed in the lower floor due to the commercial shower unit dimensioning. The toilet function was close to the equipment lock that allowed the easy exporting of biological waste. This placement, while out of the direct line of sight, was still quite close to the most public of utilized spaces. In future test facility designs, the placement of a full-body hygiene facility and toilet needs to be away from the dining and public gathering locations.

The second level provided for few crew accommodations. By design, it was the equipment level. During a portion of the chamber tests, additional exercise equipment was located on this level. In addition, a maintenance/laboratory workstation was installed, providing a necessary surface for repairs. All future workstation environments must be evaluated for proper lighting, ventilation, surface area, and ability for the crew to access the equipment that requires maintenance or change-out of components.

The upper level provided sleep quarters and for the privacy of each individual crewmember. Separate quarters were outfitted with bunk beds (each secluded from the adjacent crewmember), stowage for supplies and personal belongings, a workstation, and private communication capability. All quarters were lined with acoustic insulation material to further isolate the sound of the equipment on the level below the quarters and to keep sound from traveling between the quarters. External to the quarters, a small hygiene facility provided for hand washing and urination. To further provide for the safety of the crew, a lift was installed on the upper level over hatches on each level that, in the event of an emergency, would allow for the incapacitated crewmember to be taken to the lower level and out of the chamber. In future crew quarters designs, the types of activities that the crew will conduct need to be traded with the amount of space required to support those functions. In addition, the crew, if so desired, should be able to reconfigure their personal spaces within the limitations of the exterior geometry.

Chamber studies on all habitability issues affecting the well-being and performance of the crew must continue to be conducted. Any future facility that will test advanced life support systems will provide an environment to study a wide variety of issues from lighting, color, configuration, and function, to communication, training, maintenance, and repair. The internal configurations of the test facilities and their evaluations should be developed and designed in tandem with those disciplines addressing human performance. By utilizing a multidisciplinary approach, coupled with advances in technology and materials application, the lessons learned will have direct applicability to humans leaving the familiar habitat of Earth and being sustained by an environment designed for maximum performance.