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The Skylab Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions

Kjell N. Lindgren[1], Karen L. Mathes[2], Richard A. Scheuring[3], David B. Gillis[1], James D. Polk[3], James M. Duncan[3], Jeffrey R. Davis[3], Richard S. Williams[3]

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August 2009

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1 INTRODUCTION

From May 1973 to February 1974, NASA conducted a series of three human missions to the Skylab space station, which was a voluminous vehicle largely descendant of Apollo hardware and the first U.S. space station. The crew members of these three missions spent record-breaking durations of time in microgravity (28 days, 59 days, and 84 days, respectively) and gave the U.S. space program its first experiences with long-duration space flight. The program overcame a number of obstacles (including a significant crippling of the Skylab vehicle) to conduct a lauded scientific program that encompassed life sciences, astronomy, solar physics, materials sciences, and Earth observation.

Skylab has more to offer than the results of its scientific efforts. The operations that were conducted by the Skylab crews and ground personnel represent a rich legacy of operational experience. As we plan for our return to the moon and the subsequent human exploration of Mars, it is essential to use the experiences and insights of those who were involved in previous programs. Skylab and Skylab Medical Experiments Altitude Test (SMEAT) personnel possess unique insight into operations that are being planned for the Constellation Program, such as umbilical extravehicular activity (EVA) and water landing/recovery of long-duration crew members. The Skylab Program was also well known for its habitability and extensive medical suite; topics that deserve further reflection as we prepare for lunar habitation and missions beyond Earth's sphere of influence.

The Skylab Medical Operations Summit was held in January 2008. Crew members and medical personnel from the Skylab missions and SMEAT were invited to participate in a 2-day summit with representatives from the Constellation Program medical operations community. The purpose of the summit was to discuss issues that will be pertinent to future Constellation operations.

The purpose of this document is to formally present the recommendations of the Skylab and SMEAT participants. As we look to the future of space exploration – our return to the moon and quest for Mars – we must remain mindful of those who opened the heavens to the long-duration exploration of space. The International Space Station (ISS) and Constellation Programs are the stewards of the Skylab legacy. The hard-won lessons of Skylab can still guide us as we extend mankind's presence in space.

2 METHODS

The purpose of the Skylab Medical Operations Project was to produce a set of recommendations that is relevant to issues in current and future long-duration space flight based on the experience of Skylab Program participants. Several steps were required to arrive at these recommendations.

2.1 Constellation Research

First we sought to identify the operational issues and concerns that are facing the Constellation Program. An informal survey of hot topics and program risks provided a starting point. A list of issues and potential questions was prepared and refined by members of the Constellation Medical Operations community. This refined set of topics and questions served as a starting point for research into the Skylab Program.

2.2 Skylab Background Research

We then familiarized ourselves with the Skylab Program architecture and operations, not only to identify areas where the Skylab experience could be instructive, but also to ensure that these questions had not already been answered in the Skylab documentation. Skylab Program reports were gathered from the NASA Technical Reports Server (ntrs.nasa.gov), the NASA Science and Technical Information Center (www.sti.nasa.gov), the Wyle Integrated Science and Engineering Space Medicine Library, and the University of Texas Medical Branch (UTMB) Charles Berry Space Medicine Library.

2.3 Pre-summit Questionnaire

Once a set of key Constellation issues had been identified and compared against the architecture and experience domain of the Skylab Program, a set of critical questions was created and refined. This question set was vetted by Dr. Joe Kerwin, Skylab 2 astronaut and crew representative for the Medical Operations summit. With Dr. Kerwin's approval, the questions were presented to the Skylab and SMEAT crews for review. Although the crew members had the opportunity to evaluate the questions and provide written responses prior to the summit, most of the Skylab and SMEAT crew members opted to provide verbal responses at the summit.

2.4 Summit Responses

The Skylab Medical Operations Summit was conducted over 1.5 days, on January 23–24, 2008. In attendance were representatives from Skylab and SMEAT missions and the Skylab Medical Operations community. The first day of the summit was a closed session due to the confidential nature of some of the discussion that focused on Medical Operations, Habitability, and Water Landing and Recovery. The second day of the summit was open to invited guests from the larger NASA and Constellation community. The second day started with a summary of the recommendations that had been generated by the Skylab participants from the discussion that was conducted on the previous day. The summary was followed by a question-and-answer session and a final set of questions/recommendations that was related to Launch/Thrust Oscillation and Umbilical EVA operations. During the summit, a moderator presented each question from the Summit Questionnaire to the Skylab participants. During both closed and open sessions, a panel of Constellation Medical Operations Personnel had an opportunity to pursue discussion or present follow-up questions to the Skylab guests. The responses of the guests and discussions that followed were recorded for further analysis.

2.5 Post-summit Review and Validation

The audio recordings and written notes from the summit were used to create the Skylab participants' recommendations and an edited transcript of the summit. The completed document was sent out to the Constellation Medical Operations summit participants for their review and approval. The refined document was then sent to the Skylab and SMEAT participants for their review and approval.

2.6 Document Organization and Formatting

A complete transcript of the summit is not provided in this document. The purpose of this document is to present Skylab participant comments and recommendations. While participant comments are preserved, tangential and/or redundant conversations are not presented here. In addition, given the uncertainties of design and occasionally sensitive nature of the discussion, detailed conversations concerning the Constellation Program have also been removed.

Some participants provided both written responses and verbal comments during the summit. The verbal responses are presented here unless that participant's written comments provide additional novel information.

Various formatting symbols are used to reference meta-information throughout the document. These formatting symbols include: parentheses enclose references to other sections of this document; superscript numerals refer to documents delineated in the Reference/Bibliography list; and square brackets enclose editorial comments and clarifications.

Consensus recommendations are provided in Section 4. Each recommendation is followed by a brief discussion/rationale that is referenced to specific comments or written responses. These select and representative responses are provided in Section 5. Crew/participant comments are grouped under the applicable question/topic heading. On occasion, a participant presented additional thoughts or comments on a previous discussion. These comments were moved to the applicable question/topic. Moreover, a participant or a panel member would occasionally present a question that was not found in the Summit Questionnaire. These questions and their responses have been added to Section 5 as well.

3 RESULTS

3.1 Data

We received feedback from 100% of the surviving Skylab/SMEAT astronauts. Eighty-two percent (nine of 11) of the astronauts were able to participate in the summit. The remaining two crew members provided written responses, and their comments were presented during the summit discussion. In addition to Skylab and SMEAT crew member input, we received written responses from Dr. Harrison Schmitt, who was an Apollo scientist-astronaut and is chair of the NASA Advisory Committee. Dr. Chuck Ross, Skylab/SMEAT Flight Surgeon, participated in the summit and provided invaluable medical operations perspective. These data are presented in Table 1 below.

Table 1. Skylab Medical Operations Project Participation

Participant Role	Available	Pre-summit Responses	Summit Participants	Total Unique Responses
Skylab Crew member	8	4	6	8
SMEAT Crew member	3	2	3	3
Apollo Scientist-Astronaut	1	1	0	1
Skylab/SMEAT Program Flight Surgeon	1	0	1	1

3.2 Participants

The following personnel were key participants in the Skylab Medical Operations Summit discussion:

Skylab Program Representatives

Mr. Paul J. Weitz	Skylab 2 Pilot
Dr. Joseph Kerwin	Skylab 2 Science Pilot
Capt. Alan Bean	Skylab 3 Commander
Col. Jack Lousma	Skylab 3 Pilot
Dr. Owen Garriott	Skylab 3 Science Pilot
Col. Gerald Carr	Skylab 4 Commander
Col. William Pogue	Skylab 4 Pilot
Dr. Edward Gibson	Skylab 4 Science Pilot
Capt. Robert Crippen	SMEAT Commander
Col. Karol Bobko	SMEAT Pilot
Dr. William Thornton	SMEAT Science Pilot
Dr. Charles Ross	Skylab Flight Surgeon
Dr. Harrison Schmitt	Apollo Scientist-Astronaut

Constellation Medical Operations Representatives

Dr. Kjell Lindgren	Moderator, Flight Surgeon, Constellation Medical Ops
Dr. Jeff Jones	Flight Surgeon, Constellation Medical Operations Lead
Dr. Richard Scheuring	Flight Surgeon, Constellation Medical Operations
Dr. Pete Bauer	Flight Surgeon, Constellation Medical Operations/Orion

Dr. Serena Aunon	Flight Surgeon, Constellation Medical Operations/Orion
Dr. Keith Brandt	Flight Surgeon, Constellation Medical Operations/EVA
Dr. David Alexander	Flight Surgeon, Constellation Medical Operations/EVA
Mr. Michael Chandler	Constellation Medical Operations/Landing and Recovery
Dr. Doug Hamilton	Flight Surgeon, Wyle Advanced Projects
Dr. David Gillis	Flight Surgeon, Wyle Advanced Projects

4 CREW CONSENSUS AND RECOMMENDATIONS

4.1 Medical Operations

4.1.1 The presence of a physician as a crew member was helpful, but not mandatory, for the low-Earth orbital profile that was flown during Skylab.

While there was no firm written requirement to have a physician fly on Skylab, Dr. Kerwin's assignment was beneficial to a research and operations plan that was heavy in biomedical research and life sciences (5.1.1a). Crew members felt that pre-flight medical training, an excellent on-board medical checklist, the availability of the flight surgeon in Mission Control, and an ability to deorbit in an emergency were adequate to address most medical concerns (5.1.3a,b; 5.1.4a,b; 5.1.6b). There was a mixed consensus regarding the assignment of a physician to future long-duration crews. Some crew members felt that a physician should be included in more remote missions where a quick deorbit is not possible (5.1.4a,c). Other crew members felt that the best-qualified astronauts should be assigned to missions, regardless of their prior professional training (5.1.4b).

4.1.2 Real-world, hands-on activities (splinting, dental extractions, establishing intravenous access) are an important part of the medical training curriculum.

There was general agreement that the medical training and, more specifically, the hands-on training that both the SMEAT and Skylab crews received was beneficial. The training that was provided in the Ben Taub Emergency Department and in the military dental clinic was effective from both a procedural perspective, as well as from the perspective of breaking down barriers/inhibitions to performing invasive procedures (5.1.3a–d).

4.1.3 Crews should have equipment to sample, identify, and quantify potential atmospheric contaminants.

The loss of the thermal shielding during the launch of the Orbital Workshop (OWS) resulted in high temperatures and a concern for toxic off-gassing within the habitable volume. Skylab 2 (SL-2) crew members were able to sample the atmosphere for suspected toxic contaminants, including carbon monoxide (CO) and toluene diisocyanate (TDI) (5.1.9c). Based on experiences during both Skylab and shuttle flights, it is important to have the ability to sample the atmosphere (especially in the presence of an unknown odor) and identify/quantify potential atmospheric contaminants (5.1.9d–f).

4.1.5 Long-duration crew activities should be scheduled in a manner that provides flexibility, minimizes ground micromanagement, and acknowledges the crew commander's prerogative.

Skylab provided NASA with its first opportunity to manage long-duration crew activities. While there was disagreement as to whether or not Mission Control and the Flight Director should be actively protecting sleep/eat/exercise time, it was generally agreed that the crew commander should be actively involved with scheduling issues (5.1.10a–c,h). The schedule should be flexible and avoid micromanaging trivial tasks (5.1.10a,c–e). The Skylab 4 (SL-4) crew members felt that they were much more productive when the "shopping list" method was adopted for non-time-critical tasks

(5.1.10d). However, there are time blocks that need to be protected, such as the sleep period prior to deorbit and landing (5.1.10f,g).

4.1.6 An entire ISS Expedition of 6 months' duration with a crew of six should be planned, equipped, staffed, and carried out exclusively or primarily for life sciences, and devoted to verifying countermeasures.

Life sciences research formed a major pillar of the Skylab research agenda.[1] *Biomedical Results from Skylab* was a seminal work in the field of space medicine and physiology that carefully documented many of the physiologic changes that were induced by long-duration space flight.[2] This document played in important role in subsequent long-duration flight preparation and continues to serve as a reference for physicians and researchers alike (5.1.13f, 5.14.9j). A similar undertaking in the form of an Expedition-class life science research program would allow the ISS Program to not only further our understanding of deconditioning and countermeasures, but pave our way to Mars (5.1.1b).

4.2 Umbilical Extravehicular Operations

4.2.1 Crewmember EVA umbilicals should receive oxygen from individual loops rather than from a single common loop, if at all possible.

When conducting EVAs from the Skylab vehicle, each crew member was on an individual regulator that was hooked to a individual high-pressure loop, so that if one crew member lost suit pressure, the other crew members would be unaffected (5.2.3b). When conducting EVA operations from the command module (CM), all crew members were on a single loop. In this case, if one crew member lost suit pressure, the other crew members would also be affected. This was not felt to be an ideal system (5.2.3b,d).

4.2.2 A well-designed umbilical system will work fine for extravehicular activity.

The umbilical system that was used by the Skylab astronauts during EVA on the Skylab cluster used an open oxygen loop that proved to be simple, reliable, and safe (5.2.1a). Unfortunately, this type of open loop system vents excess gases from the suit and requires a sizable oxygen reservoir (5.2.1a). Care should be taken to ensure that the umbilical is long enough to reach all potentially repairable parts of the vehicle. During the solar panel deployment, Pete Conrad found himself at the end of his umbilical and almost unable to effect the repair (5.2.1a).

4.2.3 Pre-positioned handrails and mobility aids are ideal, but deployable mobility aids should work okay as long as the connectors and path have been well thought out and properly designed.

Handrails and mobility aids, which were pre-installed for planned EVAs to the distal end of the Apollo telescope mount (ATM), were a "joy" to use (5.2.1a). Unplanned EVAs were conducted to parts of the Skylab cluster (i.e., solar panel deployment) that had no pre-installed mobility aids. The crew completed these activities using improvised translation paths and tools (5.2.1a). If mobility aids are not pre-deployed, a plan to attach them where they are needed is both feasible and attractive as long as it well thought out (5.2.1j; 5.2.8a–c). Be careful not to declare any part of the vehicle "immune" to the need for EVA (5.2.8b).

4.2.4 Training in the Neutral Buoyancy Laboratory and "zero-G" plane are not sufficient for EVA planning and preparation. Planners and crew should get a crew member with actual EVA experience involved in training and preparation.

Early in the shuttle program, neutral buoyancy training and "zero-G" flights were thought to provide adequate preparation for procedure development and the execution of shuttle EVAs (5.2.1o). Problems that were encountered during early satellite rendezvous disproved this thinking, however, and underscored the importance of using input from crew members who are experienced in EVA (5.2.1o).

4.2.5 Ensure that EVA training covers all anticipated tasks.

During Skylab EVA training, one crew did not perform one small part of a task in the pool because it involved flight hardware (5.2.1r). As it turns out, this task was the most difficult obstacle that was encountered in all three EVAs during that crew's mission (5.2.1r).

4.2.6 If strenuous work is anticipated during EVA, a liquid cooling system is preferred over an air cooling system.

EVAs that were conducted from the Skylab vehicle used a liquid cooling system that worked very well (5.2.7a). The EVAs that were conducted from the CM were very limited in duration and degree of exertion, so the air cooling system proved to be adequate (5.2.7c). If strenuous activity is anticipated, however, the life support system should provide liquid cooling for EVA, as was clearly demonstrated during the Gemini Program (5.2.7c).

4.3 Launch

4.3.1 The crew did not recall significant thrust oscillation or pogo effect. The vibrations that were encountered did not interfere with operations.

By all accounts, the ride was fairly smooth (5.3.1b,i,j; 5.3.2a).

4.4 Water Landing and Recovery

4.4.1 Cost and weight aside, land landings were preferred over water landings.

While land landings were largely preferred (5.4.5m,o), two crew members preferred water landings (5.4.1hh; 5.4.5q). Land landings provide for quicker accessibility to the crew for medical care/rescue, if needed (5.4.1a). This recommendation was made with the understanding that putting weight and cost issues aside is not easily done (5.4.5r).

4.4.2 The architects of the Constellation Program should consider an architecture that allows the crews to re-enter the atmosphere without pressure suits.

Skylab crew members took their pressure suits off after undocking and re-entered in coveralls (5.4.1r,z,aa). Given the state of post-mission deconditioning, a crew member expressed concern about being able to egress the side hatch into a raft (5.4.1aa; 5.6.1a). It was agreed that the suit should definitely come off before a crew member gets in the water (5.4.1w; 5.6.1cc; 5.11.2e). One participant commented that crew members would have more flexibility in dealing with contingencies if they were unencumbered by the suit (5.4.1v). Hazards encountered in the past that would seem to support suited entry (i.e., the toxic exposure experienced by the Apollo-Soyuz Test Project (ASTP) crew,

and the fatal decompression that occurred during the reentry of Soyuz 11) are felt to be outliers (5.6.1dd). From a hardware point of view, a Soyuz-type of depressurization could not occur on the Apollo CM or the Constellation crew exploration vehicle (CEV) (5.6.6a,e; 5.7.4b). Precautions against fatal depressurization could still be taken, however, by wearing pressure suits during vehicle separation; but these should be doffed prior to reentry (5.6.1dd, 5.6.6a, 5.7.4b). Atmospheric contamination could be addressed with emergency breathing apparatus (5.6.5b).

4.4.3 Rather than spend a lot of time on how to support the crew in the vehicle for long periods of time post-landing, the program should focus on conducting precision landings that occur within close range of recovery forces.

This was a problem that was discussed during the Apollo Program. But with the appropriate mid-course correction and all of the improved technology that is available today, a precision landing should not be a problem (5.4.2g,h).

4.4.4 Crews should be hoisted onto the recovery vessel while still inside the capsule, and not be forced to egress the vehicle and hoisted individually from a raft.

There was a strong consensus among participants that hoisting the crewed capsule was much safer than hoisting individuals from the water (5.4.4a,d). Safety aside, a lot of financial and training overhead goes into individually hoisting crew members from rafts (5.4.5f).

4.4.5 Post-landing activity planning must take physiologic space-related changes into account.

In addition to loss of strength and balance, neuromuscular deconditioning could limit a crew member's ability to immediately egress the spacecraft after landing (5.5.5b,d). In the absence of any post-landing emergency, crew members might be able to self-egress if given the opportunity to hydrate and acclimate for a few hours (5.6.1j). Given the difficulty in defining the constraints that are caused by deconditioning, consider having ISS crew members who are returning from 3- to 6-month missions attempt Orion recovery procedures soon after their return (5.10.1b).

4.4.6 In all but the most extreme of circumstances (fire, toxic atmosphere, sinking), crew members should stay in the capsule until they are recovered.

As long as the capsule is seaworthy, it is the safest place for the crew (5.6.1dd; 5.8.4g).

4.4.7 Emergency breathing masks should be within reach of each crew member during all unsuited phases of flight.

Crew members should not have to dig through stowage to access the emergency breathing masks (5.6.5a), nor should the masks be accessible to only one crew member, who is then responsible for their distribution. This could be a problem if the responsible crew member is incapacitated (5.6.5d).

4.4.8 After reentry, returning crews should be able to maintain constant, direct communications with search and rescue (SAR) forces. In addition, other resources (Mission Control Center (MCC), recovery vessels, medical personnel) should be monitoring the loops and be available for direct communication with the crew, if needed.

Aside from a few glitches, Skylab crews were happy with the performance of their location and recovery communications equipment, which allowed them to be "aware

of what recovery was doing at all times."[3] It was felt that future crews should continue to have constant, direct communication capability with SAR forces (5.9.1a, 5.9.3c,h). Furthermore, it was felt that with the current and future state of networked communications, resources such as Mission Control and medical personnel should be monitoring capsule communications and be available for immediate, direct consultation with the crew (5.9.3a,f,h,j; 5.9.4a,f–h; 5.9.5a).

4.4.9 Returning crews should be equipped with a Global Positioning System (GPS) receiver and a satellite phone.

Given the advances that have been made in consumer technology, a GPS receiver and an emergency locator beacon are absolute necessities for returning crews (5.9.1d–g, 5.9.2a). A satellite phone would also be a valuable tool in a contingency (5.9.6a).

4.4.10 Strongly consider whether a life raft is necessary. If a raft is used, it must be deployed in a fashion that allows the crew to fall into it from the hatch and not require ingress from the water.

One crew member suggested that is seems somewhat impractical to haul 100 lbs. of raft to the moon and back. It was suggested that the raft is a holdover from Mercury and Gemini, when landing accuracy was a little more suspect (5.10.1o). Many crew members felt that it was probably impossible for a deconditioned crew member to ingress a survival raft from the water (5.10.1c,e,f,n). If there is no raft, crews should re-enter wearing life preserver units (LPUs) or an inflatable life preserver (5.6.2b).

4.4.11 Care should be exercised when determining post-flight activities.

Lifting heavy loads, climbing ladders, and doffing a pressure suit would be difficult (5.6.1c,e; 5.10.1a,n). Crews should not be expected to swim to stay afloat or climb into a raft (5.10.1n). At no time should returning, deconditioned, long-duration crew members get into the water wearing a pressure suit (5.4.1w; 5.6.1a,cc; 5.11.2e).

4.5 Habitability

4.5.1 An assessment program like the SMEAT could be a useful endeavor, depending on the specifics of the mission, equipment, and protocols that are to be studied.

The 56-day SMEAT test contributed to the success of the Skylab missions by vetting protocols and identifying faulty equipment.[4] A program like this would be most beneficial for evaluating long-duration missions using new equipment (5.14.1a–b). Many Skylab systems would probably have failed in orbit had they not been tested in the manner that was undertaken by the SMEAT (5.14.1.c–d, 5.14.2a). The most benefit will be derived if testing is conducted with flight hardware under rigorous, real-world conditions (5.14.1c–d, h).

4.5.2 A Skylab-like Waste Management System (WMS) should be considered for future vehicles.

The Skylab WMS was highly regarded.[5] Once the deficiencies that were identified by the SMEAT were corrected, the system performed well and was considered by many to be superior to the system that is used by the space shuttle (5.14.2j-l). While somewhat constrained by the mass of the consumable containment bags, the Skylab WMS was felt to be effective and efficient, especially when it was stripped of the scientific research overhead (mass/volume measuring, sampling, drying, storage) (5.14.2h–l, 5.14.3e). The

WMS should be positioned in a sealed compartment with a door that can be latched to contain odors and "debris" (5.14.3g).

4.5.3 Odor control in the habitable volume is important.

Odors were not a great problem during the Skylab missions.[3] This was felt to be a function of the activated charcoal filters (5.14.3a), the reduced atmospheric pressure (5.14.3b), the low humidity (5.14.3c), the clean environment (5.14.3c), and good containment for both WMS areas (5.14.3g) and trash (5.14.3h-j).

4.5.4 The use and architecture of the habitable volume is important. Separate volumes should be allotted for private and group use. Private quarters/sleep compartments and a wardroom-like space are both important and should be incorporated into future vehicle designs where practical.

Crew members had private sleeping compartments on Skylab. While some slept in other parts of vehicle, many of the crew members felt that it was important to have a private space (5.14.4b–d). The wardroom was a place in which the Skylab crew could congregate, play, and work, and the crew members felt that it was a necessity (5.14.81d). One crew member commented that for a Mars mission, it would be important to have "a place to be alone and a place to be together. You need them both" (5.14.8d).

4.5.6 Future vehicles should incorporate designs that facilitate on-orbit repair. Internal systems should be accessible via removable panels and compatible with common tools.

Some Skylab crews encountered situations in which equipment needing repair was located behind "permanently" mounted panels (5.14.4f,i). Equipment should not only be accessible, but it should also be compatible with everyday tools (5.14.4g). Specialized tools can quickly increase the volume and mass of a toolkit (5.14.4g).

4.5.7 Future vehicles should be designed to minimize light and noise near the sleeping compartments.

The Skylab WMS was located next to the sleeping compartments, such that its use at night could waken other crew members (5.14.4e). Both light and noise should be minimized near the sleeping compartments (5.14.4f).

4.5.8 Future vehicles and habitats should be designed to facilitate housekeeping and cleaning.

The Skylab WMS was built with smooth walls and nonabsorbent surfaces to make cleaning easier. Making "nooks and crannies" generally accessible for cleaning should prevent unfavorable growth and odor production (5.14.4j).

4.5.9 Future vehicle designers should remember that lunar gravity offers a whole new set of opportunities.

Issues that are associated with the WMS, mass measurement, exercise, and fluid shifts in microgravity may not be as problematic on the lunar surface (5.14.4.h).

4.5.10 Food is important, and the menu must be carefully considered. Special care must be taken to avoid making the crew subsist on food bars.

Skylab had a large dry volume and a freezer allotted for food storage. Many crew members thought the nominal Skylab menu was excellent, and better than that available to early shuttle crew members (5.14.4k–l). Despite the palatable menu, nutrition and

metabolic experiments required the crew members to consume a certain number of calories each day, which proved difficult for members of the extended third Skylab mission, requiring them to augment their diet with calorie-dense food bars (5.14.4m).

4.5.11 While a shower is probably a luxury item for long-duration space flight, the Skylab shower was refreshing and might be an especially welcome tool for dealing with lunar dust.

While some crew members felt that the shower was a pleasant experience (5.14.5b,e), other crew members felt that it was a luxury that could have been easily replaced by sponge baths (5.14.5c,d). A major complaint is that it took too long to set up and clean up (5.14.5a–c). In spite of these concerns, a shower may be desirable in a setting such as the lunar habitat in which lunar dust contamination will be a problem and the presence of a gravity field will eliminate some of the engineering obstacles that were encountered in Skylab (5.14.4h, 5.14.5f, 5.14.6e).

4.5.12 Humidity control is important. The low humidity that was experienced in Skylab and the SMEAT led to skin cracking and fissuring.

Some crew members felt that the dry Skylab environment led to skin fissuring and cracking, and that a relative humidity of 45% to 50% is ideal (5.14.6a–d). Low humidity leading to skin dryness is not an insignificant issue, since fissuring and cracking can lead to skin infections and sores (5.14.6a–b).

5 PARTICIPANT RESPONSES

5.1 Medical Operations

5.1.1 Dr. Kerwin, Skylab had a large medical cache and an intensive biomedical research agenda.[2] How did your experience as a physician affect/influence the SL-2 flight and the program as a whole?

a. **Kerwin (Written):** There was no firm written requirement for a physician on any of the Skylab missions either. However there was a physician astronaut in the corps and this mission was uniquely suited to that set of skills, because for the first time in NASA's history the medical experiments and research were the top priority activity on the program and on the first flight.

There were a couple of facts about Skylab which justified physician presence on the flight crew:
1) Medical research had major priority on the mission – for the first time in NASA's short history. A physician to perform certain procedures, and importantly as an observer and judge of crew well-being was value added.
2) The relatively long duration of the flights made medical problems more likely (still not very likely,) and it was in NASA's interest to avoid aborting a flight to bring home an ill or injured crewman.

Consequently, I had many crew assignments before flight as the Astronaut Office representative – feasibility and risk of the medical experiments, the food system, the medical kit and training for it, and so on.

We came to an agreement that two members of each crew would receive training as 'Crew Medical Officers', able to perform a few basic medical examinations and treatments and to relay their findings to the Crew Flight Surgeon. Not much training time was available – about 80 hours – so it had to be used efficiently.

First, the medical staff did some thinking about what illnesses/injuries were probable enough and treatable enough to be included (including first aid for things serious enough to abort the mission.)

Based on that thinking, a document was prepared, the "IMSS Checklist." IMSS stood for In-flight Medical Support System. It was aimed at being a practical, visual, easy-to-use manual for the crew, showing and telling how to examine and report, and how to conduct basic treatments at the direction of the Crew Flight Surgeon.

In parallel with the manual, of course, was the assembly of the actual system – four lockers full of medical equipment and drugs. All the equipment was classified 'A' or 'B'. 'A' items could be utilized by the crew at their discretion (e.g., aspirin, otoscope, bone saw (!)); 'B' items required the presence or approval of a medical doctor. There was considerable discussion about whether 'B' items could be justified at all. I urged

their inclusion, explaining to Deke Slayton that a certain amount of experimentation with the use of diagnostic and laboratory equipment would prepare NASA for longer missions, even if we didn't strictly need them aboard Skylab; and that view prevailed.

Then the training took place. Pilots learned to draw blood, perform CPR (cardio-pulmonary resuscitation), use an otoscope and ophthalmoscope, extract teeth and do other wonderful things. They witnessed Friday nights in the Ben Taub emergency room. They extracted molars from patients (Air Force volunteers). They did all these things with their Crew Flight Surgeons, and some of them with the team of specialists which NASA assembled as in-flight advisors.

The result was a pretty well integrated medical team, from the CMOs (Crew Medical Officers) (and me) in flight, through the flight surgeons, to the specialists, none of whose services were actually needed in flight, but whose presence and interest was gratefully acknowledged.

So was the physician needed, and/or useful? You might ask the other crewmen about that. My personal judgment is that he/she's not needed on the moon, at least until stays become long and crews large; but is mandatory on a Mars mission – and therefore some medical doctors should be included on lunar crews for training, experience and hard-ware & procedure development. That's one of the main reasons we're going to the moon, right?

b. Kerwin (Written): I have one recommendation that goes beyond the Skylab data and conclusions, but I believe in it: 'An ISS Expedition of six months' duration with a crew of six should be planned, equipped, staffed and carried out exclusively or primarily for Life Sciences, and devoted to verifying countermeasures.' This would take at least three years to plan and provision, and international participation to crew, and would rescue ISS from the present triviality of its scientific results.

5.1.2 Did you have any evidence base for why you brought the equipment you included? We are going to look at what has actually occurred during space flight, look at risk assessment data, and see what we need to bring along. ISS transfers have medical issues but they will be different for moon missions. What was the kit based on? Did you have it because you could?

a. Kerwin: To some extent, we had it because we could have it. Skylab was unique in that we had, especially compared to CEV, no weight constraints. There was some work done looking at U.S. Navy incidents, particularly on submarines – PJ [Weitz] did some work on that. In the dental area, we went to the dental clinic and asked Dr. Fromme what his experience was with the astronaut corps. Now this is from memory and this may be wrong, but there was around one serious incident per six man/months for terrestrial care. This added up to a 5% probability that a serious dental incident could occur in flight, just randomly, not based on weightlessness. That appeared to justify the dental kit and training, and the ability to deal with those injuries so we wouldn't have to abort a flight.

b. Ross: During Apollo, we did have small medical kits that came in useful for issues like sinus blocks and headaches. We did have some issues with diarrhea (some of

which (were) possibly caused by the water system with hydrogen bubbles in water or potassium added to the Tang). We did have to use Lomotil® – so things like this need to be anticipated.

5.1.3 It was reported that crews "spent 98 hours in medical training, receiving practical training in diagnosing illnesses at an outpatient level."[4] One crew member commented that "I thought the paramedical training we got was very useful." Another stated that "I think we were really prepared for a large number of things up there." Was there a designated crew medical officer, or did all crew members receive training? Any other comments on the medical training?

a. Garriott: There were no designated crew medical officers on the last two flights; all three crew members went through everything on our flight.

One thing we did routinely was blood draws. We took turns drawing on each other. We all did everything, and if there was a question then we could ask the ground or the commander could tell us what he wanted to do. We all agreed that it was very useful training that we got, and we wouldn't have wanted to go without it. We planned to rely on the telemedicine when necessary, and I think that is the way to go for the future.

b. Carr: The same went for SL4; we all got the training. Our crew [SL4] designated Ed Gibson as the crew medical officer because he was the only one with a doctoral degree [in physics].

c. Gibson (Written): All of our crew received medical training, both operational and experiments. We were as well prepared as we could be considering the small amount of training we received. Actual hands-on training (ER (emergency room) and other) was useful to have us break down what inhibitions we might have for hands-on treatment.

d. Ross: We took crews to Ben Taub Emergency Room on Friday nights. The guys got some experience doing suturing, got to see some fractures and how they might be attended to.

e. Lousma (Written): All crew members were trained. Training was excellent for Skylab and much of it was applicable to non-space field medicine scenarios for activities in remote areas.

f. Schmitt (Written): In addition to the cross-training [discussed below] crew should be well-trained in protocols designed to understand adaptive responses to one-sixth gravity. The Lunar Biomedical Workshop strongly recommended that basic biomedical data should be rigorously collected on all lunar crew as a critical component to preparation for Mars exploration. The Skylab protocols should be examined as potential prototypes for lunar data collection. As the use of the CEV will be no more prolonged than for Apollo missions, specialized medical training may not be warranted beyond that of a general nature related to the use of medical supplies. Some CEV missions may have a physician on-board as a consequence of other crew manifest requirements.

5.1.4 When do you move from paramedic training to having an actual physician on board? In the level-of-care system that we outlined, we have kind of done that by mission distance and duration.[6] Where is that line? When is it good to have a physician?

a. **Lousma:** The criteria we used were based on the fact that we could get home rather quickly, if we needed to, from Skylab. We did not want to come home for something that could be solved during flight, but, on the other hand, we weren't all that far away. When you talk about going to the moon, you're talking about being 3 days away rather than 24 hours. I think that is a good dividing point.

b. **Bean:** I always feel like the people who go on a rocket flight into space are willing to take some chances. Now that doesn't mean we shouldn't solve every problem we can, but I would have to say that some of the conversation is not what we worried about on a day-to-day basis. I always felt like we had great communication with the doctors on Earth, and I would have had full confidence in Owen [Garriott] or Jack [Lousma] to do any of those things that could have come up – where the doctors would brief them and then they would do it, so I think taking a doctor to Mars is the wrong idea. I think we ought to take the best-qualified people to do the exploration. We ought to take the best people up there to do what we need to do on the space station and then allow or provide for telemedicine, which worked great for us.

c. **Schmitt (Written):** Once a lunar outpost is established and crew sizes reach beyond four, a crew physician should be available; however, this physician should be cross-trained in at least one of the other required disciplines and one of the other crew should be cross-trained to at least a level of a Physician's Assistant as a back-up to the primary physician. The most likely crew to be so crossed-trained would be one with some other professional scientific specialty.

5.1.5 In the Constellation medical concept of operations, we anticipate a capability to bring advanced medical equipment back with the crew if there is an illness or injury on the moon. Did you have a capability to carry advanced medical resources with you down to the ground?

a. **Kerwin:** No. We had no plans and no real capability to carry medical diagnostic or treatment equipment with us back to Earth. The first I ran into that was with Mike Chandler when we were working on the assured crew return vehicle (ACRV) in the late 1980s. Only then did we begin to develop significant plans for bringing equipment back, and where to put it on a special couch, and to have the crew medical officer in the adjacent couch. But nothing on Skylab.

b. **Thornton:** I hope you are interfacing with the USAF (United States Air Force) air evacuation community. Those people are doing incredible things with great, small carry-on medical capability.

5.1.6 Did crews without a physician receive any medical "refresher" training on orbit?

a. **Pogue (Written):** No. However we had a daily radio link with our flight physicians. As with our radio links with the family, these interchanges were recorded but not released

to anyone. The only person who heard these interchanges other than the participants was the COMTEC (Communications Technician) who set up the link and monitored to maintain the link. The interchanges with the flight physicians covered operational as well as medical topics. Deke [Slayton] insisted on the recordings so that if an accident or incident occurred, they might be useful in an investigation. The family conversation recordings were all returned to the applicable crewmen.

b. Lousma (Written): Not that I recall. Medical ops manuals were very thorough.

c. Gibson (Written): No, not on our mission.

5.1.7 Skylab had a well-stocked medical suite.[7] In a technical debriefing, a crew member stated that "as far as quantity of medications and supplies, I would guess we used about 0.01 percent of the available medication."[3] Another crew member agreed that quantity was not an issue, but organization and inventory could have been better.[8] Skylab had adequate supplies, but were they the right supplies?

a. Ross: We had 62 medications in the IMSS kit, and we had to look at their shelf life. And with the heat problem experienced on the first mission, we had to restock after that because it was felt that we could not take a chance on degradation of the medications that were up there. So that may be another thing that you all may need to talk about, medication turnover and possibilities of degradation, etc.

b. Kerwin: I think you people are probably miles beyond us with all the shuttle and ISS experience. Sure, they were not the right supplies for today, and, sure, they were more than we needed for then, but we had the basic stuff – we had pain medication, we had skin medication, we had stuff for URIs (upper respiratory infections) and for sleep, but there was a lot of stuff we didn't use.

c. Lousma: We also had extensive sensitivity sessions for those medications. We each took all of them to see how we reacted to them if we had to use them. We did this 6 months or so prior to flight.

d. Pogue (Written): I'm not qualified to say other than for time-critical treatment (e.g., cardiac arrest), the CPR equipment should be stowed where it is readily available, identifiable with dedicated power supplies, etc. So you don't have to assemble anything or string out conductors/look for a power outlet. On Skylab we had one locker in the wardroom used for this. It included a heart needle (cardiac arrest or pneumothorax), an ampule of epinephrine, and a tracheotome for blocked airway.

e. Lousma: We had a bone saw that we didn't use on anybody, but we used it to fix some things! [The bone saw was used to score bolt heads so that they could be manipulated with a screwdriver.]

f. Lousma (Written): They seemed right for Skylab durations, but longer missions in harsher environments will undoubtedly need additional and more recently developed meds and equipment.

g. **Gibson (Written):** Since we used very little of the medications, it is hard to assess if the right medications were available. I did not feel that I could adequately prescribe medications for myself or my crewmates since we did not focus on that in our training. We always assumed that consultation with the ground docs would be available.

5.1.8 The Constellation project is evaluating CEV seat design. Apollo reports suggest that the shift from the unitized, contoured, individualized couch to an adjustable, foldable couch allowed the crew to quickly disassemble and stow the seats for intravehicular activity (IVA) and EVA.[9] One crew reported some difficulty installing the CM center couch in preparation for deorbit.[8] In CEV, a modified crew seat (electrically isolated) is being evaluated for use as a patient restraint.[10] How quickly could a stowed seat be deployed for medical use?

a. **Lousma:** It depends on how you make it, but it needs to be quick and simple.

b. **Thornton:** You know the criticality of time under those circumstances when using the defibrillator. I'd look carefully at this.

c. **Kerwin:** My recollection is that unstowing and restowing the command module middle seat was pretty easy to do. We didn't have any problems with it, and I think it's practical.

d. **Gibson (Written):** We had little difficulty stowing and unstowing the center couch. If the seat is well designed and the stowage is simple, it should not be an issue.

e. **Lousma:** I wouldn't compromise the ability of the seat to withstand a landing to make it into a restraint system.

5.1.9 According to a crew debriefing, "There was a terrible smell in the workshop – really indescribable" on entering the OWS for the first time – likely a by-product of heating due to the loss of the micrometeoroid shield.[3] Did you have any concerns about toxins, despite your charcoal-filter masks and the CO and TDI testing that you conducted?

a. **Weitz:** According to the reference, that must be my statement and I sure don't remember that being the case. I don't remember the smell being that bad.

b. **Kerwin:** There was an odor, but it went away.

c. **Ross:** This problem was looked at, and apparently the heat never got up to the level where pyrolysis would occur and break the chemical bonds to release TDI. However, we were very much impressed by the possibility that carbon monoxide could be present. The equipment that we had was able to do some sniff testing, and that showed we were free of TDI and there was no appreciable load of carbon monoxide.

d. **Lousma:** I think you should worry about it!

e. **Bean:** I do, too.

f. **Lousma:** I remember in the Space Shuttle *Columbia*, I smelled things that I didn't think I was going to smell, and I didn't know what they were and they were probably

normal, but on the other hand maybe they weren't. I think that can happen any time – it could have happened on Skylab – I don't remember any event like that where I was concerned about an odor, but I do remember that in the space shuttle. And the first thing that enters your mind is: "What is it?" and "Is it dangerous?" "Is there some way to figure out what it is?" and "Is there a way to solve the problem if there is one?" So, it is a concern, and it ought to be addressed.

g. **Gibson (Written):** No, I never had a concern even with the initial strange smell in the OWS because of the survival of the two "evaluation" crews before us.

h. **Pogue (Written):** I was on the third visit and we had no problem with odors. I think the overheating of the workshop before the first crew entered was the problem. In between missions the workshop was dropped to 0.25 psi (pounds per square inch) and repressurized to 5.0 psi before the next crew arrived. The charcoal canisters did a great job of removing odors. Only in the MDA (multiple docking adapter) did I ever smell anything unpleasant. The air exchange wasn't as good in the MDA and flatulence could be detected in there.

5.1.10 Operational pressures have a tendency to impinge on personal time. The crew debriefings repeatedly touch on the topic of preserving time to sleep, eat, and exercise. One crew member stated that "Not only must we plan to do it this way but we must have our flight planners on the ground, flight directors, and the crew members realize that the most important thing that they can do is keep healthy and happy at that critical time. And make sure that, for example, if they're hustling along with a few things that come up like they always do and if it gets much past dinner time, the flight director should remind them to eat. Everybody should settle down to offload the crew members so they can eat right on time. And the same thing goes for exercise and going to sleep on time."[8] Any further comments on this issue?

a. **Garriott:** I think there will be disagreement on this issue. I would throw all of these out. I think the crew knows when to eat. I don't think there is a problem with delaying the time at which you eat by 30, 45 minutes or an hour or something like that. The crew knows when an issue is important enough to delay their sleep time by an hour or so. And so I would leave a lot more of this up to the crew. We did modify those things on occasion on our own time. We were strongly motivated to do what we thought was important on that flight. And we would not have liked for the ground to superimpose these kinds of timing issues on our activities. Now I know I'm speaking for myself here, and I don't know if Jack [Lousma] or Alan [Bean] feels as strongly on that issue as I do or not. I did not feel like we were imposed upon, and I would have wanted the flexibility to remain up longer, as we did. That flexibility is important to getting a larger fraction of the total work accomplished, which was our prime objective.

b. **Lousma:** I agree with Owen, I think it is the commander's prerogative. People on the ground ought to plan for there to be time, but the crew should be prime to decide how on how to use their time.

c. **Crippen:** I'd like to comment from a CAPCOM (capsule communicator) perspective, as I was CAPCOM during Skylab. The ground really doesn't have a very clear picture

of what is going on on board. So I really agree with what Jack [Lousma] said – the commander ought to be directly involved with scheduling issues. On Jerry's [Carr] flight, the ground kept scheduling like they had when Al's [Bean] flight was at its peak. We started off slow and they got good, so we kept scheduling at that rate. We started scheduling the last Skylab flight at the same rate as the other guys had finished up with – to the point that we overdrove them. So the ground needs to be involved, but the crew needs to be involved as well. Jerry [Carr] did the right thing and came down and said "Hey, whoa, this is too much." Do you want to comment on that, Jerry?

d. Carr: Yeah. I refer to that call we made as the "first sensitivity session in space," where we told the people on the ground what they were doing that was driving us crazy and we had to sit and listen to them tell us what we were doing wrong that was screwing up their schedule. The crux of the issue was over scheduling. When you get to the point where you are scheduling trivial things to be done at a precise time, you are going to start affecting productivity. When we loosened up the schedule on Skylab 4 and went to what we called "the shopping list" and only scheduled at a certain time that which was important because of where we were in the trajectory, we became more productive. I think that's something we got to keep in mind. I've heard interchanges with the old SpaceHab where the MCC started pushing the crews and then you start getting some snappy remarks back and forth. There is a little bit of it from ISS, I'm told. There are issues when people forget about flexibility and productivity just goes to pot when you have to follow the carrot all of the time.

e. Lindgren: So, the consensus is that we should reduce micromanagement and that flexibility is a key to improving efficiency, is that correct? [General agreement]

f. Ross: One issue is sleep time. We learned from the first Skylab mission that there were about 17 hours from the time of wake-up to landing. I think it is a real problem if the guys have to work halfway through the night to deorbit and try to make a landing and feel good. I agree with everything Owen [Garriott] said, except on this landing day sleep time.

g. Garriott: I agree with that. too.

h. Lousma (Written): Better planning is good in theory, but the crew will usually put work ahead of eat, sleep and exercise. The commander should make sure the crew's personal needs (eat, sleep, and exercise) are met, not the Flight Director, who should focus on directing the ground planning to accommodate the crew needs.

i. Pogue (Written): My only comment relates to scheduling an exercise period too soon after a meal. I was scheduled right after breakfast one day and upchucked about 15 minutes into a 30-minute ergometer protocol. I reported the event to our flight physicians and that never occurred again.

j. Gibson (Written): For long missions, the productive work-relaxation cycles [that have] evolved over many centuries on the ground should be used. Also, the crew should

not be chasing an overly detailed flight plan that usually puts the crew in the position of being behind. This subject has been treated in detail in our crew debriefings.

k. **Schmitt (Written):** The primary keys to behavioral health, in my experience, are (1) a well defined and agreed to command hierarchy, (2) useful and productive work and (3) periodic recreational and private time. Hopefully, ISS planning already takes this into account. Again, CEV mission times will be limited so this will not be much of an issue. Lunar Outpost (and Mars mission) planning, however, will need to carefully take these keys into account, remembering that there will always be useful and productive work to do (including refresher operational training) and that lunar EVA activities have a strong recreational component to them.

5.1.11 One of the problems still seen today is in the relationship between the science and the operations communities. Skylab maintained an excellent rapport with the scientific community, both programmatically and day-to-day. The relationship between the crews of the second and third Skylab missions had a particularly good relationship with the science principal investigators. How did you manage the schedule so well?

a. **Carr:** Well, you remember on Skylab 4, they finally allowed the unspeakable, one of the scientists was allowed to speak to Ed Gibson directly without a CAPCOM, and I think that was the beginning of a much better relationship between the scientists on the ground and the crew trying to do the job for them.

b. **Garriott:** We did a number of things that improved that relationship substantially. We talked also with Bob McQueen, the PI (Principal Investigator) on the solar occultation experiment, directly. I think the most important thing was, we went to extra effort. As soon as we got up [in the morning], one of us went straight to the ATM, one of us fixed breakfast for all three, and the other set about doing the housekeeping activities. After dinner in the evening, one of use went back to the ATM. So, we were monitoring that thing almost every waking hour. And we did that partly because we felt that we were behind. So, I think working with them on that, talking with them individually and talking about the kinds of activities that they were interested in, I think made a great relationship, and I think it continued on into SL-4. And so, I think it is just getting to know these folks personally, understanding what their objectives are, and doing everything possible to maximize their research. I look upon us as being their "hands on orbit," their "graduate students in flight." I think that kind of relationship developing with the PIs on each of the experiments was what mattered.

c. **Thornton:** Just a word of warning on that. The scientists need to get some training in communication, other than from the TV. Exact communication, that is. It was a huge problem with people talking just for sake of talking. Scientists need to be able to make real-time inputs; but at the same time, there needs to be some discipline on the scientific side.

d. **Garriott:** In fact, if you go back and look at what the communication really was, it was not all that important, it was trivial things. As much as anything, it was a help to establish rapport between the flight and the ground activities.

e. **Carr:** One of the most important things that was done on the Skylab Program was when the scientific community and the astronauts got together and developed the JOP (Joint Observing Program), I think that document went a long way to make things a lot better on Skylab in making sure that all of the scientists knew what they were going to get and what their part of the pie was.

5.1.2 With regards to scheduling issues during the pre-flight period, some of the Apollo crew members stated that they were frustrated at having trivial training introduced into their schedules in the month prior to launch. How can we protect the crews in that last month prior to launch so that we don't launch a tired crew?

a. **Weitz:** I don't know how you decide what you ought to expose the crew to as far as trivial procedures go, but I remember one time that our training guy, Jake Smith, decided to give us an extra lesson in collapsing the probe in the command module, which turned out to be time well spent! We couldn't get a proper docking when we made our final hard dock, and Joe [Kerwin] and Pete [Conrad] had to apply that procedure to collapse the probe.

b. **Kerwin:** We also had an 18-day quarantine period before flight, which turned out to be almost a month with the delay. That kept us from a lot of external pressures and made it easier for us to do that final prep.

c. **Lousma:** I think that in the final month when you are getting ready for a flight and everybody comes to you with all of the things that ought to be done, I think it ought to be the Commander's prerogative to decide what the crew needs to know the most. I think Al [Bean] did a good job with that on our flight, and I did it on a shuttle flight. Because otherwise your priorities are all wrong and you don't get the training you need. It ought to be up to the Commander to decide what training [the crew members] get all through the training process and especially that close to flight.

d. **Ross:** There are a couple of incidents that you have to consider. I agree with Commander's prerogative, but with some cooperation with the crew surgeon. For example, one Apollo crew delighted in running on the beach. And to make a long story short, this crew probably launched slightly dehydrated, which led to problems I won't get into. Some crews wanted to go flying. That was a great activity as they wanted to test themselves out because of some of the vestibular issues that had come about and had been noted in the earlier mission. You have to allow astronauts things that are right for them.

5.1.13 Mission planners did not understand many of the issues that were faced by crews during flight. As a result, tight operations schedules were often felt to decrease efficiency. How did intra-crew relationships and crew leadership styles affect crew efficiency?

a. **Garriott:** Skylab 3 had a great commander. We got along extremely well and I liked his style of leadership. Al [Bean] takes a laid-back approach, a very sensible approach. He didn't say, "Jack, Owen, you go do this." He allowed decisions to be made among the group, but yet the final decision had to be the Commander's. I appreciated that very much. He and I were motivated by different things, it's a difference of approach and yet

it worked extremely well. He allowed us to motivate ourselves as we chose but provided the example for all of us. You need that kind of a Commander.

b. **Carr:** I might point out that we were all mentored by the same guy, Pete Conrad, who was, in my opinion, one of the really great leaders in NASA.

c. **Kerwin:** It is interesting to note that all three of crews think they had the best Commander, and that's the way it ought to be!

d. **Bobko:** I was going to make the comment that the team that we are working with is not only the crew on the spacecraft but includes the ground folks as well. You know, I think we had a nice tight group here in SMEAT as well as the Skylab guys. Mainly the problems that I have heard that have taken place have been between the ground and the folks on board. You have to expand your concept of team to include a lot of the folks on the ground as well.

e. **Lousma:** One of the reasons we had such good relationships with the medical groups and our flight surgeons was that we had all these medical experiments to do and it was one of the major objectives of the Skylab mission. We not only wanted to survive and see if we could do it, but we wanted to bring back all the data we could. So we were motivated to get everything done that the Principal Investigators did, not only in the solar physics and Earth resources but especially in the medical area. And so I think it was the dedication on their part to convey that information to us, and they knew that we wanted to do the best we could, and that really improved team coherence on the ground and in flight as well.

f. **Carr:** Several years after my mission, I spoke with Valeri Polyakov and several of the other cosmonauts that flew on *Mir* and, to a person, they all told me that they were very grateful for the medical aspects of the Skylab that were published because it made their planning much easier to accomplish.

g. **Pogue (Written):** Tight scheduling is really difficult to deal with because of the domino or cascading effect. That is, if a job can't be completed in the time allocated one task has to be sacrificed (the one at hand or the next one up). In my experience, [in] intra-crew relationships, [crew] leadership styles were not an issue.

h. **Gibson (Written):** [Leadership affected crew effectiveness] tremendously. Jerry was a great leader and made sure that, despite the problems we encountered early in the mission, we worked well together as a cohesive team.

5.1.14 The absence of a standard method for private communications affected the relationship between Skylab crews and mission planners, as there was a desire not to highlight problems on the open loops.[8,11,12] Aside from improvements in communications, how else can we optimize the crew-ground relationship?

a. **Kerwin:** Again, you've probably come a long way on that. Do today's crews, on ISS and shuttle, can they call home when they want to?

b. Jones: Yes, they have the IP (internet protocol) phone and e-mail. They can communicate directly through those routes to personnel on the ground. [They] are a means to privatize the space-to-ground communications. We have the ability to do private medical conferences daily or weekly on a routine basis. The ground or the crew can call one at any time and we can privatize those loops.

c. Garriott: Thirty years ago, the medical community in particular did not want a private loop where you could discuss medical problems that they were not aware of. And I don't know if that same concern would be present today.

d. Kerwin: It wasn't the medical community, it was the press. It was the organized press that prevented us from effectively utilizing private communications.

e. Jones: The Medical Privacy Act of 1974 basically enabled us to do that private communication because now that communication is privileged and protected by law.

f. Carr: I might add that we probably would have had our "sensitivity session" in space at least 10 days earlier if it hadn't been for the concern about having everything in the open media.

g. Pogue (Written): I think the TDRSS (Tracking Data and Relay Satellite System) has solved a lot of those. We only had [comm.] for about 18-20% of our orbit. A lot of time we had a question for ground at the next AOS (acquisition of signal). As soon as the [Quindar] squawked, ground started talking and we couldn't get a word in edgewise before LOS (loss of signal) occurred. With e-mail available and the almost continuous voice comm. possible, communication flow is greatly enhanced and the cessation of the asinine PAO (Public Affairs Office) policy of releasing everything has gone a long way in taking care of the "private communications" issue.

h. Gibson (Written): 1. Plenty of crew-ground interactions before flight in simulations and discussions of this subject; 2. PRIVATE communications on a regular basis with the planners on the ground without the intrusion of the press.

5.1.15 So if you had private communications, would you have reported more medical conditions?

a. Kerwin: We wouldn't because we didn't have any. We talked to Chuck Ross on a daily basis. We didn't have any serious medical problems, but we did have the exercise problem which was a major problem – learning how to ride the bike. We discussed that with Chuck. [With regards to the cycle ergometer], Pete had a private management conference that he called on his own, outside the rules, but it solved the problem.

b. Lousma: It allowed Al [Bean] to ride the bike around the Earth!

c. Ross: One of the problems in the private communications session was that I was tasked to take a sheet [of paper] and to get information that the crew would give me to translate back to PIs at the morning PI session. So, I had to take a bunch of data down, numbers, remarks, whatever, and cover this whole sheet. Well I don't think that should

have to be done. I think the private communication ought to be for legitimate medical concerns and problems that are evolving, and they ought to be kept privileged and confidential.

5.1.16 Did you feel like these communications were truly private?

a. **Thornton:** Let me say that certainly our experience on SMEAT – we just gave up on that; there was so much cross-talk on the line. It was obvious there were people listening in on the line. That doesn't help. It shouldn't just be medical privacy.

b. **Jones:** We concur, and I think we've gone a long way to implement that so that the crew can have some confidence that their discussions are private.

c. **Bauer:** It's a whole lot different now than it was before. Even in the Shuttle-*Mir* Program, the only access the crew had to the ground was through the Mission Control Center in Russia. They would have regularly scheduled weekly conferences with their family, and then, when they would fly overhead in Houston, we'd talk to them on the ham radio. There is electronic communication, they have a phone up on station. They can dial any number they feel like dialing, and it is very interesting to pick up the phone and it's the guy up on station, and it sounds like he's down the street. They have great access to all sorts of resources and their friends and family easily on the ground.

d. **Scheuring:** Based on the Apollo debriefs; many crews did not report medical problems because they didn't want things broadcast across the Flight Control Room. Did you have any in-flight medical conditions that were not brought down to the ground because of the privacy concerns?

e. **Bean:** I can't think of a thing on our mission where we didn't tell everybody. I have always had the feeling that if you sign up to go on one of these missions, at government expense and they trained you all this way, that you've got to do everything to make the mission as good as you can. I can't think of a single thing that could have happened to me up there medically that I wouldn't have come on normal radio, and I didn't care if it was in the press or not, to talk about. Now, I'm in the minority; but, in general, if you're going to be a crew member, then you've got to do whatever it takes to pass any information to Earth, whether its science or medical, to make the mission as good as you can. We'd never have held back information.

f. **Lousma:** I got an extra $1.30 per day for doing that.

5.2 Umbilical Extravehicular Activity "We can fix anything!"

5.2.1 The Skylab missions are held in high regard for their ability to recover from serious setbacks with well-executed repairs, many of which were EVA-based. It has been reported that neutral buoyancy simulation and hi-fidelity training were well regarded.[3] What else contributed to the success of the Skylab EVAs?

a. **Kerwin:** As to what contributed to the EVA success, we had a long period of training; we had an excellent water immersion facility at MSFC (Marshall Space Flight Center).

We were very well trained and had a lot of experience in the suits, even though we had no maintenance missions on Skylab. The only EVA mission we had was the film retrieval mission on the Apollo telescope module – the ATM. And for that, we had a prepared set of handrails, foot rails; we had a special device for transporting film canisters from the EVA hatch up to the ATM. It was a very well-designed system. When we came on our flight and discovered that we had to do an EVA to try to pry up the solar panel, we were faced with a situation where we had no lighting, no handholds and no footholds, and a relatively difficult situation. I want to talk about umbilical management on that because I think that is the core of what we can contribute. We found that, and I wish Pete was here to talk about this because he was the lead guy on this – having walked on the moon – Pete went out of the airlock first, and the first thing I did was undo most of his umbilical and he sort of guided and tucked it behind him. He was standing in a set of footholds outside the hatch. Then we assembled a 25-ft pole out of 5-ft sections with a number of sections; and I would take the section out, connect the other section, and hand it to Pete. We eventually built this pole with a telephone company "limb lopper" at one end and a couple of ropes tied down at the other end so it could be operated remotely. Once we got that done, I deployed my own umbilical, pulling it out of the sphere in which it was stowed in the airlock – and these were 60 ft umbilicals – pushing it outside away from the path that I was going to take, over the circumference of the S4B to a point adjacent to that base of the solar panel, as close as we could get. Pete stayed where he was with the pole and I went up and over the circumference, and Pete guided my umbilical; and he told me when I had to stop or turn to prevent snagging. It was a pretty easy operation; it was just that you had to spend a little time managing one another's umbilical when you made a major move. When I got there, Pete handed me the pole as he came up and I stowed it away somewhere, then he came up and I did the same thing. I could see his umbilical behind him, which he could not. Once or twice I had to tell him to stop and make a 180-degree turn in order for the umbilical to remain clear. Once we were out there, the umbilicals didn't really bother us at all. The only potential snag arose when Pete had taken the 25-ft pole and put the jaws on that aluminum strap that you may have remembered seeing in the picture. Pete now had to use that pole as a handrail to go down, and connect some other ropes to the solar panel cover. His umbilical almost didn't make it; he started down and ran out of umbilical, and we said "oh hell" or some word like that. I just went back and pulled his umbilical around and eased it out, and we found 5 ft or so. He had just enough umbilical at 60 ft to get to where he was going. And the lesson there for an umbilical EVA is to assure the length of your umbilical is sufficient to reach all areas that you might need to reach because, once in flight and you reach the end of that umbilical, you have had it. You can't go any further. We didn't have to fool with tethers; the umbilical was our tether. We had great confidence in it as a tether, so when Pete got down there and connected his ropes and I tightened the rope at the other end and we both got under that rope, we finished cutting the scrap and the panel pooched up about 6 in. and stuck on a frozen hinge. We both had to stand up under that rope, crawl up under it, and then stand up the wall of the S4B and exert as much tension as we could on that rope until it pulled the frozen hinge loose. When it did, we went "pop" and went "ass over tea kettle," as the phrase goes, into outer space and came to rest at the end of our umbilicals, and pulled ourselves back. It had a nice stout cord to hold it, and we deployed the panel

successfully. Managing the umbilicals on that EVA was time-consuming but not all that difficult; it was much easier than it was in the water tank. I was pleasantly surprised, and using the umbilical to go to the sun end of the ATM with handrails in place was just a joy; it was a piece of cake. For that reason, my personal vote is if conditions are such that you could practically use an EVA with an umbilical of reasonable length to do your work, it is a good thing because it is a simple system; it's reliable; it's safe. Ours was open-loop; we were flowing oxygen at an intermediate pressure through the umbilical, through our suit, and out vents in the suit. So, you have to have enough oxygen consumables to do that. And that is the only drawback.

b. **Jones:** Joe, what if your umbilical was thicker because it was a closed-loop system as opposed to an open-loop system? Would your umbilical have been as manageable with a thicker umbilical to accommodate a closed-loop system where you are returning your atmosphere back into a scrubbing system to scrub CO_2 (carbon dioxide)? Because we don't have that big oxygen reservoir that you are talking about. Is that reasonable to have a thicker cable? And will you still have that mobility that you were talking about?

c. **Weitz:** Go try it in a water tank.

d. **Carr:** What are you talking about, extra thickness? How much more is the diameter of the umbilical? Two inches added to the diameter or the circumference?

e. **Attendee:** Two inches is the total diameter of the umbilical.

f. **Weitz:** Well, that is about what ours was.

g. **Jones:** This will probably be stiffer.

h. **Weitz:** With regards to the question about the neutral buoyancy center, obviously this was a situation for which we had not trained ourselves before launch, although we did do a lot of EVA training in the neutral buoyancy simulator. Rusty Schweickart and Story Musgrave did go to Marshall and did a lot of work once they got the downlinked photos from our fly-around and understood pretty much what the situation was; and they developed the procedures, which then took several hours to read up, and then we had a practice day. So, if you are talking about neutral buoyancy simulation when you have an EVA capability, it's my opinion that you need it.

i. **Scheuring:** Dr. Kerwin, did you say the handrails were already pre-deployed? You did not have to go out and deploy them?

j. **Kerwin:** Yes, all the aids outside the airlock and around the ATM were pre-installed, and we didn't have to do any work on that. However, I think we would all say that it is quite feasible to install handholds and footholds where connectors have been properly designed for them to create your trail as you go.

k. **Scheuring:** That's good to know, because I think the current CEV plans are to deploy them as you go.

l. **Carr:** If you want to see the handrails we had, I think they are probably over there at the visitor's center in that big mock-up because that is the mock-up that we did a lot of training on.

m. **Lousma:** I also think if you are talking about installing handrails, you should talk about installing them on Skylab. I think it would be a bigger problem to install them on CEV, so let's make sure we are talking about the same thing. They are going to burn off on the CEV or be a special kind of mobility aid, so I think we are talking about apples and oranges in terms of pre-positioning of handrails.

n. **Pogue (written):** Good motivation all the way around on the part of procedures developers, training specialists, training facilities providers and crew in my opinion contributed to the success of Skylab EVAs.

o. **Lousma:** While we are talking about training, then I have a few comments on that because I think we have been misled in some of the earlier shuttle missions on the EVA performance. I think the reason is because the neutral buoyancy tank is thought by those who have only trained in the neutral buoyancy tank to be the "end all" of zero G. So you not only train on your mission but you also develop equipment by using the neutral buoyancy tank and the zero-G airplane. My observation is: neither is perfect. If you do not know what those imperfections are, you are going to mislead yourself when you go up there; and I think that was clearly seen on the early satellite rendezvous, and we weren't able to connect with the Solar Max, and we weren't able to connect our gear with the other satellite. I can't remember which one it was, Crip [Bob Crippen] maybe – you can remember – we had some severe problems because the astronauts who were out there and had trained with the equipment had only done so in the water tank or the zero-G airplane and didn't have any real input from people who had actually done it. I think we wised up after that when we got to the Hubble telescope, and Story Musgrave and a couple of others who had done it before were able to make those EVAs very successful. So, the point is: if you are training and developing equipment for EVA, don't rest your total faith in what you learn in the water tank or in the zero-G airplane. Have somebody who has already been there help you do those kinds of things and help you understand where the deficiencies are in both of those training and development aids so that you will get it right when you get there.

p. **Brandt:** Where was the IVA crew member during your EVAs?

q. **Kerwin:** On the command module side ,just in case. And if for some reason you could not close the airlock hatch, we had a system for depressurizing the MDA, getting the two EV (extravehicular) crew members into it, closing that hatch, and repressurizing it. And you were on the side where the mission was done because you could not get back to the workshop, but you could get to the CSM (command and service module) and go home.

r. **Garriott:** It turns out Jack and I deployed the twin pole sunshade on our first EVA consisting of two 11-section poles and on which we had to pull up the sail and went to practice that about 3 months after these fellows came back. We practiced everything underwater except the one aluminum panel on which these 22 poles were mounted. When it came time to practice that procedure in the pool, it turns out the panel on which these poles were mounted was flight hardware. They said, "Do you really want to take that underwater and risk getting it rusty and that sort of stuff?" We said, "No, we'll just do that here on the top panel before we went under water," and took a simulated panel down to do the procedure. Well, when we got into space, I found that the most difficult task I had to do on all three EVAs was the fact that with my gloved hand, each finger was about twice the diameter of the ungloved hand here and I couldn't just pull the elastic band off the way they were strapped. I had to squat down, with one hand raise that whole stack of poles, and put another hand underneath that aluminum band and try and slip it out. So, I was really working by the time I did that. And it all comes about that we did not train for the one specific task that was the most difficult that we had to accomplish. The point that I was trying to make after that rather lengthy discourse is that if there is any way to train for the task, make sure you do the whole thing because those little things that are not so obvious are apt to come up and be the most difficult to complete. In terms of the mobility, to directly answer your question, we had no problem with that. We thought the suits were pretty good except that you can't really move your legs up and down; it takes a lot of effort to move shoulders and arms; it took a lot of effort to move arms and legs; and any improvement in the mobility of the suit would certainly be a benefit to any of the EVAs you might need to accomplish.

s. **Carr:** We're probably singing to the choir, but it was the glove mobility that hindered us the most out there, and I would come in and my hands were so tired they almost ached.

t. **Gibson (written):** [Success was a result of] many practice sessions in the tank on nominal and off-nominal tasks. What is really needed is the equivalent functionality of spray-on gloves.

5.2.2 Skylab EVAs were conducted using umbilical lines. One crew reported that their umbilical lines got tangled during a nominal airlock-based EVA.[11] Yet, another crew member commented that "One of the nice things that occurs in zero g is that the umbilicals tend to mind themselves and not get into trouble."[8] What other operational issues did you face that are not encountered in self-contained EVA operations?

a. **Gibson (Written):** The umbilicals did manage themselves to some degree, but some thought is required before making traverses or rotations. At the end of our mission, we tried the clotheslines for ATM film transfer. These lines did get tangled with the umbilical connection to the suit and opened it up, causing a spurt of frozen cooling fluid to be ejected. It was a good lesson in design that got ignored when we debriefed it.

b. **Pogue (Written):** Ed Gibson and I did the "dog leash around the clothesline pole" routine but it only took a few minutes to correct. We stuffed the 60-foot umbilicals back in the spherical stowage receptacles in the airlock until we could do "ring around the rosy" to remove the tangle and went back to work. Ed Gibson's water line leaked at the point where the PCU (pressure control unit) attached to the suit.

c. **Schmitt (Written):** My experience with this is limited to CMP (Command Module Pilot) EVA during TEC (trans-Earth cruise) on Apollo 17. I was involved primarily to manage the CMP umbilical that had significant storage memory (curls). I am not a fan of using umbilicals in general; but if necessary, some device or human management of them may need to be planned for. EVA training in the water tank probably needs to incorporate artificial curl memory to simulate the problems in weightless vacuum.

5.2.3 In a crew debriefing, it was noted that "ventilation…, liquid cooling, and circulation were adequate. We had all three guys on one loop. That worked well."[3] CEV engineers are planning a similar system. Did you have any valves available to isolate other crew from a leak in an individual suit?

a. **Weitz:** So you could get rid of them, you mean? No, I don't remember anything like that, do you?

b. **Kerwin:** Well, I want to probe that a little bit. The system on Skylab, we were all on one high-pressure loop, but each crew member was on a separate regulator attached to the suit that regulated the suit gas. The thing is, if one crew member lost pressure in his suit the other two [crew members] were not affected except in the command module. In the command module, the suit loop was one loop and in that case, if PJ [Weitz] on his out-the-door EVA had managed to cut up his suit, we would have all gone with him, which is not a good system.

c. **Weitz:** The reference on this is from our debrief, and I think this is probably Pete's comment from our command module.

d. **Lousma:** When I was answering that question, I was thinking about the EVAs that we did from the airlock where we were all separate, and I got to thinking that you are more worried about doing an EVA from the CEV, which is like our command module; and like we have already said, we were all linked together, which I think is a bad idea. If you can avoid doing it and you would like to have everybody separate. I think we learned that lesson on Apollo 13 with the cryo oxygen tanks: when one leaked, they all leaked. This is an analogous situation, and I think you would like to separate them if you could.

5.2.4 Did the front-mounted umbilical interface interfere with work?

a. **Carr:** We got it all done.

b. **Pogue (written):** I didn't notice it. Most of the arm work is done at chest height and the only detriment to the front mount is reduction of access to a work site. That wasn't a problem on Skylab.

5.2.5 Did umbilical line rigidity/memory make movement or positioning difficult?

a. **Carr:** No.

b. **Pogue (written):** No. I didn't notice memory was a problem. The umbilicals were all coiled up in the spherical stowage provision but I didn't notice any tendency of the umbilicals [to] retain a coil as we pulled them out.

5.2.6 During EVA prep and post, were there any issues with umbilical plug-in locations, umbilical length, stowage, or management in general?

a. **Gibson (written):** Not that I remember. I would have liked the freedom of movement without an umbilical, but training and a little thought in the use of the umbilical made their use perfectly acceptable.

b. **Lousma:** They were all pre-plugged EVAs from the airlock, which was in the sphere, attached inside the sphere, and the other end to the suit and that worked just fine.

c. **Lindgren:** What kind of length were the umbilicals from the command module?

d. **Kerwin:** From the CM? I don't know numbers, but I suspect they were pretty short. PJ [Paul Weitz] was at the full extent of the umbilical when he was two-thirds out the hatch. Now, during Apollo, they did SM EVAs; and I recall Ken Mattingly talking about doing one, and they must have had an extension added to the hoses to do that. I think the only umbilical management problem was just the work of putting those 60-ft umbilical cords back in those two spheres was the most physically difficult thing that we did during the EVA. It was hard work, and there is probably a better way to do it. If you are going to do a lot of nominal EVAs, you might want to consider a different hose arrangement; but for our contingency EVAs, it was fine.

e. **Lousma:** I think you ought to go back and read the reports on Apollo 15, 16, and 17. I know that for sure Al Worden on 15, Ron Evans on 17, and, like you say, Ken Mattingly on 16 all did an EVA on the way back from the moon out of the command module hatch, which they had to go to the rear of the service module. That would be a whole lot better data point for that question.

5.2.7 Could you please comment about the difference between liquid and air cooling for the suits?

a. **Kerwin:** Ours was liquid-cooling system, and it was fine.

b. **Lousma:** But that was on Skylab; and when we did the command module, it was air, right? Maybe that is what you are asking. If you are going to do an equivalent out of the CEV without water, you better not make it too strenuous; but I think Paul [Weitz] and Joe [Kerwin] are be better able to answer that because they did both.

c. **Kerwin:** Yes, we did a pretty limited EVA in time and in effort. I would vote strongly that if you are going to do real EVA work out of the CEV that you have a liquid-cooling system. We learned that during Gemini. Let's not forget that lesson.

d. **Carr:** I was just trading notes with Jack [Lousma]; and at the end of our EVAs on SL-4, we just got into the airlock and we pulled all that stuff back with us, and we were just

covered with snakes. Once we repressed and got out of the suits, then we went back and stuffed the umbilicals back into the spheres.

5.2.8 EVA mobility aids are important.[13] It was stated in a crew debriefing that "on future vehicles, provisions should be made for attaching crewmen to structures, for handholds, and for places to put footholds, even if you don't think you're going to need it."[3] The CEV will be scarred for EVA mobility aids, which are to be installed on orbit as needed. Any concerns or risks associated with this approach?

a. **Gibson (written):** It's a good approach, although designers and mass managers probably do not think so. It is essential that one's feet are anchored if they have to do any challenging work. Bill and I went where there were no foot restraints to repair an EREP (Earth resource experiment package) antenna and it made more difficult because of it.

b. **Pogue (written):** I'm assuming the CEV suit will have lights like the current shuttle EMU (extravehicular mobility unit). Lack of lighting, crew restraint and lack of handholds/transfer aids were the biggest problems on Skylab EVAs. Also, certain areas were declared immune to EVA. Lighting, transfer aids, crew restraint provisions and handholds were not provided. Well, we did do EVAs where it had been assumed that they would not be needed. All the pre-flight wisdom and policy accomplished was to make the job more difficult. I really like the idea of having lots of receptacles for mobility aids, which can be installed in a variety of configurations.

c. **Carr:** My impression of the EVA mobility aids on the stations sounds to me like, I haven't seen them, but it sounds to me like they have been able to define way ahead of time what their EVA trail was. We had the capability built in to attach handholds whenever we needed them. I think that was a good thing, and you need to continue to think in that kind of direction.

5.2.9 Paul Weitz and Joe Kerwin performed a "stand-up" EVA from the command module during SL-2 in an attempt to free the solar panel wing. According to the debriefings, things got a little sporty. Please compare this activity with the nominal EVAs conducted from the Skylab airlock.

a. **Weitz:** The sportiness applied more to Pete trying to station-keep rather than to management of the umbilicals or the performance of the EVA. First thing we tried before we tried to cut the strap is: we flew with what was called a shepherd's crook. It was a big crook. And some of our friends in blue suits had given us some information about what was going on up there; and they had this hook, and we were going to hook it under the end of the solar beam that held the solar array and see if we couldn't just pull it loose. Now the hatch is open and I am out the hatch and Joe is holding on to my ankles, firmly. But the hatch opened over this way, so that half of Pete's field of view was blocked from the command module hatch. Pete had us right in position when it started, but I'd pull on that shepherd's crook and it would pull the command module in towards the workshop. Surprisingly, the workshop weighed about 100 tons; and one time I noticed that when I gave it a good yank, the cold gas thrusters on the workshop started firing. So, we were moving the combination of the command module and the workshop. So, it got

a little frustrating. That didn't work, and we tried to cut it; and that didn't work because of the wrong angle on it. The sportiness of it came from Pete trying to maintain good station on the thing.

5.3 Launch – Thrust Oscillation and Vibration

5.3.1 The pogo thrust oscillation phenomenon was an issue for the Saturn V. Was it a problem for the Saturn 1B?

a. Weitz: Not in our case.

b. Bean: Not in our case either, and I don't remember it on Saturn V either. Maybe it was on there, but it did not appear to me to be a problem, and I've never heard any of my fellow crew members say it was a problem or even noticed it. I think that was solved before manned flight of the Saturn V came up, or it was around for Apollo 8, which flew it first. But, I don't remember any of this as being a problem.

c. Crippen: It was the unmanned launch of the Saturn V that really had the pogo problem.

d. Weitz: An engine on the S2 shut down on Apollo 13. Joe was the launch CAPCOM and I was at the Cape.

e. Bean: When you are scared, you don't see a lot of things going on!

f. Weitz: Yeah, you had a couple of things on your mind, Al.

g. Scheuring: Did they have sensors to measure oscillation?

h. Weitz: Yeah, all kinds of acceleration sensors on the vehicle, both on the launch vehicle as well as in the command module and service module.

i. Bean: You could get accurate data on all of this. But, if you take a look at either flight that I flew, whatever that level was is ok.

j. Pogue (Written): No. I never noticed a pogo on either stage.

5.3.2 With respect to thrust oscillation during launch, one crew reported "There was no pogo. The S-IVB was really smooth as silk all the way" "The whole ride was smooth."[3] A crew member from a different mission noted that "Lift-off was three or four very distinct, rapid, hard vibrations, enough to rattle my head in a helmet, or almost enough to rattle my teeth…"[6] Did anyone think the vibration environment interfered with operational duties, such as monitoring for overspeed?

a. Kerwin: We're getting denial here. Nobody remembers that. Liftoff was fairly rough, but the S-IVB stage was very smooth.

b. **Pogue (Written):** On the Saturn IB, during first-stage flight, the vibration was sufficient to prevent me from using a hard copy checklist to determine if we were approaching the 16-g limit line for abort. My arms were shaking the checklist so much I couldn't read it. I had no trouble reading the computer readout on the instrument panel. Once we topped 50,000 feet everything smoothed out. As advertised, the S-IVB ride was as smooth as silk. Monitoring for overspeed (I'm assuming that's insertion stage cutoff) manually would really be a good trick. In the seconds before cutoff the numbers are increasing so fast that it is almost impossible to watch for a specific velocity value.

c. **Gibson (Written):** The ride on the first stage is noisy and rough, like a high-speed train with square wheels. At about around one minute into the flight, you go through the speed of sound and also reach the maximum of the aerodynamic forces and turbulence. For about 10 or 20 seconds, the vibration becomes severe; you feel like a fly glued to a paint shaker. Then it smoothes out a little until staging at two minutes, which is like a head-on crash quickly followed by a second impact from the rear. The second stage is like a long, smooth elevator ride that accelerates ever faster as the mass of the propellants burns away. Eventually you weigh five times your normal weight, which is not bad because your heart is at the same elevation as your head. But it's hard to lift a hand, and you notice your cheeks and ears sliding towards the back of your head. Monitoring for overspeed was not a problem and we could have performed a manual shutdown if it was required. Training for this type of shutdown is essential. It takes close monitoring of the apogee and leading it. A graphical display would help.

d. **Schmitt (Written):** My one major surprise as a rookie on Apollo 17 was the level of instrument panel vibration on the S1C that actually prevented monitoring of system indicators during launch. This might be incorporated in the new simulators if Ares vibration will be comparable.

5.4 Water Landing and Recovery – Architecture

5.4.1 According to NASA TN D-6979, *Apollo Command Module Land-Impact Tests*, 51 test land landings were conducted with full-scale boilerplate and spacecraft command modules to simulate post-abort land landings.[14] Despite extensive vehicle damage (often resulting in RCS [Reaction Control System] rupture), crew survival was judged to be excellent.[14] From a crew standpoint, what are the risks and benefits of land landings?

a. **Kerwin:** As the old saying goes its terra firma, and the more firma, the less terra! Land landings are safer with quicker accessibility to medical care and rescue if you need it. You are not going to sink. The drawbacks are: it weighs more, it requires a more accurate entry and landing guidance system. Whether it requires a parachute that is steerable or not I guess depends on how much accuracy you require, and it has all those programmatic drawbacks. I believe that land landings would be a wonderful improvement over water landings for the reasons I mentioned. However, our Skylab experience with water landings is probably what you are interested in.

b. **Weitz:** Except you still have to design a vehicle to handle a water landing in the event of a launch abort. Do you want to design it for both, or just for one? Can you have a system that accommodates both perhaps? It's both?

c. **Garriott:** From what I understand, they are doing that now. You can plan for a water landing, but you still have to be able to at least survive a land landing if there is a launch abort.

d. **Weitz:** I know in Apollo, we didn't have the stroking couches like in Skylab. We had a mission flight rule that you had to that make sure that the winds were such that they didn't blow you back to land. I think that is where we are. You are playing the balls one against the other. You have to design the vehicle for a water landing, right?

e. **Garriott:** I think so, to at least survive it for a reasonable length of time, 48 hours or whatever the right number is.

f. **Weitz:** I know we have been fortunate. Who was it, Oleg Makarov? Did he have two launch aborts or just one? Just one. The Russians have had several launch aborts. One Soyuz rolled off the edge of the cliff on a parachute landing.

g. **Crippen:** That is the point, that land is not as nice and flat all over. In the water, you may get some waves, but…

h. **Kerwin:** When doing ACRV back in 1990–1991, we were looking for circles of 5-mile radius, as I recall, that were or could be made clean and flat enough that they didn't have trees, large building, cows, and other things that could move and endanger landing. A 10-mile-diameter circle was plenty big enough for a decent descent trajectory program and a good parachute to find, even without steerability. It's kind of like building airports; it is feasible, but you made the point that if you are coming back from the moon you might not be able to hit one of those. And there is a lot more ocean out there that is available.

i. **Crippen:** And we still have failure modes that if you need to go ballistic, then you are not going to land where you planned.

j. **Kerwin:** That's where the contingency planning comes in. We are trying to design something, and we don't know all the parameters. This is a key question and maybe it will come up later, but with our physical condition after extended periods in space, how well were we able to handle the landing and post-landing situation? Is a survivable condition doable with deconditioned people?

k. **Lindgren:** That does come up later, but it may be pertinent now to talk about risks and benefits of land landing vs. water landing for a deconditioned crew, and whether the risks of getting in the water and trying to stay afloat vs. trying to just stay within the capsule or being able to get out on land. Programmatically, it has been decided, but…

l. **Lousma:** I don't think the idea of floating out there in your suit is any good at all. Maybe in a raft, but you got to get in there, too…maybe falling out of the hatch into the raft.

m. Ross: May I ask a question? Where are the landing zones for the water recovery operations? For Apollo, we were going out the mid-Pacific line down by American Samoa tracking the mission for recovery. For Skylab, it was a different zone for recovery. The whole issue of where you are recovering becomes very pertinent to landing operations and your survival gear and everything else, so can you give us a little background about where the considerations are and where your contingencies are?

n. Chandler: The plan is to recover south of San Clemente Island. They found an area out there where they have some buoy data that is a good-sized place where the water is calm there for a good part of the time. They are also looking at an area down by the Baja Peninsula.

o. Ross: What are the water temperatures there?

p. Chandler: It was cool enough. The cold is not the problem, the problem is landing in hotter areas because of the humidity in the area and, because of the suits, they are anticipating a heat-stress problem. Because, right now, you are going to overheat if you are in this vehicle for very long, and that is the problem they are working right now. We need to keep crews cool. So, that is why they are looking at cooler water, because that becomes a real driver for them.

q. Weitz: So, the water temperature is the driver.

r. Crippen: I had forgotten until Jack reminded me this morning that you guys actually got out of your suits prior to deorbit? Was that a problem?

s. Kerwin: Not in the least.

t. Garriott: No.

t. Carr: On Skylab 4, and my memory is pretty old, but I don't even remember wearing a suit for undocking. It seems like the command module was so full that we couldn't take the suits with us. So, we came back in unsuited.

v. Crippen: I thought that was the case. I was wondering why they were choosing to wear the suits on entry because that can become a problem. You have more flexibility dealing with contingencies if you are unencumbered by that suit.

w. Kerwin: I agree that that answer should come out. Above all, get that damn suit off on the water.

x. Bauer: Those are discussions that have happened and probably will happen again. To oversimplify a bit, in a nutshell, there are concerns that Apollo-Soyuz had that nitrogen tetroxide leak and, of course, the Russians had deaths on reentry due to the depressurization; so the fear is that you have no redundancy if there is a cabin pressurization problem, so that is where there is some angst to suit the crew, and I don't think the issue is entirely

closed yet. They don't even have a suit seat interface established yet because we don't have a final suit architecture. That's a very open issue, and I think your input will be very important here.

y. Weitz: Let me endorse something that Al [Bean] said earlier. People sign up for this knowing there is risk associated with them. I think sometimes you just have to go on and accept it. Do the best you can in design and training to make sure those untoward events don't happen.

z. Lousma: We took the suits off after undocking during our deorbit coast, and it wasn't all that difficult to do. We had to do the opposite when we went up; and the same thing, we took our suits off during the rendezvous and got in our brown coveralls. And just coming back, why we came back in the coveralls, but after we had undocked. So, I don't think that caused any problem after being up there a couple months.

aa. Kerwin: No, but, Jack – and we did it the same way you did – I personally don't believe I could have gotten out of the side hatch or into the raft safely or made it across the carrier deck to sick bay wearing that spacesuit.

bb. Ross: Well, Joe, here is an operational question: Didn't we, on all three missions, have one person designated to wear the counterpressure capstan [anti-g suit] to help with the principle evaluation of people?

cc. Kerwin: We didn't have a designated person. That was an individual decision. I know I wore it pressurized; I think we all did.

dd. Ross: Did you pressurize it though? Well, I can see being out of the suits. I don't have a problem with that; but based on our own experiences it seems to me based on the deconditioning issues that we were concerned about that and we wanted to have some measurement that inflation of the countermeasure garment was important. The reason I am saying that is: I was a control for that and did some of these same things that the actual astronaut flyer did.

ee. Weitz: I did. I know Pete did, too.

ff. Carr: We all wore the g-suit and inflated it.

gg. Pogue (Written): *Land Landing Risks:* In my view, most of the risks come from high winds and rough terrain/surface (including structures). During Apollo there was a lot of talk about "stubbing your toe." That is, the crew survives a touchdown in high winds (the couches stroke, absorbing the shock of touchdown) but the spacecraft is yanked by the wind with enough force that the spacecraft stops sliding and begins to tumble, thus exposing the crew to injury. A rough surface simply aggravates the problem. Contingency/emergency landings conceivably could be made in a country, non-signatory to the Space Treaty. Signatory nations agree to assist astronauts/cosmonauts, etc. who land in their country. *Land Landing Benefits:* No need to deploy recovery ships. One

advantage of water recovery is that there's more surface to work with in the event of an emergency return and outside coastline limits the waters are international.

hh. Gibson (Written): Benefits: More of the vehicle could be reused. Landing and recovery forces at sea not required. Downside: One-chute-out case would bust up the vehicle and crew much more than the three-good-chute case. Water works, use it. The land landing with airbags requires the vehicle be aligned directly into the wind, which is hard to accomplish.

5.4.2 Despite the ability of the command module to sustain a crew for 48 hours, recovery forces were required to retrieve the Skylab crews in under an hour.[4,15] It has been suggested that the key driver for this requirement was a desire to preserve crew physiology for biomedical research.[4] Is this correct? Were there other drivers for the 1-hour recovery requirement?

a. Kerwin: It sounds to me like a requirement Apollo probably had. I don't remember changing the Navy recovery process just to accommodate physiology.

b. Lindgren: If I recall correctly, there was one recovery ship for Skylab? You were able to effectively target the primary landing site? For the lunar skip landings, we don't have a large amount of resources for landing as far as the recovery vehicles. If we have to do search and rescue, then we have a requirement that they be protected by the vehicle for 36 hours.

c. Lousma: Tell me about this skip landing. When you come back on return, you could skip out of the atmosphere? But, you don't want that to happen on the way back from the moon.

d. Lindgren: A skip entry that we are describing extends the landing recovery area.

e. Lousma: So, this would be a nominal procedure during some conditions, is that right?

f. Bauer: We have two defined landing re-entries: direct entry, which is what Apollo did, and skip. As I understand, there is not the risk of skipping off into space, but you had an off-nominal skip, you could end up anywhere on the Earth's surface. They seem fairly confident that it won't happen; but at the same time, we can't get them to say we have it solved. You had either the nominal landing in the short 5 miles radius or the off-nominal [landing]. That is not the case in this situation. You can either be nominal or off-nominal and be very far away. This issue is not resolved.

g. Bean: These are the same discussions, as I recall, from early Apollo, and we got ready to fly it. Even in Apollo 8 somebody said, "I'm not gonna get captured and let go again. So, we aren't gonna skip," and this was everybody. It wasn't just one or two guys. We said, "Look, we are not going to do that. We are going to get captured the simplest way," and when you chance to go out and finally do, it that's one. And the other part of the equation is when you leave the moon after that burn, you know where you are going to enter on Earth. And if you are not in the right spot, you are going to do a mid-course correction because NASA is not going to have you land in Alaska or somewhere else.

And you have a day-and-a-half to two [days] to do mid-course correction to put you just below San Clemente. I think it is time for NASA to – we are better at this now and more accurate, better technology, better electronics. We ought to be able to land right exactly where we want to. It costs a lot of money to NASA. The Navy may do it, but we pay the bill. If we can land the shuttle on runways, we can land this thing; and it is easier to land more accurate coming from the moon because you have a day-and-a-half to plan for it and get this thing so perfect, and they can do it and they have demonstrated they can. So, I think it is, we can talk about it, but when the chips are down, everybody is going to say we are going to land this right where it is supposed to be and we are not going to do any of these other things.

h. **Lousma:** I want to ask a question because I never heard of that before, unless there was an emergency or some kind of problem that would be fatal. I don't know why they would ever consider a skip reentry. You ought to baseline a nominal reentry and outlaw the off-nominal idea. Why worry about it if you spend more time doing it right then you don't have to have this back-up problem?

i. **Garriott:** I would just as soon have a back-up capability, but not the one suggested here. But, you ought to really try to do it correctly within your 5- or 10-mile radius. This 48-hour recovery period is irrelevant, because if you miss it, you're going to be a lot further away than 48 hours from some ship steaming over to pick you up. I think you ought to provide for the nominal situation, where an equivalent of the *USS New Orleans* is going to pick you up in a nominal way or have a different recovery procedure completely which would not require the crew to hop out of the vehicle into a dinghy, which, I agree with Joe, does not have a very high probability of survival anyway. You ought to be thinking about a recovery procedure that involves dropping airborne resources into the water to help the crew out, put them on board something, and keep them there safely. Don't rely on the crew to do that. Don't rely on a ship to go get them; rely on airplanes to drop people in there to go get them. To me that would be a better recovery scenario and strategy than what is implied by this question.

j. **Chandler:** We are looking at just exactly what you talked about. That is one of [the] reasons we just talked to DOD (Department of Defense) to do just that if we ended up with contingency operations.

k. **Kerwin:** Al, do you remember where Gemini 8 came down and what ship eventually came and picked them up?

l. **Bean:** I don't remember but it was a destroyer and they didn't have any problems that I remember. They just went over there and picked them up. It wasn't that far away and they hadn't been up that long, so they weren't in the same physical condition that might exist after people have been up for 6 months or something like that. Sounds like we're in better condition at the end of 6 months that maybe we were at the end of 2 months. Of course, Jerry's group was better off because they exercised, so I am sure they have made a lot of progress there.

m. **Pogue (Written):** I don't know for sure but as soon as the band stopped playing on the deck of the *USS New Orleans*, we were hustled below deck for several hours of medical/physiological tests. I don't know of any other drivers for the 1-hour limit.

n. **Gibson (Written):** I do not know. We were one of the few spacecraft that ended up in stable 2. That meant that we were hanging upside-down in the straps, bobbing on the water in a closed damp cabin with the heat of reentry soaking back in – the worst part of the whole flight! Eventually, we inflated 3 air bags and popped upright. After that and when we got some outside air into the cabin, we could have stayed there quite comfortably for several hours.

5.4.3 A hoist/elevator recovery is being considered by the Constellation Program. Skylab astronauts were hoisted, vehicle and all, onto the deck of the recovery ship.[4] It has been suggested that key drivers for this requirement were: (1) a desire to preserve crew physiology for biomedical research,[4] and (2) concerns related to water egress by a deconditioned crew. Is this correct? Were there other drivers?

a. **Kerwin:** This is correct.

b. **Garriott:** Obviously number 2 is a lot better option than number 1.

c. **Kerwin:** If testing of physiology was the primary thing, they would not have allowed us to egress and walk on the deck to the medical trailers; they would have carted us over there. They didn't do that.

d. **Lousma:** They came into cabin before we got out to see if we were still warm. There wasn't a lot of testing as I recall.

e. **Kerwin:** There was some hands-on for a pulse rate. Chuck [Ross] would have known the plan, but Pete Conrad wouldn't allow that on our flight – he was poised at the hatch and, when it opened, up he popped out like a wooden doll.

f. **Ross:** Pete's words to me were: "Chuck, get us out of here."

g. **Pogue (Written):** Those are the only two drivers that I recall.

5.4.4 Hoisting was viewed as too hazardous for use in the early Apollo Program.[16] What changed?

a. **Bean:** I don't remember really. And I don't remember anybody saying it was too hazardous. It just seemed to always be in my memory that's the way we did it. We did it that way in Gemini; we did it that way in Apollo. I think hoisting is the best way to go. I don't think we ever talked about whether we had that option. I think it is a lot safer.

b. **Lousma:** I don't think hoisting was ever thought of as being too hazardous, but I'm guessing before anybody ever flew in a command module they hoisted a whole lot of them out of the water from test articles.

c. **Kerwin:** I was thinking the same thing. They probably hoisted your command module after you were out of it. So, the Navy got a lot of practice doing it and said, "This is easy."

d. **Ross:** That's true; because on the ship, while I was sitting out there waiting for your return, I can't remember if it was a 5-ton crane or a 10-ton crane, but they absolutely had no problem with the pickup. However, I was out on a couple of the Apollo recovery missions, and I can tell you, as a crew surgeon, I was practiced to jump out of the helicopter into the water, and that was something not to be taken lightly. They'd tell you, "We are going to let you jump 10 ft at 10 kts or 5 kts," and I can tell you I made an illustrious bona fide faux pas on my jump, so you don't want to do that but let the underwater demolition team do it. The point is: you let DOD take that stuff over. You've got swimmers to put the harness, the floatation collar on; you've got good UDT (underwater demolition team) guys. The problem with Apollo was that each guy had to go up into the raft, then into the Billy Pugh net, and then be hoisted into the helicopter to be taken on board. I agree that is more hazardous than lifting the command module right out of the water.

e. **Pogue (Written):** I don't know. Sometimes policy is changed by necessity. It could have been a trade. The risk of trying to get the crew in a raft could have been viewed as higher than hoisting the entire S/C (spacecraft) up to the deck.

5.4.5 In the scenario where we do a water hoist recovery, what precautions would you suggest that the crews take during the time in the vehicle itself, during the time that it took to get you out? Is there anything in particular that you would recommend? How did your exercise prepare you, or could it have prepared you better for that?

a. **Lousma:** I don't remember being in the vehicle more than half an hour before I got picked up. I mean, the divers were right there before we even got right side up. As soon as we got right side up, they came in and put the flotation collar around, opened the hatch, and the ship was right along side. So, they got us out fairly quickly.

b. **Garriott:** I would suggest that we were all fairly euphoric at that point. Glad to be back.

c. **Lousma:** On dry water?

d. **Garriott:** We were crawling around a little bit while inside because we had been bouncing around and we didn't know what the legs were going to do. But the actual lift-out, it wouldn't hurt to be back in your couch and maybe put a strap across your body so you wouldn't drop, or if you banged the side of the ship or something you wouldn't go flying all over the place. That would be about the only constraint that I could think of for the post-splashdown.

e. **Lousma:** We were upside down looking through the water. It was green and kind of nautical out there, and a diver came and looked through the window and wanted to

know if we were okay, and we gave him the thumbs up. And I didn't know if this was up or this was up, but I'm okay.

f. **Ross:** If you are looking at operational costs also, I recall that, in Apollo, we had the retriever down at Galveston. We practiced retrieval maneuvers during all times of year – winter, spring, summer, and fall. It seemed like we were always down at Galveston, which when you start taking on all the people that have to support that to get the crew out of capsule and into the raft in a recovery situation., this was costly training. I also remember out in San Diego Harbor when we recovered, it was colder than you know what. I was out in the raft with Story Musgrave, and I went up in the Billy Pugh net with Rusty Schweickart. And I looked at him and I said, "Rusty, your lips are purple." He said to me, "You don't have a mirror in front of you though either." There is a lot of stuff that could be cut from a cost basis if you went to the hoist methodology.

g. **Carr:** I would think that the downside of hoisting would be heavy seas. You really worry about banging the spacecraft against the ship. It seems to me that the Navy has some amphibious vehicles that are designed to lay Hovercraft in the water, and they have equipment like an LST (landing ship, tank) or something where you put an elevator or something like that around the spacecraft and lift it out of the water. That would certainly be a very benign way to do it, and a very safe way, I would think.

h. **Bobko:** Question: Years ago, when they were talking about the assured crew return vehicle (ACRV), there were all sorts of things about being able to get to a definitive care facility within 4 hours; and has all that just passed away?

i. **Kerwin:** I guess it has. The ACRV had the three primary missions, and the most important one was as an ambulance from ISS for a more or less severely ill or injured crew member who had to be gotten back to care. A water landing would not do for that for a number of reasons, one of which was because of [the] time required to get to a definitive care facility and because of time and conditions in the water after landing. If that requirement were still taken seriously, I would think you would go to land landing as a primary mode.

j. **Chandler:** This vehicle does not have the medical mission that the ACRV did. Therefore, we do not have those requirements.

k. **Garriott:** One question that is not in here, particularly from the basis of this discussion, would seem to be important. And that is: Weight aside, and cost aside, which would you prefer – a water landing or a land landing? I don't know if there is any unanimity on that or not, but I would think that would be relevant to this discussion.

l. **Lindgren:** Can we take a vote? Weight and cost aside, who would prefer a land landing?

m. **Lousma:** I like landing on a runway.

n. **Lindgren:** Cost and weight aside, anyone prefer a water landing?

o. **Garriott:** None of us are in favor of water landings.

p. **Kerwin:** I'd go for a water landing only if the water is 18 in. deep.

q. **Crippen:** With the vehicle that you are bringing back, I would vote for the water landing.

r. **Lousma:** Weight aside is not an easy thing to throw off, however.

5.5 Water Landing and Recovery – Operations

5.5.1 What were the major time constraints for emergency deorbit (availability of recovery forces, weather, preparation of the CM, etc.)?

a. **Lousma:** Yes.

b. **Lindgren:** All of the above?

c. **Lousma:** I have written here that the CM could be made ready in a few hours, whereas the recovery forces and weather would take several days, depending on nominal returns.

d. **Lindgren:** I recall they had a 24-hour turnaround or preparation requirement. Does that sound reasonable, or did it take longer for recovery forces to migrate to where they needed to be?

e. **Lousma:** I recall the ground track over the nominal landing site was in the same spot in the water every 5 days. So, you might want to come down in the same spot in the water. It all depends on how far you have to go. I have no idea. Thirty knots in 24 hours is how many miles? Seven hundred?

f. **Pogue (Written):** Some of the pre-departure procedures on Skylab included manual reconfiguration of panel switches over which MCC had no control. It was no big deal (didn't require a lot of time). Other possible considerations were the biological samples, namely, fecal bags (250) and frozen urine samples transfer to the CM. The urine samples were frozen, stowed in a freezer and then transferred to a return box with a thermal capacitor (like the blue ice for picnic boxes) to keep them frozen. If recovery forces didn't retrieve them before they thawed, it would have compromised the evaluation of the urine samples.

g. **Gibson (Written):** If it's truly an emergency deorbit, the priorities are: 1. Prep spacecraft and deorbit ASAP; 2. Weather if the time can be afforded to make a choice; 3. Location of recovery forces; 4. Close to CONUS (continental United States).

5.5.2 Apollo command module specifications required the vehicle be able to handle ambient air and sea temperatures up to 85ºF, wind velocity up to 28.5 kts, and sea states with waves up to 8.5 ft, all for up to 48 hours.[15] Could recovery force elements (recovery vessels, swimmers, support aircraft) operate in the CM worst-case environmental conditions?

a. **Ross:** Part of my duties ,when I was in flight medicine during Apollo, was to work directly with the recovery crew operations teams. I knew nothing about some of this recovery operation, but it is important that crew surgeon or deputy work with the recovery operations people to look at these parameters. I think it is critical. And try to put some common-sense ideas forward when there is a difference of opinion. But then again, it is operational maturity that has to develop between the people that are coordinating.

b. **Lousma:** I think given those three methods for recovery, my gut feel is that the recovery vessels and support aircraft could operate very well in heavy seas, but the swimmers would probably have a hard time.

c. **Bobko:** What about at night?

d. **Lousma:** Wait till morning.

e. **Ross:** Jack, we were up to about 8 ft during the first Skylab return. Joe, you can attest to that.

f. **Kerwin:** I would have said they were less than that.

g. **Ross:** It was up to, I'm not saying they were constantly that way. But it was not a really calm sea that day.

h. **Kerwin:** It was not a bad environment for us. I would have said 5 ft instead of 8 [ft], but I'm not sure.

i. **Weitz:** Didn't it say somewhere it was 2-and-a-half-foot waves with 8-ft swells, or something like that?

j. **Lindgren:** I had read that it was 2- to 3-ft waves with 8-ft swells.

k. **Weitz:** Swells are easy to ride out in rowboat.

l. **Carr:** Bo's [Bobko] question about night I think is a good one. You just need helicopters to have lights at night. The helicopter recovery people would have to have one or two lightships while the other people did whatever else they had to do.

m. **Bobko:** We see now, with going to the ISS, we have night launches and landings because that is the ISS orbit. If you have to do it that way, and especially if you only have one landing recovery area, I think you have to worry about it.

n. **Garriott:** If it is an abort, and you have missed your daytime landing spot but you have landed at night, you are thousands and thousands of miles away.

o. **Bean:** Or you launch at night and then you have to abort. They have those procedures worked out, don't they?

p. **Bobko:** If you want to land at a certain time in San Clemente, then you might have to land at night. Coming back from the moon, you might have to land at night, depending on what the orbit is doing. So, I was just curious about that. To me, it is a pretty good-sized problem to overcome.

q. **Bean:** I think Bo has a good point, but I have always found it more difficult to find a nice landing spot for the shuttle than it will be for this. Don't they have all those techniques worked out for landing? If they can land the shuttle at night, they ought to be able to land this thing at night.

r. **Lousma:** Well, you can land it but you might not want to be in it. Did we ever land a capsule at night? No.

s. **Bobko:** I would imagine that Soyuz coming back from ISS sometimes lands at night, is that correct?

t. **Chandler:** Yes, they have landed at night.

u. **Crippen:** I personally think for a nominal landing, even though you may have to wait a couple days to get it, you should plan on day landing. And you are going to have to deal with an abort-from-launch at night. I don't see how you can get around it because you will never get rendezvous, there just aren't enough spots to go launch.

5.5.3 With regards to seasickness, it sounds like your crews were fairly comfortable and yet the Apollo crews related some real issues with seasickness. Did something change in the vehicle environment? The Apollo crews stated that after landing, they got hot fairly quickly, which contributed to seasickness. What changed?

a. **Garriott:** As a non-medical type, I think we had adapted to weightlessness and that one thing somehow desensitized the communication between your neurovestibular apparatus and your stomach. Perhaps a physician could describe it better from his perspective.

b. **Kerwin:** On our flight, I was busy there in the command module getting sick and threw up in sick bay on the carrier. I did that because I did the fluid loading wrong. I "chug-a-lugged" the strawberry fluid on the water post-splashdown, and that was a bad thing to do. How about you, Jerry, did your crew all not get seasick?

c. **Carr:** None of us got sick. Despite the fact that one of the guys was Air Force, none of us got sick. That sure was a waste of strawberries.

d. Kerwin: There was a finding out of the vestibular experiment that resistance to motion sickness was somewhat improved after long-duration flights, so Owen [Garriott] may have something.

e. Thornton: Sometimes the vestibular adaptations last a lot longer than a couple days after landing. For example I went out flying with the PLT (Pilot) after my first flight, and I'm only moderately resistant to airsickness, as was he. We took turns trying to get each other airsick, and we did some fairly vigorous things with the aircraft. It's not only here that you lose all kinds of sensations after adapting to weightlessness, even in a matter of 3 or 4 days. It seems the vestibular system is reprogrammed and you are remarkably more insensitive to unusual attitudes. This has been a very common experience. Joe, was there anything else? You didn't have any gas exposure on your landing, did you?

f. Kerwin: No, we didn't have any.

g. Weitz: As the "deputy flight surgeon" on board, my conclusion is, and Joe touched on it, we'd all fluid-loaded a little before reentry, and Joe was saving his, and he wanted to make sure that Pete and I had more fluid available if we could. As soon as things were relatively under control in the water, I think Joe's mistake was getting out of the seat and busying himself with preparing those drinks. And I think if he would have stayed on the couch, he would have not have had any problems at all.

h. Crippen: I would also submit to the fact that they were not in the pressure suit, and not getting as hot was a significant factor in that.

i. Scheuring: Apollo 15–17 [crew members] just wore their constant wear garments. They didn't wear their suits, and they still complained about getting overheated. Mr. Bean, was there a lot of difference between what you experienced during Skylab and Apollo?

j. Bean: I don't remember any difference really. Both times I was so glad to get back to Earth, everything just passed by and it was okay. It was not a problem. You are back on Earth and all the big risks you are taking are over. And you are sitting there, and maybe you do get sick, so what? You are going to have so many problems to solve that are life-threatening and this isn't one, so don't worry about it. Any solution is probably okay.

k. Carr: We landed in February and it was nice and cool, so we didn't have the heat problem at all. We didn't even feel like the spacecraft was holding any residual heat. We landed in the cold Pacific and were not hot.

l. Aunon: Did you take any seasickness medications before landing?

m. Kerwin: I don't think anyone took anything.

n. **Garriott:** Why not take the suits off before landing?

o. **Scheuring:** All the crews are going to come back suited. That is a requirement. They have to come back suited because of decompression and toxic exposure issues.

p. **Garriott:** Why don't they take their suits off before they re-enter the Earth's atmosphere?

q. **Scheuring:** For the reasons that Dr. Bauer previously described, because of the history of decompression, toxic environment; that's really the requirement that they have to be suited. That is a given that they will be suited.

r. **Garriott:** There is that one ASTP experience where they missed their own switch.

s. **Crippen:** It doesn't make that much sense to me.

t. **Lousma:** I agree. We had the same two issues [toxic exposure and decompression] on Apollo/Skylab and did not worry about it. Why now? We may get so "risk averse" that we will not (or cannot) go anywhere!

5.5.4 What risks or issues concerned you most about the post-landing environment?

a. **Lousma:** I remember after landing I felt like sitting down or lying down for 2 days instead of standing up. I remember the hardest job was to stand up in San Diego during the presentation when we were getting the keys to the city.

b. **Pogue (Written):** An uncorrected stable 2 situation after landing in the ocean. The contingency egress called for the crewmen to go down through the docking tunnel and out the tunnel with continued egress up the side of the CM to the water's surface.

c. **Lousma (Written):** This would have been tough, maybe fatal, even in just coveralls.

d. **Gibson (Written):** Post experience: Hanging upside down in the straps, bobbing up and down in a closed damp cabin with the heat of reentry soaking back in. After upright, spending many hours in a high sea state could get old.

5.5.5 According to crew debriefings, post-landing and recovery operations went smoothly.[3] Was there any additional training or preparation that could have been provided to account for deconditioning?

a. **Kerwin:** Fluid load properly on orbit and not while sitting on the water would have helped. And an easier landing day so you are not landing after 19 or 20 hours awake.

b. **Thornton:** Let me offer another gratuity here. One of the things that has not been recognized, as far as I can tell, is the neuromuscular adaptation that occurs. Now, I am not talking about strength loss through loss of somatic mass. One of the old heads told me to "be careful when you first get up," and what he told me was exactly right because when I first started to get out of that seat I might as well as left the straps off because I

had to really push and shove just to stand up. This is a phenomenon that I've known only one person who claimed not to have experienced it. Unfortunately, it hasn't been studied but is real. You stagger up and sit down quickly. Then you stagger up and stand a bit longer and repeat the process until you are able to walk off, feeling as if you're pulling 2g's with a firm grip on the handrail. Recovery is rapid, and my neighbor reported that I was able to put the garbage can out as usual the next morning. This is simply adaptation in weightlessness and readaptation on return to 1g by the somatosensory system beginning with the muscle spindles, tendon organs, and other sensors. The shuttle commanders first observed how hard the brakes were to actuate on landing. Crip, I bet you were working on the brakes on the way down, weren't you? Didn't you exercise?

c. **Crippen:** Yes.

d. **Thornton:** And for good reason, because that is the worst time it can hit you. All I am saying is: leave some time to readapt, and don't expect crew members to jump out of their seat and grab 100 lbs or whatever. It is a transient phenomenon that you recover from, but it takes a matter of hours to recover completely.

e. **Brandt:** Bill, this sounds like there is a neuromuscular memory similar to pulling G's in an aircraft.

f. **Thornton:** It makes all the sense in the world. You can dissect out a muscle spindle and you can change the sensitivity on that by the way you pre-load it. There is a good, solid basis for it.

g. **Pogue (Written):** I was on the third Skylab visit and I agree that post-landing and recovery ops went well. We had more time for exercise than the two previous crews and, although we were up longer, we were in the best condition at recovery time. The biggest problem related to exercise is clean up afterward. We daily got heart rates of 170 so we were hot and sweaty when we finished on the ergometer. I'm not sure it's possible to eliminate deconditioning in a weightless environment. The Russians have tried two [1-hour] exercise periods daily and say that helps but I don't know if they have hard data to back it up.

h. **Gibson (Written):** A rehearsal of the period between getting out of the couch and into a chair on the deck would have helped, although none of us had a problem.

i. **Lousma (Written):** One additional suggestion might be to avoid making major sleep-cycle changes in too few days prior to entry.

5.6 Water Landing and Recovery – Flight Crew Equipment

5.6.1 Reflecting on your state of deconditioning at landing, what challenges are associated with donning/doffing a pressure suit in the closed cabin?

a. **Kerwin:** I think we have a strong consensus on this side of the table – that we would advise against wearing a pressure suit for landing. If I did land in it, I might want to get

out of it in the command module because I wouldn't want it if I had to egress and get into a raft. If I was being hoisted up onto the deck of a ship, I might want to leave it on, but I would require assistance on egress.

b. Bauer: So, assuming that you landed and did need to take the spacesuit off in the capsule, based on your memories of how you felt immediately post-landing, do you feel like you would be able to do it?

c. Weitz: You wouldn't, because you'd have to get up out of the couch to doff the suit, and I don't think you could do it because of the neuromuscular changes and because of the unaccustomed gravity vector that torques your gyros every time you move your head.

d. Bauer: So, it would be difficult with assistance, at best?

e. General Consensus: Yes.

f. Lousma: I think it's difficult to do in the simulator.

g. Bean: I think Joe's right. It ups your chance to get sick, and you're not good at it and you don't want to do it. But if you had to do it, you could do it. I think one of the nicest things I can remember about Skylab was that there were a lot of doctors when we stepped out on the deck of the ship. They were there on either side, and I kept thinking, "Why are they standing there holding me?" And I found out later after thinking about it that I thought the ship was rocking, and it wasn't; it was me, and they were catching me. So, I remember that as a good thing. Any time you can get people helping you after a long-duration mission, it's a good thing. Some of these questions could be addressed by crew coming back from long-duration ISS missions. What are they like?

h. Carr: I think that is a good question. Some of these folks have been up there for 6 months and longer. What kind of condition do they come back in compared to Skylab? Are they having the same problems we had, or a lot more?

i. Alexander: Some crew members have difficulty even getting out of the capsule, much less moving around. A big part of it is getting their gyros reset – not moving about a whole bunch. Some crew members are pretty weak and require assistance just getting out of the capsule. But there is rapid recovery and over the first 4 to 8 hours, you see their muscles start to work and they are able to walk around. But originally, they need assistance getting out. We have to carry them to seats, especially after Soyuz landings.

j. Kerwin: I'll speculate that if we were in a contingency situation and could not get out of the capsule and be rescued for 8 to 12 hours, and if we could get a little fluid into ourselves, we might be better off 12 hours after landing than right at the time of landing.

k. **Scheuring:** Right now the program can't guarantee that the crews won't need to perform an unaided egress. So, we're going to have a suited crew doing an unaided egress and have to open up a 100-lb hatch.

l. **Garriott:** Doesn't make sense.

m. **Scheuring:** So, this is a big driver in getting exercise equipment on board. Crews would have to be able to maintain at least some kind of strength, even though the neurovestibular issue is a prime component.

n. **Garriott:** What is driving the need to egress by yourself suited?

o. **Scheuring:** It gets back to the availability of recovery forces, that the crews would not be able to be cooled and could be sitting on the water for hours upon hours.

p. **Kerwin:** How much water can a capsule take on before it starts to sink? I was just thinking about opening the hatch for fresh air?

q. **Aunon:** Our ISS crews train for contingency water landings with the Russians. The Russians will tell you that if you get a little bit of water into the capsule – they won't tell you how much – it will go down in 40 seconds. Our ISS crews are trained to doff their pressure garments after landing and don an immersion suit and then egress out of the capsule. This is done inside the capsule, practically lying on top of one another, assisting each other. Well, there are huge thermal loads. We were doing this in people who were not deconditioned, and they commented on seasickness and the huge thermal loads inside, and how much difficulty they had pushing themselves up and out of the capsule, and seriously questioned whether they would be able to do this after an extended orbital stay.

r. **Garriott:** Has anyone considered doffing the suit before reentry?

s. **Bauer:** The Russians lost three crew members during reentry.

t. **Scheuring:** There's more to the story than that. It is a survivability issue, and there are many more reasons for that decision.

u. **Garriott:** Well, just in general, what are the reasons for leaving it on?

v. **Scheuring:** Aside from the reasons we've already talked about?

w. **Garriott:** Except for the mis-thrown switch of course, which depressurized the capsule, what are the other reasons for not taking the suit off?

x. **Scheuring:** Well, there is toxic exposure.

y. Garriott: Okay, so that is the mis-thrown switch on ASTP.

z. Ross: Is there any commonality with the event back in Mercury, with Liberty Bell 7 and Gus [Grissom] and the hatch opening and water filling the capsule and how quickly it sank?

aa. Garriott: Well, that is still unanswered and I don't see the commonality in terms of depressurization of the Russian vehicle or the ASTP.

bb. Ross: No, I'm looking at the commonality of what might be an operational procedure in the water for the next generation of capsule here.

cc. Garriott: I think I would rather take my chances in hopping out in street clothes in [60°F] water and surviving for several hours as compared to trying to hop out in a pressure suit and surviving for 15 or 30 minutes. I think our chances of not drowning are much higher in street clothes in [60°F]. I'm not sure if that takes all the trade-offs into consideration. It's not a good idea to get out in a pressure suit in a halfway stormy sea. You'd certainly drown yourself if you tried to do that.

dd. Lousma: It seems to me that there are too many crossed requirements conflicting with each other. Some of the requirements are less important than others. The top requirement is to survive. Surviving a sinking capsule event is possible unsuited. It is not probable if suited. I think to use the ASTP situation as a concern about toxic gases is an outlier. And I think the situations the Russians had is also an outlier. They weren't in their spacesuits because they wanted to put three men in a capsule so they couldn't get spacesuits in. The Russian problem can be averted with high probability by ensuring capsule pressure integrity after undocking prior to doffing spacesuits. Undock suited. Doff suits in zero-g; it's much easier than in one-g on the water. Splash down in coveralls. If we were to come back, that's the way I'd want to do it. Being inside a sinking space capsule is no time to try to doff a spacesuit. Once we were in the water, I wouldn't open that side hatch for nothing unless I was going to get out of it for sure, because that's where the water is going to come in. You've got a top hatch. The question is: Can you get to it in a deconditioned state?

ee. Pogue (Written): We didn't have any trouble donning pressure suits on Skylab even toward the end of the flight. Our last EVA was about a week before the end of the mission and I don't recall any problems. The CM was cramped but in zero-g, I think we could have wiggled into and out of them without too much trouble.

ff. Gibson (Written): Doffing a pressure suit would have been a challenge in a bouncing cabin. We were not wearing these suits.

5.6.2 According to technical reports, Apollo crews wore a life vest harness during launch, entry, egress and recovery, with flotation tubes mounted under each arm.[17] With the hoist recovery, and absence of water egress under nominal conditions, was the life vest harness worn by Skylab crews? Presumably the harness was separate from the pressure suit and could be worn over the flight suit. Is this true? What else was incorporated into this harness?

a. **Pogue (Written):** The "water wings" were worn on the outside of the suit and I recall that the only purpose they were to serve was as a flotation aid if one got dumped into the water after an emergency landing following a launch abort. The strap-on life vest (it really didn't look like a vest) can be easily seen in the pictures showing the Apollo and Skylab crews leaving the MSOB [Manned Spacecraft Operations Building, at the NASA Kennedy Space Center] and walking toward the van for the ride out to the launch pad.

b. **Lousma (Written):** Don't recall, but highly suspect we wore deflated life vests. It would be foolish not to wear a life vest. Fighter pilots wear an unobtrusive life vest routinely despite the availability of a raft also.

5.6.3 Skylab crews had a three-person life raft designed for use in off-nominal and contingency situations.[17] It was to be crew-deployed and inflated by CO cylinders with a manual inflation backup.[17] Are there any procedures or equipment needed for raft deployment and use by a deconditioned crew?

a. **Lousma (Written**): No, except to make it readily available and easily deployed and inflated. Deconditioning? If you had to deploy a raft to survive, you would get it done!

5.6.4 Do you think an immersion suit is needed in addition to a life raft? Is a pressure suit with neck and wrist dams sufficient? Do you think you could don an immersion suit in a deconditioned state?

a. **Lousma (Written):** I don't know what an immersion suit is, but it seems to me that coveralls, a life vest harness, and a raft are all a survivor needs. A jet fighter raft has an integrated cover to preserve body heat.

5.6.5 Current planning suggests that in the CEV, portable breathing masks will be stowed in the aft compartment during dynamic phases of flight.[18] According to [Apollo] technical reports, in the event of a toxic atmosphere in the CM, each crew member had access to a full-face, hose-fed oxygen mask providing 100% oxygen via demand regulator.[19,20] Was this system available during all phases of flight, including post-landing?

a. **Lousma:** I think it was. I think those oxygen masks were handy whenever you were in the couch, and I think the notion of trying to dig them out during a dynamic phase of flight is the wrong way to go. I think everybody ought to have one that is available, and putting them where they can't individually get to them is a bad mistake.

b. **Garriott:** Not only that; wouldn't that obviate the need for coming back in pressure suits? You'd have these available in case of a toxic environment.

c. **Lindgren:** If you have pressure suits, portable breathing masks are not necessary.

d. Lousma: What if the person who is supposed to hand out the masks is incapacitated?

e. Lindgren: That is a good point.

f. Lousma: I'll take the breathing mask and coveralls vs. pressure suits for splashdown. It's safer!

5.6.6 Given the tragedy that was suffered by the Soyuz 11 crew (vehicle depressurized during reentry), what redundancies existed for protection against cabin depressurization in your vehicle?

a. Garriott: The procedure that Jack [Lousma] has outlined, where you separate and then take off the suits, is different than the procedure that the Soyuz had where there were two separate units that had to be separated. And it's the separation of those two units that caused the depressurization. That wouldn't happen with either the command module or the CEV. And so, it looks to me like that you are adequately covered if you just delay it until you perform the separation and everything is airtight, and then you also have an oxygen mask available in case of toxic gases. That way it looks like you've got both bases covered in almost all cases.

b. Weitz: Well, we had to separate from the service module.

c. Garriott: Yeah, but there's no atmospheric connection between the two.

d. Weitz: Oh, I see. I thought you meant the shock of separation causing problems.

e. Garriott: Of course it was a valve that wasn't closed manually.

f. Gibson (Written): At least two actions were required to open hatch or perform some other action that would decompress the cabin.

5.7 Water Landing and Recovery – Vehicle

5.7.1 According to various reports, the CM was required to provide a habitable environment for up to 48 hours.[15] In addition, the Environmental Control System was required to maintain a relative humidity of 40% to 70% with an ambient temperature of 75 ± 5°F (except during re-entry where temperatures up to 100°F were permitted).[19] Did the system live up to these requirements? In one debriefing, crew members reported that "prior to egress, prior to hatch opening even,…it tends to get hot in there." "It sure does."[12] Could the vehicle really have supported you for 48 hours?

a. Pogue (Written): The standards were not met for Apollo 13. We were in the CM for 15–30 minutes and I don't remember it getting hot, but then it was February 8, 1974 and we landed about 150 miles southwest of San Diego. I just don't know if the CM could have supported us for 48 hours. If the sea state was moderate, one could open the side hatch for ventilation and temperature control.

b. Gibson (Written): Yes, if the upper hatch was removed and we could get airflow.

c. **Lousma (Written):** It might seem warm inside the capsule after splashdown, but the heat due to reentry would stabilize at sea water temperature soon. I don't recall feeling warm after Skylab 3 splashdown. Also, I don't expect to be "comfortable" in a 48-hour survival situation. If I had to do so, I would, despite temperature and humidity, as long as the capsule was still afloat.

5.7.2 What was the definition of "habitable" that was used by the 48-hour requirement?

a. **Pogue (Written):** Good question. I assumed in reading the introduction to this section the definition of habitable was the RH [relative humidity] of 40%–70%, and temp range [75 ± 5°F]. From question 5.7.1 there is an implication that opening the hatch alleviates the temperature rise. If one concludes that an open hatch is essential to preventing overheating (48 hrs) then it suggests that a habitability requirement should include an upper limit for the sea state (one that would allow the side hatch to stay open for 48 hours). Also, a cooler temperature reduces the tendency to get seasick (personal experience). On Skylab we used a drag-through duct to pump fresh air into the CM from the multiple docking adapter. A contingency duct affixed to a delivery vent in the ECS [Environmental Control System] could provide even better control of the CM temperature.

b. **Gibson (Written):** I would use the words, "survivable without illness."

5.7.3 Does the definition of "habitable" change when applied to long-duration vs. short-duration fliers?

a. **Pogue (Written):** It seems obvious that the definition changes simply because a person can tolerate out-of-comfort conditions for a short time knowing that relief is on the way, whereas long-term out-of comfort conditions would soon compromise operations. I have no idea of how to define habitable in the long-term other than rely on the conditions provided on the various space stations that have been flown. Incidentally, I think the definition of habitable should include limits on the noise level, especially in the long term.

b. **Gibson (Written):** Probably because of the amount of deconditioning. Short-duration troops should be able to withstand more.

5.7.4 Was crew activity needed to meet the "habitability" requirement (such as opening a hatch)?

a. **Lousma:** You had to throw a switch to get right side up, as I recall.

b. **Bean:** I missed something I guess, now, trying to talk about the Soyuz 11. Now in our spacecraft, we don't have any way to depressurize it with a switch. The only way we can depressurize it is manually opening a valve, or some explosive event like maybe Paul [Weitz] was thinking about could open it for us. Maybe jettisoning a docking probe that blows off the front of the tunnel, maybe that would blow in the hatch or something. So, that's a good time to wear the suit even though a lot of times we didn't get to it. But there's no connection between what we've got and Soyuz 11. So, we shouldn't be defending ourselves against that, because that can't happen. Some guy

would have to get up and open the thing manually during the parachute descent to kill anybody. So, if we're making the CEV protect us against what happened to Soyuz 11, and I'll bet that the CEV doesn't have an electrical switch you can throw or short out that will vent the cabin, then you can forget thinking about this. And also, protecting ourselves from that accidental failure to throw a switch – there's probably better ways to do it than staying in your spacesuit. We should be able to interlock the switches; we've done that before. We've done things like, you have to put in the circuit breaker before you throw the switch; if you fail to do either, then it won't happen. Those sorts of things, I think, were good and we felt safe about it. We don't have to defend ourselves against some of these. And I don't know if you can ever defend yourself against things like throwing the wrong switch at the wrong time.

c. **Lousma:** It's a government thing to protect everybody from everything.

d. **Bean:** You can't do it; you end up not being able to operate. You're going to have enough problems here without defending yourself against these two situations, in my opinion.

e. **Lousma (Written):** Risk averseness can kill the whole program. It surely would be safer to stay on the ground and watch someone else do it!

5.7.5 Was the side hatch usable in all sea states?

a. **Kerwin:** Well, we could physically open it…but then we would drown. [Laughter]

b. **Lindgren:** Okay, safely usable?

c. **Kerwin:** I don't know what the dividing line was, but our marching orders were: Don't open that side hatch until somebody has put a flotation collar around the command module. And that implies a sea state low enough for that to happen.

d. **Gibson (Written):** No. I would not want the side hatch open in high sea states.

5.7.6 According to reports,[9] a double-acting attenuator system that was used in all three axes protected the crews against contingency land landings. A crew member mentioned that during a nominal sea landing "we hit like a ton of bricks at 12, and I thought it was a very gentle impact."[3] This suggests that in spite of a dramatic impact, the attenuator system worked well. Did anyone else experience any untoward transient g-forces in spite of this system?

a. **Weitz:** Let me offer what I think is a clarification here. Your reference for the second bullet is from SL-2 crew debrief, and I suspect that if you change "at" to "on," that that was Pete [Conrad] comparing their water landing on Apollo 12 and what he experienced on Skylab 2.

b. **Lindgren:** Ah, okay, that makes sense.

c. **Lousma:** I don't think anyone here stroked the couch.

d. **Garriott:** I'm not sure how we would know.

e. **Carr:** I don't remember hearing any report that we had stroked the couch. We landed in sort of a slicing maneuver, anyway, that flipped us over.

f. **Kerwin:** Which Apollo flight was it that landed on two chutes? Fifteen? They probably stroked the couch, didn't they?

g. **Weitz:** I think if you stroked the couch, you'd know it.

h. **Carr:** Yeah.

i. **Pogue (Written):** I only landed once and it was a noticeable whop in the back, but I don't think our struts stroked.

j. **Gibson (Written):** No, just a firm hit.

k. **Lousma (Written):** I don't recall feeling any side forces. I was not surprised by the "smack in the back."

5.7.7 According to crew debriefings the CM self-uprighting system[21] reportedly worked well.[8] The CEV will have a similar system. Egress options and Environmental Control Systems are presumably affected by vehicle orientation. How important is this system to the decon-ditioned returning crew member?

a. **Weitz:** In the Apollo CM system, I think it was a circuit breaker followed by a switch. I think you could reach it from the couch.

b. **Lousma:** For a deconditioned crew, I think the crew would rather be lying on a couch than hanging from a ceiling. So, I think it is a pretty good idea to have one of those.

c. **Pogue (Written):** We went "stable 2" but the up-righting bags worked fine. I think the worst-case scenario would occur if "stable 1" could not be achieved and contingency egress through the docking tunnel had to be used. In recalling our training for the worst case, there was no inordinate physical demand. The most exertion required was when we pulled ourselves up into the life raft. Is a raft automatically deployed to be available for either type of egress? I can't remember. Something I just remembered is the pooling of water condensate in the bottom of the CM. As we were descending on mains, a pressure equalization valve opened to equalize inside and outside pressure. When that warm moist sea air came in and circulated over cold panels at [70°F], it condensed and then began to drip off and drop to the bulkhead above the heat shield. When we went stable 2, we heard water sloshing across the lower bulkhead and we all said simultaneously, "Oh No!" We had 250 fecal bags stowed in the lower equipment bay (below the optics station) and feared they would get doused. They didn't, but the accumulation of water in the bottom of the CM during descent should be considered. This condition was caused

by the 5-psi pressure in the CM. The extent of the condensation could be greatly reduced if the pressure were increased to near one atmosphere. A pressure equalization valve will still be required but air exchange would be much less.

d. Lousma (Written): With regards to raft deployment – in stable 1 (upright), we had to throw the deflated, tethered raft out of the side hatch. If stuck in stable 2 (inverted), it would have been necessary to swim with the deflated raft down through the top hatch and deploy it when we swam to the surface.

5.7.8 After landing, one crew member commented that "You could smell the explosives, the pyro fumes come into the cabin."[8] Was this unexpected? Had precautions been taken to prevent fumes from entering the cabin?

a. Lousma: I don't recall pyro fumes. What flight was it?

b. Lindgren: I'd have to look it up.

c. Lousma: Is this ASTP?

d. Lindgren: This is not referring to the ASTP experience. This is from Skylab crew debrief.

e. Garriott: I don't remember it; do you remember it?

f. Weitz: According to the reference list in the back, that's from the SL-3 debrief.

g. Garriott: Well, I don't remember it.

h. Carr: Must have been the other SL-3. [Laughter]

i. Crippen: There shouldn't be any way that the pyro fumes could get into the cabin.

j. Garriott: Increase the atmospheric pressure from 5 up to 15, and then you've got those gas fumes on the outside, and some of it gets sucked in. I think that's how it happened.

k. Pogue (Written): I didn't notice any pyro fumes after landing.

l. Gibson (Written): Not procedurally, as I can best recall. Going to stable 2 precluded us smelling anything immediately after landing.

5.8 Water Landing and Recovery – Procedures

5.8.1 What conditions would have required you to egress the CM and enter the water?

a. General response: If the CM was sinking.

b. Weitz: The same reason the people got off the *Titanic*. [Laughter]

c. **Kerwin:** Also if you are in stable 2 and it fails to go back to stable 1, you might have to get out eventually. In stable 2, are you going to eventually get hypoxic? Is your source of ventilation blocked off? If you're stuck in stable 2, you might have to egress because the air would get too foul. You'd have to go out the tunnel hatch, swim out from underneath. And if you were deconditioned…good luck. But basically, if the ship is sinking, you're going to want to get out.

d. **Carr:** I guess everyone got the training in the tank at JSC (Johnson Space Center) where they flipped it over and you had to get out with your suits on. I don't know if everyone knows our story on that one, but we were in there with our suits on and they flipped it over. Now they told us that you are going to watch the water rise up in the command module and when it gets to about here, it's going to stabilize, kind of like a milk bottle floating upside down. It's all going to stabilize, so you can take your time and get your neck dams and wrist dams on and get the hatch out and get out. Well, we sat there and put our neck dams and stuff on. We watched the water rise and when it got to that point, it didn't quit; it kept on going. Well, I told the guys, "I think we better step it up a little bit." And we got out of there, but we found out that somebody had left a valve open. Well, it wasn't a milk bottle floating upside down; it went all the way down to the bottom. And we had all our families there watching us, too.

e. **Pogue (Written):** The two things I can think of are contamination of the environment and a fire. Neither of these is likely.

f. **Gibson (Written):** Toxic gases that could not be vented and/or fire.

5.8.2 What actions would have been required of you for an emergency egress?

a. **Gibson (written):** Open hatch, secure to CM then throw out raft, take supplies and food, and exit.

b. **Lindgren:** From a written response, I have "turn off power, unstrap and disconnect, pop open the hatch, deploy the raft, help the center seat astronaut egress, egress himself, and help the commander exit." Is that a pretty good summary?

c. **Carr:** Now that's just for stable 1; it would be different for stable 2.

5.8.3 Were you only required to egress the side hatch? Were there any conditions that required you to egress from the top hatch with the capsule in stable 1? Could you have done it?

a. **Carr:** My first thought is: how heavy is that hatch? Is it going to fall in your face when you unlatch it? Does it have a hinge and swing? With three deconditioned guys, that's going to be a wrestling match.

b. **Bean:** We've got to be careful about piling too many off-nominal things on top of each other. The minute you do, you can't go fly in space. You end up building a heavy spacecraft. I can't imagine putting the weight on there for hatch lowering

or something like that. You can imagine a number of failures; but, as I remember for Skylab and Apollo, there was kind of a rule about how many off-nominal situations you could have in a row. And whatever that rule was, you quit trying to solve problems after that because you never could do it all.

c. **Pogue (Written):** Not that I'm aware of unless you had a side hatch that wouldn't open. Climbing up through the docking tunnel would have been difficult.

d. **Gibson (Written):** Deconditioned, toxic gases, fire lapping at your butt, opening hatch, removal of probe, all in a high sea state – it would be tough.

5.8.4 According to reports[22], crew members trained to egress the CM from the stable 2 position and swim up to climb into a raft. In retrospect, was this egress scenario compatible with your post-flight state of deconditioning?

a. **Carr:** You could tough it out and try to do it but it would be very dicey, especially after hearing Bill Thornton talk about your neuromuscular situation. You might have a really tough time getting that hatch out of there and figuring out how to swim down and up the side of it.

b. **Scheuring:** Is there something you could have done during the mission to improve your chances if this happened?

c. **Kerwin:** I think this is one of Al Bean's cascading failure scenarios. If it happens and you are in stable 2 and you have to get out, you are going to try to wrestle that hatch out somehow. And swimming out, that may actually be a little easier than climbing up. It's kind of like returning to a zero-g condition, and I think we could handle that. It's risky, but I wouldn't go out of my way to prevent its necessity.

d. **Lousma:** We trained for this in the water tank.

e. **Garriott:** I would think that the first option for stable 2 is just stay there, stay with it. Now are you also assuming that it is filling up with smoke or other requirement that forces you to egress? Why try to egress in stable 2?

f. **Lindgren:** This question was not driven by any Constellation requirement. It was simply to understand whether crew members should attempt something like this after long-duration space flight.

g. **Garriott:** My opinion is that in stable 2, you don't try to egress. If you have to egress for some other reason… First of all, the docking probe doesn't fall down onto you; it falls down into the ocean. So, you just have to get outside and you'll float by yourself. You don't have to worry about mass of the hatch falling in your lap like you did in stable 1. The best option, though, is to stay put.

h. **Bean:** And not to beat a dead horse, but let's think about it. It means... If this situation arises, it means: (1) you didn't land in your primary area where frogmen land about the

same time you do putting a collar around you; (2) you've gone into stable 2 and you've got redundancy on those [uprighting] bags and somehow those have failed; (3) you've probably got redundancy on the pumps and those fail; (4) you've got a high sea state that's not part of the plan; and (5) you're leaking so you've got to get out. We need to quit thinking about these things and back up and say, "Are we sure we are capable, on a normal landing in a nice place where we plan, that this is an easy way to do it, and it's safe and nobody is going to accidentally fall out of the raft and drown?" Then maybe take a failure or two, isolated by themselves. But if we concentrate on this, we spend money and time and effort when the chances of it actually happening are so far down the list that we shouldn't do that. We are going to have so many problems that we really have to solve that are worth the money, time, and effort. We are stacking too many failures; it just took four to get into this discussion.

5.8.5 How do answers to questions 5.8.3 and 5.8.4 above change when considering an abort scenario (healthy crew) vs. an end-of-mission (deconditioned crew) scenario?

a. **Pogue (Written):** The crew of an aborted launch would be able to do everything easier.

5.9 Water Landing and Recovery – Location and Communication

5.9.1 According to reports, the CM was equipped with a VHF/AM transceiver and a VHF recovery beacon.[15] This system was supplemented with a specially developed handheld VHF "Apollo survival radio" that provided beacon and voice capability.[23] In a technical debriefing, it was mentioned that the "L and R (location and recovery) communications worked well. We were completely aware of what recovery was doing at all times."[3] Another crew had a communications failure (transmit only) after landing.[8] Any comments or concerns with regards to recovery communications?

a. **Carr:** I think it is important to have the crew in the loop with constant communications. If somebody is having a problem, you don't need people relaying back and forth; you need to be right in the middle of the loop. It's just a matter of communications discipline, y'know; keep the small talk out and keep it to professional discussion.

b. **Brandt:** Would any of you have been comfortable had there been no radio communication after landing?

c. **General Consensus:** We would not be comfortable without communication.

d. **Lousma:** Especially now with GPS and all the stuff you could have to keep in contact.

e. **Kerwin:** I would assume that you would provide GPS data to the crew so that they would know exactly what their latitude and longitude was, so they could relay it, if necessary, to the recovery forces.

f. **Chandler:** We had a meeting last week with the DOD, search and rescue, and the Coast Guard. We got them all together and had the SAR people tell us what they needed. In a splinter group, the SAR folks told NASA that you need to have a beacon that has GPS capability, because GPS takes the "search" out of search and rescue.

g. **Lousma:** I can't believe that you'd do it any different. I mean, every little Cessna 172 has to have an emergency location transponder to a satellite so everyone can see, and we can't have it in the most modern space program in history?

h. **Weitz:** Keeping in mind what I was saying before, you need backups for backups. Are you all going to fly a sextant also? [Laughter]

i. **Pogue (Written):** I think GPS is the way to go. My Honda CRV can be tracked if it is stolen, so the technology is available to locate an errant spacecraft.

5.9.2 During lunar return, a skip reentry could result in loss of CEV position tracking and an unknown landing location. During Apollo/Skylab, recovery aircraft utilized the specially developed AN/ARD-17 direction-finding system with an orbital VHF range of 1,123 nm and a surface VHF range of 195 nm.[24] Recognizing that skip returns were not an issue for Skylab, did you have any concerns about this localizing system?

a. **General Consensus:** GPS is an absolute requirement.

5.9.3 Command module VHF/AM hardware permitted voice communications with recovery aircraft and swimmers.[25] One crew member commented that "I was happy to see that the ship did not talk with us too much."[8] Is it necessary to be able to communicate with surface recovery ships?

a. **Carr:** Yeah, I think so. For instance, if you had some sort of medical emergency, The ship is in the loop as a listener only, but you could quickly reconfigure your comm. system if you need to in order to talk with a doctor on the ship or something like that. You could have a lot of people on the loop, but most of them in a listen-only mode.

b. **Chandler:** This is one of the things we have been having discussions on. They were in a weight reduction mode and were trying to set up the comm. so that you could talk with the ship, but you wouldn't be able to talk with a search and rescue aircraft or helicopter that was going to come out. We thought it was more important that you be able to talk with the SAR helicopter, with the para-rescue specialists, and those kind of people.

c. **Weitz:** Absolutely.

d. **Bean:** So, someone on water would be able to talk to Mission Control and these other people?

e. **Chandler:** Yes. What we are hoping for is the communication from the ship would be able to go back. What we were really interested in was that the people in the capsule would be able to talk with those rescue guys on the other side of the hatch and in the helicopter. We think that there is going to be comm. back to Mission Control, if I understand the requirement correctly.

f. **Bean:** I may be in the minority, but you want communication back to Mission Control. You've got people in there that are smart and can solve any problem. And when you are on the water and bobbing around and can't see out very well and don't know how to solve these problems, and so if you can talk to Mission Control and they can talk to you, that is a lot. These other things are gravy. I think you want Mission Control to solve your problems. [They've] got more people and they are smarter. We are bobbing around and don't know all that.

g. **Chandler:** I'm fairly sure that is the case that you've got both. But we want you to be able to talk to rescue guys, too.

h. **Garriott:** I think I'd invert the priority. First of all, you want to be able to talk with the guys who can get you out safely. The second is to let the Houston guys know what is wrong. The highest priority is getting out safely.

i. **Bean:** I understand.

j. **Ross:** One of the operational requirements at the time was that the ship had to be able to listen to what was going on between the CM, the [helicopter], and the UDT swimmers. Now I don't know how that totally worked, but on the Skylab mission the ship had to be able to listen for the condition of the crew prior to pulling them up. The reason was the DOD surgery crew had to be ready to handle any adverse problems. Once they got a thumbs up that there was no big time event, they could stand down.

5.9.4 Is it necessary to communicate with MCC-H (Mission Control Center-Houston) after landing?

a. **General Consensus:** Yes.

b. **Kerwin:** I don't know. Al, I guess I would have thought that after splashdown that Mission Control would delegate to the recovery team leadership, which would be aboard the recovery ship, at least in the nominal case.

c. **Bean:** Maybe they do.

d. **Gillis:** Now, it's been 4 years since I've been on a ship, but I think that the ships that will be involved in this recovery will have networked radio communications that tie into the internet. As senior medical officer on a carrier, I could talk with other ships, I could talk with people back in the States, and get a printed record of it all. Certainly by the time that we will be doing these flights, the net-centric warfare resources will be mature to the point that none of this will be a problem and it will be in place for general use.

e. **Bauer:** In terms of talking back to Houston, I know with the shuttle you have a fairly extensive system shutdown checklist after wheels stop. I presume it was a lot quicker and simpler on Apollo. Did you really have anything that you would foresee that would go wrong post-splashdown where you might need to troubleshoot with Houston before shutting down, or was it pretty much just a matter of "get us hoisted out of here?"

f. **Weitz:** Well, as it was just mentioned, you are going to have worldwide communications anyway, so what's the harm? I mean, if they are there, you get a hold of them if you need them.

g. **Lousma:** I think if you have a spacecraft problem, you want to talk with Mission Control. If you have recovery problem, you want to talk with recovery. So, I think they both need to be there. You'd like to have everybody that you'd like to talk to somewhere on the loop, but you don't want them all talking to you at the same time. Crip [Bob Crippen], correct me if I'm wrong, but as I recall, Mission Control turns it over to the landing officer.

h. **Crippen:** From a comm. standpoint, when you are on the water, MCC is there, but they are not talking to you. They are available if you needed assistance, but they are just listening.

i. **Pogue (Written):** It would be desirable (if a problem is encountered after landing) because MCC can work through GSFC [Goddard Space Flight Center] to coordinate all communication assets.

5.9.5 Is it necessary to have communications access to medical personnel after landing?

a. **General Consensus:** Yes, if there is a need.

b. **Ross:** I think this is covered by my previous answer on how we did it during Skylab 2.

c. **Pogue (Written):** If you have a link with MCC the medical support in MCC would be available to help.

5.9.6 Crews returning in the Soyuz are equipped with a satellite phone and a GPS. Do you have recommendations for localization and communication procedures or equipment?

a. **Crippen:** The satellite phone is a great idea for contingency.

b. **Pogue (Written):** I think having a satellite phone is a great idea.

5.10 Water Landing and Recovery – Crew Activities

5.10.1 After returning from a long-duration mission, what post-flight duties are acceptable? Vehicle safing? Hatch opening (side/top)? Climbing a ladder? Swimming to stay afloat? Climbing in a raft?

a. **Kerwin:** Certainly vehicle safing and hatch opening are reasonable. Climbing a ladder? I don't know.

b. **Garriott:** If you are really thinking about adopting this, it might be worth a try with some of the folks who come back after 3 to 6 months [on orbit]. Really give it a try before making a commitment to it.

c. **Thornton:** Crip [Bob Crippen] and I were talking about getting into a survival raft. For me, it was always harder getting into a larger raft. When I was in great shape, I found that it was a considerable workload.

d. **Bean:** I don't know about the other two Skylab crews, but if we had to lift a heavy life raft out the top hatch, we'd give that job to Jack Lousma! [Laughter]

e. **Crippen:** Climbing into a one-man raft, even when you are in good condition, can be challenging in the open sea sometimes.

f. **Kerwin:** If we are talking deconditioned crew members, the optimum way is to egress the side hatch into a raft which is attached to the vehicle so you don't have to do a water ingress. I'm with Bill [Thornton] in that I think that a water ingress into the raft might be impossible.

g. **Ross:** It seems to me that the last two items, swim to stay afloat and climb into a raft – we are assuming that they have successfully gotten out of the command module, but do they have personal floatation devices already hooked up?

h. **Kerwin:** How soon after long-duration flights do the water rehab sessions start?

i. **Alexander:** Anywhere from 3 to 5 days.

j. **Kerwin:** It would be very interesting on their first water rehab session to just have a raft in there and have them try to get in.

k. **Bean:** Where does the raft come from? I don't remember them.

l. **Kerwin:** Yes, there were personal life rafts and personal life vests, but we never broke them out.

m. **Bean:** I remember the vest, but I don't remember the rafts.

n. **Lousma:** I think you ought to go down that list and get a vote on yes or no. It seems to me the last two, you can just forget them. And the first one is, yes, vehicle safing. As for hatch opening, if the side hatch has an assisted boost, once you push it open it continues on its own; you could do that. The top hatch is marginal, and climbing a ladder is marginal too. The last two are drowners, right there. I think you could climb in a raft if it was outside the hatch. You could fall into it without being in the water. [There is general consensus from the group on this assessment]

o. **Bean:** Sometimes we do things at NASA because they were a good idea long ago, like in Mercury when we didn't know where people were going to land. So, we said, "We need to get a raft and some other things in case they land like Scott Carpenter, way out." He wasn't even supposed to be out in his raft, by the way, but he did get in it. He was supposed to stay in the capsule. Okay, then we come to Gemini. We have an emer-

gency on Gemini 8 and we land where we are not supposed to. They didn't get out in their raft. They wait until the ship comes alongside until they get out. We didn't do anything like that in Apollo. We didn't do this thing in Skylab or anywhere else. They didn't need a raft in shuttle. We should think about getting rid of these rafts. We are better at putting people down where we want them. We are not going to put anybody down in an unknown spot. That's something that might have happened in Mercury or even Gemini maybe. We are not doing that anymore. We could maybe get rid of that. I think you all ought to think about this. To carry up 100 lbs. to the moon and back for a raft…we've to rethink these things.

p. **Pogue (Written):** In my opinion the most difficult tasks would be opening/removing the top hatch (Is it hinged?) and climbing a ladder. Remember that a deconditioned crew member also has a poor sense of balance and a ladder climb might cause disorientation. Acceptable tasks would be vehicle safing, swimming to stay afloat (the arms are deconditioned the least) and getting into the raft.

q. **Lousma (Written):** I disagree. Having to swim to stay afloat is not a good idea.

r. **Gibson (Written):** All activities other than climbing (ladder, raft) are OK. Climbing with deconditioned legs and shaky vestibular equipment could be a challenge. Assumes a g-suit is worn.

s. **Pogue (Written):** Small rafts are easy to get into because the sides (rims) are small. One pulls the raft under his chest down to his belly and rolls into the life raft. Obviously, you can't do that with a six-man raft because the sides are so high. I've done it with a fully inflated Mae West (life vest). To deploy a large raft and get a deconditioned crew in it from a side hatch that's, say, six feet above the water will not be easy. However, consider the inflatable slides used to evacuate passenger aircraft. The slides incorporate sides that also inflate and they're stiff enough to keep passengers from rolling off the slide and falling to the ground. The idea is to combine such a slide, which is integral to the raft and deployed from the side hatch after attaching it to internal structure near the hatch. The whole assembly would enable crew members to slide in sequence from the side hatch and be delivered to the center of the raft. The only exertion required of the crew is to climb out the side hatch and get into the slide. There are a lot of problems with this concept. How do you keep the raft in the right relative position to the spacecraft, especially in a rough sea? Once everyone is in the raft what do you do with the slide? It would have to be removable.

5.10.2 **Much has been written with regards to the physiologic deconditioning seen after long-duration space flight. Crew debriefings made frequent reference to an "awareness of the gravity vector" and neurovestibular issues. [3,8] In your experience, what is the most operationally limiting component of deconditioning (neurovestibular dysfunction, muscle weakness, orthostatic intolerance)?**

a. **Thornton:** This is highly individualized process. You can't rank it. Some individuals aren't going to be bothered by one thing, others may be incapacitated by it. That's been my experience.

b. **Kerwin:** I agree with you, Bill [Thornton], but I went ahead and ranked them anyway as an individual. For me, orthostatic intolerance was number 1, because I felt excellent as long as I was horizontal. Muscle weakness, number 2, and neurovestibular, number 3.

c. **Thornton:** Well, I had muscle weakness. An initial strength inhibition was my worst problem, while I had relatively little neurovestibular problem and virtually no orthostatic intolerance.

d. **Lousma:** You're saying neurovestibular dysfunction – that's a big word for a Marine; I call it recalibration of the sensory system – and I think that's a big one. We weren't weak in a muscular sense. We did a lot of exercise; and it's just that when you got down to one-gravity, it felt a lot different. Orthostatic intolerance was next, and muscle weakness was last.

e. **Thornton:** Well, there you have three people with three different ideas about this.

f. **Garriott:** I would put the recalibration of the neurovestibular system number 1, just like Jack [Lousma] did. And orthostatic intolerance, I would put near the bottom, if you would give us a couple of hours to rehydrate.

g. **Pogue (Written):** Neurovestibular dysfunction. For the first few days my body wanted to turn to the right while I was trying to walk straight. I also drove off the right side of the road twice in the first three days after return. Thankfully, it wasn't to the left.

h. **Gibson (Written):** 1. muscle weakness, 2. neurovestibular dysfunction, 3. orthostatic intolerance (would be number 1. If no g-suit is worn).

5.10.3 If two to three pieces of life support equipment, each weighing 50 to 60 lbs., needed to be deployed, do you feel that neurovestibular or musculoskeletal decrement post-mission would have prevented you from doing so?

a. **Pogue (Written):** I think both of these would have made the task difficult if one person were trying to do it. Use two people or prepare a mechanical assistance device for deployment.

b. **Lousma (Written):** Neither would prevent, but would make the job more difficult.

5.10.4 Would you have been able to assist in the egress of an ill or injured crew member?

a. **Carr:** You do what you have to do.

b. **Pogue (Written):** I think so unless the individual was incapacitated. A 150 pound crew member would be a lot to handle. We donned a hyperbaric garment before reentry to offset the post-landing orthostatic intolerance. It worked fine; we were able to walk when we got out of the spacecraft (84 day flight).

c. **Gibson (Written):** Assist, yes. Totally carry, no.

d. **Lousma (Written):** Yes, but more by pulling and shoving vs. lifting because the capsule quarters are cramped and crowded.

5.10.5 Many crew members suffered from seasickness after landing. How did that affect your post-landing operations?

a. **Carr:** Not on board.

b. **Kerwin:** It didn't in our case. It could, if you were in a survival situation.

c. **Pogue (Written):** We did not experience seasickness.

d. **Lousma (Written):** No problem for our crew – Bean, Garriott, Lousma.

5.10.6 Were crew directed to take anti-motion sickness medication prior to landing? Did you take it? If you did, did you get sick?

a. **Ross:** Joe [Kerwin] is absolutely correct. The only Scope-Dex that was used during Skylab was this one capsule that was used on launch day. There was no other Scope-Dex used. However, I'd like to make one comment about vestibular adaptation. We all know that we have some crew members that are affected in the first 2 to 3 days on launch. And I think that's one of the reasons that it is 2 days before you dock. Everybody's basically got their head back by that time. When we looked at the M131 [vestibular experiment] on Skylab and the great results we were getting, we thought we had arrived because we were getting such benign information back. Yet, to be fooled again, when we got people coming back, we began to see vestibular effects. I don't think there is any doubt, and I wouldn't try to rank what was first second or third, because we had muscle weakness, we had neurovestibular effects, and we had orthostatic intolerance. But the combination again proves somewhat disconcerting as to how to operationally handle these people upon immediate return and putting them through tests. It seems to me that when you are coming back and you are going to have a water landing, the sooner you can get them out of the capsule and on to the ship, which I am hoping can happen so close to landing that we won't have to have them in the capsule very long, the better it will be to assess these parameters. I don't think we can say that we can be totally comfortable in keeping the vestibular effects from occurring. I think we are going to need some countermeasures to again address this situation.

b. **Pogue (Written):** We were not directed to take anti-motion sickness medication.

c. **Gibson (Written):** We did not take any as best as I can recall and did not get sick.

d. **Lousma (Written):** The crew were not directed to take it. Used it for the first two days on orbit, but not used after that for orbit ops, pre- or post landing.

5.11 Water Landing and Recovery – Capsule Environment

5.11.1 Cabin temperature (namely, heat) is a major concern to CEV planners right now. In a crew technical debriefing, one crew member stated that after landing, "…the vehicle was cool."[3] Another crew [member] commented that "the environment inside the spacecraft was very acceptable."[8] This is in contrast to the comment previously noted that the vehicle became hot with the hatch closed. Please provide any additional comments regarding the post-landing cabin environment – temperature, humidity, etc.

a. Lousma: Was the overheated one a capsule that came back from the moon?

b. Lindgren: No. This was from the Skylab 2 debrief.

c. Weitz: All I remember is that it got humid. But I've always been sensitive to humidity. It was uncomfortable, but I don't remember it getting warm or hot.

d. Kerwin: Me neither. It was probably on the warm side of neutral, but we weren't in there for very long. It was a non-issue for us, and, therefore, we can't comment fruitfully on what that temperature environment would be like for 36 or 48 hours.

e. Lousma: What did returning lunar crews say about this question?

f. Scheuring: They said it was humid and they couldn't get any cooling. I don't recall any comments related to the heat in the cabin.

g. Lindgren: There was an interesting comment in one of the responses that was returned to me suggesting that the vehicle that settled in stable 2, there was a sense that maybe with the heat shield not in the water cooling, that with the heat shield exposed, that contributed to making the cabin a little bit warmer. Any thoughts on that?

h. Weitz: How much heat does the heat shield absorb? It gets rid of most of it, correct?

i. Ross: On Apollo 16, for example, we landed in the South Pacific in warm water. I don't want to say that I can remember that it was [90°F], but it was darn hot and humid. I know that Young, Duke, and Mattingly were anxious to get out of there.

j. Pogue (Written): The post-landing environment was acceptable. I don't remember having any discomfort. I think landing site location and the season of the year has a lot to do with the heating and relative humidity problem.

k. Gibson (Written): It felt hot and humid. Might depend on outside environment.

l. Lousma (Written): Neither heat nor humidity were noticeable.

5.11.2 Given a deconditioned state, motion sickness, temperature concerns, please comment on what you think would be needed to make the suited capsule environment tolerable for up to 36 hours. Ventilation? Active cooling?

a. **Weitz:** Well, I think the answer to that question is active cooling.

b. **Kerwin:** Well, being that this is a contingency, I hate to ask for a room air conditioner given that this is a contingency.

c. **Weitz:** No, I'm answering the question. I didn't say it was a good idea. [Laughter]

d. **Garriott:** Well, if you are going to stay for 36 hours, why would you stay in the suit?

e. **Bean:** I can't imagine that you wouldn't get out of the suit. I can't think of a reason to stay in the suit. You are going to be safer if you are out of the suit, if you are going to abandon the ship. You shouldn't struggle with this issue, because nobody is going to do it. Nobody is going to do that, so you shouldn't spend any money or time on that issue.

f. **Lindgren:** Clearly you all are in favor of getting out of the suit as soon as possible. [Laughter]

g. **Bean:** Even if we weren't, everybody would still be getting out of their suit, I can tell you that right now. They would say, "I'm not going to stay in this suit, I'm back on Earth, Mission Control is 2,000 miles away – they can't bother me," and they'd take their suit off.

h. **Lousma:** I think you are right, Al.

i. **Lindgren:** If the suited requirement stays, we'd like to encourage the suit designers to design a suit that somebody would be able to get out of in a deconditioned state in a cramped space like the CEV.

j. **Pogue (Written):** Fans for ventilation, active cooling would be great, using a modified LCVG [liquid cooling and ventilation garment] may be more efficient, lighting at night. If you are assuming all crew members are suited then active cooling is mandatory. One really gets hot fast even if you're passive or inactive.

k. **Lousma (Written):** Ventilation – yes. Active cooling – no. And I don't think we should splashdown wearing a pressure suit.

5.11.3 Do you have a sense of how much reentry heating contributed to the cabin temperature?

a. **Pogue (Written):** I didn't think it had any effect.

b. **Gibson (Written):** I thought it was significant because it was only 70 – [75°F] outside.

5.11.4 The loss of the micrometeoroid shield caused temperatures in the OWS to soar up to 160°F.[4] Attitude adjustments and the parasol reduced temperatures to 90–100°F.[4] Please comment on working conditions and operational impact.

a. **Weitz:** It was [140°F] when we got there because they did the pitching maneuver. Pete and I first stripped down to our skivvies to go inside, and it didn't take long to realize why folks wear a lot of clothes in the desert. So, we ended up putting our shirts, trousers, and jackets back on to work in. We would make short excursions into the workshop to extend the parasol. We didn't stay down there very long. We worked until we felt uncomfortable. I tell you, it was about [60°F] in the MDA. It was nice and cool in the MDA and it was cool in the command module. So, we had a place to come back to and keep Joe [Kerwin] posted on what was going on. I was going to argue with you on that 90–[100°F] because it did come down, and you can see in those photos that the parasol did not deploy quite correctly, which is why these folks put out the twin-pole sunshade. That made it better when they got all of the hotspots on the workshop covered up. I don't think it affected our working conditions at all, do you, Joe [Kerwin]?

b. **Kerwin:** Once we achieved equilibrium, which I recall was low to mid 80's [degrees Fahrenheit], everything was fine.

c. **Weitz:** Yeah and that was about day 4 or 5.

d. **Carr:** When you first went down there, how long did you stay before you came back up? Ten minutes?

e. **Weitz:** It depended on the job. First, I went down and made an inspection. Then Pete [Conrad] and I went in and once we started extending the parasol; I would guess that it wasn't much more than 15 minutes. Jack Kinsler designed a good system, and it didn't take much to get that parasol out.

f. **Lousma:** Did the inside temperature change day to night?

g. **Kerwin:** Didn't change that much day to night. It had soaked into the structure of the workshop, and it was radiating such that you had to wear clothes. It was too hot to touch on the sun side.

h. **Weitz:** The water tanks on the sun side never did cool off the whole time we were there. I could always feel heat radiating from those practically until the day we left.

i. **Crippen:** Did the sail make any difference as far as total temperature? I was thinking that the parasol started to degrade after a period of time.

j. **Garriott:** True and true.

k. **Bean:** I can remember that the beta angle made a lot of difference to us. When it would get right, boy, it would cool off in there and really be great.

l. **Pogue (Written):** By the time we arrived the corrective devices worked quite well except at times when the beta angle was high. At those times we were in continuous daylight for over 80 hours and the workshop area below the parasol and sail really heated up. If you were within 10 feet you could feel the IR [infrared] from the workshop. Ed Gibson's sleep compartment was also under the hot area and he had to move his framed sleeping bag into area of normal temperature. Aside from that there was little effect on operations.

m. **Gibson (Written):** They were great by the time we got up there. The first two crews did a great job of erecting sunshades. But what's so bad about [160°F]? It was a dry heat!

5.11.5 The OWS humidity was reportedly kept fairly low, resulting in chapped lips and dry mucosa.[8] Any other impacts? Did low humidity make the heat more tolerable?

a. **Kerwin:** Low humidity made the heat more tolerable ,and there were other beneficial effects as well. The surfaces remained dry, moisture didn't condense on surfaces, and the spacecraft therefore stayed cleaner, I think, and smelled better – except in the command module, where all kinds of condensation took place.

b. **Bobko:** One thing that hasn't been mentioned, at least in SMEAT, we had the 5-psi atmosphere and your airflow didn't carry heat away from your body as quickly as it does in a 14.7[-psi] atmosphere. And so, at 10.3 [psi], there's probably going to be some of that in the CEV.

c. **Gillis:** At the low humidity, was there any problem with static electricity?

d. **General Consensus:** No.

e. **Pogue (Written):** I had chapped lips and dry skin for the first two weeks but after that it wasn't too bad. The low humidity affected the hematometer, which we were supposed to use to get a red cell count. It didn't work properly in the low-humidity environment. During the periods of high beta angle the heat had little effect on me because I stayed away from hot areas.

f. **Gibson (Written):** I had no problems.

g. **Lousma (Written**): I had a split lip for the last couple of weeks due to the dryness. The low pressure and humidity made showering a cold experience due to the high evaporation rate.

5.12 Water Landing and Recovery – Environmental Concerns

5.12.1 How did weather drive or impact operations?

a. **General Consensus**: Weather was not a problem.

5.12.2 How did sea states drive or impact operations?

a. **General Consensus:** There was no impact.

5.12.3 Please comment on sea conditions during your landings. Skylab 2 reportedly had 2- to 3-ft waves, but with 6-ft swells.[26] Skylab 3 reportedly had 6-ft waves.[26] How did this affect recovery operations?

a. **Carr:** Skylab 4 sea conditions were pretty calm. We had very little wind and very little swell or waves.

b. **Jones:** So, there were no weather delay on return?

c. **Kerwin:** We had no weather delays, at least for us, and no impact on operations.

d. **Jones:** So, they were able to pick you up within the timeframe regardless of the sea condition?

e. **Kerwin:** That's correct.

f. **Jones:** And were 6-ft seas accurate for you landing conditions?

g. **Weitz:** Like I said before, swells are pretty easy. You can take a nice swell in a rowboat, especially along the length. I don't remember us moving around much at all.

h. **Kerwin:** Bad weather had just moved out of the area where we landed. It was still cloudy.

i. **Weitz:** So, the bottom line is: whatever the conditions were, they weren't bothersome.

j. **Pogue (Written):** It didn't affect the recovery operation for Skylab 4.

k. **Lousma (Written):** No effect for SL3.

5.12.4 According to CM specifications, the vehicle could handle wave heights up to 8.5 ft in the first 48 hours.[15] The "rescue" crew (Brand, Lind, Lenoir) got to experience 6-ft waves during CM seaworthiness trials in the Gulf of Mexico.[4] How confident were you in the vehicle's seaworthiness? Did you participate in any other integrated training with recovery forces?

a. **Lousma:** None of them ever sank.

b. **Ross:** I think the point is on this one: I was assigned to the Skylab rescue crew, and I was out on that session with those guys, and I can tell you it was a rough day. I

guess the point is that nobody sank and everybody did a professional job. I think they did get beat up that day.

c. **Crippen:** I'll tell you, they had 6- to 8-ft seas, not swells – waves – and it was pretty cotton-pickin' rough. I don't take my boat out in that.

d. **Lousma (Written):** I was not particularly confident in the vehicle's seaworthiness due to previous reports. We did not participate in any integrated training with recovery forces.

5.12.5 Do you recall how the CM was modeled/tested for worst-case sea conditions?

a. **Gibson (Written):** No.

b. **Lousma (Written):** No.

5.13 Water Landing and Recovery – Recovery Forces

5.13.1 Skylab recovery forces hoisted the command module onto the deck of the recovery ship, crew and all. What role did swimmers and small watercraft play in the recovery effort?

a. **Weitz:** I think the guys operated out of motor launches to attach the hoisting gear.

b. **Kerwin:** We had swimmers that attached the flotation collar. I don't know who it was that attached the hoist cables to the command module, but they were key members of the team. We couldn't have done it without them.

c. **Weitz:** Seems to me there were motor launches out there.

d. **Garriott:** Swimmers definitely.

e. **Ross:** It looked like there was plenty of support from my vantage point, as I was over on the point watching for the lift to take place. But the safety people kept us away. They had plenty of lines, and the command module was 6 tons, so I'm sure that we had a 10-ton crane. They had plenty of support personnel, and it looked like they knew what they were doing. There was no banging or buffeting of the command module against the ship's side. It went very smoothly.

f. **Pogue (Written):** On Skylab 4 we didn't even open the side hatch until we were on the deck of the recovery ship, but while we were waiting to be hoisted we saw the divers recovering the chutes and attaching the rig for the hoist. I don't remember seeing their watercraft.

g. **Gibson (Written):** They checked on the crew. I'm not sure if they also put a flotation collar in place

h. **Lousma (Written):** Swimmers looked in the windows to verify our condition while we were in stable 2. They also attached the flotation collar.

5.13.2 Were there protocols developed for removing the crew from the capsule prior to hoisting?

a. **Ross:** I don't remember any protocol for removing them. During Apollo, we did of course. For Skylab, I don't remember them talking about "if such and such happens we're going to have to take them out." I don't think they were prepared to do that. I don't remember there being a Plan B.

b. **Carr:** We had no training in that area at all.

c. **Kerwin:** We didn't do an exercise in the Gulf or anything. We had water wings, we had one-man life rafts. Depending on what the problem was, I suspect that the swimmers would have assisted us out into our one-man life rafts and helped us to stay safe until we were hoisted onto the chopper or the ship eventually came.

d. **Weitz:** Once they got the flotation ring in place, there were swimmers all around.

e. **Bean:** So, it wasn't going to sink. So, you'd have to think of a reason as to why you would want to get out. That was the whole idea: get that on there, it's more stable, and it won't sink. So, why would you get out?

f. **Jones:** Well, if you couldn't hoist, if the hoist failed...

g. **Bean:** Oh, I see. Well, my guess is that the helicopter has got one of those big rafts like we had in Apollo, and another one has one of those hoists and they would drop it out and we'd get in it, although we never practiced that. But it would be right next to the vehicle, and we'd get in there and they'd come over and pick us up one by one. Because in regular survival training, we'd practiced using slings and everything else. So, I think we could have easily done the job. That would be my guess.

h. **Crippen:** I would suspect, knowing the way NASA works, whether or not you guys were directly involved, that the Navy or somebody had a plan if the hoist was broken of how to get them out of there.

i. **Lousma:** I don't know of any other protocols. We were trained to lay down and wait.

j. **Pogue (Written):** Not that I'm aware of but the Apollo post-splashdown procedures would have worked had they been needed. The only differences perhaps would have been special allowances/protocols for deconditioned crewmen.

k. **Gibson (Written):** Yes, but I do not recall the details.

5.13.3 Were there handholds and attach points on the CM for recovery forces, or did they need to be placed?

a. **Lousma:** They were already there.

5.14 Skylab Habitability

5.14.1 The 56-day SMEAT provided an invaluable assessment of Skylab protocols and equipment. The SMEAT crew identified problems with experimental procedures and data-handling, experimental hardware (LBNP [lower body negative pressure], vectorcardiogram) and habitability equipment like the urine volume measuring system.[5] One crew member stated that "Skylab has a much better chance of success because of what we learnt in SMEAT."[4] Should all programs be preceded by testing like this?

a. **Crippen:** It depends entirely on the specific program. You certainly don't need it for the station or the CEV. The lunar [habitat] might be something that people would look at. One of the reasons that we did SMEAT was that they wanted to isolate out the effect of the 5-psi environment on medical experiments. You have to look at the specific program to determine whether it would be useful or not.

b. **Bobko:** I agree with that. If you look at the urine collection device for shuttle, it went through a lot of changes in the early days. Well, if you had taken that original thing off to the moon, it would have been a problem. If you are just going on the shuttle for a couple of days, you can live with it. With SMEAT, we identified some of the problems in their urine collection device, and so that meant that when they got on orbit for 28 days, it was working much better than if we hadn't done that. I think if you are talking about a 2- or 3-day mission, you could probably get along even if something doesn't work right. If you are talking about a 60-day mission, you might want to have something like a SMEAT to make sure that it has been wrung out.

c. **Garriott:** Joe [Kerwin] and I have interviewed a lot of people on this issue of habitability in relation to SMEAT in the last couple of years. And they mostly talk about the urine collection device, the exercise bicycle, and the medical tests. Had it not been for SMEAT, we wouldn't have been able to do half the experiments on board. Marshall Space Flight Center was responsible for the medical experiments. Bill [Thornton] managed to break their exercise device not once, not twice, at least three times. If it had not happened, we would not have had a successful experience. The folks at Marshall came to that conclusion themselves. They said, "He really did us a favor." It was really important to have these guys doing the medical experiment tests on the hardware that was going to be used, to make sure that it was going to be working right for actual flight.

d. **Thornton:** You can imagine my take on it. Look at the things that changed. First of all, there was the diet, the 2,000-calorie diet that was going to be augmented with sugar cookies and lemon drops. I still can't eat lemon drops even though I loved lemon drops. I still lost weight; I think I set the record for weight loss. The flight surgeons finally said, "I don't care what you want to do; you start eating." Now it took all three missions, but I think Jerry Carr finally came off with no loss at all. I'm not talking about fluid shift or rapid loss; I'm talking about the somatic loss that was caused by diet. So, that was the first big war that we had. I don't even like to think about the urine collection system. Now remember what they did: They tested it with water, they had never tested it with urine, and that thing failed seven times. That thing was totally redesigned. I suppose I'm notorious for the flight qualification bicycle failures, but I simply rode it at what it was rated for. Other equipment, like the metabolic gas analyzer, was totally revised.

Now admittedly, this stuff was not ready to fly, and that was proven, so it depends on what stage the equipment is in. If you have flown something a half a dozen times before, then there isn't much point. But I strongly feel that you are going to be better off running as realistic [simulations] as you can, using actual hardware.

e. **Kerwin:** I want to comment on the Apollo command service module testing that was done in the vacuum chamber. Both the Block I and Block II spacecraft were tested, with crew for 7 days in the big chamber in Building 32. The difference between the outcomes between those two tests was like night and day. The Block I test was a sad story of multiple failures, problems, and inadequacies. The Block II [test] was a beautiful success that paved the way for Apollo 7. Very worthwhile.

f. **Carr:** Bill, I just wanted to tell you that, on SL-4, the sugar cookies were legal tender.

g. **Ross:** Not only were the SMEAT crew the "canaries" in the 20-ft chamber, the equipment were "canaries" as well. We were running a 70% oxygen, 30% nitrogen mixture at 5 psia (pounds per square inch, absolute). We were maintaining CO_2 levels as would optimally on Skylab. We had a 21-day pre-chamber phase, a 56-day chamber test, and [an] 18-day post chamber phase. The area of greatest test contribution was the impact on flight hardware. During in-chamber testing, several items either broke or revealed operational degradation and had to be sent outside the chamber for re-evaluation, repair, or engineering modifications or redesign. Some of the problems had to do with the Urine Volume Collection Measuring System, the metabolic analyzer, the bicycle ergometer – which was also essential for crew member exercise, which Bill Thornton did a heavy amount of work on. Additional problems we encountered were with the blood pressure measuring system and the cardiotachometer. Data were obtained for all of these items which could be used in their redesign to ensure complete acceptability for Skylab. And again, we need to thank some of the efforts of Dr. Bill Shoemaker and Dr. John Stonesifer, who were heavily involved in these activities. The guys in SMEAT did an outstanding job interfacing themselves to the outside world. I can't give them enough credit, because they really put up with a lot of BS. I wrote that there was no appreciable degradation of crew performance over the duration of the test. Significant individual differences were noted, however, to selected features of the test environment. In the case of the SPT (science pilot), the dietary requirements were well underestimated for his size and personal activity requirements. And that created the need for those free calories. The thing that Bill did not say was: after we felt sorry for him, with all of his lean body mass loss, the SPT opted for the free calorie supplementation because he felt that if he was actually on the Skylab, he would not be able to free change and add to his diet as he could in the altitude chamber, which had an in and out lock. So, I wanted to put this in the perspective that not a lot of people are going to talk about SMEAT in the future, I don't think. But I want to make sure that I have something on the record besides the SMEAT book.

h. **Gibson (Written):** There should be a wring out of the equipment that's new and not yet demonstrated. Otherwise, we should know how to run a space station by now.

i. **Schmitt (Written):** Rather than just testing for habitability, the CEV and lunar habitats, both development and each flight vehicle, should be fully tested in flight crewed chamber runs to build confidence and to provide flight vehicle familiarization.

5.14.2 Current CEV plans call for a WMS (instead of Apollo bags). Aside from a few minor issues, the Skylab WMS was well-regarded. One crew member stated that "I thought we had a great urine and fecal system."[27] A lessons learned document suggested that higher airflow for fecal collection was desirable, that the seat should be fabricated of softer material, and the outside diameter should be widened. It was also mentioned that the lap belt and handholds were absolutely required.[13] Do you have any other comments or suggestions?

a. **Crippen:** Just a comment. Having flown the first mixed-gender crew, we had a lot more privacy on the shuttle than you are going to have on the CEV. It is something you need to be worried about. I also wanted to point out that the Skylab system probably would have failed on orbit if we hadn't wrung it out. The shuttle system failed on orbit several times before we had a chance to finally resolve it; so, whatever you do, there needs [to be] some kind of a "wring-out" test prior to flight.

b. **Carr:** Crip, how would you rate the Skylab Waste Management System with the shuttle system, once we got the bugs out of that?

c. **Thornton:** Wait a second. Unfortunately, I got pushed into something that I never wanted to deal with, and that was the fecal collection system. Urine is one thing, but fecal collection… Anyway, let's face it, the shuttle system was a disaster. Remember the concept was that it was going to sling around and, like concrete, stick to the walls. I came down and one of the crew members said, "Bill, look at this." Periodically, he had the shutter system on the fecal collection system open and, periodically, you would see this little object come flying out. Well, the first thing that they did was to stop chasing food in flight after that. After that it started to sound like a concrete mixer. What it did is it would knock off chunks, and it would amplify from there until it was just a floating mass. I will not go through all of the, quote, "fixes" that they tried. They ended up with a kitchen spatula on one flight where you would push the feces away to make room. I won't go further on that. Unfortunately, I don't know what happened with the "Super Dixie Cup" collector on space station. Now remember, a much more efficient system was designed, flown, and recommended. If there are mass problems on lunar missions, it should be looked at again.

d. **Kerwin:** Let's talk about the Skylab system a little bit. I think it is fair to say that the system you had in SMEAT had to be so extensively changed for Skylab, that it wasn't representative, is that right?

e. **Crippen:** Well, the basic techniques were all still there, so it wasn't that different.

f. **Thornton:** Well, it is easy in gravity and it was a very simple but very effective system. It was just a wire mesh with a bag. But remember, you all had to bag and mass and everything else.

g. **Bobko:** And you [Skylab crew members] dried it; we didn't dry it. We just shipped it outside. As a matter of fact, they accused us once of not shipping everything outside.

h. **Kerwin:** The question before the house is: is the Skylab system, stripped of its mass measuring necessities and the requirements to sample the urine and freeze-dry the fecal material…if you strip all of that out, would it be a good system for CEV, or is it still too heavy?

i. **Thornton:** If you are willing to put up with the bags…conversely, the system I was talking about, the efficient system, requires only one sheet between each, in contrast to the fairly complex bag. Everybody uses the system, which, when collected, is compressed between two sheets. Each time you add another sheet and you end up with a very compact, minimum mass. Now if you can afford the mass of the bags, it would work quite well.

j. **Crippen:** Back to Jerry's [Carr] question. In my opinion, the Skylab system was far superior to what the shuttle ended up with.

k. **Bobko:** No question.

l. **Carr:** I feel the same way, too.

m. **Ross:** One thing you should remember is that during Apollo, we had a "shoot off" with three companies that were developing the Skylab Waste Management System. I flew more parabolas than I want to think about with different personnel that urinated and defecated during those 30-second parabolas until they finally got to the company that had the best design for Skylab. My bottom line opinion was that based on listening to the crews from the three missions, it seemed like it was a satisfactory system on orbit.

n. **Carr:** I would say it was. And the other thing was that we didn't have much of an odor problem in the waste management compartment; it was easy to clean.

o. **Bean:** I'm glad we've got astronauts like Bill Thornton, because we need those kind of guys around NASA because they solve problems. They get in and test this gear and keep talking about it, and they've got original ideas. I can remember when you solved the problem about balance. After our flight, we didn't have much lateral balance and you solved that problem with a simple device. We need more guys like Bill Thornton. My hat's off to you, Bill, for everything you've done in this program.

p. **Thornton:** Coming from you, you have no idea how much I appreciate that.

q. **Scheuring:** How did the system handle off-nominal "output" so to speak, i.e., loose stools?

r. **Kerwin:** Good question! I don't know that we had any diarrhea episodes or problems. [General consensus that there were no problems]

s. **Thornton:** We had some diarrhea in SMEAT, and the system handled it well.

t. **Gibson (Written):** I agree with these recommendations and thought the system worked well even as it was designed. There's a mistake that you will only make once – forgetting to turn on the airflow when using the urine collection device.

u. **Schmitt (Written):** CEV facilities are not a critical as long-term Lunar Habitat facilities. Apollo level of hygiene provisions should be adequate for the CEV as it will not be require to support crew longer than did the CSM, but a Lunar Habitat must provide for stays much longer than the LM.

5.14.3 Good odor control is desirable in the CEV (especially for the WMS). Odors were well-controlled in Skylab.[3] Do you attribute this to the charcoal filter system, the diluting effect of the large gas volume, or both?

a. **Thornton:** There's no question that it was the charcoal. Activated charcoal is one of the most remarkable substances on Earth. It is incredibly efficient at removing odors, because I promise you, one bad defecation, even in the Skylab volume, would have fouled the atmosphere.

b. **Weitz:** I believe one of the factors, personally, was the reduced pressure in Skylab, the 5 psi. My personal opinion was that when we were working, wearing those beta-cloth outfits that absorb zero sweat, so it would just lay there and get moldy after a little while, it would get so that I could hardly stand myself. But I never smelled the other crew members. I don't know what that says… My impression was that odors just didn't carry that far. I think charcoal had a lot to do with it, but I also think that it was the 5 psi.

c. **Lousma:** I think one of the things on Skylab that kept odors and everything else down was that the in addition to the low pressure, the humidity was extremely low. The place was built in a clean room, and we didn't sweat that much, so everything was clean. I don't recall odor control being much of a problem at all, but I think it had something to do with the environment we were in, which is probably different than the one you have now.

d. **Bobko:** I don't know if it was the food that we ate or the reduced pressure, but there was quite a bit of gas generated during our stint, probably due to the food. I don't know how you guys felt. [General agreement]

e. **Kerwin:** I think we've reached some consensus that the Skylab urine and fecal systems were miles better than Apollo and should be at least a candidate for use on the CEV if the weight could be stripped, by taking out the mass measurement requirements.

f. **Garriott:** Agreed. But Bill Thornton did have an alternative system that ought to be looked at because it could be lighter and smaller and more convenient than Skylab, but based upon the same kind of a principle. And you also need to think about using vacuum drying, if you have that available, to further reduce the volume.

g. **Lousma:** The Skylab WMS had a sealed compartment with a tightly fitting door, so odors were contained within the small volume, with less chance to have an odor problem than you might with just a curtain for example.

h. **Lindgren:** There was also a trash airlock on Skylab, and an ability to move trash into the vacuum and out of the habitable volume, which probably contributed to odor control.

i. **Kerwin:** Jerry [Carr], didn't your crew experience some odor out of the trash airlock at the end of your mission?

j. **Carr:** Yes ,we did. There got to be an odor after a while, and so we ended up going down and doing a little cleaning job because, apparently, one or two of the bags leaked a little bit. We cleaned it up, and it was okay.

k. **Bobko:** The Shuttle has two or three trash levels, and the worst trash level went into a "lock" or volume that has a bleed outside.

l. **Gibson (Written):** Both. Plus I am no longer sure if our sense of smell was reduced in 0-g. Maybe it was because body odors were not even a problem.

5.14.4 Lessons learned were applied to the layout of the Skylab internal volume; for example, do not co-locate waste management equipment with the galley. What lessons related to general layout or habitability should be applied to the lunar habitat?

a. **Carr:** Well, in the pictures I've seen, I'm glad to see that there will be a mudroom in the lunar habitat. Because, apparently, that was a real problem in the Apollo Program, with tracking dirt in the spacecraft. Having an airlock or a mudroom out there is a really good idea. Anyone that lives in New England knows the value of a mudroom.

b. **Crippen:** What about your sleep area and having your own little private spot? Now, I don't know if any of you ever used it since you slept all over the vehicle…

c. **Garriott:** We all used it. We all appreciated having our own space. It was a telephone-booth-sized compartment. It was so good that this guy wrote a 60- to 80-paged diary in-flight, neither Jack nor I knew anything about, till about 30 years later. And so, it really did provide a lot more privacy than one might expect. And so, I think it was very important if you can have it, you ought to.

d. **Carr:** I agree with Owen. I wrote a diary, too, and having the privacy of your own quarters in a spacecraft is important. Bill Pogue and I lobbied for years with Boeing and NASA to get quarters in the habitat section on ISS, but it didn't happen. I haven't heard anything recently from the ISS Program, but I suspect that there are folks that wish they had a private place they could go to.

e. **Kerwin:** I'm trying to think of criticisms; and a minor one was that if someone used the urine system in the middle of the night, you'd probably wake up your crewmates

because the compartments were adjacent. I don't know if there is anything you could do about that in CEV.

f. **Lousma:** I was going to mention that you want to keep both noise and light away from the sleep compartments. One thing that caused a real problem on Skylab was that equipment failed that was behind compartment walls. Some of the engineers thought that the stuff they built were never going to fail, and so the compartment walls were screwed in with permanent-type screws, so we had to be creative on how to get the screws out. It was a tough thing to do, but we did it. You need to make sure things are accessible. Don't put covers on so tight so that you can't get them off in space, even if the engineers think you'll never have to do it, because it'll happen.

g. **Lousma:** It was also nice to have things that could be fixed with the tools you have in your garage. If you have to have special tools for everything, you are just loading up the toolkit with things you shouldn't have to bring up. We should build things that can be repaired with standard tools.

h. **Thornton:** This may be out of place, but I didn't really see another place for it and I think it is very relevant. Planning for spending 6 months on space station vs. going to the lunar surface as both of you alluded to, it is a whole different ball game. That one-sixth gravity offers you all whole new set of opportunities. Mass measurement becomes trivial. Exercise, fluid shifts…all of these things are a whole different game on the lunar surface.

i. **Carr:** We were talking about maintainability and access to things. We had that Coolanol®, that magically disappear and we had to re-service the Coolanol® system. We would have been in deep trouble if we hadn't had access to those Coolanol® lines. And we basically used a good old saddle valve on it in order to re-service that system. So, this is a case that speaks well for having accessibility.

j. **Kerwin:** Going back to Jerry Carr's comment regarding the trash airlock. Be sure that you design the spacecraft so that all of the nooks and crannies can be cleaned or it will eventually catch up to you.

k. **Bobko:** There is nothing about food in the habitability section. The Skylab food was significantly better than how the shuttle food started out. Some of that is because you didn't have the free water that you had on the shuttle, and so a lot more things were de-hydrated on the shuttle menu compared to the Skylab menu. And, of course, you had a freezer on Skylab, which had things like ice cream and steaks, which were great. Many of you have flown shuttle, too. What do you think?

l. **Garriott:** The Skylab food was much better. It's the best that has been flown in space.

m. **Carr:** On the last mission, because of the food quantity situation, it was clear that we were going to need to augment our diet. You remember we got into the food bar business. We endured it because we wanted to make sure that the experiment got done

properly, so that we ended up with the right kind of nutrition; but, boy, if you can avoid doing that to a crew… Don't put people in a position where they have to subsist on food bars, even if it is one every 3 or 4 days.

n. **Gibson (Written):** Put the sleep compartments as far away from other living facility noise sources (comm. center, galley, [experiment] facilities, exercise area). Separate the exercise area from the galley.

o. **Schmitt (Written):** Be careful about over-doing "comfort" versus what is fully adequate for long-term exploration. Remember that explorers are highly motivated and, historically, require less comfort than settlers.

5.14.5 There have been many comments regarding the Skylab shower. Please comment on its use, cleanup, etc. Is a shower needed in the future?

a. **Lousma:** The shower in Skylab was actually added after the fact, after the whole Skylab and all of the plumbing was designed. Well, somebody thought we ought to have a shower. It was bolted to the floor with a fabric cylinder that latched around a fitting at the top. You had to mix water in a 3-quart container – so much hot, so much cold. You had soap that was probably better used in a veterinary practice, because it made you itch. We sprayed water on ourselves with a sprayer and then had to vacuum it off with a suction device. One thing worth noting is that we were in this low-pressure environment and so whenever you got that water on you and went to dry yourself off, it got extremely cold because it was evaporating so rapidly. It took a lot of vacuuming to get all of the water out from inside of cylinder. You had to use a lot of towels to get dry. During our mission, we usually just took sponge baths every night with a washcloth and a towel. We probably could have done without a shower, since it was low-humidity and low-pressure environment. It's different on ISS and perhaps in the habitat with higher pressure and more humidity, so you may want to have a shower. I don't know about the other guys, but Al [Bean] took two showers and I took one.

b. **Carr:** Well, I took a shower every 10 days, whether I needed it or not. But I found the shower to be quite refreshing, and I enjoyed it. The only downside was that it just took too doggone long to do all that stuff. So, if they can find a way to take a shower a little more quickly, they'd be on the right track.

c. **Garriott:** The average time for a shower was about 1 hour. You can clean up with a washcloth in 10 minutes or less. To me, I would skip the whole thing. You don't need a shower, even on ISS.

d. **Thornton**: We didn't have a shower when I grew up, like many other Americans at the time. The sponge bath works. Frankly, I consider it a luxury item in space flight.

e. **Kerwin:** Well, you certainly don't need one on CEV, but I agree with Jerry [Carr] that it was a pleasant experience. On a really long trip, you might want to have one. The physics of recycling the water is something you need to look at. We used towels and hung them up around the workshop afterward. Eventually, the water evaporated in

the air and was recycled by the life support system. If your system can tolerate that, I think it's great.

f. **Lousma:** One more thing about the shower. On the moon, lunar dust is going to get into everything. It gets into all of the equipment; it's going to get into the habitat, and it is going to get on you. Just dealing with your suits, you're going to want a way to get that dirt off; and I think that shower is going to be a good idea.

5.14.6 How much humidity do you need to prevent skin chafing, cracking, etc.? What duration of exposure do you expect to have before you begin to see some adverse effect on crew performance?

a. **Ross:** That's something that needs to be considered, too. First, the low-humidity effect and also the issue if you are going to wash enough to examine your skin. Some of the documents that Joe [Kerwin] and I put together for a presentation discussed the dryness with some fissuring of the skin – the lips, palms, and soles – due to the low relative humidity. You need to consider this in the lunar habitat. For prophylaxis, you may need to use skin moisturizers.

b. **Lousma:** It's not a lot different than what you see on the ground. I lived in Michigan in the winter and when you've got the heat on, the humidity would get down to about 40%. Your nose starts to get dry and cracked inside. I developed a pretty severe lip crack on Skylab, so I think the humidity got down to about 30% on Skylab, but I'm not sure. It seems to me that 70% [is] too high; you start to sweat when you don't want to. So, maybe somewhere between [50%] to 60% is about right.

c. **Thornton**: I think that [45%] to 50% is an accepted rule of thumb. Cracking of the skin is not necessarily benign. I had an example of that and came out of SMEAT with a pretty good infection, because of such cracking.

d. **Crippen:** I guess having lived for 5 years in Utah, where the humidity is around 10%, you can get a lot of problems. You know if it is just getting low at the nighttime and you are keeping it around 50% while the crew is up and moving around, I wouldn't think that would be much of a problem, personally.

e. **Garriott:** Perhaps you can quantify it, but a lot of water vapor comes from just exhalation and not necessarily exercise activity, so I wouldn't expect there to be that much of a diurnal variation. And don't forget what Bill said moments ago about showering necessity between weightlessness and one-sixth gravity. It might be a definite requirement for the moon and you might not need it for ISS, which was my comment earlier.

5.14.7 Was there any concern about the 5-psia system and the oxygen concentration for any 24-hour time period? Could it have led to some form of overt or subclinical hypoxic episode?

a. **Kerwin:** Absolutely not. My judgment would be that we were normoxic. Our alveolar oxygen partial pressure was normoxic. All of the experiments that were run, including the exercise experiments, show results perfectly commensurate with the ground-based

baseline. There was no adverse effect on our medical condition or on the research that was done.

b. **Thornton:** With regards to that, I did 300 watts on the bike ergometer for 45 minutes, and it was not bad. I can tell you that there was no performance decrement.

c. **Gillis:** I just wanted to make a short comment about the limit on the hypoxic end of the oxygen issue. You may tolerate a given level of hypoxic gas mixture well. The downside occurs during exercise. The limiting factor becomes the passive diffusion of oxygen across the capillary alveolar border. That is a passive, not [an] active process. As the cardiac output increases with exercise, the pulmonary capillary transit time decreases because of the higher blood flow rates. The partial pressure drops to the point that the passive diffusion time is not adequate during the shortened transit time to saturate the hemoglobin. The hemoglobin oxygen saturation subsequently falls, and you end up with mixed venous blood with a lower oxygen content. There is an interaction between the partial pressure of oxygen and the level of exercise. That's why the incidence of mountain sickness isn't decreased that much by being in good physical condition, which actually allows you to drive to higher cardiac outputs, shorter pulmonary transit times, and gets you into trouble quicker, even though you are in better shape.

5.14.8 Skylab had a nice wardroom, an area where the crew could congregate, eat, and do work. It also served as an entertainment area. Is a wardroom important?

a. **Garriott:** Look at that picture behind you with that window there; it's very important.

b. **Weitz:** It took us a long time to convince those engineers at Marshall to put that window in there. I think it was very significant, very important to have a wardroom.

c. **Lousma**: I think we've already been through that with the ISS. I remember in the early design stages that issue was debated long and loud. The answer is that you need it. The answer to that question is that you need a separate area.

d. **Kerwin:** All the previous studies, and I'm probably generalizing beyond the data a little bit, have reached a conclusion that on that Mars mission you need a place to be alone and a place to be together. You need them both.

e. **Carr:** Yeah, I'd agree with that, too.

5.14.9 What did you think about the provisions for exercise on Skylab?

a. **Carr:** Well, I recall the treadmill that Bill Thornton invented for us to get that kind of exercise on SL-4. And, Bill, I wanted you to know that on our mission we referred to that as "Thornton's Revenge."

b. **Thornton:** [laughing] I deserved it.

c. **Ross:** Jerry [Carr], didn't your crew ramp up to an hour and a half of exercise a day?

d. **Carr:** Yes, we did.

e. **Ross:** That's probably why you guys returned in exceptionally good shape as compared to the other two missions. Not that they were in bad shape, but you could see decrements in their operations and reasons for it. Obviously, the first mission, with all the repair work that had to be done… You guys had the time to do an hour and a half, is that right?

f. **Carr:** We made time to exercise, although it wasn't always easy. Sometimes we had to fight for it. We did return in good condition. Ed Gibson went out and ran a mile the third day after splashdown.

g. **Lousma:** I think that was a recommendation we made on the second mission. We confined our exercise to about an hour, and that was what was planned. I think we made the recommendation that it ought to be upped a little bit, and it looks like an hour and a half was about right.

h. **Carr:** I agree with that. Also, I've heard talk about splitting the exercise period. They wanted to do that on SL-4 when we were starting to have schedule problems and we fought that. I understand that it's been done on ISS. I don't think that makes a lot of sense.

i. **Pogue (Written):** If you have two exercise periods, do you have two clean-up periods or do you stay grungy between and wait until the last exercise period to clean up?

j. **Kerwin:** Jerry, I ran into cosmonaut Titov and we got to talking about long-duration flight and exercise. He said that they owed a lot to Skylab, because they noticed how much exercise you guys did and adapted that to their program. He was up there for a year in the late '80s. They did an hour in the morning and an hour in the afternoon; they broke it into two halves.

k. **Thornton:** One of the great things about Skylab was its adaptability. We started off with a lot of programmatic misconceptions. The crew worked hard and freed up time and allowed development and studies to improve exercise. They weren't about to let me put on any real exercise devices. The changes that occurred in the exercise program turned out to be a beautiful experiment. At first, there was no upper body exercise equipment. For Al's [Bean] flight, I was able to get some pretty crude upper body exercise devices on. By the last mission, the lower body protocol was markedly reducing the rate of leg [volume] loss. So, the first Skylab mission was very different from the last mission. The ability to add things as you went along is absolutely invaluable.

l. **Carr:** Who took the seat off of the bicycle and put the padding on the ceiling? Was that the first crew? I tell you, I think we blundered into a good thing there, because we were

standing up with our head against the ceiling as we pedaled the bike and we were able to stress the skeleton, which we weren't able to do anywhere else.

m. Weitz: As I remember, Joe [Kerwin], I think we both maxed out in 7 to 8 minutes trying to use those restraints. It was Pete's idea. We took the seat off and removed the harness from the bike.

n. Thornton (Written): The only reason that your neck was able to sustain such loads is that the bike produces such low force loads. If you want to load the truncal skeleton properly, add reasonable counter forces with bungees and a harness. Rigidly attaching the harness restricted respiratory exchange and rapidly increased CO_2 and reduced pH.

5.14.10 Was noise pollution a problem in the Orbital Workshop?

a. Weitz: The Marshall folks, who designed most of the fans in there, did a great job on muffling the sound from the fans. I don't remember being close to a fan. I used to go look out the window of the MDA all the time and it felt like something out of an Arthur C. Clarke book because there was no sound at all. You were basically scooting around the Earth.

b. Kerwin: I know the low pressure made sound propagation less and, therefore, we had to raise our voices to be heard at 10 ft. And if you were at the other end of the workshop, you really had to get on the intercom. That was the downside of the low pressure. The upside of it was that the vehicle was nice and quiet, which is a good thing to have.

c. Lousma: Made it hard to whistle, too.

d. Ross: It was constructed for a 55- to 65-dB level, and not to exceed a 72.5-dB level. I think that would be pretty acceptable.

e. Kerwin: From memory, the workshop would be in the mid to low 50s [dB], and the only place significantly noisier than that was the aft end of the structural transition section of the MDA, which was in the low 60s [dB].

5.14.11 What is the minimal amount of habitable volume needed for a long-duration orbital or planetary-based research facility?

a. Garriott: Are we talking for lunar habitat?

b. Jones: Mainly for lunar habitat, for planetary surface operations. So, since you won't be floating around, how much habitable surface area – including room for sleeping, eating, hygiene, and science – how much room is needed for you to be effective and efficient in your tasks for a minimum 6 month-long mission?

c. Kerwin: Clearly, the answer is going to be much more than the command module and quite a bit less than Skylab.

d. Ross: Let me give you some actual numbers here that I came up with. From Mercury through Apollo, you went from 1 to 8 m^3 of habitable volume. For Skylab, the Orbital Workshop was 294 m^3.

e. Kerwin: What I was going to suggest to my fellow Skylab crew members is that we use our imaginations and ask, "Could we do that in volume of the downstairs part of Skylab? Could we do it in the MDA?"

f. Bobko: What about the shuttle?

g. Kerwin: I didn't fly in the shuttle, but it is a valid question for those who did.

h. Bobko: I think two people could work in the shuttle middeck, but that was about all. Once you get more than that, you've got trouble getting into lockers and things, causing problems.

i. Garriott: The question related to more than just the Spacelabs, which were 2- to 3-week missions. We're talking 6 to 24 months, including all of the other activities that you've got to do. I would think Spacelab was still too small. You could do it, but it would be tough.

j. Bobko: You're including the shuttle volume as well?

k. Garriott: Yeah. I think the whole shuttle, including the payload bay with the Spacelab, is not enough for a 6-month mission. Also, the architecture is wrong. You'd have to completely redesign the architecture. So, I think you are going to have to have something between that and Skylab, if you really want to plan a decent mission doing reasonable kinds of science.

l. Bobko: 'Course you typically had seven people on a Spacelab mission.

m. Garriott: We had six, but of course you'd get up to seven or eight [people].

n. Weitz: What Jeff [Jones] just said would satisfy requirements and, based on what you said, in my mind, I just conjured up two big motor homes.

o. Jones: Two motor homes is enough for four-crew? Because we're talking a minimum of four-crew for these missions.

p. Lousma: Somebody once told me that Skylab was equivalent to two 60-ft house trailers, volume wise.

q. Kerwin: I would guess, off the top of my head, that the Skylab experiment compartment, which contained our sleep stations, our bathroom, and our ward room and a substantial experiment area, might be adequate for two or three people for periods that

long; and if you added the multiple docking adapter volume to that, you'd probably have more than sufficient space for good science for long periods of time.

r. **Weitz:** Okay, but you're talking volume. For a lunar stay, it's not going to be volume; it's going to be floor area, so you've got to do that conversion.

s. **Garriott:** Maybe another reason that we are thinking too short on this issue. Think of Bigelow; he can provide lots of volume at minimal cost. So, I don't think that volume is necessarily the real problem deciding what we want to do for the moon or Mars. I think we can have larger volumes, and, if we need to, we can have inflatable things like Bigelow is doing for Earth orbit. So, if you go with a larger volume, it is a question of how you implement it, what architecture do you use inside to make it comfortable to live in, work in, and do the experimental work that you want to do. So, go with a larger volume, if you have reason for it. I don't think that should be the major constraint in settling the overall architecture.

t. **Crippen:** Does any of the Antarctic data for their stayovers give you any of that kind of data?

u. **Jones:** Yeah, we are looking at that. In fact, one of our team members just got back. They did an inflatable-structure-type experiment just recently, looking at that volume for their crew – they had six [crew members] in that particular mission, a little more than we were planning on for these Exploration flights, and that was for a short stay. A 6-month winter-over is another paradigm that you could use as well as submarine tours. However, the ability of individuals to effectively conduct missions is limited by the mission profile. These mission profiles are very narrow with a very strict set of activities. They don't have the wide range of activities that we are going to expect these crew to participate in: EVAs, suit maintenance, geoscience, planetary science, life science, plus the habitability concerns that you guys have already expressed. We think that the volume is going to be more than any experienced in those kinds of scenarios because the range of activities and the range of expectations are going to be broader, and the performance level is going to be high in terms of expectations.

v. **Kerwin:** If it is too big, you still have to heat it and cool it and there are ECLSS (Environmental Control and Life Support System) impacts. While you guys were talking, I was trying to convert volume into floor area for the experiment compartment. I think about 300 ft^2, and the MDA maybe another couple hundred [ft^2].

w. **Garriott:** I've visited Antarctica twice, and for the winter-over down there, they only had about 28 to 30 people. As you know, they've just commissioned a brand new one, and they'll probably jump that up to 60 to 100 people for the winter-over personnel. Far larger area and volume than we are talking about for these space trips. In the end, I think your answer is somewhere between the full volume of shuttle/Spacelab and the volume of Skylab.

x. **Lousma:** For four people, you need the volume of Skylab at least.

y. **Garriott:** But the internal architecture is going to be very critical.

z. **Ross:** Just a quick extrapolation: If you are looking at six crew for ISS, and what I put out is the number cubic meters of habitable volume, you are looking at around 500 [m^3]? Just extrapolating, the shuttle is 71 [m^3]?

aa. **Hamilton:** The shuttle is at 71 [m^3]. Right now the ISS is at around 425 [m^3], but when Columbus and [the] JEM (Japanese experiment module) go up, it will be well above 600 [m^3]. The lab has around 99 [m^3] and the service module has 91 [m^3].

bb. **Lindgren:** So, maybe 100 [m^3] per person?

cc. **Jones:** You had about 100 m^3 per person on Skylab, if I remember right. And they are talking about trying to push that number to 80 [m^3] for planetary surface ops, for the habitat.

dd. **Hamilton:** Skylab had a huge volume.

ee. **Kerwin:** It was more volume than we needed; it was just what we had. We don't need to start there; we might end up there, but we sure as heck don't need to start there.

ff. **Bean:** Do you have any tests in progress where people go live in trailers? You don't need anything too complicated. I'm just talking about NASA renting some trailers and having four guys live in it for 3 or 4 days. I tell you, I think they could have a better idea about what we need than at least I could ever guess. A final thought is that you can't make it too big, because it is going to fill up. Any of those things are going to fill up with experiments and places for equipment. I have a hard time relating the volumes of spaceships into something that is sitting on the moon and how much you need to work around.

6 LIMITATIONS

The purpose of the Skylab Medical Operations Summit was to gather operational insights from Skylab/SMEAT crew members and medical operations personnel. While the recommendations that were generated by the summit represent the consensus opinion of the participants, there are limitations to this methodology.

First of all, the crew and flight surgeon participants represent a small fraction of the Skylab Program community. Mission planners, scientific investigators, flight directors, mission managers, and numerous others may have diverging opinions on many of the questions that we presented. The scope of participation was limited in the interest of focus and efficiency.

This summit was dedicated to a program celebrating its 35th anniversary. As such, some recollections may have been subject to recall bias. Indeed, some summit comments occasionally diverged from the opinions that were voiced in post-mission crew debriefings. This is a benefit to the users of this document, as the recommendations and opinions voiced at the summit have been tempered with post-Skylab experience in shuttle operations, space station design, and program leadership.

7 GLOSSARY

ACRV	assured crew return vehicle
AOS	acquisition of signal
ASTP	Apollo-Soyuz Test Project
ATM	Apollo telescope mount
CAPCOM	capsule communicator
CEV	crew exploration vehicle, also known as Orion
CM	command module
CMO	Crew Medical Officer
CMP	Command Module Pilot
CO	carbon monoxide
CO_2	carbon dioxide
COMTECH	Communications Technician
CONUS	continental United States
Coolanol	Trade name for silicate ester industrial coolant used on Skylab
CPR	cardiopulmonary resuscitation
CSM	command and service module
DOD	Department of Defense
ECS	Environmental Control System
ECLSS	Environmental Control and Life Support System
EMU	extravehicular mobility unit
ER	emergency room
EREP	Earth resource experiment package
EVA	extravehicular activity
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
IMSS	In-flight Medical Support System
IP	internet protocol
IR	infrared
ISS	International Space Station
IVA	intravehicular activity
JEM	Japanese experiment module
JOP	Joint Observing Program
JSC	Johnson Space Center
LBNP	lower body negative pressure
LCVG	liquid cooling and ventilation garment
LOS	loss of signal
LPU	life preserver unit
LST	landing ship, tank
MCC	Mission Control Center
MCC-H	Mission Control Center-Houston
MDA	multiple docking adapter
MSFC	Marshall Space Flight Center
MSOB	Manned Spacecraft Operations Building

Orion	also known as the crew exploration vehicle
OWS	Orbital Workshop
PAO	Public Affairs Office
PCU	pressure control unit
PI	Principal Investigator
PLT	Pilot
psi	pounds per square inch
psia	pounds per square inch, absolute
RCS	Reaction Control System
RH	relative humidity
S/C	spacecraft
SAR	search and rescue
SL-2	Skylab 2
SL-3	Skylab 3
SL-4	Skylab 4
SMEAT	Skylab Medical Experiments Altitude Test
SPT	science pilot
TDI	toluene diisocyanate
TDRSS	Tracking Data and Relay Satellite System
TEC	trans-Earth cruise
UDT	underwater demolition team
URI	upper respiratory infection
USAF	United States Air Force
UTMB	University of Texas Medical Branch
WMS	Waste Management System

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From May 1973 to February 1974, NASA conducted a series of three human missions to the Skylab space station, which was a voluminous vehicle largely descendant of Apollo hardware and the first U.S. space station. Crew members of these missions spent record-breaking durations of time in microgravity (28, 59, and 84 days, respectively) and gave the U.S. space program its first experiences with long-duration space flight. The program overcame a number of obstacles to conduct a lauded scientific program that encompassed life sciences, astronomy, solar physics, materials sciences, and Earth observation. Yet Skylab has more to offer than the results of these scientific efforts. The operations that were conducted by the crews and ground personnel represent a rich legacy of operational experience. As we plan a return to the moon and subsequent human exploration of Mars, it is essential to use the experiences and insights of those who were involved in previous programs. Skylab and Skylab Medical Experiments Altitude Test personnel possess unique insight into operations that are being planned for the Constellation Program, such as umbilical extravehicular activity and water landing/recovery of long-duration crew members. The Skylab Program was also well known for its habitability and extensive medical suite.

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