NASA Contractor Report 3943

Space Station Habitability Recommendations Based on a Systematic Comparative Analysis of Analogous Conditions

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Every age has its dreams, its symbols of romance. Past generations were moved by the graceful power of the great windjammers, by the distant whistle of locomotives pounding through the night, by the caravans leaving on the Golden Road to Samarkand, by quinqueremes of Nineveh from distant Ophir... Our grandchildren will likewise have their inspiration--among the equatorial stars.

They will be able to look up at the night sky and watch the stately procession of the Ports of Earth--the strange new harbors where the ships of space make their planetfalls and their departures.

--A.C. Clarke*

*References to introductory quotations are provided as the final Appendix to this report.

EXECUTIVE SUMMARY

This report documents research conducted by Anacapa Sciences, Inc., for the Space Human Factors Office at the Ames Research Center. The purpose of the project has been to systematically analyze conditions analogous to the proposed NASA space station in order to extrapolate design guidelines and recommendations concerning habitability and crew productivity. The following outline summarizes the recommendations for each of the 14 behavioral issues identified during the study.

SLEEP

- Maintain regular schedules of sleep for crew.
- Implement a sleep hygiene program, to hasten the onset of sleep.
- Dim interior lighting, automatically, to correspond to nighttime at mission control.
- Insulate sleep chambers.
- Shield sleep chambers from sound and light using doors or insulating covers.
- Locate toilet and hygiene facilities away from sleep chambers.
- Avoid or minimize shift work.
- Avoid "hot bunking."
- Include an alarm/communications system in sleep chambers.
- Locate sleep chambers near "exit" or radiation storm cellar.

CLOTHING

- Provide at least weekly changes of outer garments.
- Provide daily changes of undergarments.
- Provide clothing for physical exercise.
- Establish schedule of hygiene/clothes changes.
- Allow idiosyncratic dress--at least color variability.
- Prewash clothes and towels to reduce lint.
- Provide short pants as alternative to long pants.
- Locate exhaust fan/filter near clothing and towel dispensary.

EXERCISE

- Apply the principle of tangible results:
  - -- Develop compact zero-gravity isotonic and isometric devices.
  - -- Maintain personal physical ability/performance records.
  - -- Design ergometer-driven power generator with readout.
- Apply the principle of recreational exercise:
  - -- Design system to allow placement of ergometer near window.
  - -- Place CRT with variable programming near ergometer.
  - -- Encourage the development of zero gravity physical games.
- Apply the integration of activities principle:
  - -- Incorporate physical exercise in routine operations (e.g., manual trash compactor).
  - -- Incorporate routine operations in physical exercise (e.g., task preparation while exercising).
- Design exercise area/equipment as dedicated "mini gym."
- Provide adequate ventilation.

MEDICAL SUPPORT

- Provide onboard medical support capability for **all** potential emergencies.
- Routinely monitor mental health of onboard crew.
- Provide psychological support personnel at mission control to monitor crew and to assist with intervention procedures, if necessary.
- Provide onboard capability to sedate a seriously disturbed individual.
- Include remote diagnosis capabilities.
- Provide technically accurate assurances and procedures concerning emergency conditions.
- Monitor premission health status closely (e.g., to avoid kidney stones, deep dental problems, etc.).
- Consider voluntary removal of appendix for station crew.

PERSONAL HYGIENE

- Provide personal hygiene facilities for: dental and oral hygiene, hand and face washing, body bathing, hair and scalp cleaning, hair and nail trimming, shaving, and clothing disposal or laundering.
- Provide facilities for daily sponge baths (e.g., following exercise period).
- Provide a facility to allow **at least** weekly full-body showering; twice weekly showers would be better.
- Develop and implement a personal hygiene schedule to allow for variations in thresholds of subjective hygiene.

- Provide at least one full-length mirror to reinforce concepts of self image.

FOOD PREPARATION

- Design the food system to allow self-selection.
- Design the food system to provide a variety of dietary alternatives.
- Design the food system to require minimal meal preparation times.
- Allow flexibility in preparation mode (one crew member prepares for all or each prepares individually).
- Encourage special dinners (in terms of both hardware and station management philosophy).
- Encourage crew members to eat together by provision of adequate space and adherence to regular schedule of meals.

GROUP INTERACTION

- Provide individual communicators for all crew.
- Provide audio announcement/paging system.
- Provide a commander's "office" or central workstation for overall coordination of station operations.
- Design commander's office to allow private conversations with individual crew.
- Provide a bulletin board in wardroom/galley.
- Design wardroom/galley to accommodate all crew for meetings and meals.
- Design wardroom/galley tables to facilitate conversation.
- Design sleep compartments with removable partitions.
- Consider husband and wife teams as candidates for initial mixed crews.

HABITAT AESTHETICS

- Design sleep station interiors to accommodate personalization of decor.
- Discourage personal decor in common areas.
- Provide variation of visual stimuli through color (either surface pigmentation or reflected illumination).

OUTSIDE COMMUNICATIONS

- Allow moderate amounts of personal audio-channel transmissions (e.g., once or twice each week).
- Design communications system to allow calls to be made from private quarters.
- Ensure privacy of personal transmissions.
- Allow unlimited electronic mail (teletyped letters).
- Provide guidance to communications network users concerning proper network etiquette and the potential for problems in their communications.
- Provide news of current events to on-orbit personnel.

RECREATIONAL OPPORTUNITIES

- Allow books on board.
- Provide space for both personal and common storage of volumes.
- Provide onboard storage of literature in digital form to supplement hardcopy library.
- Provide personal, compact tape players with lightweight earphones for leisure, exercise, and selected work-time music appreciation.
- Provide onboard capacity for tape player battery recharging.
- Provide capability for onboard videotape viewing (a group activity).
- Provide capacity for storage of videotapes (wide variety of materials).
- Schedule at least one hour of uninterrupted leisure time prior to each sleep period.
- Encourage conversation among crew by designing areas and equipment (e.g., tables, workstations) conducive to communication.
- Provide constructive leisure opportunities such as formal courses of study.
- Allow musical instruments aboard.
- Apply the principle of integration of activities:
  - -- Include botanical experiments in station operations as early as possible to incorporate leisure "gardening" with task-related activity.
  - -- Encourage the development of zero-gravity physical games.
  - -- Design ergometer to render exercise more recreational (e.g., with CRT).
  - -- Allow special dinners and their preparation to provide recreation as well as nourishment.
- Design the space station to include as many windows as possible (to reduce feelings of isolation and to provide opportunities to exercise distant vision).
- Allow leisure time viewing of station exterior and surroundings via system of exterior-mounted video cameras.

PRIVACY AND PERSONAL SPACE

- Include a "library" compartment aboard the space station to allow crew members periodic opportunities for privacy and quiet reflection.
- Design individual "privatized" sleep chambers incorporating approximately 84 cubic feet of space if library and other common areas are provided. If common areas are not provided, sleep chamber volume requirements increase substantially.

WASTE DISPOSAL AND MANAGEMENT

- Include at least two toilets to provide redundancy and to accommodate peak use periods.
- Design toilets for maintainability.
- Design manually-operated trash compactor.
- Design manually-powered trash ejection system.

ONBOARD TRAINING, SIMULATION, AND TASK PREPARATION

- Provide an area for onboard training, task preparation, and technical communication (e.g., combine with library).

BEHAVIORAL AND PHYSIOLOGICAL REQUIREMENTS ASSOCIATED WITH A MICROGRAVITY ENVIRONMENT

- Design space station interior architecture to incorporate familiar (Earth-like) features (e.g., room-like chambers).
- Maintain, to the extent possible, a consistent interior orientation (e.g., local vertical).
- Provide visual and perhaps tactile cues to reinforce reference frame.
- Develop devices to restrain small objects during maintenance and repair operations.
- Develop solutions to problems associated with the stowage of small objects.

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INTRODUCTION

This report is the third in a series documenting research conducted by Anacapa Sciences, Inc., for the Aerospace Human Factors Research Division of NASA's Ames Research Center. The NASA Contracting Monitor's Technical Representative for this project has been Dr. Trieve Tanner, Chief of the Space Human Factors Office at the Ames Research Center. We are grateful to Dr. Tanner and to Dr. Alan Chambers,* Chief of the Aerospace Human Factors Division, for recognizing the potential contribution of the research documented in this report, and for the guidance provided during the course of this project. We are also grateful to many others who gave unselfishly of their time and expertise to further the objectives of this study, in particular Dr. E.K. Eric Gunderson, Captain Noel S. Howard, MC, USN, Captain Brian Shoemaker, USN, and Dr. Benjamin Weybrew. The conclusions, design guidelines, and suggestions presented in this report, however, are ultimately the author's responsibility and do not necessarily reflect NASA opinion or policy.

This report consists of three sections. The Introduction presents a statement of the project's objectives, a background discussion summarizing the need for habitability research, and an explanation of the comparative method; the Introduction concludes with a description of our systematic approach to the research. The second and principal section of the report presents discussions of our 14 behavioral issues with design implications. Design guidelines and suggestions are presented and in turn supported by information drawn from our archival research and personal interviews. The final section of the report summarizes the behavioral principles supporting our recommendations and presents a general discussion of issues relevant to human productivity and space station design. To contribute to continuity we employ the liberal use of reference notes throughout the document to further support or amplify our design recommendations.

PURPOSE OF THE PROJECT

The objectives of the current study have been: 1) to identify critical behavioral issues that have design implications for a NASA space station, and 2) to

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study conditions analogous to a space station in order to derive design guidelines and suggestions by extrapolation from those conditions. We have limited our concern to those biological, psychological, and sociological issues which have been described as "the intangibles of habitability" (Fraser, 1968a). We are not concerned with the overall configuration of the space station, that is, whether it assumes the appearance of a raft, a cruciform, a torus, or a tetrahedron. Nor does our research address issues such as temperature regulation, radiation protection, illumination requirements, or other well-documented and specified habitability variables.

Further, we have focused our attention only on those behavioral issues with architectural or design implications. Clearly, other issues such as personnel selection, training, and management are of critical importance to the development of an effective space station. However, at this early stage of concept development, it is imperative that the architectural requirements of habitability be identified in order to maximize human productivity and to minimize system costs. Those potential costs include both operational compromise and expensive retrofitting to mitigate design flaws.

During the initial phase of this project, we identified 14 behavioral issues with design implications (Stuster, 1983). These issues, listed below, served to focus our research activity and to provide structure for the development of design guidelines and suggestions.

- Sleep
- Clothing
- Exercise
- Medical support
- Personal hygiene
- Food preparation
- Group interaction
- Habitat aesthetics
- Outside communications
- Recreational opportunities
- Privacy and personal space
- Waste disposal and management
- Onboard training, simulation, and task preparation
- Behavioral and physiological requirements associated with a microgravity environment

BACKGROUND

It is inevitable that a permanently occupied, working space station will someday be a reality. Assume, for a moment, that this reality is ours within the next decade. What will the space station be like? Clearly, it will differ vastly from anything else that has been attempted by man. Yes, we have constructed complex spacecraft, we have walked on the moon's surface, and we have even experimented with the concept of a space station (Skylab and Salyut). But a permanently occupied facility, one that will support meaningful and productive activity well into the twenty-first century, is a unique challenge, representing a new era in human endeavor.

It is likely that the construction of NASA's space station will be an evolutionary process. In the earliest phases it may be a single cylinder attached to an enormous wing-like array of solar cells. Gradually, additional modules will be added until the space station will appear, from the flight deck of an approaching shuttle, as a grand, high-tech tinkertoy. Because a principal function of the station will be to provide a zero gravity platform, it is unlikely that our first space station will assume the familiar toroidal shape. Consequently, it will not conform to the popular conceptions of what a space station should be. It will lack the lyric quality of orbiting stations depicted in novels and films; there will be no gleaming giant wheels rotating to the pleasant strains of a Strauss waltz. Rather, by the closing years of this century, NASA's space station will a busy factory in the sky. It will be, first and foremost, a place of work.

Initially, the work will be conducted by six to eight technicians and scientists, and crew size may grow to a dozen or more as the station matures. The professional backgrounds and personal interests of crew will be vastly different. Some will come from industry, others from the academic community, and it is possible that a military presence will be maintained. NASA personnel will administer the facility and be responsible for coordinating overall operations. Those operations will range from facility maintenance, to basic science, to commercial production of commodities.

In the latter category, several modules may be dedicated to the processing of materials in zero-gravity. Currently, six different crystalization processes are used commercially and each is affected in fundamental ways by gravity. Many metal alloys have never been attempted on Earth because the components are immiscible, separating before the mixture can solidify. The results of recent experiments have indicated a bright future for zero-gravity materials processing. Consequently, it is likely that a metallurgical laboratory and foundry will be an early tenant of the space station. Similarly, it has been found that zero-gravity electrophoresis yields 400 times the output and up to five times the purity of pharmaceuticals made under conventional procedures on earth. As a result, another probable tenant of the space station will be manufacturing commercial quantities of insulin-secreting beta cells, interferon, growth hormones, and countless additional substances of value.

Other modules may house service centers for refurbishing or repairing worn out satellites or satellite components. This function may be associated with a launch base and fuel depot for satellite recovery missions beyond low earth orbit. It is also likely that an early role of the space station will be to provide an astronomical perspective outside Earth's atmosphere. However, such a telescope would require a separate, free-floating structure to avoid the space station's inevitable vibration. The telescope will eventually be joined by a flotilla of satellites, equipment pallets, and scientific experiments floating freely in formation around the space station or trailing behind connected by umbilicals and tethers. Maintenance of this fleet will require the routine attention of technicians venturing into the void of space.

These and other potential functions and operations of the space station make it abundantly clear that **factors affecting human productivity will play a central role in determining the success or failure of the space station.** Although the initial missions will be the focus of public attention, during the planning stage we must look beyond to the routinization of space station activities. We **must** assume a long-term perspective in order to fully anticipate the problems associated with the human component.

We know from countless heroic examples that carefully selected and/or motivated individuals may be both willing and capable of performing adequately under adverse conditions when those conditions are of short duration, extreme novelty, or when the rewards for enduring the conditions are significant. However, when humans are subjected to adverse conditions for long durations, on a routine basis, and in the absence of substantial reward or recognition, performance degradation **must** be expected.

The current study is not concerned with system tests or even with the first several missions of a NASA space station. Those crews would likely perform admirably under extremely inhospitable living and working conditions. Rather, our concern is with **routine operations.** Our word "routine" is derived from the French for "traveled way." It is clear that what must be designed from the start is a system that would be not only acceptable, but also **conducive** to work when low earth orbit has become a well-traveled highway, for instance during the fifth year of operation, or during an individual crew's tenth 90-day tour on a rotational basis. It is imperative that we design truly functional habitats--environments that routinely support life and encourage productivity--if the full potential of the proposed space station is to be achieved.

We have identified several issues associated with long-duration space missions that will inevitably affect human performance. In subsequent sections of this report we discuss those issues and offer design suggestions based on our systematic comparative analysis of analogous conditions. Simply by identifying those issues we take the initial step toward avoiding problems and mitigating effects; at the very least, once identified, problems can be anticipated. Essentially, though, we need to know what factors characteristic of confinement and isolation contribute to the degradation of human productivity. We need to explore those issues in order to design systems that avoid or minimize the negative effects on the human component. If isolation is, as Carlyle has described it, "The sum total of wretchedness to man," how may we render it less wretched?

THE STUDY OF ANALOGOUS CONDITIONS

Because the proposed space station represents a unique venture, we must be creative in our approach to discover solutions to problems associated with human adaptation to the isolation and confinement involved in space station operations. A fundamental assumption upon which our approach to this research is based is that a vast and relatively untapped source of behavioral and habitability data exists in the forms of naturally occurring groups living and working in confined and isolated conditions. Further, it is believed that an approach to the comparative study of groups in operational contexts is aided by the naturally occurring conditions, rather than hindered by the absence of controls. It must be agreed that field conditions are imposed with greater force and fidelity than a researcher could possibly produce in a laboratory setting (Radloff and Helmreich, 1968).

The study of analogues is referred to in the social sciences as "the comparative method." It is a valuable tool of scientific inquiry when applied in a thorough and systematic fashion. Our use of the comparative method is based on the recognition that the future occupants of NASA's space station are likely to encounter some of the same problems experienced by submarine and Antarctic personnel, participants in underwater habitat experiments, and others living and working under conditions of isolation and confinement. Our approach assumes that it is possible to identify and anticipate the habitability problems associated with long duration space missions by studying available data from similar situations.[1]

Although people have lived and worked under conditions of isolation and confinement for countless generations, only within the past three decades has there been an interest in understanding the problems of human adjustment to those conditions. For the most part, this interest can be traced to two "events": 1) the lamentable recognition during the Korean War that isolation and confinement can contribute to substantial changes in attitudes, and 2) the development of a florid and highly disruptive case of schizophrenia among the U.S. Antarctic team during the 1957-58 International Geophysical Year (Rasmussen, 1973). These occurrences led, on the one hand, to programs of research concerning sensory deprivation, and on the other to studies of small groups living and working in confinement and isolation.

Sensory Deprivation

Acute interest in brainwashing led directly to a series of studies in the 1950's involving individual isolation and sensory deprivation. Experimental work by Hebb, Vernon, Zubek and others has resulted in limited agreement concerning the effects of perceptual or sensory deprivation. Early studies reported a variety of unusual subjective phenomena, such as vivid and highly structured hallucinations, delusions, and gross alterations in perception upon emerging from isolation. In addition to these introspective accounts, objective evidence was obtained indicating increased susceptibility to persuasion, impairments in cognitive and perceptual functioning, and a progressive slowing of alpha frequencies with increasing duration of isolation and sensory deprivation (Zubek, 1973). It was later learned that two persons isolated together, where some social exchange was possible, did not exhibit the serious perceptual distortions characteristic of individual isolation. Apparently, the stimulation provided by just one additional person is sufficient to effectively mitigate most of the perceptual effects of isolation and confinement. Because the proposed space station would be routinely inhabited by several individuals at a time, studies of sensory and perceptual deprivation are not considered to be central to the habitability issues with which the current research is concerned.

Antarctic Research Stations

The Antarctic incident in 1957, however, did lead to an area of study directly relevant to the problems associated with long duration space missions. Psychological studies, sponsored by the Navy Bureau of Medicine and Surgery, were begun at U.S. Antarctic stations during the International Geophysical Year (1957-58). Mullin and Connery (1959) interviewed and tested members of two wintering-over parties, and Rohrer (1961) collected interviews and made observations concerning individual and group adjustment problems. Smith (1961) and Smith and Jones (1962) evaluated selection procedures for Antarctic scientists, and Smith (1966) studied group structure and social relations during a dangerous seven-man Antarctic traverse of four months duration. Based upon the results of psychological tests, diary observations and medical records, McGuire and Tolchin (1961) evaluated individual and group adjustment at South Pole Station in 1959. Also, Nardini, Hermann, and Rasmussen (1962) studied the psychiatric screening program during and immediately following the IGY. They concluded that psychiatric evaluations had been relatively successful in predicting the performance of individuals as determined by leaders' ratings.

Between 1961 and 1976, the bulk of all research concerning the behavior and selection of Antarctic personnel was conducted by E.K. Eric Gunderson of the Naval Health Research Center (formerly the Medical Neuropsychiatric Research Unit). Dr. Gunderson's objectives were to study the nature and degree of stress experienced in the Antarctic environment, to construct improved selection methods, and to develop effective performance measures. Gunderson studied groups ranging in size from 8 to 36 men and composed of approximately 60% Navy personnel and 40% civilian scientists and technicians. The primary sources of data for these studies were clinical examinations, military records, questionnaires, station leaders' logs and diaries, debriefing interviews, and site visits (Gunderson, 1973). Gunderson found that although cases of psychosis or severe neurosis have been extremely rare at Antarctic stations, minor emotional disturbances are very common (Gunderson, 1963). Since 1977, Antarctic selection procedures have been administered by the Naval Medical Command.

Remote Military Outposts

Like Antarctic research stations, several additional conditions of isolation and confinement have been the objects of behavioral analysis. These include remote military outposts, submarines, and underwater habitats to name a few. For example, Sells (1962) found that men who adjusted well to remote Arctic military bases were those who also adjusted well to their military assignments elsewhere. Wright, Chylinski, Sisler, and Quarrington (1967) investigated the adjustment to Arctic isolation of nearly 200 civilian electronic technicians employed by the Bell Telephone Company to staff the radar station of the Mid-Canada Defense Line; technicians lived in remote groups of two to eight men each. Wright, et al., suggested that the factors which differentiated between well-adjusted and poorly adjusted groups appeared to be relatively independent of Arctic conditions.

Nuclear Submarines

The advent of nuclear-powered submarines stimulated interest in the behavioral/psychological feasibility of long-duration submerged patrols. The earliest such study, known as Operation Hideout (Faucett and Newman, 1953), was concerned primarily with the effects of a hyperbaric environment on human performance; 23 volunteers endured two months aboard a sealed submarine tied to the docks. Measurements of psychomotor performance and alertness revealed no significant decrement in function. In another early study, Weybrew (1957) identified some of the symptoms of stress resulting from submerged isolation and confinement aboard the U.S.S. Nautilus: fatigue, dizziness, headaches, muscular tension, and amotivation. In 1960, Dr. Weybrew was aboard the Triton during the historic 84-day submerged circumnavigation of the globe, tracing Magellan's course. It was this experience which helped to define the optimal SSBN patrol length at 60-70 days (Webrew, 1979). In a later study aboard a Polaris-class submarine, Serxner (1968) identified some of the primary causes of stress among crewmen on 60-day submerged patrols. These included the inability to communicate with persons in the outside world, lack of sufficient personal territory, monotony, and concern for the conduct and welfare of family members ashore. Serxner found depression to be the common mode of adjustment to the confined and isolated conditions aboard the submarine.

A continued Naval program of behavioral research aimed at maximizing the productivity and readiness of nuclear submarine crews has resulted in the incorporation of several design features, and organizational and motivational techniques in FBM and attack-class submarines. These include: a) "gold" and "blue" crews (rotated on 90-day tours); b) extensive self-paced educational opportunities; c) recreation opportunities (films, arts and crafts); d) superior food (also open mess, ice cream locker, soft drinks and snacks--anytime); e) psychologically benevolent interior color design; and f) "periscope liberty."

Undersea Habitats

The vast depths of the world's oceans have frequently been compared by scientists and novelists alike to the isolation of outer space. In many ways the preparations necessary to sustain human life in these radically dissimilar environments are the same. Although the initial undersea habitat experiments involved commercial, scientific, or military matters, the similarity to space missions has been recognized and made a focus of research concern (i.e., Tektite I and II). The similarity is apparent from Radloff's description:

> Saturation divers are under severe stress; furthermore, those stresses have not been imposed or contrived by psychologists. While their spatial separation from a normal environment may seem slight, they are separated by many hours or even days....from a return to the normal world, because of decompression requirements. Saturation divers live in constant danger from equipment failure or human error which could result in fatal or disabling accidents. They live in close confinement and are highly dependent on each other and on surface support personnel (1973:197).

The first serious underwater habitat experiment was conducted in 1962 by the French adventurer and entrepreneur, Jacques Cousteau. The Conshelf program, culminating in Conshelf III in 1965, was designed to test the feasibility of extended duration commercial diving operations at extreme depths. Six "oceanauts" spent over three weeks living in a self-contained, spherical module breathing a mixture of exotic gases. Work was conducted outside the habitat, located beneath 328 feet of the Mediterranean Sea, to demonstrate the range of human capability concerning seabed industrial operations. All performance was closely monitored by topside personnel. Only technical problems resulting from the pressure and humidity were reported (Cousteau, 1966).

The most widely known underwater habitat was the U.S. Navy's Sealab program, conducted between July 1964 and October 1965 (Radloff & Helmreich, 1968; Radloff, 1973). Sealab I, located at a depth of 192 feet in the clear warm waters of Bermuda, was a 9 by 40 foot laboratory. Four Navy divers lived in and conducted marine observations in the vicinity of the habitat for a period of eleven days. Sealab II, larger than the previous system, was located at a depth of 205 feet on the continental shelf off La Jolla, California. Three ten-man teams, consisting of Navy divers and civilian scientists, each spent 15 days in the habitat. In addition to extensive psychological tests and monitoring, the behavior of the men was systematically observed and recorded. These data included eating and sleeping habits, activity levels, variation of mood, morale, motivation, and cooperation. Following the submersion period, each participant completed questionnaires, was interviewed, and subjected to a medical examination. Sealab III was a 10 by 10 foot domed cylinder with an open bottom; the habitat was located in 50 feet of water off Anacapa Island, California. Two four-man teams each made dives of 12 hours to evaluate the performance of the Mark VIII diving equipment and umbilicals, and to establish a human performance baseline. The project was marred by the accidental death of a participant.

Conclusions that may be drawn from the Sealab program concerning behavioral issues are: a) all future ventures of a similar nature will require improved coordination of medical and engineering phases with a great deal of control vested in the medical complement of the team; b) a degradation of human performance was evident which increased with the complexity of the task (data indicated that a portion of the performance decrement was associated with personality variables); c) persons who were "good mixers" tended to achieve more in their diving operations; and d) social interaction was strongly related to successful adaptation to the rigorous undersea environment.

Project Tektite (1969-70) was a multi-agency experiment conducted by the U.S. Navy, NASA, the Department of the Interior, and the General Electric Company. The habitat consisted of two domed cylinders 12.5 by 18 feet high, connected by a tunnel. The habitat was mounted on a support structure in 49 feet of water in Great Lanreshur Bay, St. John, Virgin Islands. The crew of Tektite I was composed of four male marine scientists from the Department of the Interior. They performed domestic chores, habitat maintenance and repair, marine science research, and biomedical and behavioral science programs; the duration of the mission was 60 days. Tektite II involved crews of four scientists and one engineer each. There were four missions of 14 days duration and six missions lasting 20 days each; one mission was performed by a crew of five women.

One of the primary goals of Project Tektite was to evaluate the behavioral dynamics of small groups over long-duration mission operations. This was accomplished by administering a variety of testing instruments, collecting personal interviews, and continuously monitoring operations by closed circuit video and audio channels. Some of the relevant conclusions derived from this project are: a) individual gregariousness was positively correlated with performance; b) privacy was very important, especially to individuals who did not relate well to the group; c) "aquanauts" tended to sleep longer during the mission than during pre- and post-mission periods; d) conversing was the most frequent leisure activity; and e) one of the most popular places in the habitat was the bridge (control room) where contact with topside personnel was available. Further, it was recommended that future habitat or space vehicle design provide variability (particularly visual), good quality food with dietary variety, adequate work aids, individual privacy, and to the extent possible the design should avoid multiple-use spaces (Miller, Van Derwalker, & Waller, 1971).

Other Conditions of Isolation and Confinement

There are many other relevant studies and reports available, including laboratory experiments simulating confinement and isolation. These conditions range from French caves and university penthouses to fallout shelters and ersatz space capsules. Another area of analysis has concerned circumstances involving involuntary isolation, such as shipwrecks, disasters and prisons. Because the risks and motivational factors inherent in both laboratory and involuntary contexts differ radically from those of an actual space station, these research areas are not considered to be a central concern of the current project. We have limited our attention to those conditions which have been described as the naturally occurring laboratories of human experience.

We believe that a wealth of data, possibly superior to that generated by laboratory and involuntary studies, exists in the form of analogues with high fidelity to a space station, such as those described in the preceding paragraphs. This summary has **not** included all of the examples that met our criteria for analysis. Additional, less documented candidate analogues considered in our comparative approach include marine research vessels, merchant ships, distant-water commercial fishing vessels, offshore oil rigs, and other space missions. The objective of this approach has been to systematically analyze this wealth of analogous experience in order that recommendations may be made to support informed judgments regarding the biological, psychological and sociological issues associated with a manned, permanent presence in space.

A SYSTEMATIC COMPARATIVE ANALYSIS

Many attempts have been made to draw behavioral inferences from situations simulating long-duration space flight. However, with the exception of Sell's (1973) attempt to develop a taxonomy of confinement and isolation, little attention has been given to the relative **appropriateness** of the analogues, or to the likely utility of the inferences. Although the comparative method has been recognized by several investigators as a potentially valuable source of data, there has been little attempt to discriminate between the relative values of the many alternative analogues. There are several problems associated with **a priori** judgments in this area. For instance, a submarine making a 90-day submerged voyage is very similar to the proposed space station in length of tour and perhaps in the hostility of the outside environment, but fundamental behavioral differences may arise as a consequence of substantially different crew sizes, activities, backgrounds, outside communications, or other dissimilarities.

Several features distinguish our approach from other efforts to study behavior in the naturally occurring laboratories of human experience. Most notably, our approach avoids **a priori** judgments regarding the relative merit of the many conditions of isolation and confinement which may be compared to the proposed space station. Others have assumed that underwater habitats, submarines, or Antarctic research stations, to name a few, provide good examples from which to extrapolate concerning human behavior aboard a space station. We made no such assumptions. Instead we developed a methodology to evaluate the "relative degree of relatedness" of several candidates, or alternative analogues.

To evaluate alternative analogues, it was necessary to first prepare a list of dimensions, or metrics, to be used to define space station conditions.[2] In developing these definitions, we were interested in establishing the parameters or assumptions concerning expected onboard conditions; these assumptions were required to allow the comparative evaluation of alternative analogues. To satisfy this objective, we compiled the following list of dimensions.

- Size of group
- Type of tasks
- Perceived risk
- Duration of tour
- Physical isolation
- Personal motivation
- Amount of free time
- Composition of group
- Psychological isolation
- Preparedness for mission
- Physical quality of habitat
- Form of social organization
- Hostility of outside environment
- Quality of life support conditions

Please note that the list of dimensions should not be confused with the list of behavioral issues with design implications presented earlier. The dimensions allow the comparison of alternative analogues for purposes of evaluation; the behavioral issues provide a focus for the study of the most analogous alternatives. Although both lists contain 14 items, there is not an item-to-item correspondence.

Certain of the above dimensions are, in fact, variables rather than givens. For instance, the quality of food is considered within the dimension, "Quality of Life Support Conditions." But, the quality of food that may ultimately be served aboard the proposed space station--along with many similar decisions--has not yet been determined. Also, in apparent contradiction, studies such as the current effort may be used to affect determinations regarding issues such as food. It was necessary, however, at the early stages of this project to specify conditions as completely as possible for purposes of comparison with alternative analogues. Even the dimensions that are clearly variable required some degree of specification--if only in general terms--to allow the systematic comparative effort.

Evaluation Methodology

In addition to describing the proposed NASA space station in terms of the 14 dimensions, we prepared descriptions of several alternative analogues also using the same dimensions. A survey instrument was then developed to allow the comparison of the space station assumptions to the descriptions of the alternative analogues. The evaluation effort involved a dimension-by-dimension comparison and the use of a seven-point scale. Data collection sheets used in the evaluation are included as Appendix A. When combined, the information contained in the data collection sheets forms the matrix illustrated in Figure 1.

Originally we had planned to evaluate the relatedness of the analogues in-house, using a variation of the Delphi technique. When the richness of the comparative data became apparent while preparing the summaries, it was determined that a more systematic approach was in order. A list was made of potential participants for an expanded survey; the list contained behavioral scientists, design engineers, flight surgeons, and other aerospace professionals. Although the sample was by no means random, we were careful to ensure that all major aerospace companies, the military, research firms, and academic institutions were represented. Evaluation instruments (documents containing the descriptions and data collection sheets) were then mailed to the 76 individuals on our list (Stuster, 1984). Instructions were provided and we acknowledged the difficulties inherent in quantifying subjective phenomena; Appendix B provides a summary of those instructions. It is believed, however, that by providing systematic descriptions and then combining the judgments of many individuals, we apply a more scientific method and, consequently, transcend the customary anecdotal approach to this subject. The importance of a systematic approach was stressed in our instructions, because the results of the evaluation would guide our subsequent research efforts.

	ANTARCTIC RESEARCH STATIONS	SEALAB II	TEKTITE I	TEKTITE II	COMMERCIAL OIL-FIELD DIVING	SUBMARINES (FBM)	RA EXPEDITION	LONG-DISTANCE YACHT RACING	COMMERCIAL FISHING VESSELS	RESEARCH VESSELS (COASTAL)	SUPERTANKERS	OFFSHORE OIL PLATFORMS	SKYLAB 4
SIZE OF GROUP													
COMPOSITION OF GROUP													
FORM OF SOCIAL ORGANIZATION													
DURATION OF TOUR													
TYPES OF TASKS													
PREPAREDNESS FOR MISSION													
PERSONAL MOTIVATION													
HOSTILITY OF OUTSIDE ENVIRONMENT													
PERCEIVED RISK													
PHYSICAL ISOLATION													
PSYCHOLOGICAL ISOLATION													
AMOUNT OF FREE TIME													
QUALITY OF LIFE SUPPORT CONDITIONS													
PHYSICAL QUALITY OF HABITAT													

Figure 1. Matrix formed by combining information from data collection sheets (Appendix A).

A total of 54 of our sample responded by completing the evaluation of alternative analogues; this represents a response rate of 71%. The inordinately high degree of cooperation received is even more remarkable due to the time required to participate. Respondents reported that they spent between one and eight hours each reading and evaluating, resulting in an average of slightly over three hours per person. We are grateful to the many friends, colleagues, and strangers alike who furthered the interests of the current project by devoting time and effort to the evaluation of space station analogues. A list of participants and their affiliations is presented as Appendix C.

Results of the Evaluation

The results of the evaluation were analyzed summing the mean values of the 14 dimensions for each analogue. This represents a columnar approach to the matrix depicted in Figure 1 (the sums of all cells within each column). This provides an overall measure of relative relatedness to the assumed space station conditions, that is, the higher the value, the greater the fidelity. Table 1 summarizes the results of this procedure. A secondary, or row analysis, was presented to identify those analogues which may not have high **overall** fidelity to space station conditions, but may correspond closely on specific dimensions. Table 2 presents the results of that analysis.

TABLE 1
OVERALL RESULTS OF THE
EVALUATION OF ALTERNATIVE ANALOGUES

Rank	Analogue	Combined Mean Values*
1	Skylab 4	86.81
2	Sealab II	70.93
3	Tektite I	69.40
4	Tektite II	66.89
5	Submarines	63.46
6	Antarctic Research Stations	59.35
7	Commercial Oil Field Diving	57.12
8	Long-Distance Yacht Racing	56.66
9	Commercial Fishing Vessels	54.10
10	Research Vessels (Coastal)	53.45
11	Ra Expedition	52.99
12	Supertankers	49.21
13	Offshore Oil Platforms	41.52

*A value of 98 was possible (7 x 14 dimensions).

The Research to Develop Design Guidelines

On Table 1 you will note that the four most highly ranked analogues are no longer available as living laboratories of human experience. They are available to us, however, through archival sources and the memories of principal participants.

TABLE 2
HIGHEST RANKED ANALOGUES BY DIMENSION

Size of Group

Ra	6.48
Oil Divers	5.90
Sealab	5.73
Yachts	5.52

Preparedness for Mission

Skylab	6.51
Submarines	5.19
Sealab	4.70
Tektite I & II	4.26

Psychological Isolation

Skylab	6.70
Sealab	5.79
Tektite I	5.72
Tektite II	5.60
Supertankers	4.83
Fishing vessels	4.76

Composition of Group

Skylab	5.77
Tektite II	5.13
Tektite I	4.76
Antarctic	4.62
Research vessels	4.55

Personal Motivation

Skylab	6.64
Tektite I	5.93
Tektite II	5.98
Sealab	5.76
Research vessels	5.00
Antarctic	4.94

Amount of Free Time

Sealab	6.51
Supertankers	6.04
Submarines	5.70
Skylab	5.57
Fishing vessels	5.23

Social Organization

Skylab	6.22
Sealab	5.33
Tektite II	5.18
Tektite I	5.16
Yachts	4.80
Antarctic	4.77
Submarines	4.71

Hostility of Environment

Skylab	7.00
Antarctic	5.92
Sealab	5.40
Submarines	5.29
Oil Divers	5.12

Quality of Life Support Conditions

Skylab	5.76
Submarines	4.25
Tektite I & II	4.23
Sealab	4.00
Yachts	3.74

Duration of Tour

Skylab	6.49
Fishing vessels	6.43
Tektite I	6.25
Submarines	6.23

Perceived Risk

Skylab	6.77
Sealab	5.28
Submarines	5.02
Oil Divers	4.98

Physical Quality of Habitat

Skylab	5.77
Tektite II	5.06
Tektite I	5.00
Submarines	4.91
Antarctic	4.47
Sealab	4.38
Fishing vessels	4.13
Research vessels	4.06
Yachts	4.02
Oil Divers	3.79
Oil Platforms	3.21
Supertankers	2.43
Ra expedition	2.34

Types of Tasks

Skylab	6.64
Antarctic	5.66
Sealab II	5.55
Tektite II	5.55
Tektite I	5.51
Research vessels	5.28
Submarines	4.40

Physical Isolation

Skylab	6.91
Submarines	5.91
Antarctic	5.87
Sealab	5.59
Oil Divers	5.49
Tektite I & II	5.38

Similarly, though submarines, Antarctic stations, saturation diving, and the like **are** currently available, the penalties and costs involved place field observation in such exotic environments beyond the scope of the current project.

Though we have been limited to archival research and personal interviews, both means have been found to provide wealths of information and insight concerning the issues associated with living and working in isolation and confinement. The bibliography accumulated during the course of this research includes detailed discussion of all of the analogues included in our original analysis. However, during the primary data gathering phase of the project, we limited our reading and interviews, somewhat arbitrarily, to the seven analogues which scored highest in the evaluation. There is much of relevance to be learned from fishing and research vessels, and perhaps from supertankers and expeditions, but in order to focus our effort and to maximize the likely utility of the inferences obtained, we limited our concern to those analogues with the greatest fidelity to what we might reasonably expect of a NASA space station.

The most highly ranked analogue, as expected, was Skylab 4. Skylab, the first experiment in actual space station building, was constructed primarily of surplus hardware from the Apollo program; the spacecraft was launched May 14, 1973. In addition to the unmanned launch, there were three manned missions, 28, 59, and 84 days in duration (conducted between May 1973 and February 1974). Skylab will be recalled in the history of technology for many reasons. Perhaps most notable among them was the role played by man in salvaging the missions through on-orbit repair following damage caused during launch and deployment. Figure 2 presents a diagram of Skylab.

As part of the research program aboard Skylab, evaluations were conducted concerning the crew quarters and overall station habitability (Skylab Experiment M487). Habitability was viewed in this evaluation as comprising nine elements: environment, architecture, mobility and restraint, food and drink, garments, personal hygiene, housekeeping, interior communications, and off-duty activity. It was concluded that while habitability is often considered only in terms of comfort and convenience, the Skylab experience indicated that effective habitability features could be measured in hours made available to productive tasks. "In many instances, slightly improved habitability provisions would have saved valuable time" (Johnson, 1975).

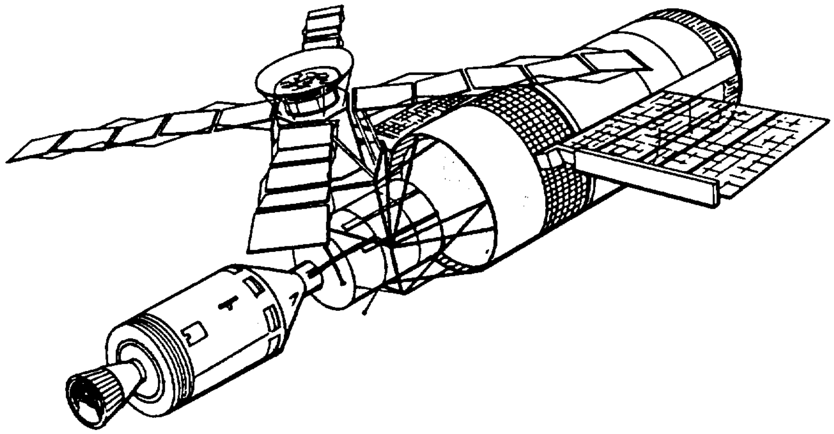


Figure 2. Skylab.

Sealab II, the second ranked analogue to the proposed space station, was an underwater habitat experiment sponsored jointly in 1965 by the Office of Naval Research and the Special Projects Office of the U.S. Navy. Three ten-man teams of civilian and military divers, scientists, and salvage experts spent 15 days each in the 12' x 57' cylinder at a depth of 205 feet of water; habitat atmosphere consisted of a heliox mixture at 6.8 atmospheres. The purpose of the project was to demonstrate the feasibility of opening the vast areas of the continental shelf to human habitation and exploration. Figure 3 presents a diagram of Sealab II.

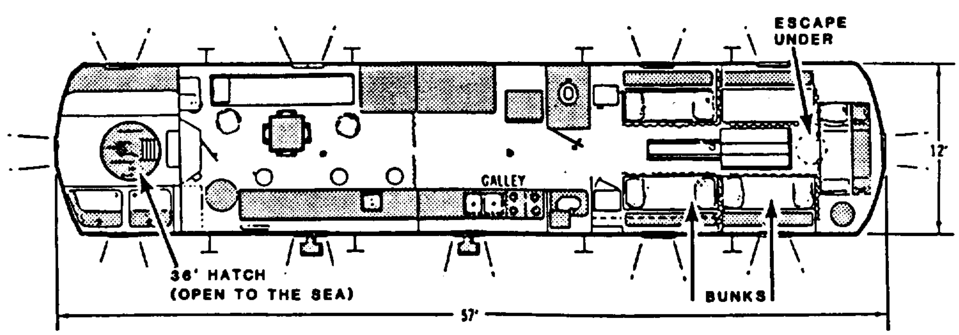


Figure 3. Sealab II habitat.

Tektite I and Tektite II, the third and fourth most highly ranked analogues, employed the same dual cylinder habitat (each cylinder 12.5' x 18'). Project Tektite was a multi-agency undersea experiment; one of the primary goals of the project was to evaluate the behavioral dynamics of small groups over long-duration mission operations. Tektite I consisted of a crew of four male marine scientists and a tour of 60 days; Tektite II consisted of five-person crews and tours of 14 and 20 days. The habitat was located at a depth of 49 feet of water, requiring a 19-hour decompression period. Figure 4 presents a diagram of the Tektite habitat.

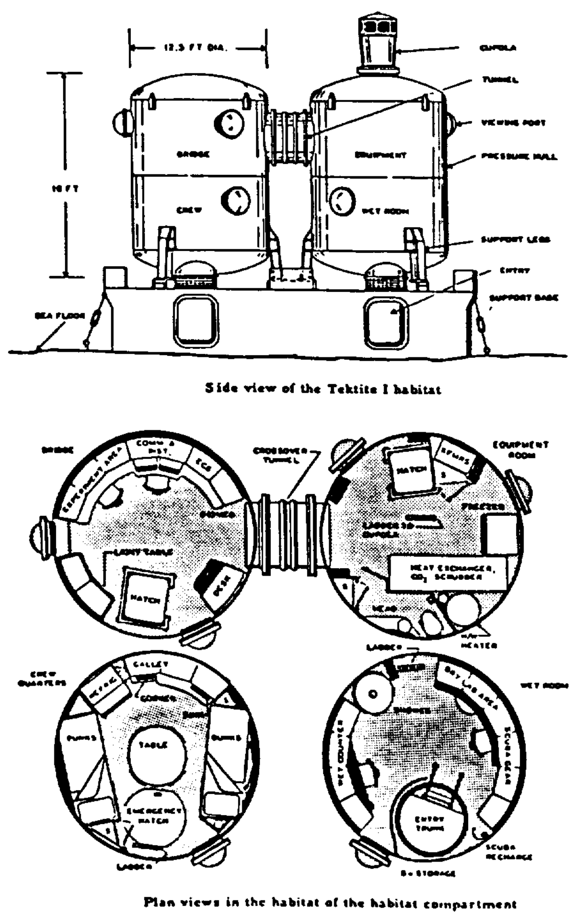


Figure 4. Project Tektite habitat.

Submarines represent the fifth most highly ranked analogue to a space station in our analysis. Submarines, along with Antarctic research stations, have frequently been mentioned as appropriate analogues from which to extrapolate behavioral guidelines regarding long duration space missions. Clearly, the evolution of submarine technology provides a model of the development of complex systems involving human performance under adverse conditions. The award-winning German film, **Das Boot**, illustrates the severe conditions aboard U-boats of the Second World War. Fortunately for submariners, conditions have improved dramatically. Crews of U.S. fleet ballistic missile submarines (FBM) are large, approximately 140 officers and enlisted personnel, and missions involve 60 to 90 days in the isolation of submerged cruising.

Although the overwhelming emphasis in submarine psychology since 1953 has been on the selection of the most appropriate persons to endure the conditions (rather than on the habitability of the conditions), an enormous data base has been developed. It is truly remarkable that, at any given moment, approximately 10,000 American submariners are living and working in confined and isolated conditions beneath the waves. Figure 5 provides a diagram of an FBM, or "boomer" as they are called by their crews.

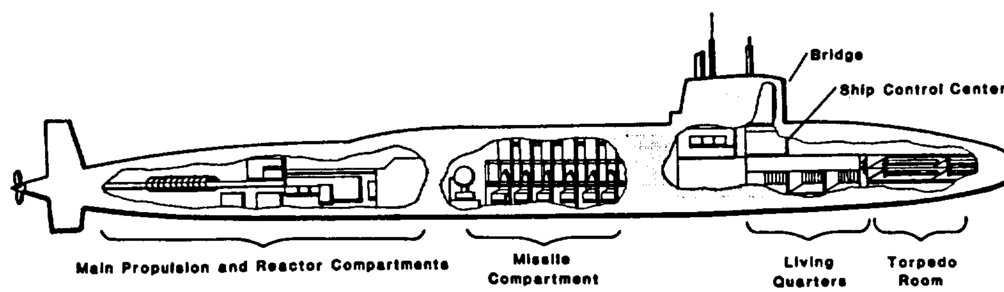


Figure 5. Fleet ballistic missile submarine.

Small Antarctic research stations, such as the South Pole Station depicted in Figure 6, represent the sixth analogue in our overall analysis most closely resembling a space station. (Even the diagram appears similar to some proposed space station configurations.) Of the several nations maintaining permanent Antarctic stations, the U.S. program is unique in its organization and heterogeneity of personnel. The U.S. Navy provides the facilities, maintenance, and support personnel; the National Science Foundation provides the scientific staff. At the South Pole Station a group of about 20 Navy and scientific personnel spend a year living and working, eight months of which they are totally isolated and confined to the station and its immediate surroundings. The United States has maintained a permanent presence on the Antarctic continent since 1955.

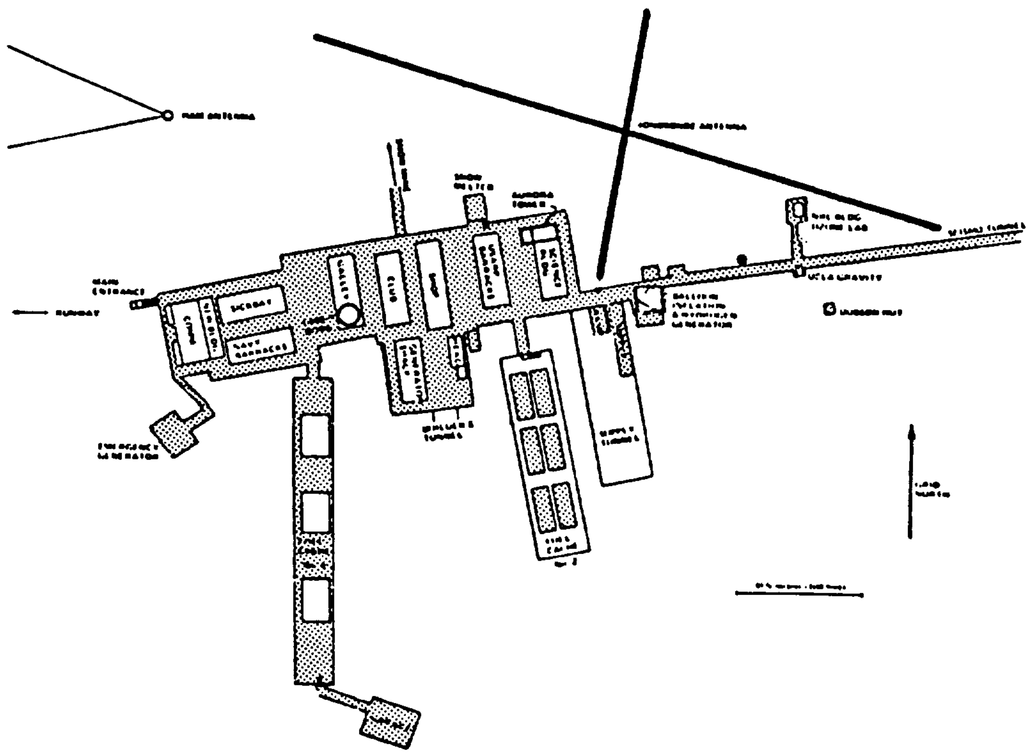


Figure 6. South Pole Station.

The analogues considered by our evaluators to be the seventh most closely related to the proposed space station are commercial saturation diving operations. Underwater habitat experiments and the cumulative experience of saturation divers have resulted, in the past 15 years, in the development of systems allowing divers to work at great depth for extended durations. These divers, most of whom work in offshore oil fields, may spend as many as 10 hours underwater each day and travel between the confinement of a pressurized deck chamber and the sea floor in a small diving bell. Groups of six divers are common, living and working together in saturation for a month or more at a time. The deck chambers, like the 8' x 30' unit depicted in Figure 7, are characterized by spartan living conditions. Most of the ammenities such as leisure gear and comfortable mattresses, are disallowed due to the potential for oxygen fire when compressing and decompressing.

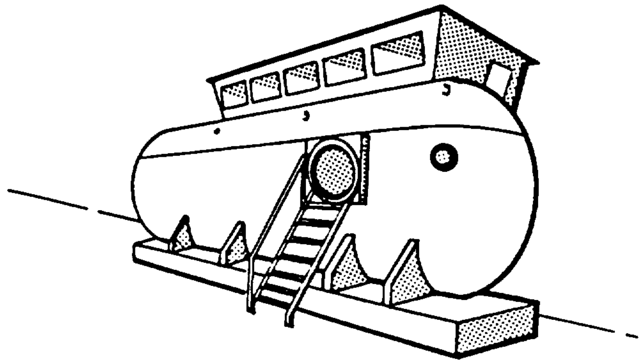


Figure 7. Commercial saturation diving deck chamber.

The bibliography contained in this document provides a listing of the books, papers, technical reports, bulletins, logs, and other archival sources used in the development of the design guidelines and suggestions presented in subsequent sections. Appendix D provides a list of those persons interviewed during the course of this project. All of those interviewed gave unselfishly of their time and wisdom in the hope that their particular experiences and observations might contribute to the design of a successful space station. We are grateful for the cooperation extended and we will acknowledge specific contributions where appropriate.

HABITABILITY ISSUES WITH DESIGN IMPLICATIONS

Before proceeding with the discussion of habitability issues, it is appropriate that we first determine a useful definition of the term "habitability." During the course of the current research project we reviewed many technical reports and design studies prepared during the past two decades which offer definitions of habitability.[3] Although there is little agreement among the authors concerning concepts, terms, and the elements that constitute habitability, there is a common theme. Essentially, it is this: habitability encompasses all the things people need to remain happy and/or productive.[4] The questions remain, what are the things, and how much of them are needed? We state it similarly in operational terms: Habitability is defined as those aspects of an environment that affect human performance and productivity, either immediately or in the long run. But which aspects of the environment, and how much do they affect the human component?

We believe that the first question is answered well by our list of 14 issues. Others have constructed complicated taxonomies and cumbersome sets of categories, yet our list of only 14 items appears to include the major issues. Also, our definition acknowledges both degrading **and** enhancing elements. But a definition that also includes the relative degrees to which issues contribute to habitability is elusive. Due to the vast differences in individual personalities and motivations and to the plasticity of human behavior, it is safe to state only that these are the critical issues and to varying degrees they influence human performance.[5]

Difficulty in prioritizing habitability issues is not a serious constraint because all of them are important and require resolution. Also, the problems associated with most of the issues have already been solved in other contexts. Perhaps "solved" is an inaccurate term, for in our analogues that involve routine operations (e.g., submarines and Antarctic research stations) solutions to habitability problems have for the most part **evolved** over time in response to recognition of the problems and allowable technology. By viewing these and other analogues as models for the development of complex systems, we might more effectively learn from them and avoid the penalties which would result from encountering the problems unprepared during the evolutionary development of the proposed space station.

The following pages present discussions of the 14 behavioral issues with design implications identified earlier. A separate section is devoted to each issue, and design guidelines and suggestions are presented and supported by inferences drawn from the study of analogous conditions. Recommendations concerning each issue are summarized at the conclusion of each section.

SLEEP

> Blest be the person who first invented sleep--a cloak to cover all human imaginings, food to satisfy hunger, water to quench thirst, fire to warm cold air, cold to temper heat, and lastly, a coin to buy whatever we need.
>
> --Cervantes

Although the physiological functions of sleep remain unknown, we are able to specify with considerable accuracy the requirements for particular stages of sleep (Moore-Ede, Sulzman, and Fuller, 1982). Stated in operational terms, the variables associated with sleep include schedule, total amount per cycle, and "quality" (quality is defined as time to onset and number of awakenings). Variation in each of these dimensions can affect human performance and the effects may be immediate and/or cumulative. Our comparative analysis has identified three topics of concern within the general issue of sleep: sleep management, noise control, and safety.

Sleep Management

Early reports of a particularly virulent form of insomnia among Antarctic personnel, known as "polar big eye" (Mullin, 1960), precipitated an extensive program of sleep research at American Antarctic stations. That research indicated that while the sleep of Antarctic personnel is affected somewhat by conditions (e.g., hypoxia due to altitude), there was no evidence of the polar big eye phenomenon among the subjects studied (Shurley, 1974).[6] Though reported by 60% of the personnel in debriefings (Strange and Klein, 1973), the actual experimental analysis of this bizarre phenomenon was not possible.

As operations-level experience in Antarctic conditions accumulated, an explanation of insomnia and some cases of hypersomnia under those conditions became apparent. For eight months of the year, the Antarctic continent is shrouded in darkness. Lacking the normal circadian cues of daylight and darkness, individuals, when allowed, tend to become desynchronized. That is, they retire to bed at a later hour and remain awake longer each night. Although the actual sleep periods may remain approximately the same duration, they gradually encroach upon subsequent 24-hour periods until such time as one has cycled completely around the clock.

E.K. Eric Gunderson, who spent over a decade studying adaptation to Antarctic conditions, found that this pattern, known as "free cycling," results in irregular work habits and schedules, which in turn negatively affect task performance and overall productivity. Commander Bill Weiner, a clinical psychologist and senior reviewer of Antarctic personnel, has observed that desynchronized individuals can affect group morale as well as personal and overall productivity. For example, if one is asleep or not fully awake when needed to assist with a task, both performance of the task and interpersonal relations may be negatively affected.

In the absence of normal diurnal cues, or **zeitgebers** (Moore-Ede, Sulzman, and Fuller, 1982), it has been found that adherence to a schedule of sleep and activity is critical to maintaining sustained productivity. Dr. Gunderson also found that those Antarctic personnel who did remain on a schedule did not suffer as many physiological symptoms as those who free cycled. Most station leaders now insist that schedules be followed. Captain Brian Shoemaker, a winter-over leader early in his career and currently the Commanding Officer of all Naval personnel in Antarctica, suggests an 0800 muster as a means to encourage adherence to a sleep schedule. This approach offers sufficient latitude to accommodate individual differences and requirements, yet serves the intended purpose of discouraging free cycling.

Clearly, the maintenance of regular schedules of sleep is recommended for the proposed space station. However, due to the acknowledged importance of quality sleep and to the proclivity for task overloading in manned space operations, it may be necessary to institute a program of sleep management to assist individuals in conforming to the schedule.[7] The U.S. Navy is currently developing a program of "sleep hygiene" that could serve as a model for space station operations. The program involves regularity of schedule and autogenic routines to follow which hasten the onset of sleep.[8]

A related recommendation concerning sleep management is to automatically dim or alter the color of illumination in space station common areas for 8 to 12 hours each mission "night" to correspond with the day-night cycle at the site of the principal mission control facility. Living and working on "Houston time", with appropriate zeitgebers to facilitate maintenance of normal circadian rhythms, would contribute to individuals' abilities to adhere to sleep schedules and ultimately to overall station productivity. Dr. Benjamin Weybrew, the principal submarine psychologist of the nuclear age (from 1953 to 1979), reports that dimmed lights contribute to the maintenance of normal circadian rhythms and sleep schedules among submariners. Based upon his extensive operations-level experience (rather than on laboratory studies) he is a firm believer in the importance of obtaining quality sleep to the maintenance of psychological health and sustained productivity. Aboard submarines, and by extrapolation aboard a space station, a pattern of sleep irregularity can result in an increased propensity for human error and decreased efficiency.

Noise Control

Although some individuals can literally "sleep through a storm," it is a folklore belief that all people adapt to regular sounds and are not awakened by normal noises perceived during their sleep. Actually, the sleep of many individuals is disturbed by even the most regular sounds, and for some the quality of sleep may be reduced without conscious recognition or complete awakening.

In each of the analogues considered in our analysis, evidence was discovered of systematic sleep disturbance resulting from inadequate noise control. Skylab astronauts were repeatedly awakened by the sounds of others' nocturnal visits to the waste management facility (the toilet), by the reverberations of a weightless elbow or knee striking a thin wall, or by a variety of clicks and hums associated with the normal automatic functioning of the station.[9] The crews of Project Tektite also complained that noise affected sleep. In particular, conversations and use of the communications channel were impossible without disturbing those in the crew quarters. Aboard submarines and in the deck chambers of saturation divers, sleeping crew are frequently disturbed by the changing of watches or shifts during 24-hour operations. The relatively larger size of Antarctic stations affords greater insulation from sound than the other analogues, but those staffing the earlier stations were compelled to endure the constant sound of diesel-powered generators.

The analogues studied suggest that sleep chambers aboard the proposed space station should be well insulated to absorb sound, "privatized" (e.g., openings fitted with doors or sound absorbing coverings to shield noise and light), and the toilet(s) (head or waste management facility) should be located away from the sleep chambers to minimize the disturbance caused by plumbing and equipment sounds during the sleep period. Also, shift work should be avoided due to the inevitable disturbances to sleeping crew members caused by changing shifts; it is believed that extended work weeks would be preferable, but perhaps not sufficient, as a means of increasing overall station productivity. Likewise, the sharing or rotational use of sleep chambers, known as "hot bunking," is considered by all observers to be the alternative of last resort. Wherever it is employed, hot bunking is despised for several reasons.

Primary reasons for avoiding hot bunking are not so much related to sleep as they are to the importance of maintaining privacy and a sense of personal space. The exclusive nature of one's bunk assumes added importance under conditions of isolation and confinement. Some observers have described this importance in terms of territoriality. This issue will be discussed in a subsequent section.

Another argument against the sharing of sleeping space is hygiene. Wherever hot bunking is employed, there are complaints that personal hygiene suffers (e.g., body lice). Among commercial oil field divers, tenders, and standby personnel, hot bunking and 24-hour schedules are common. The practice is so disliked, however, that a daily bonus is paid to those forced to share a bunk. Also, sheets are supposed to be changed between shifts "in the sack." Divers typically mark their sheets in an inconspicuous place to ensure that the stewards actually change the bedding.

Safety

If sleep chambers are insulated and "privatized" as suggested, it becomes imperative that each sleep chamber be equipped with a communications device. The minimum requirement for safety purposes is an alarm or set of alarms. Although a simple annunciator would be sufficient to alert sleeping crew members to danger, an interactive system with voice capability would surely prove to be superior, since it would have functions in other than emergency conditions. For example, routine communication could be conducted with a minimum of internal locomotion.

Our final design recommendation relevant to sleep is one that we are simply passing along from the crews of Skylab. Before retiring each evening, the commander of each mission would typically make a final inspection of the station. With checklist in hand, he would ensure that the flare alarm on the solar console was activated, that the ground control alarm was functioning, that the fire alarm was operational, and finally that the air pressure alarm was in the on position. The latter would sound in the event the station was punctured by a meteoroid. Cooper reports that, "Although no noticeable meteorite pierced Skylab, and there were no fires, the astronauts frequently wished their bedrooms were closer to the command module, their only means of escape if anything went seriously wrong; and they urged that bedrooms on future space stations be not so far from the exit" (1976:170-171).

Summary of Design Recommendations: Sleep

- Maintain regular schedules of sleep for crew.
- Implement a sleep hygiene program, to hasten the onset of sleep.
- Dim interior lighting, automatically, to correspond to nighttime at mission control.
- Insulate sleep chambers.
- Shield sleep chambers from sound and light using doors or insulating covers.
- Locate toilet and hygiene facilities away from sleep chambers.
- Avoid or minimize shift work.
- Avoid hot bunking.
- Include an alarm/communications system in sleep chambers.
- Locate sleep chambers near "exit" or radiation storm cellar.

We have asked architect Loren J. Solin to translate into graphic form some of our recommendations concerning space station design. Figure 8 presents a rendering of what we consider to be a reasonable design for individual quarters--a sleep chamber; Figure 9 illustrates an overall module configuration that would accommodate this design. Additional sleep chamber architectural requirements are presented in our discussion of privacy and personal space.

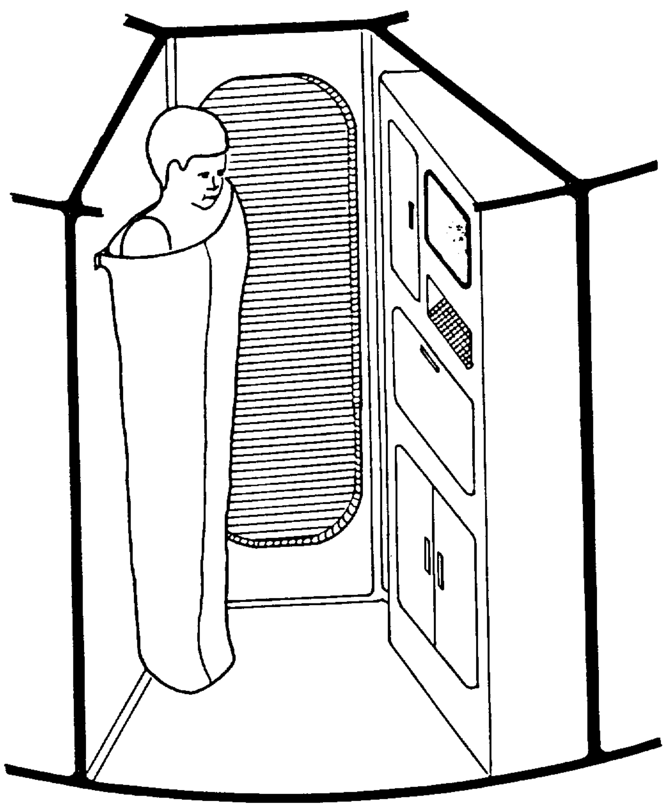


Figure 8. Space station sleep chamber.

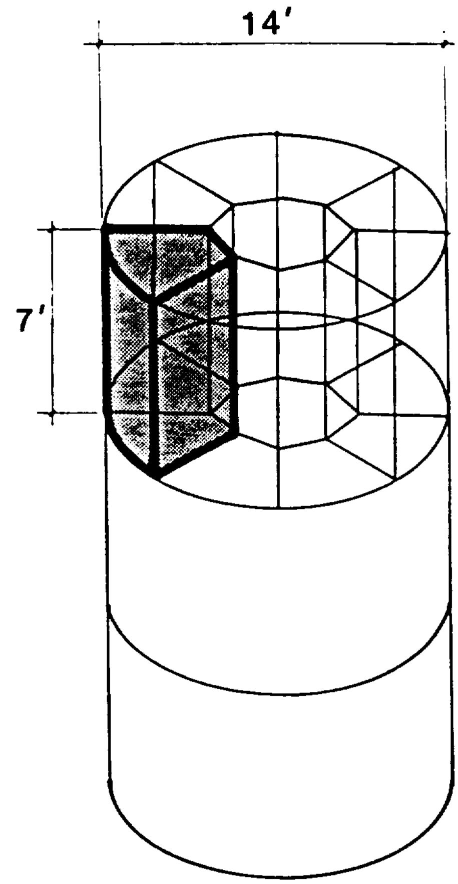


Figure 9. A module configuration.

CLOTHING

Beware of all enterprises that require new clothes.

--Thoreau

Much has been learned from the Skylab missions regarding clothing for a "shirt sleeve" working environment in space. For example, two-piece garments (i.e., pants and shirts) were considered convenient by Skylab astronauts for the same reasons as on Earth (less sensitive to fit than coveralls, more adjustable to clothing requirements, and more convenient to personal hygiene procedures). Skylab crews, however, disliked the fabric from which their outer garments were made. Besides the color (a brownish gold considered by some to be boring), the fireproof fabric did not breathe and in fact developed a peculiar odor, especially following exercise. Conventional cotton undergarments were also provided.

We have identified three sub-issues with design implications concerning the topic of space station clothing: hygienic functions, psychological effects, and fugitive lint.

Hygienic Functions

While it is difficult to separate the issues of clothing and personal hygiene, it is important to recognize that clothing may appear clean on the outside, yet be contaminated by excessive wearing. While it is unlikely that this condition would have physiologic or pathologic implications for a space station, certain attributes of soiled clothing could result in problems. Fraser (1968a) suggests that the attributes of concern are those associated with mechanical and chemical irritation, hypersensitivity, and provision of media which encourage microbiological growth on the skin or in body niches; the latter presents the most serious concern. Skylab astronauts believed that their clothes rarely became soiled, and suggested one to two weeks wear for outer garments and daily changes of underwear (NASA, October 1974). We suggest **at least** one change of outer garments each week, daily changes of underclothes, and the provision of special athletic gear (shorts and optional shirt) for daily physical exercise. These may be considered the minimum requirements. Additional research is needed to identify the range and importance of personal preference in clothing use-rates. These data are needed in order to define the architectural requirements of clothing storage.

Psychological Effects

There is a tendency among some of those who find themselves in isolated and confined conditions to allow standards of personal hygiene and appearance to slip. Captain Noel Howard, the Chief of Naval Psychiatry, describes this phenomenon as a common form of regressive adaptation to a captive situation (one may be held captive by others or by an environment). Usually at each small Antarctic station there is at least one individual, typically among the scientific rather than the military staff, who seems to take some pleasure in "grubbing out," that is, becoming and remaining dirty and slovenly. This phenomenon is also occasionally reported among the crews of nuclear submarines, and in both conditions there is cause for concern. The substandard cleanliness or appearance of an individual is a common source of interpersonal conflict under conditions of isolation and confinement. It must be understood that under these conditions, issues that would be insignificant elsewhere are typically magnified beyond all reasonable proportions.

Essentially, there are two separate psychological effects of a clean set of clothes: on the individual and on the group. We are all aware of the invigorating effect of a shower (in our culture); part of that effect is attributed to the clean clothes associated with the shower. Similarly, the subjective feelings of group cohesion and morale are affected by the appearance of others within the group. To this end, military managers have encouraged, over the years, adherence to standards characterized by a crisp and clean appearance.[10] The psychological value of clothing is believed by military psychologists to be a definite factor in morale and productivity.[11] To facilitate positive individual and group perceptions and to minimize a potential source of social conflict, we recommend that individual crew be encouraged to change clothing according to a predetermined hygiene schedule.

Before departing the subject of the psychological aspects of clothing, it is important to note that a lack of variability is one of the principal stressors in confined and isolated conditions. In this regard, it has been suggested that idiosyncratic dress be allowed. Variability of style and color of garments may prove beneficial.

Fugitive Lint

A principal design concern of the habitability group at Johnson Space Center is fugitive lint, that is, the fine ravelings and short fibers which are generated by fabrics and which escape into the weightless atmosphere of the habitat (this is analogous to the fugitive dust caused by construction projects). Several problems are evident, including the fouling of ventilation systems and the potential for inhalation, and food and equipment contamination. Fugitive lint is apparently an issue aboard STS and it is a concern for the proposed space station. Since larger crews would occupy the space station than the shuttle, more clothing and towels would be required, and consequently more lint would be produced.

Our suggestions in this regard are not drawn from the comparative analysis--only aboard submarines is there a serious lint problem and it is countered by use of a lint-free material in the construction of garments. Rather, our suggestions simply state the obvious: prewash clothing and towels to reduce on-orbit lint generation, encourage the wearing of rugby or "safari" shorts rather than long pants (less material to generate lint), and locate an exhaust fan/filter near the primary clothing and towel dispensary.

Summary of Design Recommendations: Clothing

- Provide **at least** weekly changes of outer garments.
- Provide daily changes of undergarments.
- Provide clothing for physical exercise.
- Establish schedule of hygiene/clothes changes.
- Allow idiosyncratic dress--at least color variability.
- Prewash clothes and towels to reduce lint.
- Provide short pants as alternative to long pants.
- Locate exhaust fan/filter near clothing and towel dispensary.

EXERCISE

> Well, Walter, I believe that the good Lord gave us a finite number of heartbeats, and I'm damned if I'm going to use up mine running up and down the street.
>
> --Neil Armstrong to Walter Cronkite

Exercise is a critical concern on long-duration space missions. Due to the many effects of muscle atrophy and the particularly insidious bone decalcification characteristic of microgravity environments, special attention must be given to defining specific forms and amounts of exercise. Many of the required data are already available from previous space missions, in particular Skylab (National Academy of Sciences, 1972; Gibson, 1975; Kerwin, 1975). It is apparent, however, that additional work is needed in order to address the psychological aspects of routine exercise. That is, what may be required is the development of methods of exercise which are less boring and more motivating than those employed or proposed for astronaut use.

We had hoped that our comparative study would lead us to innovative examples of exercise developed by the confined and isolated occupants of analogous conditions to a space station. We had assumed, erroneously, that elsewhere people had already developed forms of exercise more recreational in nature, and consequently more motivating, than those performed aboard Skylab and the shuttle. Rather, what we found is that in all conditions studied, the exercise available is considered to be either boring or superfluous. What we did discover, however, is a set of principles with potentially greater value than any single device or exercise program. These principles are discussed in the following subsections, tangible results, recreational exercise, and integration of activities.

Tangible Results

During the course of our research we observed that those people who do engage in regular exercise under isolated and confined conditions tend to do so for one of two reasons: either for the recreational value, or to achieve some tangible result. The latter category includes building-up muscle tissue, trimming away excess body fat, and/or achieving a performance goal. It appears that it is a rare individual who engages in daily exercise simply for health maintenance, at least to the extent necessary to counter the zero-gravity effects of muscle atrophy. In almost all cases, either recreation or some tangible result of the activity is the objective. This is particularly apparent in those conditions where physical activity is part of the normal work, yet some individuals spend their leisure time "pumping iron."

There are several means by which tangible results for exercise can be offered to crews of the proposed space station. The Navy has found that by appealing to vanity (in conjunction with command emphasis) seamen regularly use with enthusiasm the recently developed compact exercise units installed aboard ships and submarines. Similar devices, using both isometric and isotonic principles, could be developed for use aboard the space station (resistance caused by friction rather than gravity, of course). The evidence suggests that such a device would be consistent with some individuals' personal motivation to build-up tissue.

Some people may respond better to competition, either against others or themselves, as a means of achieving a tangible result for their exercise effort. In this regard, station physical ability/performance records could be maintained as motivators. At the very least, individual performance trends would serve this purpose effectively for many crew. Cooper reports that the Skylab astronauts, "...kept their records on the wall of the experiments room and consulted them as avidly as hospital charts" (1976:105).[12]

Another motivating technique involving tangible results might be to design a bicycle ergometer for on-orbit use that drives an electrical generator. The generator could be connected to the station's power grid, and crew could then monitor their individual contributions to the station's overall energy budget; this approach might serve as an effective motivator for some individuals. It is important to realize that not all persons respond to the same motivational framework or incentives. It may be necessary to provide a **range** of exercise alternatives to ensure that all crew are sufficiently motivated to maintain a daily exercise schedule to counter the zero-gravity effects of muscle atrophy and cardiovascular deconditioning.

Recreational Exercise

The exercise equipment aboard Skylab consisted of a bicycle ergometer, and on the final mission a Thornton treadmill was added. The treadmill was a sheet of slippery Teflon attached to the floor, on which the astronaut walked in stocking feet. Bungee-cords formed a harness to substitute for gravity (Compton and Benson, 1983). The latter device served to effectively exercise the calf muscles, but the bicycle was preferred for overall conditioning. The crews were all pleased to have access to the ergometer to the extent that they complained bitterly if their time on the device was abbreviated by mission managers. Edward Gibson (1975) reported that he always felt good after using it, and Joe Kerwin felt that "strong glow of health" associated with a good workout on Earth (Cooper, 1976). There was a problem, though, in maintaining interest in the activity. After about 15 minutes on the ergometer the astronauts felt they needed mental diversion. Some listened to recorded music and found that sufficiently stimulating to allow them to continue, but what they **really** wanted to do was look out the window while exercising. This is, perhaps, the most frequently recalled habitability recommendation of the Skylab astronauts; we concur with their judgment.[13]

Because two ergometers will probably be needed to satisfy the daily exercise requirements of a crew of eight, we offer an alternative solution to rendering exercise recreational. The alternative involves mounting a tunable CRT in front of the ergometer. Programming could be selected from a tape library ranging from recorded scenes of famous bike paths of the world to feature films or other commercial productions, including daily network news.[14] Clearly, such a solution could provide sufficient diversion to allow one to exercise daily for 90 days at a time at an otherwise monotonous activity. But a more important value may be served as well. **That is, to the extent that recreation is embedded in exercise, the amount of separate recreation time needed to maintain individual productivity may be decreased.** Because productivity is a primary goal of space station habitability, any time freed from other required pursuits could conceivably be redirected to productive activity. Consequently, for those crew who derive their principal recreation from exercise, that activity becomes doubly effective.

Integration of Activities

The third and final principle associated with exercise is related to the previous discussion. That is, where practical it would be wise to incorporate physical exercise in routine operations, as well as to incorporate routine operations in physical exercise. The latter is accomplished by fusing leisure with exercise (e.g., entertainment, news, etc.) but it could be extended as a matter of individual preference to include mission-related reading or task preparation (though this is not recommended for all). It is the first part of the principle, however, that offers a truly creative opportunity for design engineers. Namely, to design equipment and devices, the power for which is provided by the astronauts themselves.

For example, a pressing concern of the JSC habitability group is the design of a trash compactor capable of handling the volumes of paper and plastic waste generated by the crew during normal operations. An automatic trash compactor will require a fairly sophisticated design, complex machinery, and power to operate it. A simpler solution would involve a far less complex design and be operated manually by an astronaut; manual rather than electromechanical operation could also contribute to reliability. To the extent that the exercise involved in operating the device counters the effects of muscle atrophy, the astronaut-operators are well-served. If this principle were applied systematically in other contexts (e.g., hatches, pumps, etc.) the time dedicated to actual physical exercise could conceivably be reduced, again freeing time for other more productive pursuits.

Other Exercise Sub-Issues

In addition to the prophylactic value of exercise, there is evidence that physical activity can also contribute to the maintenance of morale. Because many of the potential crew personnel are physically active while Earthbound, it is likely that the availability of exercise opportunities while working in space will be appreciated; this was clearly the case aboard Skylab. Also, there is some evidence which suggests that structured exercise improves task performance and cognitive functions as well (Zubeck, 1963). In this regard, it is important to note that physical exercise aboard the proposed space station would have value beyond its efficacy in countering the negative effects of the weightless environment on muscle tone and cardiovascular conditioning.

There are two final exercise suggestions we have identified from the Skylab experience. Due to the lack of convection aboard Skylab, body heat generated by physical exercise tends to remain near its source. Consequently, a small fan was mounted on the wall near the ergometer during the third mission to provide some relief. Also, the space allocated to the ergometer aboard Skylab was too small to allow other task-oriented work in the vicinity. The exercise area designed for the proposed space station should address these issues. For example, the area should be dedicated, perhaps exclusively, to physical exercise (with an 8-person crew it is likely to be in use much of the time--8 x 1½ hours each = 12 hours per day), and the "mini gym" should be well ventilated.[15]

Summary of Design Recommendations: Exercise

- Apply the principle of tangible results:
  - -- Develop compact zero-gravity isotonic and isometric devices.
  - -- Maintain personal physical ability/performance records.
  - -- Design ergometer-driven power generator with readout.
- Apply the principle of recreational exercise:
  - -- Design system to allow placement of ergometer near window.
  - -- Place CRT with variable programming near ergometer.
  - -- Encourage the development of zero gravity physical games.
- Apply the integration of activities principle:
  - -- Incorporate physical exercise in routine operations (e.g., manual trash compactor).
  - -- Incorporate routine operations in physical exercise (e.g., task preparation while exercising).
- Design exercise area/equipment as dedicated "mini gym."
- Provide adequate ventilation.

Figure 10 illustrates our principal design recommendations concerning the proposed space station's "mini-gym." The area depicted represents two segments of the module depicted in Figure 9.

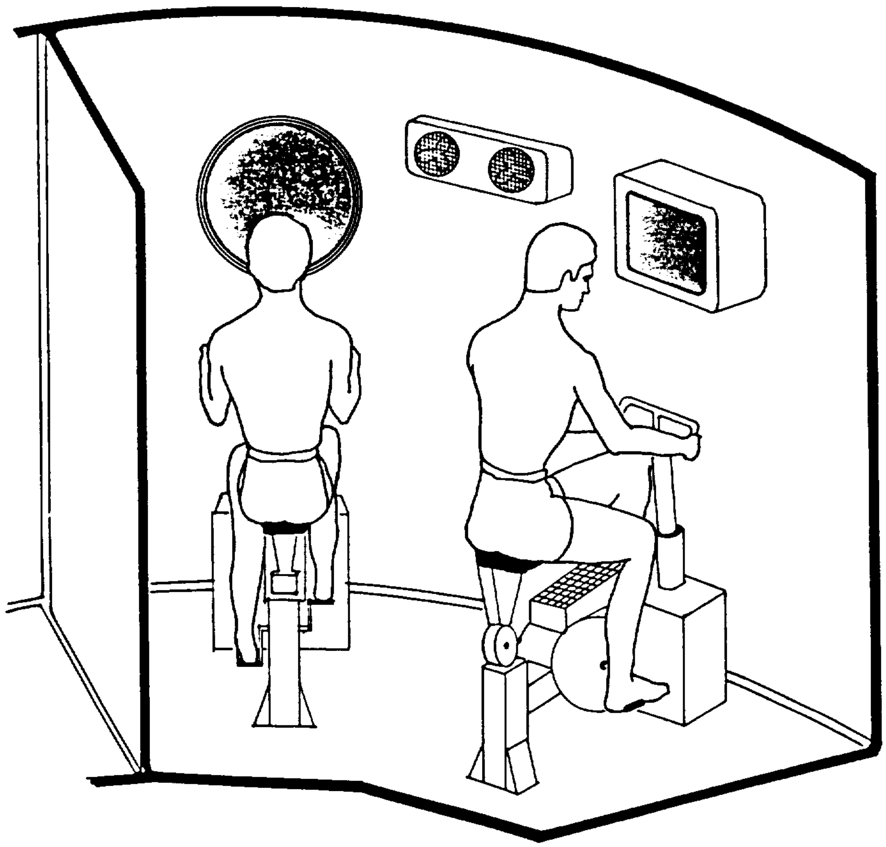


Figure 10. Space station mini-gym.

MEDICAL SUPPORT

> Cabin'd, cribb'd, confined, bound in
> To saucy doubts and fears.
>
> --Shakespeare

The importance of an onboard medical support capability increases with mission duration. Identification of the equipment and design features necessary for on-orbit medical support is, however, beyond the scope of the current study. Recent reports have addressed radiation protection (Jordan, 1983), space station medical science concepts (Mason & Johnson, 1984), health care delivery systems (Logan, Shulman, & Johnson, 1983), and the management of trauma and emergency surgery in space (Houtchens, 1983; Rock, 1984). Houtchens, in particular, provides a detailed inventory of most of the medical emergencies for which mission planners must be prepared, and a protocol to assist the diagnosis of medical conditions.[16] A design for a zero gravity surgical facility is also included.

There is, however, a behavioral aspect of space station medical support that is within the scope of our habitability research. It concerns psychological disturbances, and the fear of medical emergencies or accidents.

Psychological Disturbances

Conditions of isolation and confinement have long been recognized for their potentially devastating effects on the mental health of some individuals.[17] During our comparative analysis we learned that while cases of psychosis or severe neurosis are somewhat rare among Antarctic personnel, minor emotional disturbances are quite prevalent (Gunderson, 1963; Gunderson, 1973); Shurley reports that "minor mental troubles are both common and temporary" (1974:86). Similarly, neuropsychiatric disorders among submariners occur at a significantly greater rate than observed on surface ships (Tansey, Wilson, and Schaefer, 1979). In both submarines and surface ships, however, the rate of neuropsychiatric disorder is very low compared to that of the general population.[18] Concerning saturation divers we have only anecdotal accounts on which to base an estimate, but we have heard sufficient reports of aberrant behavior and mental health problems in that context to suggest that no condition of isolation and confinement is immune to incidence of psychological disturbance.

Strange and Klein (1973) identified a set of psychiatric symptoms that occurs regularly among the winter-over personnel at Antarctic research stations; four of these symptoms are so common in their occurrence that they may be considered part of a typical and expected adjustment pattern. Strange and Klein refer to the following symptoms as the "Winter-Over Syndrome": 1) Depression, 2) Hostility, 3) Sleep disturbance, and 4) Impaired cognition. Normally, the syndrome does not interfere with an individual's task performance, but occasionally the syndrome becomes truly pathological and normal functioning may be seriously impaired. The most common forms of psychopathology to develop among Antarctic personnel appear to be: depression, alcohol abuse, paranoid reaction, and psychosomatic manifestation. Also, symptoms at the smaller stations (e.g., eight persons) tend to be more frequent than at the larger stations such as South Pole (Gunderson, 1968).

Similarly, Earls (1969) has found a seven-stage pattern of adjustment to polaris submarine missions:

Pre-mission--depression
First week--elation
Quarter way syndrome--increase in sick call visits, subjective symptoms
Half-way syndrome--depression
Three-quarter way syndrome--elevated mood
Final week syndrome--apprehension and depression
Final days of voyage--"channel fever" (hypomanic state)

Earls maintains that the common mode of adjustment to long duration submarine patrols is depression:

> The crux of the various forces leading to this depressive position would appear to be the anger experienced by the various members of the crew. The anger is an outgrowth of the frustrations experienced by the submariner in dealing with his environment. However, there appears to be no personally or culturally acceptable means of discharging this anger. The paternalistic organization of the military system is one which does not permit the direct expression of anger and aggression toward the military system. In addition, there is the personal fear that the overt expression of anger may lead

> to a socially isolated position within an already isolated community. The individual has little opportunity to handle his hostile affect by sublimation, except through humor. The submariner is then forced to deal with his anger by denial, suppression, or turning against himself. The hostile affect becomes internalized, but it ultimately manifests itself as a depressive phenomenon (1969:122).

While this pattern may be a characteristic adaptive mechanism of submariners in general, for some the stresses of long duration submergence become too severe and result in identifiable pathology. Weybrew summarized the incidence of neuropsychiatric diagnoses aboard submarines and found that of the 58% labeled as neurotic, 54% were specifically described as anxiety neurotic, 22% as depressive, and 12% as phobic. It is believed that this sustained and slowly developing anxiety, depression, and phobic symptomatology reflects a reactive pathology, "caused presumably by the emotion-evoking properties of the submarine environment itself" (1979:577), as opposed to acute stages of long-standing personality disorders which would have been detected during psychological screening and other selection procedures. Weybrew further believes that the submariners manifesting these neurotic symptoms must have developed relatively effective coping mechanisms for the elevated anxiety and depression since only 17% of those affected suffered significant performance decrements.

Although published acknowledgement of serious psychological disturbances in conditions of isolation and confinement are relatively rare, there is reason to believe that the actual incidence of all disturbances is under-reported. For example, the phenomenon known as "screamin' seaman" aboard submarines and surface ships, actually an anxiety reaction, may be reported as other than psychiatric in nature, or it may be considered insufficient of note or undesirable on an individual's record.[19] It is important that a systematically underreported incidence of acute anxiety attacks in analogous conditions be identified in order that we are not misled by published data. That is, based on our understanding of analogous conditions, we must expect and prepare for transitory anxiety reactions among space station crews. Further, we must design features of the space station that mitigate the development of anxiety.

Though extremely rare in the analogues studied, a case of **severe** psychosis could be catastrophic for the proposed space station. In addition to the effects on productivity and the potentially infectious nature of some conditions,[20] there exists the danger of a manic or paranoid individual disabling the station. The examples of psychosis reviewed during the current study suggest strongly that the space station medical support capability should include psychiatric intervention options.[21] This should probably take the form of psychological support personnel located at mission control. While an elaborate complex such as the Soviets are reported to have (Lenorovitz, 1982) may not be necessary, at least one clinician should be on call at all times to provide psychological intervention support, perhaps counseling or therapy, in the event aberrent behavior is reported or detected among the station's crew. Ideally, the clinician would have a preestablished rapport with the crew to facilitate the process.

In the highly unlikely event that extreme measures are required, the station medical supplies should include the capability to incapacitate by sedation a seriously disturbed member of the crew; thorazine is used most commonly in the analogues studied. Special consideration is required to ensure the security of these drugs and to define the procedures by which intervention would escalate to this level.

Fear of Medical Emergencies

Although we have avoided Soviet accounts in our research for reasons of credibility, there is one source that seems to be truly believable. William Haynes, who supports the U.S. Air Force's Manned Spaceflight Engineer program for The Aerospace Corporation, provided to us translated excerpts from the diary of Valery Ryumin (Ryumin, 1980). Ryumin, a Soviet cosmonaut, spent 175 days, nearly six months, aboard the Salyut 6 space station in 1979. His account refers to a period during which he developed an irrational and seemingly disturbing fear that he might experience an attack of appendicitis or an abscessed tooth. Neither calamity occurred, but for a while he suffered from nightmares and daily preoccupation with the possibility of experiencing a serious medical emergency.[22]

Inordinate fear of a medical emergency aboard the proposed space station could manifest itself in several forms, each of which could affect performance and productivity. We were unable to locate any further accounts of this phenomenon in either published or unpublished archival sources. Our personal interviews did, however, yield some insight to the issue. For example, Captain Shoemaker reported that a certain fear of the hostile Antarctic environment resides with each of the winter-over personnel. It is not a fear of illness or accidents, but a concern for the capability to be rescued. These fears are discussed openly during the brief summer, but not during the winter when the stations are as isolated, perhaps more so, than a space station in low-earth orbit. Fears such as these are countered by the Captain with assurances that if the emergency is serious enough, personnel can be rescued within three or four days, and he relates the concrete examples of rare mid-winter medical evacuations.

Most of those interviewed observed that the onsite medical personnel, whether in Antarctica or aboard submarines or surface ships, can either contribute to or remove crew concern regarding medical problems. Confidence in the doctor's or corpsman's ability to handle an emergency is a critical issue for some individuals.[23] Drs. Weiner and Howard suggest that in extreme cases, concern for health status typically involves a personality trait of long standing; this is something that could be anticipated and possibly detected during selection procedures.

Confidence in the medical support capability seems to be the key in eliminating the fear of medical emergency as a source of stress aboard the proposed space station. A solution would include both the provision for medical support **and** the effective communication of those provisions to station crew. Dr. Weybrew offered that it is very important that crews be confident in a submarine's ability to maintain structural integrity and to handle any medical emergency. Support capabilities aboard submarines include computer assisted diagnosis for chest and abdominal pain, two of the most common complaints with serious implications. Also available is a remote diagnosis system for the transmission of x-rays, EKGs, and other information to and from a Naval hospital to ships at sea. Similar capabilities should be considered to provide space station autonomy and to contribute to personal confidence in onboard medical support.

Overconfidence concerning safety and emergency provisions should, however, be avoided. For example, it was learned that several years ago the fears of submariners focused on a concern for the possible effects of living and working in proximity to the nuclear reactors which power the boats. Psychologists and others explained to crewmen that every precaution had been made and that virtually no possibility of exposure to dangerous radiation existed during routine operations. Confidence was raised in some crews to the point that individuals stopped wearing the required dosimeter. A separate effort was then required to sensitize personnel to the need to wear their radiation detectors and to avoid "hot" areas of the submarine. Similar fears concerning cosmic radiation or micro meteorite collision could develop aboard the space station. Protection from these risks is required as well as accurate communication to crew of the risks and the associated countermeasures.

Summary of Design Recommendations: Medical Support

- Provide onboard medical support capability for **all** potential emergencies.
- Routinely monitor mental health of onboard crew.
- Provide psychological support personnel at mission control to monitor crew and to assist with intervention procedures, if necessary.
- Provide onboard capability to sedate a seriously disturbed individual.
- Include remote diagnosis capabilities.
- Provide technically accurate assurances and procedures concerning emergency conditions.
- Monitor premission health status closely (e.g., to avoid kidney stones, deep dental problems, etc.).
- Consider voluntary removal of appendix for station crew.

PERSONAL HYGIENE

> Cleanliness is next to godliness.
>
> --John Wesley

> Hygiene is the corruption of medicine by morality.
>
> --H.L. Mencken

Hygiene parameters for long-duration space missions are likely to differ substantially from what is acceptable during short forays into space. While "camping out" conditions pose little threat to productivity during short-duration missions or during emergencies, "camping out" can be expected to seriously degrade human performance on routine long-duration missions such as those proposed for the space station. We distinguish personal hygiene in this context from sanitation. The latter refers to those measures designed to maintain an uncontaminated environment, while personal hygiene concerns the maintenance of body and clothing cleanliness. As in our previous discussion regarding clothing requirements, there are essentially two sub-issues associated with personal hygiene: the need for provision of adequate hygiene facilities, and the need to ensure that the facilities are used.

Hygiene Facilities

Fraser (1968a) summarized, in excruciating detail, the results of several studies concerning the effects of minimal personal hygiene. From those reports it can be concluded that human subjects in scientific studies are capable of great endurance, but under routine conditions in operational environments, reduced standards of personal hygiene can significantly lower overall habitability. There is a definite cultural component to concepts of cleanliness, and perhaps most Americans are extreme in their concern for personal hygiene. While Fraser and others suggest that it may be possible to train people to accept reduced standards, and to a certain extent this occurs already, it is our position that it is unwise to expect optimum performance unless optimum conditions are provided.[24]

For optimum conditions, it is necessary that provision be made to accommodate personal hygiene in the following areas:

- Shaving
- Body bathing
- Hand and face washing
- Hair and nail trimming
- Hair and scalp cleansing
- Dental and oral hygiene
- Clothing disposal or laundering

Of these requirements, most have been adequately provided aboard either Skylab or the shuttle. Rather than discuss issues for which solutions are readily available, we will focus our attention on the question of full-body showering.

In all of the several analogues studied, full-body showering is provided. In Antarctica and on ships and submarines, showers are well-appreciated luxuries; in the underwater habitats and in the deck chambers of saturation divers, hot showers are considered a necessity to counter the effects of working in debilitatingly cold water. A collapsible shower was also included aboard Skylab. Showers were truly appreciated by some of the Skylab crew, but the time required to set up and then clean and secure the stowable device was considered excessive. Showered crew felt invigorated but the inordinate time requirement may have significantly eroded the positive effect on productivity. One of the astronauts reported that:

> After you finished the shower, instead of being able to dry off you had to stand around inside the shower for an additional ten minutes and halfway freeze (while using the vacuum hose to remove the water). So it turned out to be easier just to forget the whole thing, although it gets you nice and clean (Bean in NASA, October 1974:28).

Skylab crew varied in their attention to personal hygiene. Most took a sponge bath each day and a weekly shower. Gerald Carr, commander of the third crew, commented that:

> I think we kept ourselves extremely clean. It was one of the more pleasant aspects of the day. When we did our exercises, we worked hard, we sweated hard, and the opportunity to clean ourselves afterwards was welcome. It took a lot of time because all we had to clean ourselves with was a washcloth and a water squeezer, and that's a time-consuming process.

> Let me just at least say that the drive to keep yourself clean is still with you up there. We found it's easier to stay clean up there because we didn't sweat as much. We found that one full body wash per day was quite adequate, and that one shower per week was adequate. In fact, you could get along without the shower, if you kept up with the body wash and did a good job with that. But there's no substitute for running water all over your body and getting it in your hair and a shower is a very refreshing thing, but again it's very time consuming (NASA, October 1974:43-44).

Our analysis of the Skylab reports indicates that while sponge baths are satisfactory for cleaning the skin on long-duration missions, they are generally considered to be inadequate for cleaning the hair and scalp. (At least two of the Skylab astronauts reported that their heads developed offensive odors between their infrequent showers.) In addition to inadequate cleaning, sponge baths lack the psychologically refreshing value of full-body showering. For these reasons, a shower facility is strongly recommended for the proposed space station. The shower should probably occupy a space dedicated to that function to minimize set-up and clean-up time. We envision a compact facility similar to those which have been developed for recreational motor homes. Negative pressure, air suction, and hand operated squeegees for the walls would allow for minimum clean-up time.[25]

Use of Hygiene Facilities

At the old Antarctic stations and aboard diesel submarines, personal hygiene standards were constrained by the availability of water. Now, with more effective ice melters at the stations and unlimited fresh water-making capacity aboard nuclear submarines, there are fewer hygiene problems. Where both groups considered one shower every ten days a luxury in the "old days," now the crews are encouraged to take two two-minute showers each week. Commander Weiner refers to these showers as "baptisms of cleanliness" in a society that has practically made a religion of personal hygiene. Captain Howard adds, however, that since perceptions of cleanliness are culturally determined and highly variable, the hygiene standards established for the proposed space station should not be based on "excessive" showering. It is unlikely that this will occur because water will remain a precious commodity in space.[26]

Daily sponge baths and one to two full body showers each week would appear to be adequate for purposes of cleanliness and subjective value. Whatever the space station hygiene schedule is ultimately determined to be, it is important that individuals not be allowed to slip into patterns of substandard hygiene. As reported earlier, this phenomenon occurs regularly at Antarctic stations and aboard nuclear submarines, and it is a predictable source of interpersonal conflict. Dr. Weybrew offers an explanation for the tendency in some individuals to allow standards of personal hygiene to change under conditions of isolation. He suggests that it is a function of Weber's Law (Welford, 1968; Welford, 1976), the same principle by which we understand desensitization to any base constant or stimulus. In simple terms, the more odiferous one is, the more odiferous one needs to become before the change is noticed.

The contribution of a crisp and clean appearance to productivity during isolated duty has already been noted. In this regard it is suggested that at least one full-length mirror be provided aboard the space station to reinforce concepts of self image among the crew.

Summary of Design Guidelines: Personal Hygiene

- Provide personal hygiene facilities for: dental and oral hygiene, hand and face washing, body bathing, hair and scalp cleaning, hair and nail trimming, shaving, and clothing disposal or laundering.
- Provide facilities for daily sponge baths (e.g., following exercise period).
- Provide a facility to allow **at least** weekly full-body showering; twice weekly showers would be better.
- Develop and implement a personal hygiene schedule to allow for variations in thresholds of subjective hygiene.
- Provide at least one full-length mirror to reinforce concepts of self image.

FOOD PREPARATION

> What is food to one man is bitter poison to others.
>
> --Lucretius

> The best part of dinner is not what you eat but with whom you eat.
>
> --Col. Alexei Leonov on U.S. television from the Apollo-Soyuz Test Project in low-Earth orbit

Perhaps the quintessential habitability issue is food. During the course of our comparative analysis we found much of value concerning the importance of food in maintaining high morale and productivity under conditions of isolation and confinement. It must be remembered that we are considering missions of both long duration and a routine nature. Under such conditions, attitudinal problems concerning "inadequate" food may be inevitable regardless of the actual quality of the food or the personal motivation, dedication, or loyalty of the crew. Nutritional content of meals is not in question. What requires further definition is the optimum compromise between behavioral principles and operational constraints.

Food assumes added importance under conditions of isolation and confinement, where normal sources of gratification are denied. Lacking access to friends, family, normal leisure pursuits, and other customary sources of personal gratification, there is an apparent tendency to focus on food as a substitute source. This phenomenon has at least two effects: increased eating by some, and increased complaining about available food by others. Often, both responses are observed in the same individual. In recognition of this phenomenon and its potential effects on group morale and productivity, the managers of many of the analogous conditions reviewed in our comparative analysis regularly provide sumptuous meals.

Supertankers, research vessels, commercial fishing boats, long-distance racing yachts, and offshore oil platforms all offer copious quantities of high quality food to their crews (see Appendix A for summaries). Food has become such an important element aboard fleet ballistic submarines that meals are served at cloth-covered tables in pleasant, paneled rooms; three seatings are usually required for each meal and the food, served cafeteria style, is considered to be excellent. Also, open ice-cream lockers are provided and soft drinks and snacks are always available. At Antarctic research stations food is equally important to the maintenance of both mind and body. Some observers believe that the cook at a station can even determine the success or failure of the group's winter-over experience.

While our comparative study suggests that the quality and sometimes the abundance of food are important contributions to habitability, there are two additional factors which appear to be more important. These are self-selection and variety; these and other sub-issues associated with food preparation are discussed in the following paragraphs.

Self-Selection and Variety

There is a revolution underway in this country concerning eating habits. Everywhere people seem concerned about their weight, calories, and the quality of the food they eat. Consumption of fish and poultry has increased in recent years, along with the number of vegetarians. These societal trends are, quite expectedly, reflected in the crews of nuclear submarines and in the personnel staffing Antarctic research stations. While copious quantities of food are still consumed in these conditions, there is growing demand for less caloric entrees at mealtime, and it was reported to us that, "sometimes you just feel like having a sandwich for dinner." The caloric content of food servings are now listed on signs in the galley at Antarctic stations. This service has been provided at the request of those who wish to avoid the extraordinary weight gains experienced by previous winter-over personnel.[27]

In addition to a general trend toward selection of "lighter" foods, there is also a tendency for food preferences to change within the course of a mission. This occurs aboard submarines, sometimes with pronounced effects; it has also been reported by commercial saturation divers and Antarctic winter-over personnel. It is impossible to identify the cause of this apparent tendency, perhaps a physiological response to similar atmospheric conditions or to the monotony of available stimuli, but it is possible to anticipate the tendency for preference changes. Clearly, a system in which meals are programmed for the duration of a mission does not accommodate this behavioral pattern.

Perhaps the best evidence to support self-selection of meals is provided by Project Tektite II. During three of the 14-day missions, crew were allowed self-selection concerning their food; to the extent possible, their requests for food were satisfied by support personnel through trips to the closest supermarket, several hours away. Crew of the other seven missions were provided a preprogrammed selection of foods of good nutrition and quality. Initial crew response to the preprogrammed food was very positive (Wortz and Nowlis, 1974); the entrees were frozen prototypes of what later became a very successful retail product line. Despite the expense and care involved in the preprogrammed menus, 39 of the total 40 debriefing complaints concerning food quality came from those eating the preprogrammed frozen food. This incredible difference in acceptability was attributed primarily to the factor of self-selection:

> Our own observations would rate the frozen food higher in quality, both tastewise and nutritionally, than the meals the aquanauts chose for themselves. It is believed that totally independent judges would make similar ratings. Finally, 16 of the 20 complaints about food storage were from aquanauts in the preprogrammed food contingency, and 15 of the 19 complaints about too much waste were from the same group. Thus, it appears that the preprogrammed food not only ignored individual choices, but also was overpackaged for a small habitat (Nowlis, Wortz, and Watters, 1972: 5-7).

It appears that allowing self-selection from a variety of meal alternatives provides a solution to one of the fundamental issues of long-term habitability under conditions of isolation and confinement.

Meal Preparation Requirements

It is assumed that most of the problems encountered with food aboard Skylab have been or are being solved for STS; for instance, a pantry has been installed in response to astronaut requests. Although Skylab crew complained about their food, their primary concerns seemed to be with the time required to prepare the meals. Some of the astronauts began the preparations for a meal (rehydration, chilling, etc.) at the conclusion of the previous meal; others felt pressed by mission schedules and departed immediately for their next task. The desire to keep preparation time to a minimum is not unique to space stations, but it may be magnified there because time is even more precious in space than it is on

Earth. We strongly recommend that the food system designed for the space station involve minimal meal preparation times. This should contribute to both morale and long-term productivity.

Dr. Robert Helmreich, who has monitored both the Tektite and Sealab experiments, has suggested that the food system should have a flexible design. That is, individual crews should be able to decide how the food will be prepared (e.g., a person assigned to the task, a rotated responsibility, or individual preparation).

Special Dinners

Aboard nuclear submarines and at U.S. Antarctic research stations similar traditions have evolved; under both conditions special dinners are offered, usually on a weekly basis. On submarines, Saturday is frequently designated as "steak night" and it has been reported that crews anxiously await and discuss the impending occasion. Also, several times throughout a voyage, theme dinners are prepared, typically to correspond with the area of the world in which they are cruising at that time (e.g., when near Hawaii, the cooks may prepare a luau, complete with three finger poi).[28]

At Antarctic research stations celebrations and special dinners are used by station leaders as potent mechanisms for the maintenance of morale throughout the long winter night. In addition to the traditional mid-winter party, holidays and birthdays are also celebrated. Perhaps the most enjoyable occasions are the theme dinners; in addition to providing novelty in cuisine, there are usually some surprises involved. For example, on Chinese night Mao and Confucius customarily make an appearance, and on Italian night Don Corleone often pays a visit to the group.

It has been found that in addition to the entertainment and temporary diversion from routine operations provided by special dinners, there are additional values of a more subtle nature. Special dinners, such as those described in the preceding paragraphs, help mark the passage of time. When one is isolated and physically confined to a routine existence it is important to have tangible indicators that progress toward a goal is being made. For all of these reasons, we suggest that the food system designed for the proposed space station include the capability to accommodate weekly special dinners. This requirement may involve the bulk storage and preparation of food for these weekly theme dinners or celebrations. This represents a departure from the self-selection, cafeteria, or pantry approach recommended in the previous section. We do not believe these two approaches to be mutually exclusive.

Eating Together

As a group becomes larger there is an increased tendency for subgroups to form; this typically occurs along vocational lines. Aboard submarines, with crews of well over 100 men and several occupational specialties, subgroup formation is pronounced. At Antarctic research stations subgroups are usually formed among either military or scientific staff. Although this is a natural phenomenon, there can be negative effects on overall group cohesiveness when subgroups become cliques. There are several means by which this potential can be mitigated; our discussion of group interaction will address this problem in detail. In the context of food preparation, however, it is important to note the value of eating together as a means of fostering communication between subgroups and facilitating group stability.

This principle is well known and it perhaps should be included in the category labeled as common knowledge. The analogues studied accomplish this objective by offering meals at specific times--a schedule. Aboard Skylab, the constant pressure from mission control and a tendency to overload the schedule resulted in infrequent meals together; in a larger group this practice could contribute to the erosion of group cohesiveness and ultimately it could affect performance.[29] Without question, flexibility in the food preparation system is required; that is, it is inevitable that meals will be missed due to mission-related obligations. But it is critical that both the system and the schedules be designed to encourage the crew to eat together as frequently as possible. At least once each day is strongly recommended, and the "evening" meal is a likely candidate.

Summary of Design Recommendations: Food Preparation

- Design the food system to allow self-selection.
- Design the food system to provide a variety of dietary alternatives.
- Design the food system to require minimal meal preparation times.
- Allow flexibility in preparation mode (one crew member prepares for all or each prepares individually).
- Encourage special dinners (in terms of both hardware and station management philosophy).
- Encourage crew members to eat together by provision of adequate space and adherence to regular schedule of meals.

GROUP INTERACTION

> A pleasant companion reduces the length of the journey.
>
> --Publilius Syrus

Most behavioral scientists would agree that the issue of group interaction is probably the most important of the fourteen issues discussed in this report. This is the consensus of those interviewed during this project, and in an earlier design study for a lunar laboratory it was concluded that the primary limiting factor in long duration extra-terrestrial activities is the problem of interpersonal relationships among the isolated crew (La Patra, 1968).

Many of the critical sub-issues to group interaction do not, however, involve design requirements. For example, personnel selection, training (both technical and interpersonal), and station management, are fundamental components of and contributors to group interaction, but they lack identifiable architectural requirements for the space station. To the extent possible, we will limit our discussion to only those aspects of group interaction which clearly have design implications. These include intragroup communication, organizational structure, and sub-issues associated with crews of mixed composition.

Intragroup Communication

The importance of accurate and formalized technical communications is apparent aboard nuclear submarines. During submarine operations it is critical that instantaneous and readily comprehensible communications among crew are available for both emergency and routine purposes. A form of technical communication has evolved among submarine crews that minimizes the possibility of confusion or misunderstanding. That is, when requests are made or orders issued the communication is in a form that is both direct and precise. While underway, about 80 percent of intracrew communication concerns the operation of the boat, and consequently misunderstandings can have fatal results. Commander K.A. Lee, captain of the submarine **Gato**, explains:

> Suppose a technician wants to shut down his computer to do some maintenance work on it. He wouldn't just announce, "I'm going

> to turn off my computer for a while." Instead, he would go to the officer in charge and say, "Mr. Smith, I intend to de-energize the XYZ computer for a period of two hours to perform some maintenance duties," and then he'd name them.
>
> The officer in charge would then reply, "Very well, permission is granted to de-energize the XYZ computer for two hours." He never merely says, "OK" or "Go ahead." **Everyone has to have a clear understanding of what's going on** (our emphasis) (Sullivan, 1982:92).

For the proposed space station it is recommended that devices and procedures be developed to allow fluid and instantaneous communications among the several crew members, wherever in the station they may be. An ideal solution to this requirement would be individual radio communicators; compact, lightweight units of this type are readily available for Earthbound use and may already be in use onboard the shuttle. A more primitive and less acceptable solution would involve an audio announcement and paging system. Although the latter would be both sufficient and **necessary** to inform the entire station of events (e.g., impending docking, launch, EVA, etc.) or sudden emergencies, it would be disruptive when a message is intended for fewer than the entire crew.

Another intragroup communication requirement involves the sharing of general information or messages lacking immediacy. For example, it was reported by Skylab astronauts that they would have benefited from some form of onboard office or central repository for procedures, schedules, and the reams of teletype messages received from mission control. Skylab also lacked a bulletin board for the posting of schedules and the sharing of messages; astronauts apparently tucked notes behind wiring or bungee cords wherever convenient to satisfy this requirement. It is recommended that the proposed space station include a small area or workstation dedicated to the overall coordination of station operations; it is assumed that this facility would serve as the station commander's office. It is also recommended that a simple bulletin board be included to receive posted announcements, schedules, reminders, and other messages relevant to station operations; the wardroom/galley would probably provide the most appropriate location for the bulletin board. Even if a decentralized message system is adopted (e.g., displayed on CRTs at workstations or in sleep chambers), a centralized "hard copy" bulletin board would still be required.

At Antarctic research stations the galley, or dining room, serves to focus group activity. It is where meals are eaten, meetings are held, and where films were viewed before videotapes were introduced to the continent. Aboard Skylab the wardroom/galley served a similar purpose. The wardroom/galley will likely involve one of the largest requirements of interior space designed for the proposed space station. It should be large enough to accommodate all of the crew for meetings and for meals, and tables should be designed to facilitate conversation. A vast literature on this subject exists and has been summarized elsewhere.[30] Reconfigurable or collapsible tables may be required.

In a previous section we referred to the enhanced potential for subgroup formation resulting from increased group size. As might be expected, groups of twelve members have been found to be more likely to form subgroups than groups of six members (Hare, 1952). In a design study to establish guidelines to enhance group stability, Bender and Fracchia suggest that while this tendency is unavoidable,

> ...the environment should be structured so as to allow for maximum communication between members of various subgroups to offset, to some extent, the increased communication between members within subgroups (1971:17).

Meals provide an opportunity for this type of communication, and apparently the opportunity is appreciated. Eberhard (1967) found that men in confinement spent twice as much time eating as men in the general population, and Natani and Shurley report that men at the South Pole station spend almost twice as much time eating during the winter as they do during the summer. More important to our discussion, "the extra eating time noted is evidence that the men took advantage of mealtimes to linger over their coffee in conversation" (1974:105). This tendency offers a valuable opportunity to encourage interpersonal communication, to foster group cohesiveness, and to counter the potentially negative effects of inevitable subgroup formation. It is important, though, that group activities, such as meals, be encouraged without it appearing as if by order, for some persons will inevitably object to a mandate as a demonstration of independence or a host of other reasons. While some will find ways to eat by themselves, or otherwise withdraw from the group, it is important that the system is structured in such a manner as to encourage group cohesiveness (e.g., make the wardroom/galley available for meals only at specific times).

While the wardroom/galley would also serve as the location for meetings, briefings and group leisure activities, there will be occasions when the station commander will require a private conversation with an individual crewmember; a common area such as the wardroom/galley may not be appropriate for these purposes. In this regard it has been suggested that the station commander's sleep chamber be large enough to accommodate two persons for purposes of conversation. We agree with this recommendation, but it would not be necessary to allocate additional space to the commander's sleep area if the station office, suggested previously, can be configured to provide privacy when needed.[31]

Organizational Structure

The types of meetings requiring the privacy of the commander's office would range from technical to personal discussions, and they would include situations in which a member of the crew, possibly the commander, serves as ombudsman or arbiter. Aboard U.S. submarines, a senior petty officer serves as "chief of the boat;" in this capacity he is a counselor, a disciplinarian, and an ombudsman representing the interests of a crewman to the Navy. If a high degree of autonomy is required for the proposed space station, similar onboard mechanisms for conflict resolution will be required. No architectural implications of this requirement can be identified at this time. Clearly, additional research is needed to develop an effective approach to onboard conflict resolution.

In terms of the overall organizational structure of the space station, it appears that Antarctic research stations provide the most appropriate model. Nelson describes decision-making at Antarctic stations:

> On matters of a technical, task-specific nature, leader decisions are expected to be based upon consultations with appropriate task specialists. Decisions regarding general, routine, station policy matters, affecting all men alike (such as station housekeeping or recreational schedules), are expected to be rendered by the formal leader after consultation with the entire group ("democratic" style). Decisions on emergency matters, differing from other decisions on time allowed for decision-making, are expected to be made by the

> leader as quickly and "autocratically" as required by circumstance. In any instance, the formal leader's role is not to be abdicated; his sense of timing and appropriate relationship to his men may, however, be different from one station to another (1973:175).

The organizational structure which has evolved within NASA for STS missions, a commander, pilot, mission specialists, and payload specialists, is consistent with the Antarctic model. At U.S. Antarctic stations half the personnel are military and half are civilian scientific staff. Though there may be occasional conflict between the groups, it is typically concerning scarce resources (usually space) masked by some trivial matter such as hygiene standards, tastes in music and the like. We learned of no reports where a conflict involved a challenge to the quasi-military organization of the station; all participants seem to acknowledge the value of a hierarchical command structure under both routine and emergency operations.[32]

Several observers have, however, reported a tendency within isolated and confined groups for formal authority structures to become less tolerated over time and for group structure to become less complex. The ability of a leader to maintain authority and control in such situations is often critical to mission success.[33] Our review of station logs supports Pinks' (1949) conclusion that good leadership is often more important than good habitability.[34] Although we have identified no further design implications associated with organizational structure or leadership, it is important to note that these issues have not yet been fully resolved; there are several factors affecting group processes which require further attention. Though a beginning has been made concerning spacecraft (Helmreich, Wilhelm, Tanner, Seiber, and Burgenbach, 1979) and aircrew performance (Foushee, 1984), studies focusing on the group dynamics of on-orbit personnel are yet required.

Also required of NASA is a determination of the organizational philosophy and personnel management plan for space station operations. Does NASA intend to staff the proposed space station from a pool of professional astronauts (pilots, scientists, and engineers) who share a long-term commitment to the program, or will on-orbit personnel be drawn from industry and the academic community for relatively temporary specialist duty in space? Both approaches have serious implications for station management and operations and perhaps a combination of both staffing modes would be most appropriate. Our study of analogous conditions has provided several insights in this regard.

Additionally, important determinations concerning the cross-utilization of personnel are required. Helmreich reports that during Project Tektite the sharing of technical responsibilities among the engineers and the scientific staff had positive results on both personal satisfaction and productivity. Similarly, Weybrew suggests "co-contingencies" among roles for the proposed space station, like the co-contingency networks which help to bind together the crews of nuclear submarines. At Antarctic stations the standard leveling mechanism is "house mouse duty," or kitchen helper; all personnel take their turn on a rotational basis. The issue of cross-utilization of personnel requires further research, perhaps involving high fidelity simulation, to define an optimal solution.

Issues Associated with Crews of Mixed Composition

Several observers have predicted problems associated with crews composed of both male and female members. In several of the analogues reviewed preliminarily, problems, some very disruptive, have been reported. Upon closer inspection, though, the problems have not been directly attributable to mixed crews, but rather they are the results of immature personnel, both male and female. It is safe to disregard the examples of offshore oil rigs, drilling barges, merchant ships, and naval vessels in this discussion. In each of these contexts serious interpersonal problems associated with mixed crews have been documented and have negatively affected group performance. But in each of these conditions, personnel selection and training procedures are **not** comparable to those assumed for the personnel of the proposed space station. Only Antarctic research stations provide a model for male-female relations among professionals living and working in isolation and confinement.

Women were first allowed at U.S. Antarctic stations in 1969; four women scientists spent a few weeks at a field camp near McMurdo Station and the event drew headlines such as, "Powderpuff Explorers to Invade the South Pole" (Satchell, 1983). In 1974 the first women were included in a winter-over group when a nun and a middle-aged biologist spent an entire year at McMurdo Station (the largest

U.S. station). In 1979 the first woman wintered-over at the South Pole, along with 19 men. Since then, increasing numbers of women have been playing integral roles in Antarctic operations as scientists, naval support personnel, and civilian contractors. Although some conflicts have resulted from the presence of women on what had been considered to be a male-only continent, they have been minor. Captain Brian Shoemaker, who has the benefit of experience at Antarctic stations both before and after the introduction of women to Antarctica, believes strongly that women contribute a stabilizing influence to winter-over groups. In the old days, wintering-over was frequently an eight-to-twelve-month "animal show"; there were occasional fights, loud and boisterous behavior, and other disruptions. Now, he reports, the winter-over men tend to be more gentlemanly, less disruptive, and importantly, more productive; he attributes this change to the presence of just one woman in a group. From his unique psychiatric and operational perspective, Dr. Howard observed that, "having a woman around can make the condition much more endurable. They **are** different and they can remind you of home."

While promiscuity has had a disruptive effect at Antarctic stations, this has been rare. For the most part, if women choose to have a relationship during their stay in Antarctica, it is with one man, and the other men tend to respect the relationship. Problems have resulted when it is the station leader with whom the woman develops a relationship; other personnel tend to claim that an unfair advantage has been used. This eventuality should be avoided aboard the space station. In all other respects, it may be unwise to dictate how station personnel manage their personal lives.

Some observers have pointed to the potential for romantic involvement as a serious concern for space station operations. We believe, however, that with continued stringent selection, psychological screening, and the addition of sensitivity training for crew, these concerns can be removed. After all, we are talking about serious professionals who will have trained together, indeed who will have endured much together, and who will share the values of their organization. We do them, and by inference ourselves, a disservice to assume that their behavior will be anything but professional. If romance develops, then that is part of life, whether on Earth or in space. It is our obligation only to identify problems and to suggest solutions. In this regard, we suggest that the initial mixed crews be composed of husband and wife teams. As the public and the astronaut corps become desensitized to the issue, then a routine personnel rotation plan involving mixed crews can be implemented with a minimum of social perturbation. The only design implication resulting from this discussion involves the requirement for flexible sleeping arrangements. We suggest that sleep chamber architecture include the potential for removing adjoining partitions if this is mutually agreeable to the personnel involved.[35]

Summary of Design Recommendations: Group Interaction

- Provide individual communicators for all crew.
- Provide audio announcement/paging system.
- Provide a commander's "office" or central workstation for overall coordination of station operations.
- Design commander's office to allow private conversations with individual crew.
- Provide a bulletin board in wardroom/galley.
- Design wardroom/galley to accommodate all crew for meetings and meals.
- Design wardroom/galley tables to facilitate conversation.
- Design sleep compartments with removable partitions.
- Consider husband and wife teams as candidates for initial mixed crews.

HABITAT AESTHETICS

It is difficult to please everyone.

--Latin proverb

Much intuitive and some objective evidence supports the notion that the aesthetics of an environment affect human well-being and productivity within that environment. In terms of space station habitat aesthetics, the analogues reviewed during the course of this research ranged from the comfortably appointed suites of supertankers to the spartan confines of a saturation diver's deck chamber. In all conditions studied, regardless of the aesthetic quality of the habitat, people performed adequately--even admirably. But would they have performed even more effectively, or at the same level, without experiencing as much stress or negative feelings concerning the habitat, if the habitat had been designed to be both functional **and** aesthetically pleasing? Though "pleasingness" may not be directly related to crew effectiveness, it does contribute to overall habitability and in indirect ways it affects productivity.

Our research has identified two relevant sub-issues associated with habitat aesthetics: personalization of decor, and variation of stimuli.

Personalization of Decor

In all of the analogues studied, from the most posh to the most spartan, items of personal decor are posted by crew. Typically, the items are photographs of family and friends, but also included are houses, automobiles, and other familiar sights. Photographs of the interior of Skylab reveal that even astronauts are subject to this proclivity. The posting of personal photographs appears to be a common and gratifying coping mechanism and should not be discouraged aboard the proposed space station. In fact, the interiors of personal sleep chambers should be designed to accommodate the tastes of temporary occupants with a minimum of effort. Although personal preference and self-selection in sleep chamber decor items should be allowed, those items are subject to the same restrictions which apply to all onboard materials (i.e., the potential hazards from fire and outgassing). These constraints may conspire to limit conventional decor items to a few small photographs. This does not, however, preclude the development of graphic materials which meet established safety standards.

The personalization of public spaces is another matter. This is also practiced in the analogues studied, though under considerably greater leadership control. For example, policies concerning the posting of "pin-ups" in common areas are established by individual submarine commanders and Antarctic station leaders. For the most part, they are officially discouraged, but commonly posted. During Project Tektite, each crew decorated the habitat differently with pictures, pin-ups, and photographs. While the choices did not seem to matter to some crew members, they provided obvious sources of gratification to others.

It is our position that since appreciation of form is very much a matter of personal preference, it is important that any formal graphics adorning common areas be either quite temporary or acceptable to all users of those areas. For example, there are many who appreciate the works of Jackson Pollack, Norman Rockwell, or the photographers of **Playboy**, but it would be unfair to inflict those tastes on others on a regular basis unless it were mutually agreeable. Differences of opinion concerning art posted in common areas could be a source of conflict aboard the space station, and one that can be easily avoided. Please recall, trivial issues are typically exaggerated beyond reasonable proportions among isolated and confined groups. For these reasons we suggest that individually selected formal graphic materials be discouraged in common areas of the station, but allowed in private chambers. Formal graphics selected by group consensus, however, would be acceptable and could contribute substantially to habitability (e.g., tranquilizing or stimulating scenes of Earth or the cosmos).

Variation of Stimuli

The preceding discussion does not mean that visual variety should be avoided in common areas. To the contrary, the need for variation in stimuli has been acknowledged in all of the design studies reviewed and in many of the analogous conditions. It is not that the proposed space station or its analogues are stimulus deprived, but that their crews experience a constant high level of stimulation. Though some of the work may be changeable and quite exciting, much of space station operations will have a routine sameness similar to Earthbound laboratory and production work. The monotony experienced by those so engaged is exaggerated by the sameness of the confined environment. Only glimpses of the Earth, around which the station is navigated, and occasional leisure activities will be available to counter the monotony of routine station operations. Even conversations, it is reported, assume a monotonous tone among small isolated groups; following initial bursts of interpersonal exploration, there is a sameness to conversation as one becomes weary of repeated stories and mannerisms, and of the predictability of fellow crew members. Monotony of stimulation, even a high-level of stimulation, can be a serious source of stress.

The need for variation in visual stimuli can be served through Earth viewing, other leisure activities, and by the decor of the space station. While we have discouraged the use of formal graphics, unless approved by the user group, we strongly encourage variation in interior color. This can be accomplished by use of colored surfaces or reflected lighting. Whereas variation in the color of surfaces (e.g., color code walls, ceiling, and floor; use color with contrasting trim, etc.) would probably provide an adequate level of visual stimulation and be aesthetically pleasing, the use of colored indirect illumination of surfaces offers greater variation.[36]

Fraser, summarizing the work of Tinker (1949), states:

> In relation to illumination, color may serve more than one purpose in the perceived environment. It determines the reflectance of colored objects in that environment, and, in addition, it may have an influence on the emotional set of individuals in that environment.
>
> Color, as hue, has no effect on the ease of seeing. From the point of view of visual perception, the reflection factor of walls, ceilings, and furnishings of any living or working space is more important than the color used, since the reflecting surfaces become, in effect, secondary sources of illumination (1968:46).

In this regard, it has been determined that some colors are perceived to be cool, tranquilizing, and restful; these are the blues, greens, and violets, which may be appropriate in sleep chambers and recreational areas. Red, orange, and yellow are considered to be warm or stimulating colors, and may be useful in laboratories, workstations, and other productive areas of the station. Generally, light colors are considered to be cooler than dark colors.

Fraser summarized a lengthy discussion of color and illumination with the following.

> ...a variety of colors can be selected for the interior of spacecraft and space dwellings. Cool, work-stimulating, colors are recommended for the work area, with bright contrasting accents on trim; warm, relaxing colors are recommended for public rest and recreation areas, again with contrasting accents and trim; while subdued, "homely" colors will be appropriate for personal areas. Generally lightening of color values will assist in providing brighter interiors with a lower level of illumination. The latter, as much as feasible, should be indirect, diffuse and non-glaring[37] (Fraser, 1968:51).

In addition to the psychological effects of color on mood, distinct color preferences exist among individuals. Several older studies indicate the following order of color preference among over 20,000 subjects: blue, red, green, violet, orange, and yellow.

From our comparative research, we are convinced that aesthetics, in particular the variation in visual stimuli, is an integral component of overall space station habitability. Further research is required, however, to determine an optimum solution among the following variables: 1) the effects of color on mood, 2) individual preferences of the user group, and 3) the physical properties of surface coating materials. Once the behavioral and technical parameters have been established, it would be wise to involve the expertise of those specializing in interior design. If we would not ask an interior designer to design a life support system, why should we expect an engineer to select the most appealing combinations of colors, tints, and hues? Though many engineers are capable of selecting effective interior designs, we believe that specialists in the field should be allowed the opportunity to contribute to space station habitability by providing interior design suggestions related to aesthetics and visual variety.

Summary of Design Recommendations: Habitat Aesthetics

- Design sleep station interiors to accommodate personalization of decor.
- Discourage personal decor in common areas.
- Provide variation of visual stimuli through color (either surface pigmentation or reflected illumination).

OUTSIDE COMMUNICATIONS

> People who lead a lonely existence always have something on their minds that they are eager to talk about.
>
> --Anton Chekhov

The analogues studied during the current project varied considerably in all dimensions, including both physical and psychological isolation. Merchant, research, and fishing vessels are all separated from shore by several hours to several days of running time. Submarines are isolated for the durations of their missions, and the personnel staffing Antarctic research stations are isolated for months by geography and weather conditions. Saturation divers, such as the crews of Sealab, Tektite, and offshore oil operations, are similarly isolated by several hours to several days of decompression time, though they may actually be only a few feet away from their support personnel. All of these analogues share with the proposed space station a physical isolation from family, friends, and familiar environments; the analogues also share with the station a separation in time from rescue in an emergency.

Outside communication is a salient issue in all of the analogues reviewed. We have chosen to discuss outside communication in terms of the following sub-issues: personal communications and mission-related communications.

Personal Communications

In all of the analogues studied, some form of personal communication is permitted. Tektite had an intercom link with the surface, Sealab was equipped with a direct telephone line, Antarctic research stations rely on HAM radio with telephone patches, and surface vessels of all sorts use ship to shore radios to contact a marine telephone operator. Even submariners are permitted to receive as many as four 20-word "family grams" during a patrol; they cannot respond, however, since even a brief transmission could reveal the submarine's position.[38] Commercial oil divers are also prevented from direct communication by helium voice and the prohibition against electronic devices in the explosive atmosphere of the deck chambers; supervisors do convey personal messages to and from the divers in saturation, and many divers become inveterate letter writers.

Although personal communications with family and friends are considered by all observers to be necessary to maintain morale, serious risks to personal adjustment and productivity are involved. There are two components of this risk: the potential for negative information to reach an isolated person and affect his or her performance, and the potential for one who is isolated to become obsessed with outside communications.

Receiving negative information from home can have a catastrophic effect on the mental health of those isolated. For example, receiving word that a child is ill or has been seriously injured frequently precipitates great remorse and guilt in a father; they typically believe that if they had only been there the tragedy could have been prevented. It has been reported that some Antarctic personnel have developed psychopathology in response to negative information received by radio or the mid-winter mail drop (Pope and Rogers, 1968). For this reason, station leaders frequently serve as a filter, preventing some information from reaching individuals for whom it is determined that psychological risk exists. Such decisions are made on an individual basis and only when it is clear that no purpose would be served by conveying the information. Commander Weiner observed that, "sometimes no news is good news, since we cannot evacuate someone with an existential dilemma." We have not identified a design requirement associated with this concern, but evidence from our comparative analysis suggests that mission control and station leaders should consider withholding negative information from a crew member if it is determined that information may have a deleterious effect on adjustment and behavior.

The second component of the risk of personal communication involves the potential for isolated personnel to become obsessed with personal calls home. In the Antarctic and among commercial oil divers, serious problems have resulted from men's suspicions concerning their wives' activities. Some Antarctic personnel have become so obsessed with calls home, calling frequently and at all hours, that they enter into a pathological and disruptive pattern; in extreme cases among oil divers, submariners, and Antarctic personnel, acute anxiety reactions have been associated with these obsessions. In this regard, Dr. E.K.E. Gunderson has suggested that during space station operations, personal calls should be moderately limited (e.g., biweekly or weekly transmissions of about 15 minutes each). From his experience with Antarctic personnel, he believes that a certain amount of personal outside communication is morale enhancing, but the risks involved demand that priorities be established. We agree that most of the potential crew members of the proposed space station would be willing to accept reasonable limitations on their personal communications. No objection was noted, however, to the possibility of unlimited electronic mail, or typed messages transmitted at high speed to Earth stations. This may serve as an adequate supplement to limited personal voice communications.

It is further suggested that personal communications be conducted from crew members' private quarters rather than from a "public" onboard facility. This has been suggested before (Bender and Fracchia, 1971), and the suggestion draws support from several of the analogues reviewed, where privacy is a scarce commodity. A superior solution would ensure the privacy of the transmission as well, through use of a scrambler or similar device. Because radio messages may be intercepted by anyone tuned to the frequency, there are many humorous and embarassing anecdotes attributed to misunderstandings concerning the privacy of radio transmissions. This privacy should be guaranteed for space station personnel.

Helmreich found aboard Sealab that the heavy users of the telephone for personal communications tended to be the poor performers. He viewed the telephone as a safety valve for poorly integrated crew, and heavy telephone use was considered to be a symptom of an underlying problem of adjustment to the isolated and confined conditions. Despite its negative implications, telephone use among isolated groups can be a valuable outlet and a potent unobtrusive measure of adjustment. (Helmreich believes that because isolated groups are both living and working together, adjustment **is** performance.) Dr. Helmreich suggests that requests for outside communication could be used by NASA under routine space station operations as an unobtrusive measure; excessive outside communications could be the signal for clinical intervention to prevent further deterioration and performance degradation. We concur with this suggestion, but further research is required to identify meaningful criteria and intervention techniques.

Mission-Related Communications

During the course of our comparative analysis, we frequently heard and read about the relationship between isolated groups and their headquarters personnel. In all of the conditions studied, this relationship periodically becomes strained and occasionally overt hostilities erupt. For saturation divers, the rack operators and diving supervisors are the objects of scorn, and for Antarctic personnel and submariners, they perceive the Navy as never fully comprehending the constraints under which they operate. Even Sealab and Tektite, relatively short-duration experiments, experienced problems between divers and "Earth people," as the topside staff was called (Radloff and Helmreich, 1968:168). Sells describes this phenomenon:

> A mechanism of displacement of hostility frequently observed among isolated groups is the tendency to direct anger, scorn, and even ridicule, with intensity often out of proportion to the focal issue, on external competitors and superior authorities. The naval literature, as well as reports of expeditions and military operations, reveals repeated instances of antagonism toward headquarters by field parties, and of complaints about "excessive demands" by outside persons who are said to be "unaware" of the ongoing realities. Some occurrences of this type have been suspected in the space program and may be expected with greater vehemence as time and distances increase. While the effects may be hygienic, insofar as they furnish a common target for the venting of repressed hostility, the positive values for group mental health may be more than offset by disruption of significant communications with base support groups (1973:294-295).

While this phenomenon may be inevitable, certain measures can apparently mitigate the effects. For example, NASA's practice of using members of the astronaut corps as communicators must be beneficial in terms of establishing confidence and the appropriate rapport with on-orbit personnel. Also, it was discovered during project Tektite that the use of a two-way closed circuit television system seemed to eliminate much of the hostility characteristic of relationships between isolated crews and support personnel. The participants were able to observe each other at work and during leisure time and it is believed this visual contact contributed to a better understanding of the conditions under which both groups operated.[39] For this reason, it is suggested that NASA consider a two-way video capability between selected work stations of the proposed space station and mission control. Further research is required, however, to evaluate the efficacy of such an arrangement.

Similarly, aboard Skylab, it was found that, "Frequent informal communications between the scientist astronaut in orbit and the scientific ground-support personnel significantly enhanced the amount and quality of experiment data obtained" (NASA, July 1974:90).[40] The value of this suggestion may have been confirmed on STS missions, though communications problems between ground-based investigators and on-orbit personnel were egregious during Spacelab's maiden flight. The implications of the communications difficulties on Spacelab 1 strongly suggest that all of those using the communications network (scientists, mission controllers, and astronauts) receive some guidance concerning proper network etiquette and the potentially explosive nature of the relationship between isolated individuals and their support personnel.

Finally concerning outside communication, news of the world below must be provided to the space station crew on a regular basis. Nowlis, Wortz, and Watters (1972) reported that a lack of access to news was rated as **the** most disliked characteristic of the Tektite habitat. Also, in other analogues, news concerning current events, especially events that could affect their isolated condition, is desired and eagerly awaited. Earlier, we alluded to the possibility of making available to the space station commercial network programming including news; summaries similar to those provided to Antarctic stations may be sufficient to satisfy some crew members' interests, but others will require additional information in either print or video form.

Summary of Design Recommendations: Outside Communications

- Allow moderate amounts of personal audio-channel transmissions (e.g., once or twice each week).
- Design communications system to allow calls to be made from private quarters.
- Ensure privacy of personal transmissions.
- Allow unlimited electronic mail (teletyped letters).
- Provide guidance to communications network users concerning proper network etiquette and the potential for problems in their communications.
- Provide news of current events to on-orbit personnel.

RECREATIONAL OPPORTUNITIES

All work and no play makes Jack a dull boy.

--James Howell

Since the time when manned space missions were measured in minutes rather than days, there has been serious concern regarding the manner in which astronauts will occupy their leisure time. In one of the earliest studies, Eddowes (1961) conducted a survey of 80 male aerospace professionals to determine preferences in leisure activities; it was believed that this sample would more closely resemble potential space crews than the general population. Eddowes found that reading was by far the highest ranked leisure activity among the group.[41]

A few years later Eberhard (1967) produced a three-volume treatise on the subject entitled, appropriately, **The Problem of Off Duty Time in Long Duration Space Missions.** In these documents he reviewed nearly 400 sources in an effort designed to identify solutions to what was believed to be one of the principal problems associated with a three-year trip to Mars. Since it was assumed that there would be relatively little work for astronauts to perform while in deep space, questions concerning the meaningful use of off-duty time were considered to have great importance. While this approach lacks relevance to the busy schedules expected for the proposed space station, Eberhard made the following valuable observations:

- A distinction must be made between scheduled and unscheduled off-duty time.[42]
- Often there is more free time available than had been planned.[43]

Eberhard also summarized some preliminary data from Antarctica and concluded that the implications for long-duration space missions are:

- The most likely off-duty activity is talking.
- There may be a tendency for games to occupy less time as the mission progresses.
- Movies or a video equivalent would appear to be a good daily activity, since time spent watching movies increased with length of time in confinement.

- Time spent reading may increase with mission duration.
- The importance of eating as an acceptable free time activity should not be overlooked.

Fraser's (1968a) study of the intangibles of habitability also includes an interesting review of the role of recreation and leisure on long-duration space missions. Fraser suggested that space crews should be encouraged to use their leisure time for creative self-development. However, he concluded that,

> Just as one cannot expect a man to divide his time between sleeping and working, one cannot expect him to devote all his leisure to self-development. Part of that time is reasonably spent in relatively passive amusement (Fraser, 1968:55).

In 1969, Gunderson's report concerning the hobby interests and leisure activities of Antarctic personnel concluded that differences in interests and activities exist between Navy and civilian staff. Both groups, however, consistently rated movies, a passive amusement, as the favored leisure activity.[44] The implications of Gunderson's work are:

- There are not vast changes in activity preferences during a mission.
- Study courses seem to have less appeal for civilians than military personnel.
- Fiction is preferred to biographies and religious materials.
- Games (cards, chess, etc.) and graphic arts are not common pastimes.
- Musical preferences can be a source of interpersonal conflict if allowed.

In a 1971 study concerning habitability guidelines for a space station with a 12-member crew of mixed composition, Richter, et al., identified eight requirements of on-orbit leisure:

- Physical exercise for countering behavioral impairment.
- Physical exercise for countering physiological effects.
- Leisure time for the development and maintenance of group morale and intragroup communication.[45]

- Leisure time for countering feelings of deindividualization.
- Leisure time to increase daily variety.
- Maintenance of social contact with the world and with one's home.
- Constructive personal development and expanded educational repertoire.
- Leisure time for tension-induced autonomic arousal to return to basal levels.

Concerning the latter requirement Weybrew (1963) hypothesized in an earlier study that some individuals may, when exposed to successive stressors, fail to recover autonomic nervous system displacement induced by a stressor before a subsequent stressor is imposed. This may result in a "stair-stepping" response sequence to the stressors of an environment and ultimately contribute to chronic autonomic nervous system disequilibrium. It is believed that exercise, recreation, and leisure time allow tension-induced autonomic displacement to recover by insertion of a relatively tension-free time interval in the sequence. Essentially, this means that a schedule of all work and no play is not only dull, but possibly risky to mental health. Weybrew's hypothesis encompasses the full range of human variation in attitudes regarding work. Even "workaholics" and "Type A" personalities require tension-free time intervals to recover homeostasis. The principal problem associated with members of these groups, however, is that they typically fail to recognize the requirement.

Again in 1971, Karnes, et al., conducted a survey of test pilots, military pilots, aerospace engineers, and scientists to determine preferences in leisure-time pursuits. From the results of their survey, they concluded that,

> The populations spend the greatest amount of leisure time in self-improvement, active recreation, and passive entertainment activities and the least amount of time in games and hobbies. Correspondingly, active recreational and passive entertainment equipment were most preferred and games and hobbies least preferred as leisure-time equipment for a space journey (p. 57).

Though much attention has been devoted in the last 25 years to the subject of off-duty time on space missions, we believe that very few of the data are of relevance to the NASA space station proposed for the final decade of the 20th Century. Much has changed in society since the most recent formal survey of leisure preferences; it is probable that social and technological changes would be reflected in a survey conducted now, or nearer the time when the proposed space station will be operational. More important, it is believed that at least for the first few years of operation there will not be very much scheduled leisure time available for the crew of the space station. There are, however, three critical yet undefined variables contained in that assumption:

- How long until station evolution allows the luxury of more than a modicum of leisure time?
- What is the probability of unscheduled leisure time, resulting from equipment failure and consequent inability to perform scheduled tasks?
- How many tours of duty can be performed until highly motivated professionals develop what will certainly come to be called "station burnout"?

Because of the uncertainties associated with the need for recreational opportunities and leisure time, we believe that it is important to include preparations for recreation and leisure activities in initial space station design. Even though leisure time may be a precious commodity, perhaps well into the lifetime of the system, we must plan both for contingencies and for the ultimate routinization of station operations.

Although many of the analogues studied during the current research are characterized by relatively large amounts of free time, several relevant observations are apparent. Our discussion of recreational opportunities will encompass the following three sub-issues: passive recreation, active recreation, and windows.

Passive Recreation

In all of the analogues studied, reading, listening to music, and watching films or television are favored leisure pastimes. Paperback books are particularly well suited to confined and isolated conditions since they are compact, portable, and reusable. In fact, certain volumes receive so much use aboard submarines that a new copy at the beginning of the cruise will be falling apart by the time the boat surfaces. In addition to satisfying cultivated interests in specific genres or authors, books also provide a relatively harmless mechanism for escape. This is particularly apparent in the intense confines of saturation chambers, where divers are forced to endure several days of inactivity during compression and decompression. Unable to escape one's fellows for even a moment causes some divers to turn inwards; many who had never finished a book before have surprised themselves by becoming avid readers in saturation. Even aboard Skylab, the only planned leisure activity conducted by the astronauts was reading.[46] We recommend that books be allowed aboard the space station as items of personal baggage. We do not recommend a CRT-displayed mode for leisure reading due to the relative inflexibility of such systems. It would be wise, however, to maintain an onboard library in digital form to supplement the personal reading materials of individual crew members.

Listening to recorded music is also a common and highly appreciated leisure activity; significantly, it is an activity that can be incorporated in routine tasks as well as in other leisure pursuits. Differences in personal preferences for musical styles, however, have been sources of interpersonal conflict at Antarctic stations (i.e., fairly notorious disputes between Seabees and scientists concerning preferences for country-western and classical music). Such conflicts obviously predate the advent of the small portable stereos with lightweight headphones; these ubiquitous devices seem perfectly preadapted to confined conditions such as the proposed space station. We suggest that "walkman-type" units be provided to crew for use anytime they feel it is appropriate (e.g., while working, exercising, relaxing in sleep chambers, etc.). An onboard battery charging capability will be required to support sustained use of the devices.[47]

Aboard nuclear submarines and at Antarctic research stations, daily viewing of feature films is an overwhelming favorite leisure activity. Before videotapes replaced films in Antarctica, a station's limited collection might be viewed dozens of times during the long winter; dialogue was frequently memorized and chanted in unison by the audience. Occasionally, a collection of particularly bad films would be creatively respliced, resulting in humor which the original film editors had not intended. In this regard,

> Kinsey (1959) makes the interesting, but dubiously validated, suggestion that the selection of a few poor quality movies is desirable, not only to make the good quality appear better by contrast, but to mobilize, activate, and release anxiety, particularly that occurring from a more or less repressed feeling of hostility (Fraser, 1968:64).

Though we do not subscribe to this interpretation, we do believe that a wide variety of video programming should be available aboard the space station for leisure use. As mentioned during our discussion of exercise, programming should include educational and cultural materials as well as serious drama and comedy. Items which should be restricted from the onboard video library include films such as **Alien** and **The Thing**, which concern confined groups in positions of extreme jeopardy. Additional research is required to identify other programming which, less obviously, might serve as an indirect source of stress.

It is further suggested that viewing films in groups, rather than individually, may have similar positive effects on group unity as experienced in Antarctica. When videotape players became available at Antarctic research stations, people tended to watch movies in their rooms. In an attempt to counter this tendency toward withdrawal or "cocooning" as it has been called, Captain Shoemaker has recently removed the television sets from private quarters and located them in common areas. This, he hopes, will help recapture some of the good-natured fun and comraderie of the days when this form of recreation was, by technological necessity, a group activity. Likewise, for the proposed space station we recommend that leisure-time video watching be, to the extent possible, a shared activity.

The final passive form of leisure activity identified as relevant to the proposed space station is unstructured relaxation--an opportunity to simply contemplate preceding and impending events and activities. The following exchange recorded aboard Skylab illustrates this requirement.

Question: Aside from your families, what do you miss most about being away from Earth?

Science Pilot: ...the ability to recoup at the end of the day and to be able to analyze where you're going the next day. And to be able to take a really fresh, creative approach to the things you're doing.

Commander: I miss the opportunity to just sit down and--and relax (NASA, February 1976:7).

During the early phases of the Skylab missions, astronauts complained that they were frequently scheduled to perform operational tasks right up to the beginning of their sleep period. Some found it difficult to relax immediately and, consequently, the onset of sleep was delayed. In our previous discussion of sleep we suggested autonomic means, a program of sleep hygiene, to hasten the onset of sleep. We also concur with the recommendation from Skylab crew that, "A presleep period of one hour of mentally nondemanding activity should be planned in the crew's time line" (NASA, July 1974a:86).

Active Recreation

Conversation is the leisure pastime in which those isolated and confined engage most frequently. This is particularly true during the early phases of missions when the confinees are learning about each other and sharing the excitement of their mutual adventure. In the analogues studied, conversations, frequently called "bull sessions," encompass a wide range of topics. It is reported that most conversations among isolated groups can be classified as either work-related or "sea stories;" there is a general avoidance of politics and religion as topics of conversation among isolated groups. Also, later in missions there is a tendency for conversation to involve sexual matters; this is interpreted as evidence of underlying sexual tension handled largely through joking behavior. Conversation is a leisure activity requiring no equipment and involving no power consumption or weight penalty. Conversation should be encouraged aboard the proposed space station because it also can mitigate the tendency to withdraw from more intense social contact. Conversation can be encouraged by habitat designers by providing areas for interpersonal exchange (e.g., wardroom/galley, table design, insulated partitions forming quiet areas, etc.).

Dr. Gunderson and others (e.g., Rohrer, 1961) have reported that a common pattern among Antarctic personnel has been to make ambitious plans prior to their departure to use their leisure time in Antarctica in a highly constructive manner, such as studying a language, reading worthy literature or technical volumes, listening to scientific lectures and the like. Rather quickly, though, these good intentions are abandoned in favor of more fundamental activities, such as reminiscing, telling stories, and watching films. However, Dr. Weybrew confirms Ebersole's (1960) earlier observation that aboard nuclear submarines there is typically an **increasing** desire for complexity of reading material and significant interest in the formal study courses offered. Coursework is frequently pursued as a means to advance in rank or grade, but interest in coursework may also reflect the high morale aboard submarines. Fraser (1968b) has interpreted the creative use of leisure as both a function of morale and a factor in maintaining high morale. Since in many ways crews of the proposed space station will resemble the crews of both submarines **and** Antarctic research stations, we recommend that formal courses of study be made available, on a self-selection basis, as on-orbit leisure activities.

Other active leisure pursuits identified from our comparative analysis as appropriate for space station personnel include the making of music, gardening, and journal or letter writing. Participatory musical activities are particularly enjoyed by Antarctic personnel; in one of the logs reviewed during our study it appears that choir practice may have provided an effective coping mechanism for key station personnel. Though the effects of a saxophone aboard STS-8 are unknown to us, it is believed that some musical instruments (e.g., guitars, electronic keyboards, etc.) could be sources of personal gratification and group enjoyment if played with consideration for fellow crew members.

Since the earliest days at Antarctic research stations, there has been an abiding interest in growing plants. Ryumin (1980) also describes the pleasure that he derived from tending the experimental garden aboard the Soviet Salyut 6 space station. The activity apparently transcended the experimental requirements and the cosmonauts found themselves devoting much of their leisure time to gardening. Since gardening is an activity that provides substantial gratification to many people in both isolated and nonisolated environments, we recommend that botanical experiments be included early in routine space station operations. We are confident that a fusion of leisure and task-related activities will result.

The "fusion of activities" was proposed in an earlier section of this report as a principle to be applied whenever possible in space station operations. In this regard, many potential crew derive pleasure from the writing of letters, the maintenance of personal journals, and the preparation of scientific papers. These activities are suggested as particularly appropriate to the space station since they involve little in the way of equipment and materials. Also, as suggested earlier, this principle could be extended to the fusion of recreation with exercise. The development by crew members of zero-gravity physical games and contests should be encouraged, and some individuals, for whom exercise is already recreational, will find that the video-bicycle ergometer tours (described previously) may satisfy both recreation and exercise requirements. Similarly, some crew may derive enjoyment from the preparation of food. Those so inclined would be obvious candidates for "chef duty" for the special or theme dinners suggested earlier. Those special dinners, likewise, represent a fusion of activities, eating and leisure. We believe that, to the extent the integration of activities principle is applied, habitability of the proposed space station will be improved.[48]

Windows

The favored leisure activity aboard Skylab was viewing the Earth from the wardroom window. The Skylab astronauts were transfixed by the sights beneath them and amazed at the clarity with which features were visible. The anecdotal accounts suggest that visual acuity from low Earth orbit may be far greater than expected; this may have contributed to the intense interest focused on leisure time Earth viewing.[49] One Skylab astronaut even recommended that future space stations be equipped with clear, bubble-like observation domes to allow unobstructed views.

The Tektite habitat had a feature similar to the previous suggestion, a cupola allowing 360° of visibility; Tektite was also equipped with smaller, domed windows. Dr. Helmreich reports that the windows served a very important function on Tektite. Anytime crew walked by one of the windows, they glanced outside, thereby experiencing short "packages" of leisure throughout the day. Windows also provided a focal point for conversation, and a favorite location to read was in front of a window.

While windows appear to be important sources of enjoyment in the analogues reviewed, the evidence from submariners is somewhat disturbing. Dr. Weybrew reports that among submariners on patrol there is a marked preference for films which contain sweeping vistas and scenes of open country. This has been interpreted as a felt need on the part of submariners to identify with the surface and to experience the illusion of long distance or infinite focus. Aboard submarines there is little opportunity to focus one's eyes on objects more than a few meters away. Recently, it was discovered that submariners' eyesight is affected in very specific ways by the absence of distant objects on which to focus. Submariners tend to develop temporary esophoria (crosseyed-ness) during their 70-day submerged missions, and distant vision may be permanently degraded over the course of a submariner's career (Kinney, et al., 1979). The latter effect was discovered during a longitudinal study of submariners to determine the long-term consequences of exposure to the confined environments of nuclear submarines. Esophoria was identified as a systematic problem when long-duration cruises were initiated and crew personnel were involved in an inordinate number of vehicular accidents upon arrival at port. Submariners are now not allowed to drive for three days following their return from a cruise.[51]

A related phenomenon aboard submarines is the importance of an occasional opportunity for a quick peek through the submarine's periscope. This practice was introduced by Dr. Weybrew over two decades ago and it has become a tradition in the FBM fleet. In a history of submarine psychology, Dr. Weybrew reports,

> ...significant peaks in the morale curve appeared during each of the 24-hour periods during which "periscope liberty" was granted for the crew. It was hypothesized that allowing men to line up for a few seconds of periscope viewing of the sea, a landfall, a cloud or a bird in flight provided a "cognitive anchor"--reassurance that there was still a real world out there (1979:11).

Weybrew further reports that when periscope liberty is allowed there is a noticeable decrease in reported physiological symptoms, and when periscope liberty is expected then cancelled, there is a precipitous increase in symptoms among the crew.

The evidence from the relevant analogues, both psychological and physiological, suggests that as many windows as possible should be included in the design of the proposed space station; the wardroom/galley, the exercise area or "mini-gym," and a separate quiet area or library are good candidate locations for windows. At least one of the station's windows should be as large as Skylab's window and it should be free of nearby interior obstructions to allow several crew members to gather for Earth viewing. As a supplement to windows, the station could also be equipped with CRTs to display exterior scenes captured by the many video cameras necessary to monitor EVAs (extra-vehicular activities) and to conduct routine inspections of the station's exterior and immediate surroundings.

Summary of Design Recommendations: Recreational Opportunities

- Allow books onboard.
- Provide space for both personal and common storage of volumes.
- Provide onboard storage of literature in digital form to supplement hardcopy library.
- Provide personal, compact tape players with lightweight earphones for leisure, exercise, and selected work-time music appreciation.
- Provide onboard capacity for tape player battery recharging.
- Provide capability for onboard videotape viewing (a group activity).
- Provide capacity for storage of videotapes (wide variety of materials).
- Schedule at least one hour of uninterrupted leisure time prior to each sleep period.
- Encourage conversation among crew by designing areas and equipment (e.g., tables, workstations) conducive to communication.
- Provide constructive leisure opportunities such as formal courses of study.
- Allow musical instruments onboard.
- Apply the principle of integration of activities:
  - -- Include botanical experiments in station operations as early as possible to incorporate leisure "gardening" with task-related activity.
  - -- Encourage the development of zero-gravity physical games.
  - -- Design ergometer to render exercise more recreational (e.g., with CRT).
  - -- Allow special dinners and their preparation to provide recreation as well as nourishment.
- Design the space station to include as many windows as possible (to reduce feelings of isolation and to provide opportunities to exercise distant vision).
- Allow leisure time viewing of station exterior and surroundings via system of exterior-mounted video cameras.

PRIVACY AND PERSONAL SPACE

> The personal life of every individual is based on secrecy, and perhaps it is partly for that reason that civilized man is so nervously anxious that personal privacy should be respected.
>
> --Anton Chekhov

Perhaps the most frequently asked space station habitability question concerns spatial requirements, in particular, how much privacy and personal space is necessary to facilitate sustained human productivity? In the Lovelace report, cited earlier, Fraser asserts that:

> It is not yet within the state of the art to define the optimum free volume per man required for long-duration space missions, even if there were no other constraints. It can be stated, however, that if the available volume is inadequate, problems, largely physiological in nature, are likely to arise if the confinement is maintained for a long enough period. Space, of course, is at a premium in any operational vehicle. The **Manual of Submarine Medicine** notes that overcrowding leads to decreased freedom of movement, absence of privacy, limited hygenic and personal facilities, and points out that deprivation of these factors gives a man a sense of frustration in commonplace activities. Paucity of space accentuates the friction that arises; he becomes overly aware of the mannerisms of others, and becomes irritated at the compulsive habits of himself and his colleagues.
>
> The almost unanswerable question arises as to what then is adequate or optimal (1968a:18-19).

For most areas of the proposed space station, spatial requirements may be determined by an objective human factors analysis of the tasks and functions associated with those areas. Our approach to the design of functional areas, such as work stations, hygiene and waste management facilities, and other spaces, is presented in Appendix E. The remainder of the current discussion will focus on the subjective requirements of privacy and personal space.

Subjective Requirements

Most designers and behavioral scientists have assumed that a relationship exists between mission duration and spatial requirements. Figure 11 summarizes this relationship for a few analogous conditions and several design studies. Figure 12 provides a graphic representation of those sleep chamber volumes, actual and proposed.[51] These figures do not allow direct comparisons among examples because designers have failed to express volumetrics in a standard form. In some cases "free volume" is implied, while in others "enclosed volume" is provided. From enclosed volume must be subtracted the space required for necessary equipment and storage. The figures do, however, provide a general and relative picture of sleep chamber volume designs.

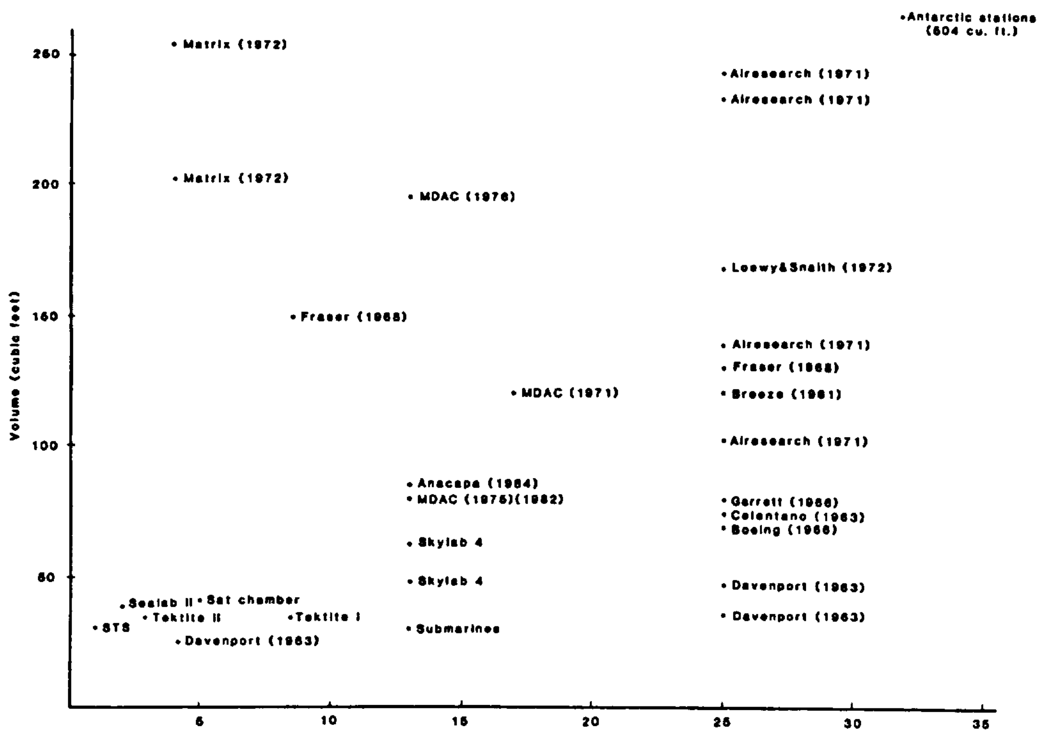


Figure 11. Sleep chamber/bunk volumetrics: The relationship between volume and duration of tour.

C-2

25–50 cu. ft.	volume	duration
Davenport (1963)	25	30
Davenport (1963)	36	180
Davenport (1963)	48	180
Submarines	30	90
STS	31	7
Tektite I	35	60
Tektite II	35	20
Sealab II	38	15
Ben Franklin	39	30
Sat chamber	41	35
Skylab 4	48	84

51–100 cu. ft.	volume	duration
Boeing (1966)	70	180
Celentano (1963)	75	180
Garrett (1966)	77	180
MDAC (1975)(1982)	80	90
Anacapa (1984)	84	90
Skylab 4	63	84

101–150 cu. ft.	volume	duration
Airesearch (1971)	103	180
Breeze (1961)	120	180
MDAC (1971)	120	120
Fraser (1968)	130	180
Airesearch (1971)	138	180
Fraser (1966)	150	60
CDG (1984)	150	90

150–504 cu. ft.	volume	duration
Loewy & Smith (1972)	169	180
MDAC (1976)	196	90
Matrix (1972)	202	28
Airesearch (1971)	234	180
Airesearch (1971)	244	180
Matrix (1972)	265	28
Antarctic stations	504	240

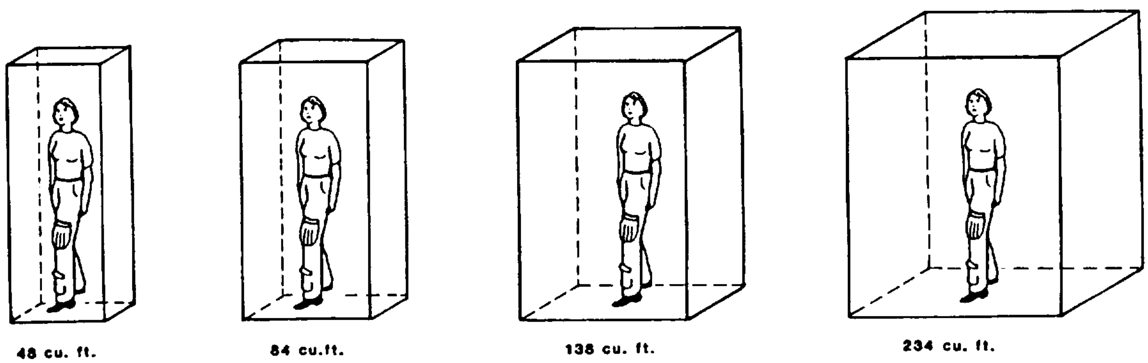


Figure 12. Graphic representation of sleep chamber volumes.*

Although several spacecraft design studies have suggested rather capacious volume requirements (e.g., over 150 cubic feet), our comparative approach has led us to the conclusion that large sleep chambers are **not** necessary to satisfy the subjective requirements of privacy and personal space as long as the primary function of the chamber is sleep. We have determined that moderately-sized chambers are adequate if there are other areas onboard available for individuals to use periodically to "get away;" that is, to read, compose a message, make a journal entry, or just for quiet contemplation. Skylab astronauts reported that their

*All heights have been normalized to seven feet; durations are in days. The astronaut depicted represents a 95th percentile female and a 50th percentile male (approximately 5 feet 8 inches tall); a seven-foot ceiling accommodates the anticipated range of human variation.

relatively small sleep chambers were adequate for sleeping, but not for use during the day, for instance to read, because the only restraint system available was the sleep restraint. Consequently, if an astronaut wanted to be alone for awhile in his quarters, he had to climb into bed.

Evidence for the need to occasionally remove oneself from the group is found in all conditions analogous to a space station. Aboard all vessels, from the humblest fishing boat to the grandest supertanker or high-tech aircraft carrier, crew members regularly seek the solace of the stern, the bow, the flying bridge, or some other area away from fellow crew. This occurs at Antarctic research stations as well, and Dr. Gunderson has observed that it is critical for some individuals to occasionally be by themselves for awhile. This need to withdraw from close personal contact can become very pronounced, but it is not necessarily unhealthy. In fact, seeking occasional moments of privacy can be an effective coping mechanism. Gunderson and others believe that quiet moments alone are actually necessary to "recover psychological homeostasis," that is, to be **under**stimulated for awhile.

For some crew members aboard the proposed space station, a laboratory, office, work station, or sleep chamber will satisfy this apparent human need to periodically withdraw from interpersonal contact. For others none of these will be either available or sufficient. For this reason, we strongly recommend that the NASA space station include a "privatized" area, separate from the wardroom/galley and sleep chambers. The area may be viewed as a reading room, library, or study, and it would logically be the repository for the onboard collections of books and recorded disks and tape cartridges. Though it should probably be large enough to accommodate two crew members in conversation, its primary function would be to allow individual opportunities for quiet and privacy. An optimum design for the library would include a small window for Earth viewing and star gazing; a window in the library would help reduce the inevitable feelings of isolation from Earthbound activities.[52]

Among submariners it is frequently difficult to find a refuge from fellow crew members. Consequently, the importance of a personal bunk may become exaggerated. Aboard submarines, bunks, cramped though they are, serve many functions. They are a place for sleep, reading, letter writing, and conversation.

Curtains are frequently drawn to shut out the light and to avoid the direct visual inspection of others. Bunks are perceived by submariners as a "home" and personal territory. When long duration cruises were initiated there were 15% more crew than bunks and "hot bunking" was required. This practice was quickly abandoned since the rotational use of a bunk was viewed by submariners as an unacceptable invasion of personal territory.[53]

Concerning these subjective requirements of privacy and personal space among isolated and confined groups, it has been reported that, "Needs for privacy, solitude, and territoriality become accentuated, even in short-term confined living and tend to intensify over time" (National Academy of Sciences, 1972:202). This is consistent with the Skylab experience where nearly all crewmen believed that private individual sleeping quarters were necessary; this feeling became more imperative as missions progressed. Altman, however, believes that territorial behavior can be adaptive and facilitative of group harmony:

> One major function of territorial behavior is to set boundaries among group members, to facilitate and establish bases of interaction, and to smooth out functioning in a way analogous to social norms and conventions (1974:250).

Fraser has eloquently summarized the factors associated with privacy and personal space:

> The term "privacy," although commonly used in this connection, is perhaps not the most appropriate term. No doubt there are times when an individual seeks actual privacy, that is, the quality of voluntarily being alone and secluded from his fellow men, and certainly for optimum habitability some provision for privacy in sleeping quarters, toilet operations, and perhaps for command prestige, is desirable. A more fundamental need in man, however, would appear to be the provision for territoriality, or in other words, furtherance of the concept of possession of property and rights of ownership. The sailor in his bunk and the soldier in his barrack room have very little privacy, but the bunk, the bed, the ditty bag, and the foot locker are recognized by his peers as being his property, and are only invaded with his permission. It would seem reasonable that some similar provision be made in long-term spacecraft, although no studies would appear to have been performed to support the concept, nor is it clear how much "territory" an individual might need (1968a:24).

Certain of the analogues reviewed during our study were or are characterized by exceptionally small bunks or sleeping areas. For example, FBM and attack class submarines only allow about 30 cubic feet per bunk, barely enough room for a tall man to stretch out. Tektite, Sealab II, and the Ben Franklin submersible all offered bunk volumes less than 40 cubic feet, and commercial saturation chambers provide approximately 41 cubic feet per bunk. While these examples would appear to suggest that very small volumes may be acceptable for a space station sleep chamber, it is important to note that "confinement" is the most frequently mentioned aspect of submarine life disliked, and dislike of the confined conditions is the most frequent reason for withdrawing from submarine service. Similarly, the Sealab aquanauts complained of overcrowding: "Because of the crowded conditions, there was no private space, no chance to be alone, and almost no storage space for personal gear" (Radloff and Helmreich, 1978:74).[54] Concerning Project Tektite, it was reported that despite the efforts to design the habitat to ensure that there would be areas for privacy, in particular the bunks and cupola, and even though missions were relatively short and workloads heavy, "areas for private reflection received among the very lowest ratings of the various features of the habitat" (Nowlis, Wortz, and Watters, 1972:6-2)[55]

Fraser (1966) summarized the volumetric considerations for several spacecraft design studies and Righter, et al., (1971) prepared a set of interior design alternatives for a 180-day tour space station. These and other proposed sleep chamber designs are summarized in Figures 11 and 12 and in Note 51. Our comparative analysis of analogous conditions, coupled with our review of previous design studies, has led us to suggest what we consider to be an appropriately-sized sleep chamber for the proposed space station. We believe that a volume of approximately 84 cubic feet (e.g., 3' x 4' x 7') would be sufficient to accommodate the objective anthropometric requirements of the chamber as well as most of the subjective requirements of privacy and personal space. An 84 cubic foot chamber would also allow a few cubic feet of storage for personal gear, and the inclusion of a small, wall-mounted terminal with CRT; we assume a vertical orientation of the chamber, similar to that found acceptable aboard Skylab. A seven-foot ceiling would accommodate a 95th percentile male astronaut (6'4" is the maximum height allowed by NASA), while providing both the perception and the reality of relative spaciousness.

There **is** disagreement concerning this subject. Some believe that the space station's sleep chambers should be designed to accommodate a variety of activities in addition to sleep and other quiet, individual pursuits. For example, it has been suggested that sleep chambers should be large enough to accommodate more than one astronaut to allow private conversations or group leisure activities. While relatively large sleep chambers might be an attractive objective, we believe there is a more cost-effective way to satisfy these requirements. That is, by providing common areas such as the wardroom/galley and "Ames library" and using flexible, reconfigurable designs, most potential activities can be effectively accommodated. To provide each crew member with personal spaces large enough to accommodate group activities would result in much under-used space; the excess capacity would be intolerably inefficient.

Similarly, others have suggested that a seven-foot ceiling would not allow certain activities typically assumed for sleep chambers, in particular, the donning and doffing of garments. Our analysis, using soft mock-up, experimentation, and zero-gravity anthropometrics indicates that the sleep chamber suggested here would easily accommodate the changing of clothes. Only a few exceptionally tall astronauts might be inconvenienced by the allotment of space. Those so affected might utlimately choose to don their pull-over garments in the larger central passageway.

Please recall that sleep chambers of moderate size, such as those recommended here as a minimum requirement, are appropriate **only** if there are other areas aboard the space station where individuals may occasionally find moments of privacy or opportunities for quiet conversation. It is critical that sleep chamber design be linked to the design of other areas, such as the proposed wardroom/galley and library.[56] **If adequate common areas are not provided, the volume requirements for individual sleep chambers increase dramatically.** Volumes of at least 150 cubic feet would likely be needed for each member of the crew. Additional research, perhaps following the methodology outlined in Appendix E, is required to establish precisely sleep chamber functional and anthropometric requirements.

Summary of Design Recommendations: Privacy and Personal Space[57]

- Include a "library" compartment aboard the space station to allow crew members periodic opportunities for privacy and quiet reflection.

- Design individual "privatized" sleep chambers incorporating approximately 84 cubic feet of space.

Earlier in this report, Figure 8 was presented to illustrate our design recommendations concerning crew sleep chambers. Figure 13 is presented to suggest what we believe to be a reasonable interpretation of the requirements for an onboard library/task preparation area. The area depicted represents the spatial equivalent of two sleep chambers.

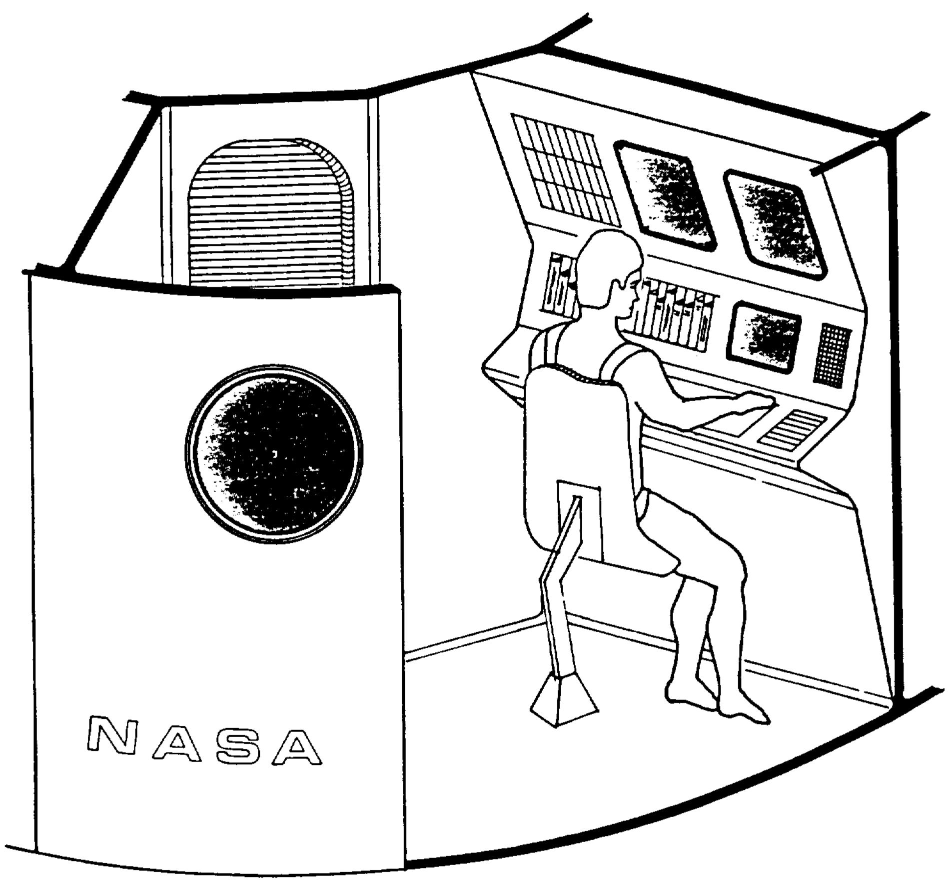


Figure 13. Ames library/task preparation area.

WASTE DISPOSAL AND MANAGEMENT

A place for everything and everything in its place.

--Samuel Smiles

The issue of waste disposal and management has been a particular crew concern since the earliest manned space missions. From the beginning, inadequate solutions have been developed for missions of short duration, and while these words are being written (September 1984), the crew of the Space Shuttle Discovery is prevented from using their onboard toilet due to a "plumbing problem." This comes as no surprise to observers of the program, since toilets have malfunctioned on every STS mission to date.[58] Only the crews of nuclear submarines, of all the analogues reviewed, experience comparable problems. Aboard submarines there is frequently a "blowback" of sewage vapors when the contents of the holding tanks are discharged overboard. This results in noxious odors and an unhealthy growth of ecoli bacteria in the mouths of the submariners.[59] Though humans are capable of enduring much, and submariners provide heroic testimony to this fact, problems with the sewage system have frequently been cited by submariners as reasons for declining to reenlist.

To ensure optimum habitability aboard the proposed space station, to facilitate career continuity, and to reduce the potential for attrition of personnel, NASA must develop solutions to the problems associated with waste disposal and management. Our discussion in this regard will be brief; we will focus our attention on the requirements for disposing of biological wastes, and the disposing of solid materials such as paper and plastic wrappings.

Biological Wastes

The classes of human waste materials have been adequately documented in previous reports and specifications.[60] It is sufficient for our purposes to understand that most human wastes are those resulting from metabolic function and they are eliminated as urine and feces. From our comparative analysis of conditions analogous to a space station, we have determined that at least two toilets would be required for a space station crew of eight. Righter, et al., (1971) specify three toilets for a twelve-man crew, though we believe that two would also be sufficient for a crew of twelve. Two toilets are strongly recommended for the following reasons: 1) to provide redundancy in the event one toilet fails, and 2) to accommodate demand during peak use periods.

The need for redundancy is obvious from current STS operations, as is the capacity for maintainability. That is, it is unwise to accept a toilet so complex in design that it cannot be maintained under operational conditions; a crew member must be able to repair a toilet if it malfunctions. Concerning peak use periods, it is assumed that on-orbit use patterns will approximate those of Earth. In this regard, greatest demand for toilet facilities is likely to occur prior to and following breakfast. In order to minimize the personal inconvenience and system costs of waiting in line, a second toilet is required.

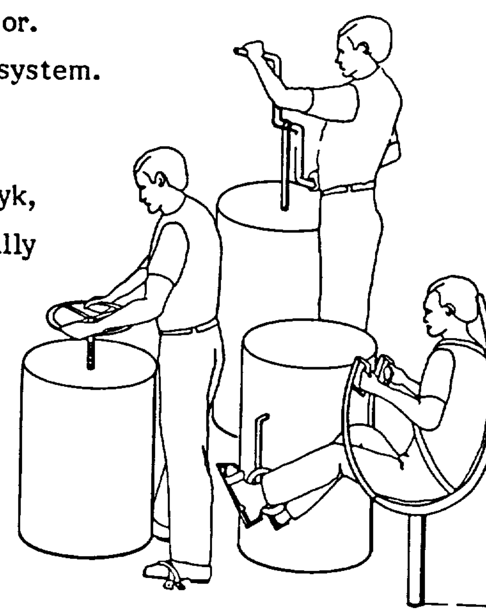
Paper and Plastic Wastes

In a previous section we suggested that it may be appropriate to incorporate physical activity in the performance of routine operations. The design of a manually operated trash compactor is to us an obvious application of this suggestion. Benefits would accrue in terms of the exercise value of the activity, minimal power requirements, enhanced reliability, and maintainability. Compacted trash bundles could either be returned to Earth aboard a shuttle for disposal, or preferably they could be ejected into the atmosphere for incineration. For the latter alternative, we suggest a hand-drawn, spring-powered catapult rather than a technologically complex design solution.

Summary of Design Recommendations: Waste Disposal and Management

- Include at least two toilets to provide redundancy and to accommodate peak use periods.
- Design toilets for maintainability.
- Design manually-operated trash compactor.
- Design manually-powered trash ejection system.

Figure 14, prepared by artist Gail Langedyk, illustrates alternative concepts for a manually operated trash compactor.



ONBOARD TRAINING, SIMULATION, AND TASK PREPARATION

> Practice does not make perfect. Perfect practice makes perfect.
>
> --B.F. Skinner

Premission training for the crews of the proposed space station will be extensive. However, it is assumed that during long duration missions additional onboard training will be required in the early stages of a mission for tasks to be performed during a later stage. This preparation may involve:

- Task simulation.
- Review of procedures and specifications.
- Focused discussion with ground-based personnel.
- Physical inspection of equipment to be used during a task.

Although we believe that some form of onboard work station or learning center may be required to accommodate these preparation activities, we found little support for design suggestions among the analogous conditions. At Antarctic research stations the lounge, or reading room, is frequently used by scientific staff to prepare for an experiment and other research activities. Also, among commercial saturation divers there may be several occasions during a job when blueprints are "locked in" (passed into the sat chamber through an air lock) and a conference with the engineers convened; this frequently involves the rack operator or diving supervisor serving as interpreter for the helium-voiced divers. Other divers may go through the motions required during tasks kinesthetically, mentally rehearsing the procedures in preparation for actual performance of the tasks.

Video conferences and a kinesthetic rehearsal technique may be appropriate for use aboard the proposed space station in preparation for both internal and external maintenance, construction, and experimental activities. In this regard, we suggest that an area be provided aboard the space station for these purposes. For some personnel, preparing in a laboratory or communicating from a work station will be more effective. The need will arise, however, for crew members to have quiet study time and perhaps technical or confidential discussions with ground support personnel. It is apparent that the library suggested in a previous section would satisfy this task preparation requirement. The uses are complementary since both library and task preparation functions involve only occasional utilization of the space provided.

Summary of Design Guidelines: Onboard Training, Simulation, and Task Preparation

- Provide an area for onboard training, task preparation, and technical communication (e.g., combine with library).

BEHAVIORAL AND PHYSIOLOGICAL REQUIREMENTS ASSOCIATED WITH A MICROGRAVITY ENVIRONMENT[61]

> "It will take you some time to get used to this," he said, as he unbuckled my safety strap. "The thing to remember is--always move gently...".
>
> --A.C. Clarke

Arthur C. Clarke's prescient advice concerning some of the hazards of a weightless condition is as applicable to the crews of the future space station as it was to his fictional Inner Station personnel over 30 years ago. Skylab and STS experience has confirmed Clarke's suggestion--always move gently in space. This is particularly sound advice with regard to head movements and the effects they frequently have in inducing symptoms of the infamous Space Adaptation Syndrome. This syndrome, apparently a variation of typical motion sickness but with exacerbated vestibular and perceptual components, is currently the subject of much research effort.

Although a discussion of the space adaptation syndrome is beyond the scope of this report, several introspective comments by Skylab astronauts are directly relevant to the relationship between internal spacecraft architecture and perceptions of psychophysiological symptoms. Many habitability recommendations based on the Skylab missions are contained in Skylab Experience **Bulletins, Lessons Learned on the Skylab Program,** and **Skylab Experiment M487: Habitability Crew Quarters.** Additional insights are provided by Dr. William Douglas. Dr. Douglas, the original flight surgeon of Project Mercury, has interviewed many former and current astronauts concerning a wide range of issues, and his report to the Ames Research Center is relevant to the current discussion. Our comments in this regard are limited, however, to Skylab, the only analogue we reviewed that was characterized by an absence of gravity.

Questions concerning the specific effects of the microgravity environment on human performance can only be studied in terms of that unique environment. Consequently, we are limited to operational space missions (STS-Spacelab) and archival sources when seeking to resolve major design questions such as vertical versus horizontal configuration of modules and whether the consistent application of a local reference frame is desirable, for instance to counter the effects of the adaptation syndrome. In this regard, we have found the Skylab archives to be valuable sources of data concerning these and other fundamental design questions. Subsequent paragraphs will present design recommendations drawn from the Skylab experience concerning the sub-issues: local reference frame, use of available space, and restraint of small objects.

Local Reference Frame

Though the Skylab missions did not produce the first instances of space adaptation syndrome, they did provide the first opportunity to analyze the perceptual and physiological effects of living and working in a weightless environment. Previous spacecraft were too small to allow complete freedom of movement, and even shuttle astronauts do not experience the absence of restraint enjoyed aboard Skylab. Indeed, it is unlikely that enclosed spaces comparable to Skylab's Saturn workshop will be available again in space for human habitation for many years.

Each of the three Skylab crews included a "science pilot" (Owen Garriott, Edward Gibson, and Joseph Kerwin) who are largely responsible for our understanding of the behavioral issues associated with a weightless condition. Kerwin's comments and analyses were particularly perceptive:

> It turns out that you carry with you your own body-oriented world, independent of anything else, in which **up** is over your head, **down** is below your feet, **right** is this way, and **left** is that way; and you take this world around with you wherever you go (in Cooper, 1976:23).

The concept of local vertical is alien to Earthbound conditions because it is consistently subordinated to the effects of gravity on the vestibular system. Kerwin's observation, however, explained the odd feelings, disorientation, and occasional nausea experienced by astronauts when they would look up from a task and find themselves floating sideways or upside-down with respect to the interior architectural orientation. According to this interpretation, vestibular/perceptual confusion results when there are two conflicting sets of vertical cues, one's own local vertical, and the vertical cues provided by the interior space.[62] Several additional hypotheses are currently being evaluated by NASA.

The importance of local vertical to individual orientation in a weightless environment was particularly evident when Kerwin attempted to answer a radio call in the dark:

> "It was pitch black," he said later. "When I scrambled out of bed, I had no way of determining up from down; I had no visual reference in the dark. I had to turn on the lights, but I just didn't know what direction to put my hand in. So I had to **feel** things to orient myself--I had to use touch instead of sight--and everything felt different because I didn't know my relationship to them. It took me a whole minute just to get the lights on." The confusion passed as soon as he had lined himself up visually with the room's local vertical; indeed, when an astronaut's own vertical was lined up with that of his surroundings, the two seemed to click into place, like a compass needle onto magnetic north (in Cooper, 1976:72)

Similarly, on the third mission Gibson observed,

> It's as though your mind won't recognize the situation you're in until it sees it pretty close to the right orientation, and then all of a sudden, zap! You get these transformations made in your mind that tell you exactly where you are (in Cooper, 1976:72).

Though all of the Skylab astronauts adapted to the weightless environment, the vestibular/perceptual phenomena contributed to their marked preference for the low ceilings and more Earthlike rooms of the lower deck. It is reported that the astronauts felt most at home among the small rooms and enclosed spaces of their living quarters (sleep chambers, wardroom, experiments room, hygiene area); there is apparently less risk of losing one's sense of local vertical when consistent orientation cues are readily available.

These and other observations suggest that the proposed space station interior architecture should incorporate familiar or Earthlike designs (e.g., low ceilings) and should provide abundant cues to reinforce perceptions of vertical orientation. It is suggested here, as it has been suggested elsewhere, that color-coding of ceilings, walls, and floors might help to mitigate the disorientation inevitably experienced in weightlessness. The latter hypothesis requires experimental evaluation.

Use of Available Space

Related to the problems experienced with regard to local vertical were difficulties adapting to uses of interior space which did not conform to Earthbound practices. For example, the docking adaptor, a long, narrow cylinder, included instruments, boxes, and work stations arranged radially around the interior of the structure. So lacking in consistency was the docking adapter that the two primary work stations, the solar console and the Earth resources experiment console, were about 90 degrees out of alignment. Cooper reports:

> The docking adapter has been built that way because the designers of Skylab had wanted to see whether men could get along without a single vertical; if the astronauts liked the docking adapter, the designers had thought, then they could use the entire volume of a room in planning future space stations; they could, for example, multiply the use of a room sixfold by putting equipment not only on the floor, but on the ceiling and the four walls as well (1976:109).

Well, eight of the nine Skylab astronauts **disliked** the use of space in the docking adapter. Probably no single issue received more negative commentary from the crews than the configuration and design philosophy supporting this segment of the space station. Only Gibson seemed to appreciate the apparent efficiencies achieved through maximum utilization of available space, but he too experienced difficulty when attempting to locate items within the cylinder.

It was a noble experiment, but the dismal results should come as no real surprise. After all, we are a terrestrial species. Until very recently we have been confined to the Earth's surface, and throughout our evolution we have been subjected to a consistent force of one gravity. Clearly, there are cultural (learned) components to our preferences and behavior, but there is something fundamentally different and truly alien about living in three dimensional space. Even those species that occupy three-dimensional habitats, the fish and mammals of the world's oceans and the birds that inhabit the oceans of air above the Earth's surface, do not use their spaces randomly. They also adhere to a single orientation dictated by Earth's gravitational force. It seems reasonable to assume that in order to ensure optimum habitability of the proposed space station and to facilitate maximum productivity of crew personnel, it would be wise to provide interior configurations and uses of space that are consistent with biological and cultural preadaptation. Certainly crews could be selected, trained, and/or desensitized to perform adequately in a space station composed of docking adaptor-type modules; human behavior is truly plastic, but penalties inevitably accrue when individuals are required to routinely tax their capacities for adaptation.

Restraint of Small Objects

One of the most obvious recommendations resulting from the Skylab missions concerns the need for a device to restrain small objects during maintenance or repair operations. The astronauts described what they needed aboard Skylab as an "aerodynamic workbench," and what they ultimately used were the life support system exhaust filters. In fact, all unrestrained small items (loose screws, pocket knives, pencils, etc.) eventually found their way to the filters. We assume that a device designed to effectively restrain small electronic parts, pins, screws, etc., will be included in the station's maintenance area, and perhaps similar, smaller versions would be useful in laboratories or work stations.

Small objects cause problems in microgravity environments. Aboard Skylab the crews experienced what they called the "jack-in-the-box phenomenon:" whenever they opened a storage locker or drawer, the contents tended to pop out and float away weightlessly. Required for the proposed space station will be storage systems that prevent this annoying and time-consuming process. Certainly STS operations will contribute to effective design solutions concerning this and other requirements associated with a microgravity environment.

Our experience has indicated that the Skylab archives are valuable sources of data. For example, they strongly suggest that a consistent local reference frame should be maintained and that walls and ceilings are inappropriate locations for equipment that we would normally expect to find on the floor. Unfortunately, the Skylab data will not provide all of the answers, and even the most ingenious Earthbound study cannot effectively simulate conditions to allow the evaluation of those issues unique to a weightless environment.

We can, however, construct the appropriate questions to allow the experimental analysis of hypothesized solutions. For instance, the effects, if any, of compartments and/or work stations arranged without reference to a consistent local vertical could be evaluated by conducting simple experiments in a temporarily and superficially reconfigured Spacelab or orbiter mid-deck. The results of these experiments could then be used in conjunction with the accumulating anecdotal accounts and systematic observations to define optimum internal orientation.

Summary of Design Recommendations: Behavioral and Physiological Requirements Associated with a Microgravity Environment

- Design space station interior architecture to incorporate familiar (Earth-like) features (e.g., "room-like" chambers).
- Maintain, to the extent possible, a consistent interior orientation (e.g., a consistent local vertical).
- Provide visual and perhaps tactile cues to reinforce reference frame.
- Develop devices to restrain small objects during maintenance and repair operations.
- Develop solutions to problems associated with the stowage of small objects.

SUMMARY OF DESIGN GUIDELINES AND SUGGESTIONS

The Executive Summary, presented as the first few pages of this document, includes a complete recapitulation of all design recommendations associated with our 14 behavioral issues. The purposes of the current section are to summarize some of the behavioral principles that support our recommendations, to identify salient research requirements, and to discuss some of the ironies apparent from our comparative analysis.

BEHAVIORAL PRINCIPLES

In previous sections we have commented on several principles of human behavior that appear to shape individual and group responses to conditions of isolation and confinement. Webster defines a "principle" as a general or fundamental truth or something from which another thing takes its origin. Certainly, the universality of the principles identified during our comparative analysis can be challenged. We are confident, however, that our objective evaluation of alternative analogues, concentrating on fidelity to assumed space station conditions, and our systematic approach to the subject has contributed to the utility of these principles, or behavioral tendencies and to the design recommendations derived from them.

Some of the behavioral principles identified during our research support only one or two design recommendations. Others support several recommendations and transcend the boundaries of a specific issue. The following annotated list presents a summary of those behavioral principles discussed in previous sections of this report.

Trivial Issues are Exaggerated

The stresses associated with conditions of isolation and confinement consistently result in minor interpersonal problems. This tendency applies to both intragroup relations and to relations with support personnel. Typically, the problems involve issues which otherwise must be considered to be trivial or inconsequential. Yet, in confined and isolated environments, trivial issues are predictably exaggerated beyond reasonable proportions.[63] Several of our design recommendations address the needs to facilitate communication among individuals and between groups, and to avoid potential sources of interpersonal friction.

Some Individuals Will Allow Standards of Personal Hygiene to Slip

We agree with Weybrew's explanation that this tendency among isolated and confined groups is a logical extension of Weber's Law. That is, there is a logarithmic transformation between physical stimulus and central effect. In other words, as one allows personal hygiene standards to slip, greater "increments of slippage" are required to notice the change. Though it is unlikely that health would be jeopardized, adherence to hygiene standards is important to enhance morale and to avoid sources of interpersonal conflict.

Zeitgebers are Important

In the absence of normal or customary cues to the passage of time, it is important to provide substitutes. This applies to diurnal cues to facilitate the maintenance of normal circadian rhythms; the principle also applies to the passage of time on a grander scale. In this regard, we have suggested the dimming of station lights to approximate nighttime at mission control, and weekly special dinners, mid-mission celebrations, and similar events. Likewise, mission managers should structure missions with several intermediate goals during the tour, rather than one large objective at the end, to engender the feeling among crew personnel that progress is being made toward an ultimate goal. In isolation, days tend to blend one into another and external cues are required to help mark the passage of time.

Some Individuals Respond Best to Tangible Results

Though somewhat related to the previous item, we found that many individuals in both isolated and nonisolated conditions tend to require tangible results for their efforts. Based on this observation, we recommend exercise modes which require tangible results as motivators.

The Integration of Activities Can Improve Productivity

Anytime two objectives are satisfied simultaneously, efficiency is enhanced. Though this principle is limited in its application, we recommend that, to the extent possible, exercise be integrated with recreation and other routine tasks (e.g., manually operated trash compactor).

Humans Tend to Thrive on Variation of Visual Stimulation

It has been suggested that variety is the spice of life, and the importance of variation in stimuli is pronounced in confined environments. This principle supports several design recommendations concerning habitat aesthetics and recreational opportunities.

Self-Selection is Desirable

This statement should certainly come as no surprise to anyone. We all tend to believe that we know what is best for ourselves, and clearly, personal preferences play large roles in many decisions. Under the technical and logistical constraints imposed by a space station, alternatives must be limited. The importance of self-selection, however, supports several recommendations concerning food preparation and recreational opportunities.

The Larger the Group the Greater the Tendency for Sub-Groups to Form

Sub-group formation is inevitable, even within groups composed of fewer members than that assumed for the proposed space station. Though sub-groups are not necessarily negative features of group dynamics, (they can serve as coping mechanisms--to gather with those of like interests), there is a clear potential for the solidarity of the larger group to suffer. In this regard, we have made several recommendations to mitigate the negative effects of sub-group formation. In particular, dining together at least once each day and special dinners have been suggested to facilitate communication among individuals and between subgroups.

Most People Like to be Informed

This principle applies to information of a general nature, such as current events or news, as well as information pertaining specifically to an individual's immediate interests, such as task requirements and changes in the program. The apparent human desire to be informed supports design recommendations in the areas of outside communications, recreational opportunities, and group interaction.

The Longer the Tour, the More Important is Privacy and Personal Space

As the stresses resulting from confined and isolated living accumulate, a typical coping mechanism is to withdraw from high levels of social stimulation. This is a natural and healthy process and it should be facilitated by providing both private sleeping quarters and other areas where privacy can be obtained without having to go to bed.[64] In this regard, we have offered rather specific recommendations concerning the designs of crew sleep chambers and a library/task preparation center.

It is Important for Designs to Conform to Human Expectations

This is a basic principle of sound human factors engineering. It applies to the design of commonplace items, such as faucets and knobs (e.g., left and right turns, respectively, to turn on), as well as the design of complex and exotic habitats such as the proposed space station. Just as we would not suggest violating expectations concerning faucets and knobs, we have recommended that space station interior architecture conform, to the extent possible, to Earthbound human expectations.

Waste Management Systems Will Malfunction

Although this is not a behavioral principle, it is directly related to fundamental human behavior. Essentially, there are four means by which spacecraft designers plan for technical contingencies: 1) a system can be overbuilt, that is, constructed to withstand stresses greater than anticipated, 2) a system can be designed to degrade "gracefully," without abrupt termination of function, 3) a system can be designed to be easily maintainable to allow nearly continuous operation, and 4) redundant systems can be designed. We recommend that both maintainability and redundancy be incorporated in the design of the space station's waste management system. That is, two toilets are necessary to ensure that **at least** one of them is operable at all times; maintainability is required in order that repairs can be performed during a mission.[65]

ADDITIONAL RESEARCH REQUIRED

Much additional research is required to identify and solve many problems associated with living and working in the confined and isolated conditions of a NASA space station. Some of the most salient research requirements identified during the course of the current project are listed below.

- Additional research is required to develop an effective approach to onboard conflict resolution.
- Studies focusing on the group dynamics of on-orbit personnel are required.
- Determination of organizational philosophy and personnel management plans are required.
- Determinations concerning cross-utilization of personnel are required.
- Further research is required to identify an appropriate compromise among: 1) effects of color on mood, 2) personal preferences of potential user groups, and 3) physical properties of surface coating materials.
- Research is required to identify the range and importance of personal preference in clothing use-rates.
- Research is required to determine what programming, if any, should be restricted from the onboard video library.
- Research is required to determine if monitoring frequency (amount) of personal communication is a reliable unobtrusive measure of personal adjustment to space station conditions.
- Research is required to determine if two-way video capability enhances the quality of technical communications.
- Research is required to establish specific sleep chamber use and anthropometric requirements.

IRONIES OF HABITABILITY

Evidence from several of the analogues reviewed indicated that "comfort" is one of the least important factors contributing to habitability. This was made particularly clear during Project Tektite. The Tektite habitat was not well designed for work; all areas of the habitat were designed as multi-purpose areas resulting in frequent interruptions of tasks and procedures. Also, the lack of readily available reference materials and necessary equipment were constant annoyances to the crews. The habitat was apparently better designed for comfort and it contained many ammenities such as abundant windows and the cupola. Interviews with crew members and observations conducted during the missions made it very clear that work support was of much greater importance to crew than was comfort support. Nowlis, Wortz, and Waters are emphatic:

> The single most important variable in the perceived habitability of this habitat was the degree to which aquanauts found the habitat supportive of their scientific and engineering tasks (1972:6-3).

It seems ironic that a habitability study must conclude that the primary concern of space station designers should be with work-related operations rather than the intangibles of habitability. **We are convinced, however, that while work support is of paramount importance on all missions, the importance of the intangible issues increases with mission duration and the routinization of operations.**

A second irony is apparent from the following conclusions drawn from our comparative research.

- Structure is a key to effective and productive operations.
  Yet
- Self-selection and variety are keys to individual adjustment.

We believe that both statements are correct, and that they are not mutually exclusive. Clearly, choices from among alternatives should be allowed and personal preferences should be honored, but it is critical that this self-selection occurs within a structured framework. For example, it is important for health maintenance that crew members take regular nourishment, and for group interaction that the crew eats together as frequently as possible. Consequently, mealtimes must be scheduled, yet within that structure, self-selection of food items should be allowed. Similarly, exercise is required to counter the effects of muscle atrophy and cardiovascular deconditioning, and leisure time is required to forestall the onset of stress responses. These activities must also be scheduled and individuals must comply with the schedules, but within that structured framework, considerable opportunity for choice among alternative activities should be allowed. Sleep is another issue that requires a structured approach to prevent "free cycling" and its behavioral consequences. Yet, there will be individual differences in the sleep requirements of personnel; not everyone needs to retire at the same time, but all should be ready for work at a specific hour. We perceive the apparent requirements for both self-selection and imposed structure as complementary rather than contradictory components of habitability.

Finally, we believe that just because a minimum habitability standard may be acceptable for space station operations does not mean that we should provide only the minimum standard. We believe that if it is feasible to enhance the quality of on-orbit life, we should, even if no immediate payoff is foreseen. Wherever humans go, they take with them humanistic issues--even to a space station, the operation of which is determined by efficiency and productivity. We owe it to the future crews of the NASA space station, as well as to those remaining behind, to design and build the most humane environment possible, not just what is minimally necessary to accomplish the job.[66]

CONCLUSION

Several years ago a Harvard professor conducted a study of the leisure pursuits of 19th Century American whalers in the hope that similar activities would help pass the time for the crews of long-duration submarine missions. With high expectations and good intentions, he presented his results to the submarine service: carving, needlework, knitting, etching, copperworking, and painting were found to be the most common activities of whalers on their long voyages, and these pursuits were recommended as leisure activities for submariners. Those familiar with isolated and confined environments, such as submarines, can probably imagine the ridicule with which the whaler report was met. Each of the alternatives offered by the professor was either too dangerous or it involved materials with serious outgassing potential. None of the suggestions was adopted.

It is likely that some of our design recommendations will also be considered technically inappropriate for various reasons. However, the current study, by design, has not been concerned with the engineering requirements dictated by habitability considerations. Rather, the principal objective of this project has been to develop habitability guidelines and suggestions to aid engineers in the design of optimally functional and productive environments.

We believe that this objective has been satisfied. In the literature referred to as "analogue studies," the current report represents the first attempt to systematically evaluate the potential utility of behavioral inferences drawn from conditions analogous to a space station. Also during the project, critical habitability issues with design implications were identified, most of them transcending the context of space station operations. Finally, design guidelines were extrapolated from the analogues and presented in the form of usable recommendations; approximately 100 habitability recommendations are itemized and supported in this report.

Our systematic, comparative approach to the study of habitability issues associated with isolation and confinement contributes to the efficacy and value of our design recommendations. In fact, civilian and Navy managers and psychologists who reviewed a draft of this report, expressed interest in applying some of our suggestions to the design of isolated environments for which they are responsible. This response is both gratifying and illuminating. We are pleased that those with operations-level experience in conditions of isolation and confinement recognize the merit of our analysis. We are also reminded that the design guidelines and recommendations presented in this report represent a synthesis of much previous research and lessons derived from the operational experience of many others. We are convinced that it is only through such an interdisciplinary and cooperative approach that habitability and productivity can be ensured aboard the NASA space station.

NOTES

1. Our approach is consistent with the following suggestion.

> The investigator should use as many methods in combination as the situation permits to increase breadth of understanding as well as reliability of observation. As Webb and his colleagues (1966) have it, "So long as we maintain, as social scientists, an approach to comparisons that considers compensating error and converging corroboration from individually contaminated outcroppings, there is no cause for concern. It is only when we naively place faith in a single measure that the massive problems of social research vitiate the validity of our comparisons" (Nelson, 1973:181-182).

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2. Several attempts have been made during the past two decades to identify the dimensions, or metrics, to be used in defining the conditions of hypothetical and proposed extended duration space missions. A NASA symposium on the effects of confinement on long duration manned space flight identified seven mission conditions affecting responses to confinement: physical environment, sensory-motor limitations, psychological environment, crew tasks, crew size, work cycles, and individual differences (NASA, 1966). Similarly, but based upon a broader range of examples (including laboratory studies, sea voyages, disasters, submarines, etc.), Smith (1969) developed the following list of factors potentially related to tolerance for and performance during small group confinement.

- Size of group
- Composition
- Compatibility
- Privacy
- Group motivation
- Group morale
- Past history of group accomplishments
- Group-maintenance skills
  - Leadership
  - Grievance handling
  - Avoidance of interpersonal hostility
- Interdependence and trust
- Confinement-endurance training
- Duration of confinement
- Perceived monotony of the environment
- Perceived importance of mission and tasks
- Variety and interest value of subtasks
- Rewards to be gained from success

- Costs of failure or poor performance
- Awareness of mission duration
- Ability to keep track of time
- Acceptability of the food and water
- Work-rest cycles and work load

Sells' (1973) taxonomy of enclosed and isolated groups likewise attempts to describe the conditions of confinement. Sells uses the following descriptive categories to define isolated microsocieties.

- Objectives and goals
- Philosophy and value systems
- Personal composition
- Organization
- Technology
- Physical environment
- Temporal characteristics

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3. Fraser (1968a) defines habitability as the equilibrium state resulting from the interaction of components in the man-machine-mission environment complex, which permits physiological homeostasis, performance and social relationships. Kubis (1965) describes habitability as the sum of interactions between man and environment. The interactions include: physical (the physical environment and its interactions with man), physiological (the homeostatic response of the man in the environment), psychological (the effects of environment on performance and behavior), and social (interpersonal relationship). To Kubis, habitability is structured in several layers: "a bedrock of sheer survivability, a segment of tolerable discomfort with a possible but tolerable reduction in efficiency, and a relatively comfortable condition characterized by effective performance."

Fraser (1968a) maintains, however, that "comfort per se is not a critical attribute of habitability, nor is it likely to influence crew effectiveness to any significant extent." To Fraser, and to most observers, there is no ultimate standard of habitability. It must be considered and defined relative to the duration of the tour or occupancy and to the purpose of the occupancy. Further, the standards will vary substantially according to the previously established customs and practices of the occupants. The latter is a principal component of Webster's definition as well.

Along these relativistic lines, Celentano, et al., (1963) in an earlier study defined habitability as the presence of desirable qualities to which the tenant is accustomed, and to ensure habitability one provides an environment as close to the natural environment as engineering resources permit. White and Reed (1963), when considering these issues, defined habitability as "the resultant of the interplay of all the factors relating to the man, his machine, his environment, and the mission to be accomplished."

Fraser (1968a) interprets White and Reed to mean that a particular man-machine-environment system defines its own habitability in terms of the assigned mission. That is, habitability is defined by other factors in addition to the acceptability of an environment. Consequently, habitability can be manipulated by altering any of the components of the total system--man, machine, environment, or mission. "Man has a dual role within such a system. He is an interactive component of the system, contributing to the habitability, and at the same time he provides the criteria by which the habitability is judged." Though Webster defines habitability in terms of the "class of tenant" (expectations), the interactive model of Fraser and others suggests that by modifying the habits, requirements, and tolerances of the occupants, the habitability needs are changed. Modifications of these types may be effected through selection, training, and enculturation. Human capacity for modification, however, is limited. Also, duration of tours are somewhat fixed by mission/technical/economic factors. That leaves the environment to be altered as a principal means of improving habitability.

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4. Not all students of human performance agree on the relationship among productivity, morale, and group cohesiveness. Logic and some empirical evidence suggests that groups with high morale and pronounced cohesiveness tend to be more productive than groups lacking these characteristics. Helmreich has suggested that the actual causal relationship is in the reverse; that is, groups that are productive tend to develop high morale and cohesiveness. This argument is also compelling, since it has been demonstrated that, for most professional people, at least, work is a primary source of satisfaction in life. When one is pleased with either the quantity or quality of work performed, it tends to have a positive effect on individual and group morale.

Clearly, both observations are correct. Satisfaction with work engenders high morale and group cohesiveness, which in turn contributes to productivity and job satisfaction. Under optimum conditions, a positive feedback relationship exists.

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5. Most of those concerned with habitability issues have fairly firm opinions regarding the relative importance of at least a few of the issues. Typically among experts, favored issues reflect professional interests (e.g., social psychologists believe group interaction to be most critical, engineers believe design issues to be paramount, etc.). Even those who have not studied the issues, including the most casual observers, offer opinions, sometimes convincing, concerning the overall importance of particular issues and the value of specific design solutions. Alas, habitability is one of those areas, like human nature and weather prediction, in which everyone considers themselves expert.

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6. It was found that time to onset of sleep was longer among Antarctic volunteers (15.4 minutes) than among the same men when in temperate zones (3.5 minutes). Also, there was a reduction in REM sleep (rapid eye movement) of about 20%. Neither of these differences was statistically significant.

A major change was found, however, in the nearly complete loss of SWS (slow-wave sleep, or Stage 4) at the end of the polar winter. Also, SWS had failed to return six months after the subjects returned home from Antarctica (from a baseline mean of 20 minutes of SWS per might, to 2.8 minutes during the winter, to one minute following return to the U.S.) (Shurley, 1974; Natani and Shurley, 1974).

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7. Although we perceive no architectural requirements in the statement, the following observation concerning Skylab is presented due to its obvious relevance to our discussion.

> In the early phases of the mission, Skylab crewmen complained that too often they were scheduled to perform operational or experimental activities right up until the beginning of their sleep period and that it was quite difficult to relax abruptly and go to

sleep. The 1 hour of uninterrupted presleep activity was observed as a constraint during Skylab 4 (NASA, July 1974a:86).

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8. The importance of sleep and regularity of schedules, even for space station operation, is well known, at least by crew. The following comment by Jack Lousma, the pilot of Skylab 3, illustrates this recognition.

> It is a real paradox that the things that suffer when you want to get something done or you're running behind are the eat period, the exercise period, and going to bed on time. And these are the three highest priority that you need to do on time and regularly (NASA, February 1976:6-15).

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9. Cooper (1976) reported that Skylab astronauts sometimes had difficulty falling asleep. "Whenever the spacecraft passed from sunlight into darkness, or back again, the hull banged and popped loudly with the change of temperature, like a tin roof... If Skylab's thruster jets fired during the night, they sounded like bursts of machinegun fire. If anyone got up during the night, he invariably awoke the others" (p. 172).

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10. According to Drs. Howard and Weiner, even Captain Cook insisted on weekly bathing for his crew (including the time spent in Antarctic waters) and frequent changes of clothes.

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11. Dr. Weiner suggests that the powerful psychological influence of clothing has been used in the reverse, as well. Dressing prisoners poorly is frequently an initial step in the process commonly known as "brainwashing."

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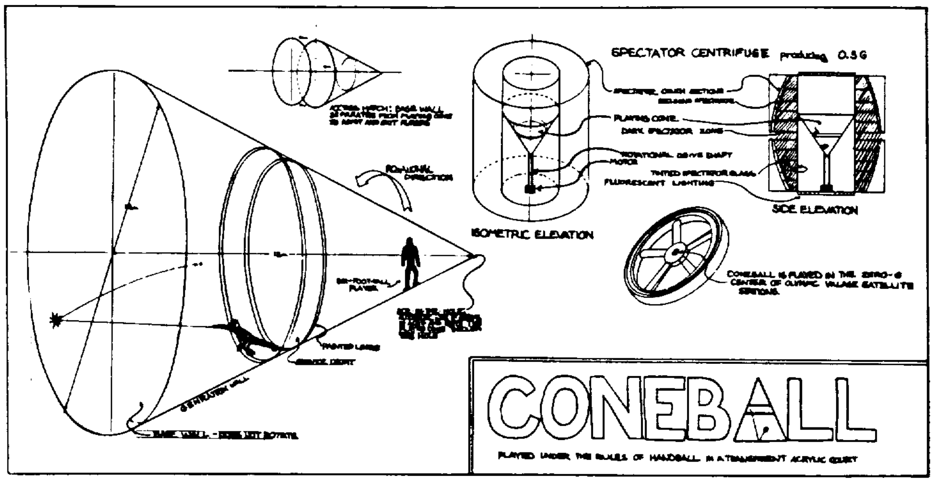
12. In this regard, zero gravity physical games (perhaps played in jumpsuits fitted with bungee cords) may serve as appropriately motivating activities as the station matures. This suggestion should be distinguished from **Omni** magazine's recent contest to design games for a zero-gravity Olympics, circa 2084 (see

diagram for a grand prize winner). It should also be distinguished from Kraft Ericke's suggestion that a three-dimension tennis game will be possible in space (reported to Walter Cronkite during an episode of the **21st Century**).



Source: Morris, 1984:133

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13. It is reported that Charles Conrad, commander of the first Skylab mission, pedaled continuously for 90 minutes, or approximately one revolution of the earth. This allowed him to claim that he had bicycled around the globe (Cooper, 1976). Perhaps a window nearby would have motivated others to do the same.

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14. The range of possible programming is practically limitless. Video recordings of great bicycle paths of the world is a favored suggestion. Imagine touring the Rhine Valley, the Swiss Alps, Mt. Haleakala, or Jakarta on an ergometer; headphones and a stereo audio track of the actual sounds (documentary style) would lend realism to the experience and contribute to the diverson. Initially we believed this to be an original concept. We recently learned, however, that a similar system has already been developed by Perceptronics. The system uses video disc rather than tape, which allows an interactive component.

Many alternatives are available. The author knows of a man who watches the syndicated **20 Minute Workout** (three attractive women leading aerobic exercises to upbeat music) while exercising with his rowing machine. In addition to exercise-related material, the full range of commercial programming is available for use at little cost, from science and education to serious drama, to mindless entertainment. The key operating principles in this regard should be variety and self-selection.

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15. An unresolved issue, one that is beyond the scope of the current project, is the question of individual versus group exercise. The recent aerobics phenomenon suggests that for some crew, group exercise may be more effective than individual pursuits. Additional research is required to determine appropriate tradeoffs for space station design and operation.

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16. **System for the Management of Trauma and Emergency Surgery in Space** (Houtchens, 1983) covers the full range of possible injuries (chest, abdominal and pelvic, genital-urinary tract, limb, thermal and electrical burns, etc.). Certain other medical conditions are also addressed such as urological emergencies (there is increased risk of renal stone passage during space missions due to hypercalcuria, dehydration, and increased concentration of urine). A category of emergency that is not addressed, however, involves the complications occasionally associated with pregnancy. During a 90-day tour aboard the space station a previously undetected pregnancy could result in any one of several problems, spontaneous abortion and tubal pregnancy being the most common. It is important that the medical support capability of the space station include the capacity to respond to all potential emergencies.

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17. Admiral Byrd is reported to have included in his Antarctic expedition supplies two coffins and a dozen straight jackets (Howard, personal communication).

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18. The incidence rates of neuro-psychiatric illnesses on submarines with 9 cases/million man-days and surface fleet with 6 cases/million man-days are low compared to those of the 25-34 year age group in the

> general population, which had a rate of 18 cases/million man-days in 1971, based on data from public outpatient psychiatric services. The higher incidence of headaches and neuropsychiatric disorders in submarine personnel may be related to greater overall stress effect imposed by two months of isolation in the submarine. However, at present there is (sic) no data to substantiate this (Tansey, Wilson and Schaefer, 1979:240).

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19. It has been reported that on one of the initial long-duration submarine voyages of the early 1960s over a dozen acute anxiety reactions occurred. This is the most common pathological response to stress and it is typically characterized by screaming, hyperventilation, and chest pain. Since it is nearly impossible to abort a submarine mission, due to factors of national security, nuclear medical corpsmen have been trained in intervention techniques including simple yet effective behavior modification procedures. The procedures involve anchoring the diffuse anxiety to a specific fear, then applying behavior modification to extinguish it. Obviously, most of this therapy occurs ashore, but the submarine service is prepared to respond to such emergencies when they happen.

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20. "Appreciable increases in anxiety, depression, or irritability among even a few members of a small closed group become a serious threat to group solidarity and harmony" (Gunderson, 1963:79).

Along this line, Captain Shoemaker reported that at one of the small Antarctic stations seven of the men became depressed and dangerously withdrawn. The eighth man in the party is credited with the survival of the station by his conscious attempts to counter the deteriorating situation by daily cheerful contact with the others throughout the long winter.

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21. The following example illustrates the issue.

> The most spectacular instance of emotional disorder occurring in these isolated stations during this recent three-year period was a case of paranoid psychosis. Although the final specific diagnosis might be debated by psychiatrists of different backgrounds, there can be no doubt that this patient was overtly psychotic with paranoid delusions and assaultive behaviour. It eventually became necessary

to treat him with high doses of phenothiazine medications and isolate him from the other station personnel. It was later learned that he had ill-defined but probably similar, although less severe, problems in the past. It is significant that his delusions developed in a tense emotional milieu which was marked by conscious homosexual anxiety stimulated by a schizoid, effeminate and seductive member of the group. There was unusually heavy alcohol intake, chronic suspiciousness, and much hostility. It was a climate well designed to reinforce the unhealthy psychological defense mechanism of projection and thereby breed paranoia. The confined intimacy of these isolated groups encourages tendencies to projection, and paranoid feelings can occur. As might be expected, alcohol use makes them worse (Strange & Klein, 1973:414).

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22. There is a cultural component to extreme fears that is reflected in specific symptomology. For instance, at the turn of the last century many paranoid delusions involved mind control by electricity. This shifted to radio control during the 1930s, and atomic control immediately following World War II. The most recent manifestation has involved mind control via cable television.

Eighty years ago complications associated with appendicitis were a leading cause of death in the U.S. It is possible that in the Soviet Union fear of appendicitis still haunts people as it must have here in years past. Now, the foci of our fears tend to be the long-term implications of exposure to toxic substances. This, in turn, has implications for the medical and psychological support personnel for the proposed space station.

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23. At U.S. Antarctic stations and aboard submarines it has been found that although a physician is desirable in an emergency, a well-trained senior corpsman usually provides adequate on-site medical support. To a large extent, physicians have been dropped from crews not because they are not wanted, but because their services are required so infrequently that they lack satisfaction in their work. Crews appear to have as much confidence in the corpsman as they do in the young Navy doctors.

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24. The influence of culture is very strong. While most Americans believe we are entitled to **at least** one shower each day, in other countries daily bathing is considered to be a fetish. We are, of course, not alone in our concern for cleanliness and inoffensiveness. Professor Helmreich reported on the behavior of a British participant in an underwater habitat who felt compelled to scrub the wash basin each time before he used it.

Concerning the suggestion that individuals can be trained to accept different hygiene standards and practices, we need look no further than the military. Where water is scarce, sponge baths are common and they are commonly known as "GI baths" or "Navy showers."

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25. It is estimated that less than thirty seconds would be required to remove the water clinging to the walls of the chamber using a simple hand-held squeegee. The water would be moved with the squeegee to the base of the chamber near the air/water intake. Many Earthbound people use a squeegee in their showers to maintain spotless tiles and shower doors. In the space station there would be the added advantages of physical exercise and the elimination of the need for a complex engineering solution to the requirement of removing the water from the chamber following a shower.

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26. In 1968 Dr. T.M. Fraser of the Lovelace Foundation prepared an excellent discussion of the intangibles of habitability. The following information relevant to the topic of on-orbit water requirements is excerpted from that source.

> The prime requirements, then, in the maintenance of personal hygiene would seem to be the provision of an adequate supply of water, cleansing agents, facilities for their use, and capacity for changes of clothing. To allow for variations in threshold of subjective dirtiness it might also be necessary to outline a schedule of use. Of these, perhaps the most significant requirement is an adequate water supply. Ebersole (1960) points out that in the long-duration submerged missions of the nuclear submarines the incidence of skin disorders was negligible in comparison with that in the conventional submarines, and attributes the fact to the abundance of fresh water bathing available in nuclear submarines. Adequacy, however, is a relative term. Assuming optimal conditions, and the existence of as

yet undesigned facilities for the provision of showers and laundering in the weightless or reduced gravity state, guidance can be obtained from other experience.

Breeze (1961) lists the water requirements per man prepared by various organizations, as shown in Table 6. These show a range varying from a minimum of 10 gallons per day at Allied Military Advance Base in World War II to a maximum of 150 gallons per man day at USAF permanent bases. He also points out that a study of the record of several Navy ships over a 4-year period showed an average fresh water consumption per man day of 28.3 gallons, while IGY Antarctic personnel used about 11 gallons per man day in a facility which included hot and cold showers and a washing machine. He concludes that a realistic figure, with minimization of water requirements, would be in the region of 2-4 gallons per man day.

The Boeing Company (1966), in their study of requirements for earth orbiting missions of more than 45 days duration, have suggested a much lower figure, namely 8.5 lbs of water per man day, which is less than one gallon. For optimal conditions, however, this latter figure appears very low. Celentano, et al., (1963) suggests 6 gallons per man day. It seems probable that the optimal lies somewhere between 6 and 23 gallons.

TABLE 6a. COMPARISON OF WATER REQUIREMENTS

Organization	Gallons Per Man-Day
IGY polar expedition	11
Military advanced bases	
(World War II)	
Allied	10
United States	25
U.S. Air Force	
Permanent bases	150
Advanced bases	75
U.S. Navy	
Permanent bases	100
Advanced bases	25 to 50
Surface vessels	25
Submarines	20
Space system recommendation	6

TABLE 6b. CONSUMPTION OF FRESH WATER ABOARD SHIP

Organization	Gallons Per Man-Day
Drinking	0.5 to 1.0
Kitchen	1.5 to 4.0
Washing	5.0 to 20.0
Laundry	5.0 to 10.0

Source: Celentano and Amorelli

> It is not the purpose of this paper to discuss engineering solutions to these problems, which are indeed great. In viewing these matters from the point of view of habitability, however, it is evident that while man can obviously tolerate squalid conditions and maintain adequate performance over the period examined, while taking no active measures to maintain cleanliness, he does so in considerable discomfort and some potential hazard. How long the conditions described could be maintained is not known, although it might well be for a very prolonged period; but for optimal habitability it is desirable to provide optimal facilities for full personal hygiene, although it must be reemphasized that personal hygiene as practiced in the U.S. today is largely a cultural fetish, actively promoted by those with commercial interests; with suitable training these cultural compulsions could no doubt be reduced. As Mattoni and Sullivan (1962) remark, the man who can drink his own treated waste products is not as likely to feel dirty when he knows he is hygienically clean as is the average man.

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27. The following observations made during the IGY illustrate the importance of food in isolated groups.

> As might be expected, 'oral needs' were enhanced because of the absence of other basic gratifications. Appetite and consumption were enormous. Weight gains up to 20 and 30 pounds were not unusual and slight pot bellies on otherwise slender young men were notable. Fortunately, the cook was competent, imaginative, and very anxious to please. His prestige was enormous (Mullin and Connery, 1959: 294).

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28. At the Captain's discretion, submariners also enjoy the tradition of "splicing the mainbrace" (mixing fruit juice, etc., with ethyl alcohol) as a reward for group performance. Alcohol is considered to be an infrequent luxury aboard submarines, while cigarette smoking is allowed at all times. The reverse is apparently the case in the Royal Navy, where cigarettes are used as an infrequent reward for exceptional performance of a drill, and daily rum rations are issued.

In this regard, Cooper (1976) maintains that most of the Skylab astronauts would have preferred a drink with dinner "...and indeed there had once been a wine-tasting party at the Space Center for them to pick the one they liked the best." This plan was later abandoned.

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29. The following comments illustrate the constraints under which Skylab astronauts operated.

> We didn't try to eat together because of time constraints. We found it more efficient to eat otherwise. I think we would have probably enjoyed meals had we had the opportunity to eat together. If you're pressed for time and if you're trying to get a lot done, that's not the most efficient way. So, I have no complaints about the way we did it; it's just the way we had to work (Garriott in NASA February 1976:6-13).

> It's too easy up there in periods of high workloads to just let your meals skip. You tend to let that slide because it can slide and you'll end up all of a sudden finding you're eating lunch at 4:00 in the afternoon, which means not only have you taken a chance of dehydrating partially, but now you got another meal coming along in an hour or so which you're having a tough time in getting it down (Bean in NASA February 1976:6-13).

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30. Bender and Bracchia (1971:25-35) provide an interesting review of the relationship between communication and table shape and size. Also, Kleeman has prepared an excellent summary of the effects of table shape, suggesting that round tables are perhaps the most conducive to conversation; this is actually a function of the human eye's ability, "to fully comprehend facial expressions and facial muscle movements up to about a 66-inch distance, and the possible inability of the human eye to comprehend them beyond that distance" (1981:82).

Somewhat tangential to this issue, Seidel (1978) has traced the history of conflicts over table shape and seating position in diplomatic meetings and peace negotiations. Instances are described from the end of the Thirty Years War in

1640, the Turkish-Russian War in 1878, World War I in 1919 (Versailles), and at the conclusion of the Korean War in 1953. It is believed that the substitution of a round table for rectangular tables shortened the latter truce talks appreciably. Perhaps the most spectacular and certainly the most recent dispute of this type occurred preceding the negotiations to end the Vietnam War in 1969. This disagreement concerning table shape and size became so heated, Seidel reports, that a writer for the **New York Times** suggested that, "It is likely that the next winner of the Nobel Peace Prize will be a furniture designer." Originally, both the North Vietnamese and the U.S. negotiators proposed tables with right angles, rectangular and square; a round table was finally agreed upon and the negotiations began.

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31. It has been suggested that the station commander's quarters should be slightly larger than the other sleep chambers to reinforce the status and authority of the commander symbolically. To this, Professor Helmreich responded, "If the commander needs the symbolic value of a larger cabin, they probably didn't do a very good job of selection."

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32. Project RIM (Restricted Isolated Monotony) involved two and three-man crews of naval personnel isolated for 21 days at a time and performing vigilance tasks. Several interesting conclusions were reported by Donenfield (1970) including:

- The traditional military model with experienced leadership operated relatively efficiently in the worst possible conditions of the study.
- Senior leadership was more effective than junior.
- Compatible groups manifested less hostility toward partners, but were more annoyed with physical features of the habitat.

The conclusion that hostility may have been internalized or directed at physical features of the habitat rather than at fellow crew members is suggestive. This may help explain the tendency in isolated groups to react with hostility toward mission control or headquarters. To preserve group (crew) cohesiveness, aggression may be redirected to external sources of irritation such as the habitat or mission managers.

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33. In the **New York Times** of October 6, 1970, Walter Sullivan reported on the analysis of group dynamics conducted by two Soviet members of Thor Heyerdahl's international crew aboard the papyrus raft, **Ra** (Y.A. Senkevich and M.A. Novikov):

> The two Soviet scientists reported that, in their view, an international crew, in a situation of confinement, prolonged isolation, and peril was beneficial. Confrontation with common problems and dangers soon broke down the barriers rooted in nationality, they said, as when the raft began sinking and had to be lashed together.
>
> The patterns of alliance and hostility fluctuated, they reported, although Mr. Heyerdahl always retained his position of leadership and good relations with all. A commanding personality, in such a situation, is "extremely important" they said, and Mr. Heyerdahl well fulfilled that role.

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34. Pinks (1949), studying Air Force Arctic Loran stations, found that, in general, morale and efficiency were maintained at a higher level in those situations where living conditions and habitability were better. Demonstrating the inter-relatedness of the issues, however, he also found that morale and efficiency were higher with poor conditions and good leadership, than with good conditions and poor leadership.

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35. In a report concerning the behavioral, psychiatric, and sociologic problems associated with a two-year mission to Mars, Kanas and Fedderson offer the following discussion under the heading "Tension Reduction."

> The question of direct sexual release on a long-duration space mission must be considered. Practical considerations (such as weight and expense) preclude men taking their wives on the first space flights. It is possible that a woman, qualified from a scientific viewpoint, might be persuaded to donate her time and energies for the sake of improving crew morale; however, such a situation might create interpersonal tensions far more dynamic than the sexual

> tensions it would release. Other means of sexual release (masturbation, homosexuality) would be discouraged because of the confined quarters and the lack of privacy on such a mission. Thus, it appears that methods involving sublimation are more practical than these more direct alternatives (1971:38).

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36. Righter, et al., provide an interesting discussion of "perceptual richness" and several design suggestions. They begin their discussion with:

> Perceptual richness is the sensible variety offered by a given ambient. One method of providing perceptual richness is to vary the color, texture, and illumination of the surroundings. This can be done more easily if the basic interior color is white. White will pick up and reflect colors from the lights, act as a space expander, and provide a good background for bright color accents (1971:5-1).

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37. To summarize the effects of intensity, as considered by Tinker (1949), visual efficiency increases rapidly up to about 5 foot-candles, more slowly to 10, very slowly to 20, and by insignificant amounts thereafter, when the object to be discriminated occupies about 3-6 minutes of arc. When the object is smaller, vision improves perceptibly up to 40 to 50 foot-candles. The greater the brightness contrast, the better is the visual efficiency, and both acuity and speed of vision continue to improve slightly up to and beyond 100 foot-candles (Fraser, 1968a:45).

The following from the Skylab experience suggests that the subject of illumination for task effectiveness requires special attention in confined conditions.

> Local lighting was marginally adequate. In several areas, illumination levels were much less than handbook values, and portable lights were necessary. In some instances, switches were located so inconveniently that the crewmen "made do" without proper light rather than take the time to go to the switch panel in another area. Lack of local control of lighting sometimes interfered with scheduled activities. When an experiment was conducted that required the operator and experiment station to be in darkness, the entire experiment area and living area had to be darkened. Lighting and compartmentation did not allow sufficient localized control of light (Johnson, 1975:21).

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38. Participants in isolated and confined conditions which did not allow outside communications, such as Grumman's Ben Franklin submersible (Ferguson, 1970: Vol. III), typically recommend the capacity to improve overall habitability.

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39. "Some crews on Tektite enjoyed the two-way TV so much that they spent considerable leisure time just watching it. For this reason, some requested that it be installed in the crew's quarters instead of on the bridge" (Righter, et al., 197:7-3).

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40. Data collection for the Apollo telescope mount experiments was significantly increased in quantity and quality by the frequent and rapid uplink of solar activity data generated by the National Oceanic and Atmospheric Administration by weekly (and later daily) discussions between the scientist pilot (SPT) in orbit, the Principal Investigator (PI) or his representative, and the ground-based scientist astronaut. The SPT used special uplinked data on flares and coronal and disk transients to obtain data he would have otherwise missed. His discussions with the PI's and the ground-based scientist astronaut clarified changes in procedures and program priorities and informed him of the results of current data analyses. The PI's were informed of favorable opportunities for taking data on solar phenomena of interest (NASA, July 1974:90).

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41. The data were analyzed by counting the number of times an activity was indicated in the survey, then dividing the result by the number of subjects; the resulting fraction he termed the "relative frequency" of an activity. The following table presents the results of Eddowes' analysis.

Rank Order of Leisure Time Activities
(After Eddowes, 1961)

Rank	Activity	Relative Frequency
1.	Reading	.725
2.	Television	.300
3.	Musical activities	.275
4.	Manual activities	.213
5.	Playing bridge	.163
6.	Educational activities	.150
7.	Miscellaneous work	.125
--	Social activities	.125
9.	Travel and driving	.100
--	Family activities	.100
--	Photography	.100
12.	Sports	.088
--	Hunting and fishing	.088
14.	Gardening	.075
15.	Chess	.063
16.	Art activities	.050
17.	Playing golf	.038
--	Sailing	.038
--	Solving crossword puzzles	.038
--	Walking	.038
21.	Making models	.025
--	Attending movies and plays	.025
23.	All others	.025

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42. Eberhard (1967) defines scheduled off-duty time as that time **allocated** on a mission time line for crew members to engage in activities of their own choosing. Unscheduled off-duty time is time **available** during the course of a mission due to excessive allocation to scheduled activities or due to equipment or atmospheric problems which preempt scheduled activities. Excessive amounts of unscheduled off-duty time can have serious negative effects on performance and effectiveness since frequently there are inadequate activities to prevent personnel from becoming disturbed or bored.

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43. In a survey of actual and scheduled missions, Eberhard found that while the allotted (scheduled) off-duty time in mission planning is less than that which is common in the general population, off-duty time is greater due to unscheduled events or breakdowns, and faster than expected performance of scheduled tasks.

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44. The following table, adapted from Gunderson (1969:7) summarizes the results of his study of the hobby interests and leisure activity behavior among Antarctic research station members.

Rank-Order of Leisure Activity Means
(Early and Late) within Occupational Groups

Activity	Seabee		Technical Administrative		Civilian	
	Early	Late	Early	Late	Early	Late
Movies	1	1	1	1	1	1
Bull sessions (present job)	2	2	4	4	4	4
Bull sessions (past job)	5	4	5	3	6	7
Bull sessions (general)	12	12	10	10	8	8
Reading fiction	14	9	12	6	7	6
Reading biographies	20	17	20	16	20	15
Reading religious literature	16	18	17	20	16	19.5
Reading technical magazines	7	6	9	8	5	5
Studying courses	10	7.5	7	7	9	9
Ham radio	9	14	8	9	11.5	11
Writing letters	13	16	13	18	10	18
Physical exercise	19	15	15	12	15	10
Painting and drawing	17	20	16	17	17	19.5
"Happy Hour"	11	7.5	14	15	14	13
Cards	15	11	18	14	19	17
Chess or checkers	18	19	19	19	18	14
Pool or billiards	8	10	11	11	11.5	16
Classical music	6	13	6	13	2	3
Popular music	4	3	3	2	3	2
Western-country music	3	5	2	5	13	12
N	91	84	75	70	101	81

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45. Group morale could make extreme differences in perceived quality of life in any given habitat. The most relevant evidence for the importance of the development of group morale during leisure time would seem to come from reports concerning successful and unsuccessful isolated military and scientific outposts. Shared meals, film watching, and hobbies can become highly important to the men of such outputs. For example, in Thule Air Force Base in Greenland, "To counterbalance the low morale and high 'psycho' rate at Thule,

the Air Force built a hobby shop and stocked it for a variety of interests. Morale went up. An Air Force doctor stationed at Thule said, "We found that a good hobby is one of the best methods of "shock" prevention, because anything that will help pass a day at Thule is worth its weight in psychiatric couches." Other Air Force bases have reported similar occurrences (Righter, et al., 1971:9-24).

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46. Cooper reported that the time between eight and ten at night was supposed to be the astronauts' own to use as they pleased, but mission control invariably had something else for them to do following dinner.

> It got so that the astronauts had almost no leisure time at all, in spite of the fact that in the wardroom there was a sort of games cupboard, called the off-duty equipment assembly, which was filled with taped music, balls, darts, playing cards, and books. (Before the books--paperbacks selected by the astronauts themselves--had been allowed aboard Skylab, NASA had had to test them for flammability; some engineers at the Space Center had set fire to a number of books and found that--contrary to what a casual reading of history might indicate--they were extremely fire resistant. They turned out to be what one engineer called "great ablators," for one page had to be on fire before the next reached the kindling point; books even flake in a heat-dispelling manner, like the ceramic shields of spacecraft.) The astronauts had little chance to read a book and less to use any of the other off-duty equipment, with the exception of the taped music that they played constantly. Once, when Gibson was asked how he liked the games, he replied, "Off-duty activities? You gotta be kidding. There's no such thing up here. Our days off, the only thing that's different is that we get to take a shower" (1976:161-162).

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47. By the early 1990s, miniaturization of electronic devices and other developments may facilitate solutions to several space station problems, including the feasibility of leisure equipment.

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48. Other leisure activities, which have been reported as common among commercial oil field divers, include: gambling, crafts, (needlepoint, carving, and knife making), and planning investments. Apparently some divers also spend much of their leisure time sending for mail order items and items offered free in magazines. Most of these activities, of course, are inappropriate for the proposed space station.

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49. Cooper (1976) reported that when the Skylab 4 crew took a day off mid-mission, they spent much of that time gathered around the wardroom window watching the endless progression of sights below.

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50. Kinney, et al., report that,

> All of the studies to date agree that the average submariner, though healthy and without signs of pathology, exhibits specific visual characteristics that are somewhat below normal; these are poor distant vision, more myopia, more esophoria, and less accommodative power.
>
> Though there are undoubtedly many possible explanations of these findings, one (which has the advantage of providing a unitary reason for all the changes) centers on the confined environment of the submarine. It has been hypothesized that the small size of submarine compartments necessitates almost constant accommodation for near distances; this, of course, is in turn accompanied by binocular convergence (Alpern, 1962). The presumed result is a loss of ability to relax accommodation. Consequently, there is an increase in myopia and loss of distant visual acuity, and the two eyes begin to assume some degree of convergence in the resting position.

This explanation of the "submarine syndrome" (Schaefer, 1979:10) is supported by additional evidence of increased myopia and loss of visual acuity among the underground launch control crews for ICBMs (Greene, 1970).

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51. The following table provides dimensions and explanations for analogues and design studies cited in Figures 11 and 12.

Submarines	75" x 28" x 24" = **30.4** cubic feet
STS	72.8" x 30" x 26" = 32.9 - 1.9 = **31** cubic feet
Tektite I & II	72" x 28" x 30" = **35** cubic feet
Sealab II	78" x 28" x 30" = **37.9** cubic feet
Ben Franklin	78" x 29" x 30" = **39.3** cubic feet
Sat Chamber	76" x 30" x 31" = **40.9** cubic feet
Skylab 4	78" x 38" x 28" = **48** cubic feet
Skylab 4	78" x 48" x 29" = **62.8** cubic feet
Antarctic stations	6' x 12' x 7' = **504** cubic feet
Davenport (1963)	30 days min. vol. = **25/5** man x 180 days = **36;** 10 man x 80 days = **48** cubic feet
Boeing (1966)	Earth orbiting space station: 180 days = **70** cubic feet

Celentano (1963)	200 days: tolerance = **40**; performance = **75**; optimal = **134** cubic feet
Garrett (1966)	LESA (Lunar exploratory system) 180 days x **77** cubic feet
MDAC (1975)	MOSC (Manned orbital system configuration) 90 days x **80** cubic feet
MDAC (1982)	SAMSP (Science and applications manned space platform) 90 days x **80** cubic feet
Anacapa (1984)	Systematic comparative analysis 90 days x **84** cubic feet (3' x 4' x 7')
Airesearch (1971)	Habitability guidelines and criteria; 12 men x 180 days, 4 options: 5' x 7'6" x 6'6" = **244**; 5' x 7'6" x 6'3" = **234**; 4' x 5'6" x 6'3" = **138**; 3' x 5'6" x 6'3" = **103** cubic feet
Breeze (1961)	Space vehicle for "many months" = **120** cubic feet
MDAC (1971)	Modular space station (Phase B) 120 days x **120** cubic feet
Fraser (1968)	Lovelace/Intangibles study - "long duration" = **130** cubic feet
Fraser (1966)	60 days x **150** cubic feet
Loewy & Snaith (1972)	Earth orbital space station: 6'6" x 6'6" x 4' = **169** cubic feet
MDAC (1976)	SSSAS (Space station systems analysis and study) 90 days x **196** cubic feet
Matrix (1972)	Lunar habitability system: 6.75' x 6' x 6.3' = **255**; 6.75' x 5' x 6' = **202** cubic feet

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52. Perhaps rather than a window, a CRT displaying, upon command, images from the externally mounted video cameras would be adequate for the library. We have labeled this proposed facility the Ames library, and we believe it to be potentially the most valuable of our design recommendations.

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53. One of the most disruptive events possible aboard a submarine is the theft of a personal item from a bunk (many things are stored in and under the mattresses). Reportedly, the entire crew is offended.

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54. SEALAB was crowded. Had the capsule been bare of any equipment there would have been fewer than 70 square feet of space per man in this combined home and workshop under the sea. (The U.S. Navy recommends 90 square feet of floor space for each enlisted man's berthing area alone.) But the capsule was not bare, much of the floor space being taken up by bunks, stove, refrigerator, sinks, counters, gas and electrical monitoring equipment, showers, water heater, and so on. In addition, a large amount of necessary gear had to be stored within the capsule, such as wetsuits, and bulky gas bottles and Mark VI units, tools, equipment, scientific samples and food. Consequently, there was a shortage of space in which to move around, not to mention space for work and recreation. The major problem was the entry area. The crowded conditions in the entry were listed by the divers on the debriefing questionnaire as the number one problem in the entire operation. Their sentiments are summed up in the following two comments:

"That habitat is big enough to live in but it is not big enough to work in."

"There was too damn many men in this. I think ten is five too many. You get ten men in a confined space and you got problems, just getting in each other's way, more than anything else" (Radloff and Helmreich, 1968:73-74).

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55. Tektite aquanauts reported in interviews that they would have liked more individual and private working space, both for research and writing, and several mentioned that they would have appreciated opportunities for quiet reflection (Nowlis, Wortz, & Waters, 1972:6-2).

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56. Totally collapsible interior architecture has been suggested by some observers as the most efficient and flexible use of space. While the logic of this suggestion is compelling, we believe that the behavioral requirements involved (e.g., time constraints, noise insulation, privacy, territoriality, etc.) render daily interior reconfiguration unacceptable to long duration missions. Long-term flexibility of design, however, should be incorporated. Habitat design should acknowledge the dynamic and/or evolutionary nature of the system; what may be an appropriate design solution in the early stages of development may not be appropriate as the system matures.

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57. The following are the conclusions and recommendations resulting from architectural evaluation of Skylab sleeping quarters (NASA, July 1974b:21-22).

CONCLUSIONS/RECOMMENDATIONS

1. Private sleeping accommodations appear to be necessary, particularly for long missions.

2. The 0.71 meters (28 inches) by 0.96 meters (38 inches) cross sectional area of the Skylab sleep compartment is adequate for sleeping. The Skylab sleeping area floor to ceiling height of 1.98 meters (78 inches) appears to be marginal.

3. A personal stowage compartment suitable for restraining and stowing small pocket items should be available in the sleeping area. Incorporating a writing surface into this unit would be highly desirable.

4. Stowage provisions should be provided in each sleep area for the clothing worn during the day which will be redonned the following day.

5. The individual sleeping areas need to be made reasonably sound and light proof to permit crewmen to sleep while others are awake and moving about.

6. The individual sleeping areas need to be, in general, cooler than the general working volume. 75° F appears to be a maximum comfortable sleeping temperature. An individual variable air diffuser appears to be an excellent method for permitting the crewman to vary the sleeping area temperature to his own satisfaction. However, the air flow should not be directly upon the sleeping crewman.

7. An individually controlled light should be installed in each sleep area.

8. The practice of providing air-to-ground communications in each sleep area should be continued.

9. Provisions for off-duty music tape players should be provided in each sleep area.

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58. Reportedly, astronauts aboard the current STS mission (41-F) have resorted to use of Apollo-style adhesive bags. On previous missions, clouds of fecal dust generated by the zero gravity toilet have caused some astronauts to stop eating in order that they reduce their needs to use the facility. Clearly, these are unacceptable solutions for both short duration and long duration space missions.

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59. Hence the submariner's term "sea-going sewer pipes" to describe their craft.

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60. Synopsis of Weight and Volume of Biological Waste Generation From All Sources in the Closed Environment of a Manned Space Vehicle.

Values are given per man per day:

	Mass/Grams	Volume/ Milliliters
Miscellaneous Cabin Compounds	0.700	0.720
Food Spillage	0.700	0.700
Desquamated Epithelium	3.000	2.800
Hair-Depilation Loss	0.030	0.030
Facial-Shaving Loss	0.300	0.280
Nails	0.010	0.010
Solids in Sweat	3.000	3.000
Sebaceous Excretion-Residue	4.000	4.200
Solids in Saliva	0.010	0.010
Mucus	0.400	0.400
Seminal Fluid-Residue	0.003	0.003
Urine Spillage	0.025	0.025
Fecal Particles	0.025	0.023
Flatus as Gas		2,000.0
Microorganisms	0.160	0.140
Solids in Feces	20.0	19.0
Water in Feces	100.0	100.0
	Mass/Grams	Milliliters
Solids in Urine	70.0	66.0
Water in Urine	1,400.0	1,400.0
Insensible Water	1,200.0	1,200.0
TOTAL	2,802.363	2,807.341
TOTAL EXCLUDING URINE, FECES, FLATUS, AND INSENSIBLE WATER	12.363	12.341
TOTAL SOLIDS	102.363	97.341
TOTAL WATER	3,700.000	3,700.000
TOTAL GAS		2,000.000

Sources: Mattoni and Sullivan (1962) and Fraser (1968a).

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61. In addition to specific exercise, hygiene, and food preparation requirements demanded by the absence of gravity, there are several related yet unresolved issues associated with a weightless condition. These include the design of consoles to effectively accommodate personnel in a neutral gravity position, the design of workbenches to hold small parts in place, development of foot restraints, eating utensils, and storage/labeling systems to name a few.

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62. Evidence for this interpretation has been provided by anecdotes from STS missions. For instance, an astronaut who was focusing on an object in his hands while upside-down with respect to the orbiter's interior orientation, suddenly felt nauseous when he looked up and found that he had drifted into a vertical orientation. It appears to this observer that discrepancies between expectations and reality play key roles in the onset of space adaptation syndrome.

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63. Many observers have commented on this phenomenon. Gunderson provides the following examples.

> ...minor emotional problems are not uncommon during the winter months. Stress and tension may arise from or be expressed in incidents of interpersonal friction, some of which seem to be triggered by trivial events, as illustrated by the following excerpts from station leaders' logs:
>
>> One civilian's coffee cup had become so dirty that I threw it in the garbage can. We had soup for evening meal and he used his cup. After finishing his soup he hung his cup in the rack without cleaning it. About an hour later he found the cup and he wanted to know why I had put it where I had. I told him why whereupon he lost his temper and started acting like a child.
>>
>> Morale not very good. C-- who has generally been in good spirits was antagonized by the scientific leader over an inconsequential matter. Later C-- after drinking, finally departed for the summer camp because "he couldn't stand anybody any longer."

Some degree of emotional regression is suggested by occasional temperamental displays:

> Cook's at it again. He's moody, definitely emotionally immature. Threw a lemon pie and cookies all over the galley the other day, then went to his room for a couple of days and wouldn't come out (1973:150).

----

64. Extreme withdrawal, or "cocooning," reflects an inability to adjust to the conditions and can seriously affect morale and performance. Dr. Howard uses a drug analogy to describe the function of privacy: "too little doesn't work, and too much can be harmful. It's a matter of providing the optimum dose."

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65. Clearly, the shuttle crews to date have performed admirably despite repeated problems with their onboard toilet facilities. We cannot, however, expect long duration crews to endure similar conditions without significant effects on performance and morale. The extended duration of the tours proposed for the space station is a factor, but perhaps more important will be the relative anonymity of space station crews. The rewards, primarily in the forms of personal satisfaction and recognition, which are received by current astronauts, will not accrue to space station personnel. There will be more of them and recognition will be diffused; anonymity will be the result of routine operations. Obviously, this factor will play a key role in personal perception of all issues associated with habitability.

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66. There are many additional issues associated with isolation and confinement. Though the issue of personnel selection is beyond the scope of this study, it has been the focus of most research concerned with isolated and confined groups. That is, the Navy's principal concern has been to determine the constellations of personality traits that reflect abilities to adapt to the extreme environments of submarines and Antarctic stations. Only tangentially have research efforts addressed the conditions which cause stress in those isolated and confined environments.

Concerning personnel selection, Dr. Weybrew offered the following relevant item.

> The selection of men for hazardous duty during aerial or submarine war patrols or space flight involves a dilemma alluded to in a list of recommendations submitted by the officers of the submarine **Puffer** (No. 1), after having been exposed to 203 depth charges (Duff, 1947, p. 80).
>
> > Be careful and slow to form an estimate of a man's value until he has been observed under stress. To a great extent the men who were on their feet, working to save themselves and the ship, when the long dive was over, were not the normal leaders of the crew. The people who lasted out were those of a more phlegmatic disposition who didn't bother too much when things were running smoothly. The worriers and the hurriers had all crapped out, leaving the plodders to bring home the ship (Weybrew, 1963:108).

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APPENDIX A

RESEARCH INSTRUMENT USED IN THE EVALUATION OF ALTERNATIVE ANALOGUES

* * SIZE OF GROUP * *

NASA Space Station: Since the construction of a NASA space station would be an evolutionary process, we have selected the range of 6 to 12 persons for our definition. We assume a resident crew of 8 within two years of station deployment.

1	2	3	4	5	6	7
Not Close to Target Conditions						Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: The size of groups wintering-over at the four U.S. stations has ranged between eight and 30 personnel in recent years. The average size is 16, and the mode is 20. During the four summer months, as many as 1,000 Americans live and work in Antarctica; during the eight-month winter, fewer than 100 remain in isolation and confinement. For our purposes, we will assume a group size of 20, the most recent number to winter-over at the South Pole station.

Sealab II: Three 10-man teams.

Tektite I: Four.

Tektite II: Five.

Commercial Oil-Field Diving: The size of the group varies with the job. The most common group size is seven (six divers and one tender).

Submarines (FBN): Crew size of ballistic missile submarines ranges between 133 and 168 personnel depending on vessel class; 140 is most common.

Ra Expedition: Eight.

Long-Distance Yacht Racing: Twelve.

Commercial Fishing Vessels: Crew size ranges from two to six persons; four is most common.

Research Vessels (Coastal): Twenty-three.

Supertankers: Supertanker crew sizes range from 29 to 40 persons. The "Ardshiel's" crew was at the lower end of this range due to a high degree of on-board automation (e.g., only the day shift of the engine room was manned).

Offshore Oil Platform: Approximately 60 personnel of various categories.

Skylab 4: Three-man crew.

* * COMPOSITION OF GROUP * *

NASA Space Station: It is expected that composition of station crews under routine conditions will be somewhat mixed in terms of sex, age, ethnicity, education, and work history.

1	2	3	4	5	6	7
Not Close to Target Conditions						Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: Approximately one-half of those wintering over are civilian scientists (meteorologists, geologists, and biologists) and one-half are Navy personnel. The Navy group is composed of about equal numbers of Seabees (construction, logistics, and maintenance responsibilities) and administrative/technical positions (coordination and communication responsibilities). The educational backgrounds range from high school to advanced degrees. The range of participants' ages is 18 to 45 years; most are in their 20s or 30s.

Sealab II: Teams were composed of civilian and military divers, scientists, and salvage experts. "The men were as varied as the occupational backgrounds, ranging in age from 24 to 50, and in educational achievement from less than ninth grade to graduate degrees" (Radloff & Helmreich, 1968:2). There were 16 Navy enlisted men, two Navy officers, and 10 civilian participants--a total of 28 with two men participating in two teams each.

Tektite I: The group was composed of four male marine scientists, between 31 and 35 years old, from the Department of the Interior. One of the men held a Ph.D. degree, two others held Masters degrees, and the fourth held a Bachelor's degree.

Tektite II: A total of 40 scientists and eight engineers participated. There were five subjects in each mission (four scientists and one engineer). The five 20-day missions were organized as two sets of three missions, with four engineers serving for 30 days each and rotating at the halfway point to each set. There were also four missions of 14 days duration. One mission was conducted by five women. The ages of participants were between 23 and 45 years.

Commercial Oil-Field Diving: Most divers are in their 20s. A diver is considered old at 30, although some are in their 40s. Many are former Navy Seals; others have graduated from technical schools specializing in commercial diver training.

Submarines (FBN): Approximately 14 officers and 126 enlisted personnel are required; no female crew. Composition is mixed in terms of educational background. "Perhaps nowhere in the military service are there found so many small, clearly delineated, almost impermeable subgroupings as are found among the 80 to 170 men making up the crew of a submarine" (Weybrow, 1963:98).

Ra Expedition: The crew was composed of one Norwegian adventurer/author, one Italian photographer, one Japanese photographer, one Mexican anthropologist, one American amateur oceanographer, one Egyptian chemical engineer/frogman, one Russian doctor, and one Chaddian papyrus boat builder. All were males.

Long-Distance Yacht Racing: The crew was composed primarily of Americans, but representatives of Sweden, France, the Netherlands, Mexico, and England were also included. There were no female crew members aboard, although other vessels in the race carried female crew.

Crew composition was mixed, consisting of businessmen, professional sailors, a boat builder, a chef, and others whose background we were unable to determine.

Commercial Fishing Vessels: Composition is frequently mixed in terms of educational background, work history, sex, ethnicity, kinship, and fishing experience.

Research Vessels (Coastal): The group consisted of one marine scientist, one marine technician, ten graduate students, the vessel's captain, and ten crew members. The crew ranged in age from the late 20s to early 60s. All had previous experience as either merchant seamen or commercial fishermen before working aboard a research vessel; some had college training. For many of the graduate students, it was their first experience of working on the ocean. All crewmen were males; the marine scientist was also male; the remainder of the "scientific staff" was composed of approximately equal numbers of male and female students.

Supertankers: The crew of the "Ardshiel" consisted of 14 general purpose seamen (GPs) and 15 officers (officers include engineers, navigators, electronics technicians, and ships officers). The P&O is Britain's largest shipowner and they follow the tradition of employing primarily Indian, Pakistani, and some Chinese crews under British officers. There are very few female crew members, although females represent about 6% of American tanker crews, mostly unlicensed personnel.

Helmreich maintains that "the modern domestic merchant seaman by no means lives up to the stereotype of the uneducated, aggressive social outcast...the group is relatively well-educated, with officers being better educated than the unlicensed. Indeed, the majority hold degrees from maritime academies."

Offshore Oil Platforms: Personnel working on Platform Hondo range in age from early 20s to over 70 years old. The vast majority, though, are of two age groups, about 35 and about 52, corresponding to recruitment during the two major periods of domestic oil exploration in the industry's recent history. Educational backgrounds range from high school through graduate programs. The platform requires chemists, engineers, mechanics, and administrators, in addition to the roustabouts who perform the general purpose heavy-duty labor associated with rigging and drilling for oil. Several women currently work aboard Hondo as technicians and supervisors; it is estimated that about 8% of the offshore work force are women.

Skylab 4: The crew consisted of one Marine Lieutenant Colonel, one Air Force Lieutenant Colonel (both pilots), and one civilian physicist (Ph.D.).

* * FORM OF SOCIAL ORGANIZATION * *

NASA Space Station: It is assumed that the form of social organization that has evolved within NASA for STS missions will be applied to the organization of work aboard a NASA space station. That is, a quasi-military structure with a commander, mission specialists, and payload specialists.

1	2	3	4	5	6	7
Not Close to Target Conditions						Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: There is a Navy and a civilian group leader at each station.

Sealab II: One group leader and nine subordinate crew members per team.

Tektite I: Group leader and three subordinate aquanauts.

Tektite II: Group leader and four subordinate aquanauts.

Commercial Oil-Field Diving: All operations are controlled and directed by the superintendent of the barge and the supervisor of the diving company. The latter is responsible for the divers, tenders, and the instrument technicians who monitor and control the life support systems for divers while in the water and while in the pressurized deck chamber. Among the divers, a seniority system based on time with the diving company determines relative authority.

Submarines (FBN): Hierarchical, military command structure.

Ra Expedition: Heyerdahl served as expedition leader. Each of the others had situation-specific authority: photographer, quartermaster, navigator, underwater expert, medical officer, and papyrus expert.

Long-Distance Yacht Racing: At sea the skipper is responsible for resolving the controversies that arise, whether they be questions of tactics or questions of who gets next turn at the shower. The watch captains ensure the safety of the yacht and make certain that each watch is sailing her as efficiently as possible. Each watch has a navigator's observer in addition to the skipper/navigator in order to have an hour-by-hour information back-up for making tactical decisions. On "Alaska Eagle" everyone is invited to speak with an open mind, but everyone has to be ready to accept the final decisions as the skipper makes them.

Commercial Fishing Vessels: Vessel captain and subordinate crew. Occasionally a respected or experienced crew person may have considerable influence in decision-making, especially if it is the skipper's wife.

Research Vessels (Coastal): There are two distinct groups aboard a research vessel: the crew and the scientific staff. There is usually one chief scientist whose project is the reason for the cruise. He or she directs the activities of all subordinate scientists, graduate students, and technicians. Crew personnel operate all deck machinery and maintain the vessel under the direction of the captain; each crew member has one or more specialist functions as well as more general responsibilities (such as standing watch).

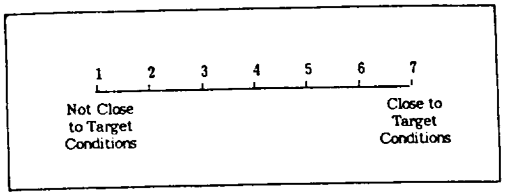
Supertankers: The form of on-board social organization retains the customary hierarchical structure characteristic of voyaging through the ages. Conditions have begun to change, however. Increasingly, captains receive orders throughout a voyage from the line's home office; a vessel may change its intended destination several times due to fluctuations in the price of crude. Also, captains are increasingly considered by shipping lines to be managers, rather than traditional captains of ships.

Offshore Oil Platform: The field superintendent is responsible for overall platform operation. The field foreman answers to the superintendent and coordinates the activities of several subordinate foremen (e.g., maintenance, operations, etc.). Drilling, transportation, food preparation, and other services are provided by contractors or vendors, the activities of whom are coordinated by the superintendent.

Skylab 4: Skylab had a hierarchical organization: mission commander, pilot, and science pilot. Direction was received from ground control personnel.

* * DURATION OF TOUR * *

NASA Space Station: We anticipate tours of 60 to 90 days under operational conditions. Schedules of personnel rotation cannot be specified at this time.



Evaluation Scores:

Antarctic Research Stations: A total of 13 months: one month in transit, four months of summer, and the eight-month winter-over. For our purposes, we will only consider the eight-month period.

Sealab II: Fifteen days for each team. One man from Team I remained to continue with Team II. One man from Team I joined Team III.

Tektite I: Sixty days.

Tektite II: Twenty days and fourteen days.

Commercial Oil-Field Diving: The durations of tours vary with operational requirements and individual company policy. Most responsible firms limit their divers to 30-day tours; some diving companies allow 120-day tours. Longer durations under pressure and humidity increase the incidence of infections.

On a 30-day tour working at a depth of 250 feet, a diver will spend 27 days working and three days in decompression. At 1,000 feet the diver can only work for 15 days, since 15 days decompression is required. For our purposes we will assume a 30-day tour in isolation and confinement.

Submarines (FBN): Each submarine is assigned two alternating crews designated "Blue" and "Gold." Each crew mans the vessel during a 60-day patrol and partially assists during the intermediate 28-day refit alongside a tender.

Ra Expedition: From Morocco to Barbados in 57 days.

Long-Distance Yacht Racing: The distance traveled by race participants is about 27,000 miles. There are four legs, or segments, to the journey and each is over 6,000 miles long: 1) Portsmouth, England to Cape Town, South Africa; 2) Cape Town to Auckland, New Zealand; 3) Auckland to Mar del Plata, Argentina, and 4) Mar del Plata to Portsmouth. The entire journey requires about eight months to complete, but port time is subtracted from total time to calculate corrected or racing time. Most vessels that finish the race spend a total of between 135 and 170 days under sail. The duration between ports is about six to seven weeks.

Commercial Fishing Vessels: Trips range from 60 to 90 days.

Research Vessels (Coastal): When conducting coastal research, cruises are usually between one and ten days duration. Deepwater cruises range between 21 and 70 days in length. For our purposes we will consider a five-day cruise to be a typical tour for a smaller research vessel engaged in coastal studies.

Supertankers: Supertanker voyages are the longest unbroken sea journeys since the days of sail. The two routes for which supertankers were principally designed are: 1) Persian Gulf to Europe via the Cape of Good Hope, and 2) Persian Gulf to Japan via the Straits of Malacca. The distances traveled are over 11,000 miles, or roughly equal to a circumnavigation of the globe. At a speed of 14-15 knots, the journey is about 10 weeks long, occasionally longer. The voyage between the Gulf and North America takes about the same time.

Because loading and discharging of oil is conducted at offshore terminals, it is not uncommon for crew to spend a year or more without setting foot on land (much longer periods are frequently reported). The policy of most American carriers is to limit crew personnel to two consecutive voyages (five to six months), separated by six weeks to two months of leave.

Offshore Oil Platforms: Schedules for regular employees are seven days on, followed by seven days off; all work 12-hour shifts.

Skylab 4: The duration of Skylab 4 was 84 days. Missions 2 and 3 were 28 and 59 days, respectively.

* * TYPE OF TASKS * *

NASA Space Station: Although specific information regarding the tasks involved in zero-gravity electrophoresis and materials processing are clouded by proprietary issues, we may safely assume that most onboard tasks performed by station crew will be of a vigilant and hand manipulative nature. Repair and replacement of components may be a frequent function. Extra vehicular activity (EVA) to service unmanned platforms and satellites, which is quite strenuous, will also be required.

1	2	3	4	5	6	7
Not Close to Target Conditions						Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: Work activities include habitat maintenance (generators, heating and ventilation, etc.) scientific laboratory work, brief field trips in winter gear, housekeeping, food preparation, and administrative tasks.

Sealab II: During their tours, divers worked on such tasks as salvaging a sunken jet airplane, conducting censuses of marine life, studying current, water temperature, and visibility, experimenting with underwater acoustics, evaluating the effectiveness of a trained porpoise, and testing a variety of experimental equipment. The aquanauts also served as subjects for both physiological and psychological research.

Tektite I: Direct marine research, primarily in the water using scuba and hooka gear, involved tagging lobsters, observing lobster and fish behavior, and taking measurements for a geological map (432 man-hours were spent in the water). Marine science support encompassed such activities as filling tanks, preparing for and securing from dives, reading reference materials, and handling equipment logistics with topside personnel. Biomedical-behavioral science activities included completion of mood-adjective checklists and testing with the Langley Complex Coordinator (psychomotor device). Habitat maintenance activities included monitoring gauges, standing watch, repairing equipment, and replacing the baralyme in the CO_2 scrubber. Housekeeping and food preparation tasks were also performed.

Tektite II: Direct marine research, primarily in the water using scuba and hooka gear, involved tagging lobsters, observing lobster and fish behavior, and taking measurements for a geological map. Marine science support encompassed such activities as filling tanks, preparing for and securing from dives, reading reference materials, and handling equipment logistics with topside personnel. Biomedical-behavioral science activities included completion of mood-adjective checklists and testing with the Langley Complex Coordinator (psychomotor device). Habitat maintenance activities included monitoring gauges, standing watch, repairing equipment, and replacing the baralyme in the CO_2 scrubber. Housekeeping and food preparation tasks were also performed.

Commercial Oil-Field Diving: Underwater tasks include welding, cutting, studding flanges, inspection, and other construction activities. No housekeeping or food preparation tasks are performed.

Submarines (FBN): Tasks include administration, equipment maintenance, monitoring, standing watch, radio operation, housekeeping and food preparation functions.

Ra Expedition: Tasks included vessel maintenance, food preparation, fishing, photography, standing watch, manipulating the sail and steering oar, radio operation, and navigation.

Long-Distance Yacht Racing: Tasks include manually hauling and setting of sails and other sailing gear, equipment maintenance (both preventive and corrective), navigation, communication, housekeeping, food preparation, and administration.

Commercial Fishing Vessels: Tasks include equipment maintenance (engines, electronics, and refrigeration), monitoring of electronic gear (sonar, radar, RDF, and radios), preparing meals, housekeeping functions, food preparation, operating hydraulic fishing gear, and stowing fish in the refrigerated hold.

Research Vessels (Coastal): Crew tasks include maintaining and operating all machinery (main and auxiliary engines, refrigeration, deck winches, etc.), communications, navigation, food preparation, housekeeping, and administration. Tasks performed by scientific personnel include maintenance of scientific equipment (e.g., core sampling rigs), deployment and retrieval activities, inspection and analysis, housekeeping, and administration.

Supertankers: On-board tasks include standing watch, navigation, electronics and communications work, machine operation and maintenance, inspection of equipment, housekeeping and cooking, and administrative functions. The inspection of empty tanks on the return trip to the Gulf requires special mention. Small groups descend the 90 feet to the bottom of each tank to ensure the proper operation of valves and other equipment. The atmosphere in the tanks is always noxious and potentially explosive.

Offshore Oil Platforms: Tasks include heavy equipment rigging and operation, inspection, monitoring, chemical analysis, electrical and mechanical maintenance, housekeeping, food preparation, communications, and administration.

Skylab 4: Tasks included biomedical experiments, life sciences experiments, earth resources monitoring, visual inspection, photography, astronomical observation, communication, maintenance, housekeeping, food preparation, and administration. Astronauts ventured outside the spacecraft only during Missions 2 and 3.

* * PREPAREDNESS FOR MISSION * *

NASA Space Station: It is expected that a great degree of preparation for space missions will continue to play a substantial, yet diminishing role in the future. Space station crews are likely to be at the extreme on this dimension compared to all other analogous conditions.

1 2 3 4 5 6 7

Not Close to Target Conditions — Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: Each group usually includes a few men with polar experience. For the most part, though, participants have never experienced anything like an Antarctic winter. Also, Navy personnel receive some technical training, and scientific staff receive an orientation concerning conditions to be expected. The Navy is responsible for psychological screening of potential winter-over personnel.

Sealab II: The average diving experience of Sealab II aquanauts was 11 years.

Tektite I: All participants had extensive diving experience. There was a one-week training and medical testing program prior to the mission.

Tektite II: All participants had extensive diving experience. There was a one-week training and medical testing program prior to the mission.

Commercial Oil-Field Diving: All divers have had some formal technical training. Also, most have spent between two and four years as a tender, or apprentice, before "breaking out" into diving. The turnover rate is very high in the profession.

Submarines (FBN): Potential submarine crewmen must pass at least six selection and training hurdles before they are qualified for active duty. These include preselection (eliminating 10-50% of volunteers), physical exams/aptitude screening (10-20% attrition), escape training (1-5% attrition), basic s/m school (5-20% attrition), advanced s/m school (0-2% attrition), submarine qualification (5-12% attrition).

Ra Expedition: Only Heyerdahl had previous similar experience (Kon-Tiki, 1947), and the American serving as navigator was the only crew member with sailing experience. The crew members were either acquaintances of Heyerdahl's or substitutes for acquaintances. Most met for the first time a few days prior to departure. No training was involved.

Long-Distance Yacht Racing: Most crew are experienced sailors, but typically few on any vessel have had exposure to around-the-world racing. The skipper and most core crewmen generally spend several weeks or longer together prior to the race in planning, shakedown exercises, and learning to work together as a team.

Commercial Fishing Vessels: Crew personnel vary in their fishing and related skills from novice to expert. Also, some crews may be very familiar with a particular vessel and/or skipper, having fished together for years, while others may join the boat for the first time moments before a trip.

Research Vessels (Coastal): All crew members are licensed seamen. Since there is little turnover, the crews of most research vessels have worked together on many previous cruises.

Of the scientific personnel, usually only the chief scientist has had much experience at sea. Frequently, the members of the scientific staff meet for the first time the morning the cruise begins.

Supertankers: Most personnel aboard supertankers have considerable seafaring experience. Formal training for officers is most complete, but crews also receive training from the shipping lines in safety and emergency procedures. Since the turnover rate is relatively high, the concept of a permanent crew does not apply.

Offshore Oil Platforms: Personnel range from recent hires with no previous experience to some who have worked in oil-fields around the world. The company provides training in fire, gas, and blowout prevention, emergency procedures, maintenance, and operations. There are daily 15-minutes safety meetings and weekly fire and evaluation drills.

Skylab 4: All personnel were professional astronauts. Each had undergone extensive training and simulation in preparation for the mission.

* * PERSONAL MOTIVATION * *

NASA Space Station: It is anticipated that there will be many more volunteers for positions aboard a space station than there will be positions available. It is also assumed that government pay scales are not primary motivating factors for application. For these and other reasons, it is assumed that the personal motivation of crew personnel will be other than financial.

1	2	3	4	5	6	7
Not Close to Target Conditions						Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: The prospect of scientific discovery is a paramount motivation for scientific staff. Navy personnel frequently cite the opportunity to earn and save money as their primary reason for volunteering for Antarctic duty.

Sealab II: Project Sealab II had great potential significance in terms of the history of diving and as a contribution to the future development of offshore resources. Sealab was national news and personal career benefits were anticipated by most participants; diving pay was received by participants for the entire duration of the project.

Tektite I: The divers in Project Tektite I were eager volunteers. While previous saturation diving programs had included marine science projects, this was the first habitat experiment designed to collect marine science data as a primary objective. All divers expected to receive benefits to their careers as well as additional pay for their participation.

Tektite II: All participants were eager volunteers.

Commercial Oil-Field Diving: Personal motivations include a desire for high status (in certain regions and subcultures divers are "superstars"), and for travel (oil-fields around the world employ the services of diving companies). Clearly, though, the most salient motivation is financial. Divers can make over $100,000 per year. Most opt for a six-month schedule and make about $60,000 in that time.

Submarines (FBN): The reported reasons for volunteering for the submarine service are (in decreasing order of frequency mentioned by a large group of enlisted men), "pay, good food, and opportunities to learn interesting skills." It is also understood that men volunteer and later reenlist largely because of the personal satisfaction of belonging to a closely-knit, high-status group and because of the privilege of wearing the coveted dolphins, the emblem of the submarine service.

Ra Expedition: Motivation of individual crewmen included: direct financial gain, indirect financial gain (material for a book, sale of photos, etc.), adventure, recognition, "scientific" merit, and politics.

Long-Distance Yacht Racing: For all participants, but especially for the skippers, the race is a very serious undertaking. They want to win. "And what about the crews? What are they racing for? For most, the answer has to be the physical challenge and the knowledge that, after it is over, you have stood up to whatever the southern ocean has thrown your way... I guess most of all it is the adventure" (Mason, 1981:14).

Commercial Fishing Vessels: For most, the motivation is financial, tempered by a desire to be at sea, work outdoors, or get away from something or someone on land.

Research Vessels (Coastal): Crew members of research vessels tend to be very interested in the marine research conducted by the scientists. Most could (and have) earned considerably more money as seamen aboard merchant ships, but they prefer the shorter trips (many can spend their weekends at home), and the stimulating environment aboard a research vessel. Crew morale on small vessels of this type is noticeably good.

The motivations of scientific personnel are primarily of a career, scientific, and academic nature. Many have selected marine sciences in response to a long-term interest in the ocean.

Supertankers: Motivation is primarily financial; a relatively high rate of pay with no opportunity to spend it attracts many to the profession. Others are attracted by the isolation from society offered by long voyages.

Offshore Oil Platforms: Many have chosen offshore work because of the challenge, and others have chosen it to avoid onshore concerns. For the most part, though, the incentive of good pay is the primary motivator. Entry-level roustabouts can make well over $30,000 per year for 26 weeks of work.

Skylab 4: No references to the personal motivations of Skylab astronauts have been located in the literature. It is assumed that crew motivations were other than financial and were probably similar to those of current astronauts.

* * HOSTILITY OF OUTSIDE ENVIRONMENT * *

NASA Space Station: Without mechanical means, human life cannot be supported in the environment outside the space station.

1 2 3 4 5 6 7

Not Close to Target Conditions — Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: The average annual temperature at the South Pole Station is -60°F. Under normal wind conditions at this temperature, exposed flesh freezes in 30 seconds or less. Temperatures drop to -112°F during the winter.

Sealab II: Sealab II was located at a depth of 205 feet of water off La Jolla, California. Visibility in the water was poor; the temperature ranged between 47° and 56° F--debilitatingly cold. Dangerous marine life was also a problem.

Tektite I: The habitat was at a depth of 49 feet in Great Lanreshur Bay, St. John, Virgin Islands. The water was clear and relatively warm (about 65°). Dangerous marine life was a problem.

Tektite II: The habitat was at a depth of 49 feet in Great Lanreshur Bay, St. John, Virgin Islands. The water was clear and relatively warm (about 65°). Dangerous marine life was also a problem.

Commercial Oil-Field Diving: In addition to the great depths and pressures experienced by commercial divers, in most cases visibility is very poor. Much of their work, including inspection tasks, must be conducted by touch rather than by visual orientation.

Submarines (FBN): Sixty days of each tour are spent submerged.

Ra Expedition: The Ra endured several storms in its crossing (using a square-rigged sail and no auxiliary power). Although few ships were seen, while crossing shipping lanes at night they were exposed to the possibility of being run down by merchant ships.

Long-Distance Yacht Racing: Following old clipper ship routes, some of the roughest waters of the world's oceans are crossed in the Whitbread race. Water temperature in the southern seas can reach as low as 33°F--deadly cold.

Commercial Fishing Vessels: The Mid-Pacific albacore fishery is conducted in both fair and foul weather, with no landfall until the hold is full or until the fuel or food is low.

Research Vessels (Coastal): Although the vessels are sturdy and safety precautions are observed, the sea always provides a dangerous environment for human life.

Supertankers: Obviously, the oceans of the world provide an environment hostile to human life. The primary routes traveled by supertankers include some of the most dangerous seas and straits known to navigation.

Offshore Oil Platforms: The Santa Barbara Channel is relatively protected and does not suffer from storms as severe as those experienced in the tropics or in the North Sea. The ocean, however, does provide an always dangerous environment for human life.

Skylab 4: The void of space.

* * PERCEIVED RISK * *

NASA Space Station: Exposure to risk will be substantial. In addition to the risk of system failures, we must consider the potential for micrometeorite collision, solar flare danger, and critical human error. The possibility exists that personnel will be required to spend a maximum of 21 days in an onboard "safe haven" awaiting rescue from a catastrophic incident.

1	2	3	4	5	6	7
Not Close to Target Conditions						Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: The primary sources of danger are accidents while working outdoors. Accidental deaths are not uncommon among those participating in Antarctic research.

Sealab II: Due to the depth and duration of the dive, the aquanauts breathed an exotic gas mixture under pressure. The aquanauts were subject to danger from equipment failure and human error which could have resulted in fatal or disabling accidents. (Sealab III was actually terminated as a result of a fatal accident.) Most Sealab II divers developed ear infections and skin rashes during their tours.

Tektite I: Due to the duration of the dive, the aquanauts breathed an exotic gas mixture under pressure. The aquanauts were subject to danger from equipment failure and human error which could have resulted in fatal or disabling accidents. All participants developed ear infections during the project.

Tektite II: Due to the duration of dive, the aquanauts breathed an exotic gas mixture under pressure. The aquanauts were subject to danger from equipment failure and human error which could have resulted in fatal or disabling accidents. All developed ear infections during the project.

Commercial Oil-Field Diving: The risk of personal injury or death is incredibly high. In addition to the bends, there are at least a dozen ways to die from the extreme atmospheric pressures under which the divers must work. Most fatalities are the result of human error by the diver, by the instrument technician, or by the diving supervisor. Approximately 3% to 5% of working divers die each year on the job.

Submarines (FBN): Submarine service is considered to be hazardous duty. In addition to the hostile outside environment, crew are exposed to potential injury and death from both human error and equipment failure. The presence of a nuclear reactor and nuclear missiles on board is a concern to many crew personnel.

Ra Expedition: The crew risked death and serious injury, mostly from drowning, on a daily basis. Since the raft was unpowered, it was unlikely that one could be rescued if washed overboard. A safety line was towed behind the craft for this contingency, but it provided little security. A six-man foam life raft was lashed to the steering platform. Many large sharks were observed as they neared the Bahamas.

The vessel began sinking from waterlogged reeds about midway through the voyage. Substantial mid-voyage modification of the hull and mast were required to remain afloat. This included cutting up the foam life raft and using the pieces to help keep the Ra afloat. The Ra was ultimately destroyed on a reef as it approached Barbados. All crew members were rescued.

Long-Distance Yacht Racing: The risk of personal injury and death is great. Vessels have been capsized and lost and each race has suffered several fatalities. Also, routes through the southern seas provide brisk winds along with an increased iceberg danger.

Commercial Fishing Vessels: Commercial fishing is one of the most dangerous occupations in the U.S. in terms of lives lost (per 1,000 man-hours)--consistently higher accidental death rates than coal mining or firefighting. All vessels carry life rafts and most fishing northern waters also carry thermal survival suits for the skipper and crew.

Research Vessels (Coastal): In addition to the risks associated with foul weather, fog, and the potential for collision, there are dangers on deck and below. Heavy equipment is frequently used to lower and raise scientific gear and skilled operators are required to perform the work safely. Likewise, engine rooms are notoriously dangerous places in which to work.

Supertankers: Crews aboard supertankers are always at risk. Fully laden, the "Ardshiel" contains as much compressed passive thermal energy as a hydrogen bomb. Ironically, though, supertankers are safest (to their crews, at least) when the tanks are full. It is the hydrocarbon gas present in empty and emptying tanks that presents the serious threat of explosion. Any spark, including that produced from static electricity, can cause incredible destruction. More than a dozen VLCCs each year explode with empty tanks, usually during the six days of tank cleaning operations en route to the Persian Gulf.

Additional risk results from the economies built into the ships. They are typically underpowered, making maneuverability a problem. All but a few have only one screw, one rudder, and one boiler, rendering them vulnerable to foundering due to the absence of back-up systems. Because of their immense length and draft, any loss of power (which is common) is potentially disastrous. The overall degree of risk involved is reflected in the fact that insurance premiums account for 54% of VLCC operating costs.

Offshore Oil Platforms: Although the potential for catastrophe is great, serious personal injuries are infrequent aboard Platform Hondo. (The Exxon group was proud of their record of 100,000 man-hours of work without a lost-time accident.) Other platforms have not been so lucky. Many fatalities in offshore work occur while being transported to and from the rigs.

Skylab 4: Exposure to risk was substantial. Although the Apollo systems had proven reliable, Skylab was a new venture. In addition to the risks of system failures, crew were exposed to the potential for meteorite collision, solar flare danger, and critical human error.

* * PHYSICAL ISOLATION * *

NASA Space Station: Since the proposed NASA space station will be occupying a low earth orbit, the physical isolation from the outside world will be complete.

1 2 3 4 5 6 7

Not Close to Target Conditions — Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: During the eight-month winter, Antarctic stations are totally isolated from outside contact. There are no visitors, no supplies, and only very infrequent radio contact is possible.

Sealab II: Because Sealab II was a saturation dive, the aquanauts were unable to venture the 205 feet to the surface, even in an emergency. They were separated from the normal world by a mandatory 35-hour decompression period.

Tektite I: Because Project Tektite was a saturation dive, the aquanauts were unable to venture the short distance to the surface, even in an emergency. They were separated from the normal world by a mandatory 19-hour decompression period.

Tektite II: Because Project Tektite was a saturation dive, the aquanauts were unable to venture the short distance to the surface, even in an emergency. They were separated from the normal world by a mandatory 19-hour decompression period.

Commercial Oil-Field Diving: Divers spend their working hours at great depth and are then transported by diving bell to a pressurized chamber usually located on the deck of a vessel or platform. Due to the nature of saturation diving, they must remain under pressure for the duration of the dive and during controlled decompression. This requires complete physical isolation.

Submarines (FBN): During 60-day submerged cruises, crews are isolated totally from the world.

Ra Expedition: The crew was totally isolated on their raft for the duration of the voyage.

Long-Distance Yacht Racing: During the race, that is while at sea, physical isolation from "normal" society is complete. No contact is made with other vessels except in or near ports.

Commercial Fishing Vessels: Although you may see other vessels, rarely does one leave a fishing boat (voluntarily) at sea.

Research Vessels (Coastal): As with all offshore conditions, the sea provides an effective physical barrier in isolating a group from the remainder of society.

Supertankers: The degree of physical isolation is not complete. Resupply of perishables and special requests by crew are provided by helicopter drop off the Cape for Europe-bound vessels. Also, officers' wives are occasionally allowed to accompany them on voyages.

Offshore Oil Platforms: Hondo is located 5½ miles offshore in 850 feet of water.

Skylab 4: Skylab occupied a low earth orbit, approximately 269 miles above the earth's surface.

*** * PSYCHOLOGICAL ISOLATION * ***

NASA Space Station: It is frequently impossible to separate physical from psychological isolation. In the case of a space station, we assume that the capacity to communicate with ground control personnel and even with family members will be allowed in order to reduce the crews' feeling of psychological isolation. We anticipate that periodic, scheduled calls home will be a part of routine station operation.

1	2	3	4	5	6	7
Not Close to Target Conditions						Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: The feeling of psychological isolation is nearly complete. Sporadic radio contact is established with support base and occasionally with ham operators. News of the outside world is a scarce commodity.

Sealab II: The aquanauts were monitored by video and audio channels. A telephone link to the outside world was established and used by all participants. In fact, Gemini V was orbiting the earth during the Sealab experiment and the Navy arranged a telephone contact between Aquanaut/Astronaut Carpenter and orbiting Astronaut Cooper. Also, at the time Sealab II was under the Pacific, Jacques Cousteau had placed a similar habitat, Conshelf III, on the floor of the Mediterranean; a call was arranged between the two crews. Neither crew could understand the other due to the language difference and the speech distortion caused by the exotic atmospheres. President Johnson also placed a call to the Sealab II aquanauts. Despite these contacts, the feeling of separation from normal patterns of behavior may be revealed in the aquanauts' reference to topside personnel as "earth people."

Radio and television were available for entertainment and they may have contributed to reducing perceptions of psychological isolation.

Tektite I: The aquanauts were monitored by video and audio channels. Video channels were turned off by divers on six occasions, to obtain privacy for periods of less than an hour. Microphones, however, were turned off a total of 54 times for relatively brief durations. Aquanauts could and did regularly establish two-way communication with topside personnel using the radio-link located in the bridge.

Tektite II: The aquanauts were monitored by video and audio channels. A favorite form of recreation was voice communication with topside personnel. Television and radio were also available.

Commercial Oil-Field Diving: During a 30-day tour, a diver communicates primarily with the instrument technician (since he is familiar with "helium voice") but may also speak with the diving supervisor and occasionally with a topside construction person. No personal communication is allowed. Also, due to the risk of ignition in the oxygen-rich environment of decompression, radios, televisions, and stereos are not allowed in the chamber. In short, the divers are isolated from the normal world and are dependent upon the instrument technicians for all sustenance, including social contact.

Submarines (FBN): Psychological isolation from normal society is equally complete. No calls are allowed. Occasionally, periscope leave is scheduled (a peek through the periscope for crewmen to obtain a glimpse of topside activity, normally waves).

Ra Expedition: A small radio transceiver was aboard. Throughout the voyage the crew was able to contact ham operators from several countries and through them send messages to friends and family.

In the mid-Atlantic, a small cargo ship en route from New York to Cape Town hailed Ra and tossed a bag to the crew containing some magazines and fresh fruit. This represented the extent of their contact during the voyage.

Long-Distance Yacht Racing: Although crews may remain away from home for eight or nine months, they are rarely at sea for longer than 45-50 days at a time. In port, repairs are conducted, supplies are taken, and contact with friends and family may be made.

Commercial Fishing Vessels: CB, single sideband, and UHF radios, equipped with scanners, are typically operating all day and night. There is no shortage of information from outside--from calls directed at the vessel by other fishermen and from calls between other boats that are monitored. Telephone links to shoreside family, friends, and business associates are also possible through the marine operator (but privacy is limited since others tuned to the same channel can listen in on your conversations).

Research Vessels (Coastal): When cruising in coastal waters, commercial television and radio are available for entertainment and as a means to remain informed of shore-side events. Ship-to-shore telephone communications via the marine operator are also possible, but few people make or receive such calls on the shorter cruises.

Supertankers: Shipowners are aware of the potential for negative effects to crew personnel resulting from feelings of psychological isolation. Aboard VLCCs, attempts are made to mitigate these effects. Films, videotapes, recorded music, and radios are provided for entertainment. Radio telephone calls home are also allowed to help reduce the feelings of isolation and to allow crew to remain informed of the performance of favorite sports teams. Despite the "creature comforts" provided, a certain sense of isolation is inevitable.

Offshore Oil Platforms: Radio and television are available to keep track of onshore activities. Emergency telephone calls are possible.

Skylab 4: The crews of Skylab were in nearly continuous radio contact with ground control personnel. Also, astronauts frequently used the B channel to record their observations, experiences, and interpretations; B channel recordings were "dumped" at high speed at regular intervals.

* * AMOUNT OF FREE TIME * *

NASA Space Station: Although this dimension is of a clearly variable nature, we feel that it is necessary to estimate the amount of free time available for purposes of comparison with analogous conditions. For instance, there appears to be an abundance of free time during Antarctic winters, but very little is expected onboard a space station. Based upon the need for maintaining high levels of productivity to justify costs and on the experiences of previous space missions, we assume approximately 2½ hours per day will be available for recreational pursuits.

1	2	3	4	5	6	7
Not Close to Target Conditions						Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: Because little work can be conducted outdoors during the winter, free time is abundant. It is estimated that 8-10 hours per day are available for self-maintenance and recreation.

Sealab II: It is estimated that approximately 2½ hours each day were available for recreation.

Tektite I: Approximately six hours per day were allocated to self-maintenance and recreation.

Tektite II: Approximately seven hours per day were allocated to self-maintenance and recreation.

Commercial Oil-Field Diving: A common schedule is for a diver to work four hours in the water, then spend four hours in the bell while his partner works. They then return to the surface chamber to eat and sleep. This allows about three hours per day of free time. During periods of decompression, though, 24 hours each day are unoccupied with work-related activities.

Favorite pastimes during decompression include gambling, reading, and crafts such as carving and rug-making. Because underwater work is very strenuous, free time while diving is generally spent sleeping.

Submarines (FBN): Approximately three hours are available each day for self-maintenance and recreation. The Navy provides much to occupy this time: self-paced educational opportunities, films, arts, crafts, and physical exercise equipment.

Ra Expedition: Perhaps as many as eight hours per day were free.

Long-Distance Yacht Racing: A common schedule used aboard vessels competing in the round-the-world race is a three-watch system with all watches running for four hours. This involves, "four hours on deck, four hours on standby, and four hours of "golden kip," where no one can touch you" (Mason, 1981:12). Some skippers amend this schedule by having two of the crew stand out of the rotation each day to perform all cooking, washing, and cleaning tasks. Once their responsibilities have been met during those days, they are free to relax or catch up on much needed sleep. On average, though, it is estimated that four hours each day are allocated for leisure.

Commercial Fishing Vessels: While running to the grounds and during days fishing, free time ranges between two and four hours per day.

Research Vessels (Coastal): To maximize the scientific value of a ship's time, operations are conducted around the clock. Personnel are usually divided into two groups each, working six-hour shifts. This schedule, if combined with the "running time" between locations, means that each person enjoys about five hours of free time each day. This time is generally occupied watching television, reading, playing cards, sun bathing, or in conversation.

Supertankers: The work of officers and crew aboard VLCCs typically consists of an eight-hour day with two hours of overtime, seven days a week. Helmreich's study indicated an average of 2.4 hours of "leisure time" per day.

Offshore Oil Platforms: Crews work 12-hour shifts. Assuming eight hours of sleep each night, this leaves four hours for eating, hygiene, and leisure. It is estimated that individuals spend less than one hour each day in recreation.

Skylab 4: The two hours between 8:00 and 10:00 p.m. each day were supposed to be the astronauts' own to use as they pleased. In reality, however, Mission Control typically found some additional task to occupy some or all of that time. They probably averaged less than one hour per day of free time.

NASA Space Station: It is assumed that the atmospheric pressure would be maintained at 14.7 psi, the same as standard sea-level conditions; the atmosphere would likely consist of 79% nitrogen and 21% oxygen, again similar to earth conditions. EVAs and emergency operations would be conducted in compartments or suits of 8 psi. These estimates are based on current STS conditions.

It is anticipated that food onboard a NASA space station will be somewhat better (variety, texture, etc.) than is currently available on STS missions. It must also be expected that improvements will be made in the areas of hygiene. We assume, however, that full body showering will remain a luxury.

1 2 3 4 5 6 7

Not Close to Target Conditions — Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: The temperature within a room frequently ranges from 0°F near the floor to 85°F six feet above the floor. Humidity is low except in the galley, where meals are taken. There it reaches 80%. Saunas and hot water showers are provided.

Water is made from melted snow and frequently tastes of diesel fuel. Food, however, is abundant and of excellent quality. Most men spend a disproportionate amount of time eating and lingering over their meals; most also gain several pounds during the winter. Copious quantities of alcoholic beverages are also consumed: a daily average of approximately 9 ounces of distilled liquor and 5.4 beers per day!

Sealab II: Habitat atmosphere consisted of 72-75% He, 21-22% N, 4-5% O_2, at 6.8 atmospheres. The temperature inside the habitat ranged between 82°F and 88°F; humidity was 60% to 80%.

Because of the nature of the atmosphere within Sealab, the aquanauts were unable to fry, broil, or roast any meats (such processes would have released toxic molecules, permanently contaminating the atmosphere). Consequently, most meat consumed was canned. Little time was devoted to meal preparation; no specially trained cooks were provided; cooking was shared relatively equally. "Some culinary triumphs were achieved in the face of these difficult conditions by some chefs, but most of the meals were quite dull and ordinary" (Radloff & Helmreich, 1968:72).

Toilet facilities were similar to that found aboard small vessels. Hot water showers were available and appreciated by the divers returning from the frigid waters surrounding Sealab.

Tektite I: Habitat atmosphere was maintained at 92% N, 8% O_2. Humidity ranged between 42% and 60%--relatively damp due to the open access hatch. Pressure was 2.3 atmospheres.

Potable water was supplied from the support barge. Food was primarily TV-dinner quality, with some fresh provisions and special food packages sent in pressurized containers by topside personnel. Toilet facilities were similar to that found aboard small vessels. A hot water shower was available.

Tektite II: Habitat atmosphere was maintained at 92% N, 8% O_2. Humidity ranged between 42% and 60%--relatively damp due to the open access hatch. Pressure was 2.3 atmospheres.

Potable water was supplied from the support barge. Food was primarily TV-dinner quality, with some fresh provisions and special food packages sent in pressure containers by topside personnel. Toilet facilities were similar to that found aboard small vessels. A hot water shower was available.

Commercial Oil-Field Diving: The atmosphere breathed is composed of exotic gasses at extreme pressures. Humidity is very high. Hot showers are available in the chamber, but toilet facilities are potentially dangerous (due to the pressure differences). Food and drinks are prepared in the ship's galley and passed through a pressure lock to the divers. In terms of life support conditions, only the food and water can be considered good quality.

Submarines (FBN): Air quality aboard modern submarines is generally good; tobacco smoking is allowed, rendering certain areas unpleasant to nonsmokers. Toilet facilities are adequate; hot showers are available. Food is excellent and served at cloth-covered tables in pleasant, paneled rooms; three seatings are usually required to feed the entire crew. It is an open mess, and an ice-cream locker, soft drinks, and snacks are available at all times.

Ra Expedition: Since the raft was constantly awash, they were frequently wet, chaffed, and cold. Fresh water was available, but no showers were possible. Toilet facilities were primitive and dangerous (there was no rail).

Long-Distance Yacht Racing: The air is clean, good quality drinking water is available (mineral water is taken in Argentina), and quality food is considered to be an important factor in crew morale. Toilet facilities are adequate and showers are available.

Commercial Fishing Vessels: The air aboard a fishing vessel is typically excellent, although it is occasionally tainted indoors by tobacco smoke, and on deck by diesel exhaust. Water quality is good and brief hot showers are usually available. Toilet facilities are available, but most crew relieve themselves at the rail.

Food is generally of excellent quality and served in copious quantities. Beer, wine, and liquor are also available on most offshore vessels.

Research Vessels (Coastal): The sea air is excellent, hot showers are available, and toilet facilities are usually better than is expected aboard vessels of this size. Perhaps the most salient aspect of life support aboard research vessels is food. In quality, quantity, and variety, the food aboard most research vessels is reported to be "spectacular-- beyond belief."

Supertankers: Food aboard supertankers is excellent by any standards. A normal breakfast menu might be stewed apples, cornflakes, oatmeal, smoked cod in milk, sausage mince cakes, fried potatoes, cheese or plain omelettes, eggs to order, rolls and toast, tea or coffee. Lunch aboard the British "Ardshiel" always features a curry, and it is always served with chutney, popadoms, diced tomato, onion, coconut, and currants. A typical dinner could be mock turtle soup, grilled sole Tartare, roast veal and stuffing, baked and boiled potatoes, cauliflower, peach Melba, and that essentially English course, the savory, such as bloater paste on toast. Following dinner, the officers adjourn to the wardroom for coffee or after-dinner drinks.

Toilet facilities are similar to those in hotel rooms. Hot showers are available, and the on-board atmosphere is clean sea air, except in the engine room and during tank cleaning operations.

Offshore Oil Platforms: Life support conditions aboard Hondo are excellent. The air is clean most of the time, hot water showers are available, and toilet facilities are similar to those in small dormitories. The most salient aspect of life aboard a platform, though, is the quality and abundance of food.

Skylab 4: The atmospheric pressure aboard Skylab was about one-third that of earth. At low pressures, sounds do not travel readily (15 feet for a loud speaking voice); consequently, astronauts were hoarse most of the time. An oxygen rich mixture was used, with filters keeping it fresh to the crew's satisfaction. Food quality and variety were better than on previous space missions. Water quality was good, but bubbles in the line, combined with the lower pressure of Skylab, resulted in severe flatulence. Showers were available only once each week. Toilet facilities were repeatedly criticized by the astronauts.

NASA Space Station: Since the building blocks that will be used to construct a NASA space station must be shuttle-compatible (i.e., they must fit in the orbiters' cargo bays), it is assumed that Spacelab-type modules will be used. For this reason, we assume that the physical qualities of the station will be similar to those aboard the orbiters and Spacelab, although modified for long-duration occupancy.

1 2 3 4 5 6 7

Not Close to Target Conditions — Close to Target Conditions

Evaluation Scores:

Antarctic Research Stations: The stations are small and usually crowded. The current South Pole Station consists of ten buildings, including homemade versions of a sauna, basketball and racketball courts, and a bar. A geodesic dome covers the station and protects it from drifting snow.

Privacy and personal space are at a premium; this is especially true for the Seabees. While the scientific and technical people usually each have a laboratory or work station they can occupy, members of the maintenance staff are limited to their bunks and the common areas. Much use is made of the galley, however, at all hours for snacking, playing cards, and conversing. Reading is a favorite pastime and all personnel appreciate weekly films and special theme dinners.

Sealab II: Living and working conditions within Sealab were "frustrating, uncomfortable, and stressful. Life for ten men and their equipment inside a 12' x 57' cylinder was crowded in the extreme" (Radloff & Helmreich, 1968:7). Each man had his own small bunk, but when the curtains were drawn to shut out sights and sounds, the circulation of air in the bunk was impeded, resulting in an accumulation of CO_2. Also, the habitat rested on uneven bottom, causing an inconvenient and uncomfortable tilt (e.g., dishes slid off tables, etc.).

Tektite I: The habitat consisted of two 12.5 x 18 foot high pressure hulls attached to a rigid base and connected by a pressurized crossover tunnel. The two cylinders were divided into two compartments each: bridge, crew quarters, equipment room, and wet room. Six hemispherical viewing ports and a cupola were provided for crew observation and safety monitoring purposes.

The bridge served as both control center for the habitat system and dry laboratory for the aquanauts. Crew quarters contained four bunks, a small galley, storage space for personal gear, and entertainment facilities (radio and television).

Tektite II: The habitat consists of two 12.5 x 18 foot high pressure hulls attached to a rigid base and connected by a pressurized crossover tunnel. The two cylinders were divided into two compartments each: bridge, crew quarters, equipment room, and wet room. Six hemispherical viewing ports and a cupola were provided for crew observation and safety monitoring purposes.

The bridge served as both control center for the habitat system and dry laboratory for the aquanauts. Crew quarters contained four bunks, a small galley, storage space for personal gear, and entertainment facilities (radio and television).

Commercial Oil-Field Diving: Deck chambers (known as pots) have patentable configurations; Westinghouse is a leading supplier with their units valued at about one million dollars each. They are sausage shaped and range in size from 8 x 20 feet to 8 x 40 feet. They are occasionally "piggy-backed" when operations require many divers. For our purposes we will consider an 8 x 30 foot unit as appropriate for a seven-man diving crew.

Interior conditions are spartan. Each diver has a tubular steel frame bunk (3 x 6 feet) with a thin pad. The danger of oxygen fire severely limits the materials and equipment that can be used within the chamber.

Submarines (FBN): Even though the size of the modern submarine has increased since World War II, the overall space per man has actually decreased as a result of increased crew size and the introduction of additional instrumentation necessary to propel and navigate the vessel and to fire its weapons. It has been estimated that there are about five cubic yards of space provided for each crew member of a nuclear submarine. Each man has a relatively large berth, equipped with a lamp, draw curtains, and built-in lockers for personal gear. Although most submariners adapt remarkably well to the conditions, one study indicated that 20% of those surveyed indicated that "confinement" was the most frequently mentioned aspect of submarine life disliked, while "general living conditions" was the second most disliked aspect.

Ra Expedition: Conditions on board were crowded, dangerous, and frequently unpleasant. They were under constant fear that the vessel would break up at any moment. The Ra was made of tightly-bound papyrus reeds. It measured 45 feet in length with a 15-foot beam. A small wicker cabin was located amidships.

Long-Distance Yacht Racing: There is a comfortable bunk for each member of the crew. A common area is provided for taking meals and for quiet socialization. Overall, conditions may be described as cozy, yet comfortable.

Commercial Fishing Vessels: Although crew quarters are customarily cramped by shoreside standards, they are adequate. Each crew person has his or her own bunk in the foc'sle with curtains to shut out the light, and there is usually plenty of room in the galley for all to eat at once in cozy comfort. The constant noise from the vessel's main engine and/or auxiliary engine can be annoying, but crews are typically too exhausted by the day's fishing activity to have trouble sleeping at night.

Recreation usually consists of listening to radio transmissions between other vessels and speculating on the whereabouts of fish. General conversation and reading are also typical leisure activities.

Research Vessels (Coastal): Although accommodations are somewhat spartan, each member of the crew and scientific staff has his or her own bunk with curtains for a measure of privacy. Breakfast is usually served in the galley, but lunch and dinner are served in a cozy yet comfortable wardroom or lounge. On the small research vessels, both crew and scientific personnel eat together and there is considerable social interaction. A small library (100 volumes plus magazines) is typically provided, along with a television and stereo for entertainment.

Supertankers: The "Ardshiel," like most British and American VLCCs, provides staterooms for all officers and suites for senior officers. All accommodations are equipped with double beds since most personnel are occasionally accompanied by wives for short trips. Crew quarters are only slightly smaller than those assigned to officers.

Also, much is provided in the way of recreation: films, radio, a library (200 volumes rotated each voyage), swimming pool, table tennis, bicycles, etc. In short, conditions aboard supertankers are for the most part pleasant and genteel, especially for officers.

Offshore Oil Platforms: Although working conditions aboard Platform Hondo can be greasy and uncomfortable, the living quarters are pleasantly efficient, much like a college dormitory. A typical cabin sleeps six in tiered bunks; occupants share a double lavatory with a second cabin. Entertainment and recreational opportunities are provided, but most personnel spend their off-duty hours either sleeping or eating.

Skylab 4: Skylab was an enormous structure. It was sometimes called "the cluster" or "the can." In fact, it appeared to be a cluster of cans of varying shapes and sizes. The largest can, the workshop, was a converted Saturn rocket booster left over from the Apollo program. It was 48 feet long and 21½ feet in diameter. At the forward end was a shorter, thinner can (about 17 feet long), at the tip of which the command and service modules docked.

Many items were provided to occupy the astronaut's leisure time. These included books, games, darts, playing cards, and taped music. What little leisure time they had they spent either reading or looking out the 18-inch diameter window in their living quarters.

APPENDIX B

SUMMARY OF EVALUATION INSTRUCTIONS

SUMMARY OF EVALUATION INSTRUCTIONS

The procedure is rather simple. For example, our space station summary assumes a group size of eight personnel. Those participating in the evaluation effort must select numbers on the seven-point scale to represent how closely they believe each alternative analogue corresponds to the assumed space station condition. An analogue with a group size of nine may receive a relatively high score on that dimension (corresponding closely to the crew of eight assumed for the space station). A group size of 90 would probably receive a relatively low score. Certain dimensions may be more problematical than others--for instance, when comparing the physical quality of an analogue's habitat to that estimated for the proposed space station. Judgments such as these must be made and recorded on the data collection sheets for each alternative analogue in terms of each of the 14 dimensions.

Specific Instructions to Evaluators

The following instructions are provided to those readers selected to participate in the study.

- First, read the NASA Space Station (Assumptions) section. Then, in turn, read each of the summaries of alternative analogues.
- Next, open the report to Appendix A and please provide the information requested on the cover sheet. Then, turn the page, opening the appendix to the first pair of data collection sheets (Size of Group). There are two sheets (facing pages) for each of the 14 descriptive dimensions.
- You will notice that the NASA Space Station assumption for that dimension is reproduced at the top of the left-hand page, followed by summaries of each alternative analogues' corresponding dimension. The NASA assumptions will be the target conditions against which you will compare the alternative analogues.
- Beginning with the first pair of data collection sheets in Appendix A, proceed through the summaries for the alternative analogues and ascribe scores from the seven-point scale to each of the alternatives. Be certain to write your scores in the correct boxes of the appropriate data collection sheets. Your scores should be measures of the "relative degree of relatedness" compared to the target conditions described in the Space Station assumptions at the top of the page.

C-3

- When you have completed the evaluation (all dimensions), please record on the cover sheet an estimate of the time you spent reading and evaluating. Then send your copy of this report with the completed data collection sheets to:

  Dr. Jack Stuster
  Anacapa Sciences, Inc.
  P.O. Drawer Q
  Santa Barbara, California 93102

  A pre-addressed and stamped envelope has been provided for this purpose. If you wish to retain your copy of this report for your files, please check the appropriate box on the cover sheet. Your copy will be returned to you after the data have been entered.

APPENDIX C

PARTICIPANTS IN THE EVALUATION OF ALTERNATIVE ANALOGUES

PARTICIPANTS IN THE EVALUATION OF ALTERNATIVE ANALOGUES

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Mr. Keith Miller
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Mr. William Nobles
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NASA/Ames Research Center

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Mr. J. Rayfield
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California State University, San Jose

Ms. Stacy Vornbrock
Independent counselor

Ms. Leslie Wickman
Lockheed Missiles & Space Company

Dr. Harry Wolbers
McDonnell Douglas Astronautics Co.

APPENDIX D

LIST OF PERSONS INTERVIEWED DURING PROJECT

LIST OF PERSONS INTERVIEWED DURING PROJECT

Norman Brand, merchant seaman

Robert Christenson, Santa Barbara City College Marine Technician Program: commercial oil diving

Gerry Clouser, Santa Barbara City College Marine Technician Program: commercial oil diving

Dr. E.K.E. Gunderson, Naval Health Research Center: Antarctic research stations

Dr. Robert Helmreich, Department of Psychology, University of Texas: Sealab and Tektite

Captain Noel S. Howard, MC, USN, Naval Medical Research and Development Command: Antarctic research stations, submarines, and surface ships

Tom Kiddie, commercial oil field diver

Carl Lueck, commercial oil field diver

Dr. R. Mark Patton, Ames Research Center: coastal research vessels

Graham Pomeroy, long-distance yacht racer

Robert Scarlata, General Electric Co.: Sealab and Tektite

Dr. Saul B. Sells, Texas Christian University: remote duty stations

Captain Brian Shoemaker, USN Commander Naval Support Force/Antarctica (Operation Deepfreeze): Antarctic research stations

Tom Webster, distant-water albacore fisherman

Commander Bill Weiner, USN, Headquarters Command: Antarctic research stations

Dr. Benjamn B. Weybrew, Naval Medical Submarine Research Laboratory (ret): submarines

Mr. John Wilhelm, Department of Psychology, University of Texas: Sealab and Tektite

APPENDIX E

WORK STATION DESIGN

WORK STATION DESIGN

The following is our approach to the design of work stations. Though this presentation is focused on the design of work stations, the six-step procedure is equally applicable to the design of **any** functional area aboard the proposed space station.

We assume that at least seven categories of onboard work stations will be required for routine space station operations. These include, but are not limited to:

- Maintenance/ECLS
- Communications
- Interior experiments/payloads
- Exterior experiments/payloads
- Construction of external structures
- Servicing of spacecraft/payloads in external bay or hangar
- Launch and docking control for shuttle and OTV

It is imperative to establish a set of principles to guide the overall design and integration of the many forms of work stations that will be required aboard the proposed space station. Among the several related principles included in our approach to this issue are:

- Maintain consistent control characteristics
- Avoid control incompatibility
- Apply uniformity of coding
- Maximize transfer of procedures, dialogues, and tasks
- Avoid negative transfer
- Increase commonality of operational and maintenance requirements

Essentially our approach, in accord with sound human factors judgment, stresses standardization to the extent possible. However, the many forms of work stations dictated by the requirements of routine and nonroutine space station operations insist that each work station be designed in terms of its intended uses, but within the framework of the guiding principles. Our approach to the design of individual work stations and station interfaces is outlined below.

Step 1. Delineate performance objectives--what is the mission of the work station? (e.g., launch and recover OTV).

Step 2. Conduct function analysis--What are the various operations involved? (e.g., communications, servicing, launch, safety).

Step 3. Conduct general function allocation--What should be automated and what should be manual? (by applying behavioral principles).

Step 4. Conduct task analysis--What does one need to see or touch, and with whom is communication necessary? (Develop flow diagrams, decision diagrams, and perform link analysis to establish links between individuals and equipment).

Step 5. Develop rationale for the organization of work stations, individual crew functions and the general organization for space station layout and operations (e.g., avoid communications "shack" entrance through sleeping quarters).

Step 6. Prepare set of specific design guidelines based on Steps 1-5.

APPENDIX F

INTRODUCTORY QUOTATION REFERENCES

INTRODUCTORY QUOTATION REFERENCES

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16. Abstract

The purpose of this study is to systematically analyze conditions analogous to the proposed NASA space station in order to extrapolate design guidelines and recommendations concerning habitability and crew productivity. Analogous environments studied included Skylab, Sealab, Tektite, submarines, Antarctic stations and oil drilling platforms. These analogs were compared and rated for size and composition of group, social organization, preparedness for mission, duration of tour, types of tasks, physical and psychological isolation, personal motivation, perceived risk and quality of habitat and life support conditions. Recommendations are provided for sleep, clothing, exercise, medical support, personal hygiene, food preparation, group interaction, habitat aesthetics, outside communications, recreational opportunities, privacy and personal space, waste disposal, onboard training, simulation and task preparation, behavioral and physiological requirements of microgravity environment.

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