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PROGRAM OPERATIONAL SUMMARY - OPERATIONAL 90-DAY MANNED TEST OF A REGENERATIVE LIFE SUPPORT SYSTEM

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16. Abstract

An operational 90-day manned test of a regenerative life support system was successfully completed on September 11, 1970. This test was performed with a crew of four carefully selected and trained men in a space station simulator (SSS) which had a two gas atmosphere maintained at a total pressure of 68.9 kN/m^3 (10 psia) and composed of oxygen at a partial pressure of 21 kN/m^3 (3.05 psia) with nitrogen as the diluent. The test was planned to provide data on regenerative life suppor subsystems and on integrated system operations in a closed ecology, similar to that of a space station. All crew equipment and expendables were stored onboard at the start of the mission to eliminate the need for pass-in operations. This report summarizes the significant accomplishments of the test, reviews some of the pertinent test results, outlines some of the problem areas, and presents conclusions and some recommendations for additional future efforts.

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Congratulating the Crewmen at Completion of 90-Day Test

FOREWORD

An Operational 90-Day Manned Test of a Regenerative Life Support System was completed in a Space Station Simulator (SSS) on September 11, 1970. This test was conducted by the Advance Biotechnology and Power Department of the McDonnell Douglas Astronautics Company (MDAC), Huntington Beach, California, under Contract NAS1-8997. The test facility and most baseline life support subsystems were provided as capital equipment by MDAC. Much of the program planning and design of the baseline life support subsystems were done under the MDAC Independent Research and Development program. This project was performed for the NASA-Langley Research Center under the direction of Mr. A. O. Pearson of the Space Systems Division, under the technical cognizance of Walton L. Jones, M. D., Director of the Biotechnology and Human Research Division of the Office of Advanced Research and Technology, NASA Headquarters, and his staff.

This report was prepared by J. K. Jackson, the Program Manager; J. R. Wamsley, M. D., Test Medical Director; M. S. Bonura, Test Engineering Director; and J. S. Seeman, Test Man/Machine Director. The program was supervised by K. H. Houghton, M. D., Chief Technology Engineer of the Advance Biotechnology and Power Department.

Contributions were made by many other engineers and scientists at the NASA agencies, the Air Force and Navy laboratories, other Government offices, several universities, the MDAC staff, and the many industrial organizations who participated in the accomplishment of this test.

The results of the 90-day test program are presented in the following reports:

MDC G2282 , Program Operational Summary—This volume presents a brief review of the program objectives, procedures, and results. (NASA CR-1835)

NASA CR-111881, Test Results—The volume provides the results, conclusions, and recommendations from the test. This volume is divided into three major sections covering the life support system, the man/machine results, and the biomedical operations.

NASA CR-111882, Final Test Plan and Procedure—This is an update of the Master Test Plan and Procedure used as a controlling document during the 90-day test. The final version includes a detailed description of test equipment and procedures as they were during the test. Also included is a summary of the implementation of the document with recommendations to improve its overall effectiveness.

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NOMENCLATURE

AMRL	Aerospace Medical Research Laboratory, U. S. Air Force
CCNY	City College of New York
CLSM	Crew Life Support Monitor (Inside SSS)
EEG	Electroencephalogram
FMECA	Failure mode, effects and criticality analyses
LCC	Langley Complex Coordinator
LRC	Langley Research Center, NASA
LSDS	Low Speed Digital System
LSM	Life Support Monitor
LSS	Life Support System
MDAC	McDonnell Douglas Astronautics Company
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
NIPA	Non-Interference Performance Assessment
RISA	Radioiodinated serum albumin
SGOT	Serum glutamic oxalacetic transaminase
SSMM	Space Station Mathematical Model
SSS	Space Station Simulator
TOC	Total Organic Carbon
USNSMC	U. S. Naval Submarine Medical Center
VD-VF	Vacuum Distillation—Vapor Filtration

Section 1
INTRODUCTION

Future manned space missions will require the design of space vehicles for operational periods of months or years. This extension of mission durations demands the development of new equipment and processes to insure reliable regenerative life support systems capable of maintaining the well being and efficiency of the crew.

Characteristically, the development of a breadboard subsystem into a working prototype configuration requires from 3 to 5 years. Another 5 to 7 years is required to develop flight-qualified system from the low-cost prototype subsystems that proved the system workable. It is hoped to reduce this 5 to 7 year development time through the low-cost systems evaluation of advanced life support subsystems. This provides the operational groups a technological base which allows selection of subsystems and components to suit specific mission requirements in a relatively short development cycle. A key element in this development cycle "to provide cost-effective and flight-qualifiable systems" is the performance of integrated manned ground tests simulating orbital conditions.

The Operational 90-Day Manned Test of a Regenerative Life Support System was one of the continuing series of integrated tests conducted as an essential part of the development cycle for regenerative life support systems. It provided data in a closed ecology simulating an orbiting spacecraft to evaluate the performance of baseline and advanced subsystems under continuous operating conditions, to determine the ability of the crew to operate and maintain the subsystems, and to determine the crew capability to maintain their physiological and psychological health to efficiently perform test objectives.

The successful culmination of this integrated test was materially affected by the cooperation and participation of engineers and scientists from Government agencies, industrial organizations, and universities. The Government team members were from four NASA centers, the Navy, Army, Air Force, the Atomic Energy Commission, the Department of Transportation, and Committees of the National Academy of Sciences. There were more than 30 industrial contributors and 7 universities involved in the test. Major contributors are listed in the Appendix.

The data resulting from this coordinated national effort will enable the NASA operational centers and the engineering and scientific communities to verify and improve their ideas and designs which ultimately will provide an increased technology base to support manned space flight programs.

Section 2
SUMMARY

A summary review of the 90-Day Operational Manned Test is included in this volume. Significant accomplishments are outlined in this section. These are followed by a review of problem areas that were encountered and recommendations for future programs. The complete test results are presented in NASA CR-111881.

2. 1 SIGNIFICANT ACCOMPLISHMENTS

In the following sections, each objective of the program, as stated in the Contract Work Statement, is included as a quotation, followed by the related accomplishments.

2. 1. 1 Operate a Regenerative Life Support System for 90 Days

"To demonstrate a capability to operate a multi-man life support system in a continuous regenerative mode for a 90-day period without resupply. The system must provide a habitable atmosphere, food and water for nutritional support, and personal accommodations consistent with man's needs in the areas of personal hygiene, waste management, comfort, and health. The system will include regenerative oxygen and water loops. It will be a goal to minimize the amount of stored, expendable materials required for the test."

- The 90-day test was completed without pass-ins of any kind, assuring the microbial isolation of the test chamber and crew. The test control area is shown in Figure 1.

- Carbon dioxide removed from the simulator atmosphere was processed by a Sabatier reactor, the 150 kg (332 lb) of water produced was in turn processed by experimental water electrolysis units, and the oxygen was returned to the atmosphere for crew consumption.

- The wash water recovery unit processed and dispensed 4, 750 kg (10, 447 lb) of water for personal hygiene, laundry, and other wash uses. The system provided enough wash water for unrestricted use by the crew.

- An integrated maintainable potable water recovery system reclaimed 1, 070 kg (2, 357 lb) of water from urine and humidity condensate which was certified for crew consumption. This supplied all the requirements for crew consumption and for potability testing after the initial startup period. Without reclamation, onboard storage would have been required to supply the crew requirements.

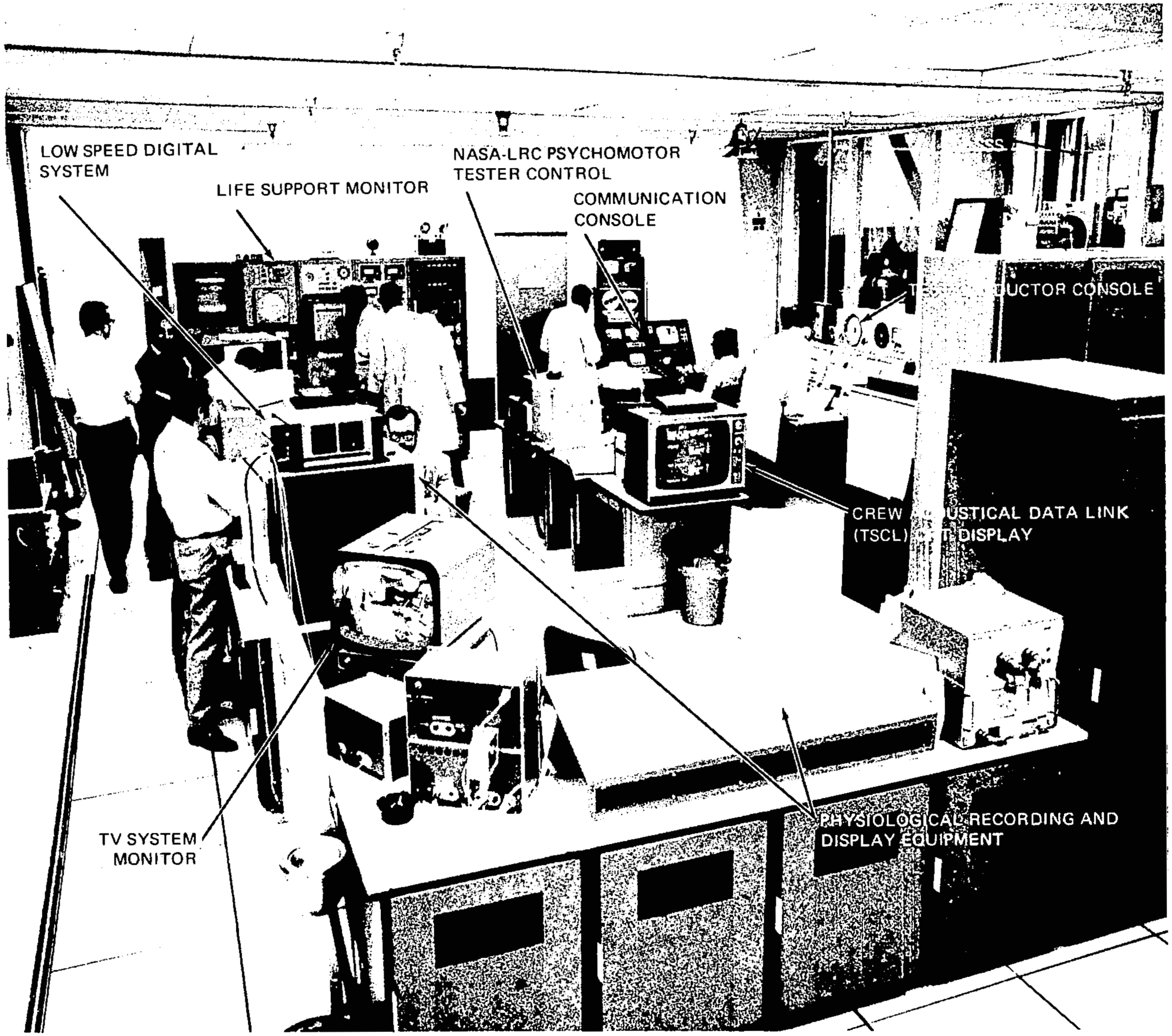

Figure 1. Test Control Area—Staff Operation Stations During 90-Day Test

- Uncompressed, freeze-dehydrated food which was especially selected for its palatability was shown to be acceptable as a diet, although periodic frozen meals provided a welcome highlight in the diet (Figure 2).

- Techniques were developed for reducing generation of waste and for handling and storage onboard which were generally acceptable.

- From a medical standpoint, operations were smooth, procedures were adequate, and no medical problems of significance were encountered except for the streptococcal infection in one crew member, which was managed without compromising the test.

2.1.2 Evaluate Advance Life Support Subsystems

"To evaluate a number of advanced life support subsystems, using the proven subsystems of the SSS as backup, obtaining operating experience and performance data under continuous testing and realistic conditions of manned loads and subsystem interaction."

- Performance was measured on the life support system over a wide spectrum of operating conditions, including transient loads. Data were obtained during startup, shutdown, and power failure conditions to assist in designing for realistic operational failure modes.

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Figure 2. Preparing a Meal from Freeze-Dehydrated Food

- An advanced regenerative solid amine carbon dioxide removal system was operated for nearly 70 days and performance data were obtained.

- A flight-type two-gas control, operating with a mass spectrometer sensor, accurately and reliably controlled composition of oxygen and nitrogen in the Space Station Simulator (SSS).

- Radioisotope heat sources (^{238}Pu) were used to produce 350-watt thermal output and were shown to be safe, presenting no problems in handling during 76 manipulations of the capsules (Figure 3d) and resulting in crew exposure well below established limits.

- Means to heat freeze-dried foods is an important contribution to their acceptability. The microwave oven was a convenient heating facility.

2.1.3 Determine Ability of Crew to Operate and Maintain Equipment

"To demonstrate man's capability to perform in-flight maintenance as a means of increasing system reliability and to demonstrate the capability for in-flight monitoring of the necessary human, environmental, and systems parameters."

- The crew operated, maintained, and repaired the life support equipment onboard, used an average of approximately 2 hours/man-day for these tasks (Figure 3). The crew capability for maintenance and repair exceeded the expectations of the test planners.

- Crew selection parameters were defined early in the program and followed during recruitment and training. The performance of the crew during the test validates these selection and training procedures for future similar tests.

- A nonintrusive method of evaluating crew behavior and performance (NIPA) was implemented for comparison with conventional methods of psychological assessment. It shows promise for use as an operational tool for providing program management guidance as well as an overall evaluation of the crew performance.

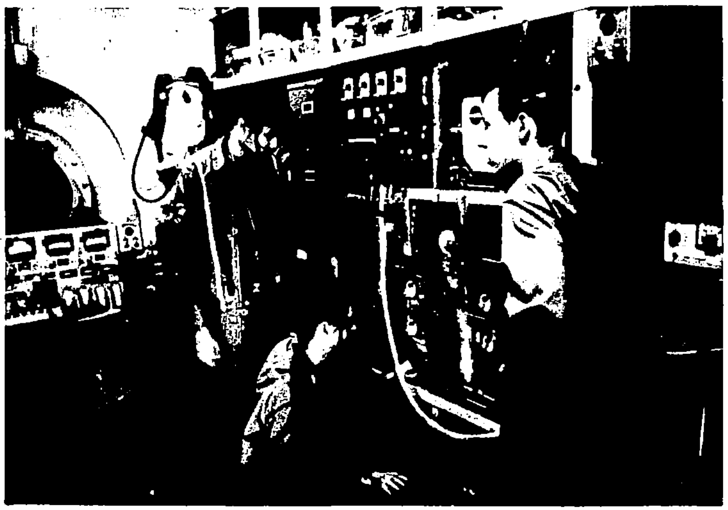
2.1.4 Reach Microbial and Chemical Equilibrium

"To operate with no materials passed into or out of the test chamber for the maximum duration possible to permit the chemical and microbiological characteristics of the atmosphere, processes and hardware to reach operating equilibrium under man-loaded conditions and to determine the capability of the system and crew to operate without resupply. If resupply is required, it will continue to be an objective to hold the passing in and out of materials to a minimum."

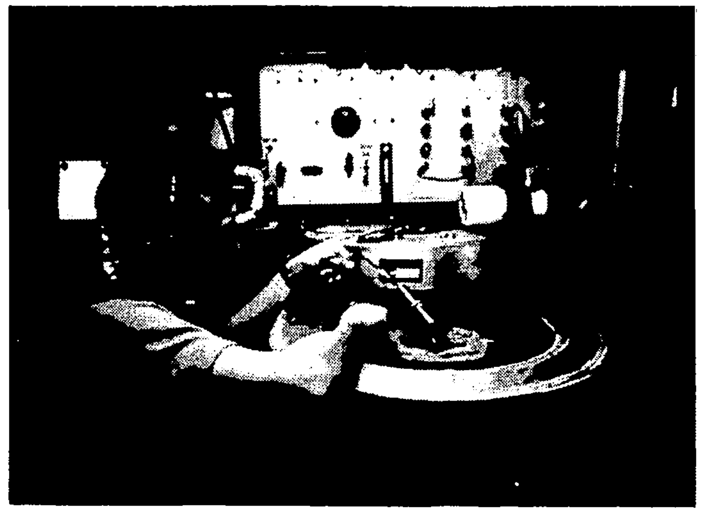
- No changes were seen in the SSS microecology of significance to crew health or to life support subsystems.

(a) Commode Unit Maintenance
(Commode liner change)

(b) Sabatier Unit Maintenance
(Completion of catalyst change)



(c) Solid Amine Unit Maintenance
(Selector valve adjustments)



(d) VD-VF Water Recovery Unit Maintenance
(Radioisotope capsule installation)

Figure 3. Typical Crew Maintenance Activities

- Observations from this test suggest that long-duration 1-g isolation does not markedly affect microecological balance or host sensitivity to microorganisms.

- There was no evidence of significant crew interchanges of microorganisms except for Staphylococcus aureus. Marker systems were inadequate for confirming that exchange.

- Observations on surfaces and subsystems sampled after the test indicate a uniform distribution but no significant buildup in bacterial or fungal populations.

- The crew were the main source of bacterial air, surface, and water contamination. Preliminary results suggest that the major source of fungi in the SSS was not the crew.

- Atmospheric trace contaminants were held at levels substantially lower than established test limits with the exception of carbon dioxide.

- Contaminant control data were obtained for the design of sensors for onboard monitoring systems.

2.1.5 Measure Effects of Confinement on Crewmen

"To obtain data on physiological and psychological effects of long-duration exposure of the crew to confinement in the cabin atmosphere; on long-term group dynamics; and on crew work rest cycles."

- Review of the results of biomedical, psychological, and microbiological studies led to the conclusion that the test environment was generally benign and not severely stressful to the crewmen.

- Clinical blood and urine studies revealed no significant medical problems during the test.

- No psychophysiological responses to the levels of carbon dioxide exposure in this test were observed.

- Exposure of the crewmen to CO_2 levels generally below 730 N/m^2 (5.5 mm Hg) for the first 46 days resulted in no perceptible biochemical alterations.

- During the last 44 days, when median P_{CO_2} levels were 810 N/m^2 (6.1 mm Hg) with peak concentrations as high as 1,500 N/m^2 (11.3 mm Hg), an apparent alteration in calcium-phosphorus metabolism occurred.

- Biochemical and psychological data from this test suggest that complete adaptation to altered day-night cycles may take 3 to 5 weeks. No operationally significant performance losses were detected during this adaptation period, but allowance must be made in interpreting biochemical measurements such as Na^+/K^+ urinary excretion following diurnal cycle changes.

- No significant changes in whole-body fluid compartments or lean body mass occurred during the test.

- No behavioral or medical changes occurred under the test conditions which would adversely affect space missions of equal duration.

2.1.6 Determine Role of Man in Performing In-Flight Experiments

"To obtain through skillful planning, time-lining, conducting and analyzing pertinent onboard crew work activities, data which will assist in determning the precise role of man in performing in-flight experiments; assist in determining the practical benefits of manned activity in space; and assist in validating mathematical models of space missions."

- A computerized method for planning and scheduling mission activities was evaluated and found to be a practical operational tool, and provided flexibility to adapt to changing program requirements.

- The crew time line data demonstrated that only 2 hours per man per day were required for operation and maintenence of the life support equipment, as previously noted, demonstrating a capability for performance of useful in-flight experiments during the balance of their work day.

2.1.7 Cabin Mass and Energy Balance

"To obtain total life support system and subsystem performance characteristics which include a material balance, a thermal balance, and power requirements."

- A mass and energy balance was obtained on equipment and crewmen. These data, in general, validated planning values in Reference 1.

2.1.8 Other Accomplishments

The following findings were significant, although not specifically relating to test objectives:

- The use of adequate control subjects was important in evaluating medical data during the test. Two methods of control were used: Baseline data were obtained pretest from the crewmen which furnished controls for use during the test, and samples were taken from staff members and standby crewmen for processing with samples from crewmen, to serve as controls on laboratory procedures.

- A backup water tank, initially containing 400 lb of water treated with iodine, maintained iodine concentration and freedom from microbial contamination throughout the test period.

- Significant differences in urine solids production between the day and night crews were apparently related to body weight differences.

- The skin fold calipers provide useful data on body fat trends and, in conjunction with daily body weight measurements, contribute meaningful data in prolonged confinement.

2.2 PROBLEM AREAS

During the planning, performance, and data evaluation of the 90-day test, a number of problems were encountered. It is believed that a definition of these problem areas is an important result of the test program, and should lead to the concentration of effort to improve procedures and equipment where the greatest benefits may be obtained. These may be classified with respect to program operations, system integration, equipment, and medical.

2.2.1 Program Operational Problems

- The absence of standards for wash water and lack of clarity in potable water standards resulted in some difficulty in test planning and pretest qualification of these units.

- The operational value of the unmanned altitude test was questionable. Attempting to operate the system remotely, which was designed for crew operation, placed a handicap upon its performance that was severe. True, there were important results from the safety standpoint but the question remains that these may have been obtained as readily during sea-level testing.

- Total system operating time before the 90-day test start was not adequate. Although a 5-day checkout test was conducted, too much equipment was installed subsequently with incomplete system evaluation. Operational problems that arose during the beginning of the test could have been more effectively handled if additional checkout time had been available before the test.

- A period of low crew morale occurred roughly between days 60 and 70 which appeared to be associated with a decline in unscheduled maintenance requirements (most equipment was operating well) and a consequent increase in available free time. Available data do not provide for definition of causes, methods of early detection, or effective methods of counteracting this tendency, which appears to be characteristic of long-term confinement of small groups.

2.2.2 System Design Problems

- Bench tests alone on life support units were not adequate to prove acceptability in an integrated system. Many instances occurred in which the system integration uncovered areas of performance which were marginal or inadequately defined; such as potability of water as produced by the vacuum distillation-vapor filtration (VD-VF) water recovery unit, the contribution of the solid amine CO_2 concentrator to high condensation loads in the thermal control and the lack of reliability of flight-type components used in its manufacture, and the failure modes encountered in liquid-gas separation devices.

- Unexpected interaction of units in the integrated system occurred resulting in imposition of severe transients, performance penalties, and outright failure (e.g., the poisoning of the Sabatier catalyst by trace quantity of Freon 113 cleaning fluid in the CO_2 removed from the cabin atmosphere by the CO_2 concentrator).

- The functions of equipment monitoring and alarm indication were not properly integrated before the test. Techniques used on individual units or subsystems were independently handled by the manufacturers. As a result, detection of out-of-tolerance conditions and fault isolation was frequently handicapped.

- Although automatic data collection existed for most engineering parameters, manual data logging was required in some areas including flow meter readings required for mass balance calculations (Figure 4). Reduction of data on a daily basis was often inadequate to present the required operational data.

2.2.3 Equipment Problems

- There were frequent major malfunctions of both the experimental water electrolysis units.

- Equipment for monitoring potential radiological contamination from the isotope heaters was unreliable, suffering from frequent malfunctions and false alarms, and requiring excessive maintenance.

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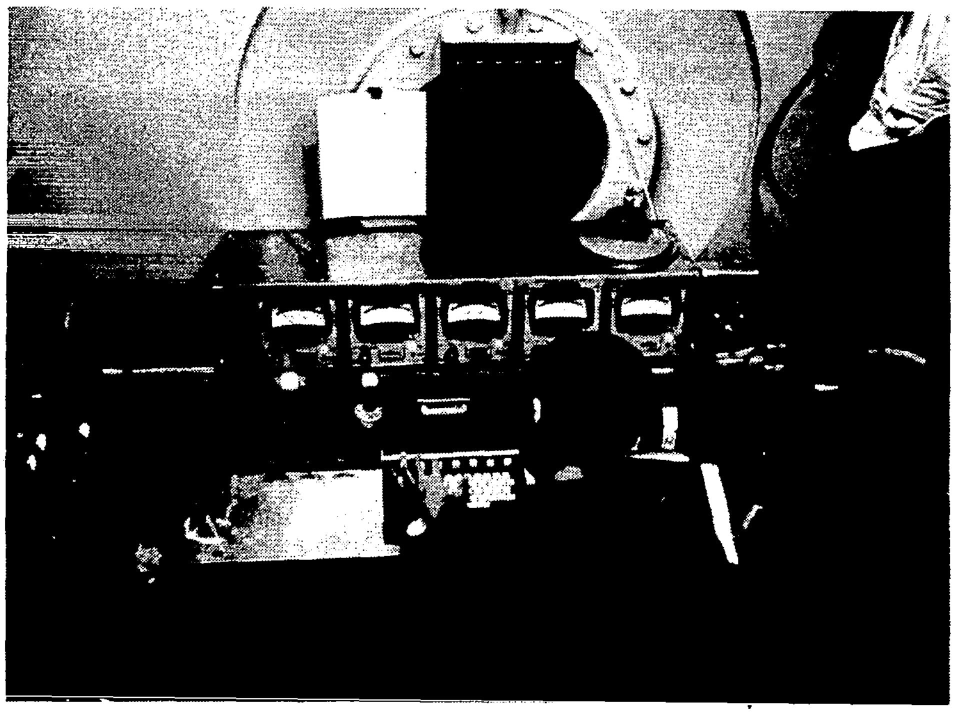

Figure 4. Entering Data into Computer

- The Sabatier catalyst was damaged by traces of Freon 113 and was replaced with subsequent satisfactory operation. Some loss in efficiency of the toxin burner may have occurred, due to the same cause.

- Microbial contamination was found regularly in the two cold potable water dispensers. This violated established standards for potability; crew consumption of potable water was limited to that dispensed by the hot water dispenser.

- VD-VF unit did not always produce water meeting rigid potability standards without further processing. Boiler 1 met standards for 17 days out of 25, boiler 2 for only 4 days out of 38.

- Failure of several zero-g liquid-gas phase separators occurred. These were associated with gas leakage through porous plates, failure of negative pressure devices, plugging of porous plates by solid material, and corrosion caused by unexpected exposure to contaminants (e.g., Freon 113 decomposition products in the Sabatier reactor; urine pretreatment solution in the urine separator).

- The water recovery system was not qualified to dispose of waste water resulting from food preparation and leftovers nor corrosive reagents from the onboard laboratory (NaOH, KOH). This required that 2,408 plastic disposable dishes be used and stored onboard during the 90-day test.

- Minor problems associated with the use of the commode include an undesirable drying effect of the induction air stream and the failure of the fecal material to adhere to the storage bowl liner. Dried feces broke into chunks which were thrown around inside the collector by the slinger during use.

2.2.4 Medical Problems

- Present methods of measurement of body fluids are not suitable for operational use, especially in space flight. They are very difficult to manage, even by experts in laboratory conditions. In view of the known effects of zero gravity on body water, these measurements provide important baseline data during extended tests.

- The exercise program (Figure 5) appeared to be marginal in maintaining general muscular tone and mass. Methods of onboard determination of lean body mass and body water distribution were not adequate, especially for flight use in zero-gravity environment.

- Sampling of two crew members was not keyed to their altered diurnal rhythms resulting in "false alarms" when test data were compared with pretest baselines.

- Pretest medical selection was adequate in ruling out potentially disabling problems but inadequate to rule out recurring minor problems.

Figure 5. Exercising on the Bicycle Ergometer

2.3 RECOMMENDATIONS FOR FUTURE EFFORT

Based upon evaluation of 90-day test results, recommendations for future effort fall into three categories. First, a number of areas were disclosed in which improvements in equipment performance are necessary to reach reliable operational capability and further unit development is necessary. Second, recommendations may be made for improving the quality of future integrated system manned tests, or for verifying trends that are only tentatively indicated from 90-day results. Third, conclusions may be reached regarding actual flight operations or equipment.

2.3.1 Equipment and Procedure Development

Results of operation in the 90-day test indicate that further design and bench tests are required on the following equipment used in space life support systems:

- Water electrolysis units.
- Zero-gravity phase separators.
- Equipment for monitoring radiation contamination, when radioisotopes are used inside living areas.
- Water recovery systems for processing food waste water and used reagents from the onboard laboratory.

- Cold water dispensers to prevent microbial contamination.
- Onboard laboratory equipment for determination of water potability and performing medical analyses, thus reducing or eliminating the need for pass-outs.
- Operational methods for monitoring body fluid distribution.
- Zero-gravity shower.
- A cleansing agent selected on the basis of both hygienic requirements and water recovery system capability.
- Flight-type microwave oven.
- Non-intrusive behavioral evaluation methods, such as NIPA, providing validation for operational use and exploring areas of application other than morale assessment.
- Heat dissipation methods for radioisotope heaters, so that capsule handling is not required to temporarily shut down a process using these units.
- Methods for onboard monitoring of airborne and surface microbial loads.

2.3.2 Future Integrated System Design

The 90-day test has shown that bench tests do not provide an adequate evaluation of prototype life support equipment. The interaction of the various units must be evaluated in integrated system tests. These tests should include as accurately simulated operational mission conditions as possible because experience has shown that there is no other way to be sure that realistic loads are applied to the LSS, either in average or in transient magnitudes. Such a test has the further advantage that many "piggy-back" evaluations can be conducted that would be impossible or economically impractical as separate investigations. It is therefore recommended that, as bench development of items in the preceding section is completed, an integrated manned system test should be conducted for their evaluation along with other advanced subsystems on which effort is presently being applied. In performance of such operational, extended tests, the following suggestions are indicated:

- More effective use could have been made of monitoring personnel if a centralized, automated system were provided for monitor, alarm and fault isolation, designed to uniform interface requirements, and providing for on-line display of data for use by the operating staff and crewmen.
- Equipment fabrication and delivery schedules should provide adequate time for checkout of the complete integrated system before test start to document performance and to achieve familiarity of the operating staff with the equipment and methods.

- Prototype instruments and prototype systems using radioisotopes should be evaluated in simulators prior to use in vehicles. This allows development of procedures and analysis of crew activity schedules both leading to optimization of protective measures and minimization of expensive safety factors necessary without these evaluations.

As a result of the 90-day test evaluation, several regenerative processes have been shown to be ready for design to meet flight qualification requirements. The following processes may be considered available for space application, with appropriate reservations where noted:

- Recovery of potable water from atmospheric humidity and urine, although reconciliation of discrepancies between in-flight potability standards and qualified monitoring methods is required.

- Processing of wash water and production in quantities acceptable for hygienic requirements.

- Recovery of oxygen from atmospheric CO_2, if necessary improvement in flight-type water electrolysis units can be achieved.

- Radioisotope sources for provision of reliable thermal energy where needed in the life support processes, if adequate monitoring instrumentation and design guidelines are available.

Experience of the 90-day test has led to a number of recommendations for improving operational efficiency in future extended manned tests and in-flight operations. The following list itemizes some of the more significant of these recommendations:

- Equipment performance requirements must be reviewed from a systems viewpoint to ensure that capacity can accommodate transient demands caused by startup and shutdown of other units, as well as those imposed by fluctuating crew activity. Conversely, the imposition of excessive transient loads should be minimized whenever possible.

- Pretest medical selection criteria should continue to emphasize potentially disabling conditions. For tests of this duration or longer, medical histories should be sufficiently detailed to rule out chronic or recurrent minor problems which, through discomfort and increasing annoyance, could compromise the test.

- Preliminary results of fungus screening suggest that future simulators and space vehicles might require fabrication under clean room conditions. The cost effectiveness of such a procedure vis-a-vis fungus testing and materials screening procedures and the actual effectiveness of clean room procedures in minimizing fungal contamination require further study.

- Computerized methods for mission planning and preparation of crew activity schedules should start early in the program to provide flexibility of response to changes and to evaluate their effect on schedules and mission plans.

- Staggered sleep schedules should be considered. In addition to providing continuous operational coverage, this technique increases the apparent space available by reducing the number of crewmen active in the living areas of the vehicle.

- The operational significance of the lag in adaptation to a reversed diurnal rhythm should be evaluated further since future long-duration space missions will most certainly require 24-hour operations involving some changes in crew sleep cycles.

- Onboard medical supplies should be sufficient to allow safe, definitive treatment of acute problems without jeopardizing mission success. This requires a thorough analysis of most probable contingencies and provision for those which can be managed in the manner described.

- Observational techniques for assessing crew behavior and performance (NIPA) should be applied and data prepared on a timely basis to aid in program operations. Improved criteria for measuring crew performance need to be developed to provide standards for measurement.

- Crew tasks should include short-term investigations which allow completion of interim milestones, rather than establishing completion of the test itself as the only goal. There should be provisions for starting such tasks relatively late in the test to counteract the tendency toward the characteristic mid-test morale slump which appears to be related to declining task time requirements.

- The procedure of collecting baseline biochemical and psychological data on the crew before and after the test should be retained and expanded. The goal is to define the subtle changes resulting from the relatively low stress levels occurring during the test. The retention of contingency samples is necessary to run supplemental analyses based upon unexpected observed trends.

- The use of outside controls for processing control is strongly recommended and should be expanded in future tests. If possible, these controls should include samples from an experimental control crew on the same regimen (including work hours, exercise, and diet) as the test crew.

- The interactions of low-level CO_2 effects on Ca^{++} -P with zero gravity must be evaluated in detail. The instability in Ca^{++} -P caused by both of these stresses, though apparently acting in opposite directions, may create special problems in Ca^{++} control even at very low levels of CO_2 exposure, e.g., less than 465 N/m^2 (3.5 mm Hg).

- Clinical biochemistries should be selected to screen a wide variety of organ systems for developing pathology. Sampling frequency in tests such as this should be increased using microtechniques. Onboard biochemical analysis capability for selected parameters should be considered at least for contingency use.

- Sampling for blood chemistry and hematology should be scheduled in consonance with the individual's diurnal rhythm. All samples should be obtained in a fasting basal state regardless of other scheduling problems.

- Although routine urinalysis did not reveal changes, this procedure remains of value in screening for pathology and should be continued in future tests.

- Exercise devices should be provided which enable whole-body conditioning (Figure 6).

- A microwave oven or equivalent means should be provided for conveniently reheating prepared foods. Food provisions should be readily prepared to minimize the interference with crew performance of mission-related tasks; reheating of suitable selected, prepared food has been shown to be acceptable for long missions.

- Equipment design, spares provisioning, and crew training should rely heavily upon the ingenuity of the crewmen to perform in-flight maintenance and repair of equipment.

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Figure 6. Two Crewmen Engaged in Ad Lib Exercise

Section 3
PROGRAM DESCRIPTION

In planning for the 90-day test an important criterion was the achievement of operational mission realism. Crew activities needed to be representative of actual missions to present the proper physical and psychological stimulation. If this were not achieved, it was quite possible that such basic parameters as food consumption, task performance, physiological changes, motivation, and morale would be seriously affected. Thus faulty data would have been obtained in many of the basic areas of the investigation because of the interacting effects of inadequate stimulation.

Since many of the operational elements of a real space mission could not be present, it was necessary to provide acceptable substitutes. Every effort was made to avoid "make-work" chores since it was assumed that a highly motivated crew would react negatively to meaningless tasks. As a result, it was possible to devote a significant effort to the evaluation of equipment and methods for many principal investigators in a variety of disciplines.

The efforts of these principal investigators increased realism of the test and also produced results of scientific value in specialized areas that would have been difficult or impossible to obtain independently of the 90-day test, but were economically practical as "piggy-back" experiments.

3.1 PROGRAM ORGANIZATION

The program operational staff was provided from the Advance Biotechnology and Power Department of the Advanced Systems and Technology Division, MDAC. This group included personnel who had previously participated in 143 days of manned, integrated systems tests including a 30-day test in 1965 and a 60-day test in 1968. Support in laboratory and facility design, fabrication, and operation was provided by the Engineering Laboratories Department of the Development Engineering Division.

The program began in April 1969 and proceeded through planning, design, and fabrication until system checkout began in March 1970. An unmanned system test and 5-day manned checkout were conducted late in April. The 90-day test was conducted between June 13 and September 11, 1970.

Facility design and program planning included extensive reviews insuring the safety of manned test. An Operational Readiness Inspection Committee was appointed during the early design phase, including specialists in industrial safety, engineering, aerospace medicine, quality assurance, and employe relations. This committee reported to the Vice President, Development Engineering, and conducted frequent reviews of the design, planning, and fabrication until the start of the manned test.

They provided reports on manned test safety aspects to the Operational Readiness Review Committee, constituted by NASA-Langley in accordance with NASA regulations.

3.2 CONTRIBUTING AGENCIES

The success of the 90-day test results from the efforts of many contributing agencies. These efforts enabled elaboration and extension of the basic program objectives previously stated, offering an opportunity to perform auxiliary studies economically in many areas related to the extended confinement of the four young, healthy, and intellectually active crewmen. Considerable baseline data were obtained on physiological, psychological, and microbiological characteristics of the crewmen before and after the test. This enabled the study of reactions of the crewmen during the test to fluctuations in CO_2 level, habitability features, acoustic environment, special diet and food preparation features, stress, and many other areas.

The participating agencies and the areas in which they made important contributions to the test program are listed in the Appendix.

3.3 SPACE STATION SIMULATOR

The Space Station Simulator (SSS) is a double-walled horizontal cylinder, 3.66 meters (12 feet) in diameter and 12.2 meters (40 feet) in length. The 116 m^3 (4,100 cu ft) chamber is normally operated at reduced atmospheric pressure to duplicate proposed space station cabin atmosphere composition. The annular space between the inner and outer walls, as well as the air lock and small pass-through ports, is usually evacuated to 1.24 kN/m^2 (5 in. water) below cabin pressure, ensuring that all leakage is outboard to provide realistic testing and evaluation of environmental control and life support equipment. The chamber is provided with 10.2 cm (4 in.) of insulation to minimize thermal and acoustic transmission.

An airlock is provided at one end of the chamber, with a volume of 4.5 m^3 (160 cu ft), for entrance and egress of the crew. A pass-through port containing an autoclave was used weekly for pass-out of samples for analysis. It was sterilized before each use to insure microbial isolation of the test chamber. A second pass-through port is installed in the chamber but not used during the 90-day test. The airlock and pass-through ports are normally held at annulus pressure, slightly below cabin pressure, when not in use.

Figure 7 shows the configuration of the SSS used during the 90-day test. This arrangement featured an equipment room and crew living area separated by an acoustic barrier. The equipment room included all the mechanical equipment of the environmental control system and its operating instrumentation. A command center was located at the "front" of this room including the crew life support monitor, a psychomotor test console, and the computer-link keyboard. Computer input and output were displayed on a large video monitor visible through the forward view port, but outside the chamber for ease of installation and maintenance. The crew living area included space for food preparation, a folding table for eating and recreation, an onboard laboratory area, and the enclosed waste management area. Two bunks were

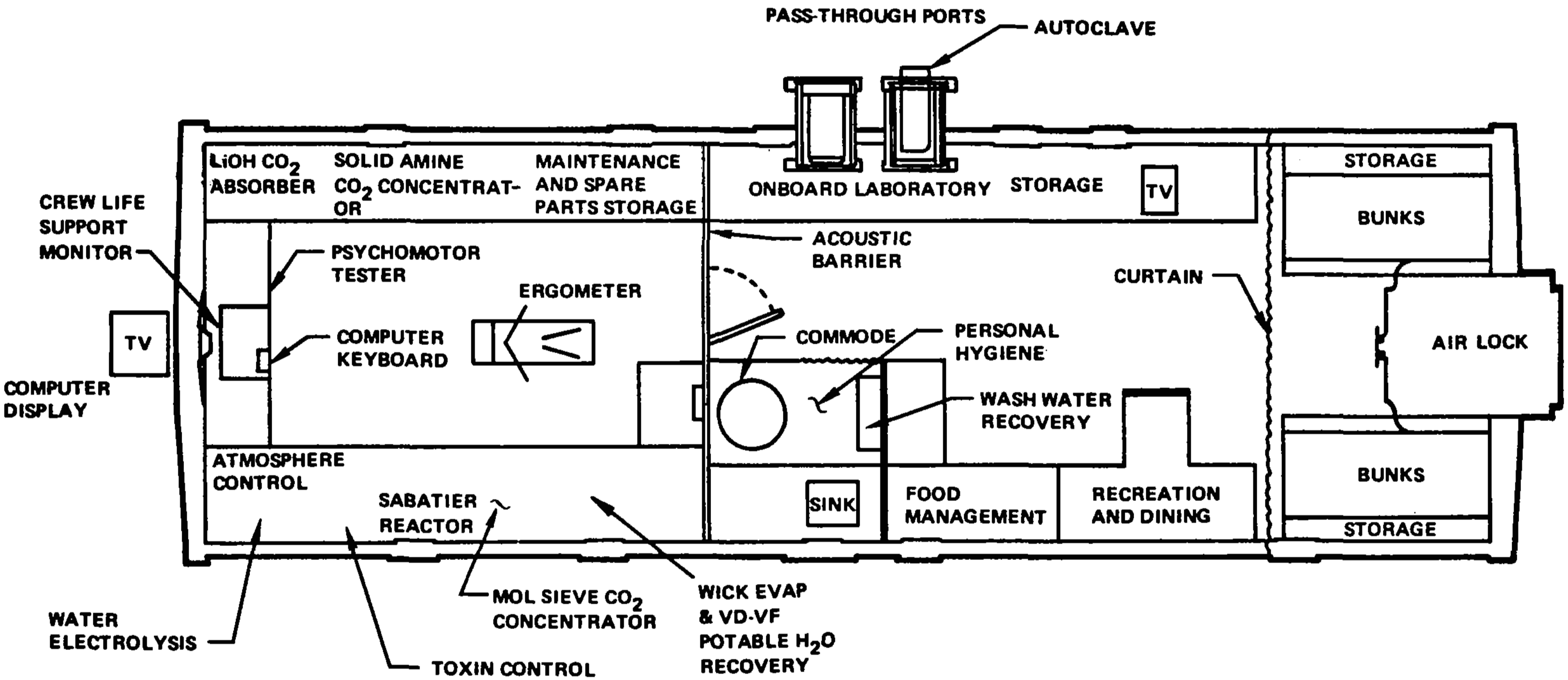

Figure 7. Space Station Simulator Arrangement for 90-Day Test

located on each side of the airlock and were isolated from the main area by nonflammable draperies. Much of the design of this installation was influenced by previous test experience which indicated equipment and living areas should be separated to reduce noise levels in the living quarters.

The regenerative LSS evaluated during the 90-day manned test is shown in Figure 8. The LSS installed in the SSS included advanced subsystem units being evaluated for the first time in a manned test and baseline LSS units whose design had been proved in previous manned tests. In the operation of the LSS during the 90-day test, the prime function was to evaluate the performance of the advanced subsystem units. A list of the advanced units, baseline units, and backup units of the LSS is shown in Table 1.

Table 1

SPACE STATION SIMULATOR LSS

Function	Advanced Subsystem Unit	Baseline Unit	Backup Unit
Potable water recovery (from urine and condensate)	Vacuum distillation-vapor filtration (AMRL)	Open-loop wick evaporator	
Carbon dioxide concentrator	Solid amine absorber (LRC-Hamilton Standard)	Molecular sieve	LiOH
Carbon dioxide reduction		Sabatier reactor	
Water electrolysis	Alkaline electrolyte (Allis-Chalmers)		*Electrolyzer
	*Circulating electrolyte (LRC-Lockheed)		
Atmosphere supply control	Flight-weight two-gas control (LRC-MDAC)	Baseline two-gas control	
Atmosphere composition sensor	Mass spectrometer sensor (LRC-Perkin Elmer)	Beckman Polarograph (O_2) Statham Strain Gage (Total)	
Waste management	"Slinger" commode (AMRL-General Electric)		
Food preparation	Microwave oven (Litton)		
Wash water recovery	Multifiltration		

*Installed outside adjacent to SSS.

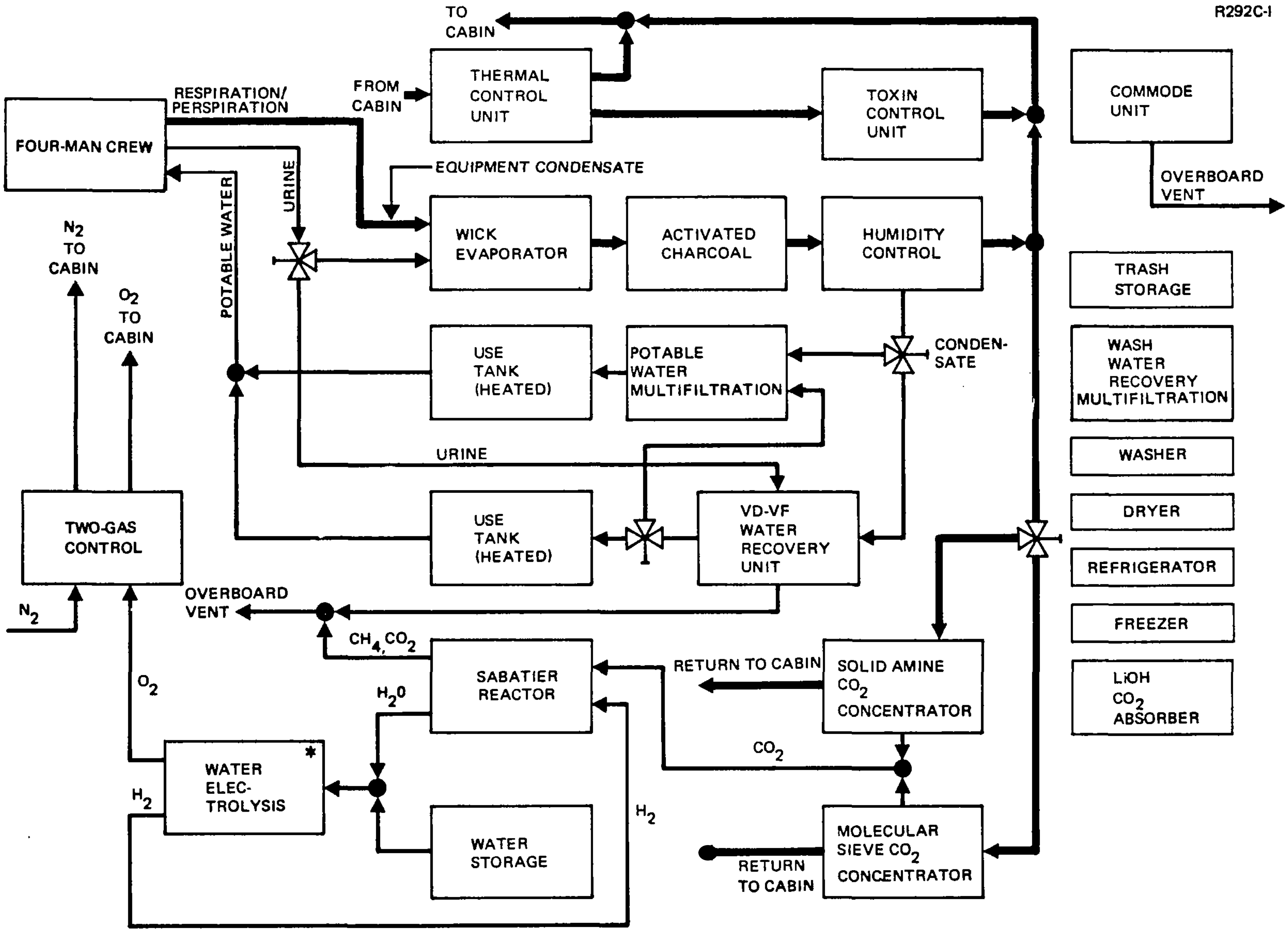

Figure 8. Life Support System Block Diagram

*SCHEMATIC IDENTICAL FOR ALLIS CHALMERS AND LMSC UNITS

In addition to the LSS design environmental conditions in Table 2, design of the life support system involved consideration of the requirement for compact installation with ready accessibility for maintenance and repair. The installation of the advanced subsystems required extensive integration with the previously tested backup subsystems. This ensured continuation of the test when a malfunction caused temporary or permanent shutdown of one or more of the advanced subsystems without compromising the remaining test objectives.

Table 2

SSS ENVIRONMENTAL DESIGN REQUIREMENTS

Total Pressure	68.9 ± 2 kN/m^2 (517 ± 15 mm Hg)
Oxygen Partial Pressure (Nitrogen Diluent)	20.7 ± 0.67 kN/m^2 (155 ± 5 mm Hg)
Cabin Temperature	$294° \pm 2.8°$K ($70° \pm 5°$F)
Relative Humidity	40 to 70 percent
CO_2 Partial Pressure	506 N/m^2 (3.8 mm Hg)

Section 4

PROGRAM OPERATIONS

This section presents an overview of the program operations, describing those activities that were most important in preparing for and performing the 90-day test. These include test planning, equipment checkout, selection of the crewmen, planning activity schedules, defining operating staff duties, and collection and analysis of data.

4.1 TEST PLAN AND PROCEDURE

The test plan and procedure used during the test has been updated and published in NASA CR-111882. This document provided a detailed plan for accomplishing the required pretest procedure, a 5-day manned checkout test, and the 90-day manned test. The initial version of the test plan was submitted to NASA-LRC in July 1969. During the 43 weeks from the initial test plan release to the start of the 5-day manned test, the test plan was continually updated. At the Operational Readiness and Safety Review just before the 5-day manned test the test plan, including all current change notices, was approved for manned testing. Additional change notices dictated by the results of the 5-day manned checkout test and further program reviews were generated before the start of the 90-day manned test. The Final Test Plan and Procedures includes a further revision accomplished at the end of the 90-day test to show the actual implementation, with photographs and illustrations added to better describe the test configuration. The above procedure allowed the test plans to be distributed widely for contributions and criticism and facilitated the broad participation of many agencies and disciplines.

4.2 UNMANNED AND MANNED CHECKOUT TESTS

Upon completion of the facility and baseline LSS equipment installation, integrated sea-level testing of the equipment was initiated. This was followed by a closed-door unmanned checkout test lasting 96 hours, then a 5-day manned test at design cabin pressure conditions.

During the unmanned checkout test, it was necessary to introduce two or three engineers and/or technicians to start the equipment, periodically to make operating adjustments, and to shut it down at the end of the test. It was found that the design of the LSS and other equipment, which was intended to facilitate operation by the crew during the actual test, was not adequate to allow reliable operation in the unmanned mode. Several times problems arose which could not be corrected rapidly enough to prevent equipment shutdown. The benefits of such an unmanned, closed-door test in providing the intended baseline data are therefore questionable.

Safety problems were encountered and solved during this unmanned test. The most severe problem was the failure of a quick disconnect in the hot Coolanol (423°K or 300°F) line supplying the molecular sieve unit. This resulted in a quantity of hot fluid (estimated at 10 to 15 gallons) being released into the equipment compartment. A heavy mist of Coolanol blocked all visibility of the TV monitors, and the test was aborted. Analysis of the failure indicated a galvanic corrosion between two different aluminum alloys used in the quick disconnect. Similar corrosion had occurred in other fittings in the hot Coolanol system; these were subsequently replaced with stainless stel fittings. No problems were indicated in the cold Coolanol system with similar aluminum quick disconnects. Following extensive cleaning procedures, the test was resumed.

On the second day of the unmanned test a fire occurred in a catalyst bed installed outside the chamber to remove contaminants in the oxygen line between the Allis-Chalmers water electrolysis unit and the two-gas control. This was extinguished without difficulty, but it was found that the hydrogen produced by the electrolysis unit was being delivered along with the oxygen. This highly combustible mixture had been ignited in the catalyst bed. Operation of the electrolysis unit was discontinued for the duration of the checkout test. Later examination showed a regulator in the electrolysis unit, which regulated hydrogen pressure and was biased by oxygen pressure, had a failed diaphragm which allowed the two gases to mix. This regulator was replaced with one having a double diaphragm and a vented intermediate space to prevent mixing of the output gases if such a failure occurred again.

The 5-day manned checkout was conducted uneventfully. Following this test a thorough review was performed, including all test data, crew comments, and staff evaluation. Necessary changes in procedure and equipment modifications were accomplished. Weak areas in training which were uncovered were emphasized in subsequent sessions, both for the test crew and operating staff. Additional operation and qualification of the potable water system was also undertaken.

The period following the manned checkout also involved installation and checkout of many of the advanced subsystems and experiments. Schedule constraints had not allowed delivery or installation of these items earlier. This activity required considerable attention by the staff; consequently complete system checkout and crew training on the new equipment was less extensive than desirable.

4.3 CREW SELECTION AND TRAINING

On the basis of results garnered from previous operational and experimental situations involving prolonged confinement of small groups, the conclusion was reached that selection of participating crew members could be of crucial importance to the accomplishment of 90 days of closed operation. Proper selection of crewmen was believed to be essential to avoid potentially disrupting developments in behavioral dynamics during prolonged confinement.

Consequently, a carefully planned approach to crew selection was undertaken which permitted repeated opportunities for crew evaluation before final selection. The process began during recruitment and continued during the training program. After the 5-day manned checkout, final selection of the onboard crewmen and crew commander were made. Evaluation was thus accomplished over a period of 6 to 7 months.

Evaluation was oriented along two lines for those applicants who were physically qualified: psychologic and pragmatic. Extensive psychodiagnostics and paper-and-pencil screening tests were employed to reduce the applicant pool to manageable size. Eight candidates were selected to commence the training program on the basis of these results and interviews with program staff personnel. Throughout the training period, repeated written tests were administered and observation of personnel was accomplished by various staff members. Information was thus obtained on demonstrated electromechanical aptitude, comprehension of subsystem functional principles, general program interest and level of commitment, patterns of group interaction, relative status of potential crew members within the group, and cooperativeness with changing schedules which arose throughout the training program.

The criteria which seemed of greatest value to successful selection were: psychodiagnostically and behaviorally verified emotional stability with low irritability; scientific training at the graduate school level in the psysical and/or biological sciences; and a willingness (lack of complaints) to comply with unusual and unexpected demands for training which occurred repeatedly. All crew members could additionally be characterized as independent and inner-directed, relying upon inner resources rather than other people to maintain their emotional equilibrium. This personality factor, more than others, can serve as a basis for explaining not only the persistence of excellent performance but also the obvious resistance to the development of an emotionally involved group throughout training and the duration of the confinement period.

Selected crew members and qualifications are identified in Table 3.

Performance data on the crew during the 90-day test revealed:

- No evidence of disruption of basic psychodynamic processes. Although minor changes in psychodiagnostic test findings were observed, these seem to be normal development resulting from a significant alteration in life style (from graduate school to the aerospace industry) rather than basic personality restructuring.

- All tasks requiring crew participation were accomplished. Those requiring adherence to time constraints were performed on time. Tasks had previously been classified as mandatory and recommended. The latter category permitted the crew to decide if the job would be accomplished. Of a total of approximately 9, 400 planned tasks in both categories, only one task was delayed by one crewman by approximately 18 hours. All other tasks were accomplished with little or no prompting required. This is considered outstanding performance which has not been approached in previous manned life support system tests.

Table 3

INFORMATION ON CREWMEN

Crewmen	Age	Academic Discipline(s)	Degree(s)	School(s)	Relevant Experience
Stephen Dennis	23	Life sciences, Neurobiology and Behavioral Genetics	BS, 1969 toward MS	MIT California Institute of Technology	Biochemical and microbiological skills
Terry Donlon	31	Chemistry Physical chemistry Medical physics	BS, 1961 MS, 1964 PhD, 1970-1	Reed College Washington State University UCLA	Radioisotope technician Clinical medicine laboratory technician
John Hall (Crew Commander)	26	Chemistry Medicine Geochemistry Geochemistry	BA, 1965 2 years MS, 1968 toward PhD	Reed College Harvard Medical California Institute of Technology	Electronics instrumentation repair technician small groups in isolation (Alaska and Peru)
Wilson Wong	22	Mechanical Engineering Aeronautics	BSME, 1969 toward MS	CCNY California Institute of Technology	Repair and test of oil refinery hardware

CREW


Stephen Dennis


Terry Donlon


John Hall


Wilson Wong

- All experimental procedures which were capable of accomplishment by reason of nominal support equipment performance were satisfactorily accomplished by assigned crew members. Additional experiments were conceived and carried out by crew members in areas relating to individual interests. Numerous attempts were made by the crew to restore function to the few equipment items which were not repairable. Some life support subsystems failed in modes which had not been anticipated but were returned to operation solely because of the ingenuity of crew members in effecting repairs. Other subsystems failed but were operated for long periods in manual modes to "coax" further performance from them. It is apparent that total system operation could not have been maintained without the dedicated crew support which was available.

4.4 MISSION ACTIVITY ANALYSIS

In planning the crew activity schedules for use during the test, the output of a computerized method was compared with a manually developed schedule. The computerized method, known as the Space Station Mathematical Model (SSMM), was developed and applied by LRC personnel. Data were taken on actual crew performance to enable comparison of the manual and computerized schedules and to provide improved inputs in future tests.

Input data for both methods included: (1) a crew event matrix, defining the activities to be performed by the crewmen and listing constraints, skill requirements, equipment used and time estimates, (2) a crew skills matrix showing the primary and secondary skill areas of the crewmen, (3) a mission events profile listing activities required for each day of the test, and (4) operating ground rules. From these, crew activity schedules were derived, both by manual methods at MDAC and by use of the SSMM at NASA-LRC.

It was found that collection of operational planning data in the above formats was equally helpful in both methods of planning. These offered a tool to provide a firm basis for activity scheduling and helped in eliminating potential scheduling conflicts, provided the capability for evaluating proposed changes as the program developed, and required consideration of mission-related effects by personnel working in the technical areas.

The crew was furnished with a full set of the activity schedules at the beginning of the test. These included 270 pages of detail activities, 8 hours for each of the four crewmen on each page. They were instructed to use them as a guide, and to make adjustments found to be necessary to accommodate unscheduled events or adjust for unexpected variations in task time requirements. The computer and manually generated schedules were presented on similar formats.

Analysis of data collected during observation of crew activities during the test shows that on each day the actual time spent on scheduled events was less than allocated and the crew free time was more than allocated. Review of the actual daily crew performance schedules and the crew activity schedules shows that the crew was able to reduce the scheduled event times to allow for necessary unscheduled engineering tasks.

Table 4 shows the average time spent in each general category by each crewman during 10 days of observation.

It was found that the Langley SSMM provided operationally useful planning data and was capable of rapid response to changes in input conditions. The preparation of the required input data was useful in both the manual and computerized planning methods, and should have been started earlier in the program to permit SSMM to assist in evaluating the proposed changes which occurred up to 3 days before test start.

4.5 STAFF AND OPERATING PROCEDURES

During the 90-day test, operations were conducted from the test control area shown in Figure 1. This area was arranged to provide a convenient arrangement of necessary equipment for the test control staff, and to minimize the presence of nonessential personnel within the enclosure. A visitors area was located adjacent, from which the test operations could be observed, and system displays were set up to provide a summary of the program and current status information.

Operation of the test required a continuous staff including a Test Conductor, Communications Monitor, Engineering Monitor, Medical Monitor, and Electro/Mechanical Technician.

Personnel for filling the above positions, with the exception of the Medical Monitor, were selected from the Advance Biotechnology and Power Department and Engineering Laboratories staffs on the basis of their experience in previous test and demonstrated ability during the program planning and facility installation and checkout periods. The Communications Monitors were also selected on the basis of their pretest relationships with the crew, having demonstrated a rapport which was expected to reduce intercrew hostility. These staff members went through a training program during the pretest period to familiarize them with test objectives, equipment, operating procedures, and safety requirements. There was crosstraining between positions to allow a man from one position to stand in for another during emergencies.

Table 4

EVENT MEAN TIME PER DAY PER CREWMAN
(FOR DAYS 31-35, 41-45)

Event or Event Group	Manual Schedule	Crew Performance	Computer Schedule
Man/systems events	1 hr 34 min	0 hr 56 min	1 hr 42 min
Medical events	1 44	1 04	1 24
Operational events	36	16	28
Scheduled crew personal	12 20	11 45	12 47
Free time	7 46	8 30	7 39
Unscheduled maintenance	-	1 29	-

In general, at least five men were trained for each position. Four teams were selected from those certified, including as broad a coverage of special areas of interest as possible, with one stand-in for each position to cover in case of sickness.

During the test each team worked an 8-hour shift for a continuous period of 21 days, then had 7 days off, and returned to work one shift later. Thus, the objectives were accomplished of adhering as closely as possible to an average 40-hour week, allowed sufficient time for each team to adjust their day-night cycle, and equalized the requirement for shift changes. On any given day, three teams covered the three shifts of operation and one team was on leave. The 7-day-off period allowed ample time for recovery from the long continuous work period yet required a minimum of updating of the returning crew, which was accomplished by having an overlap period with the outgoing crew upon their return.

The Medical Monitors were qualified physicians licensed to practice medicine in California. They were responsible for medical safety of the SSS operations and were required to provide immediate medical support in the event of an emergency. They were recruited from the local area and hired on a contract, fee-for-service basis. They normally worked 12-hour shifts although some were on duty continuously for 24 hours or more. This was possible since a Medical Monitor's room was provided adjacent to the control area and their duties allowed normal sleep periods in this room. They were not expected to carry out routine medical procedures or to participate in the special medical studies, except for recording basal signs on night and weekend shifts. Some monitors, however, who worked a number of shifts, did participate in certain medical test operations.

An emergency treatment area was established immediately adjacent to the simulator. This station was equipped with emergency drugs (under lock, controlled by the Medical Monitor), cardiorespiratory resuscitation equipment, and miscellaneous medical support items.

Additional support was provided by principal investigators responsible for water management, oxygen recovery, the other equipment in the LSS, and the experiments such as mission activity analysis and NIPA. Supporting staff was provided during normal work hours to perform analysis of atmospheric trace contaminants, water, and microbial samples. Medical samples (urine and blood) were also collected, processed, and distributed to the clinical laboratories and principal investigators at many other locations.

The Medical Director was responsible for maintaining a personal doctor-patient relationship with the crew. One important feature of this relationship was a daily confidential interview with each crewman. This interview was informal and directed toward a general assessment of crew status. This interview afforded crew members the opportunity to report medical problems, vague symtoms, or any other problems in absolute privacy. More formal medical reviews were conducted at selected times during the test. The results of these interviews were held by the Medical Director as confidential medical information, but operationally significant crew reports were shared with key program personnel during the test, with the permission of the crew member.

The Program Manager, Medical Director, and NASA Resident Technical Director were required to remain on-call at all times during manned testing. To facilitate this requirement, remote page devices were provided to these people which had a call range throughout the Los Angeles basin area. Checks of these units usually were satisfactory except when the bearer was within a metal frame, shielded building. They allowed considerably greater flexibility of action than would otherwise have been possible.

4.6 DATA COLLECTION

Data collection was performed by a variety of methods, ranging from automatic recording of engineering parameters on the Low Speed Digital System, to collection of coded NIPA observations on computer-compatible punched tape, and to manual recording in log books. Review and evaluation of these collection methods is in order since many improvements can be made by increased automation, yet a manual collection capability is necessary for backup in the event of failure of key instrumentation channels.

4.6.1 Engineering Data

Engineering data collection was performed primarily by the Low Speed Digital System (LSDS). This unit received inputs from transducers on all the life support subsystems and facility support equipment to determine their performance. This instrumentation included thermocouples, strain gage pressure transducers, turbine and Linurmass flowmeters, current, voltage, and power signals. Analog signals from these units were amplified, converted into digital data, and stored on magnetic tape. Approximately once a day the tape was processed by an XDS-930 computer which applied calibration factors and converted to engineering units. A printed output was then produced, and selected parameters used for graphical output.

The LSDS has a capacity for 200 analog input channels, with a maximum scan rate of 200 channels per second. During the majority of the test period, it was used to record a series of ten samples each half hour. Each set of ten samples was processed in the computer, which eliminated the two highest and two lowest and averaged the remaining six for further calculation and/or printout. On three occasions, data sets were taken at 4-minute intervals for 24-hour periods to provide information on power load profiles. Also, data sets were taken several times at 1-minute intervals to obtain adsorption/desorption curves on the molecular sieve and solid amine CO_2 concentrators.

Visual presentation of many analog channels as well as status and alarm indicators was done on the Life Support Monitor (LSM) in the test control area and repeated on the Crew Life Support Monitor (CLSM) at the front of the equipment room in the SSS. The LSDS also was used for visual output of selected digital data.

An acoustical data link was provided between a keyboard inside the SSS, an oscilloscope display visible through a viewport at the CLSM, and an XDS 930 computer located remotely. A program was provided to allow for daily crew input of flow meter readings and food and water consumption data, for use in a mass balance computation. The program also provided for periodic crew input of psychological questionnaire data. As part of the crew input procedure the computer was placed on-line through the acoustical data link and provided data printouts in conventional units. Due to a lack of flexibility in the program, some of the computerized calculation of mass balance data was not usable and the printed output data was generally incorporated with other inputs, for manual computation of mass balance data. Figure 4 shows a SSS crewman placing the day's data into the acoustical data link.

Additional sources of engineering data were manually recorded logs kept by the Test Conductor, Engineering Monitor, and by the technician on external equipment such as the Lockheed electrolysis unit, wet test flow totalizers on vent gases, and water accumulated in the commode and VD-VF vent freeze traps.

4.6.2 Man/System Data

Man/system data were collected in connection with the behavioral program, habitability evaluations, mission activities analysis, Non-Interference Performance Assessment (NIPA), electroencephalogram (EEG) study, behavioral acoustics programs, and psychomotor test evaluation.

The behavioral program and habitability evaluations were done by periodic application of questionnaires to the crew members. The acoustic data link and associated computer were programmed to accept the crew responses to these questions and print out tabulations of their answers. These data were then scored and evaluated manually.

Data for the mission activity analysis were recorded manually by the Mission Analysis Monitor with help from the Communications Monitor, particularly during periods of high activity inside the chamber. The purpose of this data was to validate previously generated activity schedules, either by manual or computerized techniques, and to obtain additional data on task time requirements in order to improve planning for future missions. This data recording activity was specifically concentrated over two 5-day periods during the middle third of the test. There were times during these periods in which data were lost because of the inability of monitors to keep up with activities or to identify exactly which activity was being performed. It was also found that observer fatigue limited the useful time spent to about 4 hours per shift.

Data for the NIPA program were recorded by especially trained observers. Early in the program this was done at the Communications Console, but a remote observer station was completed and used after the first 30 days. This station was equipped with TV and intercom monitoring capability. Confidential medical interviews and telephone conversations were not monitored. A teletypewriter connected to a remote time-sharing computer was used for recording coded data, and produced a paper punched tape for further processing by computer. This semiautomatic method of collecting data proved quite efficient. Observers on this program were also limited to a 4-hour shift duration.

The application of tests and collection of data on the EEG and the behavioral acoustics studies was done by the operating personnel at the time of the test. This was during the first and last 10 days of the test for the EEG study and every week, on Saturday, for the acoustic program. Data from the EEG study were processed and reduced by a special computer program developed during the test; the acoustic data were manually reviewed and evaluated.

The psychomotor testers were operated by an outside staff member while the crewmen performed the tests inside the chamber. Data were recorded manually. Strip-chart records were made of the Langley Complex Coordinator (LCC) which were returned to the principal investigator at LRC for his evaluation. Figure 9 shows the LCC in use by a SSS crewman during the 90-day test.

4.6.3 Samples for Analysis

Many samples were obtained for analysis during the test. These included cabin atmosphere; water from the potable and wash water recovery units; microbial samples from surfaces, air, water and the crewmen; and biomedical samples.

4.6.3.1 Cabin Atmosphere Samples

Three circulating air loops were provided for obtaining cabin atmosphere samples at instruments outside the SSS. Each of these included a feedthrough tube, a compressor providing a circulating air flow, and a feedthrough back to the cabin. One of these loops supplied air to the gas analysis console for

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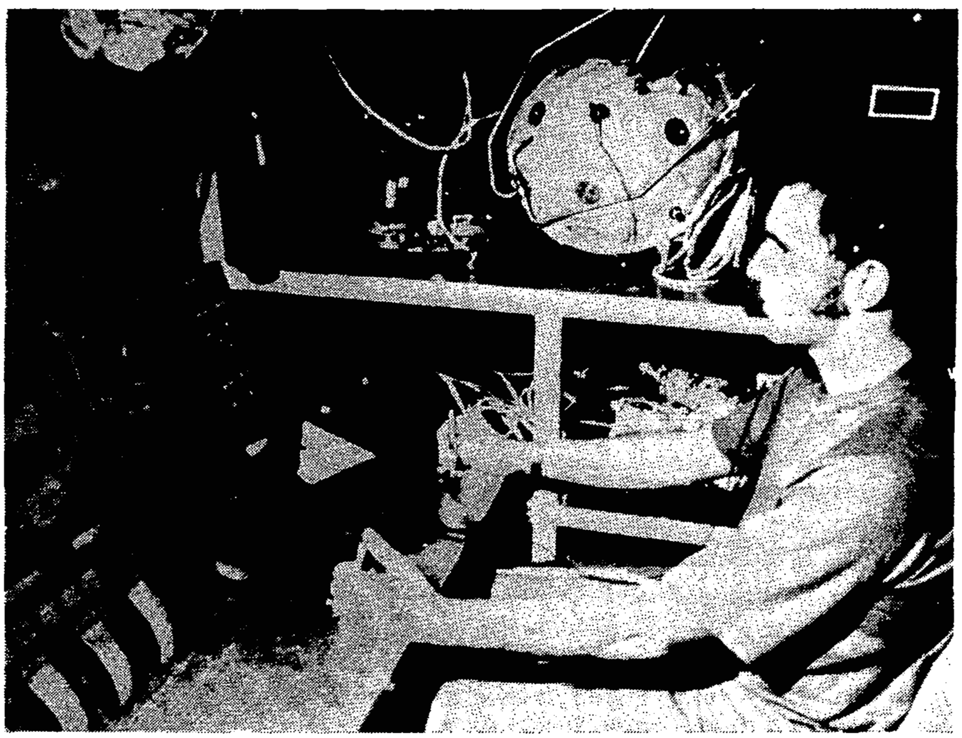

Figure 9. Crewman Operating the LRC Complex Coordinator (Psychomotor Tester)

continuous analysis of carbon dioxide, carbon monoxide, total hydrocarbons, water vapor, and oxygen. Samples were also taken from this loop for chromatographic analysis for organics and wet chemical analysis for inorganic contaminants. This loop was equipped with a bank of 24 solenoid valves at the inlet which enabled sampling from various locations inside the cabin and at various locations in the life support units. A second loop supplied an ozone monitor, built by Research Triangle Institute, and a gas sample collection unit operated by Aerojet personnel for NASA-LRC. A third loop furnished air to a Royco airborne particle analyzer. Data collected on the latter were furnished to the Department of Transportation, Cambridge, Massachusetts, for further analysis. Additionally, atmospheric humidity was measured inside the cabin by three Cambridge dewpointers.

4.6.3.2 Water Samples

Samples of potable and wash water were collected periodically and analyzed to measure unit performance in removing contaminants. These samples were analyzed for microbial and chemical impurities and physical characteristics.

Microbial determinations were done onboard, using Millipore Field Monitors which were incubated at 35°C for 48 hours. Samples were normally taken from each tank of processed water as it was filled (approximately every other day). Microbial counts above 10/ml were cause for rejection of potable water. Samples were also taken periodically from various locations in the potable and wash water recovery units and from the dispensers. All monitors showing microbial growth after 48 hours were held and passed out on the next weekly pass-out. Isolates were sent to NASA-LRC for identification. Other monitors were stored as waste onboard.

Samples for chemical analysis were passed out of the chamber via a short 1/8-in. feedthrough tube using a syringe on the inside and a collection bottle, initially evacuated, on the outside. These samples were provided from each potable tank as it was filled and also from other selected locations in the water recovery system. They were routinely analyzed for total organic carbon (TOC), and ammonia, bromine, and chromium ion concentrations. Periodically, determinations were made for metal ions, total dissolved solids, nitrates, and nitrites.

Physical characteristics of water samples were determined by the SSS crew in the onboard laboratory. These included turbidity, color, taste, odor, foaming, pH, and electrical conductivity.

Water samples processed onboard (microbial and physical analyses) were returned to the urine accumulator; those passed out were not returned.

4.6.3.3 Microbial Samples

The closure of the SSS during the test provided a biologically isolated system, and samples were taken to study the resulting effects on microflora of the crew, equipment, and air in the cabin.

The crew members obtained samples from selected nasopharyngeal and dermal sites which were passed out of the chamber each week. Reyniers air samplers located on countertop areas in the living quarters and equipment room were operated every 2 weeks, on the day before passout. Swab samples of marked surfaces in the waste and food management areas were taken every week. Samples were passed out of the chamber every week for processing in the MDAC laboratory. Additional surfaces and various subsystem components were sampled immediately after crew egress. After primary isolation, up to 6 morphologically different colonies were picked from each plate for subsequent identification at MDAC, NASA-LRC, or the Medical College of Virginia.

4.6.3.4 Biomedical Samples

The biomedical sampling program was constrained by the limited pass-outs allowed. The baseline medical sampling program was aimed at periodic systems checks by means of screening biomedical test, hematologic studies and urinalyses. These tests covered a wide range of organ systems in order to detect pathologic responses to the environment; samples were collected for every other pass-out.

Since this ampling program would only detect, not define problems, a supplementary medical program was devised to evaluate in more depth the response to predicted low-level stresses, i.e., CO_2 exposure, confinement effects on physical conditioning, forced changes in day-night biological cycles and to study biochemical correlates of stress. Samples for these programs were collected weekly and included blood specimens for analysis by the USN Submarine Medical Research Center (CO_2 study) and the Naval Medical Research Institute (stress biochemistry), and aliquots of 24-hour urine voidings in support of both the CO_2 and stress studies.

No difficulties were experienced in obtaining any biomedical samples and at no time during the test did the crew fail to obtain scheduled samples. It is felt that the complete crew cooperation was a result of their total involvement in the test and of extensive discussions with them explaining the relevancy and importance of the samples.

Samples of blood (serum) and urine from each pass-out were retained, frozen (200°K), for contingency analysis. The original intent of the contingency sampling procedure was to provide for serological evaluations in the event of viral illnesses and for urine chemistry in the event of toxicological incidents. It became apparent during the test that these samples served a broader purpose providing for additional, unplanned tests where unexpected observations ensued from scheduled sampling. In addition, once the original purpose was served, the samples could be used for further analysis after the test in support of special studies. Figure 10 shows the crew obtaining one of scheduled blood samples during the 90-day test.

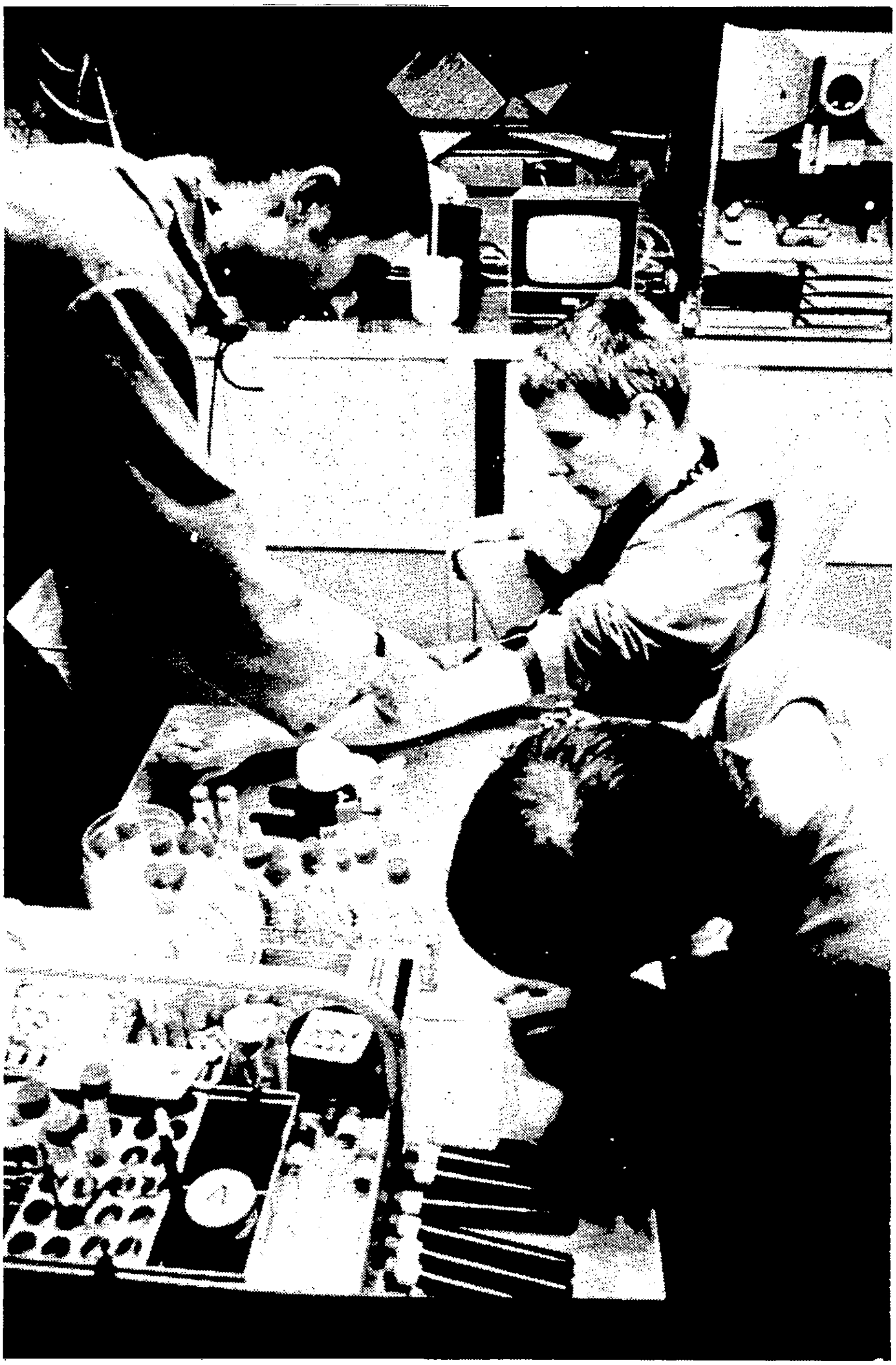

Figure 10. Collection of Blood Samples in Preparation for Weekly Pass-Out

Section 5
TEST RESULTS

This section provides a review of significant areas of the results of the 90-day test. An effort has been made to eliminate detail and present only the more important of the findings. Detail test results are provided in NASA CR-111881.

5.1 LIFE SUPPORT SYSTEM OPERATION, MAINTENANCE, AND REPAIR

The installation of the life support equipment in the SSS equipment area is shown in Figures 11 and 12. The regenerative LSS included advanced subsystem units being evaluated for the first time in a manned test, and baseline units whose design had been proven in previous manned tests. The advanced subsystem units were used to provide the prime mode of operation with the parallel baseline units held in a standby mode. Table 5 presents a summary of crew/life support system data.

A summary of the LSS operating history is shown in Table 6. Included in this table is a comparison of actual operating time, downtime, standby time, and required operating time for each unit. The actual and required operating hours were determined by the following relationships:

Actual Hours = 2, 156.5 Hours - (Hours Downtime + Hours Standby)

Required Hours = Actual Hours + Hours Downtime

The 2, 156.5 hours is the actual 90-day test duration. The downtime represents time that the unit was not available due to equipment malfunctions. Standby represents time that unit operation was not required due to the operation of the primary (or advanced subsystem) unit, the intermittent operation mode of the unit, or malfunctions of other equipment which necessitated shutdown of the unit. Since the urine phase separator failed early in the test, the downtime and standby hours were estimated based on the anticipated usage. The ratio of actual hours to required hours may be considered as a reliability factor with a higher number signifying higher reliability.

The LSS maintenance and repair operation during the 90-day test is summarized in Table 7.

Since the Lockheed electrolysis unit and system gas sample lines were located outside the SSS, the maintenance and repair activities on this equipment were performed by outside personnel. These outside activities covered 25 items in 90.2 hours. Of the totals shown in Table 7, the onboard crew performed 212 maintenance and repair items which required 151.8 hours of crew time.

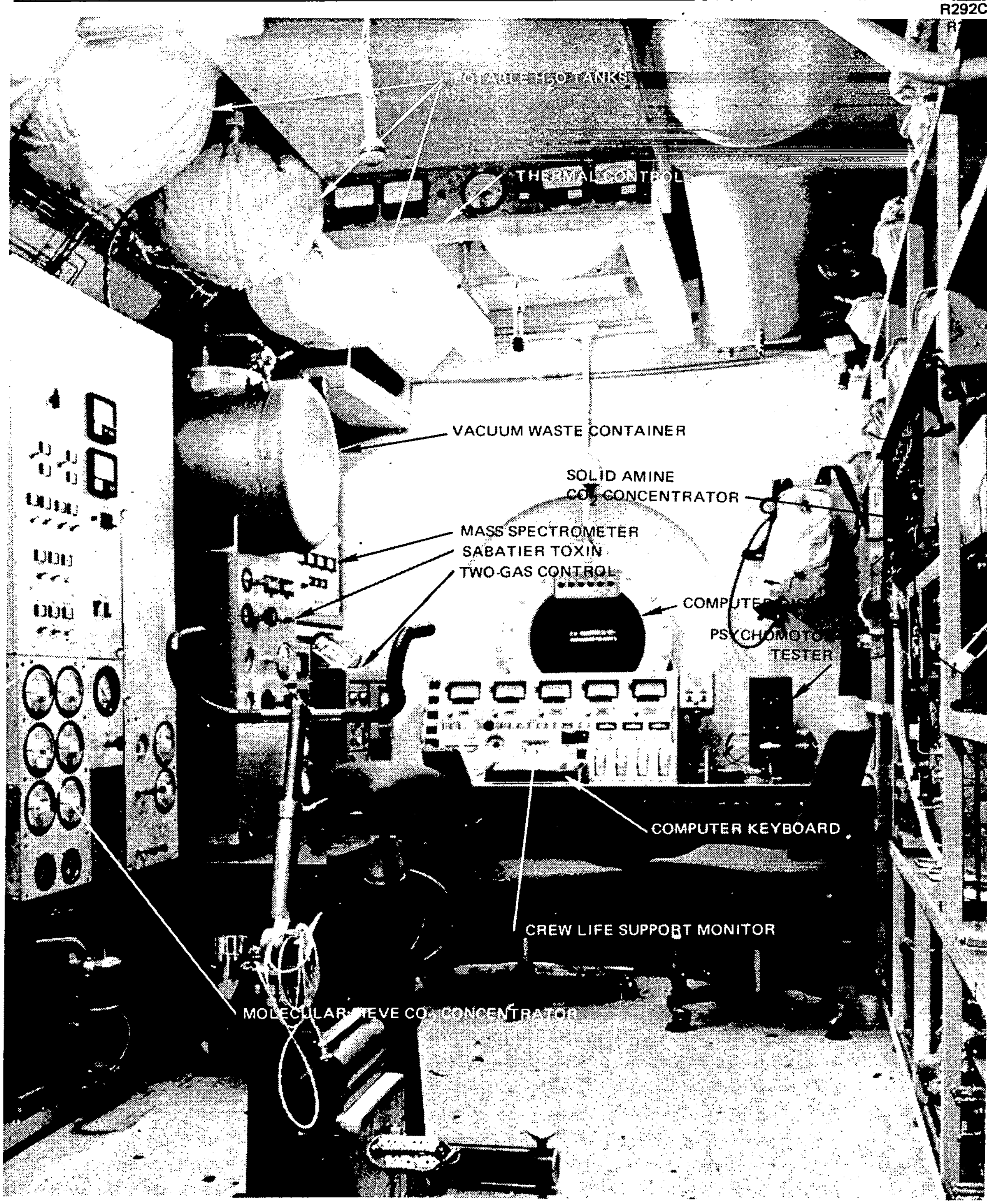

Figure 11. SSS Interior Equipment Area, Looking Forward

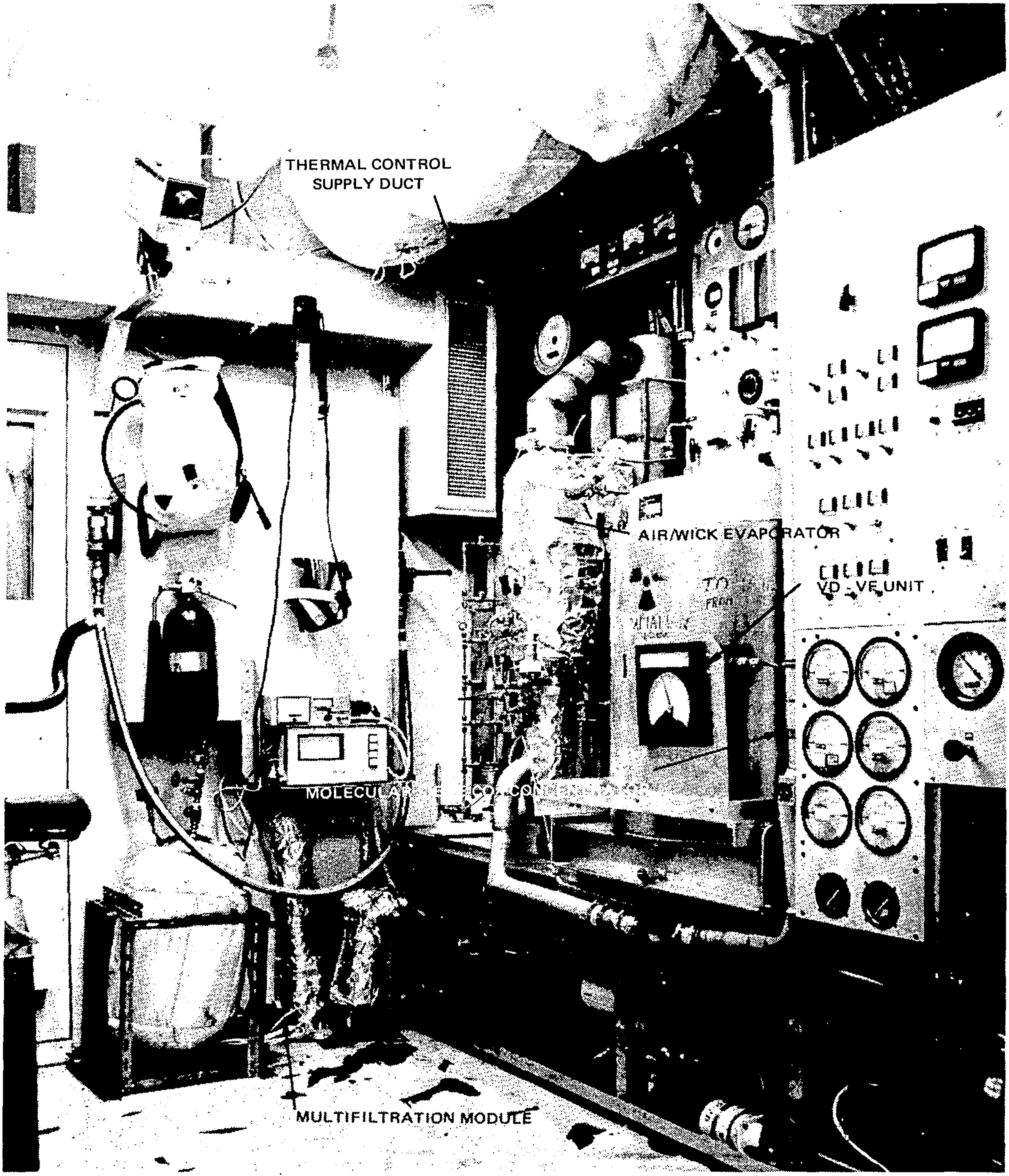

Figure 12. SSS Interior Equipment Area, Looking Aft

Table 5

SUMMARIZED CREW/LIFE SUPPORT SYSTEM DATA FOR FOUR-MAN CREW

	[1] Data Book Values		[2] Planned Pretest Values		Actual Values	
	kg/day	lb/day	kg/day	lb/day	kg/day	lb/day
CREW INPUT						
Dry Food	2.76	6.08	2.68	5.90	2.45	5.40
Total Water	11.19	24.68	10.80	23.80	10.31	22.70
Oxygen	3.50	7.72	3.38	7.45	3.66	8.05
CREW OUTPUT						
Carbon Dioxide	4.21	9.28	4.08	9.00	3.80	8.36
Respiration/Perspiration	5.04	11.12	7.71	17.00	5.31	11.70
Urine	7.11	15.68	3.67	8.10	5.94	13.10
Feces	0.47	1.04	0.63	1.39	0.40	0.88
RESPIRATORY QUOTIENT	0.876		0.883		0.75	
REGENERATIVE LSS PRODUCTION						
Potable Water Recovered			11.78	25.98	11.88	26.19
Wash Water Recovered			38.56	85.00	52.65	116.08
CO_2 Removed from Cabin			4.08	9.00	3.93	8.67
Water Recovered by Sabatier for Electrolysis			1.86	4.10	1.99	4.38
Water Added for Electrolysis			2.26	4.99	2.28	5.03
Oxygen Supplied by Electrolysis			3.65	8.05	4.27	9.41
ATMOSPHERE LOSSES						
Oxygen			0.27	0.60	0.69	1.53
Nitrogen			0.53	1.17	1.41	3.10

1. Reference 1.
2. Planned values as shown in NASA CR-111882.

Table 6

SUMMARY OF LSS OPERATION

Life Support Unit	Actual Operating (hr)	Downtime (hr)	Standby (hr)	Required Operating (hr)	Actual / Required
Waste management					
Commode*	23.3	0	2,133.2	23.3	1.000
Urine phase separator	2.5	34.9	2,119.1	37.4	0.067
Water management					
VD-VF*	1,529	597.5	30	2,126.5	0.720
Wick evaporator	744	0	1,412.5	744	1.000
Humidity control	2,156.5	0	0	2,156.5	1.000
Potable multifilter	2,026.8	0	129.7	2,026.0	1.000
Wash water recovery	2,156.5	0	0	2,156.5	1.000
Atmosphere purification					
Solid amine concentrator*	1,662	494.5	0	2,156.5	0.772
Molecular sieve concentrator	494.5	0	1,662	494.5	1.000
Toxin control	1,790.5	0	366	1,790.5	1.000
Thermal control	2,156.5	0	0	2,156.5	1.000
Atmosphere supply and pressurization					
Sabatier reactor	1,918.7	104	133.8	2,022.7	0.947
Electrolysis (Allis-Chalmers)*	96	2,036.5	24	2,132.5	0.045
Electrolysis (Lockheed)*	1,492.8	475.3	188.4	1,968.1	0.758
Two-gas control*	2,156.5	0	0	2,156.5	1.000
Mass spectrometer sensor*	2,118.8	0	37.7	2,118.8	1.000
Baseline two-gas control	0	0	2,156.5	0	1.000
Baseline two-gas sensors	37.7	0	2,118.8	37.7	1.000

*Advanced subsystem unit

Table 7

MAINTENANCE AND REPAIR SUMMARY

Activity	Items	Hours
Waste Management		
Commode	4	6.2
Urine phase separator	8	14.3
Water Management		
VD-VF	21	23.9
Wick evaporator	4	0.3
Humidity control	33	16.2
Potable multifilter	4	5.6
Wash water recovery	19	4.8
Atmosphere Purification		
Solid amine concentrator	47	33.4
Molecular sieve concentrator	8	4.4
Toxin control	0	0
Thermal control	0	0
Atmosphere Supply and Pressurization		
Sabatier reactor	12 (8)*	12.6 (6.0)*
Electrolysis (Allis-Chalmers)	46 (1)	25.5 (1.0)
Electrolysis (Lockheed)	0 (16)	0 (83.2)
Two-gas control	0	0
Mass spectrometer	5	4.1
Baseline two-gas control	0	0
Baseline two-gas sensors	1	0.5
LSS Subtotals	212 (25)	151.8 (90.2)
Miscellaneous Items		
Defrost refrigerator	9	4.5
Cleaned cabin floor	9	9.0
Cleaned dewpointer mirrors	4	1.5
Corrected leak in trash container	2	0.3
Repaired psychomotor pedal	1	1.0
Deactivated smoke alarm head	2	0.7
Repaired radiation monitor	1	0.3
Repaired particle counter	1	0.5
Replaced videcon tube	1	0.5
Repaired TV coaxial cable	5	2.5
Installed intercom call light	1	1.0
Attempted repair of visual sensitivity tester	4	6.7
Scheduled Maintenance	-	23.0
Miscellaneous and Scheduled Subtotals	40	51.5
Totals	252 (25)	203.3 (90.2)

*Numbers in parenthesis represent outside activity.

In addition to repair and maintenance of the LSS, the crew performed additional tasks on onboard experiments and other support equipment. The significant items are also included in Table 7. Scheduled maintenance was required for items such as the TV cameras, radiation monitor, and aerosol particle counters. This scheduled maintenance was estimated to be a total of approximately 23 hours. The total onboard crew time for all maintenance and repair activities was approximately 203 hours (2.3 hours/day).

A primary mission objective of the 90-day manned test was that all spares would be stored onboard with all required maintenance and repair tasks performed by the crewmen. This mission objective was met since all maintenance and repairs were accomplished utilizing only onboard spares. There were 365 majors spares stored onboard, not including items such as fluid fittings, wire, tubing, tape and sealant. Only 52 major spares were used during the 90-day test, which amounted to 14.3 percent usage of the available spares. This level of utilization is not unusual for similar spares provisioning programs.

The stocked onboard spares were sufficient to support the 90-day test, except for those required for the urine phase separator and the onboard water electrolysis unit, which were new prototype units that were not available during previous manned tests and had been evaluated by bench tests only. Since the Failure Mode, Effects, and Criticality Analysis (FMECA) is only as good as the available data, the lack of adequate spares for these two units emphasizes the importance of adequate reliability data.

5.2 CONTAMINANT CONTROL

Contaminants found in the SSS atmosphere included carbon dioxide, carbon monoxide, methane, and minor trace contaminants. Removal of carbon dioxide from the atmosphere was accomplished by an advanced steam desorbed solid amine concentrator or, when it was not operating, a thermally desorbed molecular sieve concentrator. A catalytic oxidizer was used to remove carbon monoxide, methane, and other light hydrocarbons. An activated-charcoal bed in the open-loop wick evaporator unit removed additional trace contaminants. Results of operation of this equipment and data from the contaminant monitoring program are reported below. Also included are significant findings of the biomedical investigations in these areas.

5.2.1 Carbon Dioxide

Carbon dioxide in the SSS atmosphere, which was a product of the crewmen's metabolism, was removed by the solid amine or molecular sieve concentrator and delivered to the Sabatier reactor for recovery of oxygen (Section 5.4). A lithium hydroxide unit was provided for emergency backup but was not required during the test.

5.2.1.1 Subsystem Performance

The steam-desorbed solid amine unit operated for a total of 69.5 days of the test. It was shut down twice (on days 13 and 19) when it was unable to hold CO_2 concentration below the contingency level of 1.066 kN/m^2 (8 mm Hg), and on test day 33 to install a nitrogen gas line, replacing an air compressor which had failed in supplying actuating force for the bed valves. On three other occasions CO_2 levels exceeded the contingency value (test days 45, 58, and 65); adjustments or maintenance on the unit enabled it to recover each time. On test day 81, a progressive deterioration in performance resulted in a decision to shut it down for the remainder of the test. Each time it was shut down, the molecular sieve unit was started and used to reduce the CO_2 level.

One objective of the 90-day test was obtaining comparative performance data on the advanced and baseline units. This evaluation must consider that the advanced units were built with minimal previous experience to guide the designers and, typically, were not adequately bench tested before delivery to MDAC to completely define system performance or failure modes. Therefore, the advanced subsystems were frequently at a disadvantage in comparison with the baseline units on which more previous operational experience had been accumulated.

Table 8 presents a comparison of performance variables on the two concentrator units. It can be seen that the data on the molecular sieve is superior to that of the steam-desorbed solid amine unit in all areas except fluid supply temperature. The high thermal loads of the latter appeared to be due in part to losses from an uninsulated steam line, and the high humidity output (latent loss) was caused in part by a plugging drain line in the output condenser.

Table 8

COMPARATIVE PERFORMANCE OF CO_2 CONCENTRATORS

Unit	Steam-Desorbed Solid Amine	Molecular Sieve
Heat input (fluid)	2,125 J/sec (7,250 Btu/hr)	971 J/sec (3,320 Btu/hr)
Temperature	390°K (240°F)	434°K (320°F)
Power input	762 watts	650 watts
Heat rejected to coolant	1,555 J/sec (5,300 Btu/hr)	1,328 J/sec (4,540 Btu/hr)
Heat rejected to atmosphere:		
Latent	324 J/sec (1,100 Btu/hr)	-48 J/sec (-164 Btu/hr)
Sensible	995 J/sec (3,390 Btu/hr)	327 J/sec (1,123 Btu/hr)
Water loss with CO_2	5.5 kg (12.2 lb)	0
System weight	295 kg (650 lb)	235 kg (517 lb)
System volume	0.51 m^3 (18 ft^3)	0.57 m^3 (20 ft^3)

5.2.1.2 Medical Studies

A special study of the effects of prolonged exposure to low levels of CO_2 was instituted shortly before the 90-day test began. This study was stimulated by concern in some circles that CO_2 exposure in the ranges expected in the Skylab Program (<733 N/m^2 or 5.5 mm Hg) would cause biochemical changes. These changes were not expected to be harmful but, if they occurred, would interfere with meaningful interpretation of data obtained in zero-g studies. Since the goal in the 90-day test was to maintain CO_2 in the 530 to 655 N/m^2 (4 to 5 mm Hg) range, it was obvious that an ideal opportunity for evaluating the basis for that concern existed. Although the total pressure and oxygen partial pressure differed from Skylab, these were not considered to interfere significantly with the results of the CO_2 study.

Exposure History

The CO_2 exposure history reveals a slowly rising mean P_{CO_2} during the test with significant prolonged peaks during the last 45 days as compared to the first 45 days. Figure 13 illustrates the frequency distribution of recorded CO_2 observations. Carbon dioxide levels were recorded every 4 hours. It can be seen from Figure 13 that, during the first half of the test, 80 percent of the observations were below current Skylab limits in contrast to the second half where only 33 percent were below that limit. Very low levels were not observed during the last half of the test and over 10 percent were in excess of 1,070 N/m^2 (8.0 mm Hg) during this period. These distributions suggest that this test consisted of two exposure phases with control of the CO_2 less precise during the last half with higher, more prolonged peaks of CO_2.

Biochemical Analysis Results

Blood samples analyzed at the USN Submarine Medical Center, Groton, Connecticut, reveal no apparent changes in venous plasma for red blood cell, pH, biocarbonate or electrolytes not seen also in outside controls. Analyses of these data have not been completed by USNSMC personnel, however, and these are our preliminary judgments. Serum samples analyzed by the MDAC contract laboratory reveal depression of serum calcium (Ca^{++}) during the last half of the test with concomitant increases in serum phosphorus (P).

Figure 14 shows serum calcium trends as mean values pretest, the first 53 days, the last 37 days, and post-test. It is clear that no depression in Ca^{++} is seen during the first half of the test. Analysis of the depression seen during the last 37 days shows that for the group, the mean value differs significantly from the first half and from the post-test value. Increase in phosphorus was generally observed to correspond with the depression in calcium, tending to validate this data set. Table 9 tabulates individual serum calcium values. While only sporadic changes are seen in the first 53 days, 7 of the last 8 values are significantly depressed when compared to pretest control means. Dietary deficiencies in Ca^{++} and vitamin D have not been ruled out as possible causes for the observed changes. In adults, however, such deficiencies are not likely to deplete serum Ca^{++} since bone stores are sufficient to maintain it. These changes probably reflect CO_2 storage in response to peaks of CO_2 exposure superimposed on a chronic low-level

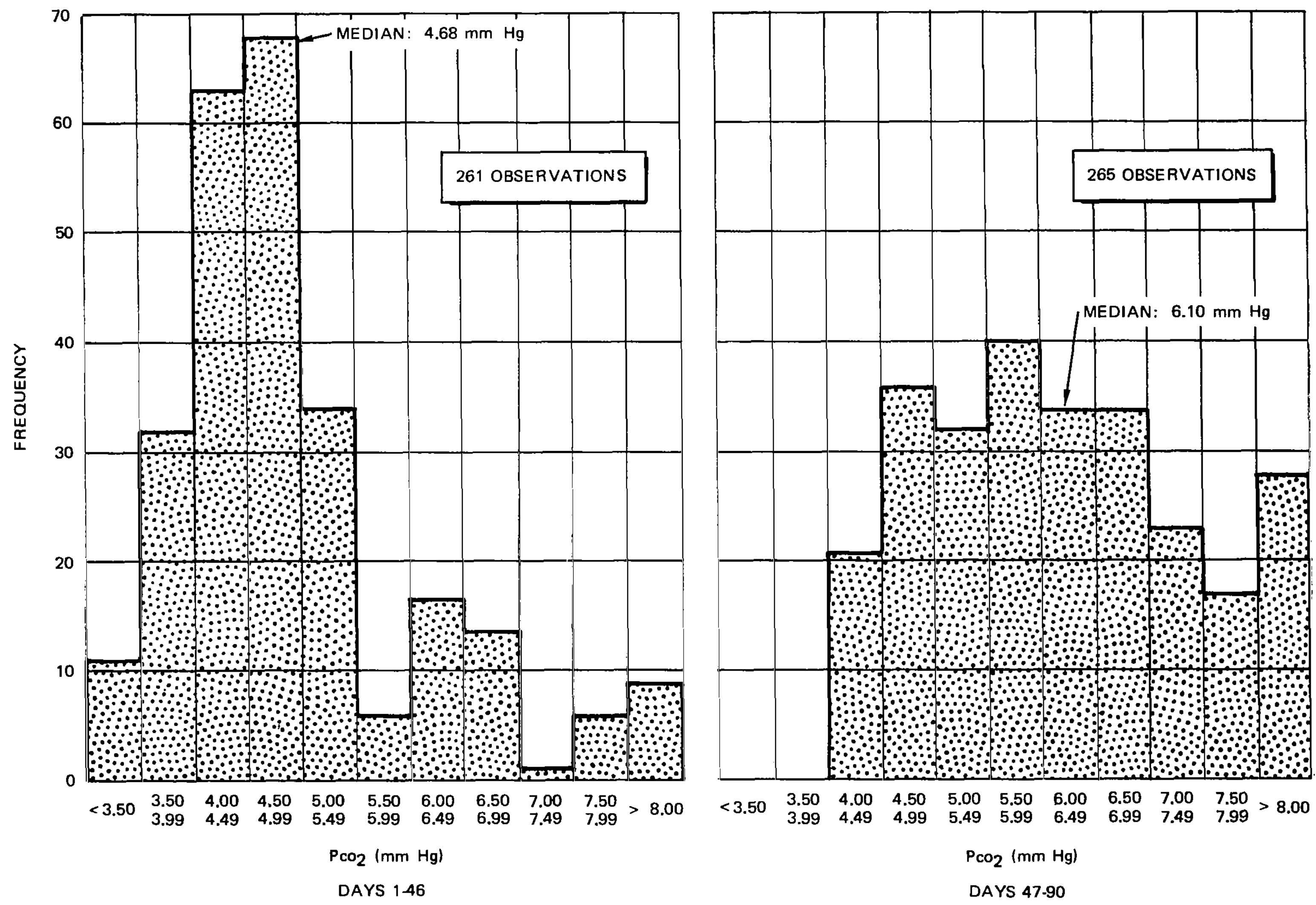

Figure 13. Frequency Distribution of P_{co_2} Recorded Observations

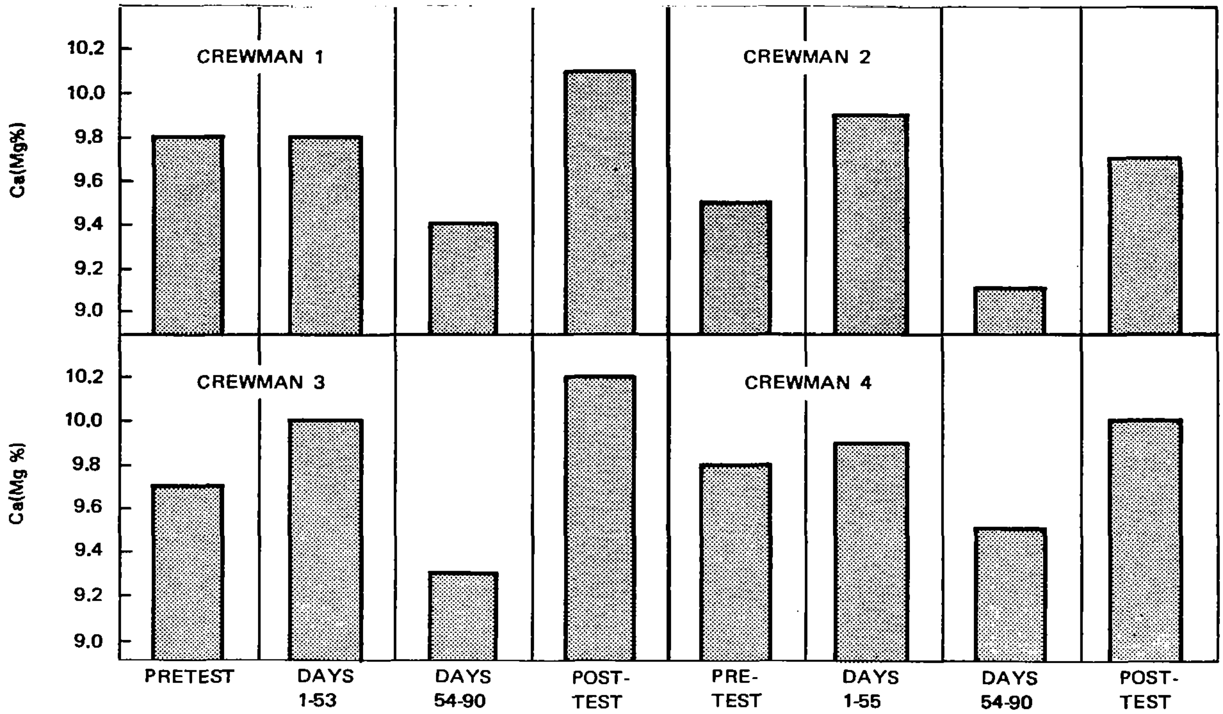

Figure 14. Serum Calcium Trends — Period Means

Table 9

TEST SERUM CALCIUM (MG %)

		Crewman			
Sample	Test Day	1	2	3	4
1	11	9.4**	9.4	9.5	9.4*
2	25	9.9	9.5	9.6	9.7
3	39	10.4**	10.0**	10.0*	9.8
4	53	9.7	9.6	9.8	9.7
5	67	9.8	9.2*	9.8	9.8
6	81	9.2**	9.0**	8.8**	9.3*
7	88	9.2**	9.2*	9.2**	9.5
8	Post-test	10.1**	9.7	10.2**	10.0*

*Significantly different from pretest mean, $P \leq 0.05$.
**Significantly different from pretest mean, $P \leq 0.01$.

exposure. Twenty-four hour urine samples did not reveal changes reflecting any alteration in acid-base balance. No psychomotor or physiologic changes were seen at any level of CO_2 exposure.

5.2.2 Minor Trace Contaminants

Analysis of atmospheric samples for the presence of trace contaminants was conducted by MDAC to ensure the continued health and safety of the test crew. Analysis was done by chromatograph on direct samples and concentrated samples obtained by freeze-out techniques to determine the presence of organic compounds. Measurement of carbon monoxide was done on a continuously circulated sample by a LIRA infrared analyzer. Inorganic compounds were measured by wet chemical analysis on daily samples.

Particular attention was directed to specific compounds to which pretest planning had assigned contingency and abort levels. Many of these levels were established upon the recommendation of the Panel on Air Standards for Manned Space Flights of the National Academy of Science.

Trace contaminants were found to fall into three general categories including: metabolic products of crewmen (at least in part); residues from pretest cleaning or solvents; and products of decomposition. Of nearly 100 compounds for which chromatograph calibrations were done, only 13 were detected in the cabin. Table 10 shows the types and concentrations of each of the compounds found in the above categories. Although tested for, the following compounds were never found in the SSS atmosphere: sulfur dioxide, hydrogen sulfide, hydrogen cyanide, chlorine, hydrogen chloride, phosgene, and ozone.

The trace contaminant program clearly showed that the cabin atmosphere was relatively clean. Levels were always well below established limits. The occurrence of relatively high levels of Freon 113, although much lower than physiological limits, was the source of catalyst bed performance loss as explained in Section 5.4. This was due to excessive use of this solvent during pretest cleaning of the chamber.

The presence of ammonia in the atmosphere was directly related to operation of the open-loop wick evaporator for processing urine. Ammonia was detected within a few days after processing started and disappeared within a few days after it stopped. Similarly, oxides of nitrogen were correlated with the combined presence of ammonia and operation of the toxin burner. During a 2-week period when the toxin burner was shut down, the oxides of nitrogen were not detected even though ammonia was present.

During the test, a recording spirometer was installed in the crew quarters, with readout instrumentation at the medical monitors station. This instrument was used once each week to obtain a forced vital capacity volume-flow (v-$\dot{v}$) loop on each crewman. This was done to monitor any variation of pulmonary performance of the crew potentially related to the effects of atmospheric trace contaminants. No significant changes were observed during the test except for enhanced respiratory flow at reduced barometric

Table 10

ATMOSPHERIC TRACE CONTAMINANTS

	Measurement Threshold (ppm)	Quantity Median* (ppm)	Quantity Maximum (ppm)	Test Contingency Level (ppm)	Apparent Source
Metabolic Products of Crewmen					
Methane	10.0	150.0	290.0	--	
Carbon monoxide	2.0	17.0	26.0	100.0	
Aldehydes	0.05	0.32	0.47	15.0	
Ethyl alcohol	0.2	0.5	1.5	300.0	
Acetone	0.05	0.5	2.39	--	
Residues of Pretest Cleaning or Solvents					
Freon 113	0.20	4.0	11.50	150	
Toluene	0.05	0.10	0.15	30	
Methylethyl ketone	0.05	0.10	0.27	--	
Dichloroethane	0.05	0.10	0.25	--	
Decomposition Products					
Ammonia	0.05	1.5	4.0	75	Urine
Oxides of nitrogen	0.05	Trace	0.15	1.5	Ammonia
2-Ethyl Butanol	0.05	0.2	0.45	20	Coolanol 35
2-Ethyl Hexanol	0.05	0.2	0.65	--	Coolanol 35

*Note: Median of nonzero data from daily samples.

pressures. This appears to be a normal result of reduced airway resistance due to the lower density. Although no changes were seen in this test, it is recommended that the recording spirometer be used in the future where pulmonary irritants may be a potential problem.

5.3 WATER RECOVERY

Water recovery was performed by separate subsystems for potable and wash water. The potable water subsystem included: (1) the isotope-heated VD-VF unit, (2) the wick evaporator and humidity control unit, (3) the detoxification-multifiltration unit, (4) the storage and distribution unit, and (5) the backup potable water supply. The wick evaporator was used as a backup for the VD-VF unit in processing urine. Water produced by the wick evaporator and humidity condensate was always processed through the detoxification-multifiltration unit, but water from the VD-VF unit was not unless it was required to meet potability standards. Because flexible operating modes were desired without risk of cross contamination, design of the potable system was considered on an overall basis. The resulting integrated system is shown schematically on Figure 15.

The VD-VF unit included a boiler assembly, condenser, condensate tank, holding tank, and pump. The boiler was provided with four wells for inserting the radioisotope capsules, a hydrophobic membrane intended to prevent liquid entrainment in the evolved vapor, and a superheater and catalyst bed with another isotope capsule well. During normal operation, a vacuum was drawn at the system outlet (condensate tank) sufficient to reduce the boiling temperature to 312 to 323°K (100 to 120°F). The superheater temperature was about 395°K (250°F). A small amount of air was drawn into the boiler to furnish oxygen; the catalyst oxidized any organic gases in the vapor to produce pure water vapor and carbon dioxide which was vented along with the excess air to an overboard vacuum pump and vapor freeze trap. A spare boiler was stored onboard for use when the urine solids accumulated in first unit.

The storage of potable water was done in spherical pressurized bladder tanks, each having approximately 100-lb capacity, each equipped with electric heaters and thermal controls to hold the contents at 345°K (160°F) to preserve sterility. Distribution was via a continuously circulating loop, in which the hot water continued to prevent microbial contamination. Dispensers provided hot and cold water to the crew. Hot water was dispensed by an Apollo flight type unit equipped with an electric heater. Cold water passed through dual redundant chillers, cooled by the Coolanol 35 loop, and was dispensed either by the Apollo cold tap or by a direct outlet in an adjacent panel.

A backup supply of potable water was stored in a 50-gallon cylindrical tank. This was pretreated with iodine (6 ppm) prior to the test start and monitored regularly to insure that the iodine remained in solution at the proper level. The concentration of iodine in this tank never dropped below 5 ppm during the test, although it was found that samples, when held for 24 or more hours, showed much lower levels (0.5 ppm). This was apparently caused by adsorption of iodine in the plastic sample container. Valid readings were obtained when samples were analyzed after only 1 or 2 hours.

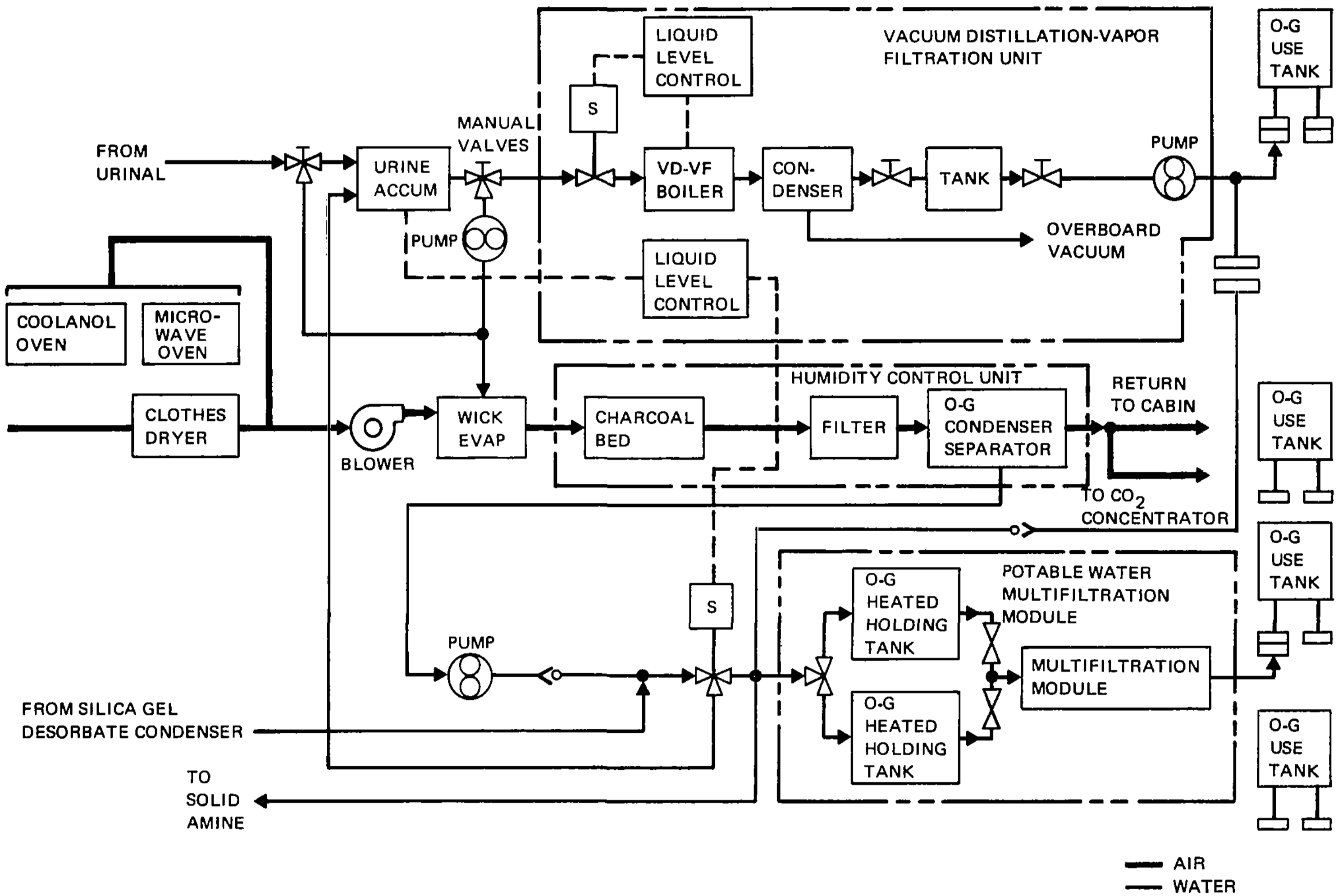

Figure 15. Integrated Potable Water and Humidity Control Subsystem Schematic

Table 11

WATER RECOVERY FROM URINE

	Total		Average Rate	
	kg	lb	kg/day	lb/day
Urine production	534.6	1,178.5	5.94	13.09
Pretreatment solution	5.4	11.9	0.06	0.13
Total	540.0	1,190.4	6.00	13.22
Urine samples (overboard)	10.9	24.1		
Other losses	1.1	2.5		
Net available for recovery	528.0	1,163.8	5.86	12.93
Urine solids residue				
Wick evaporator	9.1	20.0		
VD-VF boilers	13.5	29.8		
Total	22.6	49.8		
Water losses in VD-VF unit				
Vacuum vent	23.4	51.6		
Boiler residue	14.9	32.9		
Total	38.3	84.5		
Water recovered from urine	467.0	1,029.5	5.19	11.44
Urine flush water	94.1	207.4	1.04	2.30
(From wash water system)				
	561.1	1,236.9	6.23	13.74

Table 12

POTABLE WATER PRODUCTION

	Totals		Average Rate	
	kg	lb	kg/day	lb/day
Humidity Condensate				
Respiration and perspiration	477.8	1,053.3	5.31	11.70
Wash water evaporation	254.2	560.3	2.82	6.23
Subtotal	731.9	1,613.6	8.13	17.93
Cabin humidity caused by Solid amine operation*	487.7	1,075.1	7.01*	15.45*
Total humidity	1,219.6	2,688.7	13.55**	29.87**
Urine and urinal flush	561.1	1,236.9	6.23	13.74
Recycled water samples	19.7	43.4		
Miscellaneous sources	39.6	87.2		
Total, All Sources	1,840.0	4,056.2	20.44	45.07
Distribution Prior to Certification				
Makeup to wash water unit	232.7	512.9	2.59	5.70
Makeup to solid amine unit*	520.7	1,148.0	7.49*	16.52*
Samples passed overboard	10.0	22.0		
Miscellaneous	2.0	4.4		
Urine accumulator net increase	9.1	20.0		
Holding tanks net decrease	-3.5	-7.8		
Total Distribution	770.9	1,699.5	8.56**	18.88**
Recovered, certified potable water	1,069.0	2,356.7	11.88	26.19
Losses after certification	141.6	312.1	1.57	3.47
Consumed by Crew	927.4	2,044.6	10.31	22.72

*Note: Solid amine unit based on 69.5 days of operation.
**Note: Based on overall 90-day totals.

5.3.1 Potable Water System Performance

Prior to test start the potable water system was qualified to meet all requirements for chemical, physical and microbial characteristics established by the ad hoc Committee of the Space Science Board, National Academy of Sciences. Taste tests were also conducted to insure acceptability of the water to the crewmen. Details of these tests are presented in Section 2.2.2 of NASA CR-111881.

During the test, each tank of water was sampled as it was filled. These samples were analyzed as described in Section 4.6.3. The collected data was reviewed by the Medical Director, who certified each tank for potability before consumption was permitted. The period for analysis and certification was at least 48 hours, limited by the incubation time required for the microbial samples.

A summary of water recovery from urine is presented in Table 11. As shown in this table, of 534.6 kg (1,178.5 lb) of urine produced, losses included 10.9 kg (24.1 lb) of samples, 22.6 kg (49.8 lb) of solids, and 38.3 kg (84.5 lb) of water losses associated with the VD-VF unit. The net water recovery from urine was 467.0 kg (1,029.5 lb), or 5.19 kg (11.44 lb) per day. To this 94.1 kg (207.4 lb) of flush water was added.

Water recovery from humidity condensate is summarized in Table 12, along with the distribution of recovered water prior to certification and the changes in contents of the urine accumulator and holding tanks. Crew respiration and perspiration losses averaged 5.31 kg (11.70 lb) per day, and evaporation from the wash water loop 2.82 kg (6.23 lb) per day. The solid amine unit contributed an average of 7.01 kg (15.45 lb) per day of humidity condensate during its 69.5 days of operation. This increased the total water recovery rate from 14.36 kg (31.67 lb) per day to 21.37 kg (47.12 lb) per day, or 49 percent, when it was in operation.

Before final processing and certification, water was distributed to the wash water unit, the solid amine unit, and sample collection. These and other minor losses required 8.56 kg/day (18.88 lb/day). A total of 1,069.0 kg (2,356.7 lb) were certified for consumption. The crew actually consumed 927.4 kg (2,044.6 lb) for an average of 10.31 kg/day (22.72 lb/day). This compares with a total of water recovered from urine, respiration, and perspiration of 10.50 kg/day (23.14 lb/day) after subtracting urine samples and VD-VF losses.

Of the total water produced, 247.4 kg (545 lb) were by the first VD-VF boiler during 25 days of operation, and 366.8 kg (808 lb) by the second during 38 days of operation, averaging 9.9 kg/day (21.8 lb/day). This production rate is fixed by the constant heat output of the radioisotope capsules, less thermal losses to the environment. The water recovery efficiency, defined as actual water recovered/water available for recovery, was 94.3 percent. Of this production, about 40 percent was certified for consumption, the remaining 60 percent was treated by multifiltration due either to poor taste or microbial contamination in the condensate collection tank.

Samples from the potable use tanks always met microbial standards, as did those from the Apollo hot water dispenser. However, samples from both cold dispensers were contaminated. No means was available to resterilize these, so all water for the crew was drawn from the hot tap. A supply was kept in the refrigerator to provide cold drinks. Means must be provided to insure sterility of cold water dispensers on future systems.

5.3.2 Radiological Monitoring and Isotope Handling

Approximately 1/3 kw of thermal energy from five capsules containing $^{238}PuO_2$ was used to power the VD-VF water recovery system. Radiation doses received by the test crew were well below acceptable levels and below pretest predictions. (The worst case was only 14 percent of conservative analytical predictions.) No radiation exposure problems were encountered and there was no evidence of leakage from the radioactive isotope capsules. There were no difficulties encountered in handling the hot capsules.

Difficulties were encountered with radiation monitoring instrumentation. These problems included failures to operate and false alarm signals. The former were corrected by interchanging components of the various instruments; the latter were detected by cross-checking instrument readings. During VD-VF unit operation, four of the isotope capsules were installed in the wells in the boiler and one in the catalyst bed. When not operating, the capsules had to be removed and placed in the cooled water bath across the equipment room. Since there were several failures of the VD-VF unit, more handling of the capsules was required than expected. There were 14 separate handling operations during the 90-day test, requiring 76 capsule manipulations. These required 150 to 420 seconds for each manipulation and each resulted in an average whole body dose of 1 to 3 mrem/hr. If it had been possible to provide alternate cooling of the capsules in place, even this small exposure would have been unnecessary.

5.3.3 Wash Water Recovery

Wash water was recovered by processing through a filtration system including mechanical elements, activated charcoal, and ion exchange resin, then storing in a pressurized bladder tank, heated to 344°K (160°F) to prevent microbial growth. Wash water was used for personal hygiene, laundry, and urinal flushing.

A summary of utilization of the wash water is presented in Table 13. The unit processed 5,077 kg (11,182 lb) of water and used 13.6 kg (30 lb) of expendable filters and absorption column material. A total of 254 kg (560 lb) were lost from the system by evaporation. Uses other than washing accounted for an additional 367 kg (808 lb). After allowing for a net inventory loss (reduction in tank contents), a total of 4,744 kg (10,448 lb) were dispensed for washing. This amounts to 13.2 kg (29.0 lb) per man-day during the test.

Changes in the particulate filter elements were made whenever the processing rate dropped below 2.5 cm^3/sec. Three changes of the 30-micron element and one change of each of the 3- and 1-micron elements were required.

Table 13

WASH WATER SYSTEM SUMMARY
WATER BALANCE AND EXPENDABLES FOR 4 MEN, 90 DAYS

		kg (pounds)	kg (pounds)
Water Produced:			
Multifiltration unit			5,077 (11,182)
Water Used:			
Washing	Including evaporation loss = 254 kg (560 lb)	4,744 (10,448)	
Reprocess		227 (500)	
Urinal flush		94 (207)	
Phase change		40 (88)	
Miscellaneous		6 (13)	
Inventory change		-34 (-74)	
		5,077 (11,182)	5,077 (11,182)
Expendables:			
Four carbon columns		(16)	7.3
Two resin columns		(8)	3.6
Five particulate filters		(2)	0.9
Cleansing agent (Basic H)		(4)	1.8
Total Expendables		(30)	13.6

Heat:

Tank heaters: (817 Btu/hr) 239.4 joule/sec average

Power:

Pump: 1,056 watts for 4.32 hours total operating time.

The activated carbon and ion exchange resins were changed when indicated by crew judgment of water quality and results of chemical analysis. Four changes of the activated-carbon column and two of the ion exchange resin were made.

Based on these tests, it is recommended that standards of acceptability of wash water quality should be reviewed and adopted. This test relied heavily on subjective reactions of the crewmen since no other criteria seemed applicable. However, data which has been obtained can serve as a basis for a more formal statement of requirements.

5.4 OXYGEN RECOVERY

Oxygen recovery during the 90-day test was accomplished by the Sabatier reactor unit and the water electrolysis units. The Sabatier unit converted the CO_2 concentrated by the atmosphere purification equipment into water and methane. The methane was discharged overboard and the water was electrolyzed to hydrogen and oxygen. The hydrogen was returned to the Sabatier unit and the oxygen was supplied to the SSS atmosphere as required to make up for crew consumption and leakage.

Although not a component of the oxygen recovery equipment, the toxin burner was integrated with the Sabatier reactor to use the heat produced by the reactor thereby reducing the toxin burner power requirements.

The toxin burner oxidizes low molecular weight hydrocarbons, methane, and carbon monoxide to carbon dioxide and water vapor. This reaction occurs at a temperature of 590°K (600°F) to 644°K (700°F) in the presence of a Hopcalite catalyst. Because of the low concentration of oxidizable material, heat must be added to maintain reaction temperature. The integrated Sabatier/toxin control units are shown in Figure 11.

5.4.1 Sabatier Reactor and Toxin Burner

Operation of the Sabatier reactor during the initial 30 days of the 90-day manned test was somewhat erratic due to catalyst poisoning which was found to be caused by trace quantities of Freon 113 appearing in the carbon dioxide. Operation returned to normal after replacing the nickel-on-Kisselguhr catalyst and adding a charcoal trap to remove the contaminant from the carbon dioxide. The unit produced about 162 kg (357 lb) of water during the test. The average water production rate for the last 60 days was 1.99 kg/day (4.38 lb/day). This includes 11.4 kg (25.2 lb) of uncondensed water lost through the exhaust with the methane.

A summary material balance for the Sabatier reactor is presented in Table 14. The table shows that the overall conversion of hydrogen to water and methane was 95 percent. The design objective was 91 percent conversion. The overall CO_2 conversion was 66 percent as compared to the baseline goal of 56 percent.

Operation of the toxin burner throughout the test was routine and without operational problems. Burner temperatures were adjusted between 567°K (560°F) and 661°K (730°F) throughout the last 60 days of the run to investigate variations in cooling effect to the Sabatier reactor. The toxin burner was turned off from days 68 through 81 to observe changes in methane and carbon monoxide in the cabin are shown in Figure 16. The increase in methane level noted on days 87 and 88 was caused by a leak in the Sabatier exhaust line. The methane level decreased rapidly after the leak was repaired.

On day 68, while turning the toxin unit off, the crew observed a white powder deposit in the area of the discharge-to-cabin vent. A sample of this material was collected and passed out for chemical analysis. Preliminary results indicated the material to be mainly chlorides of aluminum, copper, iron, nickel with minor amounts of silicon, magnesium, chromium, titanium, manganese, and boron. It would appear that the material resulted from the thermal decomposition of Freon 113 in the toxin burner to form chlorides and probably fluorides with the Hopcalite catalyst and the stainless steel and aluminum components of the unit.

In light of the catalyst poisoning experience in the Sabatier and the chloride deposits, it can be suspected that the Hopcalite was adversely affected by the Freon 113. When the toxin burner was returned to operation on day 81, the CO concentration decreased over a period of 9 days from 26 to 18 ppm. This seems to indicate the unit did function to affect the CO level; however, this type of correlation could possibly be expected with an unheated catalyst. The significant lowering in methane level also tends to indicate the toxin burner maintained some effectiveness throughout the test. However, the general gradual rise in methane levels in the atmosphere during the test, up to day 67, may indicate that a gradual reduction in capacity was occurring.

Table 14

SABATIER REACTOR MATERIAL BALANCE

Material In			Material Out		
	kg	(lb)		kg	(lb)
Carbon Dioxide	288.9	636.9	Water (to electrolysis cell)	150.6	332.0
Hydrogen	36.7	81.0	Methane	69.2	152.5
Nitrogen	7.5	16.6	Carbon Dioxide	98.7	217.6
Oxygen	3.7	8.1	Nitrogen	7.5	16.6
			Oxygen	0.2	0.5
Water Vapor	2.5	5.5	Hydrogen	1.7	3.8
Total	339.3 kg	748.1 lb	Water Exhausted	11.4	25.2
			Total	339.3 kg	748.2 lb

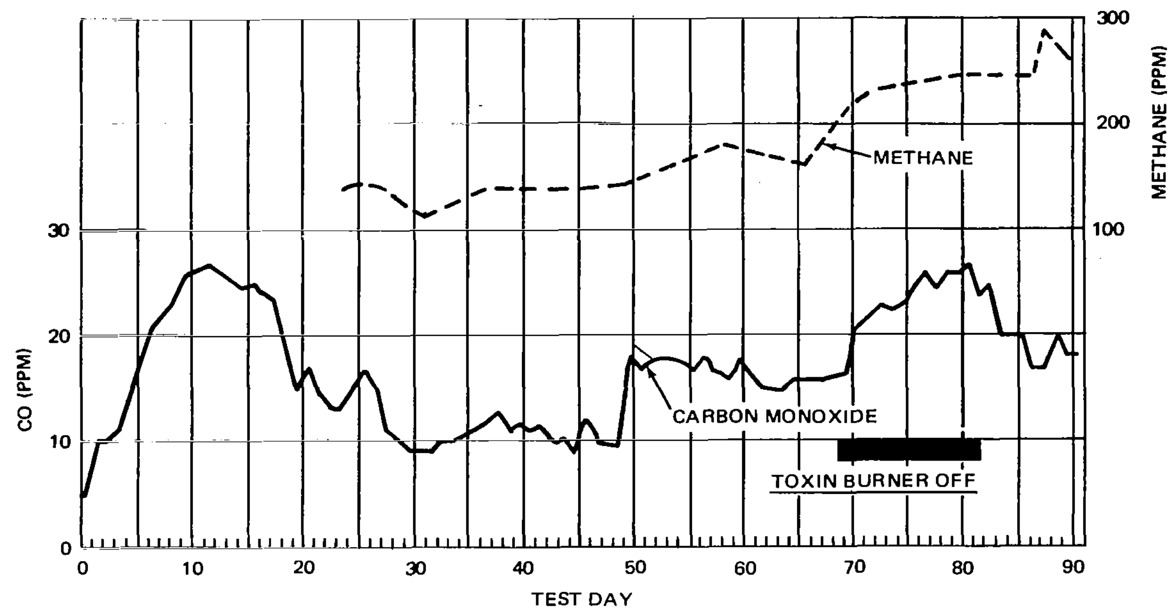

Figure 16. Methane and Carbon Monoxide Concentration

5.4.2 Water Electrolysis Units

The oxygen and hydrogen supply for the 90-day test was provided by three different water electrolysis units and a stored gas supply. The stored gas supply was used only in emergencies where demand exceeded the output capability of the operating electrolysis unit.

The electrolysis units used in this test were a commercial unit and two experimental units developed specifically for this test program. The commercial unit was installed outside of the SSS and was used for backup when neither experimental unit was capable of meeting either hydrogen or oxygen demands of the LSS. This unit was the Stuart unit, manufactured by the Electrolyzer Corporation. The other two units were manufactured by Allis-Chalmers Manufacturing Company (A-C) and the Lockheed Missiles and Space Company (LMSC). The A-C unit uses a vapor feed and intermittent circulation of electrolyte and was installed inside the SSS during the test. The LMSC unit uses a liquid feed with continuous electrolyte circulation and was installed outside the SSS during the test. All three units were used during the 90-day test and were designed to provide the oxygen requirements of the four-man crew.

In spite of numerous malfunctions and failures, the two experimental units provided 71.6 percent of the total hydrogen required and 68.3 percent of the total oxygen required. The failures experienced by the A-C unit caused early shutdown due to inaccessibility and lack of proper parts. The LMSC unit, being installed outside the SSS, was accessible for major repairs when required.

The major failures which caused unit downtime are summarized as follows:

Allis Chalmers Electrolysis—Between days 3 and 17, the unit was shut down while a failed module was replaced and all modules flushed. In addition, repairs were completed on the electronic control and an N_2 pressure regulator. Between days 18 and 20, the operation was intermittent and final failure occurred on day 20.

LMSC Electrolysis – On day 4, an H_2 leak in module 1 was repaired. On day 9, operation was intermittent because of repeated shutdowns of the 28-vdc power supply. Between days 12 and 17, the unit was shut down to replace defective N_2 purge solenoid valves and the 28-vdc power supply. Between days 45 and 48, the unit was shut down to repair a short in module 1, to repair leaks in modules 2 and 3, and to replace defective temperature switches. On day 60, a defective N_2 solenoid valve was repaired and the 28-vdc logic power supply was replaced. Between days 63 and 66, module 2 was rebuilt. Between days 73 and 74, modules 1, 3, and 4 were rebuilt.

During operation of the A-C unit, it produced an average of 57.4 percent of the required oxygen for the 4-day period. This unit provided, during its limited operating life, approximately 2.6 percent of the total oxygen and 2.7 percent of the total hydrogen required by the SSS during the 90-day test.

The LMSC unit operated a total of 1,681.2 hours (70.2 days). The unit supplied the chamber a total of 62.2 days and for 8.0 days the gas generated by the unit was vented to ambient. It delivered 68.9 percent of the hydrogen used by the Sabatier unit and 65.7 percent of the oxygen required for leakage and metabolic consumption. Average oxygen production rate for this unit was 4.13 kg/day (9.1 lb/day), which was not adequate to support the average requirement of 4.35 kg/day (9.58 lb/day).

The Stuart electrolyzer unit provided 28.4 percent of the hydrogen to the Sabatier unit and 30.0 percent of oxygen to the chamber. Also, 1.7 percent of the oxygen was provided from high-pressure storage.

A summary of the total oxygen and hydrogen supplied to the SSS from all sources is shown in Table 15.

5.5 FOOD MANAGEMENT

The food provisions available to onboard crewmen during the 90-day test consisted of a primary freeze-dried menu, supplementary snacks, frozen dinners, and a small amount of ice cream. Packaging, storage accommodations, supporting equipment, and acceptability of the food supplies were prime considerations, with emphasis on acceptability. Acceptability was felt to be a function of diversity of menu, mission duration, and initial reaction to the aesthetics of food consumption: flavor, color, consistency, and aroma.

Table 15

SUMMARY OF O_2 AND H_2 SUPPLIED TO SSS

Source	Oxygen kg	Oxygen lb	Hydrogen kg	Hydrogen lb
A-C Electrolysis	10.17	22.40	1.27	2.80
LMSC Electrolysis	256.97	566.02	25.04	55.15
Stuart Electrolyzer	117.27	258.30	10.46	23.00
Gaseous Storage	6.95	15.30	0.0	0.0
Total	391.36	862.02	36.77	80.95

Requirements placed upon the supplier of freeze-dried, uncompressed food consisted of: microbiological control deriving from NASA/Army requirements, vacuum packaging, a 10-day menu cycle, and 10.46 MJ (2,500 kilocalories)/man/day. An additional 2.09 MJ (500 kilocalories) of snacks were provided. These consisted of nuts, raisins, candy bars, and four pints of ice cream. Table 16 presents two typical freeze-dried menus.

For the frozen meals, the supplier was required to provide a minimum of 5 percent of the onboard meals, consisting of complete dinners amounting to approximately 3.347 MJ (800 kcal)/meal. NASA microbiological standards were to be met. Meals were to arrive in frozen form and were to be packaged to require no more than 0.122 m^3 (4.3 cu ft) of storage. Table 17 summarizes the frozen food provided.

Freeze-dehydrated foods were supplied in vacuum packages of a multilayer laminate, consisting of polyethylene, aluminum foil, and an outer layer of Mylar. Plastic dishes were included within some food packages; additional plastic food reconstitution dishes were stored in specially provided, tightly covered aluminum containers. Utensils provided for the crew were knives, forks, and spoons made of stainless steel. Frozen food was supplied in aluminum containers similar to TV dinner trays. These were covered with aluminum foil. Storage requirements for all food provisions approximated 2.8 m^3 (100 cu ft).

The overall acceptance of the food was unexpectedly high. This is an unusual finding for confinement studies or operational missions and reflects increased attention given to the selection of food on the basis of palatability. The frozen dinners were chosen by the crew approximately once per week, who employed them as a means of celebrating special occasions encountered during the mission. One such special occasion was a birthday party held for one of the onboard crewmen.

Table 16

TYPICAL MENU OF FREEZE-DEHYDRATED FOOD

DAY 1 Total 10.590 MJ (2,531 kilocalories)	DAY 2 Total 10.293 MJ (2,460 kilocalories)
Breakfast—3.874 MJ (926 kilocalories)	Breakfast—2.736 MJ (654 kilocalories)
(49) Orange Juice	(55) Strawberries
(57) Grapenuts w/Milk	(28) Creamed Beef
(73) Sugar	(90) on Toast (3 slices)
(30) Diced Ham	(94) Chocolate Milk (6 oz)
(31) Scrambled Eggs	
(91) Toast (2 slices)	
(75) Jelly	
(68) Milk (8 oz)	
Lunch—3.130 MJ (748 kilocalories)	Lunch—3.067 MJ (733 kilocalories)
(23) Pea Soup	(20) Consomme
(56) Crackers (6)	(56) Crackers (6)
(14) Ham and Green Beans au Gratin with Rice	(9) Beef with Rice
(96) Peanut Butter Cookies	(24) Carrot-Raisin Salad with Almonds
	(95) Date Filled Oatmeal Cookies
Dinner—3.568 MJ (857 kilocalories)	Dinner—4.489 MJ (1,073 kilocalories)
(1) Sliced Beef	(4) Sliced Ham
(70) with Gravy	(59) Noodles with Cheese Sauce
(42) Mashed Potatoes	(33) Asparagus
(35) Chopped Broccoli	(85) Chocolate Pudding
(26) Cottage Cheese w/Pears	(74) Margarine (1/2 tsp)
(76) Brownies	
(74) Margarine (1/2 tsp)	

The frozen foods were well accepted by all crewmen, but the crew indicated that they could have done without them had they been required to do so. Since they were available, they found them a welcome diversion from the freeze-dehydrated primary food menu. Negative remarks reflected the feeling that, when compared with the primary diet, the frozen meals were overly rich. This, combined with difference in strength of seasoning, apparently resulted in some minor gastrointestinal difficulties.

The crew used the microwave oven for heating water, reheating reconstituted freeze-dried foods, and thawing and heating of frozen food items. Since the latter meals were packaged in aluminum foil trays and, therefore, could not be placed directly into the microwave oven, the crew members transferred the items to plastic trays before heating.

Table 17

TYPICAL FROZEN DINNERS

Dinner No.	Constituents	Weight Kg	(oz)	Estimated Energy MJ	(kcal)
1	Sirloin steak	0.227	(8)	2.774	(663)
	Creamy potato bake	0.114	(4)	0.502	(120)
	Asparagus spears	0.085	(3)	0.084	(20)
		0.426	(15)	3.360	(803)
2	Pot roast of beef	0.085	(3)	1.109	(265)
	Beef gravy	0.067	(2)	0.209	(50)
	Duchess potatoes	0.099	(3.5)	0.502	(120)
	Glazed carrots	0.085	(3)	0.586	(140)
		0.327	(11.5)	2.406	(575)
3	Beef stew	0.284	(10)	4.477	(1,070)
	Spiced peaches	0.128	(4.5)	0.377	(90)
		0.412	(14.5)	4.854	(1,160)

The crew members reported no difficulties with operation of the microwave oven. A habitability item ranking of 2 (out of 57 items), i.e., excellent, was given to the microwave oven by the crew. The crew found the versatility of the oven to be extremely useful since it allowed the rapid preparation of boiling water for beverages and for reconstitution of freeze-dried meals.

A microwave radiation survey of the oven was performed each day throughout the test and readings were reported as consistently below 0.2 mw/cm^2 at 5 cm. The limit established prior to the test was 1.0 mw/cm^2 at 5 cm from the door. The survey was made using a Narda meter and 8121A probe. A survey of the oven post-test confirmed readings below 0.2 mw/cm^2 at 5 cm.

5.6 ATMOSPHERE CONTROL

The two-gas control included dual redundant units: the flight-weight unit (primary) and the prototype unit (baseline). Each unit included an electronics control package and a pneumatics package (see Figure 17). The primary SSS gas composition sensor was a four-gas mass spectrometer (Perkin-Elmer). A polarographic oxygen analyzer (Beckman) and a total pressure transducer (Statham) were provided for backup gas sensing.

The two-gas controller functioned by adding fixed pulses of oxygen and nitrogen to the atmosphere. The pulse frequency is controlled by an electronic signal which is proportional to the difference between the sensor output and a preselected control point. The quantity of gas added is measured by counting the pulses.

Both electronics packages used the same basic principle of operation. The baseline unit was fabricated from commercially available components. The input gas sensor signals were balanced by voltage divider networks, and the integrating amplifiers drove meter relays to activate the gas admission solenoid valves. The flight-weight unit utilized advanced microcircuits; amplifiers to balance gas sensor signals; and an integrating amplifier, binary counter, and a 10-second timer to activate the gas solenoid valves. The application of advanced technology to the flight weight unit reduced the weight and volume to 1/6 of the baseline unit.

After stabilization of initial transients, the oxygen stayed within ± 67 N/m^2 (± 0.5 mm Hg) of the control level. Nitrogen partial pressure throughout the run stayed within the limits of 44.0 ± 1 kN/m^2 (330 ± 8 mm Hg), after the transients of the first few days settled out. The relatively large fluctuations in nitrogen partial pressure were partially due to the leakage being considerably higher than expected. The low mass flow per pulse resulted in many more pulses to correct an error than desirable. The input circuit sensitivity was also much lower than that for the oxygen channel. Improvements in these parameters would result in much more accurate nitrogen partial pressure control.

No malfunctions requiring corrective action occurred at any time on the flight-type two-gas control. The calibration of the mass spectrometer unit was checked five times during the test. No adjustments were required at any time to achieve the required accuracy of the unit.

5.7 PHYSICAL FITNESS AND CONDITIONING

Confinement represents a relatively hypodynamic environment. It is well known that these environments, in the absence of adequate preventive measures, may result in losses in cardiovascular fitness and lean body mass (fat-free body tissue, e.g., bone, muscles). A special program was instituted to study changes during confinement in this test and particularly to evaluate bicycle ergometer scheduled exercise as a preventive measure.

5.7.1 Exercise Program

During the pretest training period, each crewman was required to exercise on the bicycle ergometer at a workload sufficient to produce a working heart rate of approximately 150 beats per minute for 15 minutes for 5 days each week. This level of exercise was selected to achieve and maintain a normal preconfinement level of fitness. They were not discouraged from participating in sports, informal calisthenics, or additional ergometer exercise either before or during the run.

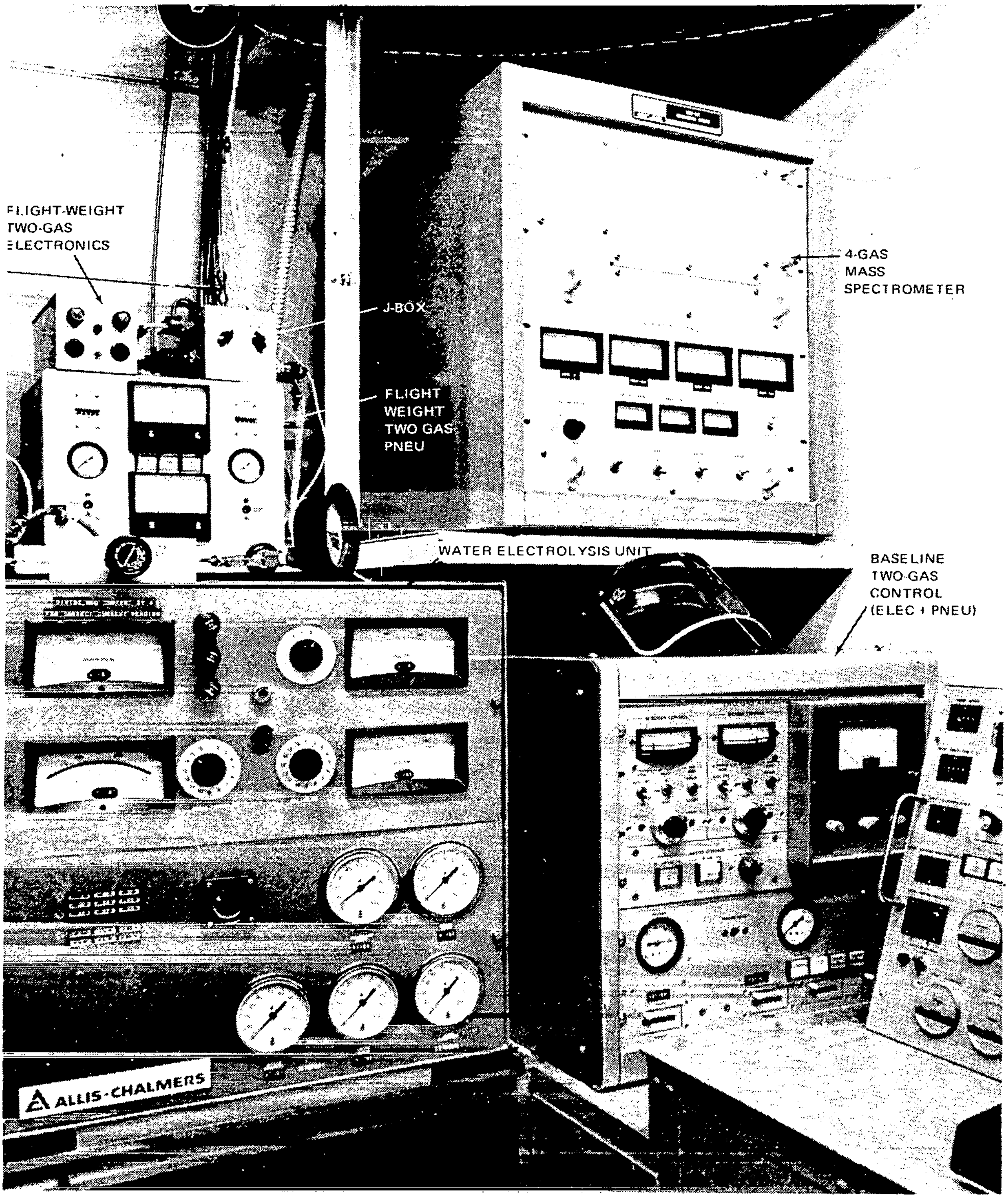

Figure 17. Two-Gas Control and Onboard Electrolysis Unit

Prior to the test start, each crewman was evaluated for cardiovascular fitness by the Balke Optimal Work Capacity Test (Reference 2). This test was repeated after the test to evaluate changes resulting from the program. During the test, heart rate and oxygen consumption were measured and physical fitness evaluated using the Åstrand-Rhyming nomogram (Reference 3).

The comparative data from the pretest and post-test Balke treadmill test are shown in Table 18. As shown, crewmen 2 and 4 showed an increase in Balke index, crewman 1 a decrease, and no change by crewman 3.

Crewman 4 followed a strenuous exercise program throughout the test period. In addition to a high ergometer workload, he performed rigorous additional calisthenics. His initially excellent fitness was further improved during the test. Crewman 2, on the other hand, started the test only in "fair" condition. He refrained from additional exercise during the first 30 days and maintained his original relatively low ergometer workload. During the middle 30-day period he gradually increased the ergometer load from 125 to 175 watts. During the final 30 days, he continued at this load with minimal extra exercise.

Table 18

BALKE OPTIMAL WORK CAPACITY TEST

(Treadmill speed = 3.5 mph, Termination heart rate = 180 beats/min)

Crewman	Time	Weight (kg)	Time on Treadmill (min)	Final Minute of Exercise		Balke Index (% of Average)
				Total Work (kg-m/min)	Work/Weight (kg-m/min/kg)	
4	Pretest	81.7	22	1,688	20.3	120
	Post-test	80.5	25	1,887	23.2	136
1	Pretest	58.9	20	1,103	18.8	109
	Post-test	58.9	17	940	16.0	93
3	Pretest	73.7	18	1,248	16.9	98
	Post-test	74.1	18	1,252	16.9	98
2	Pretest	59.2	16	888	15.0	87
	Post-test	61.9	18	1,043	16.9	98

Crewman 3 entered the test period in "good" condition and maintained this level, increasing his ergometer load from 150 to 175 watts mid-test and doing extensive additional exercise, and maintaining his "good" rating at the test completion. Crewman 1 maintained an ergometer load of 140 watts throughout the test, with minimal extra exercise, which apparently explains his decrease in fitness during the test.

It may be concluded that daily exercise on the bicycle ergometer is adequate to maintain cardiovascular fitness in confinement only if it is in the "hard" to "strenuous" range. More study is required to define suitable exercise programs in confinement, and consideration should be given to whole-body exercises.

5.7.2 Whole-Body Potassium and Isotope Studies

Potassium-40 was determined in a whole-body counter and plasma volume was measured by radioiodinated serum albumin (RISA) dilution before and after test. In addition, total-body water was determined by tritium oxide dilution before and after test and on test day 61. Significant increases in plasma volumes were observed in three of the four crewmen, coinciding with the observed differences in physical condition. Blood volume determinations were less definite but appeared to indicate generally similar results. The potassium-40 determination, indicating lean body mass, showed a significant loss in crewmen 1 and 2, which correlates with the general level of exercise during the test, if not with measured changes in fitness. Some increase in total body water for the crew as a group was indicated by the tritium oxide determination, although this finding is not consistent with other measurements. Some loss in meaningful data for this measurement occurred as a result of loss of the pretest standard samples.

5.7.3 Weight Changes and Skin Fold Measurements

Body weights were obtained immediately upon arising from scheduled daily sleep. Skin folds over the back of the right upper arm (triceps) and under the right scapula were measured weekly using a standard (Lange) skin fold caliper. The skin fold measurements were obtained to evaluate this simple procedure in following trends in subcutaneous fat. It was found that the skin fold measurements accurately reflected trends in body weight. From these data it would appear that the body weight changes which did occur were associated with body fat changes.

5.8 HABITABILITY RESULTS

Habitability results showed generally high acceptance of accommodations: 55 of 57 habitability provisions were indicated as being acceptable or better. Television, reading, writing, extra exercise, and audio musical and news broadcasts were the most common recreational pursuits. The use of communal or group games by the onboard crew members was rare. Body hygiene provisions consisted of wet washcloth bathing. Crew members were unamimous in their post-test recommendation that a shower bath facility would be desirable but not mandatory.

Illumination studies were conducted to evaluate the adequacy of Skylab lighting levels. From the standpoint of work performance, these lighting conditions were satisfactory and required only occasional use of supplementary lighting.

From the point of view of personal preferences, the crew ultimately chose to employ a light level approximately 4 to 5 times as bright as the Skylab illumination of 5 to 9 foot candles.

Features of the interior decor were evaluated by crew members. Results indicate that interior decor should be enhanced by the inclusion of more materials which have more and diverse surface textural gradients. In addition to surface texture features, the crew recommended that living quarters be sharply discernible from equipment quarters by virtue of design features, such as lighting, furniture, and acoustics.

Although the chamber only provided approximately 90 sq ft floor area for each man, crew remarks indicated that privacy provisions were satisfactory. Privacy was viewed by the crew as ability to separate oneself from others, if not in a physical sense, then in a psychological sense. At times, all four crewmen were located in the same area and were engaged in individual activities requiring no interaction with other personnel. At these times, the crew indicated they felt that their privacy needs had been satisfied.

Acoustics tests were undertaken to assess the acceptability of ambient noise levels which were approximately equivalent to NCA70 in the equipment room, NCA55 in the living quarters, and NCA45 in the bunk area. Crew members indicated some irritation with noise levels in the equipment room. They also mentioned that, in the bunk area, sleep could be disturbed by intermittent noises such as those caused by the awake crew members at the nearby table, that were superimposed on the relatively quiet normal background noise.

5.9 WASTE MANAGEMENT

The waste management subsystem included a commode unit, a urine collector unit, a waste storage container, a toilet paper dryer, a canner, a baler, and a waste liquid overboard pump.

5.9.1 Waste Collection

The commode was a "Dry John" type built for the Air Force Aerospace Medical Research Laboratory (AMRL) by General Electrical and furnished by AMRL for the test. This unit included a slinger-type collector with air induction of feces, a spherical bowl for storage, a replaceable liner, a sampling device, and disinfectant injection system. The commode was designed for 200 uses with storage for feces and toilet paper. When full, the unit is disassembled, the full liner removed and stored, and a new liner assembly is installed. Fecal sampling can be accomplished in a sanitary manner and disinfectant is administered by timed injection. Odor control is effected by a canister of Purafil odor control pellets and bacterial control consists of two bacterial filters in the air stream through the unit. Figure 18 shows the installation of the commode, urine collector and their controls.

In addition to this equipment, a toilet paper dryer was provided as a contingency in the event adequate collection capacity was not available in the commode. This was connected to the vacuum system in parallel with the commode and used a porous bag such as is used for a disposable vacuum cleaner collector. When filled and vacuum dried, these bags were sealed and placed in the dry waste storage container.

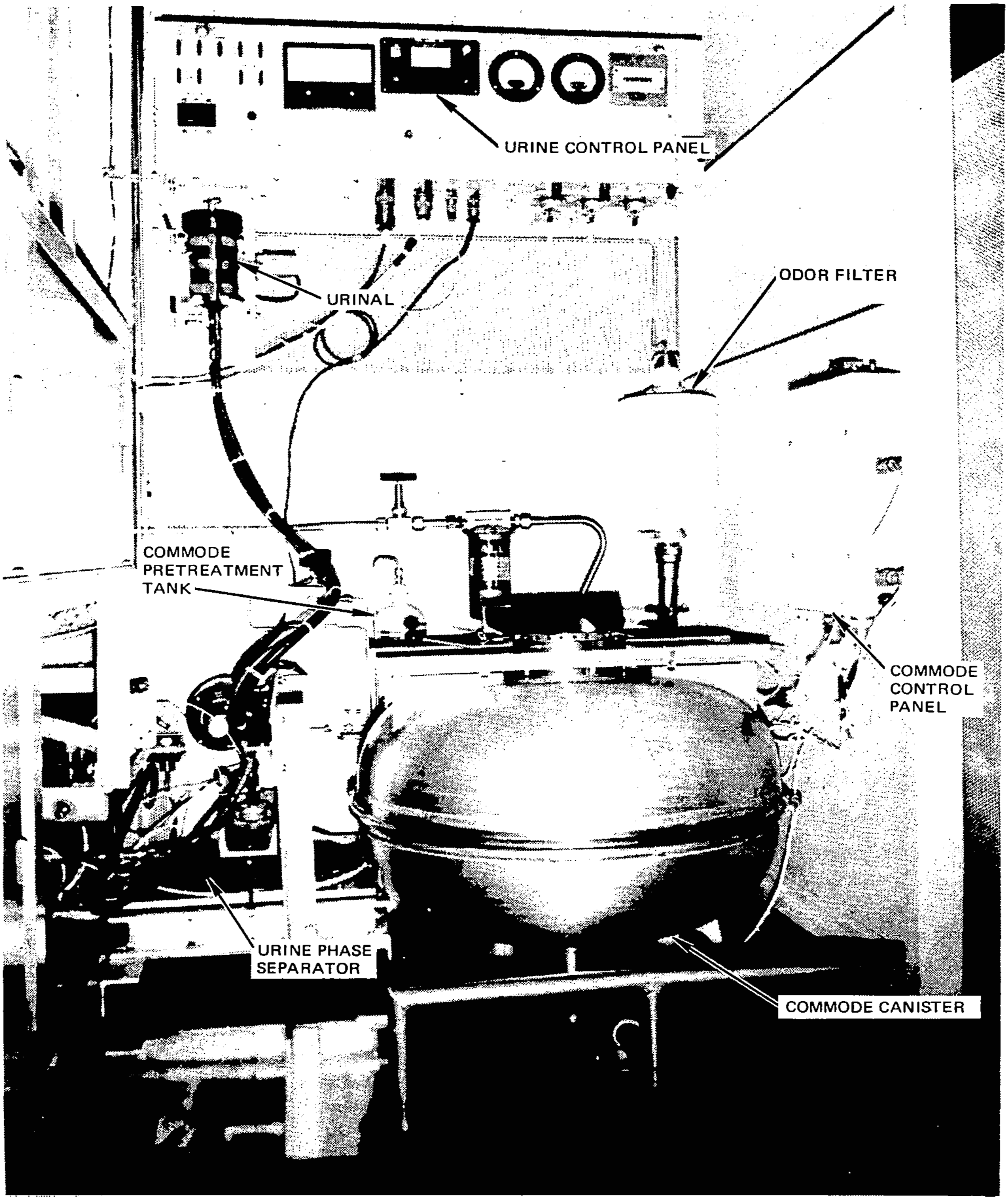

Figure 18. Commode/Urine Collector Units

The commode operated very satisfactorily during the 90-day test. Table 19 is a summary of the commode performance. During use of the first liner, all toilet paper was put into the commode. The liner had reached its capacity and was changed on day 44, at which time it appeared to be about two-thirds full. The used liner was stored in the unused pass-through airlock for the balance of the mission. During use of the second liner, the crew was instructed to place used toilet paper in the dryer. At the end of the test, the liner appeared to be about one-third full. Separate collection of toilet paper appears to be desirable for extension of liner life.

The urine collector consisted of a zero-g urinal furnished by NASA-MSC, a phase separator, pretreatment tank, blower, metering pump, and controls. The urinal was located adjacent to the commode and could be used separately or in conjunction with the commode.

The urine collection system operated until test day 6 when the time-delay relay controlling pretreatment addition remained energized, allowing a large quantity of pretreatment solution (sulfuric acid, chromic oxide, and copper sulfate) to enter the phase separator. This dissolved the polyurethane foam impeller.

Subsequent to this, urine was collected in a beaker and measured, then poured into the urine accumulator. Flush water was then manually added. Pretreatment was added in 15-ml amounts as required by urine output. Dow Corning Antifoam C was added at the urine accumulator when the VD-VF system was operating.

5.9.2 Waste Storage and Disposal

The waste storage container was an 0.166 m^3 (5.86 ft^3) aluminum container with a gasketed cover, vented to the simulator annulus or to the cabin through a three-way manual valve. It was used for waste which required treatment with 8-hydroxy quinoline sulfate and might outgas, such as the bags of toilet paper, used filter elements, rags used to clean urine from the floor, aluminum foil, and some paper and plastic containers.

Operational problems with the waste storage container consisted of intermittent leaks in the cover which caused some concern because a permanent correction could not be made. As a result, venting of the can to the annulus was done only occasionally when a noticeable odor was generated in the can. On one or two instances, significant loss of cabin atmosphere occurred when the can was left venting to the annulus. This was detected by the resulting loss in the cabin pressure and corrective action was taken within a few hours to close the vent valve.

In 90 days the container accumulated 0.09 m^3 (3.18 ft^3) of varied wastes weighing 7.99 kg (17.6 lb) including four bags of toilet paper having a total weight of about 1.36 kg (3.0 lb). A fifth toilet paper bag was in the dryer next to the commode, nearly full.

The canner for waste food collection was a commercial unit sized for No. 2 cans. It was installed on the food preparation counter. Wet garbage was treated with 8-hydroxy quinoline sulfate and then sealed in the cans. The crew was instructed to pass cans out of the chamber on the regular weekly

Table 19

COMMODE USAGE SUMMARY

	Liner 1	Liner 2	Total Test
Days used	1 through 43	44 through 91	
Uses	145	174	319
Gross solids collected, kg	6.66 (14.68 lb)	6.92 (15.25 lb)	13.58 (29.93 lb)
Toilet paper, kg	1.39 (3.08 lb)	0.11 (0.25* lb)	1.50 (3.33 lb)
Net fecal solids, kg	5.26 (11.60 lb)	6.80 (15.00 lb)	12.06 (26.6 lb)
Fecal water, from freeze traps, kg	8.98 (19.8 lb)	14.69 (32.4 lb)	23.67 (52.2 lb)
Total feces, kg	14.24 (31.4 lb)	21.50 (47.4 lb)	35.74 (78.8 lb)
Fraction water	0.63	0.68	0.66
Average uses per day	3.4	3.7	3.6
Maximum uses per day			7
Minimum uses per day			0
Average use, kg	0.10 (0.22 lb)	0.12 (0.27 lb)	0.11 (0.25 lb)
Average kg/day	0.33 (0.73 lb)	0.44 (0.97 lb)	0.40 (0.88 lb)

*Estimated

pass-out if there were signs of bulging or indications of potential rupture. As a result, 23 of the 42 filled cans were passed out during the test. Saving these cans at room environment resulted in only five discernible bulges. One of these was opened and found to contain a high concentration of potassium hydroxide, apparently included in a wiping cloth, and much resulting corrosion.

Aluminum boxes of 0.012 m^3 (0.424 ft^3) volume with latchable sealing covers were provided for storing used food trays. Five of these boxes were used in 90 days for 2,408 used food trays. The trays were sprayed with 8-hydroxy quinoline sulfate before placing in the sealed box. No problems were encountered with this disposal method although the storage volume devoted to this requirement would have been unnecessary if a dishwashing facility had been available.

The baler was a two-compartment aluminum box with two hinged covers. Avery strapping was stored in the smaller of the two compartments. The larger compartment was sized to accept the empty plastic food packages which were to be compressed tightly in the compartment and ties into bundles with the Avery strapping. After brief use, however, the crew found it more convenient to wrap the food packages and some other dry wastes in the aluminum foil in which the food had been originally wrapped. Adequate compression was easily obtained, the foil held its shape and there was ample storage space for the resulting waste. The crew in the 90-day period wrapped up 41 bundles of dry waste in this manner, weighing 89.24 kg (196.5 lb). Forty of these bundles were stored in the food compartments as they were emptied of food. One bundle was kept in the freezer.

The overboard dump for liquid waste was used for contaminated water and urine that were not put into the water management subsystem. To use this unit, an overboard pump was controlled by a crewman while watching the accumulator sight glass. The waste liquid was received and measured by the outside crew.

A summary of the types of waste with volumes and weights is shown in Table 20. This summary also shows the results of microbiological assays following the 90-day test.

5.10 MICROBIOLOGY PROGRAM

The main objectives of the microbiology study were to assess changes in crew and environmental microflora which were potentially detrimental to crew health and/or function of equipment and to monitor effectiveness of the water reclamation and atmosphere regeneration systems. Significant features were the microbiologically closed conditions, effected by the lack of any pass-in operations, the use of an autoclave in the pass-out airlock, and the record length of the simulation study.

Samples collected by crew members, using consistent and aseptic techniques, were passed out at weekly intervals. The adjacent laboratory was responsible for collection of specimens, primary isolation, gross quantitation and limited identification. Both general and selective culture media were used for recovery of major pathogenic aerobic bacteria, fungi and anaerobes from crewmen, post-test surfaces and subsystem components. Fungal-type isolates were stored for future identification in the laboratory. Bacterial cultures requiring extensive taxonomic work were submitted to the Langley Research Center. Special tests were performed at the Medical College of Virginia (phage typing of coagulase-positive staphylococci and virus isolation from potable water) and Manned Spacecraft Center - Lunar Receiving Laboratory (mycoplasma and virus studies on feces, urine and pharyngeal washings).

Table 20
WASTE SUMMARY

Waste Type	Volume m^3	(ft^3)	Mass kg	(lb)	Microbiological Contamination
Dry					
Packaged bundles	0.340(1)	(12.020)	89.24	(196.5)	Heavy(3)
Fecal solids	0.097	(3.430)	12.06	(26.6)	Heavy
Unpackaged material(2)	No estimate.		2.00	(4.4)	No samples.
Wet					
Waste storage container	0.090	(3.180)	7.99	(17.6)	Heavy
42 No. 2 cans	0.027	(0.955)	16.42	(36.1)	Heavy(4)
5 boxes of food trays	0.108	(3.820)	37.70	(83.0)	None
Overboard dump liquids	0.036	(1.276)	36.00	(79.3)	No samples.
Totals	0.698	(24.681)	201.41	(443.5)	

(1) Estimated from several measured bundles.
(2) Empty jars, containers, etc., at end of test.
(3) 6 packages sampled, 3 contaminated, 3 none.
(4) 6 cans out of 42 sampled

The nasopharyngeal and dermal (axilla, perineum, and toe web) microflora were sampled with swabs before (-4 day), during (weekly), and after (+18th day) the test. Aerobic flora of the throat and nose, with emphasis on recovery of Staphylococcus aureus, beta-hemolytic streptococci, Neisseria meningitidis, Diplococcus pneumoniae, and Hemophilus influenzae, showed no unusual quantitative or qualitative shifts, even though two crewmen were carriers (crewman 2 was a carrier of Staphylococcus aureus and crewman 3 of Neisseria meningitidis). Procedures for isolation of Hemophilus influenzae were discontinued after 53 days of nonrecovery. Beta-hemolytic streptococci in the throat of crewman 1 were eliminated after administration of erythromycin during the 10th to 11th week of the test. Marker systems (phage typing and antibiotic sensitivity) for coagulase-positive staphylococci were not obtainable, precluding transmission studies.

Dermal samples showed individual profiles of indigenous microflora throughout the test. Staphylococcus epidermidis was the predominant aerobe and faculative anaerobe. Other major types were S. aureus, species of Micrococcus, Aerococcus, Sarcina, Corynebacterium, Bacillus, and various Gram-negative bacteria. Obligate anaerobes were primarily diphtheroids. No gross changes in levels of dermal anaerobes were observed except for a significant decrease in crewman 3's toe web samples mid-test, reflecting treatment of his "athlete's foot" with Zephiran and Tinactin.

Swab samples of surfaces in the hygiene compartment were usually more contaminated than those in the food management area, probably due to more regular housekeeping practices in the latter. High levels of contamination were found in the hygiene compartment on test days 11, 18, 32, 46, 74, and 81. Gram-negative types were restricted to this compartment except on day 32, when the food management area was also heavily contaminated. Most isolates were S. epidermidis; others were S. aureus and species of Bacillus, Sarcina, Micrococcus, Aerobacter, Alcaligenes, and Pseudomonas. Selected surfaces and hardware subsystem components sampled immediately after test were found to be quite uniformly contaminated with the same types of organisms isolated during the test.

During the test, atmosphere samples were taken every two weeks, using onboard Reyniers samplers in the forward (equipment) and aft (crew) compartments. Total counts (bacterial and fungal) remained at low levels throughout the test (ranging from 0.02 to 3.0 airborne viable particles/0.03m^3) despite the lack of submicron filters in the thermal control system. The lack of a significant buildup in viable airborne particles is attributed to gravity-induced settling effects and scrubbing of particulates by various components of the atmosphere regeneration system. The distribution of microbial types was essentially uniform throughout the simulator. Most frequently isolated was S. epidermidis. Atmospheric microflora also included S. aureus, and species of Micrococcus, Aerococcus, Sarcina, Bacillus, Corynebacterium, Neisseria, Alcaligenes, Enterobacter Group B, and Proteus.

Potable and wash water supplies were continuously monitored onboard by the crew members, using Millipore field monitor techniques and an LRC-furnished bacterial sensor. Contamination levels in the drinking water consumed by the crew members met National Academy of Sciences requirements. Contaminated monitors and samples of potable water system included Alcaligenes sp. (predominant), Pseudomonas sp. (sporadic), and S. aureus (during the last 3 test weeks). Wash water isolates were species of Alcaligenes, Pseudomonas, and Bacillus and, on occasion, the ubiquitous S. epidermidis. Post-test analysis of various potable and wash water subsystem components revealed most components to be contaminated with one or more of the organisms recovered in the product water during the test.

5.11 MEDICAL PROGRAM

The basic medical program for the 90-day manned test was oriented toward constant surveillance of crew health. Procedures were of the health screening type rather than being geared to specific anticipated stresses. Since these basic screening procedures were not expected to yield other than alerting information, the basic program was supplemented by contingency samples (see Section 4. 6. 3) which allowed follow-up on unexpected screening data and by special studies in selection areas: carbon dioxide exposure (see Section 5. 2. 1), physical conditioning (see Section 5. 7), microbiology (see Section 5. 10), and diurnal (day/night) rhythm changes (see Section 5. 12). Pulmonary spirometry was considered a basic medical screening procedure and is reported in Section 5. 2. 2.

Medical operations were smooth and no serious medical problems were encountered. The one significant medical treatment for a streptococcal infection exemplified the need to provide for acute problems which can be safely solved, allowing mission completion. Medical coverage was more than adequate during the test. Full-time coverage was supplied by contract physicians, but operational requirements still dictated the presence of the medical director each day of the test.

Crew selection procedures were adequate in view of the fact that no significant medical problems were encountered. Several small problems, recurrent during the test suggest that pretest medical histories were insufficiently detailed. While there problems were minor, their chronicity could result in significant distraction and morale degradation in longer tests or in a more stressful test.

5.11.1 Crew Medical Status

5.11.1.1 Physical Examinations

Pretest and post-test physical examinations showed that, except for the weight changes previously noted (Section 5. 7. 3), the only significant changes were minor skin eruptions probably related to inadequate body cleansing.

5.11.1.2 Physical Complaints and Medication

Each crew member was interviewed daily by the Medical Director on a private communications loop. Physical complaints during the test were few and minor. Onboard medications were dispensed occasionally on medical direction as summarized in Table 21. The only significant treatment entailed the eradication of an asymptomatic streptococcal infection found on routine throat culture. Streptococcal infections, even asymptomatic, are associated with serious sequelae (rheumatic fever, kidney damage) and, in the interests of crew health, the eradication of this organism was considered necessary. Fortunately, the possibility of such an occurrence was anticipated and provided for. Erythromycin was selected as the only antibiotic to be placed onboard because of its limited bacteriostatic range—broad spectrum antibiotics were considered potentially dangerous in biologic isolation. Penicillin, ordinarily the drug of choice in streptococcal infections, was not considered because of its potential for serious allergic reactions. Post-treatment throat cultures confirmed eradication of the streptococcus. Contingency serum samples were tested for changes in antibody titer (Antistreptolysin-O) and no crew member showed any such change, indicating that the organism probably was eliminated before it invaded tissue or evoked a host response. The constancy of the titer of this antibody over the duration of the test suggests also that 90 days of biological isolation does not result in significant changes in immune status.

5.11.2 Clinical Biochemistry and Hematology

A screening battery of blood biochemistries and complete hematological indices were obtained every other week. No changes of clinical significance were observed, but certain sampling problems were encountered. The major problem involved sampling following too closely on exercise periods and out of context with altered circadian rhythms. As a consequence, false positive results in comparison to pretest baselines imposed unnecessary anxiety upon the monitoring staff. However, use of the subject as his own control allowed observations not otherwise possible if clinical limits of "normality" were the only guidelines. These observations were of particular intest in following trends in certain serum enzymes correlated with observed stressful operational periods. Figure 19 shows trends in an enzyme, serum glutamic oxalacetic transaminase (SGOT), usually used as an indicator of tissue damage as, for example, in heart attacks. The general trend for this enzyme during the test was upward, culminating in a significant elevation in two of the four crewmen on test day 67. This point in the test was associated with lowered crew morale subsequently resolved on test day 69. The trend in SGOT after day 67 is downward. The elevation on day 11 in crewman 2 was associated with muscular fatigue. Use of outside crew members as laboratory controls was of value in interpreting some apparent biochemical changes.

Aliquot samples of 24-hour urine collections were frozen for pass-out weekly for all crew members (twice weekly after day 53). These samples were subjected to routine urinalysis and a battery of chemical determinations (sodium, potassium, calcium, inorganic phosphorus, titratable acidity, ammonia, and pH). A majority of these analyses were performed in support of the special CO_2 study (see Section 5.2.1).

Table 21

ONBOARD MEDICATION USED IN 90-DAY RUN

CM	Test Day	Drug or Medication	Indication	Results
3	1	Neosynephrine 1/2% nose drops	Nasal congestion, used prior to ascent	No ear problems on ascent.
	8	Dulcolax, 1 tablet before bed, twice	Constipation	Good
3	13	Band-aid	Cut, right arm	Healed adequately
	13	Auralgan	Itching skin	Prescribed for local anesthetic property by medical monitor - marginally effective
	32	Tinactin	Itching toes	Good.
	52	Ornade, 1 capsule and Neosynephrine nose drops, before bed	Nasal congestion	
	54	Ornade, 1 capsule and Neosynephrine nose drops, before bed	Nasal congestion	
	55	Ornade, 1 capsule and Neosynephrine nose drops, before bed	Nasal congestion	(Not effective, use discontinued)
1	54	Methyl cellulose eye drops	Eye irritation	Marginally effective.
	67	Tinactin	Itching toes	Good.
1	70-80	Erythromycin 1 gram per day for 10 days	Group A Hemolytic Streptococcus throat culture - no symptoms	Eradicated all gram-positive nasopharyngeal bacteria.

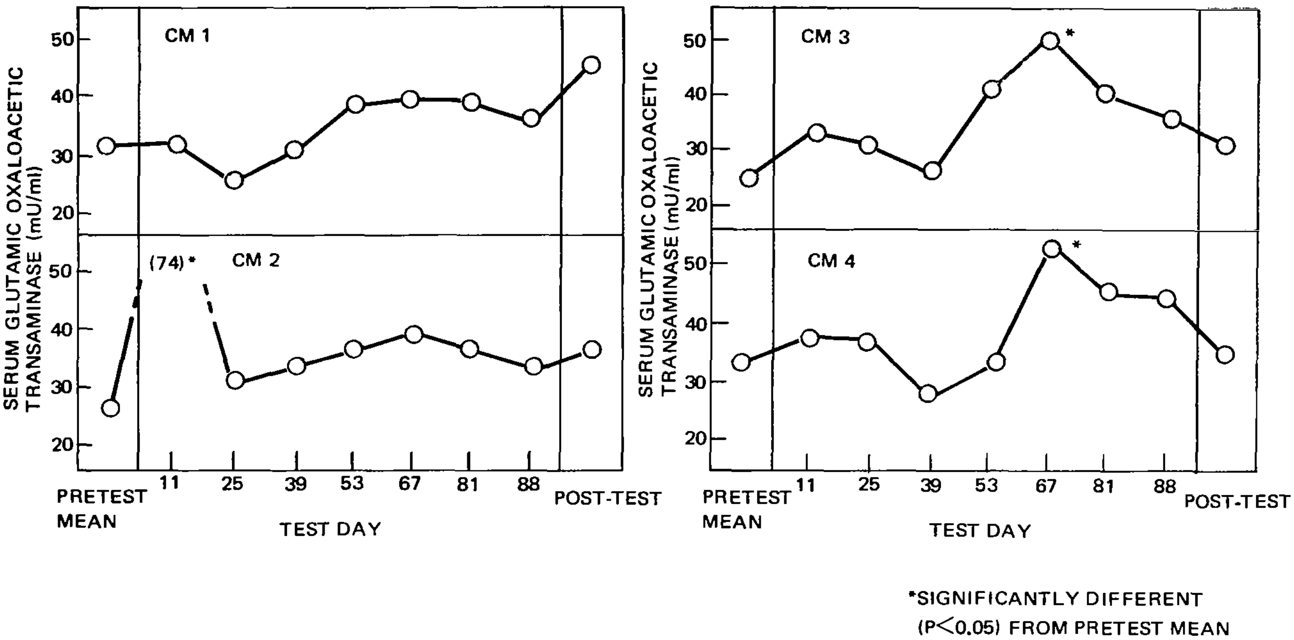

Figure 19. SGOT Trends

Routine urinalyses revealed no clinically significant changes. Differences in urine solids production between the night crew and the day crew were observed. These differences are apparently related to individual body weight and suggest that urine chemistry data should be expressed on a metabolic mass basis. We have not expressed urine data in this manner due to a lack of pretest baselines in urine chemistry and because of a lack of any other data on urine parameters so expresed. Review of sodium-potassium excretion ratios (Na^+/K^+) suggested that this simple measurement may be of value in following circadian cycle shifts (see Section 5.12) and trends in psychophysiological stress. For example, a peak in Na^+/K^+ was observed for all crew members in the samples obtained around test day 74. This peak apparently reflects the resolution of the morale problem noted above. Na^+/K^+trends are illustrated in Section 5.12.

5.12 DAY-NIGHT CYCLE REVERSAL AND SLEEP OBSERVATIONS

Primarily in the interests of safety, crew operations were conducted on a two up — two down schedule. Crewmen 3 and 4 were required to reverse their day-night cycle at the test start without preconditioning. This reversal is known to affect biological rhythms (circadian rhythm) which are keyed, in large part, to a diurnal periodicity. Generally it has been thought that adjustment to an altered diurnal cycle occurs in about 5 to 10 days, at least in subjective symptoms. Also, adjustment to the new rhythm generally takes longer than readjustment to the "normal" rhythm. Symptoms are well known and include difficulty in sleeping and excessive tiredness during the hours representing a normal clock time of 0200-0400.

In the 90-day test, crewmen 3 and 4 reported these symptoms; they were minimal in crewmen 4 but lasted about 2 weeks in crewmen 3, demonstrating the variability in individual response. These subjective data do not tell the whole story; some of the objective data are more revealing.

5.12.1 Basal Vital Signs

Vital signs (pulse rate, blood pressure, and oral temperature) were obtained daily for each crewman immediately upon arising from sleep. The physiological state at this time in the diurnal cycle is described as "basal." The temperature, pulse rate, and blood pressures should be low and constant from day to day as compared to determinations later in the awake period. Neither pulse rate nor blood pressure recordings revealed any consistant trends in regard to diurnal periodicity. Crewman 2, in conjunction with his conditioning program (see Section 5.7), lowered his resting pulse rate over the last 40 test days. Crewman 4 did not reach a consistently low pulse rate until test day 12; this may or may not signify cicardian recycling since his heart rate was very responsive to test conditions and this trend may only represent a "settling down." Neither crewman 1 or 3 showed any trends at all.

Oral temperature recordings do seem to show recycling. Figure 20 which illustrates these data in crewmen 3 and 4 shows that as long as 35 days were required to reach a steady basal level; crewmen 1 and 2 showed no similar trends and were basal from test start.

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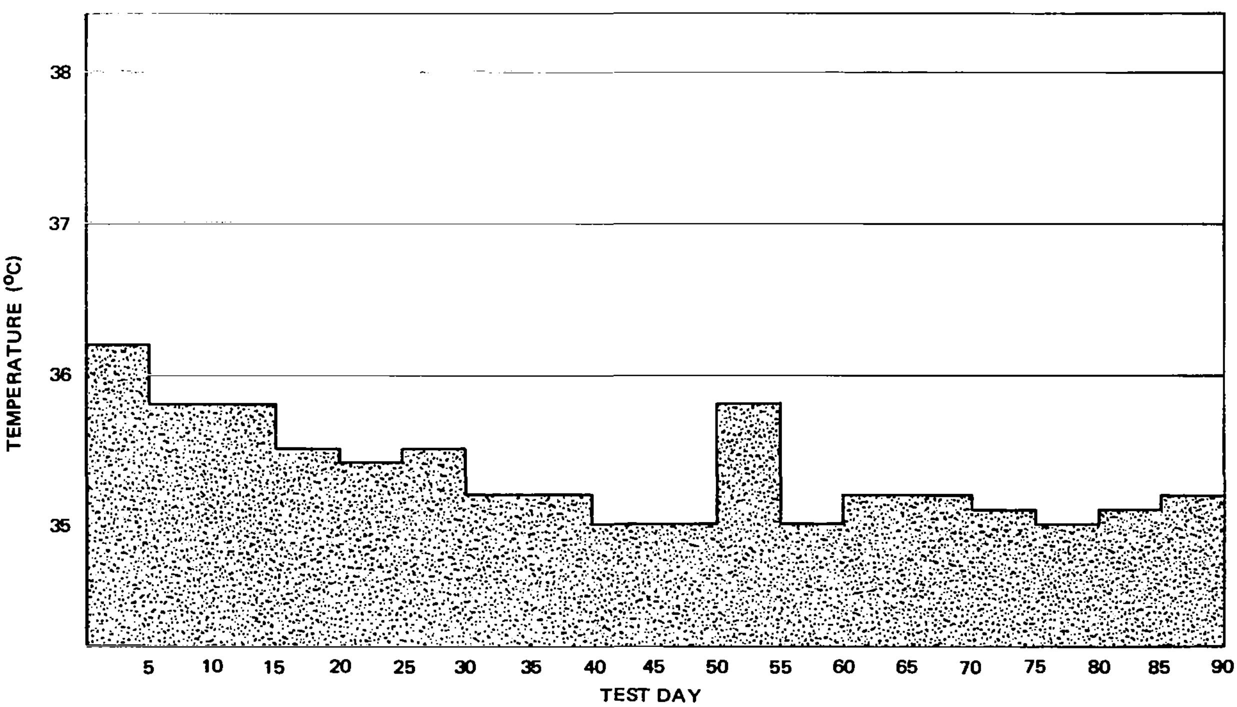

Figure 20. Oral Temperature Trends – Crewmen 3 and 4 (5-Day Mean, Both Crewmen)

It appears that complete circadian recycling requires a longer time than previously thought. This observation is supported by blood and urine studies (Section 5.12.2) and by sleep studies (Section 5.12.3). Whether this lag in complete adaptation has operational significance beyond the mild subjective symptoms remains an open question. In this test, no performance decrements were observed but the tasks may not have been demanding enough.

5.12.2 Blood and Urine Studies

As noted in Section 5.11.2, the altered work rest cycle in crewmen 3 and 4 resulted in biomedical sampling problems. Observed differences in certain of these parameters as compared to truly basal pretest controls appear to be related primarily to sampling too soon after exercise rather than being related to a basic diurnal biological rhythm. This conclusion is based on the persistance of the observations long after other evidence (e.g., Na^+/K^+ excretion in the urine) suggested complete recycling. From Figure 21 it can be seen that the mean ($\bar{x}$) Na^+/K^+ for crewmen 3 and 4 was depressed compared to crewmen 1 and 2 for at least the first 30 to 35 test days but subsequently paralleled that of crewmen 1 and 2. This seems to corroborate the oral temperature observations. Excretion of Na^+ and K^+ is largely under the control of the adrenal gland and a diurnal periodicity in this adrenal activity is well known. This periodicity is amplified by postural influences. It would appear that in this test the basic adrenal secretion periodicity persisted but was countered by postural influences at a time when low adrenal activity would normally be seen, early morning. This resulted in a probable flattening of the diurnal secretion curve and a constant Na^+ excretion rate relative to that of K^+. This entire hypothesis should be tested further because both Na^+ and K^+ could be easily determined

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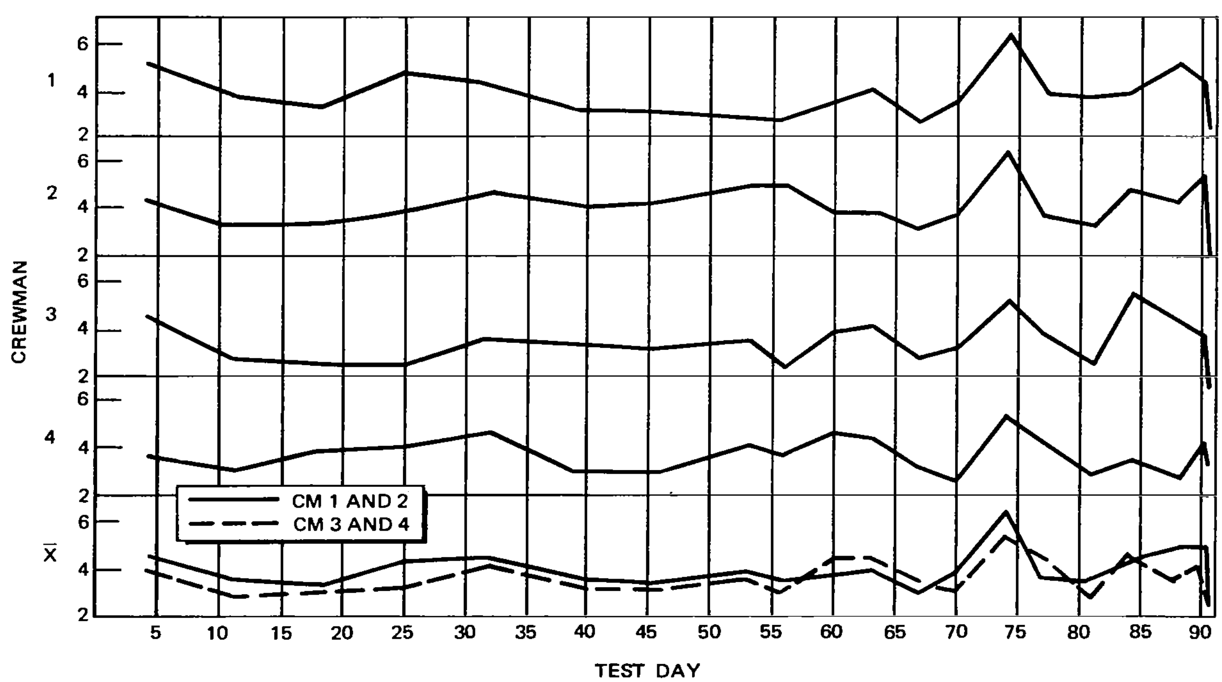

Figure 21. Urinary Excretion Patterns — Na^+/K^+ Ratios

in flight providing presumptive information on both diurnal rhythms and stress reactions.

5.12.3 Sleep Observations

Studies of sleep durations and quality were undertaken because previous studies had reported that sleep quality would become impaired while durations would increase as a function of test duration. Crew members were required to respond to a daily questionnaire soliciting information on both quality and duration of sleep.

Results indicate a tendency toward increased sleep durations as the test progressed (Figure 22). Crewmen who had been required to significantly alter their sleep-wakefullness cycle (going to sleep at 1300 hours and nominally arising at 2100 hours) showed a significant increase in sleep duration over the initial 30 to 35 day period which then stabilized until approximately day 60 when an apparent increase occurred, then returned to previous levels by day 70. This sleep duration persisted until the end of the test. Those crew members whose circadian rhythms had not been altered (going to sleep at 2300 hours and nominally arising at 0700 hours) showed a slight increase in sleep duration over the initial 25 days which then stabilized and persisted until the conclusion of the test. Data on sleep quality reveal no significant patterns throughout the test.

Two crew members (one in each circadian pair) were instrumented for electroencephalographic recordings during sleep (Figure 23). Recordings were scheduled for the first 10 days, the middle 5 days, and the last 5 days of the

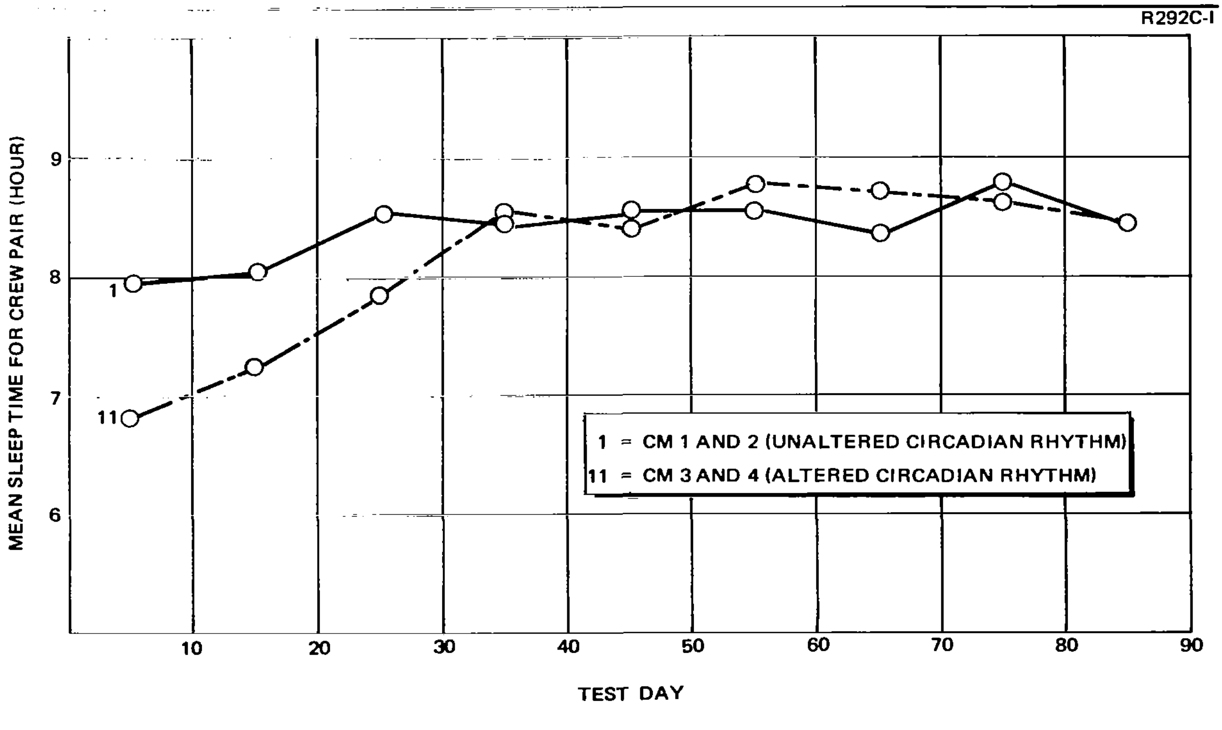

Figure 22. Sleep Questionnaire Responses Smoothed Curve Based on 10-Day Segments

Figure 23. Application of Electrodes for Electroencephalogram

test. The data were scored with an automatic pattern recognition system which had been calibrated to each man before the test. Consistent with the questionnaire results, EEG data reveal a trend toward increasing sleep durations during the first 10 days. EEG data provide greater information on the quality of sleep. EEG profiles reveal that compared to pretest baselines, there was a two- to four-fold increase in the number of sleep stage changes during the test with a significant reduction in the incidence of slow wave sleep. These findings suggest that overall sleep quality suffered during confinement. This is in agreement with results of other confinement studies.

5.13 BEHAVIOR EVALUATION

Behavioral evaluations were undertaken to determine the effects of confinement upon the crewmen. Two forms of behavioral measurement techniques were employed: intrusive and NIPA.

5.13.1 Intrusive Tests

A broad group of intrusive questionnaires were employed during the mission. These tests derived from previous research on small groups in confinement. In addition to paper and pencil devices, there were several psychomotor performance testing devices onboard for use by the crew on a scheduled basis. Results of the intrusive tests indicate a neutral to negative reaction to confinement and demonstrate the ability of the crewmen to manipulate data in response to questions. Psychomotor testing results indicate a progressive learning trend throughout the confinement with no apparent correlation with other potentially influencing factors such as stress level, boredom, or atmospheric trace contaminant variations.

5.13.2 NIPA

The Non-Interference Performance Assessment (NIPA) technique, utilizing quantitative observations of crew activities, yielded evidence that there was a progressive decline in crew morale which reached its low point at approximately day 60 of the test. Data from NIPA was available after the test concluded. Subjective indications by program management and crew comments during the test corroborated the existence of the depression in morale. Attempts are currently being made to quantitatively relate NIPA data to more objective mission performance measurements. The NIPA method avoids the disadvantage of response manipulation by the observed subjects and seems of value for future programs as the preferred method of crew performance monitoring.

5.13.3 Behavioral Findings

Incidents of overt hostility among onboard and between onboard and outside staff personnel were essentially eliminated. The relative absence of such difficulties attests to the importance of crew and communications monitor selection and the adequacy of the selection procedures.

Strong group cohesiveness (social-emotional closeness) often recommended as a prerequisite for maintaining the social integrity of small groups confined for prolonged periods, did not occur during this test, and does not appear to have resulted in any loss in performance.

Confinement itself did not constitute a significant stressor for the crew, as shown by the intrusive test methods. A loss of morale occurred, as indicated by subjective evaluations of the operating staff, approximately from days 60 to 70 of the test. This period was characterized by a reduction in activity of the crewmen, with less verbal interaction and a lack of enthusiasm. Similar symptoms were exhibited, in general, by members of the outside staff at the same time. Analysis of NIPA data shows a significant reduction in requests from the outside staff for the crewmen to perform special tasks during this time frame. No apparent reduction in crew task performance times accompanied this, however. A significant decrease in "positive affect" statements by the crew was also observed.

A reversal in mood occurred at about day 70 which may have been the result of several possible stimuli. Several special tasks were requested by the outside staff at this time, as a result of observations of reduced morale. Typical of these was a request for a design critique of the habitat, with suggestions for improvements. At the request of the Behavioral Director, a "bull-session" between the crewmen was arranged on day 69. At this time the crewmen expressed a number of complaints which had apparently been building up for some time but had not been previously stated. This helped considerably in encouraging further verbal exchanges. Also, a series of direct conversations with each crewman were undertaken by program management. The improvement in morale was apparent following day 70 until the end of the test.

It is not possible to determine, from existing data, which of the interacting variables were causative mechanisms leading to the morale slump, and which were dependent. The possibilities include increasing familiarity with equipment operating characteristics, reduced requests for special assistance from outside staff, interpersonal difficulties and declining motivation of the crewmen. Further studies are required to obtain a better definition of these relationships.

An unexpected requirement for mission activities planning was brought to light during post-test debriefings as a result of the absence of interim mission satisfactions. Crew members were unanimous in recommending that "blocks" of experiments be scheduled so as to begin and end during finite segments of the total test duration rather than beginning at test initiation and ending upon test termination. Such scheduling would permit achievement of interim goals, thereby providing a variety of experiences throughout the confinement duration rather than increasing monotony due to repeating the same tasks long after familiarity was achieved.

Section 6

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Appendix
CONTRIBUTORS TO THE 90-DAY MANNED TEST PROGRAM

The following pages present lists of participants in the 90-day test program, and their areas of interest.

PARTICIPATING GOVERNMENT AGENCIES

NASA—Headquarters (OART)

Direction

NASA—LRC (Langley)

Direction
Two-Gas Control
Four-Gas Spectrometer
EEG
Breath Analysis
Crew Selection
Psychomotor Tester
Microbial Sensor
Mission Analysis
Zero-g Porous Plate H_2O Separator
Solid Amine CO_2 Concentrator
Pulmonary Function
Zero-g Humidity Control
Water Electrolysis
Psychoacoustics
Microbiologic Analyses

NASA—ARC (Ames)

Critical Task Tester
Visual Tester
Response Tester
Glycerol Experiment

USAF—Aerospace Medicine Laboratory

VD-VF Water Recovery
Commode

AEC/Mound Lab

Pu-238 Radioisotope Heaters

US Army/Natick Labs

Freeze-Dried Foods

NASA—MSFC (Huntsville)

CO_2 Study
Habitability Evaluation
Skylab Light Level

USN—Submarine Medical Research Laboratory (Groton)

CO_2 Blood Studies

USN—Neuropsychiatric Research Institute (San Diego)

Crew Selection
EEG Studies

NASA–MSC (Houston)

Apollo Water Dispenser
Urinal
Tissue Dispenser
Teflon-Coated Fiber glass
Fluorel/Refset Elastomers
Apollo-Type Crew Suits
Fireproof Games
Fireproof Paper
PBI Fabrics
Virus/Mycoplasma Analyses
Vitamin D Assays

US Department of Transportation

Particulate Sampling

Naval Medical Research Institute

Blood Analysis
Crew Selection
EEG Studies

PARTICIPATING UNIVERSITIES

University of California at Los Angeles

Non-Interference Performance Analysis

Test Crewmen

University of Chicago

Pico Library and Projectors

Medical College of Virginia

Potable Water Virology

Texas Christian University

Crew Selection Criteria

California State College at Long Beach

Psychodiagnostics

Test Crewmen

California Institute of Technology

Test Crewmen

University of Southern California

Test Crewmen

CONTRIBUTING CONTRACTORS

Aerojet-General

Trace Contaminant Analysis

General Electric

Commode

Litton (Atherton Division)

Microwave Oven

Litton (Stouffer Foods)

Frozen Prepared Foods

MDAC-West

Thermal Control
Urine Collector
Air Evaporator Water Reclamation
Molecular Sieve CO_2 Concentrator
Sabatier Reactor
Two-Gas Control
Life Support Monitor
Wash Water Recovery

Lockheed

Zero-g Humidity
Water Electrolysis

Central Laboratories (Pico-Rivera)

Clinical Analyses

AiResearch

Sabatier Reactor
LiOH CO_2 Removal
Apollo H_2O Dispenser

3M Company

Fluorel/Refset Elastomers

Allis-Chalmers

Water Electrolysis

Mine Safety Appliances

Toxin Burner

Scheufelin Papierfabrik Company

Fireproof paper

Perkin-Elmer

Four-Gas Mass Spectrometer

Dupont

Teflon-Coated Fiber glass

Monsanto

Heat Transfer Fluid (Coolanol 35)

Monsanto Chemstrand Division

Durette Fabrics

Monsanto Research/Mound Laboratories

Radioisotope Heaters

Massachusetts General Hospital

Vitamin D Assays

Hamilton Standard

Solid Amine CO_2 Concentrator

B. Welson

Apollo-Type Crew Suits

Parker Brothers

Fireproof Games

Celanese Corporation

PBI Fabrics

Aurora Engineering

Autoclave Pass-Through

General Dynamics Corporation

Response Analysis Tester

Oregon Freeze Dry

Freeze Dried Foods

Computer Communications, Inc.

Acoustic Data Link

Warren E. Collins

Bicycle Ergometer

System Technology, Inc.

Critical Task Tester

Fabric Research Corporation

Apollo-Type Crew Suits

Webb Associates

Metabolic Rate Meter

Douglas Aircraft Company

Behavioral Acoustics

NASA-Langley, 1971 —— 5 CR-1835