SKYLAB MEDICAL
EXPERIMENTS
ALTITUDE TEST
(SMEAT)

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

Houston, Texas

OCTOBER 1973

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Managing Editors

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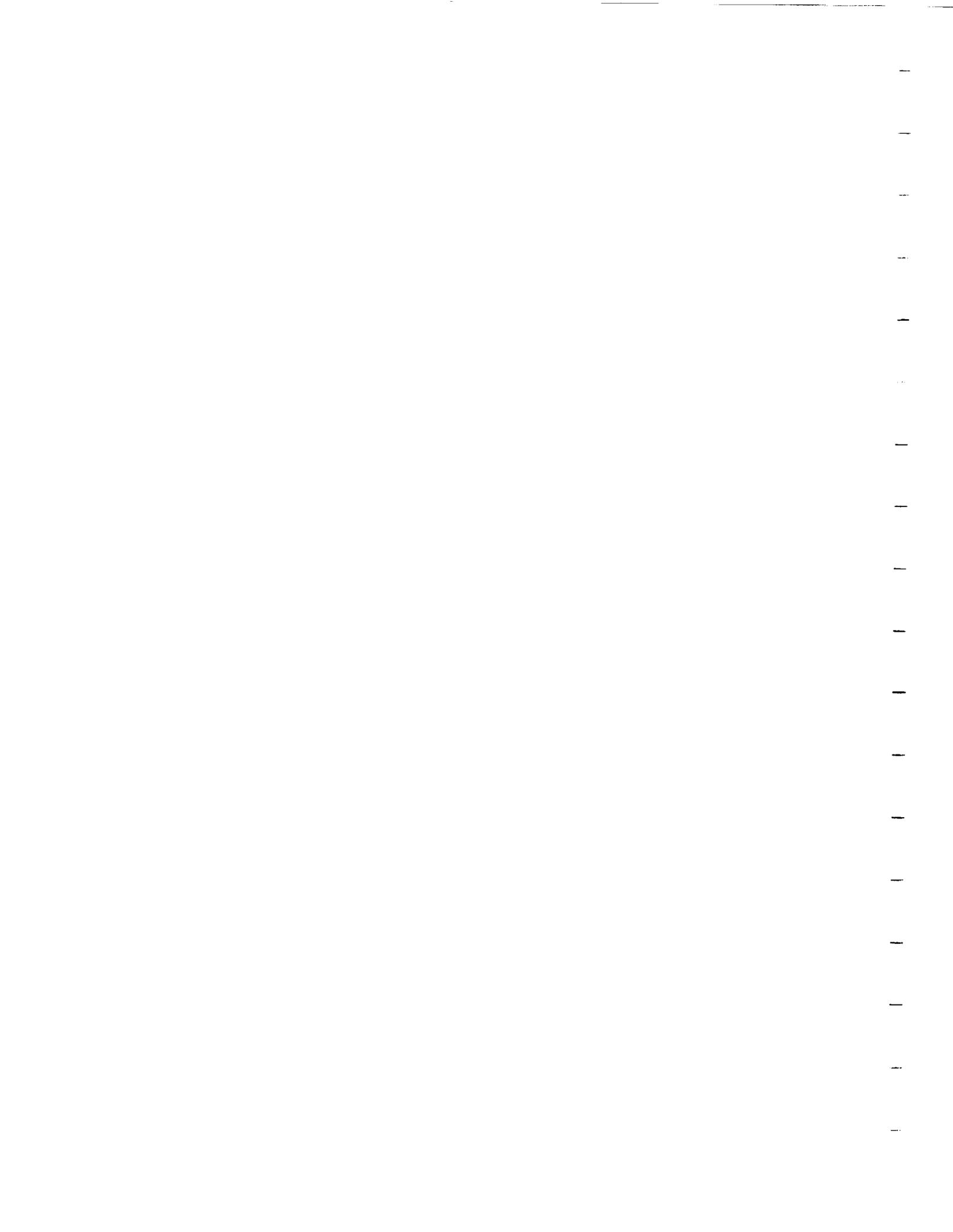
FOREWORD

Travel through our solar system and ultimately through our galaxy represents a goal which appears to be achievable by man. Most of the problems of propulsion, spacecraft structures, and guidance systems have been solved through the outstanding engineering efforts of the 1960s. Now, with the Skylab missions, attention turns from the more hardware-oriented issues to man himself. We do not know what the physiological performance of the body will be in the weightlessness of a long-duration space flight. We do not know whether the changes seen in Gemini and Apollo crewmen are self-limiting adaptative processes or whether they represent the beginnings of serious physiological deterioration. The Skylab Program will provide valuable data with which one can begin to resolve these issues.

The Skylab Medical Experiments Altitude Test (SMEAT) was an integral part of the Skylab Program. SMEAT served both to gather vital baseline biomedical data and to resolve many of the equipment and procedural problems which otherwise might have impaired Skylab. To all persons and organizations who worked on the SMEAT program, I would like to extend my sincere thanks. The preparation for and completion of SMEAT required individual dedication, a desire to get the job done, and a willingness to go that "second mile." Without such outstanding performance, it would not have been possible to complete this difficult and complex test program. Everyone should be proud of the contributions which have been made to the Skylab Program.
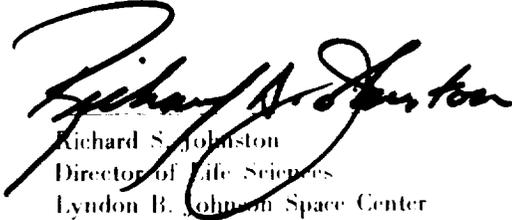
Richard S. Johnston
Director of Life Sciences
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CHAPTER 1

INTRODUCTION

Richard S. Johnston
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The Skylab Program provides a unique laboratory for the study of physiological change produced in man by long term residence in space. Valuable information will be gained concerning the real nature of changes found in earlier and shorter space missions. Inasmuch as the Skylab Program represents a new order of complexity in space activities, it required increased support and testing prior to flight. The Skylab Medical Experiments Altitude Test (SMEAT) was conducted both to test preparations for the mission and to observe, using a Skylab atmosphere and facilities at Earth's gravity, any physiological changes in crewmembers. Such changes, if found, could be attributed to the SMEAT environment in which weightlessness played no part. These results would be of great value in assessing the role of weightlessness in later Skylab results.

The Skylab Medical Experiments Altitude Test represents a quantum step forward in the progress of test and simulation procedures for mission support. The SMEAT Program was a simulation of a 56-day Skylab mission, conducted at the Lyndon B. Johnson Space Center. This simulation, in which three members of the astronaut corps served as subjects, provided an excellent test bed for the evaluation of crew procedures, flight equipment, and mission support. In many respects, the SMEAT Program was a separate space mission in its own right. It was unique in the extent to which it approximated full simulation of a space mission. The physical facility was

quite similar to that of Skylab; the atmosphere was identical (70% O_2/30% N_2 at 5 psi); crew activities were fully representative; the timeline of events was that of an operational mission; and full mission support was provided, just as would be the case in Skylab.

The antecedents of Skylab, and SMEAT, reach into the early days of space activity. At that time there were two fundamental questions to be answered. The first of these was "Is it possible to send man into space and recover him unharmed?" The affirmative answer to this question now has been demonstrated many times. The second question was "Can man live and perform efficiently in space over long periods of time?" There is not as yet a definitive answer for this question. Although results of earlier flights, such as the fourteen-day Gemini mission, are very encouraging, the information obtained does not provide a clear picture of the changes produced in man by exposure to the space flight environment and of his readjustment to the earth environment upon return.

Major manned space missions of the future can be planned only if the conditions assuring man's well-being and effectiveness are defined. Even the relatively short Apollo missions make it clear that changes take place in the major physiological systems of the body during exposure to space. The true nature of these changes is yet to be determined. It is

not known at this time whether they represent the beginnings of a gradual process of deterioration or whether they are adjustments leading to a new adaptive state. If the latter should be true, it will be necessary to obtain an accurate time profile of this adaptation process and, further, to assess the changes brought about during the period of readaptation following return to earth.

One of the primary objectives of the Skylab Program is to allow better observation of man-in-space and to determine physiological change as a function of weightless flight time, as opposed to the pre- and postflight studies of crewmen conducted in the Apollo missions. This program affords an opportunity to study biomedical questions in depth. The 28- and 56-day missions are sufficiently long for one to observe any critical changes and to make detailed records of the progress of gradual alterations in basic biological processes.

In early planning for the Skylab biomedical program, a move was initiated to consolidate the list of proposed medical research measurements into five principal categories, each of the five to be related to a major physiological system. Thus, measurements relating to the performance of the cardiovascular system were organized so that they together would comprise a flight experiment, the ultimate meaning of which would be greater than the sum of the knowledge gained from individual measures if the latter were to be conducted out of context. Similarly organized were measurements relating to the musculoskeletal system, the nervous system, the renal-endocrine-mineral system, and the respiratory-metabolic system. Under this philosophy, a set of Experiment Implementation Plans was prepared for approval by the NASA Manned Space Flight Experiments Board. As preparations for Skylab proceeded, it was necessary to make a number of changes in the organization of the measurement program, particularly where complex hardware or instrumentation systems made desirable a separately identifiable task to speed implementation and to reduce cost. However, the overall biomedical measurement program still adheres to the philosophy that the sum of these measurements should provide an accurate and detailed assessment of both gross and subtle changes

which might occur within the major physiological systems of the body.

Program Objectives

The objective of the Skylab Medical Experiments Altitude Test was to provide a nearly full-scale simulation of a 56-day Skylab mission. Through this simulation, all crew procedures and equipment operations could be tested, and final training of support personnel could be conducted. Of particular importance was the opportunity to test and refine data collection techniques for, after all, the entire *raison d'être* for Skylab lies in its ability to return meaningful measurements.

For program planning, six specific objectives were listed for SMEAT, as follows:

1. Obtain and evaluate baseline medical data for up to 56 days for those medical experiments which might be affected by the Skylab environment. SMEAT simulates the Skylab environment in terms of all major parameters except one, weightlessness. The atmosphere, the work program, and the social environment all were essentially identical to that of Skylab. Therefore, it was considered quite important to obtain baseline clinical measures as well as data from all major medical experiments to provide a baseline against which one could compare later results from Skylab missions. In this manner, an indication could be gained concerning the biomedical importance of weightlessness *per se* as an experimental variable.

2. Evaluate selected experiments hardware, systems, and ancillary equipment. This proved to be an invaluable part of the SMEAT effort. In many instances, specific hardware items failed to function appropriately. In other cases, use of the hardware made it obvious that its utility and acceptance could be increased through a redesign program. Certain items of equipment, such as the urine collection system, underwent extensive redesign subsequent to SMEAT and prior to use in the Skylab Program.

3. Evaluate data reduction and data handling procedures in a mission duration time frame. To meet this objective, all constraints imposed by an actual mission were included, even for such matters as

acquiring data only at times when such would be possible during a mission, as the Orbital Workshop passed over a network station.

4. Evaluate preflight and postflight medical support operations, procedures, and equipment. This was considered particularly important in view of the heavy biomedical orientation for the first manned Skylab mission. To this end, a flight medical operations team manned remote consoles as planned for the Mission Control Center during actual Skylab missions.

5. Evaluate medical inflight experiment operating procedures and crew checklists. SMEAT involved use of actual Skylab medical experiment hardware as it would be installed in Skylab and with the requirement to provide usable measurements. Changes were made in this equipment subsequent to SMEAT only to improve accuracy of data collection.

6. Train Skylab medical operations team for participation during the flight. In fact, the training benefit of SMEAT proved to be considerably greater than indicated by this objective. All management and support personnel received invaluable training for Skylab during the conduct of SMEAT.

Program Plans

Initial proposals for an altitude chamber test program were studied for about a year and a half, leading to approval in February 1971 of formal plans for a Skylab Medical Experiments Altitude Test. Skylab medical experiment equipment items were delivered to the Johnson Space Center starting in early 1972 and served as the test equipment for the SMEAT Program.

The SMEAT test was conducted in three phases: prechamber beginning six months prior to the chamber test; 56-day chamber test; and 18-day postchamber testing. The actual chamber test began on 26 July 1972. The test was conducted in a cylindrical, twenty-foot diameter vacuum chamber at the Johnson Space Center. This chamber was configured to resemble the part of the Skylab in the Orbiting Workshop (OWS) referred to as the Crew Quarters. During this test, Skylab mission procedures were used

to the fullest extent possible. All communications with astronauts, for example, were relayed through the Mission Control Center CAPCOM communication technique. Crew support procedures, such as those for food service and personal hygiene, also were structured in accordance with those of Skylab. The major medical experiments and the detailed test objectives (DTO's) accomplished during the SMEAT program may be summarized as follows.

Skylab Medical Experiments

Cardiovascular/Hemodynamic

M092 Lower Body Negative Pressure. Obtain baseline data concerning the time course of cardiovascular deconditioning during long term residence in zero g and predict the degree of physical impairment that may be experienced upon return to earth's gravity. Obtain verification of procedures and crew operational capability.

M093 Vectorcardiogram. Determine reference data and changes in the electrical activity of the heart caused by exposure to the Skylab atmosphere and other specific stressors. Correlate the changes that are detected with those known to occur after specific stress in normal environments.

M111 Cytogenetic Studies of Blood. Determine the preflight and postflight chromosome aberration frequencies in the peripheral blood leukocytes of the Skylab crewmen. Because chromosome aberration yields of peripheral leukocytes have been sensitive indicators of radiation exposure, this experiment could also be used to assess the radiation exposure of the crewmen.

M112 Hematology and Immunology. Determine the effects of space flight on the hormonal and cellular aspects of immunity and detect quantitative and qualitative changes in the immunoglobulins and related proteins and lymphocyte functions. Of special interest are indications of a change in man's ability to combat infections and repair traumatized tissues after exposure to the space environment.

M113 Blood Volume and Red Cell Life Span. Determine changes in red cell mass, red cell production, and red cell survival caused by a Skylab environment. The experiment will also provide analytical information in the form of plasma volume shift data that may offer insight into the mechanism of cardiovascular deconditioning and orthostasis.

M114 Red Blood Cell Metabolism. Determine the causes of any changes in red cell metabolism and in membrane integrity in man as a result of long term stays in the space environment.

M115 Special Hematologic Effects. Examine critical physicochemical hematological parameters relative to the maintenance of homeostasis and evaluate the effects of space flight on these parameters.

Musculoskeletal/Metabolic

M071 Mineral Balance. Determine the effects of space flight on musculoskeletal metabolism by measuring the daily gains or losses of pertinent biochemical substances. Substances of interest include calcium, phosphorus, magnesium, sodium, potassium, and protein. SMEAT evaluated the effects of altered Skylab atmosphere on these substances.

M074 Specimen Mass Measurement. Demonstrate the capability to accurately "weigh" masses as great at 1,000 gm with a device designed to operate in a zero g environment. The experiment provides a means to determine the mass of food residues and of feces and vomitus generated by Skylab crewmen.

M078 Bone Mineral Measurement. Measure bone mineral changes that result from exposure to weightlessness. Mineral measurements are taken of the left *os calcis* and right radius of each crewman, both pre- and postflight. SMEAT provided a method to determine if changes in bone mineral levels were affected by reduced atmospheric pressure and elevated carbon dioxide partial pressure.

M171 Metabolic Activity. Evaluate the metabolic rate measurements of man while resting or doing work during prolonged exposure to the spacecraft atmosphere and compare these results with those obtained in normal sea level environments.

Endocrine/Electrolyte

M073 Bioassay of Body Fluids. Evaluate the endocrinological inventory resulting from exposure for extended periods to the space flight environment, to space diets, and to Skylab workloads. Also, facilitate identification of changes in hormonal and associated fluid and electrolyte parameters as indicated in samples of the blood and urine of crewmen.

Neurophysiology

M133 Sleep Monitoring. Evaluate objectively the quantity and quality of inflight sleep by means of analysis of electroencephalographic (EEG) and electrooculographic (EOG) activity. Head movement, EEG, and EOG data are taken during regularly scheduled eight-hour sleep periods.

M151 Time and Motion Study. Evaluate the differences, correlation, and relative consistency between ground-based and inflight task performance of crewmen as measured by time and motion determinations.

SMEAT Detailed Test Objectives

Habitability Considerations

DTO71-7 and DTO71-8 Food Tray and SMEAT Food System. Test the acceptability of food items developed for Skylab, the reliability of their packaging, and the functional adequacy of food serving, preparation, storage, and cleanup procedures. A special serving pedestal and tray and specialized utensils were used and evaluated.

DTO71-21 SMEAT Shower. Test the adequacy of weekly whole-body cleansing during 56 days of confinement in a Skylab-type environment. The SMEAT shower was similar but not identical to the Skylab counterpart. A hand-held nozzle supplied six pounds of water per shower.

DTO71-29 Housekeeping. Test the adequacy of a housekeeping system for keeping the Skylab-like chamber clean by use of the Apollo-developed vacuum cleaner, wipes, tissues, disinfectant pads, and soap.

DTO71-30 Personal Hygiene. Test the effectiveness of the Skylab personal hygiene kit to maintain an acceptable degree of bodily cleanliness between weekly showers.

DTO71-27 Skylab Urine System Operational Evaluation. Evaluate the Orbital Workshop urine collection system.

Physiology/Health

DTO71-2 Effects of Skylab Medical Experiments Altitude Test on the Oral Health of Crewmen. Compare the microbial population dynamics in the mouths of SMEAT crewmen before, during, and after the 56-day trial and determine clinically the effects of space-simulated environments on oral health, preexisting dental caries, and periodontal disease.

DTO71-18 Tests of the Inflight Microbiology Unit. Evaluate the equipment system design to perform basic diagnostic microbiology tests during the Skylab mission.

DTO71-19 Crew Microbiology and DTO71-28 Chamber Microbial Monitoring. Examine the effects of confinement in a semiclosed ecosystem, the Skylab diet, and the Skylab atmosphere, with its reduced barometric pressure, on crew microbial burdens and on the microbial ecology of the SMEAT chamber.

DTO71-20 Operational Bioinstrumentation System. Test the Operational Bioinstrumentation System prior to its use in Skylab. The system is designed to obtain physiological data during launch, extravehicular activity, and return mission phases. The OBS can also provide full time monitoring for an ill crewman. In SMEAT, the OBS was tested principally during exercise.

Atmosphere Purification and Control Systems

DTO71-4 SMEAT Chamber Atmosphere Analysis for Trace Contaminants. Identify and quantitate trace contaminants in the SMEAT chamber atmosphere throughout the test to insure the safety of the crew from toxicological hazards and to alert the existence of any hazardous condition.

DTO71-5 Carbon Monoxide Monitor. Evaluate the performance of a compact, portable device for measuring the concentration of carbon monoxide in the chamber and for warning of dangerous levels by visual and audible indications.

DTO71-6 Carbon Dioxide/Dewpoint Monitor. Evaluate the Skylab flight configuration portable carbon dioxide/dewpoint monitor from the point of view of performance and procedures. This test also provided data on variations in carbon dioxide and dewpoint concentrations in a chamber configuration similar to Skylab in volume and geometry.

DTO71-26 Aerosol Analysis. Provide real-time count of particles in the SMEAT atmosphere by use of a small unit with a display readout. Postflight examination of filters to determine the composition and probable source of particulate contaminants was a part of this effort.

DTO71-32 Command Module Carbon Dioxide and Odor Absorber Element Exposure Test. Determine the stowage requirements for odor absorber elements designed for use in Skylab. This test was designed to verify whether the Skylab atmosphere causes unacceptable degradation of the carbon dioxide and odor absorber elements.

Data Acquisition

DTO71-23 Skylab Data Acquisition Simulation. Test, on a noninterference basis, the operational procedures involved in acquiring and processing biomedical experiment data in a mode approaching that planned for Skylab.

SMEAT Results

The SMEAT Program lasted for the full scheduled 56-day period. No major problems were encountered that threatened its success. A number of problems did develop, however, which required correction prior to the launch of Skylab. In fact, it is generally concluded that the full attainment of Skylab objectives would be in some question were it not for the contribution of SMEAT. These contributions were in the five areas of:

1. Operating procedures. The SMEAT test provided an opportunity to conduct complete team training and to evaluate all procedures in a total mission context. As a result, a Skylab "team" was developed which acquired both a mission identity and a confidence concerning its capabilities for mission control and support. Unquestionably, major improvements were made in team communication procedures and coordination during SMEAT. As a result, Skylab could be approached with a sense of complete preparedness.

2. Baseline biomedical data. Usable information was obtained from virtually all of the major medical experiments to be conducted in Skylab. These data are presented in later sections of this report. Although different astronauts will participate in the actual Skylab missions, the data obtained from the three crewmembers of SMEAT will prove invaluable when scientists attempt to differentiate between effects of weightlessness and those effects due to other features of the space environment.

3. Impact on flight equipment. The SMEAT results were very beneficial in pointing the way toward redesign and improvement of certain equipment items scheduled for use in Skylab. Major and fundamental problems were encountered with medical experiment equipment including the urine volume measuring system, the metabolic analyzer, and the bicycle ergometer. Additional problems were

encountered with use of the blood pressure measuring system and the cardiotachometer. Data were provided for all of these items which could be used in their redesign to insure complete acceptability for Skylab.

4. Data collection and handling. At a number of places in the data collection, storage, and transmission loops of SMEAT, the flow of data proved to be less than orderly. Although the schedule called for data to be "dumped" at prescribed points comparable to those in the Skylab mission profile, data backups were experienced and the dumping points were missed. Improvements were made, and the entire process now appears relatively free of bottlenecks and ready for use in Skylab.

5. Crew issues. No apparent crew health problems were induced by the atmosphere, semiclosed environment, or other test features of SMEAT. There was no appreciable degradation in crew performance over the period of the test. Significant individual differences were noted, however, in the response of crewmembers to select features of the test environment. For example, it appears that selection of diet must be more carefully tailored to the individual requirements and preferences of crewmembers than was thought to be the case prior to the SMEAT test. In general, however, the three crewmembers of SMEAT performed excellently and provided a fund of data from which to draw for the improvement of Skylab procedures and equipment.

CHAPTER 2

PROGRAM ORGANIZATION

The Skylab Medical Experiments Altitude Test was documented in the SMEAT Program Plan published on 21 January 1971. This document describes the scope and objectives of the program, the management system under which it would be conducted, requirements for configuration of the test facility, test control documentation, data processing, and detailed test objectives for the program. Revised in March 1972, the Plan provided the overall structure for the SMEAT Program and served to coordinate the efforts of the many disparate groups working toward the SMEAT goals.

Management Organization

The management structure within which the SMEAT Program was developed is shown in Figure 2-1. Overall program direction was exercised by the Chairman of the SMEAT Steering Committee. The Chairman, operating through two Test Project Managers, had six principal areas of concern. These dealt with medical equipment support, the provision of appropriate flight-rated hardware items to support the detailed test objectives of SMEAT; medical experiment coordination, the selection and development of an appropriate set of medical experiments consistent with the goals of SMEAT and, ultimately, those of Skylab; flight procedures coordination, the meshing of the activities of the SMEAT Program with other JSC astronaut programs, and with those of Skylab; reliability and quality assurance for program materials and systems; mission training coordination, the establishment of appropriate training requirements and procedures for the diverse working groups needed to support SMEAT; and chamber test support, the configuring and maintenance of an appropriate test facility.

During the course of the SMEAT Program, the Steering Committee met at regularly scheduled times to review and resolve status, problems, progress, changes and milestones of the test program. Decisions of the Steering Committee insured orderly progress and served to resolve many of the issues which arose during SMEAT. The members of this Steering Committee were:

R. S. Johnston, Chairman	Medical Research and Operations Directorate
J. C. Stonesifer (Alternate Chairman)	Medical Research and Operations Directorate
A. A. Mandell	Medical Research and Operations Directorate
W. H. Bush	Medical Research and Operations Directorate
W. H. Shumate	Medical Research and Operations Directorate
R. C. Aldridge	Skylab Program Office
T. U. McElmurry	Flight Crew Operations Directorate
D. R. Puddy	Flight Operations Directorate
C. N. Rice	Engineering and Development Directorate
J. V. Correale	Engineering and Development Directorate
J. R. Trombley	Engineering and Development Directorate
T. C. Snedecor	Administration Directorate
L. T. Spence	Reliability and Quality Assurance
J. H. Chappee	Safety Office

Medical Operations

The SMEAT Program had a heavy medical orientation since a principal objective was to obtain baseline biomedical data on a number of medical experiments to be used later in Skylab. In addition, it was necessary to maintain close medical surveillance of the subjects in the test chamber

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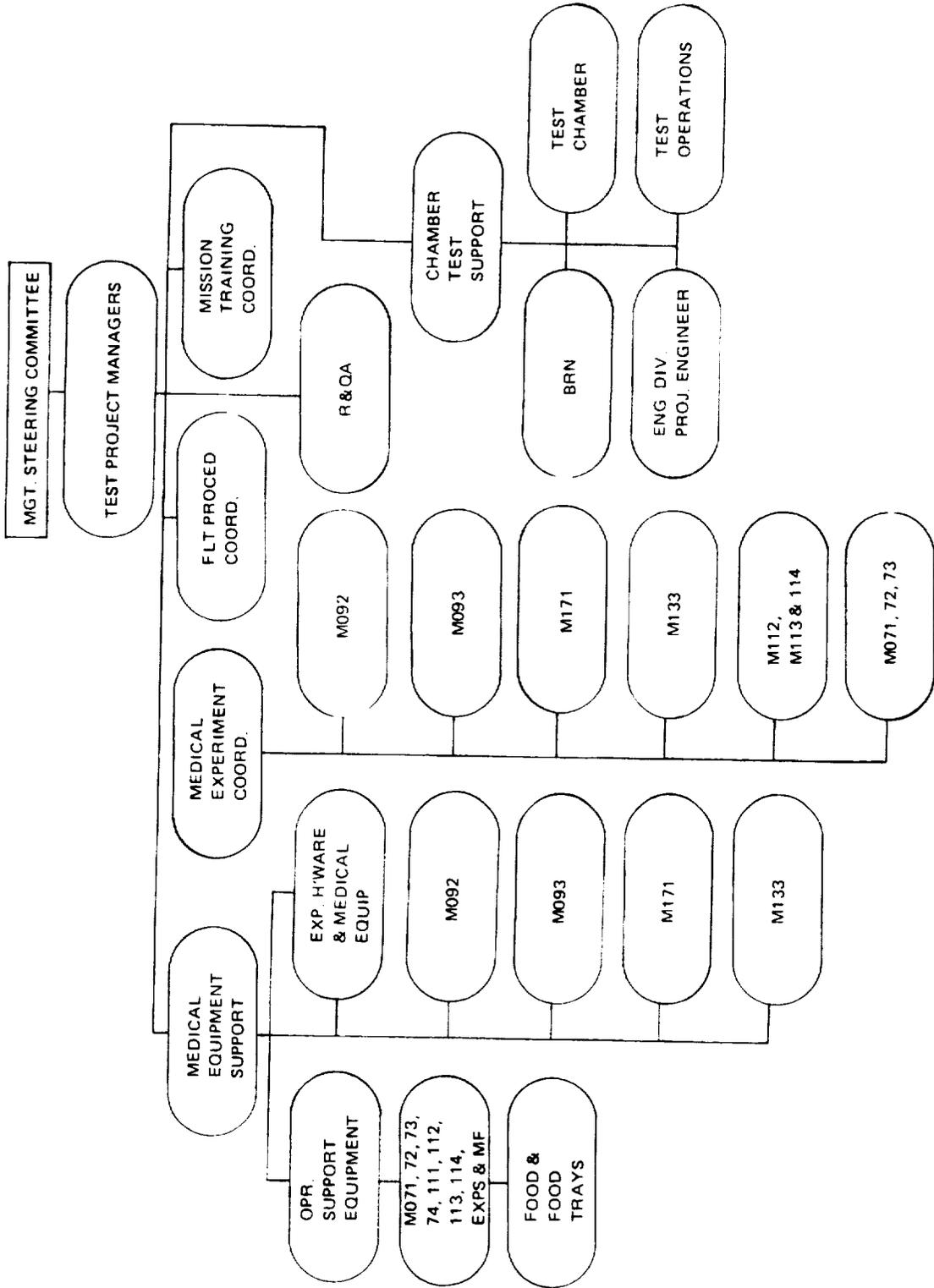
Figure 2-1. SMEAT Program Management Organization.

in order to have a clear picture of any changes which might occur in these individuals as a function of residence in a Skylab-type environment. Should any health issues arise in SMEAT, it would be necessary to make appropriate changes in the conduct of Skylab in order to preclude similar problems there.

To insure proper coverage of medical matters, a separate management structure, the SMEAT Medical Operations Team, was defined as shown in

Figure 2-2. Under the direction of the Medical Team Leader, one Medical Officer was responsible for crew health during chamber residence, another for preparation and conduct of medical experiments, and another for medical issues related to SMEAT hardware items and data processing requirements. As seen in Figure 2-2, each medical experiment was under the direction of a Principal Investigator. Since the scientists serving as PI's, in many instances, were affiliated with universities and research institutes, a Primary Coordinating
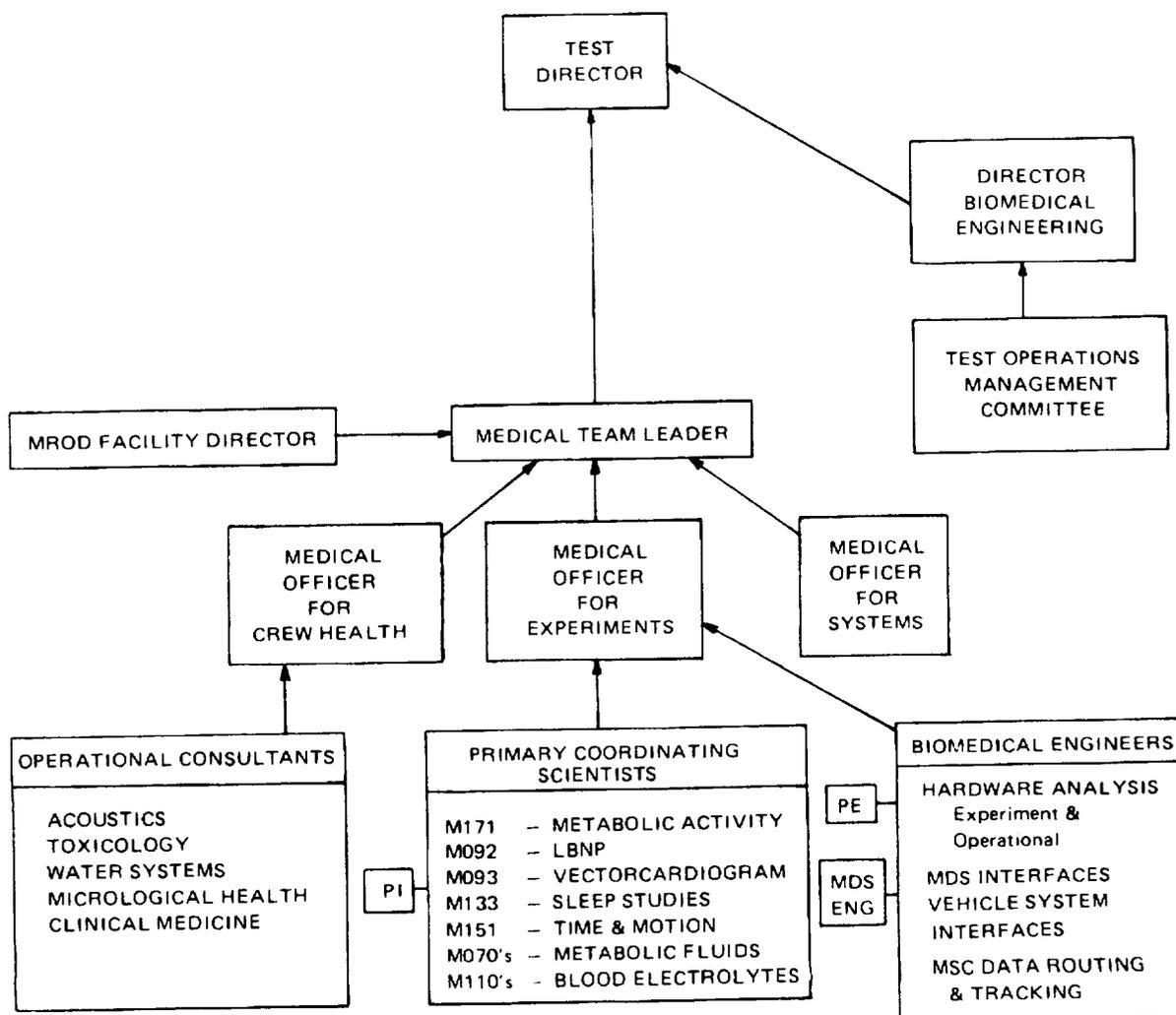
Figure 2-2. SMEAT Medical Operations Team.

Scientist, working at the Johnson Space Center, was assigned to work with the Principal Investigator of each experiment.

Chamber Operations

For actual conduct of the SMEAT Test, a Chamber Test Team Organization was defined as shown in Figure 2-3. This figure indicates the chain of command for chamber operations, part of which is seen in Figure 2-4, and clearly spells out the importance given to conduct of the medical experiments.

Prior to the beginning and during the conduct of the 56-day test, a Test Management Operation Committee (TMOC) was formed to serve in an advisory capacity to the Test Director. The purpose of the Committee was initially to institute a configuration control system and board and then to review the progress of the test during the
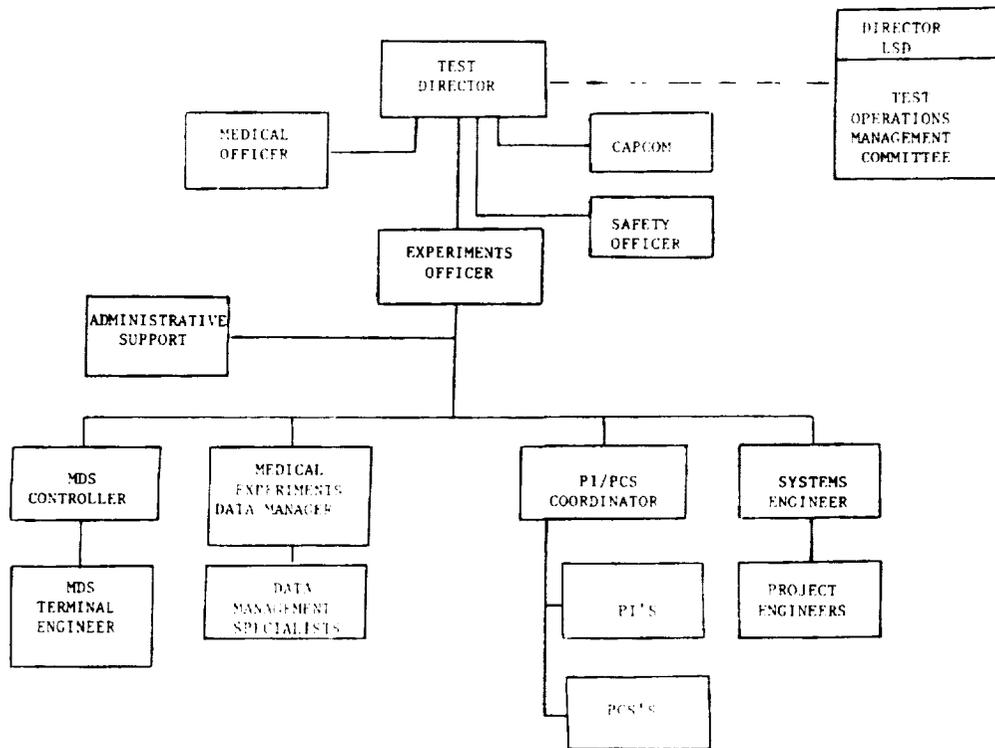
Figure 2-3. SMEAT Chamber Test Team Organization.

56 days. The Committee assessed real-time problems as they occurred, directed changes to test protocol, released daily reports, and met with the news media.

The committee was composed of personnel representing the following organizations:

Chairman: Director of Life Sciences
Members: Crew Systems Division
             Astronaut Office
             Biomedical Research Division
             Bioengineering Systems Division
             Safety Office

Typical problems requiring real-time decisions from the TMOC during the 56 days of testing were as follows:

1. Revisions of the timeline to permit reruns on the metabolic analyzer when data appeared questionable.

2. The elimination of the Skylab dewpoint instrument from the test chamber due to the erroneous readings.

3. Removing the Skylab vacuum cleaner from the SMEAT due to its poor performance and replacing it with the Apollo vacuum cleaner.

4. Redlining the amount of crew exercise to be performed on the ergometer to preclude additional failures prior to the conclusion of the 56-day test.

Figure 2-4. Chamber Operating Console.
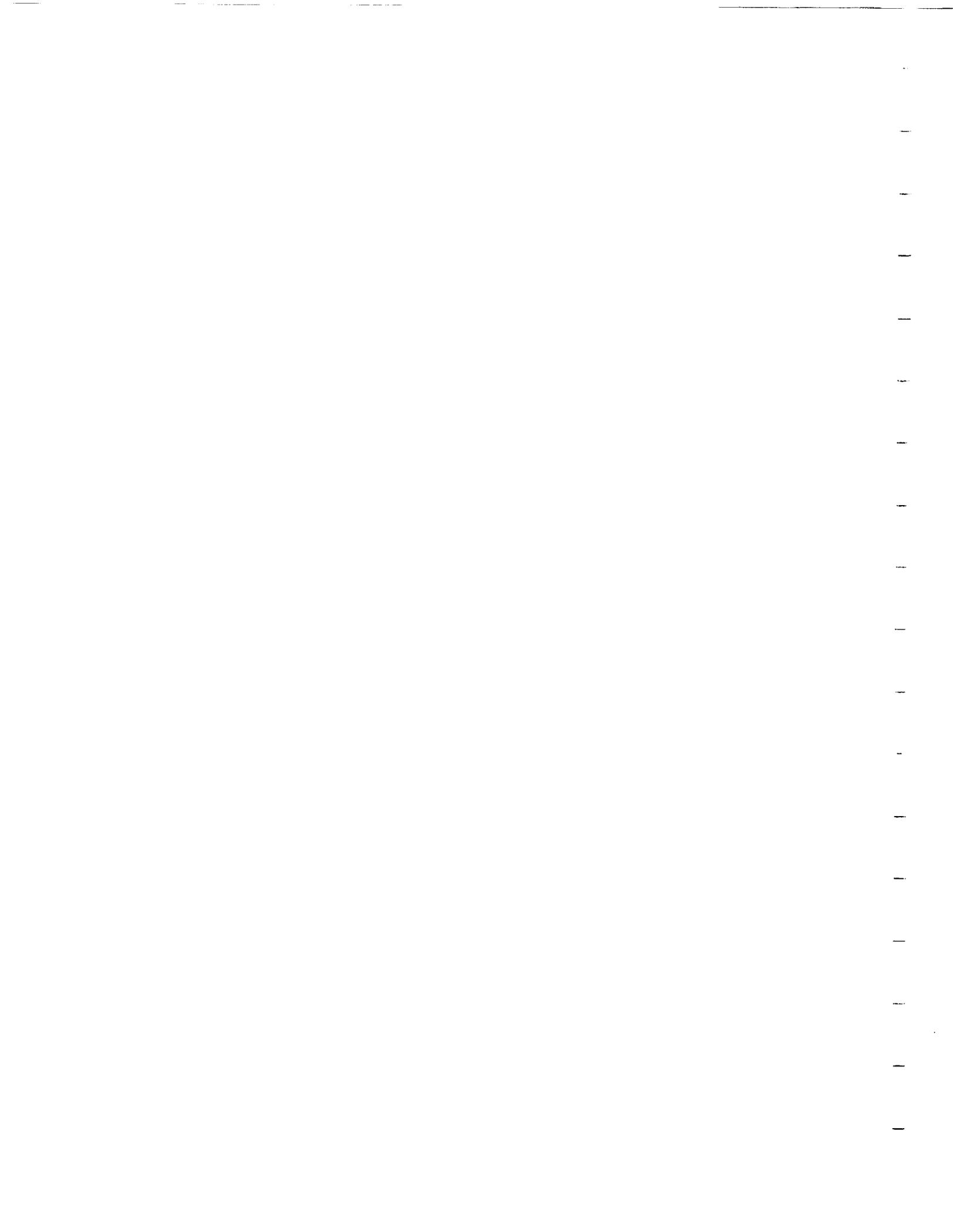
CHAPTER 3

FACILITIES

Harold F. Battaglia, Frank A. Burgett, Lewis O. Casey, James V. Correale
Jack O. Dunaway, Warren G. Glover, Arthur H. Hinners, Jr., James C. LeBlanc
Ted B. Leech, Jackie D. Mays, Dale Sauers,   James M. Skipper, L.T. Spence
Joseph R. Trombley, Kraig Jergensen, Richard L. Sauer, John B. Westover
C.T. Heinrich, G.S. Garcia, P.A. Hunter, W.P. Toland, John Hawk
J.M. Waligora, S.M. Luczkowski, W. Bush, M.C. Smith, M.A. Lowe, R.J. Marak
R.J. Young, W.F. Harriott, H.A. Rotter, and William H. Shumate

Building 7 of the Johnson Space Center complex housed the altitude chamber in which the Skylab Medical Experiments Altitude Test was conducted. The chamber had been used in many other manned tests and was modified for SMEAT to resemble the Skylab workshop. Figure 3-1 illustrates the facility photographically and schematically.

The main chamber is twenty feet in diameter and twenty feet high and is constructed of stainless steel. Connected to the chamber, as Figure 3-1 shows, are two locks in series. Each is ten feet in diameter and nine feet long. The chamber has fifteen viewports and seven penetration bulkheads around its circumference; both main locks also contain viewports and penetration bulkheads.

An additional eighteen-inch diameter lock was attached to the existing bulkhead for the SMEAT test to permit transfer of small items, food, samples, and so on, in and out of the chamber. The philosophy under which the test was conducted called access to the chamber for safety reasons only. The transfer lock made this arrangement possible. The lock was sufficiently large to permit also the transfer of small pieces of

equipment for calibration or repair. Items to be transferred into the chamber were prepared on a "clean bench" located just outside the chamber where a downflow of air insured cleanliness. When a larger item of equipment had to be passed out of the chamber and returned, the large manlocks were used.

Life support equipment, vacuum pump equipment, water supplies, and so forth, are located outside the chamber. Monitors which provide readouts of the status of chamber pressure, carbon dioxide, oxygen, and nitrogen levels flank the chamber. The crew could also monitor these parameters on a small digital display mounted in the chamber wall in the wardroom.

In all essential respects, the chamber was configured to simulate the Skylab Orbital Workshop Crew Quarters. Like the Orbital Workshop, the SMEAT chamber provided approximately 380 square feet of floor area. In SMEAT, however, the grid-like floor of the Orbital Workshop was not used. These grids facilitate movement in zero g by allowing the astronaut to "fix" himself in place by means of grips on the soles of his shoes. In a 1 g force field, such a floor would be inadequate
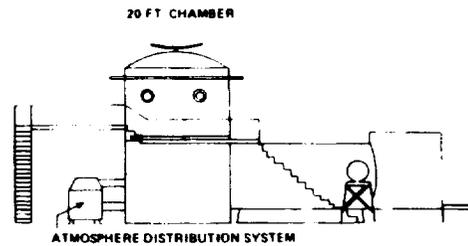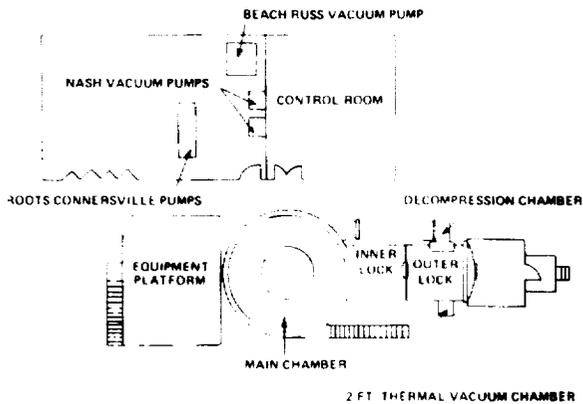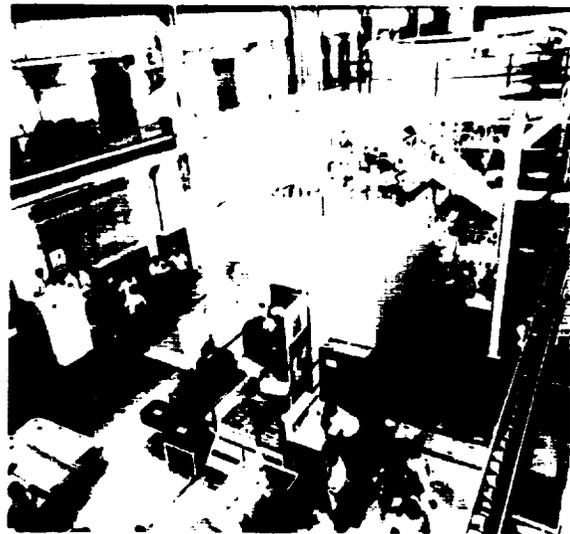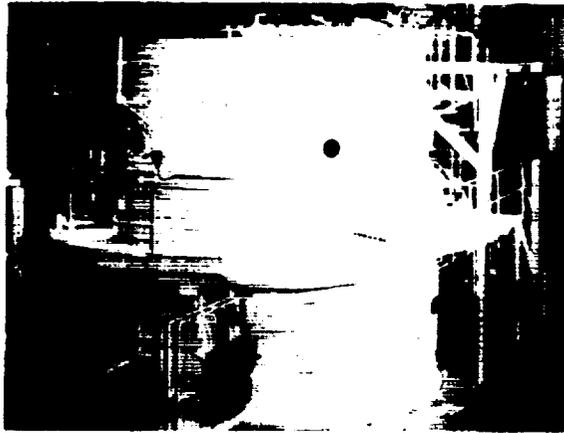
Figure 3-1. The JSC crew systems division 20-foot diameter altitude chamber. The photograph on the top right hand side shows the SMEAT Crew entering the chamber through the man lock.

for support and uncomfortable for walking. A solid floor was therefore used in SMEAT. For authenticity, the grid material was used on the ceiling of the chamber as it is in Skylab.

The layout of the main floor of the SMEAT chamber is shown in Figure 3-2. This area contained a medical experiment area, bunk areas, a wardroom, a waste management compartment, and stowage facilities. The second manlock accommodated two bunks. One of these sleep stations is shown in Figure 3-3. The third sleep station was located within the main chamber area. This deviation from the Skylab configuration was necessary

because it was not possible to simulate the Skylab sleeping arrangements in a gravity environment. In Skylab all three crewmembers occupy separate vertical sleeping compartments.

The wardroom closely simulated the Skylab equivalent. The crewmembers took their meals around a circular food pedestal which was modified for unit gravity use by being lowered to accommodate the seated crewmen.

The configuration of the waste management compartment also differed from the Orbital Workshop arrangement. In 1 g, the urine and fecal

collection unit could not be conveniently placed in the wall as is done in Skylab. In addition, because only one crewman was to test the Skylab urine collection unit, a conventional unit was also provided. The sink also differed from the Skylab configuration for 1 g operations. Figure 3-4 shows the SMEAT waste management compartment.

The remainder of the main chamber area was allocated to medical experiments equipment. Location of the main items of equipment, the bicycle ergometer and the lower body negative pressure device, can be seen in Figure 3-2. The shower, a collapsable, stowable cylindrical structure, was installed in the medical experiments

S   STOWAGE
F   FOOD
TL TRANSFER LOCK
W   WASH BASIN
E   OFF-DUTY EQUIPMENT KIT
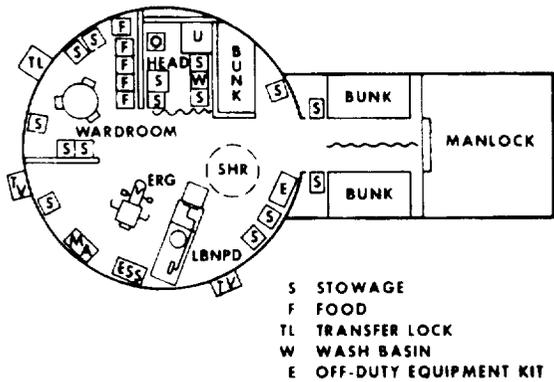
Figure 3-2. Basic chamber layout, first floor.
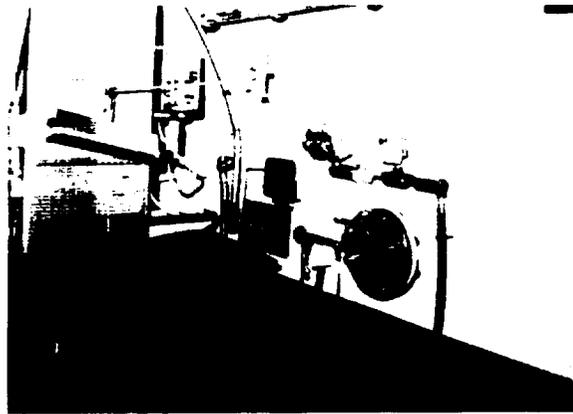
Figure 3-3. SMEAT sleep station located in chamber lock #2.

Figure 3-4. The SMEAT waste management compartment. In the photograph at the left, the fecal collector is visible. At the right the sink can be seen.

area when each crewman was to take his weekly shower. Figure 3-2 also indicates the shower location.

The twenty-foot chamber had a two-level arrangement. The second level provided a quiet area in which the crewmen could work and study in privacy. While there is no precise equivalent for this area in the Skylab Orbital Workshop, its use increased the fidelity of the simulation since the Skylab contains an "upper" level where equipment is stowed and various experiments other than medical experiments are conducted. The upper level in the SMEAT chamber had two access hatches and was reached by ladders. Figure 3-5 illustrates of the second floor of the SMEAT chamber.

The atmosphere in the SMEAT chamber simulated the Skylab atmosphere. It was a two-gas, oxygen-nitrogen breathing mixture (70:30). The basic system which maintained this atmosphere, the Environmental Control System, distributed the breathing gases, controlled the dewpoint (i.e., the temperature and humidity), maintained the partial pressures of the two gases at the required level, removed carbon dioxide, and maintained the

vacuum necessary to keep the chamber at the 5 psi level required to simulate the Skylab operating pressure. Lithium hydroxide canisters installed on the second floor of the chamber and a carbon dioxide injection system maintained the desired carbon dioxide levels.

Monitoring devices destined for use in Skylab were also tested during the SMEAT exercise. These included a carbon dioxide and dewpoint monitor, a carbon monoxide monitor, devices for sampling potentially toxic gases at trace levels and equipment for sampling the particulates in the chamber atmosphere.

The food system to be used in Skylab is essential to the conduct of the medical experiments. This system was therefore tested during the SMEAT study.

Skylab data collection techniques were also used. The main data collection post was located outside the chamber facility building, in Building 36 of the Johnson Space Center complex. This arrangement was also a faithful simulation of the Skylab situation. During operational missions, this building houses data collection equipment and
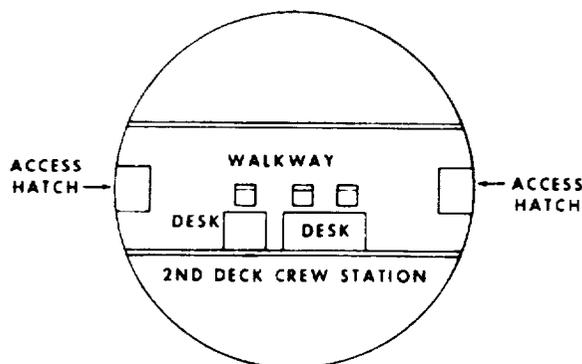
Figure 3-5. The second floor of the SMEAT Chamber. At the right, the SMEAT Commander is shown working at one of the desks located on the second level. Note the grid-like floor installed to enhance the authenticity of the chamber simulator.

is the base of operations for the principal investigators of medical experiments, as it was during the SMEAT test.

Essentially all items of equipment intended for Skylab application were verified. Crew sleep restraints, clothing and the other crew furnishing tested are described in this chapter and evaluated in Chapter 21, the *Crew Report*. Medical accessory items are discussed in the appropriate chapters and also evaluated in the *Crew Report*.

It should be noted that Environmental Control Subsystems were characterized by a considerable amount of equipment redundancy to insure that the 56-day mission would be successfully completed. The successful completion of the mission must in large measure be attributed to this redundancy plan.

Environmental Control System

The Environmental Control System established and controlled the SMEAT atmosphere. The atmospheric composition of the chamber was as follows:

Total chamber pressure	4.85 to 5.15 psia
Oxygen partial pressure	3.5 ±0.10 psia
Nitrogen, water vapor	1.5 ±0.05 psia (CO_2 = 4 – 5.5 mm Hg)
Dew point temperature	45 – 57°F
Dry bulb temperature	67 – 78°F
Air velocity	15 – 30 feet/min vertical

The Environmental Control System consisted of five separate subsystems: (1) Air distribution and dewpoint control, (2) Two-gas control, (3) Gas analysis, (4) Carbon dioxide removal, and (5) Vacuum holding.

Air Distribution and Dewpoint Control. The atmospheric gas was circulated by the chamber air-conditioning subsystem blower through ducting into the crew bay. The gas distribution subsystem (shown schematically in Figure 3-6) provided for pickup of moisture, heat, and carbon dioxide

produced by the crew and from air which had leaked into the chamber. Inboard leakage was 0.15 psia.

Gas flow into the chamber was controlled by a flowmeter in the chamber air-conditioning system. The velocity of the air within the chamber was controlled by louvers in the ceiling of the first floor. These were present prior to the test and could be adjusted by the crew within the chamber.

Specified temperature and humidity was maintained by circulating the chamber atmosphere over condensing coils set to obtain the desired dewpoint and over electrical heating elements to maintain the desired temperature in the crew bay. The ambient gas temperature was maintained using a temperature controller in the chamber air-conditioning subsystem. Return air temperature was sensed and utilized by the controller to operate immersion-type heaters to achieve the desired reading.

The Skylab Orbital Workshop is equipped with a portable device for measuring carbon dioxide concentration, humidity, and ambient gas temperature anywhere within the Skylab cluster. This device permits detection of local concentrations of carbon dioxide and water vapor that might influence the results of medical experiments. The device was used in SMEAT to provide data on variations in carbon dioxide and dewpoint concentrations to pinpoint areas of poor mixing and air stagnation within the chamber. The test also permitted an evaluation of the procedures for making measurements with the instrument and its performance.

The device, shown in Figure 3-7, measures gas and dewpoint temperatures from 40° to 100°F and carbon dioxide partial pressures from 0.1 to 30 mm Hg. It features separate, direct readout meters for carbon dioxide partial pressure and gas temperature/dewpoint temperature. Its use during the SMEAT exercise indicated there was no significant concentration of carbon dioxide or water vapor in the chamber. Some problems were encountered with drift and response times, but these
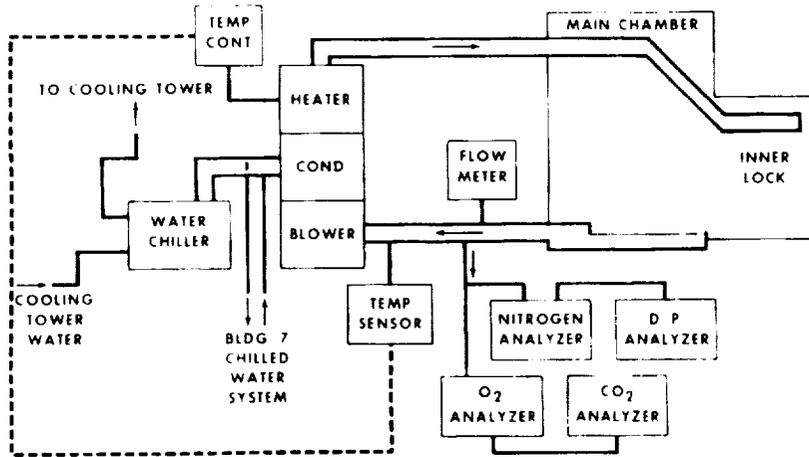
Figure 3-6. SMEAT flow distribution system

can be overcome by proper preflight instrument preparation and by procedural modifications which allow adequate sensor stabilization.

chamber by the vacuum holding pumps maintaining the pressure at a nominal total pressure of 5 ±0.15 psia.
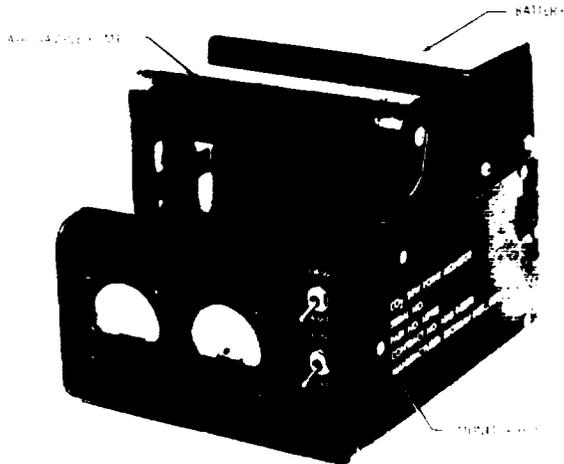
Figure 3-7. Carbon dioxide/dewpoint monitor.

Figure 3-8. SMEAT two-gas control system.

Two-Gas Control System. The two-gas control system (Figure 3-8) injected oxygen or nitrogen to maintain a mixture of 70 percent oxygen and 30 percent nitrogen. As oxygen was consumed by the crewmen and inboard leakage occurred, the resulting gas mixture was pumped from the

Oxygen was delivered to the two-gas control subsystem from the chamber oxygen subsystem. Nitrogen was delivered through one of two redundant regulators set at 500 psig. Two normally closed solenoid valves in series controlled the nitrogen flow to the crew bay compartment. These valves were operated by control signals from the oxygen analyzer which opened the valves when pO_2 was greater than 186 mm Hg and closed them at 175 mm Hg. When

the nitrogen solenoid valves were open, the two parallel oxygen solenoid valves were closed. The quantity of nitrogen gas delivered was sensed by a flowmeter downstream of the solenoid valves.

Gas Analysis. When the pressure in the SMEAT chamber fell below the preset point of 5.0 psia, the regulators sensed the pressure drop and opened to allow gas delivery to the chamber. The gas analysis system sampled the atmosphere for specified temperature, humidity, carbon dioxide, nitrogen, and oxygen concentration.

If the oxygen concentration was within the set limits (175 to 186 mm Hg), nitrogen was supplied for injection into the chamber. If the oxygen concentration was low, oxygen was injected until the pressure limit or concentration limit was reached. No gas was delivered when the crew bay pressure was above 5.15 psia.

Oxygen partial pressure was sensed by an oxygen analyzer, whose sample pickup was in the return air duct of the air distribution system. The sample pickup sensed the average concentration of oxygen in this moving stream to obtain a concentration that would be most representative of the entire crew bay. The gas sample was then subsequently sensed by a carbon dioxide analyzer which controlled CO_2.

Carbon Dioxide Removal. Figure 3-9 illustrates the carbon dioxide control system. Carbon dioxide level was controlled by the use of an Apollo suit fan (located in a duct outside the chamber) which circulated atmospheric gas through the lithium hydroxide (LiOH) assembly when required for carbon dioxide removal. When the return measured amount of carbon dioxide was at or below 4.5 mm Hg, the Apollo suit fan was in the "OFF" condition. When the carbon dioxide level rose above 5.5 mm Hg, a valve was automatically opened to allow flow through the LiOH assembly. The flow continued until the level of 4.5 mm Hg of carbon dioxide was reached. At the lower carbon dioxide level, the flow automatically shut off and remained off until the upper level was reached again. If the gas removed from the chamber by the vacuum pump lowered the carbon dioxide level to 4 mm Hg, an injection system added carbon dioxide until the level of 5 mm Hg was restored.
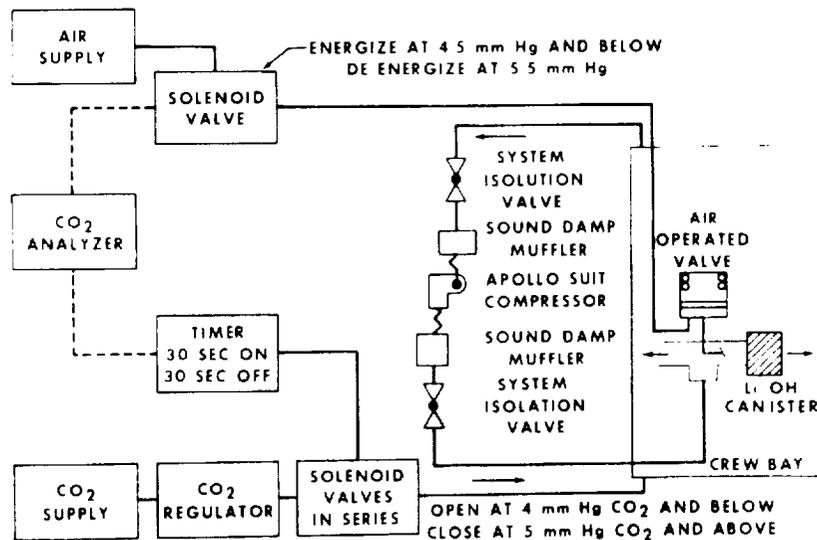
Figure 3-9. SMEAT carbon dioxide control system.

At test initiation, the carbon dioxide level increased three times as fast as the expected Skylab profile. This occurred because the SMEAT chamber volume was approximately one-third that of Skylab.

Atmosphere Contamination Detection and Contaminant Control

Any long-term habitation in a closed environment, and the SMEAT chamber was a relatively closed ecosystem, introduces a possible toxic hazard as a result of buildup of various gases and particulate matter, including microbes, in the breathing atmosphere and on chamber surfaces. Cleaning solvents, outgassing of equipment, decomposition of nonmetallic materials, and human metabolism and respiration all contribute to atmospheric contamination. Microbial contamination can be caused by activities such as food preparation and consumption, waste management, and personal hygiene.

Analysis of the chamber atmosphere for contaminants during the SMEAT test provided assurance of the safety of the crew throughout the 56 days of chamber residence. Some of the sampling equipment was also intended for use in Skylab, and the SMEAT exercise permitted evaluation of this equipment and the techniques employed.

Control of atmospheric contaminants was accomplished by three principal methods: absorption, filtration, and leakage. Atmospheric control methods and sampling methods are discussed in the following sections.

Carbon Dioxide, Trace Gas, and Particulate Control. Carbon dioxide was removed from the chamber atmosphere by use of a lithium hydroxide chemical absorption bed containing a layer of approximately 160 gm of activated charcoal. The absorption bed was changed during the test at least once every day. The activated charcoal contributed also to the removal of potentially toxic gases present in trace amounts, as well as to the removal of odors.

The SMEAT test provided an opportunity to select the optimum method of stowing the LiOH canisters during the Skylab mission. Canisters for Skylab are stowed on SL-1 at launch time. Prior to SMEAT, plans called for stowing the elements unbagged in stowage lockers. SMEAT testing disclosed that the unbagged elements swelled unacceptably; this is a critical flaw because the LiOH elements are designed for a tight fit in the Environmental Control System. On the basis of SMEAT testing, it was recommended that LiOH elements be sealed in gas impermeable bags during Skylab missions in both the Command Module and the Multiple Docking Adapter to prevent the swelling problem.

The humidity control system aided in part in the removal of trace gas contaminants, especially the water soluble compounds. The air-conditioning system recirculated the chamber atmosphere through a series of cooling coils, condensing excess water and, at the same time, water soluble trace contaminants.

The crewman himself acted as a contaminant removal system since respiration removes certain contaminants from the atmosphere, absorbing and partially metabolizing some of these. The respiratory system also removes a certain number of particulates. The bulk of the particulate matter in the chamber was removed by housekeeping operations and by entrapment in the atmosphere filtration system.

Trace Contaminant Detection. Trace gases were analyzed by whole gas sampling and cryotrapped sampling. Carbon monoxide was detected by use of a special monitor.

Whole gas sampling was accomplished daily by a sample acquisition system connected to the chamber air-conditioning return duct (Figure 3-10). A two-stage diaphragm pump provided the sample flow from the chamber to the sample cylinder.

All quantitative data were obtained by analysis of the whole gas samples. Analysis of cryotrapped samples provided detection and identification of

trace contaminants in concentrations below the detection limit for the whole gas samples.
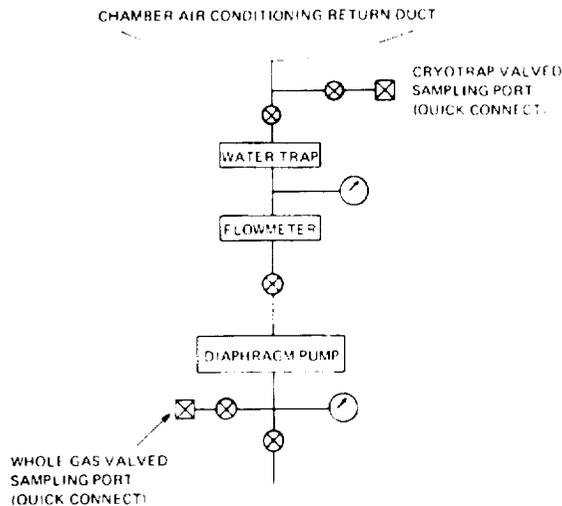
Figure 3-10. SMEAT whole-gas sampling system.

One cryotrapped sample was taken each week throughout SMEAT. The cryotrap system consisted of a stainless steel 500-cc cryotrap (Figure 3-11) cooled in liquid argon with a diaphragm pump downstream from the trap.
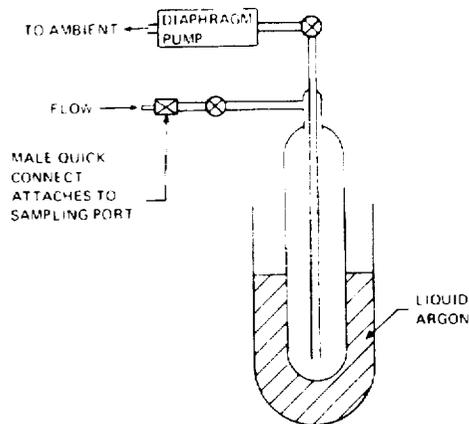
Figure 3-11. Cryotrap used for SMEAT sampling.

Analysis of the whole gas samples resulted in the identification and quantitation of 25 compounds as contaminants in the chamber atmosphere. Table 3-1 is a summary of these compounds.

Analysis of the cryotrapped samples resulted in the detection and identification of ten compounds not detected in the whole gas samples. The concentrating effect of the cryotrap technique makes possible the detection of these compounds at a lower concentration level than in the whole gas sample analysis. Table 3-2 lists all the compounds detected in the cryotrapped samples.

Levels of carbon monoxide in the SMEAT chamber were measured by a monitor which was being evaluated for possible Skylab use. The monitor contained a readout available to the crew and also provided an alarm should the reading of carbon monoxide exceed a value of 17 mg per cubic meter. The instrument did not perform satisfactorily during SMEAT and was eventually passed out of the chamber altogether.

Microbial Contaminant Detection. Prolonged confinement in a closed or semiclosed ecosystem typically produces some alterations in the type and/or distribution of the human microflora. Such changes have been seen during the relatively brief Apollo mission. Therefore, a special test was performed during SMEAT to assess the impact of 56 days of isolation and confinement in a Skylab-type environment. This test and its results are extensively described in Chapter 15.

Metal sampling strips were placed throughout the chamber for the environmental phase of the microbiological study. The strips were placed vertically at various locations on the chamber walls and horizontally under the air grids in the plenum area. In the course of the study, these strips became extremely dirty, particularly in the waste management compartment. This issue is discussed further in the *Crew Report* (Chapter 21).

Particulate Contaminant Detection. A special particulate contaminant detection study was conducted during SMEAT to gain experience with the

Table 3-1

Contaminants Found in SMEAT Chamber Atmosphere Samples

Compound	Maximum Concentration, ppm	Major Concentration Range, ppm
Acetaldehyde	72	5 - 58
Acetone	28	2.5 - 28
Acrolein	8 (MAC = 0.16)*	0 to 6
Benzene	<1	0
2 - Butanone (MEK)	20	<1 - 12
Carbon Monoxide	4.8	2.5 - 4.8
Chlorotrifluoroethylene	2.4	<1 - 2.4
Dichlorodifluoromethane (Freon 12)	1.7	<1
Ethane	<1	0 - <1
Ethanol	77	1 - 75
Fluorotrichloromethane (Freon 11)	<1	0
n - Hexane	1	0 - <1
Methane	125	50 - 125
Methanol	110 (MAC=9) *	7 - 100
2 - Methyl - 1, 3 - butadiene (Isoprene)	0.7 *	0 - 0.6
Methylcyclohexane	<1	0
Methylcyclopentane	1	0 - <1
Propane	1.2	<1
2 - Propanol	14	<1 - 4
Toluene	<1	<1
1, 1, 1 - Trichloroethane	<1	0
Trichloroethylene	<1	0
1, 1, 2 - Trichloro - 1, 2, 2 - trifluoroethane (Freon 113)	10.6	1 - 3.8
Trifluoromethane (Freon 23)	<1	<1
m - and p - Xylene	<1	0

* Johnson Space Center preliminary design requirement McDonnell Douglas values for long term environmental/thermal control and life support equipment

procedures and to verify the equipment to be used in the Skylab Inflight Aerosol Analysis Experiment, T-003.

The T-003 experiment measures the distribution of particulate matter by two systems: the real-time count of particles at specific locations within the chamber and by collection of these particles by impaction and filtration after they have passed through the real-time counting portion of the instrument. The latter function allows assessment of each particle's composition and its probable source by the morphology of the particle. The experiment was run from day 208 (the start of simulation test) to day 244, when the analyzer was removed from the chamber.

The experiment results indicated that meal preparation gave rise to large numbers of small particles by emission during heating of the microwave oven. Personal hygiene was also a prolific source of airborne particles. Eating and housekeeping, which stirred up dust, were the other significant contributors.

Mechanical Systems

Conduct of the SMEAT test required the use of various mechanical systems. A pumping system was needed to maintain the subatmospheric chamber pressure. A special fire suppression system was employed. Great care was given to the development of this system for two principal reasons.

Table 3 2

SMEAT Cryotrapped Sample Analyses

Compound	Concentration Index (Freon 113 - 100)							
	7/28	8/4	8/11	8/19	8/26	9/2	9/7	9/16
Acetaldehyde	1131	593	221	119	42	149	202	652
Acetone	40.?	135	212	46	8	41	31	160
Acrolein	36	14	4	3	<1	4	5	10
Benzene	18	31	12	2	<1	3	2	<1
2-Butanone (MEK)	308	85	168	34	8	27	5	66
* 1 - or 2 - Butene	13	10	<6	4	<1	4	<3	<5
* Carbon Disulfide	ND	ND	* *	ND	ND	ND	ND	ND
* Chlorodifluoromethane (Freon 22)	18	46	6	26	<1	18	3	10
Chlorotrifluoroethylene	52	42	7	9	<1	10	<3	8
Dichlorodifluoromethane (Freon 12)	306	742	108	56	7	88	37	65
* Dichlorofluoromethane (Freon 21)	100	163	9	22	2	20	–	17
Ethanol	1178	201	534	64	394	180	612	4219
* Ethylbenzene	2	2	3	<1	<1	<1	<1	1
Fluorotrichloromethane (Freon 11)	–	–	–	6	1	5	4	6
n - Hexane	8	3	19	2	<1	2	1	2
Methanol	84	35	58	17	6	52	24	152
2 - Methyl - 1, 3 - butadiene (Isoprene)	8	–	6	2	<1	3	1	5
Methylcyclohexane	5	4	14	<1	<1	1	<1	1
Methylcyclopentane	17	10	18	1	<1	6	2	22
* 4 - Methyl - 2 - pentanone (MIBK)	8	5	3	1	ND	ND	ND	ND
Propane	26	13	12	9	<1	11	5	20
2 - Propanol	357	32	37	–	–	–	–	213
* Propyl Acetate	6	–	7	–	ND	ND	ND	ND
* Tetrachloroethylene	< 1	<1	<1	<1	<1	<1	<1	<1
* Tetrahydrofuran	43	8	3	<1	<1	16	8	89
Toluene	48	25		10	3	17	9	29
Trichloroethylene	26	41	35	4	<1	5	2	37
1, 1, 2 - Trichloro - 1, 2, 2-trifluoroethane (Freon 113)	100	100	100	100	100	100	100	100
Trifluoromethane (Freon 23)	115	128	101	100	8	131	56	189
m - and p - Xylene	5	4	6	2	<1	2	<1	4
* o - Xylene	1	–	2	1	<1	<1	–	1

* — Not detected in whole gas samples
* * — A trace was detected

ND — Not determined
A dash (-) means none detected

First, rapid ingress and egress are undesirable in an altitude chamber because of the inherent decompression risk. Secondly, fire poses a special hazard when large concentrations of oxygen are present in the atmosphere, as was the case in SMEAT. An additional chamber safety system provided the Test Conductor with single switch response in case of any chamber emergency. One other major modification of the twenty-foot chamber was the addition of an eighteen-inch diameter lock for SMEAT. All major mechanical system are described in the following sections.

Vacuum System. Two Roots-Connersville blowers backed by a 1,000 cfm Beach Russ pump comprised the vacuum system for chamber evacuation. The pumps were controlled from the chamber control console in the control room and were used to establish a 5 psia pressure at the startup of the test. These pumps were then

isolated from the chamber and secured for standby purposes.

Gas flow evacuated from the chamber was controlled manually by small needle valves located at the system control console. This console also contained a flow meter which was used for balancing the chamber gaseous environment and a vacuum gauge which activated a warning light on the system console to indicate a vacuum rise above a preselected level (10 torr). A pneumatically actuated vacuum isolation valve automatically sealed the vacuum holding system from the chamber should chamber emergency repressurization be initiated. The vacuum system and emergency repressurization system are illustrated in Figure 3-12.
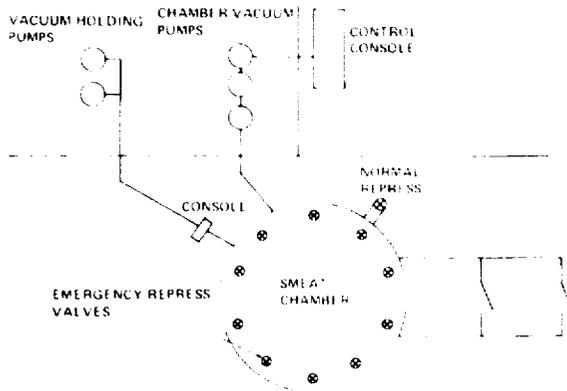
Figure 3-12. Vacuum and repressurization systems.

In addition to the chamber vacuum system, a special medical experiment vacuum system was included to provide for the needs of the metabolic analyzer equipment and the lower body pressure device. The vacuum was provided by two high vacuum pumping systems controlled at self-contained consoles. A vacuum isolation valve sealed the system from the experiment in the event of chamber emergency repressurization.

Repressurization System. Normal repressurization took place at a variable rate which was controlled by the chamber operator in accordance with the approved test procedures. Emergency repressurization was independent of normal repressurization and was accomplished through the use of ten valves located on the chamber lid. Emergency repressurization was a manually initiated procedure which could be accomplished in the control room or initiated by the crewmen themselves from within the chamber. The chamber and inner lock could be repressurized from 27,000 feet (5 psia) to sea level in nine seconds.

Fire Suppression and Detection System. The SMEAT crew bay compartment was equipped with a water deluge fire suppression system, shown schematically in Figure 3-13. This system was designed to deliver water at the spray nozzles within two seconds of system activation. The spray nozzles were located throughout the chamber so that, when activated, water was sprayed at angles that wet all chamber surfaces. Rupture disks sealed water in the lines and, upon activation, ruptured at a water pressure of 35 psi into the chamber.
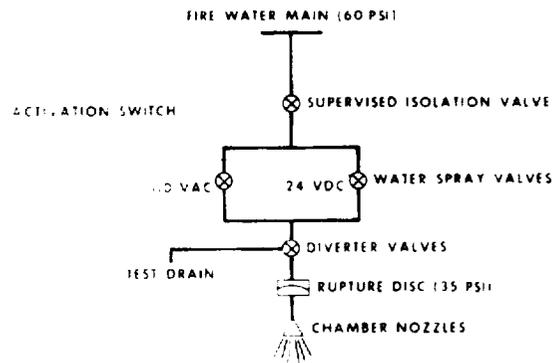
Figure 3-13. Fire suppression system.

Water spray could be activated by the Test Director from two locations in the control room or by the crew from within the chamber. There were five locally controlled fire hoses for use by the crew.

The efficacy of the fire suppression system was carefully assessed prior to the SMEAT test. A quarter scale mockup was built and tested to insure that it would be possible for crewmen to breathe when the deluge system was in operation.

The mockup study verified that there would be no problem in this area.

Two types of sensors comprised the fire detection system, a rate-of-rise sensor and an ultraviolet sensor. These sensors were located throughout the crew compartment. Activation of any detector would have been displayed to the Test Director and to a display panel centrally located in the crew compartment to provide location information for any possible fire. An audible alarm would alert the crew.

The fire suppression and detection system worked well during pretest checks and was continuously monitored during the test, but, fortunately, was never activated for cause during the test.

Safety System. A special safety system was provided which interfaced with the chamber control and water deluge systems. This system provided the Test Conductor with single switch response in the event of chamber fire, smoke, or emergency repressurization. It also permitted him to terminate chamber power should this be required.

Redundant methods for activating all control functions were provided. All functions that had to be energized could be turned on from redundant parallel circuits, and all operating functions that had to be deenergized were turned off from redundant series control circuits. Power for the safety system was normally supplied from the house direct current or site power; the safety system could be transferred automatically to battery power.

Functions controlled by the Test Conductor's panel switch could only be canceled by him. Fire, smoke, and emergency repressurization indicator lights were provided at the Chamber Operator's and Medical Officer's consoles. Activation of the emergency system was never required during the test.

Safety criteria also required that a secondary environmental control system be available in the event of any malfunction of the primary system.

To meet this requirement, oxygen masks were provided. These were equipped with umbilicals long enough to allow the crewman to breathe while egressing. They were located in the work and sleep areas of the chamber. The masks were of the quick-don, full-face type, incorporating a smoke protecting lens. Each mask had a valve to be turned on by the crewman.

Lighting and Power. The lighting system was designed to simulate the Skylab light levels as nearly as practical. Eighteen four-foot fluorescent light fixtures were used for area lighting. The lumen output could be varied from the manufacturer's specified maximum output to zero.

The Skylab light level was adjusted before the test began to within one-half foot-candle of the Skylab requirement. Prototype light fixtures were subjected to comprehensive tests at 5 psia and 100 percent carbon dioxide to determine heat rise and estimated lamp life and to verify safety features.

The normal electrical power for the SMEAT chamber was supplied by Houston Lighting and Power Company. In the event of a power failure, critical power supply would have been automatically transferred to a natural gas driven generator that was rated for continuous operation for the SMEAT load imposed on it.

Power and emergency repressurization was provided by battery-driven redundant DC/AC converters with an automatic transfer feature to the standby unit in case of failure of the primary unit. Within the chamber, zero gravity type outlets were placed at optimum locations to provide power for experiment requirements.

Equipment Transfer Lock. A small airlock (in Figure 3-14) installed on an existing chamber penetration was used for transferring items, such as food, clothing, and waste materials into and out of the SMEAT chamber. A transfer basket was used inside the lock to aid in transferring small items. The lock measured 18 inches in diameter and 24 inches in length and was sealed from the chamber by 20 inch diameter air-operated gate valve. This gate valve was electrically interlocked
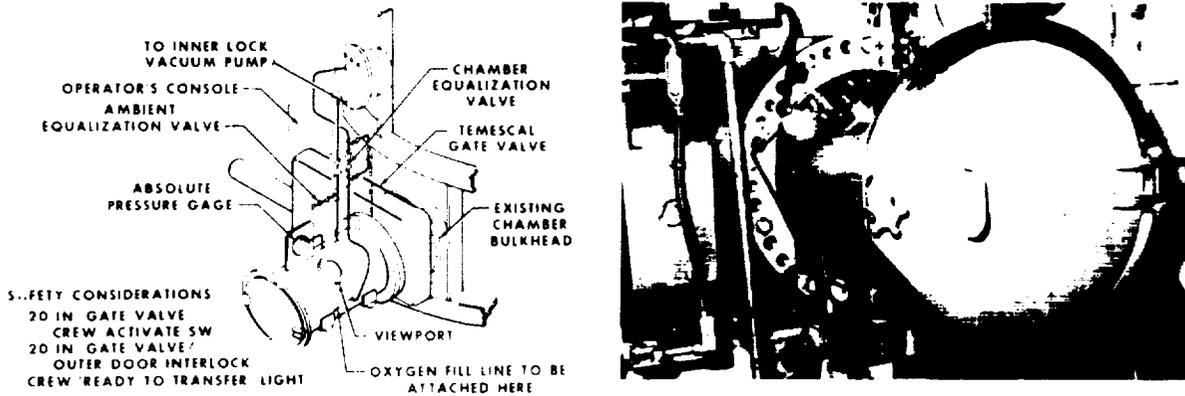
Figure 3-14. Equipment transfer lock.

to require activation by both technician and crewman. This prevented the valve from being opened inadvertently with the lock outer door open and prevented valve closure without crew concurrence. In this way chamber contamination and injury were avoided. Evacuation and repressurization of the transfer lock was manually controlled at the lock outside the chamber, with vacuum provided by the chamber inner lock vacuum pump.

Water and Waste Management

The SMEAT study provided an opportunity to test Skylab water and waste management facilities. Prior to the design of systems for Skylab, only the most basic provisions had been made for body cleansing during space missions. Urine and fecal collection measures have been highly unacceptable from the psychological viewpoint and inadequate from the viewpoint of good sanitation. Great difficulty has been experienced by crewmen in collecting fecal matter in weightlessness by the use of a hand-held plastic bag. Only small wipes were provided for washing the body.

Skylab facilities for water and waste management present a significant advance over those used previously. The Orbital Workshop features a separate waste management compartment. Provisions have also been made for weekly showering. The shower is a relatively unsophisticated device, but it

represents the first step toward whole body cleansing in space and it is the cleansing method of choice of most crewmen.

The SMEAT chamber simulated the Skylab water and waste management systems in all essential respects. Minor modifications were necessary to adapt the systems to use in a 1 g environment. The testing proved to be a very valuable experience. It disclosed, for example, that the urine collection system had major deficiencies and required redesign for Skylab application. The fecal collection system, on the other hand, functioned satisfactorily. The showering facility was a great success. The following sections discuss these findings in detail.

Potable Water System. The potable water system supplied all in-chamber water needs. It consisted of an external portable fill tank, a stowage tank, hot and cold continuously circulating water systems, food preparation pedestal and individual water guns to provide drinking and food reconstitution water, a wash basin, and a shower. One of the drinking water guns and the cold and hot food reconstitution ports on the food pedestal were of Skylab configuration. The water duplicated Skylab quality in temperature, pressure, and chemical constituents including iodine treatment.

The water was delivered in three water loops at $45^\circ F$, $125^\circ F$, and $150^\circ F \pm 5^\circ F$ (as in Skylab).

Water was supplied to all three loops from a 50-gallon supply tank pressurized to 20 psig. A second 50-gallon tank was used to transport water from Ellington Air Force Base (also the source of Skylab water) to the SMEAT chamber. The water was sampled before removal from Ellington to verify that quality met Skylab specifications. It was sampled again at each transfer into the supply tank. Additional samples were taken from the supply tank at one-week intervals for the entire duration of the test. Iodine was used to prevent bacterial growth. The concentration was 4 ppm in the drinking water. Figure 3-15 diagrams the potable water system. Separate water loops were as follows:

1. 45°F loop - circulated to the cold water drinking guns and cold water food reconstitution dispenser at the food pedestal. Cold water from this loop was also circulated to the shower cold water fill valve.

2. 125°F loop - circulated to the water basin for washing and shaving.

3. 150°F loop - circulated to the hot water food reconstitution gun at the food pedestal and to the shower water fill valve.

SMEAT provided an opportunity to simulate and evaluate a Skylab-type shower. The configuration was not identical but resembled the Skylab model in appearance and operation (Figure 3-16).

The shower enclosure consisted of a cylindrical wall composed of "two-pass" beta cloth with four ring stiffeners. The enclosure was 79 inches high and 35 inches in diameter, open at the top with an aluminum pan at the bottom. The nozzle assembly consisted of a Bete fog nozzle No. 5080F plumbed to 76 inches of 3/8-inch diameter convolex flex tubing with a quick-disconnect fitting at the ceiling level. The nozzle was hand-held by the crewman using the unit. When the shower was not in use, it was stored collapsed under a chamber bunk.

When a shower was scheduled, the water tank was filled with hot and cold water to arrive at a mixed "use" temperature of 107° to 110°F. The water tank was pressurized initially with nitrogen to 35 psia. This pressure was decreased to approximately 10 psia at the completion of each shower period. As planned for Skylab, six pounds of water were used per shower.

All three crewmen showered on the same day. At the end of the scheduled showers, the drain
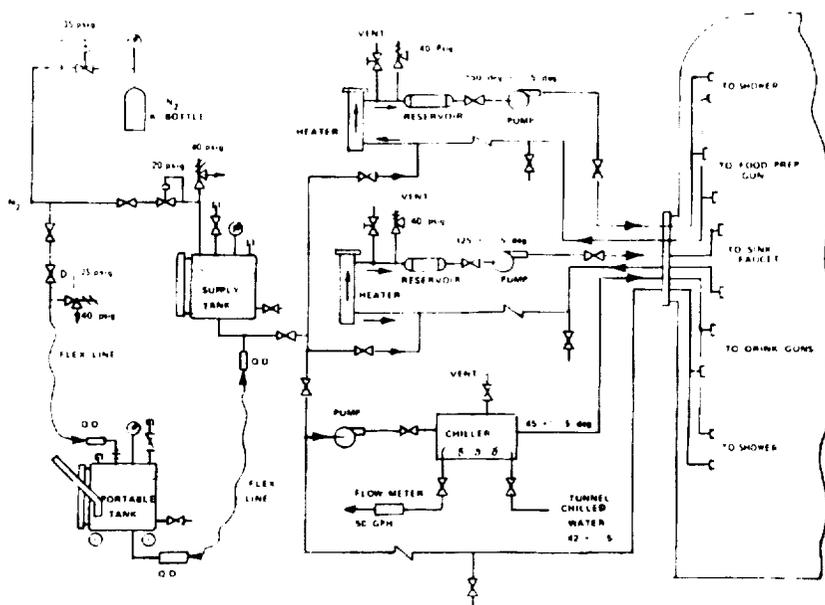
Figure 3-15. SMEAT potable water system.
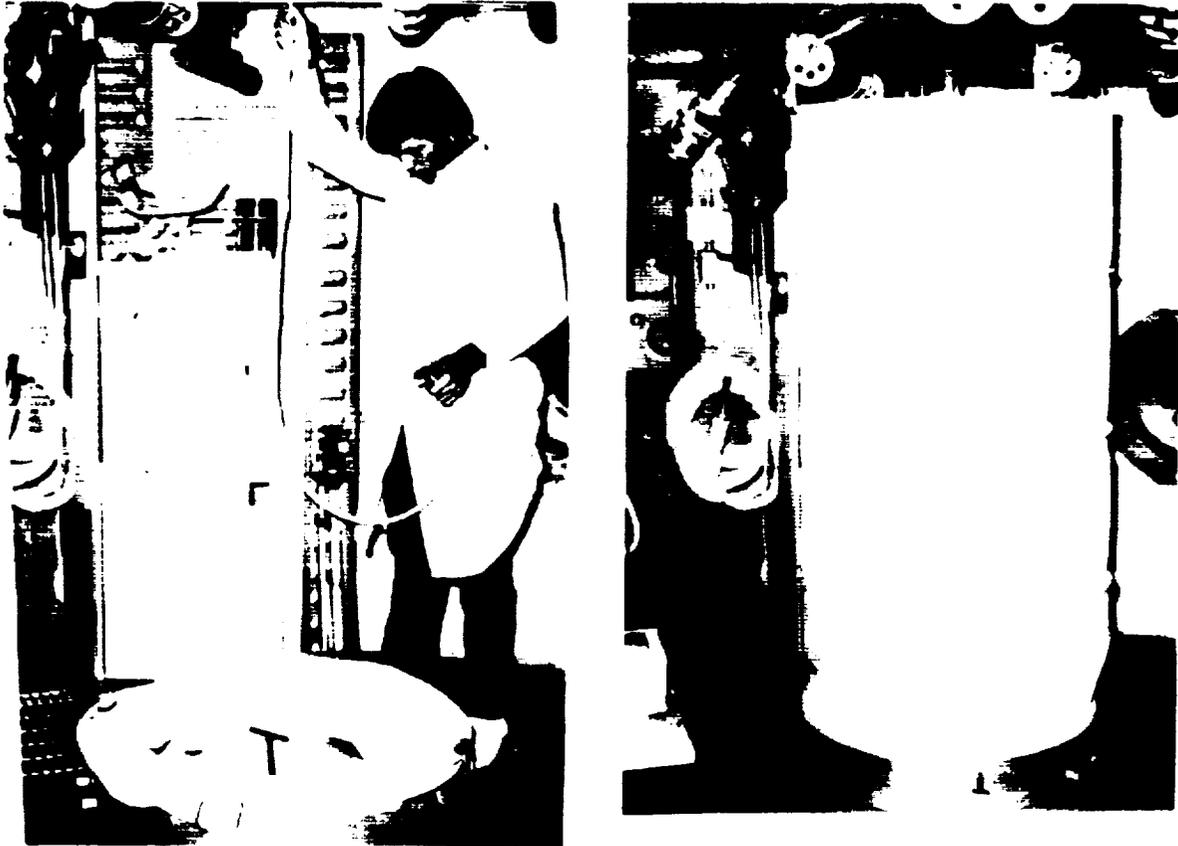
Figure 3-16. The SMEAT shower.

tank was passed outside the chamber through the transfer lock and samples were taken for analysis.

Housekeeping Systems. Housekeeping equipment consisted of wipes, tissues, betadine pads, Neutragena soap and the Apollo vacuum cleaner. Used washcloths and towels were saved and used for cleaning. Unused components of the clothing modules were also used as rags (two of the crewmembers did not wear the undershirts provided with their clothing modules).

The Apollo vacuum cleaner was requested and used after the SMEAT mission started because the Skylab unit did not generate enough suction to remove debris from the chamber. After modifications to the Skylab unit's inlet nozzle, the

operation was slightly more effective. The Apollo vacuum cleaner was designed for lunar missions and is powered with an Apollo suit compressor with a three-foot suit hose connected to the inlet side of the 28-volt, 400-cycle three-phase motor. A bristle brush is attached to the end of the hose, and a catch bag is connected at the rear of the unit to hold particles. Figure 3-17 shows the vacuum cleaner in use.

Personal Hygiene Systems. In addition to the shower already described, personal hygiene facilities included a small SMEAT-specific sink for wetting washcloths and the Skylab personal hygiene kit. Table 3-3 lists the contents of the kit.

Urine Collection. Two methods of urine collection were used during the SMEAT mission. The

Skylab primary urine collection system was used by one crewman for the entire mission, and the Skylab contingency system by a second crewman for the last ten days. The other method of urine collection was a SMEAT-peculiar system. It consisted of a simple receiver funnel interconnected (via a can used in connection with the fecal collection stool) to a refrigerated container via a flexible hose.
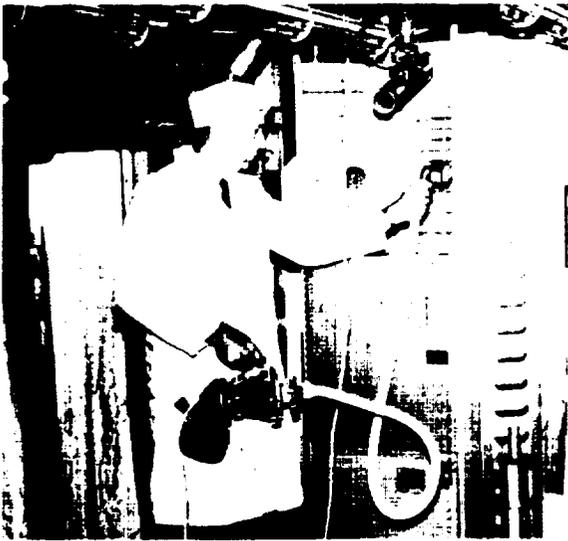
Figure 3-17. Vacuum cleaner in use in SMEAT chamber.

Table 3—3

Personal Hygiene Kit

Stypic pencil	Wind-up
Cotton swabs	shaver
Dental floss	Razor
Hair trimmer	Blades
Hair brush	Shaving cream
Deodorant stick	Shampoo
Comb	Mirror
Skin cream	Tooth paste
Nail clipper	Tooth brush

The stainless steel urine cans were designed to hold a one-day void cycle, and procedures called for them to be passed out at the end of the cycle

day. All seams were welded and polished. The urine hose assembly was composed of a convolex tube connected to a Teflon funnel.

The significant procedural difference between the Skylab and the SMEAT configuration involved the disposition of filled urine bladders and sample containers. During the Skylab mission, urine bladders are discarded through the trash lock into the LOX tank. In SMEAT, the filled bladders were passed out through the transfer airlock. Skylab samples are frozen after collection.

The results of the SMEAT evaluation of the Skylab urine system indicated drastic redesign of the system was required. Approximately 60 specific problem areas were observed. Those reflecting design deficiencies are listed below, along with changes effected to correct these deficiencies. Those deficiencies requiring major redesign are marked with an asterisk.

1. Torn foil on centrifugal separator. The foil was treated with Teflon.

2. Urine drawer tracks did not always catch. Correction did not require major redesign.

*3. Insufficient System capacity. The 2,000 ml capacity (assumed one-day void volume) was increased to 4,000 ml.

4. Sample bag did not fill in an installed position. This problem was attributed to the effects of gravity. No major redesign for Skylab was undertaken.

5. Urine recirculation could not be performed. Major redesign was not required. Final Skylab systems did not use recirculation.

*6. Pressure plate hung up intermittently. The pressure plate was dropped in favor of simple spring steel straps on the back of the aluminum plate.

*7. Urine collection hose difficult to install/remove. The hose was redesigned for easy installation. Also, the material of the collection cone was changed to Teflon-lined aluminum to reduce accumulation of urine over time.

8. Back pressure experienced during contingency collection. Redesign of the urine bladder

into a box-like form rather than an "envelope" form reduced this problem.

*9. Drawer latch difficult to open. The complex drawer latching mechanism was changed to a simple external catch.

10. Sampling bag difficult to mark; bladder serial number missing. Bags proved to be easily marked with a ballpoint pen.

11. Urine collection hose pulled out of "Y" inlet fitting. No redesign was required; Skylab design does not use "Y" fitting.

12. Recirculation door latches difficult to operate. The recirculation concept for the urine system was discarded.

13. Sample bag door difficult to operate. This was easily corrected.

14. Sample container expanded at altitude. The container was redesigned to be packed unsealed. This permitted equalization of pressure to ambient levels.

15. Sample container bound during filling. This was compensated in the redesign.

16. Viewing slot in sample bag door was too short and too narrow. Slot dimensions were increased in final design.

17. Centrifuge filter cover difficult to remove; filter difficult to install and remove. The redesign of the system eliminated this problem.

18. Corrosion on EMI connector and periphery on centrifuge. Same solution as number 17.

19. Acoustifoam odor. Acoustifoam used as a sound deadener, produced a very unpleasant odor. The solution was to remove the acoustifoam.

20. Torn bladders. The material used to construct the bladders was replaced by Teflon-coated cloth, which greatly increased resistance to tearing.

21. Volume determination reading stuck. Removal of the pressure plate with associated VDR mechanism eliminated this problem.

22. Condensation. Condensation resulted from the higher chamber humidity and low coolant temperature. No similar problem was anticipated for Skylab.

Fecal Collection. The primary component of the fecal collection system was the fecal collection stool shown in Figure 3-18. The SMEAT unit was of the basic Skylab design, but it was mounted vertically for use in a 1 g environment. Flight configured Skylab fecal bags were used. A SMEAT-peculiar blower was provided to draw cabin air into the unit and then to exhaust it through a charcoal filter back into the cabin. The filter was effective in removing odors and was changed twice during the test, in accordance with the planned maintenance procedures. SMEAT-peculiar fecal cans were provided to stow the used fecal bags until such time as they could be passed out of the chamber.

Figure 3-18. SMEAT fecal collection stool.

Food Systems

The development of food for onboard spacecraft consumption has been a complicated and difficult task. This food must comprise a nutritionally balanced, adequate diet. Additionally, it must resist the rigors of a space mission profile,

remaining stable under a wide range of temperatures, over pressures, and acceleration and vibration forces. The selection of foods for diets in earlier space missions was constrained by the weight and volume limitations of the spacecraft used. As a consequence, the feeding system relied primarily on freeze-dehydrated foods stored in plastic pouches. The reconstituted food was a tube in the pouch directly into the mouth. This was the mode of food consumption until the time of Apollo 8 when the introduction of intermediate moisture food in the form of moist turkey bits and gravy permitted for the first time the use of a spoon.

Apollo meals provided an adequate, balanced 2,500 calorie diet per day for each man onboard. While astronauts have not, on the whole, expressed many major objections to the diet that has been provided, an examination of their nutrient intake indicates clearly they have been less than enthusiastic about their food. Most have not consumed energy at levels equivalent to their calculated requirements.

Food System Development. In order to correct hypocaloric intakes, efforts have been made to develop diets for Skylab crews that are significantly more appetizing, that is, more nearly earth-style. The development of the Skylab food system was further complicated by the fact that a number of the medical experiments performed inflight are particularly dependent upon nutrient intake.

Over 72 foods were developed according to specifications which set strict limits for formulation and for chemical and microbiological composition. Nutritional and safety requirements were considered the most basic in the development of the Skylab food system. Special microbiological inspection requirements were established to insure food safety over long periods of time. Checks were made to insure that the food met or exceeded government and industry processing standards, and many routine and special microbiological and toxicological checks were made. Foods were originally selected by an interdisciplinary team of specialists who were qualified in

food technology, nutrition, dietetics, quality control, manufacturing, food packaging, systems engineering, and consumers (astronauts).

Menu design criteria were as follows:

1. Crew-food compatibility
   a. Flavor
   b. Appearance
   c. Ease of preparation
   d. Safety
   e. Non-allergenic
   f. Fecal bulk and consistency
   g. Non-gas forming

2. Nutritional requirements

3. Medical experiment requirements
   a. Calcium
   b. Phosphorus
   c. Magnesium
   d. Sodium
   e. Potassium
   f. Protein
   g. Energy

4. Physical constraints
   a. Package size
   b. Preparation equipment
   c. Stowage
   d. Waste disposal
   e. Residue mass determinations

The list of candidate foods was reviewed by the principal investigators for medical experiments and by Skylab astronauts. Foods which did not meet the aforementioned criteria were eliminated until the goal of 72 foods from four different categories was established as the baseline list of foods as shown in Table 3-4. The list was limited to 72 items since this was the quantity which could be developed, manufactured, and analyzed within the time and funds available for the Skylab food system. Also, experience with previous systems had demonstrated that approximately 70 foods were all that are needed for design of six-day menu cycle.

A menu was then developed which represented general (not individual) food preferences and nutritional requirements for the "average" Skylab

Table 3-4

Skylab Foods

Beverages

Lemonade	Tea with lemon and sugar
Grape drink	Orange drink
Instant breakfast drink	Strawberry drink
(cocoa flavored)	Apple drink
Cocoa	Grapefruit drink
Black coffee	Cherry drink

Frozen Foods

Coffee cake	Pork loin with
White bread	dressing and gravy
Prebuttered roll	Prime rib
Filet mignon	of beef
Lobster newburg	Vanilla ice cream

Wafer Food

Dry roasted peanuts	Sliced dried beef
Dried apricots	Hard candy
Sugar cookie wafers	Mints
Vanilla wafers	Biscuit
Cheddar cheese crackers	(cracker type)
Bacon wafers	Butter cookies

Thermostabilized Food

Pineapple	Meatballs and sauce
Butterscotch pudding	Pears
Turkey and gravy	Hot dogs (tomato sauce)
Tuna sandwich spread	Peaches
Fruit jam	Chili with meat
Applesauce	Catsup
Peanut butter	Lemon pudding

Rehydratable Foods

Rice krispies	Shrimp cocktail
Sugar coated corn flakes	Salmon salad
Scrambled eggs	Sausage patties
Pea soup	Pork and
Potato soup	scalloped potatoes
Asparagus	Chicken and rice
Mashed potatoes	Beef hash
German potato salad	Chicken and gravy
Cream style corn	Veal and barbecue sauce
Peach ambrosia with pecans	Spaghetti and meat sauce
Strawberries	Turkey rice soup
Green beans	Macaroni and cheese
Creamed peas	Mashed sweet potatoes

crewmember. The "average" crewmember was selected arbitrarily and did not represent the food requirements of any specific individual since crew assignments had not been announced at that time. Skylab and SMEAT crewmembers were identified and were then fed these diets to gather individual evaluations to enable revision and adjustment as necessary. These food compatibility tests also provided information needed to add, delete, or modify food items from the Baseline Food List.

Beginning in October 1971 and continuing through April 1972, conferences were held with each Skylab and SMEAT astronaut to review his menu cycle and receive comments. The menus were subsequently modified as needed based upon crew suggestions and recommendations. Conferences were rescheduled until each man had approved a six-day menu cycle. Throughout this period, foods were served and/or provided on an individual basis for crew familiarization with different combinations of foods in a meal. Skylab/SMEAT-type foods were provided at lunch periods twice weekly for nine weeks. Each crewman also completed two separate compatibility tests on a full menu cycle. Subsequent individual conferences and food item modifications resulted in six menu revisions for two SMEAT crewmembers and ten revisions for the other crewmember.

An initial set of menus was prepared for each of the Skylab and SMEAT astronauts based on each individual astronaut's food preferences and eating habits. The protein level of the initial menus was controlled to the tolerance levels specified by Experiment M071. Other nutrients were adjusted with mineral supplements to comply with the M071 tolerance levels with the exception of sodium. Sodium levels exceeded the M071 limit which was in process of change to an upper limit of 6,000 mg daily. The nutrient tolerance levels used in the planning of the menu cycle for each crewman follows (Table 3-5).

SMEAT menus were developed in cooperation with the Principal Investigator for M071 and his

staff. The menus were reviewed for compliance with the Skylab M071 study and estimated individual nutrient requirements (Table 3-6). Various methods were employed to estimate adequate daily energy levels for each of the SMEAT crewmen. These methods were: (1) Five-day food compatibility test during which time actual energy intake was recorded, (2) Calculation by the method employed by National Institutes of Health for subjects on metabolic balance studies, and (3) Calculation by the method recommended by the Food and Nutrition Board of the National Research Council in *Recommended Dietary Allowances*, 7th Revised Edition (1968). Following is a summary of the results using the three methods (Table 3-7).

The values derived by using the RDA methods were employed for the SMEAT crew menus.

Irradiated bread was to be supplied, but it was unavailable in sufficient time for inclusion in the diet. Frozen bread was substituted. Frozen food was limited by freezer space to nine items per man during each six-day menu cycle.

SMEAT Food. A six-day menu cycle was developed. The SMEAT crew consumed the Skylab diet for 28 days prior to chamber residence, for 56 days at chamber altitude, and for 18 days post-test.

Foods were provided in one of several forms. They were either frozen, thermostabilized, or freeze-dehydrated, rehydratable foods. Ready-to-eat bite-size foods were also provided and called wafers. Beverage powders were placed in a separate category for convenience.

Food packaging. All foods except beverages and puddings were packaged individually in either large or small commercially available aluminum cans. Thin plastic membranes were incorporated under the pull-tab lids to prevent loss of the food

Table 3-5

Nutrient Tolerance Levels for SMEAT Crewmembers

M-071	CDR	SPT	PLT
Energy (cals) 2000-2800	2895 ± 20	3276 ± 15	3100 ± 22
Protein (g) 90-125 ± 10	115 ± 10	110 ± 10	123 ± 10
Calcium (mg) 750-850 ± 16	850 ± 16	850 ± 16	850 ± 16
Phosphorus (mg) 1500-1700 ± 120	1700 ± 120	1700 ± 120	1700 ± 120
Sodium (mg) 3000-4000 ± 500	3900 ± 500	4000 ± 500	4000 ± 500
Magnesium (mg) 300-400 ± 25	325 ± 25	350 ± 25	320 ± 25
Potassium (mg) 3000-4000 ± 200	3921 ± 200	4000 ± 2000	3915 ± 200

Table 3-6

Estimated SMEAT Crewmen's Daily Nutrient Requirements

Nutrient	CDR	SPT	PLT
Energy (kcal)	2900	3300	3100
Protein (g)	103 ± 10	105 ± 10	106 ± 10
Calcium (mg)	850 ± 16	850 ± 16	850 ± 16
Phosphorus (mg)	1700 ± 120	1700 ± 120	1700 ± 120
Sodium (mg)	4000 ± 500	4000 ± 500	4000 ± 500
Magnesium (mg)	350 ± 25	325 ± 25	345 ± 25
Potassium (mg)	3800 ± 200	4000 ± 200	4000 ± 200

when the cans were opened in zero g. The smaller packages stored ready-to-eat foods and snack items such as peanuts and mints. The membrane in the wafer food packages was preslit so that fingers can be inserted to remove only a portion of the contents.

Table 3-7

Crew Energy Requirements Calculated by Three Methods

Crewmember	Daily Energy (Cal) Level		
	5 Day Test	NIH	RDA
CDR	2860	3055	2900
SPT	2790	3285	3278
PLT	3120	3240	3080

Larger packages stored all principal food items. The can used for storing frozen and thermo-stabilized food is illustrated in Figure 3-19. Note the plastic membrane which is pierced at the time of food consumption. Figure 3-20 shows the rehydratable food package. This package uses a polyethylene inner bag to contain the dehydrated food, which is reconstituted with cold or hot water available from the water dispenser in the food pedestal.
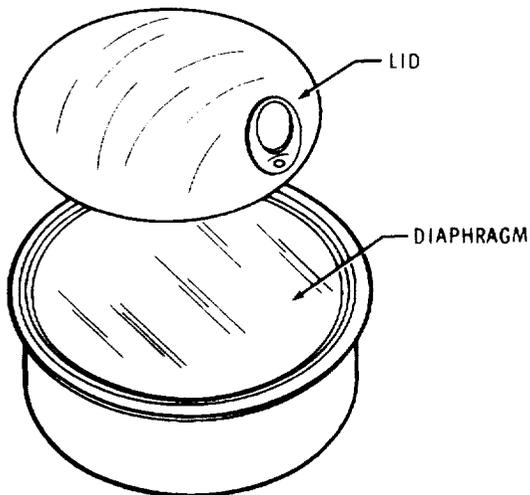
Figure 3-19. Frozen and thermostabilized food package.
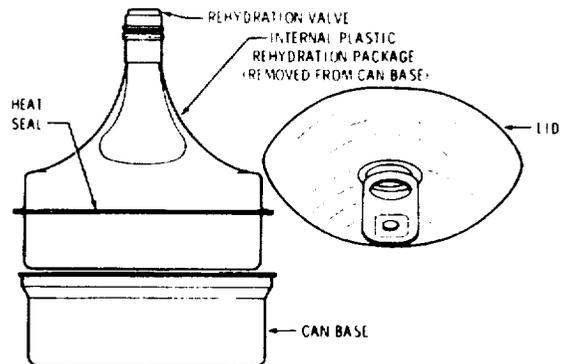
Figure 3-20. Rehydratable food package (lid removed).

The beverage package, shown in Figure 3-21, is a polyethylene bellows assembly. A nylon valve is inserted in the neck of the bellows to permit both reconstitution and consumption. The package is collapsable for storage.

Figure 3-22 shows the food protection hardware items. All food packages are stowed in sealed aluminum canisters designed to provide protection during various mission phases. The food package retainer illustrated permits packages to be extracted individually in zero g. The canisters are stored in a restraint assembly which is in turn stored in the food storage locker, two to a locker. A canister lid removal tool was provided for removing lids that might have become firmly sealed after prolonged low-pressure storage.

Food Pedestal and Food Preparatory Items. Both food preparation and dining were accomplished at the food pedestal in the wardroom, as they are in the Skylab Orbital Workshop. The food pedestal contains heating trays, food reconstitution water dispensers, and drinking water dispensers.

In SMEAT, the Skylab food heating trays were clamped to three Skylab-configuration heat sinks. This arrangement can be seen in Figure 3-23. In an operational, zero g mission, the chairs shown in the figure are replaced by thigh restraints. The astronaut is restrained by a metal "T" by grasping the crossbar with his legs.
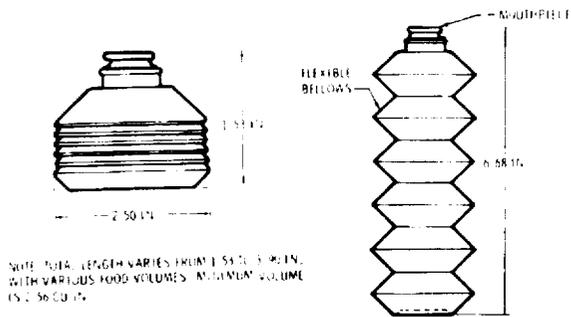
Figure 3-21. Beverage package, fully collapsed left;
fully extended, right.

The food tray, officially designated the Automatic Meal Reconstitution Module, holds food packages and has the capability for heating them to 149°F. Magnets on the surface of the module retain the eating utensils—knives, forks, and spoons. A cavity on the left side of the module holds the napkin. Figure 3-24 shows the food tray with foods and utensils in place. The utensils are cleaned by the use of individually packaged wet wipe towels impregnated with two percent Zephiran disinfectant solution. The wipes are contained in a spring-loaded dispenser. Each of these (there are five aboard Skylab) accommodates 301 individually packaged wipes.

FOOD
PACKAGE
AND
CUSHION

FOOD
PACKAGE
RETAINER

CANISTER

CANISTER
RESTRAINT
ASSEMBLY

NOTE: AMBIENT FOOD CANISTER RESTRAINT ASSEMBLY
IS SIMILAR TO FROZEN FOOD CANISTER RESTRAINT
ASSEMBLY SHOWN ABOVE

Figure 3-22. Food protection hardware.

Figure 3-24. Food tray.

Figure 3-23. SMEAT food pedestal.
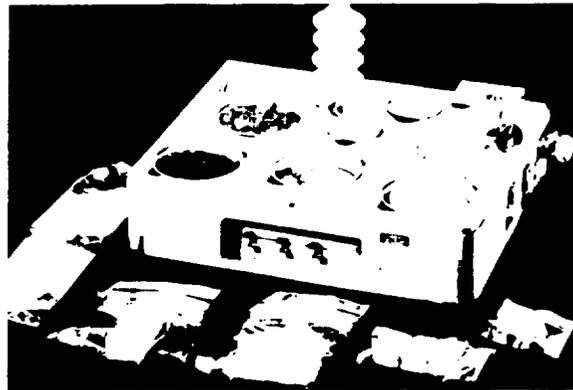
Mineral supplements, polyethylene glycol, and fecal dye markers were provided. Intended for the purposes of the mineral balance experiment, these items were included, respectively, to adjust for deviations in food intake, to account for fecal mass, and to designate the end of each six-day menu cycle. They were packaged in an aluminum food can for SMEAT; in Skylab, a special capsule and salt dispenser assembly contains these items in the form of booklets.

When the food pedestal is not in use, it makes up into a convenient work surface for crew activities (Figure 3-25). Covers are provided for the central recessed area of the pedestal and individual food trays.

Figure 3-25. SMEAT food pedestal.

Food Storage Facilities. In the operational Orbital Workshop, bulk food storage is available in eleven ambient temperature lockers, five frozen food lockers, and one food chiller. The chiller, freezers, and a six-day pantry are located in the wardroom. Ambient food storage is located in the upper level of the Orbital Workshop. Food is cycled into the wardroom at six-day intervals.

For the SMEAT mission, the volume of food stored was far less than is the case for Skylab which is launched with all the food supplies needed for three missions. Ambient temperature foods were not stored but transferred into the SMEAT chamber through the airlock at six-day intervals. Frozen food was handled in a similar fashion because the SMEAT freezer facility was too small to accommodate the total mission frozen food supply. No attempt was made to duplicate the Skylab flight freezer locker.

The coolant circulation pump elements of the freezer and chiller systems were located outside the chamber. The coolant fluid, a fluorinated hydrocarbon, was cooled in the chiller unit reservoir and circulated through coils inside the freezer storage in the chamber.

Food Preparation and Consumption. Preparation of each meal began at the completion of the preceding meal. The items to be prepared for the next meal were located; each had been marked with the name of the intended crewman, the day, and information about the contents. Foods to be served hot were placed in the trays and timers, another feature of the Automatic Meal Reconstitution Module, and were set to automatically activate the heating elements at the desired time. Foods to be chilled were placed in the chiller. Since some dehydrated items required fifteen to twenty minutes reconstitution time, initiation of rehydration at the time of the meal did not permit adequate time for proper preparation of these foods. The problem of bacterial growth precludes reconstitution of dehydrated food for a given meal at the previous meal. In SMEAT, one crewmember reconstituted the items requiring long hydration times of fifteen to twenty minutes prior to the meal.

The number of food packages consumed by the SMEAT crew was considerably higher than the number determined to be required for the Skylab crews. This is based not only on the individual nutrient requirements of the crewmembers but on the additional energy requirements imposed by 1 g operations as compared with energy requirements for zero g operations.

Trash and Cleanup. Trays and the food pedestal, as well as utensils, were cleaned with wet wipes. Trash generated in food preparation and consumption was disposed of in food canisters and passed out through the airlock. Many small trash items were generated at each meal. During the meal, this trash was deposited in trash receptacles.

A can crusher which was to be used in the event of trash lock failure was evaluated over a 60-day period. In addition, a procedure was developed for handling and freezing wastes in the event of such failure in the Skylab mission. The

freezing of wastes inside the SMEAT chamber was not necessary for the purposes of this mission.

SMEAT Food System Problems and Their Resolution for Skylab. During the course of the SMEAT testing, a number of problems related to the food system were noted. The appropriate corrective actions were taken, and these are described below.

1. *Food item-related problems.* A problem noted during the SMEAT test was that excessive gastrointestinal gas developed as a result of consuming pea soup. The SMEAT crewmen recommended that this item be deleted from flight menus. Premission testing of the Skylab crew based on this recommendation failed to produce the same results. Pea soup was therefore retained on inflight menus.

Rehydration of some beverages was found to be difficult. Changes in formulation were implemented and have resulted in improved rehydration times for these products.

In the case of one crewmember, the quantity of food provided proved to be inadequate. As a result, food items in excess of those stocked on the basis of previously determined energy requirements were carried onboard Skylab.

Investigation of the possible elimination of polyethylene glycol capsules was accomplished and the requirement for these capsules has been deleted. The data derived from the use of polyethylene glycol was not as useful as anticipated. Moreover, it was found that polyethylene glycol resulted in a stool which was soft and tended to adhere to the skin which could cause cleanup and personal hygiene problems in flight. They have been removed from the flight stowage list.

2. *Hardware-related problems.* Beverage packages were found to have leaking valves and other problems. A major redesign was accomplished and the valve was replaced by one identical to that used during the Apollo missions. All beverage packages are now inspected and random testing for leakage and for heat-seal strength has been incorporated into the manufacturing phase. Packaging failure was also noted in connection with the rehydratable food package. The package seal failed as the result of a faulty heat seal on several packages. In-process testing and rigorous inspection has also been initiated for these packages. An alternate package of the Apollo spoon-bowl type has been developed and will be used inflight for soups. Still further problems were noted in connection with the package for frozen and thermostabilized foods. During the heating cycle, the membrane separated from the can. The membrane has been incorporated into the Skylab food packages.

The fecal dye marker capsule separated during consumption. A lock capsule will be used for flight dye markers to preclude a recurrence of the problem.

A problem was noted in the food-can to food-heating-tray interface. This problem was a loose fit of the small heating tray cavity when a wafer can was inserted. The pudding can, which has a larger diameter than the wafer can and is used in the same food tray cavities, resulted in stretching of the cavity to the point that a friction fit for the wafer can could not be maintained. Change action is in process to identify one small cavity on each food tray for use with pudding cans.

At the suggestion of SMEAT crewmembers, the large, serving-sized spoon used for Apollo missions was added to the Skylab food system.

The heating/serving tray worked quite well throughout the entire test. All heating cycles worked well and postmeal cleanup was accomplished without problems. Other than the pudding package-small cavity interface problem, the trays gave only one other problem. The timer on one tray malfunctioned, but this was a one-of-a-kind failure which had no impact on the Skylab flight tray.

The can crusher tested during SMEAT worked well mechanically, but the use of this system required an additional 45 minutes to an hour each day to accomplish trash handling. The SMEAT

crew noted further that the can crusher required additional tissues for cleaning and suggested that it be modified to allow for easier cleaning.

3. *Procedural problems.* Minor procedural problems were encountered in meal preparation and galley stowage, as previously noted. As a result of the SMEAT test, detailed procedures on food handling and redesign of hardware items have been formulated. Galley stowage procedures have been updated.

As a result of the corrective actions taken on the problems noted in SMEAT, the Skylab food system is considered to be more than adequate to successfully support the Skylab missions.

Clothing

Two types of clothing were used in the SMEAT mission with two distinct objectives. Skylab garments fabricated from Durette 400 were worn to evaluate design configuration and material. Prototype garments made of three other materials were included in the test to assess the need for possible replacement of Durette 400. All the garments were evaluated from the standpoints of wearability, comfort, and the quantity provided. Figure 3-26 illustrates the Skylab garments.

All types of materials evaluated were found acceptable with the exception of the prototype material X-420. The wear, comfort, and fit of the clothes were all reported to be good, as was the Skylab configuration boot. Chapter 21 presents detailed comments by the crew on the clothing tested.

Sleep Restraint

The sleep restraint was fabricated from the baseline material chosen for use in the Skylab program, Tenum-treated polybenzimidazole. One crewman used the sleep restraint for the entire 56 days. Figure 3-27 shows the Commander in the sleep restraint. Chapter 21 presents a detailed evaluation of this item.

Off-Duty Activities

An off-duty activities equipment kit was provided in a locker in the wardroom area. The kit,

pictured in Figure 3-28, contained items such as playing cards, darts and dart board, tape cassettes, and books individually selected by the crewmen. These items, along with television viewing and the taking of courses in closed circuit television, filled any gaps in the SMEAT timeline and afforded the crew needed relaxation.
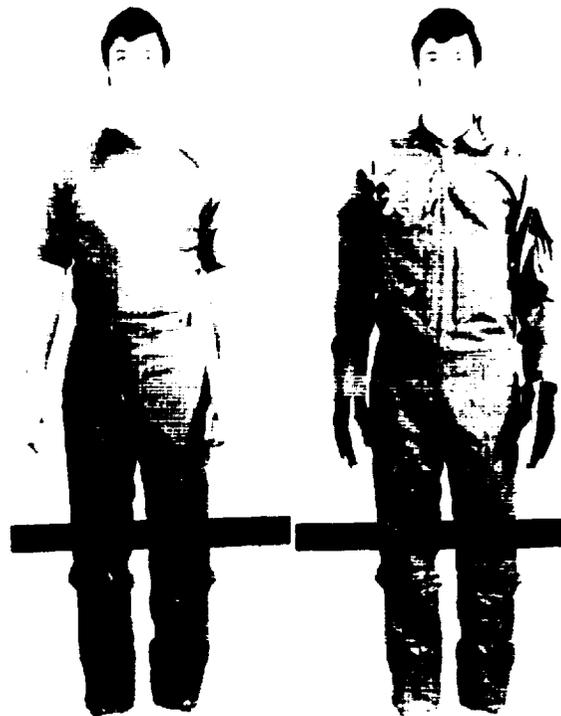
Figure 3-26. Skylab clothing.

Data Handling and Communications

SMEAT Instrumentation. The recording instrumentation used in SMEAT was divided into two general categories: test facility instrumentation and experiment test instrumentation. Test facility instrumentation was that necessary to monitor the crew bay environment (e.g., partial gas pressures, dewpoints, temperatures). Test facility data were routed through patchboards, amplified if necessary, and terminated in the 20-foot chamber control

room and at the Medical Officer's console for display, monitoring, and recording.

Figure 3-27. Skylab sleep restraint being tested by the SMEAT Commander.
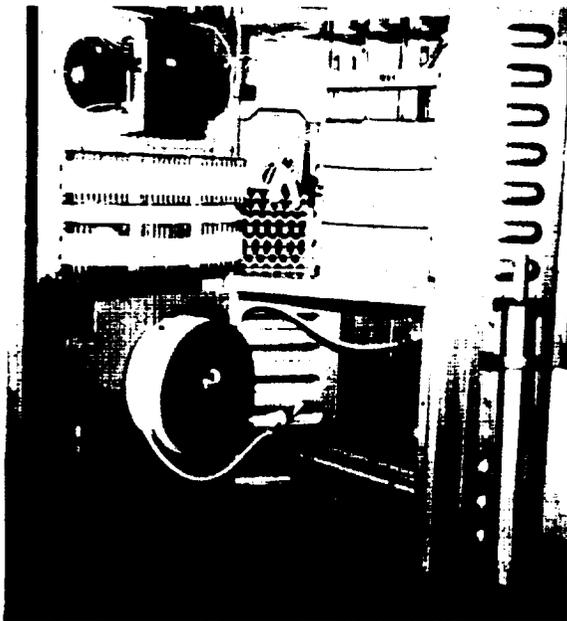
Figure 3-28. Off-duty activities equipment in the SMEAT wardroom.

Experiment test instrumentation was that concerned with monitoring the experiments. These data were routed through an analog-digital recording processor unit to Building 36, via coaxial cable, for display, monitoring, and recording. The Building 36 data console is illustrated in Figure 3-29. Test instrumentation data were also available at the outputs of isolation amplifiers in the processor unit for routing through the patchboard to the chamber control room and the Medical Officer's console, where they, too, were displayed, monitored, and recorded.

Figure 3-30. shows the data acquisition, processing, and display methods used during SMEAT. Figure 3-31 indicates the data flow for each medical experiment.

Simulation of Skylab Data Handling. DTO 71-23 was intended to test, on a noninterference basis, the operational procedures involved in acquiring and processing biomedical experiment data in a mode approaching that planned for Skylab. For example, communications from the crew and data transmittal from the SMEAT chamber were interrupted periodically during the course of the chamber test to simulate spaceflight tracking and data network acquisition of signal (AOS) and loss of signal (LOS). The sequence of events for the simulation were:

1. Performance of the experiment by the SMEAT crew with live data and voice communications available only during planned Skylab network contact periods.

2. Recording of all voice and data during the experiment performance for playback.

3. Playback of voice and data for engineering analysis by the Experiment Officer (EO) and a quick-look analysis by the Principal Investigator (PI). Concurrent with the engineering analysis, the EO recorded certain protocol event times which were necessary to key events in the off-line processing.

4. Delivery of the recorded data tape to the off-line processing facility and subsequent processing.

① TELETYPE
② AND 3 VARIAN
④ CONTROL CONSOLE
⑤ RECORDER
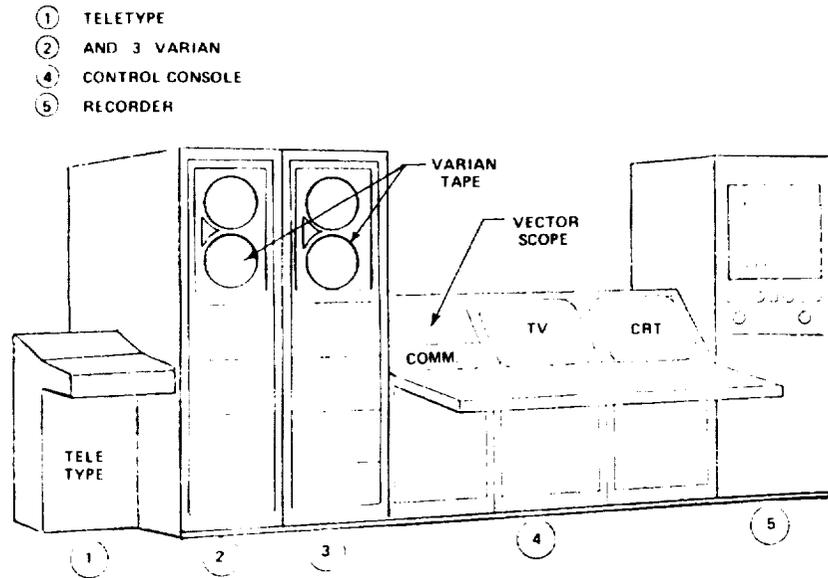
Figure 3-29. Building 36 data console.
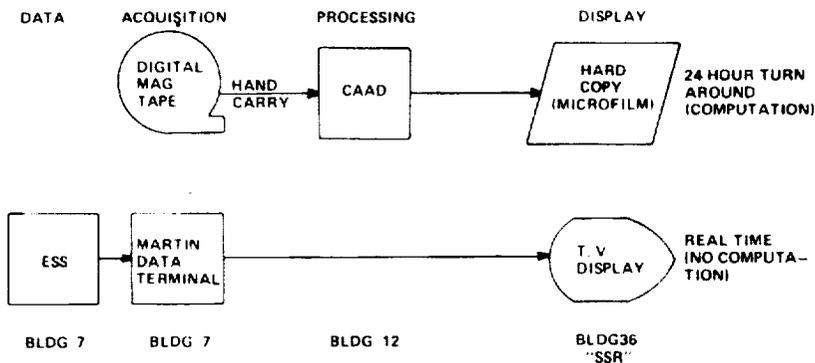
Figure 3-30. SMEAT data system.

There will be an additional sequence in the Skylab mission of the PI evaluation of the processed data for feedback into the flight planning function. Since only biomedical experiments were performed in SMEAT and the large number of other discipline experiments planned for Skylab, the quick flight plan feedback was not needed.

On the basis of SMEAT simulation of Skylab data acquisition, the following conclusions were reached relative to Skylab:

1. Assuming nominal Skylab data acquisition and handling, off-line processing turnaround times for the major biomedical experiments are reasonable.

2. Due to the data turnaround time, much of the data playback for scientific evaluation will be done on the day following the experiment runs. Unless a major problem is identified, the Principal Investigator/Principal Coordinating Scientist support will occur during normal working hours.

**SIMULATION OF CCATS AND RTCC SKYLAB FUNCTIONS
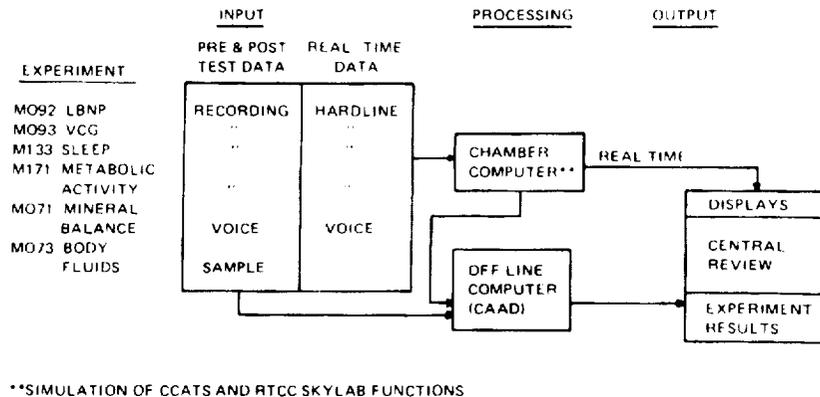
Figure 3-31. Skylab chamber test data flow.

Communication System. A voice communication system provided two-way audio communications between test team members. The basic system was composed of seven speaker intercom stations in the crew bay area and approximately 24 intercom stations located outside the chamber in the test team control rooms. The system had five normal channels and an emergency "all call" channel enabling simultaneous planned and controlled conversations on the different channels. The intercom stations exterior to the chamber were outfitted with headsets. The unit inside the chamber could be used with or without the Skylab headset. Locations of units within the crew bay are shown in Figure 3-32.

In the event of an emergency, predesignated stations were configured to switch to the "all call" audio channel. The stations that were switched to the "all call" channel also had certain previously selected stations which could transmit as well as receive for certain emergency communications. The Test Director's audio channel and the "test subject-CAPCOM" audio channel were continuously recorded for the duration of the test. A private channel available to the test crewman and CAPCOM was acoustically coupled to a telephone receiver. This allowed the astronaut crew to communicate with the outside.

Television Monitoring. A closed-circuit television system provided television monitoring and recording of activities inside the chamber for experimental and safety purposes. Four fixed, mounted cameras in the crew bay monitored the wardroom, experiments area, and second level. A fifth camera with tripod was portable. Pan and tilt mounts allowed the crewmen to manually reposition cameras.

Television monitoring of test activity was scheduled in the timeline and occurred as it would in the Skylab flight when the signal could be received by the monitoring network of receiving stations. When the crew was asleep, the crew bay area cameras were kept operating at all times with the target voltage turned down.

The closed-circuit television system and two AM-FM automobile radio units were also used to provide instruction and entertainment for the crew.
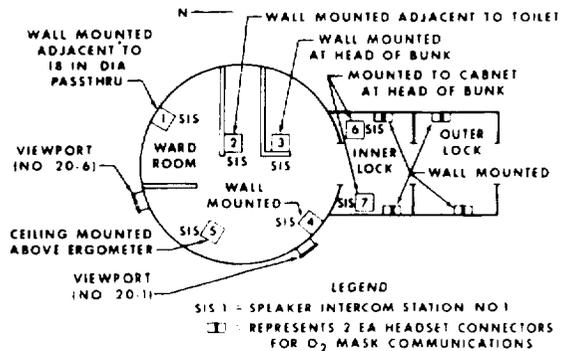
Figure 3-32. SMEAT chamber intercom locations.
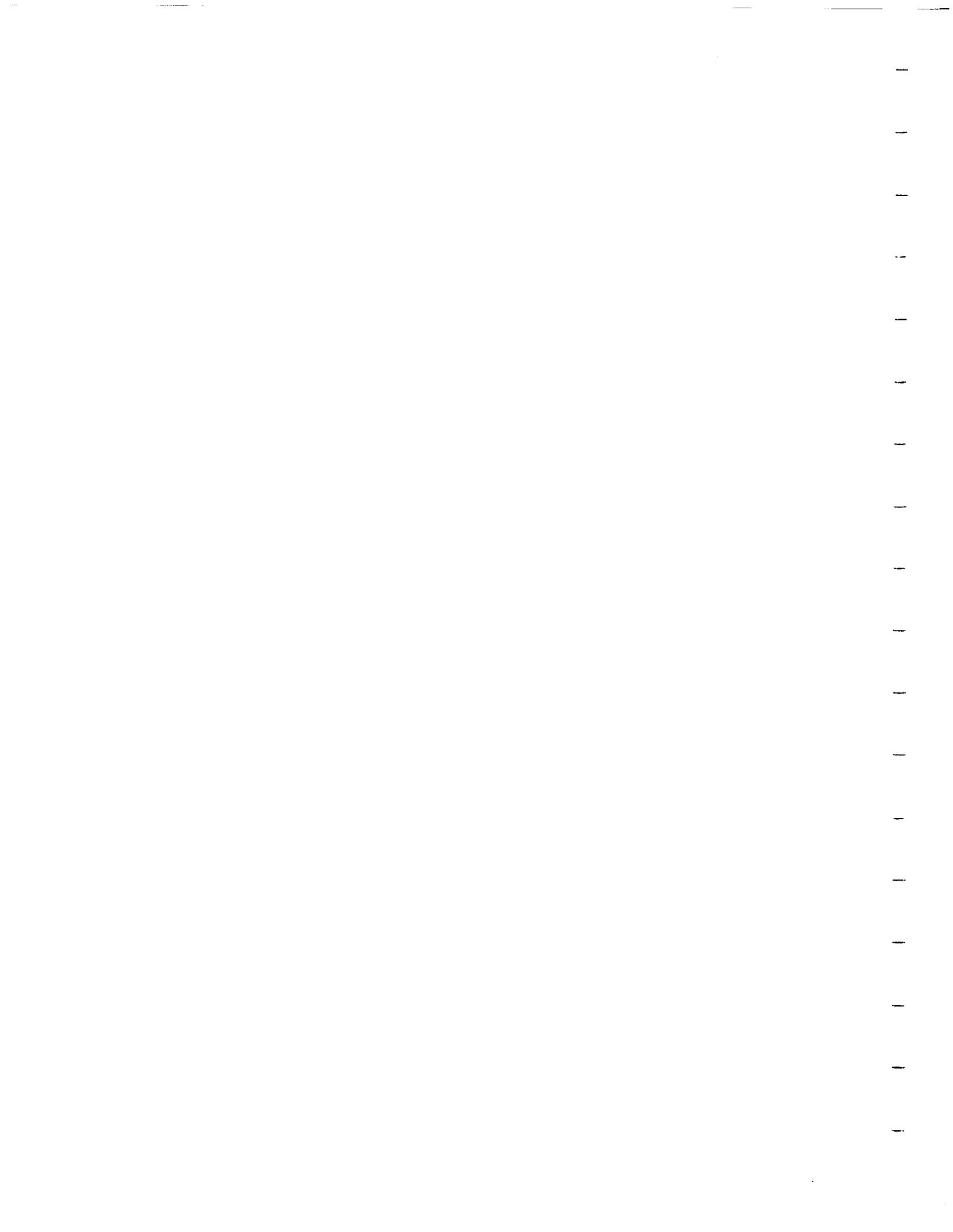
CHAPTER 4

LOWER BODY NEGATIVE PRESSURE -- EXPERIMENT M092

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Impaired orthostatic tolerance has been observed after all U.S. space flights which lasted more than several hours. Evaluation of orthostatic intolerance has been achieved by means of a tilt table, and, more recently, by the use of lower body negative pressure (LBNP). The LBNP technique, though independent of gravity, simulates its effect by exposing the legs and the lower abdomen to reduced ambient pressures. The LBNP test has been employed pre- and postflight on the Apollo missions and provisions have been made for its use during Skylab orbital experiments to document inflight the degree and time course of cardiovascular system alterations.

This LBNP experiment, conducted during the 56-day simulation of the Skylab environment, was designed to supply baseline information on cardiovascular responses to periodic orthostatic stress for correlation with future flight data and to help predict the degree of expected orthostatic intolerance. Further goals of the present experiment were to substantiate the operational efficiency of the data acquisition techniques to be implemented during actual flight missions and to evaluate hardware under operational conditions.

Equipment

The equipment consisted of a Lower Body Negative Pressure Device (LBNPD) and additional hardware for obtaining vectorcardiograms and measurements of leg volume change, blood pressure, and body temperature. An experiment support system included the equipment control and display systems in addition to the power supply.

Lower Body Negative Pressure Device

The LBNPD is a cylindrical canister of anodized metal 52 inches long and 21 inches in diameter. The canister is composed of two sections which can be separated for application of the leg plethysmographs. The forward segment has a waist seal comprised of a template with movable metal leaves and a seal of pliable material. The subject is positioned on an adjustable saddle in the LBNPD so that the waist seal is at the level of the iliac crests. Figure 4-1 shows the subject entering the LBNPD.

Reduction of pressure below ambient is effected by a vacuum pump located outside the workshop area, and differential pressure is displayed on both the LBNPD and the experiment support system panels. To achieve emergency repressurization, a vacuum release lever is provided.

Leg Volume Measuring System

The leg volume measuring system includes two plethysmographs, or leg bands, which measure volume changes in the calf. The leg bands are

essentially electromechanical devices. The skin of the leg is used as one plate of a capacitor while the second plate encircles the leg but is separated from the skin by a dialective layer of compressible foam material. One of the leg bands serves as a reference, and is placed over a stainless steel cylinder whose circumference remains constant; consequently, the band responds only to changes in temperature and relative humidity.

Figure 4-1. Subject being helped into the lower body negative pressure device.

Output of the leg band sensors is first amplified and then transmitted through the telemetry system for data reduction. Figure 4-2 shows the leg volume measuring system.

Blood Pressure Measuring System

The automatic blood pressure measuring system consists of three main components a Korotkoff sound (KS) processor (Wolthuis et al., 1971), an arm cuff pressurization apparatus with pressure sensor, and output circuitry which provides systolic and diastolic blood pressure readings. The Korotkoff sound processor first senses the brachial KS and then identifies the specific systolic and diastolic KS. The processor operates only during discrete time intervals within each cardiac cycle, synchronized to the cardiac rhythm and triggered by the vectorcardiogram R-waves.
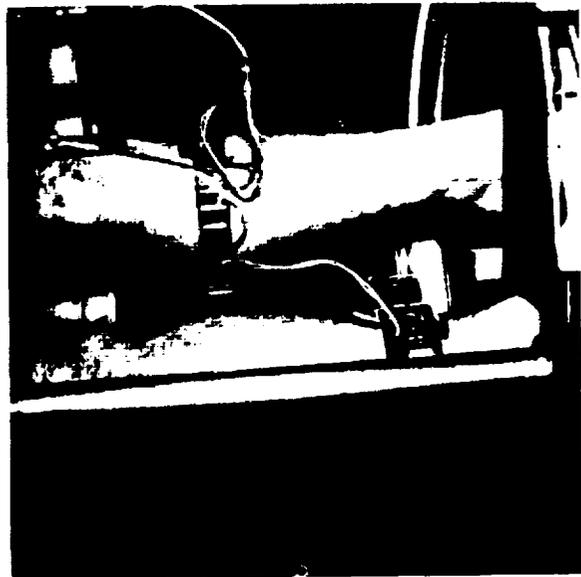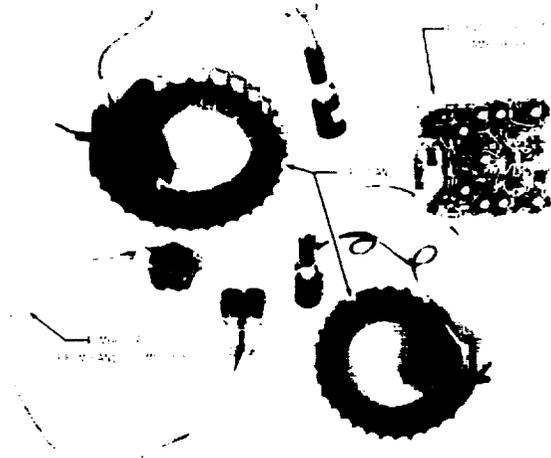
(b)

Figure 4-2. Components of the leg volume measuring system (a) and system in use on subject in the lower body negative pressure device (b).

The experiment support system controls blood pressure cuff inflation and performs a complete cuff pressurization cycle every 30 seconds. Two different

bleed-down orifices are available, one for use at 14.7 psi and one at 5.0 psi ambient pressure.

The computed systolic and diastolic pressures are displayed on the experiment support system panel and transmitted through the telemetry system. An aneroid gage provides backup for the cuff pressure.

Body Temperature Measuring System

The body temperature measuring system was originally designed to measure the temperature of the ear canal near the tympanic membrane. The system includes a thermocouple and an ear mold individually fitted to each crewman. The ear mold permits passage of the temperature probe into the external ear canal to a depth of one-eighth inch. The instrument as an ear probe was unsatisfactory. Therefore it was used as an oral thermometer.

Vectorcardiograph Recording System

The vectorcardiograph recording system produces a visual display of the computed heart rate from the Frank lead VCG and triggers the Korotkoff sound processor. The three analog signals from the X, Y, and Z components are transmitted via telemetry and recorded for further data processing. Each electrode site is identified with a permanent tattoo to assure exact electrode positioning.

Procedures

Experimental Procedures

Five control tests were performed at sea level pressure to establish baseline data. Each crewmember was his own control. During the 56-day experiment, eighteen LBNP tests were conducted in the chamber at one-third atmosphere on each crewmember. At the end of the experiment, an additional LBNP test was performed again at sea level pressure. Usually, each crewmember was tested every third day at approximately the same hour of the day with at least one hour being allowed between physical exertion, meals, showers, or venipunctures, and the start of an LBNP test. Two crewmembers were required for each test, one as subject and the other as observer. Throughout the experiment, the Scientist Pilot (SPT) was the observer for the other two crewmembers. When the SPT was the subject, the Pilot (PLT) usually was the observer.

Before each test, the observer recorded the subject's oral temperature and applied the vectorcardiograph electrodes. Then, with the subject supine in the open LBNP, both calf circumferences were measured at their maximal girth. The leg bands were attached, the LBNP body seal and knee and ankle restraints secured, and the blood pressure cuff applied to the left arm. The VCG electrode isolation and impedance were then checked. Before and after the test, calibration values for heart rate, systolic and diastolic blood pressure, left and right leg bands, and VCG were also checked and recorded.

The test lasted 25 minutes with the subject supine. The 25 minutes were divided into the following periods:

Period I	5 min at ambient pressure
(Control)	(258 mm Hg)
	1 min at -8 mm Hg (LBNP)
Period II	1 min at -16 mm Hg (LBNP)
	3 min at -30 mm Hg (LBNP)
Period III	5 min at -40 mm Hg (LBNP)
Period IV	5 min at -50 mm Hg (LBNP)
Period V	5 min at ambient pressure
(Recovery)	(258 mm Hg)

The first period provided a control phase, while the last was a recovery period. Should the subject at any time exhibit symptoms of impending syncope, LBNP was to be terminated.

Data Collection

Two sets of data were monitored continuously during the LBNP tests. The physiological data, which comprised one set, were heart rate, body temperature, blood pressure, and percent volume change in the legs. Heart rate was calculated every five beats; blood pressure was taken every 30 seconds; and percent leg volume change was sampled every 0.8 seconds. The other set of data was a series of measurements on the LBNPD itself, including air flow rate, temperature, relative humidity, and pressure. Both sets of data were transmitted to a remote control station where they were displayed alphanumerically and recorded on magnetic tape for further analysis. In addition, continuous strip charts were furnished for blood pressure, heart rate, LBNPD negative pressure, the three VCG leads, and the percent leg volume change. On several occasions,

nonreal-time data monitoring was implemented in accordance with Skylab data acquisition protocol constraints.

Data Analysis

Within 24 hours after the test, the following measurement variables were provided:

LBNP differential pressure
Heart rate
Systolic and diastolic blood pressures
LBNP internal temperature
Ambient temperature and pressure
Body temperature
Percent leg volume change

Computed mean values for heart rate, systolic and diastolic blood pressures, and percent leg volume change were then obtained, and regression analyses in time were performed for individual periods of each LBNP test. In-chamber and postchamber values were compared with their respective prechamber means, and significant differences were determined by independent t-test.

VCG measurements were calculated from a computer program called VECTAN, which computed vector loops and derived variables. VECTAN was developed especially for the Skylab program.

Results

The equipment functioned well. Data loss was minimal and was mainly due to shortcomings in the software programs. The Skylab environmental specifications were maintained throughout this experiment with temperatures ranging from 21° to 26^oC. Despite the temperature fluctuations, there were no gross differences in cardiovascular responses and no signs of impending syncope. Table 4-1 gives the mean physiological values for the prechamber, in-chamber, and postchamber periods and indicates statistically significant changes.

Heart Rate

Since increased heart rate is one of the most effective ways of increasing cardiac output in the face of greater physiological demands, heart rate was used as the major single determinant of altered orthostatic response. In-chamber mean heart rates and postchamber individual values were compared to the

prechamber mean. Table 4-1 shows that throughout the 56-day test, the (Commander) CDR exhibited an increase in heart rate, both at rest and at reduced pressure. His postchamber values were significantly higher than the respective prechamber means. The SPT and PLT showed no significant change in heart rate.

Blood Pressure

The blood pressure values of the (CDR) showed increased postchamber control values; the SPT showed no significant variation; and the PLT exhibited a statistically significant decrease in both systolic and diastolic blood pressures. None of the crewmembers showed significant pulse pressure changes.

An unanticipated finding that is under investigation was detected during preliminary inspection of heart rate and blood pressure time graphs. Time series analyses for periods longer than one day produced statistically significant periodicity across different data sets for the same individual. All three crewmembers showed approximately monthly rhythms.

Vectorcardiography

Compared to the prechamber baseline tracing, no significant changes of rhythm were observed in the crewmembers' VCG recordings. Any changes in the mean values of the PR, QRS, and QT intervals closely followed the changes observed in heart rate.

Percent Leg Volume Change

Analysis of resting supine leg calf circumference showed a progressively decreasing linear trend. By statistical regression of the calf circumference values versus time, an estimate of the percent change was computed as the difference between intercepts at the first in-chamber day and postchamber day.

The decrease in leg calf circumference together with the body weight loss are summarized in Table 4-2. The CDR and SPT showed a decrease in both leg calf circumferences, and a concomitant body weight loss. The excessive weight loss of the SPT can be partially attributed to a 500 calorie deficit in his daily diet. The PLT showed a decrease only in the right leg circumference.

Table 4–1

LBNP Physiological Measurements

	N	Control						-50 mm Hg LBNP							
		Heart Rate		Systolic BP		Diastolic BP		Heart Rate		Systolic BP		Diastolic BP		PLVC	
		X	±SD	X	±SD	X	±SD	X	±SD	X	±SD	X	±SD	X	±SD
CDR															
Prechamber	5	51	4	99	2	65	3	56	2	99	4	67	4	3.1	0.3
In-chamber	18	52	3	102	4	64	3	60	6	101	5	65	3	3.2	0.4
Postchamber	1	61 ←		110 ←		73 ←		69 ←		100		65		3.4	
SPT															
Prechamber	4	53	5	102	6	68	8	59	7	96	6	69	7	3.1	1.0
In-chamber	17	48	2	96	4	62	4	54	2	92	4	62	4	3.0	0.3
Postchamber	1	51		102		63		55		96		64		3.6	
PLT															
Prechamber	4	70	9	119	3	69	4	75	11	112	7	74	1	3.0	1.0
In-chamber	18	77	6	123	9	69	5	82	5	116	10	76	5	3.0	0.4
Postchamber	1	69 ←		112 ←		61 ←		77		97 →		63 →		2.5	

Arrows indicate direction and statistical significance of change – one arrow P > 0.05.

*P values were determined from fiducial limits computed by t-test.

Table 4-2

Calf Circumference and Body Weight Loss

	CDR	SPT	PLT
Initial left calf circ. (cm)	35.8	42.4	38.7
Slope (cm/day)	− 0.011	− 0.015	− 0.000
Intercept (R + O) (cm)	35.2	41.6	38.7
Percent decrease	1.7	2.0	0.0
Initial right calf circ. (cm)	35.8	43.5	38.6
Slope (cm/day)	− 0.017	− 0.018	− 0.008
Intercept (R + O) (cm)	35.0	42.5	37.8
Percent decrease	2.2	2.3	2.0
Body weight loss (Kg)	− 1.81	− 5.45	0.0

The percent leg volume change remained unaltered throughout all periods of the chamber study, and the experimental data suggest that a decrease in the absolute leg calf circumference had no effect upon the percentage leg volume change during LBNP stress.

Equipment Problems

The body temperature measuring system proved unsatisfactory for measuring the temperature of the ear canal; however, it was adequate for oral temperatures which were recorded before each LBNPD test.

A consistent discrepancy between the blood pressure measuring system and auscultatory blood pressure recordings was noted throughout the experiment. The values recorded by the system were below the auscultatory. A check of the system after the in-chamber phase revealed transducer offsets.

A Marshall Space Flight Center LBNPD waist seal and two prototype Welson seals of different girth were used during the experiment. The Welson seals were found to be more comfortable, lighter, and more pliable. They also showed a lower leak rate. As a result, Welson seals have been recommended for the Skylab missions.

Conclusions

Both the Skylab LBNP hardware and data acquisition system operated satisfactorily. Previous studies of individuals confined in hypobaric chambers where physical activity was severely limited have shown evidence of reduced orthostatic tolerance. Similarly, it has been reported that even strict four-day chair rest can produce this effect. In the M092 experiment, the astronauts entered the hypobaric chamber in good physical condition and exercised daily. These were undoubtedly factors in the maintenance of physical fitness. Impaired orthostatic tolerance, manifested by the increased heart rate, diminished systolic and pulse pressure, and increased tendency to syncope in the upright position, or during LBNP, was not observed in this experiment.

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CHAPTER 5

VECTORCARDIOGRAM HARDWARE REPORT – EXPERIMENT M093

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Exposure to weightlessness is known to affect cardiovascular dynamics, which are the heart of life processes. One of the most reliable and informative measures of cardiovascular functioning is the electrocardiogram (ECG), which monitors cardiac electrical activity. Because of its usefulness, the ECG has been a mandatory adjunct during space flight. To date, most in-flight monitoring has relied on one or two bipolar chest leads for data on heart rate and rhythms. Standard twelve-lead electrocardiograms taken before and after the missions have provided the information on wave form changes resulting from space flight.

Neither of these two sources allows quantitative analysis. The vectorcardiogram (VCG) is a special type of ECG whose electrode lead placement portrays the heart's electrical activity along three orthogonal axes. VCG data have the advantage of permitting quantitative analysis.

Preflight and postflight vectorcardiograms were recorded from all nine crewmen of the Apollo 15, 16 and 17 missions. It was clear from the tests that certain aspects of the crewmen's VCG's had been significantly altered. Since there were no in-flight data, however, how and when these changes occurred could not be determined.

The Skylab missions present an opportunity for monitoring VCG's inflight and expanding our current knowledge of how the cardiovascular system responds to weightlessness. During Skylab, VCG's are being taken at regular intervals. The data are collected while the crewmen are at rest and before, during, and after a two-minute exercise period. VCG's are also monitored during the metabolic activity (M171) and lower body negative pressure device (M092) experiments. Eventually, the Skylab vectorcardiograms will be correlated with anatomical shifts in the position of the heart and body fluids, changes in heart size, altered myocardial perfusion, and other modifications in cardiac function so that the effects of space flight can be clarified.

During SMEAT, the 56-day Skylab simulation, the vectorcardiograms for all three crewmen were monitored in accordance with the Skylab protocol. The purpose was to obtain baseline data and to test the VCG hardware. Because of initial data reduction

problems and subsequent shifting of priorities to the actual Skylab preflight tests, the SMEAT vectorcardiograms have not yet been analyzed. This report, therefore, deals only with the VCG hardware and its performance.

Equipment

The equipment used to perform the vectorcardiogram tests consists of five basic items. Four of the items, including the electronics module, the subject interface box, the electrical umbilical, and the electrode kit, pertain to the vectorcardiogram recording system. A picture of the system is shown in Figure 5-1. The fifth item is a bicycle ergometer exercise device.
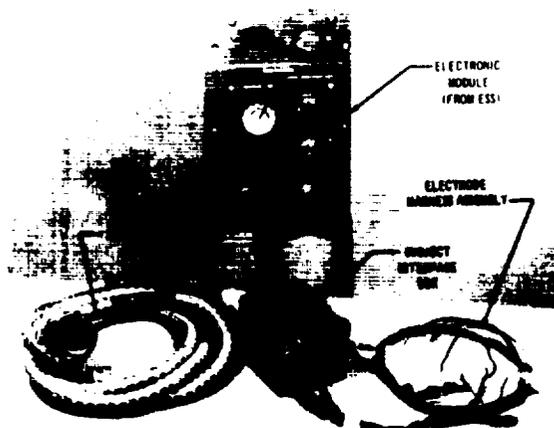
Figure 5-1. The vectorcardiogram system.

The electronics module, which is mounted in the experiment support system, has several elements. One of these is the Frank resistor network, which takes the electrical signals from the electrodes worn by the crewman and combines them to form the three VCG axes. Heart rate circuitry is another element of the electronics module. The heart rate circuit computes the average heart rate every five beats from any one of the three VCG axes. The module also has calibration circuitry, which provides a precision voltage, .5 ± .01 millivolts at 10 Hz, for signal conditioner and telemetry calibration. Finally, the module contains a system for checking the impedance

between each electrode and the ground electrode as well as isolation circuitry to ensure that there are no low impedance paths. Electrode isolation and impedance are displayed on an electrode test meter.

The subject interface box is a portable electronics package that can be mounted on the lower body negative pressure device or on the ergometer. It houses the VCG electroshock protection circuitry, preamplifiers, a signal conditioner for the body temperature measuring system, and interconnecting wiring for the blood pressure measuring system. The body temperature and blood pressure measuring systems are described in more detail in the reports on experiments M092 and M171.

The electrical umbilical connects the experiment support system to the subject interface box and provides the electrical path between these two units.

The VCG harness is the principal item in the electrode kit. The harness consists of seven active electrodes, one ground electrode, and connectors for the body temperature probe and the subject interface box. Figure 5-2 illustrates the VCG harness in place.

Figure 5-2. The vectorcardiogram harness in place.

The kit also contains electrolyte-saturated sponges which are placed inside the electrodes to provide electrical contact with the skin. Stomaseal tapes used to attach the electrodes to the skin, and wet wipes for cleaning the skin before and after each run.

The bicycle ergometer, the exercise device used in the experiment, operates like a bicycle with seat, pedals and handlebars. The pedal force is controlled by a generator that can be set for specific workloads expressed in watts. The ergometer is also part of the equipment for the metabolic activity experiment.

Procedures

The vectorcardiogram test was performed on each crewman every third day during the 56-day simulation. The protocol consisted of a five-minute rest period followed by two minutes of controlled exercise and a ten-minute recovery period. Prior to each test, the equipment was calibrated and the subject isolation and electrode impedances were checked. During the actual monitoring, the three VCG signals and the heart rate were sent via telemetry to the medical support personnel. The heart rate also appeared as a digital display on the electronics module.

Results

In general, the equipment performed well. The most important experimental data, the three vectorcardiogram signals, were received for all runs without any hardware malfunctions. Several problems did occur and were resolved in the course of the experiment.

The heart rate circuitry did not perform correctly. This was traced to a manufacturing error which caused the 4 kHz oscillator in the circuitry to malfunction. The manufacturing process was revised and a new oscillator installed.

A second problem that could be traced to the manufacturing process concerned the Bendix connectors on the VCG harnesses. The connectors showed signs of galling because the mating halves were threaded too tightly. A new manufacturing process was instituted to correct the problem.

Another difficulty with the VCG harnesses was that they did not provide enough electrical contact with the crewman's skin. The original harnesses were replaced with new harnesses which had shallow well electrodes that operated more effectively.

Two of the crewmen found the VCG harnesses too small. Larger harnesses which proved to be satisfactory were passed into the chamber during the test. Since then, the Skylab crews have been measured for harness size, and the standard size has been found adequate.

The tapes used to attach the electrodes to the crewman produced some irritation. When used over a long period of time, these tapes often cause irritation, but the procedures for attaching and removing the electrodes during SMEAT aggravated the problem. Once the crew had eliminated the vigorous rubbing that was part of skin preparation, the irritation stabilized. The Skylab crews are being tested for unusual reactions to the tape and are being given alternate electrode sites.

Finally, the VCG sponges occasionally proved to be too dry. Since the experiment, the manufacturer has agreed to include a vacuum integrity test to eliminate this problem.

Conclusions

The Skylab vectorcardiogram system was thoroughly tested during the 56-day SMEAT program. Except for a few problems which were readily resolved, the equipment functioned very well.

CHAPTER 6

HEMATOLOGY/IMMUNOLOGY (M110 SERIES)

Introduction

Man's exposure to weightless space has not been without effect upon the formed element of his blood and upon hemodynamics. One of the earliest findings was that red blood cell (RBC) mass was reduced postflight. This was true for both Gemini and Apollo spacecrews. Losses were, however, greater for crews exposed to 100 percent oxygen environments than they were for crews engaging in missions in which residual nitrogen remained in the breathing atmosphere. On this basis, it has been theorized that the decrease in red blood cell mass is a result of hemolysis caused by exposure to pure oxygen environments. Skylab experiments will study various aspects of the red blood cell, including its metabolism and life span, and blood volume changes under zero gravity conditions to determine the precise mechanism of the transient changes which have been seen on the relatively brief missions of the past.

After space flight, the number of lymphocytes has fluctuated significantly for a brief period. The net number of white blood cells has been generally decreased, but the immunocompetence of the cells appears to remain stable. This is a promising finding in that it indicates the integrity of the human immune system is unimpaired by space flight conditions. The influence of longer duration exposure awaits further investigation.

A small number of chromosomal changes has also been found in white blood cell samples from Gemini and Apollo astronauts. This change is important in itself and as an indicator of radiation exposure.

Skylab will extend the investigation of this phenomenon and, at the same time, test the hypothesis that a synergism exists between radiation and some space flight factor in producing chromosomal changes.

The Hematology/Immunology Experiments (M110 Series) in the Skylab mission present the opportunity for the first time in the American space flight program to sample blood in flight and to study it for corroboration or contradiction of previous postflight data obtained in vitro. The experiments also are expected to amplify the nature of any changes which do occur.

While the M110 investigation is an extensive one, it is not intended to be an all-inclusive coverage of man's immunohematological functions. The experiments devised and selected are those which should represent the most sensitive indicators of change in man's normal biochemical functioning in space.

The SMEAT Hematological/Immunological Series

There are indications that some hematological responses, notably red blood cell responses, may be linked to atmospheric variables. Many other factors, however, may be involved. The entire hematological/immunological series was included in the SMEAT experiment to examine the effects of Skylab conditions without the confounding influence of weightlessness. In this case, as in the case of other medical experiments, SMEAT presented an opportunity for equipment and procedures validation.

The hematology and immunology experiment series included five separate experiment elements. These were:

1. Experiment M111 Cytogenic Studies of Blood

2. Experiment M112 Investigation of Man's Immune System

3. Experiment M113 Blood Volume and Red Cell Life Span

4. Experiment M114 Red Blood Cell Metabolism

5. Experiment M115 Special Hematological Effects.

Each of these experiments will be discussed individually. As they shared common equipment and procedures in many cases, these will be described first, and only those items specific to an experiment will be included in conjunction with each experiment discussion.

Equipment for M110 Series

The five experiments in the M110 Series (as well as two in the M070 Series, mineral balance and fluid bioassay) required blood samples as part of their experimental protocol for the SMEAT test. The equipment used during the test was being developed for zero g blood drawing, processing, and storage. During the SMEAT test, no attempt was made to store the samples; they were passed out of the chamber for analysis.

The principal items of equipment required for the hematological and immunological experiment series consisted of items required for blood sampling.

Prechamber Blood Sampling Equipment. Prechamber blood samples were drawn from the crewmen by venipuncture using an infusion set with a 30 mm plastic syringe and a 21-G thin-walled siliconed needle with a 20-G bore. The samples drawn were transferred immediately to siliconed tubes containing various anticoagulants. The equipment used is illustrated in Figure 6-1.

In-chamber Blood Sampling Equipment. The equipment used to sample blood during chamber activities was as follows:

1. 30 mm disposable syringes and one-inch needles with 20-G bores.

2. Automatic sample processor. The 11 ml sample was transferred to an automatic sample processor (ASP) containing an anticoagulant (Li-EDTA).

3. Blood sample vial (BSV). On the first and last samples, 0.1 ml of the blood sample was transferred to a small capsule (2cc) for fixation (in 0.5 percent phosphate-buffered gluteraldehyde).

4. Centrifuge. The 11 ml samples were processed by centrifugation in the chamber to separate the plasma and cell fractions.

5. Automatic sample processor evacuation regulator (ASPER). This device is used to evacuate the automatic sample processor prior to each blood sample transfer.

6. Swabs, tourniquets, stowage pouches.

Blood Sampling Procedures

Blood samples were taken prior to the chamber run according to the schedule in Table 6-1, once per week during the 56-day test, and on four occasions after SMEAT was concluded. The sample data span a period of one hundred days. The size of each blood sample for each experiment is also indicated in Table 6-1. The larger samples drawn on three selected in-chamber sample days provided sufficient blood for a microbiological study specific to the chamber mission.

Pretest samples were distributed to the appropriate principal investigator or laboratory representative for analysis. In-chamber samples, as noted previously, were passed out of the chamber for analyses which were performed onsite. In an operational mission, samples are frozen and stowed.

Table 6-1
SMEAT Blood Sampling Schedule

Schedule EXPERIMENT	Prechamber Julian Date					In-chamber Typical Day	Postchamber Julian Date			
	181	182	188	195	207		264	265	269	279
MO71 - Mineral Balance	15		20	20	15	0.5 *	15	15	20	20
MO73 - Bioassay of Body Fluids	25		25	25	25	3.0 *	25	25	25	25
M111 - Cytogenetic Studies of the Blood		1	1	1	1		1	1	1	1
M112 - Man's Immunity — In Vitro Aspects	10		5	15	10	0.5 *	10		15	10
M113 - Blood Volume and Red Cell Life Span	15	3	3	3	3	4.0	15	3	3	3
M114 - Red Blood Cell Metabolism	10			10		2.0	10	10		10
M115 - Special Hematologic Effects	7		7		7	1.0	7	7	7	7
Microbiology	15				15	15 **	15			15
Total Volume (ml) Per Crewman		4				11				
Per Sample Day	98		61	81	86	26 **	98	36	71	91

* Plasma
** On Selected Days (See Table II)
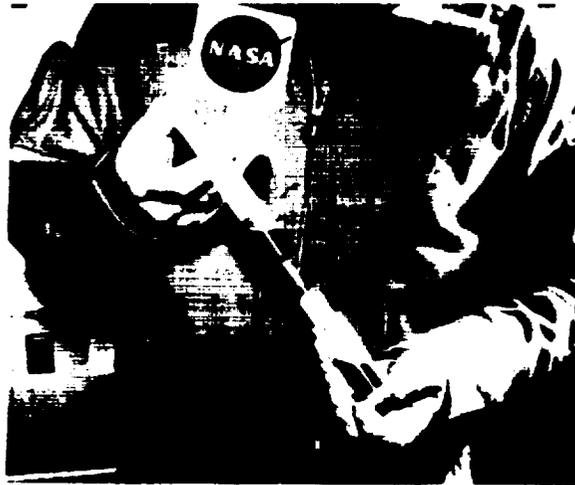
Figure 6-1. Blood sampling equipment.

Results of Blood Sampling Technique

The SMEAT crew carried out blood drawing procedures very competently. No samples were lost or compromised because of any crew procedure. The SMEAT test clearly demonstrated that it was feasible for crews to draw and process blood in a Skylab-type environment.

There were certain problems with the blood drawing procedures and equipment. Where these were relevant to Skylab equipment or procedures, the appropriate remedial steps were taken.

Blood Sampling Difficulties

The major problem experienced by crewmembers in the drawing of bloods was one which could not have been identified in the absence of an experiment conducted under chamber-simulated Skylab conditions. The crew experienced difficulty in drawing the blood from superficial veins, even with proper penetration of these veins. They believed these problems to be caused by venous spasms which may have been associated with reduced operational pressures. They did not encounter the difficulty when deeper veins (particularly the anticubital) were used.

The principal problems associated with equipment were leaking of syringes and misalignment of the centrifuge. Syringes leaked from time to time at the needle/syringe interface. This problem should be precluded in the Skylab missions which will use syringes with a threaded locking tip for positive needle attachment.

The cover of the centrifuge became easily misaligned, and the crew reported excessive vibrations associated with its use. Redesign which included dynamic balancing of the centrifuge head assembly and reduction of the clearance tolerances on the cover alignment tabs will eliminate both problems during operation of the centrifuge in the Skylab missions.

Blood processing procedures were adequate. All samples were in a proper condition for analysis and permitted successful analyses to be conducted.

PART A: CYTOGENETIC STUDIES OF THE BLOOD (M111)

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Genetic effects have been associated with space flight exposure, and these have been of greater magnitude than would be expected on the basis of the radiation doses received. The changes have been observable in the form of a slight increase in the number of chromosomal aberrations in leukocyte samples examined after both orbital and suborbital space missions. These observations have led to the hypothesis that there is a synergism between radiation and some other parameter associated with space flight (Jenkins, 1968; Sisakyan et al., 1964; Condo, 1968). The effects observed cannot presently be correlated with mission duration, extravehicular activities, or any other known factor.

The Skylab experiment M111, cytogenetic studies of the Blood, is designed to determine whether some space flight parameter produces cytogenetic effects in cells. At the same time, because chromosomal aberrations are a sensitive method of radiation dose estimation, the experiment will provide a biological radiation dosimetric capability in the event of significant radiation exposure from an unexpected solar flare event.

The SMEAT test provided an opportunity to study the effects of the Skylab environment without the weightlessness factor on chromosomal aberrations in leukocytes. Unfortunately, control subjects were unavailable for the study.

Procedures

Four prechamber and four postchamber cultures were made on blood samples drawn from SMEAT crewmembers. In-chamber bloods were also drawn.

Culture Preparation

Cultures were prepared by adding blood to a medium containing phytohemagglutinin which stimulates leukocytes to undergo DNA synthesis and mitosis. Late in the incubation period, a mitotic inhibitor was added to stop cell division in

metaphase. After centrifugation, cells were resuspended in sodium citrate, resulting in better chromosome spreading, and then fixed in methyl alcohol and glacial acetic acid. The fixed specimens were stained with Wright's stain and mounted in Euparol.

Chromosomal Analysis

A minimum of 200 metaphase cells was selected by low magnification microscopic scanning. Cells with suspected structural defects (97 of these were noted) were photographed and karyotyped.

Results and Discussion

Minor chromosomal defects were noted, including chromatid gaps and breaks, isochromatid gaps and breaks, and fragments. These defects are found in a small percent of otherwise normal individuals and increase temporarily under certain conditions including exposure to various drugs, viruses, and ionizing radiation and isotope injections. Additionally, a small number of more significant aberrations was seen.

Table 6-2 shows chromosomal aberrations identified in the SMEAT lymphocyte cultures. The table indicates minor defects as well as the more significant structural rearrangements. The time of isotope injections, given for other experiments, is also noted.

The results of the study appear to indicate that the chamber environment had no deleterious effect where chromosomal aberrations of the type studied are concerned. The first postchamber study showed values comparable to the first prechamber study (see Table 6-2). Following isotope injection, the percentage of chromosomal aberration increased to levels well above the normal range. Since the crews suffered no obvious illnesses, ingested no drugs, and had no unusual exposure to ionizing radiation during their stay in the chamber, it appears likely that the aberrations seen following isotope injection were due principally to these.

Table 6-2
Chromosome Aberrations in
Lymphocyte Cultures From SMEAT Astronauts

Date and Astronaut	Isotopes Injected	Minor Defects	% Minor Defects	Structural Rearrangements
Prechamber				
6-26-72				
A		17	2.7	
B		6	3.0	
C		4	2.0	1 - Translocation
				1 - Dicentric
6-27-72	*			
A		10	4.8	
B		7	3.4	
C		13	6.2	
7-3-72				
A		14	6.7	
B		16	7.8	1 - Dicentric
				1 - Chromatid exchange
C		10	5.0	
7-22-72				
A		7	3.4	
B		10	4.8	
C		13	6.2	
Postchamber				
9-20-72				
A		7	3.3	1 - Translocation
B		2	0.9	1 - Chromatid exchange
C		5	2.1	
9-21-72	**			
A		14	6.3	
B		6	2.6	
C		6	2.7	
9-25-72				
A		13	5.5	
B		14	7.0	1 - Dicentric
				1 - Ring
C		19	8.8	
10-5-72	***			
A		15	6.6	1 - Pulverized cell
B		5	2.3	
C		13	6.0	1 - Dicentric

*^{3}H, ^{125}I, ^{51}Cr, ^{35}S, (6-26-72)

**^{3}H, ^{125}I, ^{51}Cr, ^{35}S, ^{42}K (9-20-72)

***^{42}K (10-4-72)

Structural rearrangements of a more unusual nature were noted in prechamber cultures, prior to the injection of any radioisotope material, and in postchamber cultures in two of the crewmen.

At the cytogenetic laboratory, Department of Pediatrics, University of Texas Medical Branch, with which the author is affiliated, some 13,000 cells are examined annually, and among these, translocations (chromosomes with extra chromatin attached) are rarely seen. Chromatid exchange, dicentric chromosomes, and ring chromosomes are rarely if ever seen except in conjunction with a few conditions with which they are expected. Ring chromosomes are found only in persons with multiple anomalies.

Figure 6-2 illustrates the more serious chromosomal abnormalities in the SMEAT crew. While the number of these aberrations is quite small, such chromosomes were found in all crewmembers during all phases of the study both prechamber and postchamber and both before and after isotope injection. It is interesting to note that Gooch and Berry (1969) reported occasional defects of the same kinds in the Gemini astronauts both pre- and post-flight. The clinical significance of these findings is not apparent. Clearly, such findings bear further investigation.
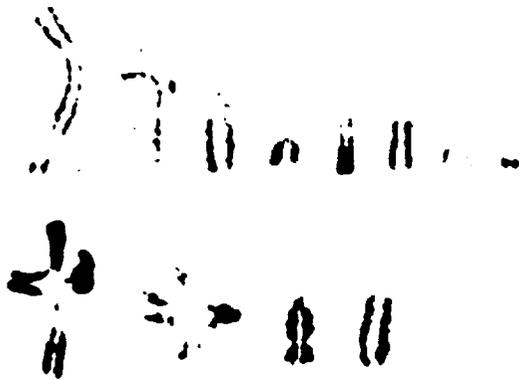
Figure 6-2. SMEAT abnormalities.

Conclusions

The cytogenetic study of the SMEAT crew appears to indicate that Skylab-type environmental conditions have no deleterious effect upon chromosomal material. The findings are, however, less clear-cut than might be desired, due in large measure to confounding of the experimental design by the administration of isotope injections for the purposes of other experiments and to the lack of control subjects.

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PART B: INVESTIGATION OF MAN'S IMMUNE SYSTEM (M112)

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Certain indications from space flight results suggest that some factor in the space environment may influence man's immune status. The human immune system comprises two "subsystems," the humoral, consisting of immunoglobulins, complement factors and related serum proteins; and the cellular, represented by small lymphocytes (T-cells), originating in the thymus, and macrophages.

The cellular portion of the immune system protects against diseases such as tuberculosis and fungal and certain viral infections. It confers transplantation immunity and delayed skin hypersensitivity, and may represent a surveillance system against autoimmunity, neoplastic transformation and oncogenesis. Serum proteins indicate the status of the human body in defending itself against foreign challenge. Many of these proteins, such as albumin, remain fairly constant during a challenge to the body while other proteins like haptoglobin change rapidly upon onset of a disease. Measurement of proteins such as the immunoglobulins (IgA, IgM, IgG, and IgD) give distinct information as to how man is responding immunologically by making antibody against an invading agent.

Some of the elements of the immune system have undergone small, temporary changes after space flight. For example, haptoglobin has been consistently elevated postflight in Apollo astronauts. While this may be related to some stress imposed, perhaps subclinical infection or physiological/emotional stresses related to reentry, the precise significance of this finding has not been determined. Individual astronauts have also exhibited significant increases in lymphocyte numbers shortly after recovery. Again, the significance of the finding is unknown.

The changes which have occurred in the immune system of the spacecrewmen have not been detrimental to health. Nevertheless, it is important to quantify the significance of the characteristic patterns noted before man is committed to extended missions. Significant alterations of the immune mechanisms, if these did occur and were of a serious nature, could reduce a crewman's ability to combat infections and repair traumatized tissue in the space flight environment and after return to earth.

The Skylab experiment M112 is planned specifically to detect quantitative and qualitative changes in the immunoglobulins and related proteins and lymphocyte functions. Inclusion of this experiment in the SMEAT Program permitted an investigation of factors of the Skylab environment other than weightlessness on the parameters of interest. It also provided baseline data for the Skylab missions. The SMEAT version of experiment M112 consisted of two investigations, one dealing with humoral responses and the other with lymphocyte reactivity.

Humoral/Immunological Responses

In this phase of the experiment, total plasma proteins were determined as were plasma protein fractions, that is, albumin, alphaglobulins, betaglobulins, and gammaglobulins.

Procedures

Prechamber, in-chamber, and postchamber samples were taken. All three SMEAT crewmen participated (see Table 6-1). Three other men served

as controls while the crew was in the chamber. All results were compared with those for Apollo mission astronauts. Figure 6-3 shows the process scheme for blood samples for both phases of the M112 experiment.
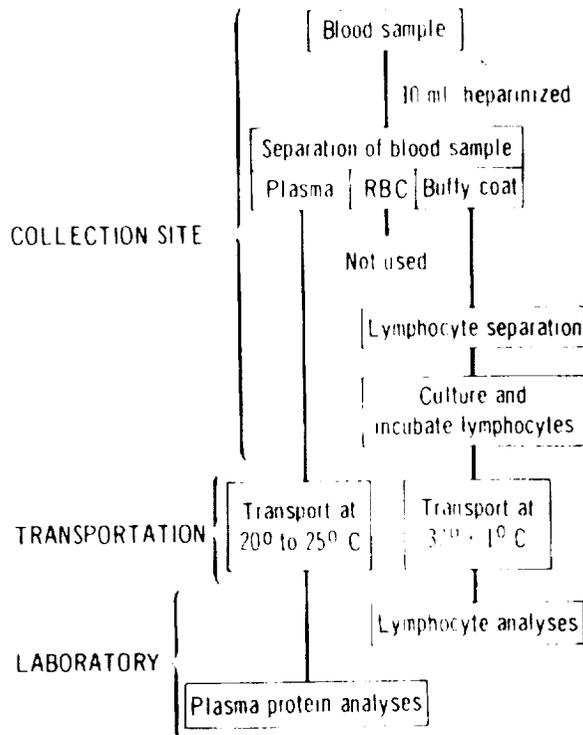
Figure 6-3. Blood processing for Experiment M112.

Various tests were used to determine serum protein concentrations. These were as follows:

1. *Total serum protein determinations.* Serum protein determinations were made using a Bausch and Lomb serum protein meter. This instrument measures the amount of protein based on the formula-corrected index of refraction of the known serum.

2. *Serum protein electrophoresis.* Electrophoresis separates elements of the albumin and globulin of the plasma, among them alpha-1, alpha-2, beta, and gammaglobulin, on the basis of the electrical charges

of these molecules.* Electrophoresis was performed on cellulose acetate membranes at 250 volts for 14.5 minutes. The membranes are fixed, stained, and dried, and scanned with a densitometer. With the use of a computer, data readouts are provided in terms of gram percent values for each protein fraction as well as percent of total protein for each separated fraction.

3. *Electroimmunodiffusion (EID).* The EID method permitted quantification of those serum proteins not identified by means of the other tests employed. These included transferrin, haptoglobin, and others. The EID process separates antigens by exposing them to specific precipitating antibodies. Identification is possible because antigens migrate at different rates when exposed to specific precipitating antibodies.

Results

A variety of humoral responses were noted after 56 days of exposure to the SMEAT environment. The most noteworthy of these was a rise in the serum immunoglobulins IgG and IgN. Total serum protein for all three crewmembers and controls remained within normal limits and was steady during the study. Findings for specific serum proteins are summarized in Table 6-3.

Conclusions

Data for the SMEAT crew suggest that an immune reaction may have occurred during the latter days of their stay in the chamber. The exact nature of the agent or agents causing the response is unknown. No clinical illness was obvious during the course of the study. The immune changes must, therefore, have represented either a subclinical illness or challenge by a nondisease-producing agent.

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*Different proteins have different proportions of acidic and basic side chains, and, hence, different isoelectric points. In a solution of a particular hydrogen ion concentration, some proteins move toward a cathode and others toward an anode; depending upon the size of the charge as well as upon molecular size and shape, different proteins move at different speeds. This difference in behavior in an electric field is the basis of electrophoresis.

Controls produced a wide variety of responses, probably because they were not confined or protected from contact with infectious agents, and showed signs of contact with agents.

Table 6-3

Humoral Responses

Serum Protein	Finding
Albumin	Normal; low in first posttest sample
a_1-Globulins	Normal
a_2-Globulins	Normal
β-Globulins	Normal; fluctuated in one control
γ-Globulins	Normal
Transferrin	CDR, PLT low-normal; controls normal
Haptoglobin	PLT steady; CDR, SPT elevated IT; controls low
Ceruloplasma	Normal, steady
Gamma A	Normal, steady
Gamma G	PLT, CDR high-normal
Gamma M	Normal
Gamma D	Normal
B_1A	Fluctuated; no significant change
a_2Macroglobulins	Normal
a_1 Acid glycoprotein	Steady trends; no significant changes
a_1 Antitrypsin	Normal
Australian antigen	Negative
CRP	No significant changes

The results of the SMEAT study do not correlate with the changes seen on most Apollo flights. During Apollo missions, there was a postflight transient increase in IgA but no significant differences in IgG or IgM. Marked elevations were observed in haptoglobin, ceruloplasmin, and a_1-acid glycoprotein after some missions. A moderate decrease in transferrin was noted in the late postflight observation interval. a_2-M-globulin revealed a biphasic pattern, with an increase immediately postflight in most cases, and subsequent decrease to below preflight control values.

Apollo studies suggest that while the humoral immune system of crewmen subjected to space flight shows some characteristic patterns, these changes are not detrimental to health and do not appear to be a limiting factor for extended manned missions.

The SMEAT results imply that the patterns characteristically observed on Apollo, especially with respect to changes in the carrier protein, may be due to a feature unique to space flight and not to the chamber environment. The addition of inflight sampling on Skylab will help to establish the time course of these changes if they persist.

Lymphocyte Reactivity

Examination of the cellular component of the human immune system, small lymphocytes and macrophages, can provide indications of the status of the immune system as a whole. Two aspects of these cells were considered. First, antigenic responsiveness was determined by quantification of in vitro rates of synthesis of RNA and DNA in the presence of an antigenic stimulant. These functional changes are paralleled by morphologic changes, which were, therefore, also examined.

Lymphocyte Antigenic Responsiveness

Lymphocytes were examined for in vitro antigenic responsiveness by quantitating the rates of synthesis of RNA and DNA both in the presence and absence of the mitogen phytohemagglutinin (PHA).

Procedures. The three SMEAT crewmembers participated along with nineteen controls. Lymphocytes were separated from heparinized venous blood by ficoll gradient centrifugation and cultured with or without PHA in appropriate media (Evans & Middleton, 1970). At the time of maximal RNA and DNA synthesis (24 and 72 hours, respectively), cultures were pulsed for one hour with either 3H-uridine or 3H-thymidine. The radioactivity incorporated into washed lymphocytes was measured by liquid scintillation spectrometry. Lymphocyte viability at the time of harvest was assessed by supravital florescent stain, and the results calculated as 3H disintegration per minute (DPM) per million viable cells by correcting for quench and counting efficiency.

Results. Lymphocyte reactivity for the SMEAT crewmen remained within previously established normal ranges during the period extending from T-20 (twenty days prior to the chamber test) to R+5 (five days after conclusion of the test). The pattern of response was similar to that exhibited by Apollo mission astronauts.

RNA

DNA
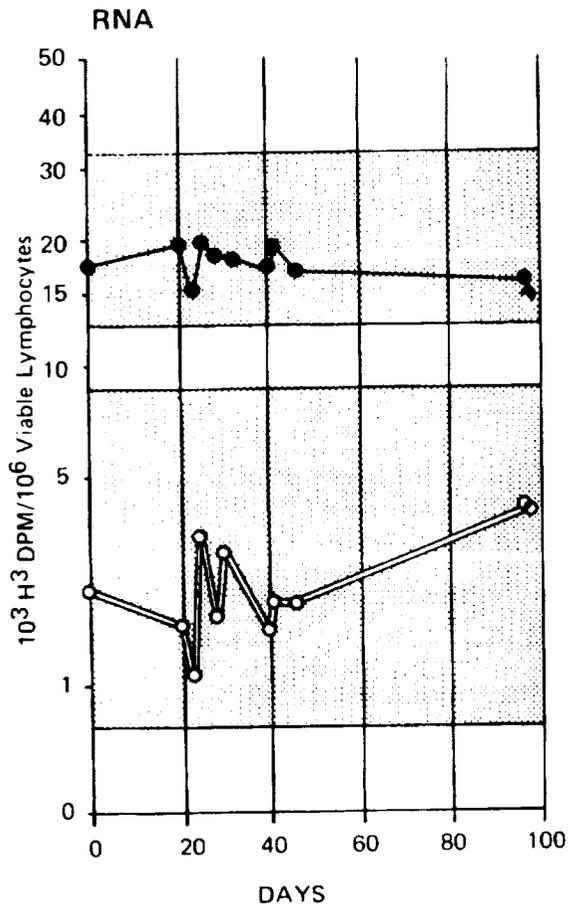
Figure 6-4. Serial determinations of RNA synthesis in stimulated (top and unstimulated (bottom) lymphocytes in control subjects. Shaded areas demark the 90th percentile normal range.

Figure 6-5. Serial determinations of DNA synthesis in normal lymphocytes in control subjects.

Figure 6-4 illustrates serial determinations of RNA synthesis by both stimulated and unstimulated lymphocytes from the nineteen controls. Figure 6-5 illustrates these data for DNA synthesis by normal lymphocytes. Figures 6-6 and 6-7 indicate the same data for lymphocytes cultured prechamber and post-chamber for the SMEAT crewmen. These mean synthesis rates can be seen to remain within the 90th percentile also, but individual values show some scattering. There was a marked decrease in RNA and DNA response on R+14 for all three crewmen. DNA synthesis rates were below normal for two of the three crewmen.

Leukocyte Morphology

Procedures. For this phase of the study, lymphocytes were cultured for a three-day period with phytohemagglutinin, extracted from the kidney bean. Appropriately stained preparations were then examined in the usual manner.

Results. Figure 6-8 illustrates the results. As can be seen, morphologic alterations of the small lymphocytes parallel the increase of RNA and DNA synthesis rates. The blastoid transformation is illustrated at the upper righthand corner of the figure.
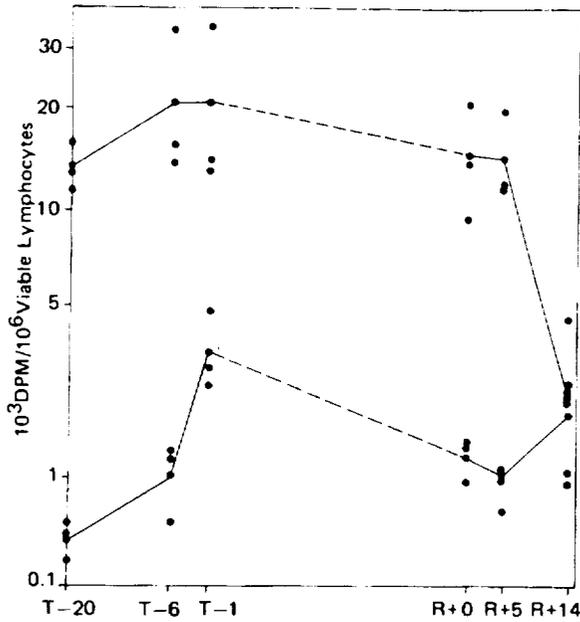
Figure 6-6. RNA synthesis rate for SMEAT crewmen, prechamber and postchamber.
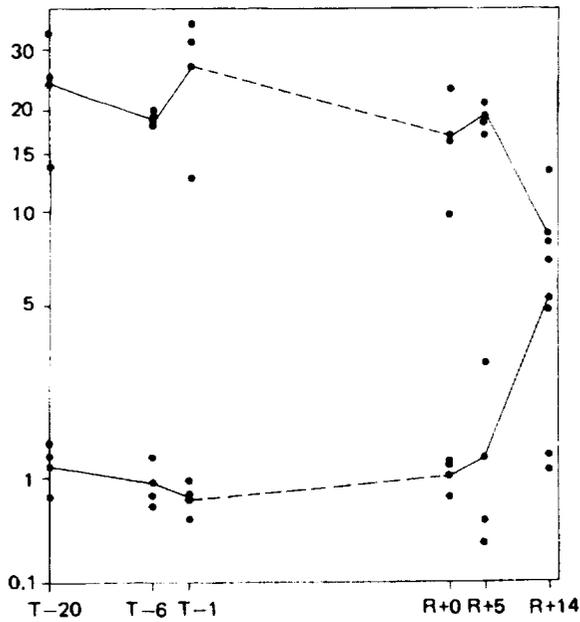
Figure 6-7. DNA synthesis rate for SMEAT crewmen, prechamber and postchamber.
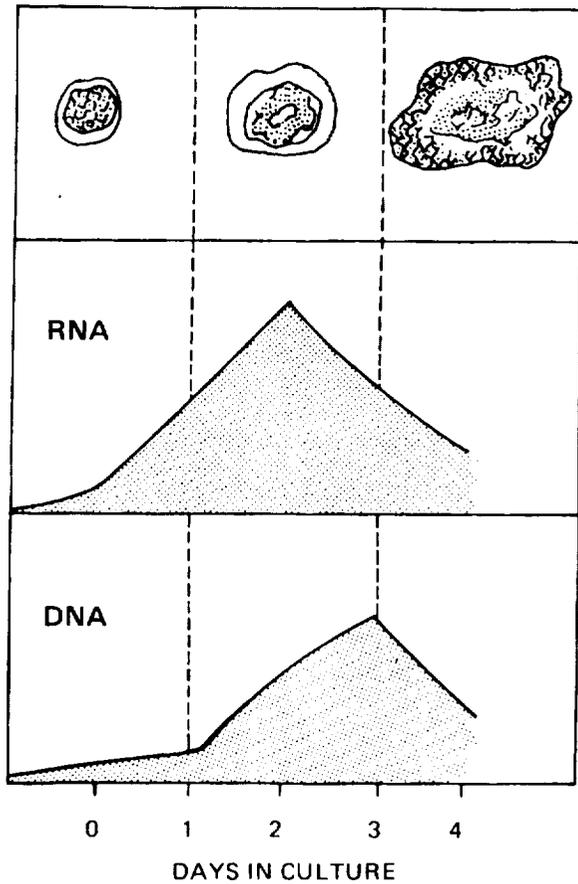
Figure 6-8. PHA stimulated lymphocytes.

Conclusions. Fifty-six days of residence in a Skylab-type environment produce essentially no change in the reactivity of the immune system, as typified by the rate of RNA or DNA synthesis in small lymphocytes. The one point of divergence between the SMEAT crew and previous Apollo crews, a marked depression in synthesis rates on the fourteenth day after the chamber study, may be due to some technical difficulty in the experiment. This issue is being investigated further. Lymphocyte morphology changes paralleled functional changes.

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PART C: BLOOD VOLUME AND RED CELL LIFE SPAN (M113)

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The oxygen-carrying capacity of the circulatory system is inherent in the red blood cell and decreases as the number of red blood cells decreases. Red blood cell mass was reduced postflight in virtually all Apollo astronauts. RBC mass reductions were, however, noticeably smaller for Apollo 7 and 8 crewmen. During these missions, there was a small amount of nitrogen in the breathing atmosphere because no operational decompressions were required which would have eliminated the nitrogen introduced at launch. These findings led to the hypothesis that red blood cell mass changes were the result of the increased partial pressure of oxygen in the spacecraft.

If hyperoxia produced RBC mass losses, it would be likely to do so by one of two mechanisms: peroxidation of the RBC membrane with destruction of the red blood cell, or inhibition of erythropoiesis. Further, if hemolysis were occurring, older cells would be likely to be destroyed before younger ones. If inhibition of erythropoiesis were occurring, RBC survival studies would not show a disproportionate number of young red blood cells. Space flight results are equivocal on the point. Gemini findings favor the first hypothesis; Apollo findings favor the second.

Red Blood Cell Studies in Skylab and SMEAT

Since the SMEAT atmosphere was not hyperoxic as compared with Gemini and Apollo atmospheres, reductions in RBC mass would not be anticipated if indeed hyperoxia were the factor responsible for the observed losses. If a decrease in RBC mass were found after SMEAT, a mechanism other than hyperoxia would have to be considered to explain the space flight data, especially if similar reductions were to be found in Skylab crews.

Failure to find RBC mass reductions in SMEAT, on the other hand, would provide further evidence in support of the theory that prior RBC mass losses in space crewmen resulted from exposure to hyperoxic atmospheres. Any changes in RBC mass or life span, should these be found after the Skylab missions, could more clearly be attributed to some factor unique to the space environment and not to the gaseous atmosphere. If reductions were found in Skylab crewmen, the RBC life span studies would help to clarify the mechanism of action.

Plasma Volume Studies in Skylab and SMEAT

Space flight has also produced plasma volume changes. These, however, have varied with the length of the mission. Crews returning from longer missions exhibited smaller decreases in plasma volume, or no decreases, than did those engaged in shorter missions. In fact, plasma volume determinations after the Gemini 7 two-week mission were above premission levels.

Bed-rested subjects also show decreases in plasma volume. However, these decreases persist for the entire bed-rest period. This does not seem to be the pattern for individuals exposed to weightlessness. In missions of varying length, plasma volume appears to decrease below premission levels during the first week and to normalize or increase during the second week. These changes may represent an adaptation to weightlessness and indicate that adaptation takes about seven days to occur.

Since it is likely that plasma volume changes are related solely to the removal of the gravity factor, one would not anticipate plasma volume changes during a 1g test. The test did, however, afford the opportunity to verify experiment procedures.

Procedures

Prechamber, in-chamber, and postchamber blood samples were taken for the SMEAT crewmembers (see Table 6-1). Data from Gemini and Apollo crews served as control subject data.

This experiment had four parts; in each a different radioisotope tracer was used: (1) To determine RBC production rate; (2) To measure RBC mass changes and RBC life span; (3) To determine selective age-dependent erythrocyte destruction; and (4) To determine plasma volume changes.

Red Blood Cell Production Rate

The rate of RBC production was measured quantitatively by injection of a known quantity of a radioactive iron tracer (^{59}Fe). The radioiron, combined with globulin, is transported to other parts of the body. The iron (nontagged and radioiron) which reaches the membranous bones is incorporated into the heme portion of hemoglobin by the bone marrow. Since not all the iron appearing in the plasma is used for erythrocyte production but is instead taken up by the iron pools of the body, a fraction of the injected radioiron will be unavailable for incorporation into developing RBC's. This can be determined by measuring the concentration of radioiron in the circulating RBC after seven days and comparing it with the initial concentration of radioiron in the plasma.

Red Blood Cell Mass and Survival

Any changes in the rates of RBC production and destruction are necessarily reflected in the red cell mass. Such changes were measured and analyzed by injection of radioactive chromium (^{51}Cr in the form of sodium chromate) tagged red cells. The sodium chromate diffuses through the cell membrane where it is converted to chromium chloride, and, in this form, bound to hemoglobin. The volume of RBC's is then calculated by allowing the chromium-tagged cells to disperse through the circulatory system and measuring the extent to which the chromium has become diluted. Chromium incorporated into the hemoglobin structure of the circulating red cells also provides a means for estimating the rate of random cell destruction by monitoring the rate at which chromium disappears from the red cell mass.

Age-Dependent Erythrocyte Destruction

To determine selective age-dependent erythrocyte destruction and mean red cell life span, carbon 14 labeled glycine (2-^{14}C-glycine) was injected into a superficial arm vein of each crewmember and control

subject. The glycine gives a cohort tag of the RBC's by its incorporation into the heme portion of hemoglobin and labels the erythrocytes during their development. Sequential blood sampling then gives the percentage of the label in the blood at a given time (days). By plotting these data, a survival curve was obtained. The resultant curve was analyzed mathematically to determine the mean life span of the cells.

Plasma Volume

Plasma volume changes were measured by adding a known amount of radioiodinated (^{125}I) human serum albumin to each crewmember's blood. (Albumin prevents plasma fluid from leaking out of the capillaries into interstitial space.)

Results

Table 6-4 indicates the findings of the ^{51}Cr RBC mass and RBC survival determinations, and the plasma volume findings.

RBC Mass Changes and RBC Survival

There was a mean red cell mass decrease of 2.7 percent which was compensated for by a mean increase of +1.6 percent in plasma volume resulting in a 2.7 percent decrease in total hematocrit. The weight change of the SPT caused his red cell mass and plasma volume per kilogram of body weight to increase postmission 6.6 percent and 13.7 percent respectively. The weight changes of the other two crewmembers were not as great so their values showed a smaller change.

Ordinarily after weight loss due to dieting, the red cell mass change is proportional to the weight loss. In the case of the SPT, the weight loss was accompanied by an increase rather than a decrease in red cell mass per kilogram of body weight. This reversal of the usual findings was probably due to the effect of the rigorous physical conditioning program followed by this individual.

RBC survival, as shown in Table 6-4, was shorter after the SMEAT mission than the values obtained premission, but still within normal range. These values are, however, still within the range of normal.

Table 6-4

^{51}Cr RBC Mass and RBC Survival Data
for SMEAT Crewmen

	SPT			PLT			CDR			
	Pre	Post	%	Pre	Post	%	Pre	Post	%	Mean %
Red cell mass (ml)	2624	2548	- 2.9	2370	2324	-1.9	2203	2127	-3.4	-2.7
Plasma volume (ml)	4219	4434	+ 5.1	3252	3484	+7.1	3436	3178	-7.5	+1.6
Blood volume (ml)	6843	6982	+ 2.0	5622	5808	+3.3	5639	5305	-5.9	-0.2
Peripheral hematocrit (%)	41.5	38.0	- 8.4	44.5	42.0	-5.6	42.0	42.5	+1.2	-4.3
Total body hematocrit (%)	38.3	36.5	- 4.7	42.5	40.0	-5.9	39.1	40.1	+2.6	-2.7
Ratio	0.92	0.96	+ 4.3	0.95	0.95	0.0	0.93	0.94	+1.1	+1.8
Red cell mass (ml/kg)	27.2	29.0	+ 6.6	27.8	27.6	-0.7	30.6	30.2	-1.3	+1.5
Plasma volume (ml/kg)	44.5	50.6	+13.7	38.2	41.4	+8.4	47.7	45.2	-5.2	+5.6
^{51}Cr red cell survival T½ in days	26.0	24.0	- 7.7	26.5	24.0	-9.4	24.0	22.0	-8.3	-8.5

Ferrokinetic Studies

These studies gave no evidence of increased red cell production.

Selective Destruction of Red Blood Cells

The results of the 2-[14C]-glycine determinations for red cell survival show no significant shortening of mean red cell life span; a value of more than 50 percent during the 100 days of the test would indicate such a shortening.

Plasma Volume

There was a slight mean increase in plasma volume (+1.6). This is well within normal range.

Conclusions

The results of this experiment do not indicate significant shortening of the red cell life span during the mission. This does not suggest that the SMEAT environment could not be associated with red cell enzyme changes. It does show that any changes in enzymes were not sufficiently great to significantly shorten red cell survival. There was no evidence of bone marrow erythropoetic suppression nor was there any evidence of increased red cell destruction.

No technical difficulties were encountered. Intramission blood samples provided additional data points resulting in more easily interpretable results.

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PART D: RED BLOOD CELL METABOLISM (M114)

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At one time the red blood cell was believed to be an inert particle composed of water and hemoglobin. Further experience, particularly in the area of viable red corpuscle preservation, has shown the erythrocyte to be a dynamic, living particle doing work and requiring energy via glucose metabolism. The average life span of the human red blood cell is estimated to be 120 days, and, during these 120 days, it is estimated that the average erythrocyte travels 100 miles between the heart and the various tissues which it serves.

In order to remain functional and serve its purpose effectively, it is necessary that the red corpuscle maintain an optimum osmotic balance against a steep ionic gradient, resist forces which try to change its biconcave shape to spherical, and maintain an active transport mechanism which allows the passage of glucose and ions across the red blood cell membrane.

Energy is required to accomplish these functions. Most important, energy is required to maintain the corpuscle's ability to transport the oxygen necessary to maintain life in the body tissues. This energy must be obtained by the breakdown of glucose within the red blood cell.

The Skylab red blood cell metabolism experiment (M114) is designed to detect any changes which space flight exposure might produce in the glucose metabolic pathway. Several key intracellular enzymes which would provide clues to such changes will, therefore, be analyzed before and after the Skylab missions. In addition, because little is known about the process by which glucose enters the red blood cell through the cell membrane, the experiment will include an investigation of the chemical composition and structural integrity of this membrane. The SMEAT version of experiment M114 provided an opportunity to examine the Skylab environmental factors excluding zero gravity.

Procedures

All analyses of glycolytic enzymes for the SMEAT crew were performed before, during, and after the chamber test. Control subjects were employed during the pretest and in-chamber period. All laboratory procedures used are contained in the JSC Skylab Laboratory Procedures Document.

Results

The results of the glycolytic enzyme analyses are presented in Table 6-5.

Reduced Glutathione (GSH). During exposure, the value 72 ± 33.3 is significantly different from all other values including simultaneous controls. P value is less than .025. Values for GSH levels after exposure return to preexposure levels.

Adenosine Triphosphate (ATP). ATP shows no significant differences; although the after-exposure level is much lower than others, no simultaneous control determinations were run for comparison.

2, 3-Diphosphoglycerate (23DPG). During-exposure levels are lower than before-exposure levels, but controls during exposure are not different from crewmembers during exposure.

Glucose-6-Phosphate Dehydrogenase (G6PD). During exposure, the G6PD values of 3.2 ± 1.4 are significantly lower ($p < .01$) than the 4.7 ± 1.3 values of simultaneous controls.

Hexokinase (HK). Although values after exposure are significantly elevated compared to others, there were no simultaneous controls, and, therefore, no definite statement can be made.

Table 6-5

Red Blood Cell Glycolytic Enzymes for SMEAT Crew and Controls

Out of Chamber Control Glycolytic Enzymes	Units	During Mean + SD	Before (Controls)	Before (Crew)	During (Crew)	After (Crew)
	M6	102+39	166+30	134.8+27	72.2+33.3	91.3+49.1
Glutathione	μ moles gm Hb	5.9+1.1	7+1.4	5.5+1.0	6.1+2.3	3.8+1.7
Adenosine triphosphate	μ moles/gm Hb	5.6+2.0	8.0+2.5	8.1+1.9	4.5+2.2	5.8+1.9
2,3 Diphosphoglycerate	Extinction Units gm Hb	4.7+1.3	2.6+.6	4.3+1.4	3.2+1.4	5.5+2.2
Glucose 6 phosphate dehydrogenase	Extinction Units gm Hb	0.94+0.31	0.67+.6	0.58+0.27	0.78+0.37	2.2+0.7
Hexokinase	Extinction Units gm Hb	24.0+6.2	37.6+11.7	29.9+11.6	16.1+6.3	21.5+12.2
Phosphofructokinase	Extinction Units gm Hb	62.4+13.0	32.9+4.1	42.2+8.9	45.2+17.9	101.9+11.1
Phosphoglyceric kinase	Extinction Units gm Hb	18.1+3.4	23.0+7.6	22.1+13.3	15.2+6.0	25.7+6.2
Pyruvate kinase	Extinction Units gm Hb	8.5+3.4	16.3+5.9	17.8+5.9	6.4+4.8	15.2+4.8
Acetylcholinesterase	Extinction Units gm Hb	56.2+9.0	61.7+6.4	60.4+4.9	51.0+5.9	69.8+6.6
2,3 Diphosphoglycerate		0.80+.43	1.14+.58	1.47+.61	0.74+.64	1.53+1.18

Phosphofructokinase (PFK). During exposure, phosphofructokinase levels are significantly lower than during controls and previous levels at all levels.

Phosphoglyceric Kinase (PGK). Phosphoglyceric kinase levels at 15.2 ± 6.0 are significantly (p < .05) lower than all other values including the 19.1 ± 3.4 of controls during.

Pyruvate Kinase (PK). PK is not significantly different.

Acetylcholinesterase (ACHE). ACHE is significantly (p < .01) decreased during exposure at 51.0 ± 5.9 versus all other values. After- exposure values of acetylcholinesterase are significantly higher than other values although simultaneous controls were not obtained.

Conclusions

Statistically significant differences were found between crews and controls for glycolytic enzymes. The absence of simultaneous controls for the pre- and postchamber analyses leaves the significance of the findings in the crew during these periods indeterminate. In future studies it will be critical to use controls during all phases of the study.

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PART E: SPECIAL HEMATOLOGIC EFFECTS (M115)

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Blood studies performed on Gemini and Apollo astronauts have shown that significant changes in red cell mass, in other blood constituents, and in food and electrolyte balance occur as a result of exposure to the space environment. The data suggest that zero gravity and high oxygen content of the spacecraft atmosphere, or perhaps a combination of the two, may be responsible for the changes observed. A number of other factors might also be involved.

Skylab experiment M115 provides for more extensive analyses of blood before, during, and after space flight to yield a better understanding of the extent, time course, and etiology of the hematological changes noted so far in connection with space flight exposure. The SMEAT version of experiment M115 permitted evaluation of blood changes of the type that might be occasioned by the Skylab atmosphere without the complicating variable of weightlessness.

Equipment and Procedures

Five prechamber, eight in-chamber, and four post-chamber blood samples were obtained from the SMEAT crewmembers.

Both routine and special hematologic procedures were utilized in this experiment. The measurements performed and the routine and special hematology procedures used are detailed in the JSC archival document, Skylab Laboratory Procedures. Table 6-6 summarizes these.

Results and Discussion

Routine Hematology

Commander. The CDR's red cell count, hemoglobin concentration, and hematocrit did not change significantly between the pretest and posttest sampling periods. There was a modest drop in hematocrit with no change in red cell count. This was reflected in a lower mean corpuscular volume (MCV) pre- and posttest and could not be attributed to chamber exposure. Mean corpuscular hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC) were unchanged. White blood cells counts showed normal fluctuations.

Science Pilot. The SPT's red cell count was not significantly changed posttest. Hemoglobin concentration and hematocrit were within normal limits for astronaut populations pretest but decreased below these normally lower-than-average values posttest. Red cell indices were normal both pre- and posttest with the exception of mean corpuscular volume values on day 195. This latter situation may, however, reflect laboratory variations. The SPT's total white cell count was below average normal values on all sample days pretest and posttest but fell within the low normal classification based on astronaut normal values.

Pilot. The PLT's red cell count, hemoglobin concentration and hematocrit were all within normal range and showed no significant trends during the sampling periods. The total leukocyte count was low normal but within normal astronaut ranges. There was a definite lymphopenia, especially during the posttest period (1,045 cells/cu mm). Leukopenia is rarely due to a reduction in lymphocytes. One cause of lymphopenia is the administration of adrenocorticotrophic hormone or adrenal cortical hormone. Plasma (ACTH) was elevated pretest and plasma-free hydrocortisone was slightly elevated during the study (see M073; Bioassay of Body Fluids Report).

All other routine hematological measurements were normal for all crewmen.

Table 6-6

Hematology Procedures
for Experiment M115

Parameter	Routine Procedure
RBC/WBC count	Coulter method
Hematocrit	Microcapillary method
Hemoglobin conc.	Spectrophotometry using Co-Oximeter Model 182
Carboxyhemoglobin conc.	Simultaneously with above
Methemoglobin conc. and percentage	Spectrophotometry using KCN to distinguish metheoglobin band
RBC indices (mean corpuscular volume, mean corpuscular hemoglobin, mean corpuscular hemoglobin conc.)	Calculated from RBC count, hematocrit, hemoglobin conc
Platelet count	Microscopically with hemacytometer
Reticulocyte count	Counting reticulated cells/1,000 RBC's (expressed as percentage)
Differential cell count	Av. of 3 counts of 100 cells
	Special Procedure
RBC critical volume, volume distribution of whole blood and age-density separated cells	Coulter particle-volume measurement, and Herz-Kaplan age-density procedure
RBC and WBC ultrastructural change	Transmission electron microscopy
RBC shape	Scanning electron microscopy
Total amount of K, P, S, S in young and old RBC's	Electron probe X-ray microanalysis
RBC K	Flame photometry
Hemoglobin content (quantitatively in RBC from whole blood and from age-density separated blood	Scanning microscope photometry
Hemoglobin levels	Hemoglobin electrophoresis

The absolute lymphopenia observed in the PLT cannot be explained. Similar low counts have been observed through the years in previous physical examinations. No clinical symptoms related to lymphopenia were observed. Since the condition was present both pretest and posttest, it does not represent a response to the SMEAT environment.

Interpretation of these data is complicated by the differences between published normal ranges and those compiled for the astronaut population. The reason for the differences is unclear but could represent differences in laboratory techniques, differences between astronauts and the total male population, or both.

Special Hematology

Red Blood Cell Critical Volume and Volume Distribution. Gemini mission data suggested that an increased intravascular hemolysis resulted in a net loss of red cell mass. Subsequent data collected in support of the Apollo program and ground-based chamber studies strongly suggest the cause of this red cell loss to be the result of failure of the red cell membrane to maintain a proper ionic balance in the cell to prevent hemolysis in the face of increased oxygen in the breathing gases.

Since the red cell regulates its volume within well-defined limits under normal conditions, a shift in the normal volume distribution profile could be indicative of either (1) a failure of the volume regulation mechanisms (which could involve a change in passive membrane permeability, in the generation of energy by metabolic processes, or in the effective utilization of energy by the Na-K pump enzyme system), or (2) a stressful situation for which the cell could not compensate. If red cells are subjected to osmotic stress in vitro by decreasing the osmolality of the suspension medium, the volume achieved before hemolysis occurs is a measure of the compliance of the cell membrane.

In addition to examining whole blood, the top ten percent (young cells) and bottom ten percent (old cells) of a packed cell column were also analyzed for their volume distribution and, in selected cases, their critical volume.

Changes in red cell volume for whole blood and age-density separated blood are illustrated in Figure 6-9 and 6-10, respectively. The subject was the SMEAT CDR. Figure 6-11 shows changes in volume distribution from age-density separated cells, again for the CDR.
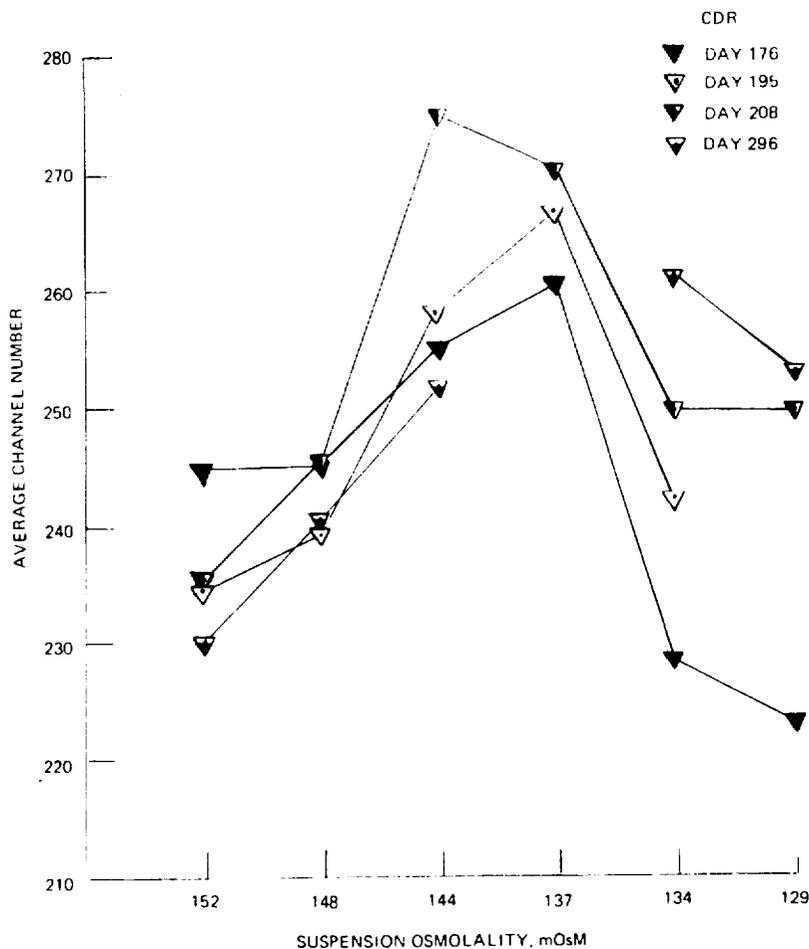
Figure 6-9. Changes in red cell volume with decreasing osmolality.

In general, the older red cell population behaved similarly to the whole blood while the younger cells had a higher critical volume. The young cells were able to withstand a greater influx of water and therefore more swelling than the older cells.

Changes in membrane compliance are characteristic of aging in the red cell. Ionic content and metabolic capacity also change in red cells with age.

Attempts at an absolute calibration of the multi-channel analyzer (i.e., volume per channel) have not yielded useful results. Measurements show the cells having a volume soome 30 percent larger than

expected. The difficulty may lie in the blood cell orientation as it traverses the aperture of the counter.

It is generally recognized that the cell measured by the Coulter method is intimately related to its residence time in the aperture and its orientation as it flows through the aperture. The degree to which the flexibility of the cell alters the volume distribution profile is illustrated in Figure 6-11. The type of curves exhibited by young, old, and the total red cell population were consistent enough to identify each subpopulation. As the red cell loses membrane compliance and becomes more rigid with age, the artifactual spreading of the distribution curve caused
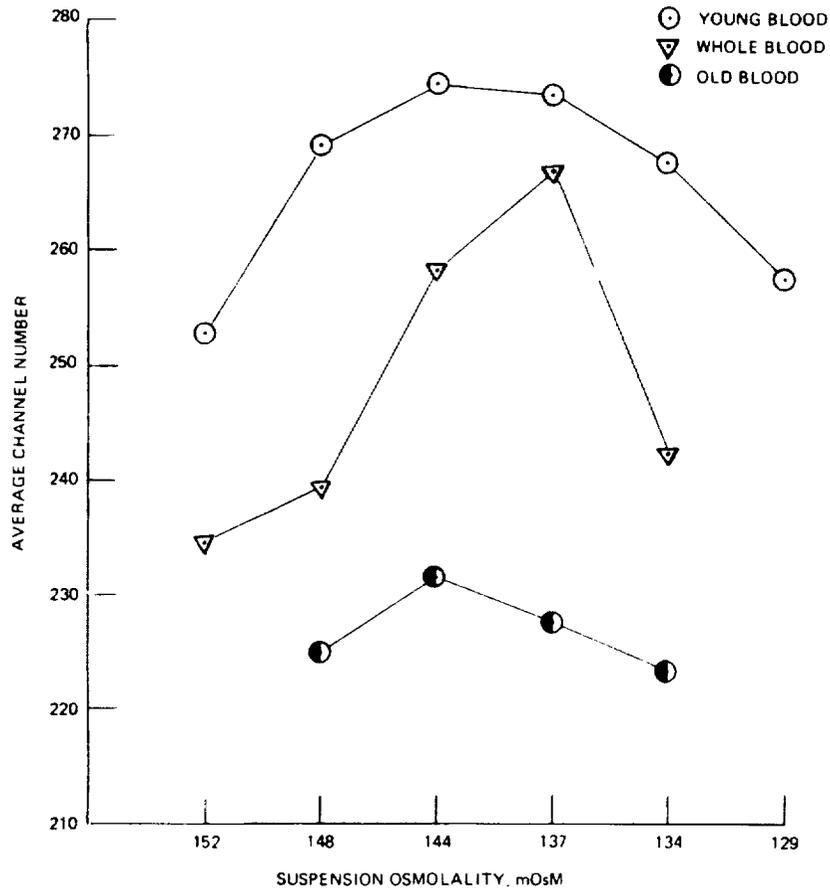
Figure 6-10. Changes in red cell volume from age density-separated samples.

by the cell's orientation in the flow channel is reduced. Fixing the cells with gluteraldehyde produces a similar effect.

An electrical modification of the Coulter Counter-MCA system has been designed which will discriminate electrical signals from cells with excessive residence time in the aperture. This, with the computer curve-solving analyses, will provide a more precise estimate of red cell volume distribution and critical volumes. Applications of these analyses to the age-separated cells will also increase the resolution of the best solution to changes in specific subpopulations of the red cell sample.

Transmission and Scanning Electron-microscopy Ultrastructural and Morphological Changes. The ultrastructure of blood cells in the SMEAT samples, as seen by the transmission electron microscope, was normal.

Transmission electron microscopy, while providing information on ultrastructure, does not delineate the three-dimensional structure of the cell. These details can be visualized by use of the scanning electron microscope with a ten-fold greater resolution than the light microscope permits and with a large depth of field.
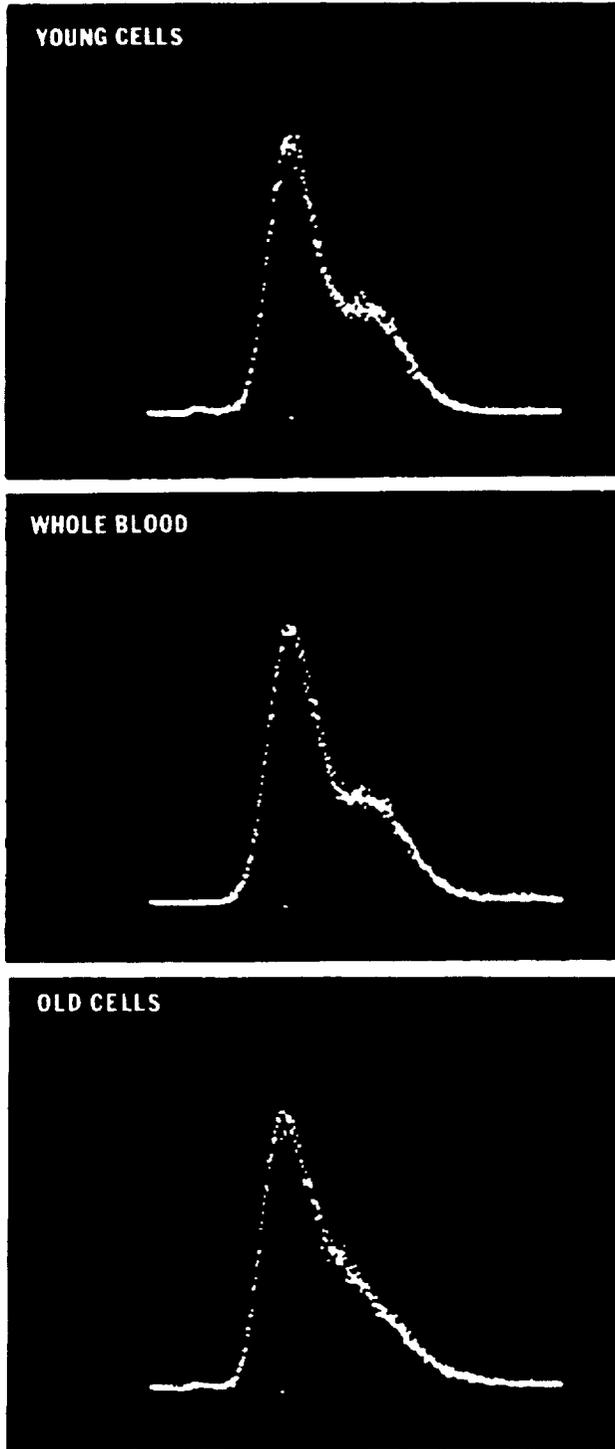
Figure 6-11. Volume distribution profiles from age density separated cells.

Because of the physiological importance of the red cell shape and the variety of pathological conditions in which red cells can undergo shape changes, a characterization system for red blood cells using the scanning electron microscope was established during this study to evaluate changes in red blood cell morphology.

Four categories of red cell morphology were defined. These were characterized as having (1) normal concavity; (2) loss of concavity, flatness, or nucleation; (3) abnormal concavity; and (4) crenation. Each of these morphologically distinct cells is indicated in Figure 6-12. Baseline data were obtained from both normal controls and crewmembers preflight, and the percentages of red cells in each category were compared with in-chamber and postflight samples. No significant abnormalities were found as a result of the chamber study.

Electron Probe X-Ray Microanalysis – Electrolyte Determinations. Data from previous Apollo flights have suggested a net loss of total body potassium during the mission and a retention of urinary potassium postflight. While the major portion of total body potassium is intracellular (primarily in muscle tissue), the mechanisms responsible for ionic equilibrium in muscle tissue also function in the red corpuscle. Thus, the red blood cell, which is more easily accessible for chemical examination, may serve as a model system to evaluate particular aspects of the other tissues of the body at the cellular level.

Because of these previous findings, potassium was the electrolyte of primary interest in this segment of the M115 studies. There are, however, additional reasons for measuring red cell potassium concentrations. Changes in intracellular potassium reflect alterations in red cell metabolic processes, which can ultimately result in cell lysis. Potassium is also an age-related parameter in red cells, decreasing in concentration as the cell grows older (Joyce, 1958). A change in the relative proportion of age groups in the red cell population would be characterized by a change in the potassium concentration profile.

Electron probe X-ray microanalysis was performed to determine changes in red cell electrolyte con-

centrations. Three additional new developments were applied to this study to increase the sensitivity of the analysis to transient changes in red blood cell composition. These were: (1) Age-density separation of the red blood cell samples to disclose a more responsive and homogeneous cell population; (2) Measurement of cellular dry mass by substrate X-ray absorption, which provides a direct correlation between cellular mass and electrolyte composition; and (3) Flame photometry on red blood cell samples to confirm the microprobe analyses.

Because of the complexity of and time required for both the collection and analysis of the electron probe X-ray data, one SMEAT crewman (PLT) was selected for detailed examination of young and old cell populations by the electron probe X-ray microanalysis technique. Selected samples were analyzed from the other two crewmen. Computerization of the X-ray analysis will significantly shorten the time required for these analyses making it possible to examine all the samples from Skylab.

The net Kα X-ray intensities for K, P, S, and Si from the PLT's young and old red cell fractions are shown in Figure 6-13; data with standard deviations are given in Table 6-7. Examination of the PLT's red cell potassium, the electrolyte of primary interest, shows a transient elevation in the younger cell fraction shortly after entrance into the SMEAT chamber and again upon egress. There is a slight rise in the older cell potassium X-ray intensity at the same time. Evaluation of the population profiles for potassium shows this transient change to be due to the appearance of a small subpopulation of cells at day 211. This may represent newly formed red cells which would be expected to have a higher intracellular potassium content. The possibility of this distribution being due to sampling error is negated by the flame photometry data.

Net potassium X-ray intensity measurements are indicative of the total amount of potassium per red cell and, because of potential differences in cell size, may not correlate directly with measurements of concentrations. Thus, a larger cell may have the same potassium concentration as one much smaller, but would have a higher net X-ray intensity. To correct for possible differences in red cell size (dry mass), the
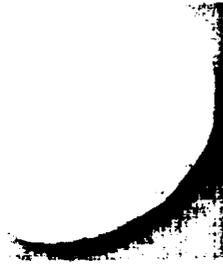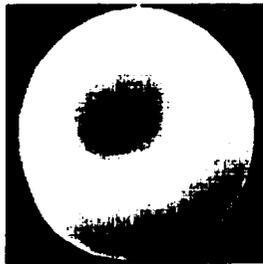
Class I Normal Concavity
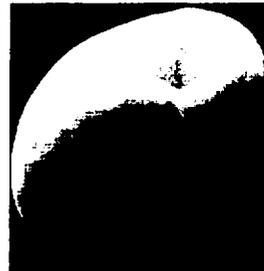
Class III Abnormal Concavity
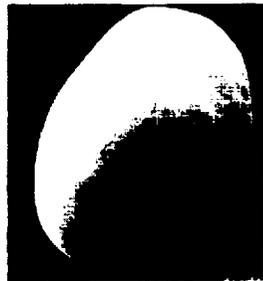
Class II Loss of Concavity Flatness
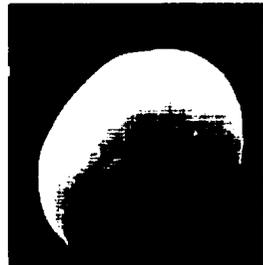
Class II Nucleation

Class IV Crenation

Figure 6-12. Representative micrographs of red cell SEM classification.

Table 6-7

Electron Probe Microanalysis
of Age-Density Separated Red Blood Cells

SOURCE: SMEAT, PILOT	X-Ray Intensity, Mean Net Counts/50 Sec ± 1 S.D.			
	K	S	P	Si Reduction (ΔSi)
PERIODS:				
Day 188, Young Fraction	2386 ± 831	1359 ± 271	611 ± 170	3733 ± 778
Day 188, Old Fraction	2376 ± 366	1479 ± 247	498 ± 109	3992 ± 834
Day 195, Young Fraction	2294 ± 381	1345 ± 152	487 ± 151	3255 ± 594
Day 195, Old Fraction	2058 ± 359	1382 ± 158	273 ± 117	3565 ± 685
Day 211, Young Fraction	3085 ± 1526	1378 ± 219	528 ± 106	3683 ± 617
Day 211, Old Fraction	2580 ± 578	1519 ± 158	474 ± 98	4291 ± 882
Day 262, Young Fraction	2440 ± 1048	1280 ± 185	497 ± 93	3209 ± 657
Day 262, Old Fraction	2670 ± 369	1455 ± 215	349 ± 94	4019 ± 803
Day 264, Young Fraction	3397 ± 1078	1298 ± 244	634 ± 189	3647 ± 963
Day 264, Old Fraction	2789 ± 626	1351 ± 256	561 ± 134	4058 ± 1133
Day 265, Young Fraction	2801 ± 1543	1314 ± 172	561 ± 215	3511 ± 753
Day 265, Old Fraction	2216 ± 417	1345 ± 278	252 ± 68	3857 ± 790

net X-ray intensities may be normalized by one of two methods. Since the X-ray counts come primarily from the hemoglobin moiety and have been shown to correlate with microspectrophotometry measurements of single cell hemoglobin concentration (Kimzey et al., 1973), these data may be used to correct for differences in cell dry mass.

The S X-ray intensity remains relatively constant throughout the SMEAT study, indicating that the cell samples analyzed are not significantly different with respect to protein content (Figure 6-13). Cell size remains constant within the respective age-separated fractions; therefore, the alterations in potassium X-ray counts in respective age fractions from different periods are probably due to changes in concentration. However, cells from the younger fractions are consistently less dense and/or smaller than cells from the older fractions.

The age-dependent nature of potassium concentration in red blood cells was demonstrated by the flame photometric analysis of the potassium content in the three age fractions, separated by density centrifugation. The difference in the younger versus the older cells is highly significant ($p < .005$) in all the subjects.

Another method for correction of cellular mass differences and for standardization of experimental technique uses the reduction in the X-ray intensity from the silicon substrate due to absorption by the cell as an indicator of the cellular dry mass. This method is independent of variations in cellular elemental composition and relies on the cell size and density. There was a consistent difference in cell mass (ΔSi) between the young and old fractions at all sampling periods. The variations which are present between sampling periods occur simultaneously in both fractions and could be representative of shifts in the behavior of the total cell sample during the age-density separation procedure.

Correlation analyses between all elements considered (K, S, P, Si) within these cell populations indicated highly (>96 percent) inverse correlation exists between S and Si in all populations. This shows, as predicted, a strong agreement between cellular protein content and absorption of the Si X-rays from the Si substrate by cell mass.

The use of the electron microprobe in this area of analysis affords the first direct evaluation on a single
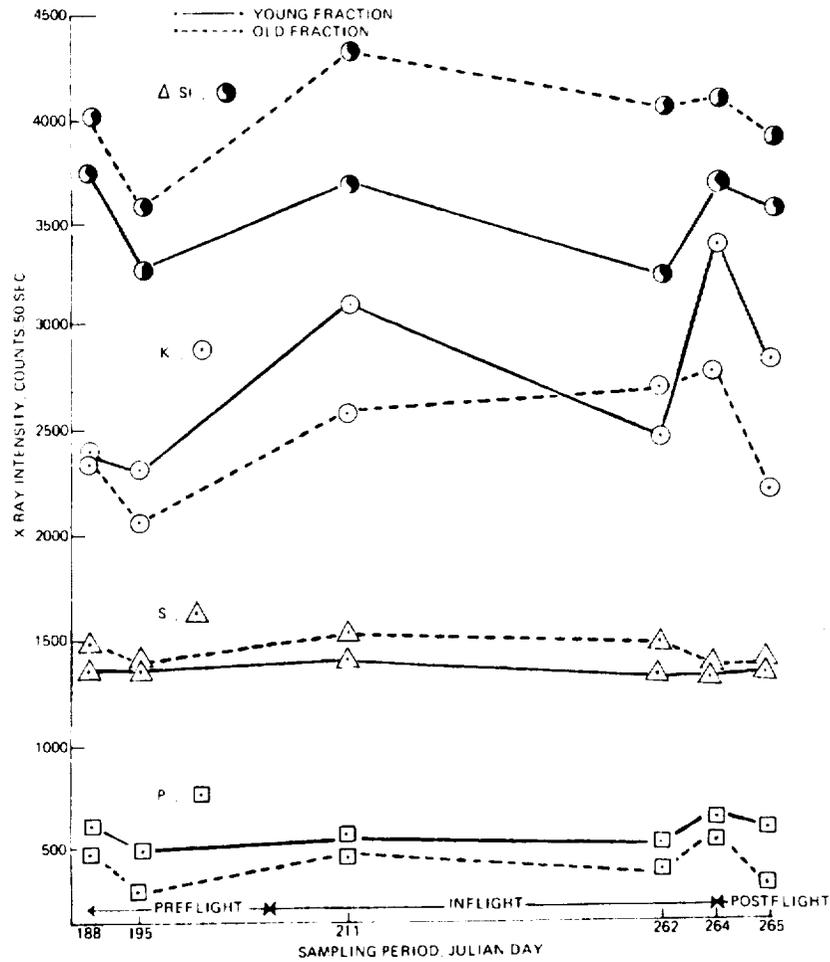
Figure 6-13. Net X-ray intensities from age density-separated red blood cells.

cell basis of the relationship between intracellular electrolyte concentration and variation in cellular mass. The probability for correlation between K and ΔSi in the young cell sample is greater than in the older fraction; P is also significantly correlated with ΔSi ($>$92 percent probability) in more of the younger cell fractions than in the older cell samples. These data suggest that the younger cell fractions are a more homogenous population of cells than the older fractions.

Additional support for this conclusion is provided by the flame photometry data. When the two independent measurements of cell K are compared (Figure 6-14), the similarity in the curves is obvious,

especially in the curves obtained from the young cells. The older cells are more varied in general. The data from the microprobe would be expected on the basis of this comparison to show the same type of curve if all time periods had been analyzed. The transient changes in K content in this crewmember upon entry and egress from the chamber are strikingly demonstrated in the correlation between these two independent observations. The advantages of utilizing the age-density separation technique to disclose changes in a more homogenous population of cells are readily apparent.

Figure 6-15 shows net X-ray intensities for K, S, and P corrected for differences in cell mass. In
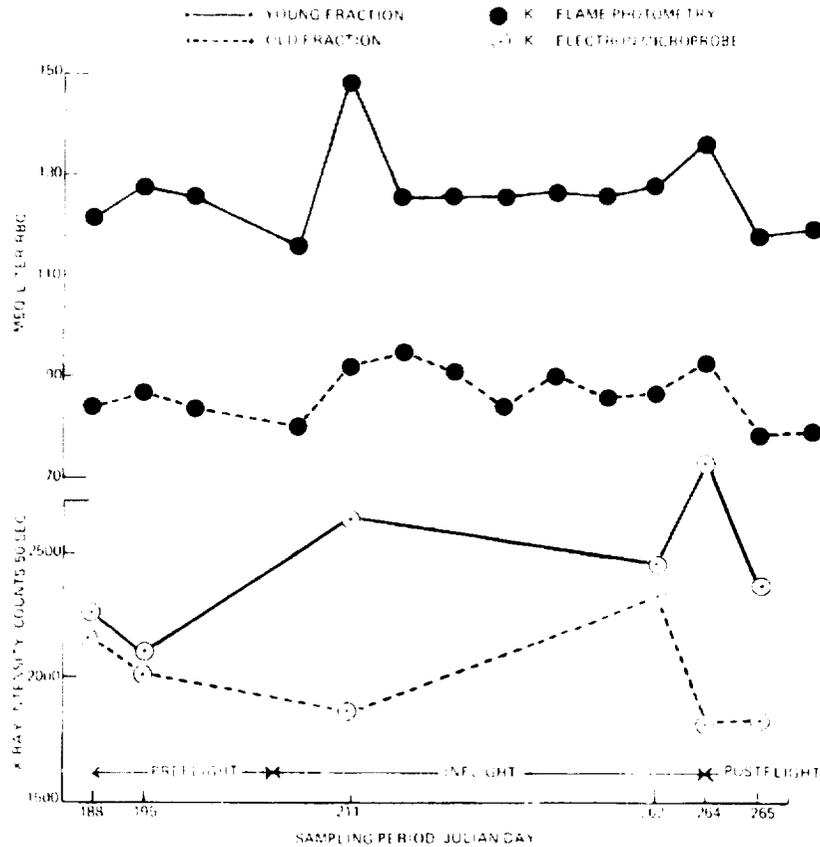
Figure 6-14. Comparison of flame photometry and electron probe microanalysis
for K from age density-separated red blood cells.

addition to the changes seen in intracellular K content at days 211 and 264, intracellular P shows a marked rise in the young cell fraction during the in-chamber period of the study. This increase is not evident in the old cell fraction which remains constant throughout the time period.

P was initially selected for analysis as an indicator of age separation in red blood cells. Younger cells contain residual ribonucleic acid, which has a high P content. At all sampling periods, the P content of the young cell fraction was greater than that of the old cell fraction. The P content of red blood cells may vary due to a number of things, including changes in metabolic activity and phospholipid content as well as age. The increase in P content during the in-chamber period does not appear to be due to the appearance of increased numbers of

reticulocytes which remain at preflight levels. No satisfactory explanation for this in-chamber increase in P from the young cell fraction can be offered at this time.

In summary, electron probe microanalysis of red blood cell K shows a transient elevation of K in the young cell fraction shortly after the crewmember's entrance into the SMEAT chamber and again upon egress. This change appears to be due to the appearance of a small subpopulation of red blood cells containing high K. These cells may represent newly formed red cells.

Scanning Microscope Photometry Analysis of Red Blood Cells. Red blood cells from whole blood were analyzed by microspectrophotometry for hemoglobin content. Computer analysis of the data
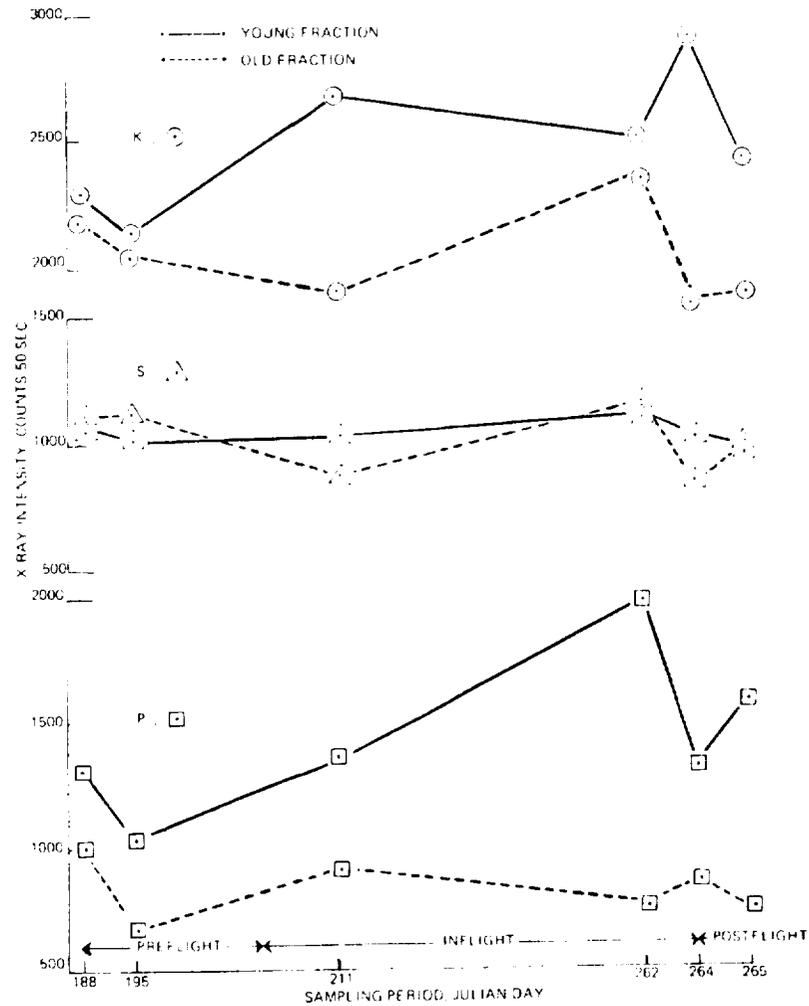
Figure 6-15. Mass-corrected X-ray intensities from age-density-separated red blood cells.

revealed no significant alterations when the parameters of cell size and hemoglobin content were compared.

Further evaluations of red blood cells from the in- and postchamber specimens are currently in progress using M-dimensional space analyses whereby n-variables from the microspectrophotometric data are used for hyperspace comparison purposes. In addition, a cluster analysis procedure, currently near completion, may provide a means of distinguishing certain individual cells or subpopulations when the in- and postchamber specimens are compared.

Hemoglobin Electrophoresis. Hemoglobin levels of the SMEAT crewmen, as determined by hemoglobin electrophoresis, remained relatively constant throughout the exercise and no abnormal hemoglobin variants were observed at any time.

Summary and Conclusions

Routine Hematology

All routine hematological measurements were within normal astronaut population limits for the CDR, SPT, and PLT, with one exception: A significant lymphopenia was observed in the PLT during

the posttest period, possibly the reflection of increased adrenal corticoid secretion.

Special Hematology

No ultrastructural red cell membrane abnormalities were observed in any of the subjects, nor were any red corpuscle morphological abnormalities noted. Slight elevations in the PLT's red corpuscular potassium were observed in the younger corpuscles after chamber entrance and again upon egress. This probably represents newly released young red cells from hematopoietic tissue. Flame photometric analyses confirm the fact that potassium is indeed higher in the younger cells of all subjects examined.

All other special hematological studies, including scanning microspectrophotometry for hemoglobin content and hemoglobin electrophoresis for detection of hemoglobin variants, were well within normal limits.

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CHAPTER 7

MINERAL BALANCE — EXPERIMENT M071

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Concern for the long term metabolic consequences of weightless flight was the basis for the conception of the Skylab medical experiment to measure mineral balance. Proper interpretation of data obtained from the inflight study required a high fidelity ground-based control study. The SMEAT test provided the opportunity for this study.

It has long been suspected that the musculoskeletal system would be particularly susceptible to the prolonged withdrawal of gravitational stress. Astronauts have been subjected not only to a nullified gravitational field, but they have also been confined in vehicles where mobility was restricted and relative physical inactivity prevailed. These conditions, singly or in combination, were expected to cause deterioration of bones and muscles.

Long before space flights were planned, the control studies by Dietrick, Whedon, and Shorr of immobilization of four healthy young men for up to seven weeks clearly demonstrated that immobilization in body casts led to marked increases in urinary calcium. These levels more than doubled in five weeks, and were accompanied by negative calcium balances, as well as related changes in nitrogen and phosphorus metabolism. Correlative decreases in the mass and strength of muscles of the lower extremities occurred and deterioration in circulatory reflexes to

gravity resulted within one week. This effect has been noted consistently in space flight.

Other studies with immobilized subjects indicated that the clinical disorders most likely to be encountered during prolonged space flight are primarily a consequence of an imbalance between bone formation and resorption. Under these conditions, there occurs loss of skeletal mass which could lead eventually to hypercalcemia, hypercalcuria, osteoporosis, and possibly nephrolithiasis (Issekutz et al., 1966).

Since the most meticulous studies have disclosed that the surfeit of calcium lost during bed rest is mainly via the urine, it is pertinent to refer also to studies of urine calcium in which balances were not measured. The total evidence indicates that a one to two percent per month loss of body calcium is a reasonable prediction for weightless persons (Hattner & McMillian, 1968).

With the advent of space flight, additional studies have been reported concerning the effects of simulated weightlessness on skeletal metabolism. Graveline et al. (1961) reported no increase in urinary calcium excretion in their study on one subject of the effect of one week of almost continuous water immersion. It should, however, be realized that one

week is a short period in which to observe significant changes in calcium metabolism. Vogt et al. (1965) have shown negative balances of small magnitude and, in addition, have demonstrated changes in bone density of the os calcis during bed rest.

Lynch et al. (1967) have investigated the role of simulated altitude in modifying the effect of bed rest. In 22 healthy men, bed rest of four weeks at ground level conditions resulted in expected increases in urinary and fecal calcium, and in urinary nitrogen, phosphorus, sodium, and chloride. In similar metabolic studies carried out with another 22 subjects at bed rest at simulated altitudes of 10,000 and 12,000 feet, urinary losses of calcium were significantly less as altitude increased. Urinary losses of phosphorus, nitrogen, sodium, and chloride were less at 12,000 feet as compared to bed rest studies at ground level. These studies suggested that diminished atmospheric pressure may have a preventive effect on mineral loss from the skeleton. Such data as are available from inflight studies tend to support the use of immobilization as a terrestrial model for alterations in calcium metabolism during space flight. During the fourteen-day Gemini 7 flight, in the only metabolic balance study in space thus far carried out, a modest but significant loss of calcium occurred in one of the two astronauts, and the changes in phosphorus and nitrogen metabolism supported the observation of some deterioration in muscle metabolism (Lutwak et al., 1969, and Reid et al., 1969).

That such losses are likely to continue unabated during prolonged space flight is evident from studies of bed rest lasting from 30 to 36 weeks. In balance studies, calcium losses from the skeleton averaged 0.5 percent of the total body calcium per month. In the same normal subjects, tenfold greater rates of localized loss from the central portion of the calcaneous were observed by X-ray transmission scanning (Vogel et al., 1970, and Donaldson et al., 1970).

In addition to weightlessness, one of the primary environmental parameters in Skylab which was thought to be a possible influence upon the metabolism of bones and muscles was the elevated partial pressure of carbon dioxide. The literature contains few studies in which elevated carbon dioxide partial pressures have been used in conjunction with dietary control studies for accurate estimation of calcium excretion and balance. One report (Schaefer et al., 1963) on twenty human subjects exposed to 1.5 percent carbon dioxide for 42 days showed no change in plasma, calcium, or phosphorus, but a slight rise in RBC calcium and fall in RBC phosphorus. In another study, Gray et al. (1969) studied twelve subjects at one percent carbon dioxide for 22 days. The authors found that serum calcium fell and urinary calcium declined initially, then rose. An unpublished study by Welch on a 30-day exposure of four subjects at three percent carbon dioxide appears to be the only study with dietary control. In this study, the mean of urinary calcium increased fifteen percent during the period of carbon dioxide exposure, and in recovery returned virtually to the controlled level.

In view of this lack of knowledge, a ground-based study was considered necessary to investigate the effects of an atmosphere containing about 5.5 mm Hg carbon dioxide or whatever pCO_2 would prevail on Skylab on the biomedical measurements that are scheduled to be made on Skylab. These studies were to be carried out under conditions (atmospheric pressure, humidity, and composition as well as diet), which duplicated insofar as possible the conditions expected in Skylab, and would use subjects matched in age and physical characteristics with the Skylab crewmembers.

Procedures and Methods

To obtain definitive information on mineral losses in SMEAT, the M071 experiment was conducted. The experiment consisted of a complete input and output measurement on all crewmembers commencing 28 days preflight, continuing throughout the 56-day in-chamber phase, and for an 18-day period post-chamber. All nutrient and water intake was precisely measured. All fecal material and urine samples were passed out of the chamber for analysis, and samples of blood were taken prechamber, in-chamber, and postchamber.

Subjects

Three male Caucasian subjects designated CDR, SPT, and PLT participated in this study. Their ages were 35, 43, and 35 years, respectively.

Activity

Each crewmember engaged in varying amounts of physical activity including daily physical exercise. No attempt was made to control this expenditure. The activity level of the SPT was particularly vigorous, but reportedly typical of his exercise pattern (SPT personal communication).

SMEAT Environment

The atmosphere of SMEAT consisted of a mixture of about 70 percent oxygen, about 28 percent nitrogen, and 2 percent carbon dioxide for a total pressure of 258 mm Hg. Temperature and humidity were maintained well within the comfort range.

Diets

For optimal interpretation of metabolic data for the effects of factors under study, diets for all three phases were made as similar and constant from day-to-day in content and composition as possible. Since each individual served as his own control for comparison in pre-, in-, and postchamber phases, interindividual differences were permitted.

The food used in SMEAT consisted of a variety of frozen, thermostabilized, dehydrated, and compressed food. A facility existed in the chamber to heat some foods prior to consumption and to maintain others in a refrigerated state.

Energy requirements for the SMEAT crew were estimated on the basis of age and body weight according to the method recommended by the Food and Nutrition Board of the National Academy of Sciences. In utilizing this procedure, it was assumed that each crewmember would engage in moderate physical activity at an environmental temperature of about 20°C. Menus meeting these energy requirements and providing constant and specified intakes of calcium, phosphorus, magnesium, sodium, and nitrogen were formulated. These menus were fed to each crewmember for a five-day test period and a six-day test period during which changes in body weight were closely observed. The menus were adjusted after each test in order to compensate for weight changes. The energy equivalent of these changes was assumed to be 29,400 kjoule per kg of weight loss in order to compensate for water loss. This energy equivalent is recognized to be only an approximation in the absence of supporting studies on the nature of body composition changes.

The energy intakes of each of the three SMEAT astronauts, during the first food compatibility test which lasted five days, are listed in Table 7-1, and the weight changes are shown in Table 7-2.

A six-day menu compatibility test was subsequently conducted. Again, the general acceptability of each food item and portion sizes was judged by each crewmember. In addition, comments were solicited relative to the degree of appeal for each menu combination. The menus utilized in this case were the ones intended for SMEAT. Weight changes are indicated in Table 7-3. The SPT's energy intake in the second test was approximately 2,520 kjoules higher than during the first test. The greater weight loss sustained in the second test indicated that the accuracy of the estimate of the SPT's energy requirement could not be further refined in this brief testing period.

The menus were designed according to six-day cycles each day of which contained the required intake levels of nitrogen, calcium, phosphorus,

Table 7–1

Energy Intake of Five-Day Food Compatibility Test (Kilojoules)

Crewman	Day 1	Day 2	Day 3	Day 4	Day 5	Mean
CDR	10311	11075	12201	14162	12327	12012
SPT	10303	13137	12444	11138	11642	11718
PLT	12554	12495	13582	14784	12096	13104

magnesium, potassium, and sodium. These core menus were provided to the crew with the admonition to consume them completely, or, if unable to do so, to report the weighed mass of the leftovers. The crew was permitted ad libitum quantities of certain other food items which were designed to contribute up to 1,260 kjoules while not augmenting the intake of any controllable element beyond tolerances. These items (apple drink, hard lemon candy, plain white mints, and NIH butter cookies) were almost entirely carbohydrate and fat. Energy intakes were, therefore,

free to vary as a function of appetite and the energy demands of varying daily rates of energy expenditure. In practice, the variance was limited by the acceptability of these elective energy items.

A system of negative reporting was employed such that the crew related at the end of each day any deviations from the nominal menu.

The prescribed intakes of the various components of the diet, as determined by actual analysis of each food item, are shown in Table 7-4.

Table 7–2

Weight Changes on Five-Day Food Compatibility Test
(Kilograms)

Crewman	Initial	Final	Weight Change
CDR	78.8	77.4	−1.4
SPT	93.7	92.4	−1.3
PLT	86.5	86.7	+0.2

Table 7–3

Weight Changes on Six-Day Food Compatibility Test
(Kilograms)

Crewman	Initial	Final	Change
CDR	77.9	77.9	0
SPT	95.1	93.3	−1.8
PLT	89.2	89.2	0

Table 7–4

Intakes of Diet Components

Nutrient	CDR	SPT	PLT
Energy (Kjoules)	12190	13840	13000
Protein (g)	103 ±10	105 ±10	106 ±10
Calcium (mg)	850 ±16	850 ±16	850 ±16
Phosphorus (mg)	1700 ±120	1700 ±120	1700 ±120
Sodium (mg)	4000 ±500	4000 ±500	4000 ±500
Magnesium (mg)	350 ±25	345 ±25	325 ±25
Potassium (mg)	3800 ±200	4000 ±200	4000 ±200

Complete ingestion of the prepared menus was well achieved. A sample menu is shown in Table 7-5.

Table 7-5

Sample Menu

Meal	Food Item
Breakfast	Chocolate instant breakfast
	Applesauce
	Orange drink
	Coffee
Lunch	Pea soup
	Chicken and rice
	Biscuit
	Grape drink
Dinner	Filet mignon
	Mashed potatoes
	Asparagus
	Lemon pudding
	Vanilla wafers
	Grape drink
	Tea with sugar and lemon
Snacks	Mints
	Peanuts
	Coffee
	Tea with lemon and sugar

In order to maintain controlled intakes of calcium, phosphorus, magnesium, sodium, and potassium in conjunction with possible deviations from the nominal menu, the crewmembers were also supplied with a series of mineral supplements by which the intake of each of these elements could be adjusted independently of the others. The mineral supplements are listed in Table 7-6.

Table 7-6

Composition of Mineral Supplements

Supplement	Controllable Element
Calcium lactate	32 mg Calcium
Orthophosphate	110 mg Phosphorus
Magnesium lactate	25 mg Magnesium
Sodium chloride	197 mg Sodium
Potassium gluconate	195 mg Potassium

A computer program was designed to calculate mineral deficits from information transmitted by the crew. The quantity of mineral supplements equivalent to the deficit was calculated and transmitted back to the crew for consumption the following morning.

The menus utilized pre- and post-SMEAT were almost identical to the in-chamber menus but included some substituted fresh foods.

Fluid Intake

Fluid intake was ad libitum. The quantities ingested during all phases of the experiment were recorded. The majority of fluid intake was obtained with the diet. In-chamber fluid intakes were measured from the water dispensing devices typical of those used onboard spacecraft. The fluid intake measured in the absence of data on insensible losses was not considered to be sufficiently precise to calculate fluid balance data.

Water employed was of the type to be used on Skylab; it was virtually free of controllable elements and contained a biocide consisting of 6 ppm iodine.

Urine Collections

During the prechamber and postchamber phases, collection facilities were established in the astronauts' office building, their homes, and in the Crew Reception Area of the Lunar Receiving Laboratory. Individual refrigerators were strategically located with labeled containers. In-chamber collection was accomplished by utilizing specially designed urine collection systems, one of which, for the SPT, resembled that which was then planned for use inflight.

In spite of best efforts to design a satisfactory system for collection of in-chamber urine, significant and frequent leakages occurred from the Skylab Urine Collection System.

The leakages were not only detrimental to the metabolic study but a source of chronic inconvenience to the crewmember employing the device. Approximately eight percent of the 312 individual specimens and 24-hour pooled urinalyses were discarded because of collection difficulties. The 24-hour urine pool was usually maintained at a temperature

below 10°C and the temperature of this pool did not exceed 10°C for more than an accumulated period of three hours during any 24-hour period. After 24 hours, all urine samples were frozen at -20°C.

Stool Collections

Carmine Red and SDS Blue were given orally to the subjects for a separation of stool periods (Lutwak et al., 1969). Unfortunately, at the dosage utilized, no changes in stool colors were apparent. Polyethylene glycol, 1,500 mg/man/day, was utilized as a nonabsorbable fecal recovery standard. Complete fecal collection was achieved.

Sweat Collections

No attempt was made to collect or measure sweat or materials excreted through the skin, since it had been shown (Gitelman & Lutwak, 1963) that losses of calcium via this route under nonsweating conditions are less than 20 mg per day. During the actual study, however, exercise was more vigorous than anticipated and, therefore, material loss greater than this amount may well have occurred.

Blood Sampling

Blood samples were taken five times prior to chamber entry, days 181, 182, 188, 195, and 207; eight times in the chamber, days 209, 211, 220, 227, 235, 244, 255, and 262; and four times following egress from the chamber, days 264, 265, 269, and 279. One-half a milliliter of plasma utilizing Lithium-EDTA as the anticoagulant was employed for this study. Chamber ingress was day 207 and egress was day 263. On days 220, 235, and 255, an additional 15 ml of blood was drawn for micro-biological sampling.

Results

The CDR's average energy intakes prechamber, in-chamber, and postchamber were 12,146, 12,188, and 12,155 kjoules, respectively. Variations in energy intake were due to the slightly different energy content of each day of the six-day menu cycle. Other variation is due to the consumption of additional "elective energy" items or to the omission of a planned food item.

The CDR's weight trended slightly downward during the chamber occupancy, but apparently not during the pre- and postchamber phases. Daily weight variation, however is considerable, and it is not possible to deduce significant differences between the rate of loss in the chamber and outside it. The total absolute weight loss was about two kg, indicating an energy deficit of approximately 680 kjoules per day if the change in body mass involved adipose tissue alone. It should be noted, however, that during this period, the CDR's total body water (M073 report) fell from 45.9 liters to 44.1 liters and his mass from 71.69 kg to 70.33 kg. There was, therefore, a loss of 1.36 kg of mass and 1.8 kg of water. The difference between these numbers is comparable to the expected variation of the total body water measurements, and no net loss in body fat can be deduced.

The SPT's average energy intake was 14,599, 14,813, and 15,703 kjoules during the pre-, in-, and postchamber phases, respectively. The variation about the mean of approximately ±1,680 kjoules per day was much greater than for the other astronauts. The periodic variation of the SPT's energy intake due to menu cycling was obliterated by the large variance due to the intake of elective energy items. It should be noted that the SPT was advised to increase his caloric intake; however, despite this increase, subject's weight loss continued. The SPT's weight loss appeared to continue relentlessly for 90 days with no noticeable changes in slope until the final week when the SPT was directed by the SMEAT Surgeon to withdraw from the constant dietary control. During this week, weight loss appeared to cease at an energy intake of approximately 16,745 kjoules per day. This energy intake was the result of ad libitum feeding by this crewmember, and was approximately 2,100 kjoules above the average in-chamber and prechamber levels.

The SPT sustained a total weight loss of approximately seven kg from F-28 to R ±14. If it is assumed that the weight loss consisted almost exclusively of fat and if that fat tissue is considered to be approximately ten percent water, then the energy equivalent of the mass lost is 34,020 kjoules per kilogram. This would amount to a total energy deficit of 238,140 kjoules over the experimental period or approximately 2,520 kjoules per day.

During the period from F-15 to R+0, the SPT's total body water (M073 report) changed from 59.3 liters to 57.5 liters. During this same period, mass changed from 93.43 kg to 88.0 kg. There was a loss, therefore, of 1.8 liters of water and 6.93 kg of mass. The loss of fat tissue may be assumed by difference to have been 5.1 kg. This represents an energy deficit of 192,780 kjoules, assuming 37,800 kjoules per kg. This, therefore, represents a deficit of 2,713 kjoules/day over the 71-day period encompassed by the total body water measurement. As will be shown later, the mass loss was almost exclusively water and fat since no significant negative nitrogen balance was apparent. Incidentally, there was no diminution of bone mineral mass.

The subject found the menus, in general, to be unattractive, and the elective energy items to be unpalatable in large quantities.

The average energy intakes of the PLT pre-, in-, and postchamber were 13,453, 13,028, and 13,091 kjoules, respectively, and no significant changes in weight were encountered.

The PLT's cyclic variation in caloric intake is easily discernible, indicating close adherence to the experimental dietary regimen. The daily weight of the PLT varied considerably but did not appear to undergo any net change.

Total body water measurements for the PLT during this period fell from 52.2 liters to 51.7 liters, indicating a net loss of 0.5 liters. No change in body weight was discernible in this crewmember over this period.

The average energy intake of the crewmembers in the chamber did not appear to differ significantly from the prechamber energy intake. In general, the crew reported the food to be more acceptable in the chamber than during the pre- and posttest periods despite the presence during these periods of additional fresh food items.

Measurements of whole body volume by stereophotogrammetry (Peterson et al., 1971), showed that decreases in body volume had occurred. The precision of this procedure, however, is not sufficiently great that quantitative estimates of body fat loss can be made from these measurements.

Creatinine

Average creatinine excretions for the CDR, SPT, and PLT were approximately 2,250, 2,300, and 2,500 mg/24 hours, respectively. Although the variation in daily excretion rates of creatinine was considerable, no change in the rate as a result of chamber exposure was apparent.

Nitrogen

There did not appear to be any change in nitrogen balance resulting from exposure to the chamber environment.

Potassium

The mean intakes and outputs for potassium are listed in Table 7-7. The potassium balances are persistently positive and do not significantly change during the period of chamber exposure.

Table 7-7

Potassium Balance meq/Day

Crewmember	Prechamber	In-Chamber	Postchamber
Intake				
CDR	100.20	99.04	99.61
SPT	102.43	103.86	118.77
PLT	101.10	101.63	101.62
Urine				
CDR	72.96	80.70	73.50
SPT	70.89	74.77	64.88
PLT	74.07	78.39	74.72
Fecal				
CDR	5.84	7.66	6.95
SPT	5.64	10.83	11.80
PLT	7.86	9.28	7.34

It is germane to note that within the sensitivity of these measurements there is no evidence for an increased nitrogen or potassium loss or diminished retention of these elements during any experimental phase by any crewmember.

Calcium

Analysis of calcium balance suggests a slightly diminished tendency to retain calcium during the period of chamber exposure. This tendency was not supported by the gamma ray photon absorptiometric measurements of bone mineral mass which showed that no losses occurred as a result of chamber exposure. This latter result is not surprising in view of the well-known gains in sensitivity which are usually realized by using metabolic balance studies rather than other techniques in studying calcium metabolism.

The persistent positive balances which are evident may be partially due to an accretion of calcium caused by relatively high calcium intakes compared to the crew's normal diet. This positivity becomes less pronounced as the study progressed.

Phosphorus

Analysis of phosphorus balance demonstrated a slightly lowered capacity to retain phosphorus in-chamber. In all three crewmembers, periods of negative phosphorus balance were encountered. These changes appear to be a result of both increased urinary and increased fecal excretion rates. Differences in phosphorus balance of 75 mg per day or more are generally regarded as significant.

Magnesium

Magnesium balance appeared not to be affected by the chamber exposure. Mean changes of 50 mg are regarded as significant.

Sodium

A diminished tendency to retain sodium while in the chamber was exhibited by both PLT and CDR, but not by the SPT.

Polyethylene Glycol

Polyethylene glycol in 500-mg capsules was fed to each crewmember three times/day throughout the study. Occasional reports of missed capsules, together with analysis of the fecal material for polyethylene glycol, indicated that less than 1,500/mg/man/day had actually been ingested. Polyethylene glycol is not absorbed from the gastrointestinal tract and, therefore, should be recovered quantitatively in the feces.

Analysis of feces for polyethylene glycol indicated that insufficiently constant quantities of this material were ingested to permit its use as an internal marker in these studies.

The analytical procedure used for the determination of polyethylene glycol in feces is adapted from the turbidimetric method of Malawer and Powell. This method is based on the development of an oil-in-water emulsion of polyethylene glycol when exposed to trichloroacetic acid in the presence of barium ions. The emulsion is stabilized by the addition of acacia as an emulsifying agent.

One gram samples of freeze-dried feces are re-hydrated with nine ml of water and centrifuged. One milliliter aliquots of the supernatant are used for the preparation of a modified Somogui filtrate which is subjected to analysis by addition of acacia and trichloroacetic acid containing barium chloride.

The authors found the response of the method to be linear, stable, and reproducible within the range of 300 to 1,000 mg/100 ml.

The method was evaluated in metabolic balance studies by Wilkinson (1971). Recovery studies of polyethylene glycol added to feces yielded a mean recovery of 99.60 percent for the standard deviation of 1.612. Recovery of polyethylene glycol from six patients was made yielding a mean recovery of 98.65 percent with a range of 95.5 percent to 100.15 percent. Five days after discontinuing administration, all the polyethylene glycol was completely recovered. Recovery studies were conducted by Lockwood, and similar recovery percentages and deviations were obtained. Recovery studies performed by our laboratory yielded a mean of 103.56 with a standard deviation of 7.47.

Water Balance

No differences are apparent in the ability of the body to retain water as a result of chamber exposure.

Overall Metabolic Balance

Average net balance of calcium, magnesium, sodium, potassium, phosphorus, and nitrogen for the three crewmembers is shown in Tables 7-8, 7-9, and 7-10.

Table 7–8

CDR Metabolic Balance Data

PHASE		CA, mg	MG, mg	NA, mcg	K, meg	P, mg	N, g
PRE							
	DIET	846.5	351.9	187.1	100.8	1697	16.2
	URINE	231.1	106.5	131.1	72.4	1074	13.4
	FECES	450.2	162.8	2.4	6.8	320	1.0
	BALANCE	165.2	82.4	53.6	21.6	303	1.8
INFLIGHT							
	DIET	854.1	342.7	187.4	99.1	1726	16.2
	URINE	262.8	108.1	150.1	80.0	1216	13.3
	FECES	453.3	164.9	3.1	7.4	374	0.9
	BALANCE	138.0	69.7	34.2	11.7	136	2.0
POST							
	DIET	842.3	342.0	184.3	99.6	1696	16.1
	URINE	207.3	98.8	126.2	73.5	1041	14.5
	FECES	495.0	168.7	2.9	7.4	367	1.4
	BALANCE	140.0	74.5	55.2	18.7	288	0.2

Table 7–9

SPT Metabolic Balance Data

PHASE		CA	MG	NA	K	P	N
PRE							
	DIET	857.1	318.3	176.4	102.8	1740	16.7
	URINE	113.5	96.2	147.5	76.7	1203	15.1
	FECES	442.2	142.8	4.4	6.3	384	0.9
	BALANCE	301.4	79.3	24.5	19.8	153	0.7
INFLIGHT							
	DIET	851.6	309.7	175.7	103.9	1736	16.5
	URINE	119.7	95.9	128.7	74.9	1225	14.6
	FECES	620.0	161.2	9.3	10.7	574	1.1
	BALANCE	114.9	52.6	37.7	18.3	-63	0.8
POST							
	DIET	930.4	354.7	179.2	120.2	1913	19.0
	URINE	96.2	75.9	101.4	65.8	943	14.1
	FECES	793.4	211.2	6.4	12.5	626	1.7
	BALANCE	40.8	67.6	71.4	41.9	344	3.2

Serum Chemistries

No changes in serum chemistry resulted from chamber exposure.

Discussion

The principal goal of this study was to measure changes, if any, that may have been produced by

Table 7- 10

PLT Metabolic Balance Data

PHASE		CA	MG	NA	K	P	N
PRE	DIET	843.4	341.8	188.4	101.4	1684	16.6
	URINE	117.5	98.3	146.9	74.6	1057	15.4
	FECES	630.6	162.6	3.7	8.0	417	1.3
	BALANCE	95.3	80.9	37.8	18.8	210	-0.1
INFLIGHT	DIET	851.6	340.3	190.3	101.6	1722	16.9
	URINE	129.1	104.3	163.5	78.4	1046	13.5
	FECES	576.6	164.9	5.0	9.2	539	1.2
	BALANCE	145.9	71.1	21.8	14.0	137	2.2
POST	DIET	844.3	328.8	187.2	101.6	1723	16.5
	URINE	88.7	97.9	152.6	74.7	1052	12.6
	FECES	732.8	155.3	2.4	7.8	493	1.4
	BALANCE	22.8	65.6	32.2	19.1	178	2.5

exposure to Skylab atmosphere conditions. Significant information, however, was also obtained on the energy demands of simulated Skylab activity and upon the ability of the Skylab diets to meet these demands.

Man's energy requirements in space flights continue to elude precise definition. Numerous studies have been made in space which convey bioenergetic information of one kind or another. Long periods of pulse rate data have been recorded from each flight. Average rates of oxygen consumption and carbon dioxide production have been obtained. Food consumption has been logged and a metabolic balance study has been performed in one instance (Gemini 7). Weight changes are well quantitated and several estimates of heat production have been made. Unfortunately, the precision associated with many of these measurements is poor, and the variation greater than the differences which are expected to exist between the cost of metabolic activity in space and on the ground.

Despite these difficulties, however, it is essential that precise estimates of the metabolic cost of space activities be made and that any energy deficits occurring in space be recognized and quantitated. It is only in this way that an adequate understanding can be gained of the etiology of changes in body

composition observed in astronauts returning from variable lengths of exposure to weightless conditions.

During SMEAT significant weight losses were observed in the SPT while no significant weight changes occurred in the other two astronauts.

It is widely recognized that rapid fluctuations in body weight do occur in normal men with no apparent relations to changes in energy status. Even though these fluctuations are short term, they introduce considerable variability into metabolic experiments. Durnin observed day-to-day changes in a group of 44 men living under highly controlled conditions of as much as one kilogram.

Elkington and Danowski (1965) measured body weights of a man on 53 out of 56 days and found a standard deviation of ± 0.389 kg equivalent to ± 0.51 percent of his weight.

Most of the short term fluctuations of body weight should be attributed to changes in the water content of the body, and this must be kept in mind when attempting to compare losses in total body water with losses in body weight.

Weight loss resulting from negative energy balance is generally regarded as giving rise to a reduction of

the fat content of the body. Depot fat is the predominant storehouse of energy and represents the material preferentially used to compensate for the energy deficit due to inadequate energy intake. However, hypocaloric diets are also characterized by losses in lean body mass and total body water during the first ten to fourteen days.

The energy requirements of the SMEAT astronauts were predicted on the basis of previously referenced formulae published by the National Research Council. It is recognized that these requirements may vary considerably for any individual. The degree of physical activity is the important variable, and, at the same time, the most difficult one to assess in advance. It is also expected, but unproven, that there may be considerable variations in activities between individuals because of differences in individual biochemical efficiency. The loss of body weight in the SPT, in contrast to the lack of change in the others, was probably due to the fact that the investigators failed to appreciate this crewmember's propensity for vigorous physical exercise.

The SMEAT diets were very high in carbohydrate and elective energy was presented in carbohydrate form. This source of energy is considered to be highly suitable under the experimental conditions.

Consolazio et al. (1962) reviewed the role of carbohydrate in nutrition and pointed out that carbohydrate appears to be the preferred energy source for the working muscle, although it can be replaced by fat during starvation periods or during carbohydrate deficient intakes. The ratio of carbohydrate to fat utilized in the production of energy for the working muscle rises with an increase in work intensity or an increase in dietary carbohydrate. Muscle glycogen stores can be altered by changes in the diet and an increase in glycogen stores increases endurance during strenuous physical activity. Carbohydrates have been found to be four to five percent more efficient than fat as an energy source for the working muscles.

An increased protein intake for athletes has been a popular concept of trainers and coaches, but scientific evidence indicates that protein is not consumed by the working muscles. An athlete in training will usually consume a greater quantity of food to remain in body weight equilibrium, which will result in an increase in protein intake during this period. An increase in protein may be required during periods of combined body weight reduction, physical conditioning, and growth. A very modest amount of protein is obviously required for the maintenance of body muscle protein stores, but the idea that high protein intakes provide any benefit to muscle metabolism or function is known to muscle physiologists as a misconception.

Variations in urinary creatinine output are considered to be a combination of physiological changes, collection errors, and laboratory errors. A number of collection errors were recognized and procedures modified to preclude their occurrence in future use. The existence of abnormally high or low creatinine values was noted on several occasions and was ascribed to laboratory error. It should be noted that creatinine was measured by the autoanalyzer procedure for blood. Urinary creatinine determinations require modification of this procedure because of the variations in the pH of different urine specimens. No provision has yet been made for this. This may account in part for discrepancies observed in urinary creatinine excretion.

The magnitude of reported daily dermal calcium losses has varied considerably. It has been as low as 15 $\pm$10 mg in old patients (Gitelman et al., 1963), and as high as 0.8 to 2.0 gm in men at hard labor in the desert. (Consolazio et al., 1962). Schwartz et al. (1965) estimated dermal calcium losses to be about 100 mg/day. Isaksson et al. (1967), in studies with thirteen patients, showed dermal calcium losses varying between 20 and 365 mg/day.

During discussion of the GT7 flight, in relation to the very modest losses of calcium, Lutwak and Whedon raised the possibility that diminished atmospheric pressure, among certain other factors, might have been "protective." Although the atmosphere in GT7 and SMEAT-Skylab differed in gas concentrations, they were the same in atmospheric pressure. Thus, it appears from this study that diminished atmospheric pressure has no appreciable effect, or at

least no protective effect, on calcium metabolism. The absence of changes in calcium metabolism in this study indicates that a stable baseline observation has been made for Skylab as far as the effects of atmosphere or calcium metabolism are concerned.

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CHAPTER 8

SPECIMEN MASS MEASUREMENT

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Mass determination forms one of the cornerstones of engineering and scientific operations. The only devices previously available for such determination were gravimetric; hence, unusable in space flight to date. Skylab will, for the first time, attempt to make mass measurements in space with experiments M074/172. These experiments will use spring/mass oscillators for both investigation of the device's performance as well as routine measurements for food residue, waste, and human mass. They form an integral portion of several other major experiments and, as such, are essential to their success.

The SMMD (specimen mass measurement device) was selected for inclusion in SMEAT to investigate its performance under conditions realistic of Skylab. Stated objectives were:

1. Demonstrate mass measurement of the mass measuring device during the SMEAT chamber test.

2. Perform periodic calibrations of the mass measurement device during the SMEAT test to ascertain long term stability and repeatability.

Although not a stated objective, this test was used to develop and validate operational SMMD

procedures. All Skylab conditions except weightlessness were present, and this was partially simulated by placing the device in a plane such that gravity effects on the instrument's operation were virtually negated.

Installation and operation closely followed those planned for Skylab. Calibrations were performed more frequently, and several modes of residue and fecal measurement were tried to allow selection of the most suitable for Skylab operation.

This is a report of the methods used, results obtained, and their implications for Skylab. Although not strictly a part of this investigation, a number of factors affecting the overall accuracy of measurement of food and fecal samples were investigated and are presented in the discussion section.

Valuable assistance in data reduction was given by Ronald R. Lanier of the Flight Control Division, NASA, Johnson Space Center.

Description of Apparatus

Skylab mass measuring devices all use a mechanical (rectilinear) spring/mass oscillator in

which the period of oscillation is a function of the mass coupled into the system. After calibration with a series of known masses, sample masses may be calculated from the period of oscillation produced.

Figure 8-1 is a schematic of such an oscillator. If the masses are displaced a small distance X_1 from rest position X_0 and released, it will undergo undamped sinusoidal oscillation whose period (T) is measured by a timer. This period is given by the equation while the mass (M) may be calculated from:

$$M = A + BT^2 \qquad (1)$$

...where constants A and B are most easily determined from calibration of the system with known masses.

Mx	Specimen Mass
Mo	Tare Mass
K	Spring Constant
Xo	Position of rest
Xo	Maximum Displacement
T	Period of Oscillation

$$T = C\sqrt{\frac{Mx + Mo}{K}}$$
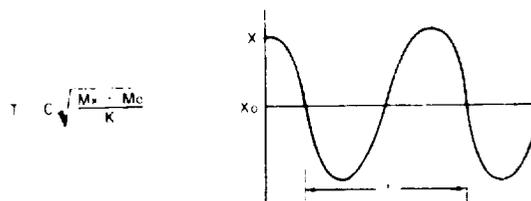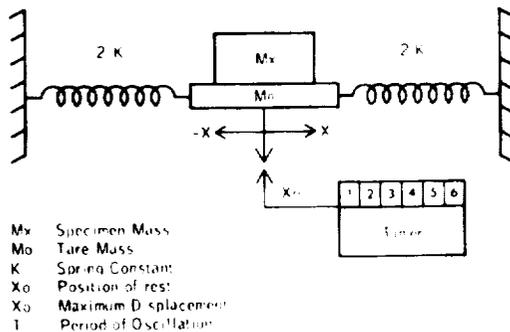
Figure 8-1. A simple spring/mass oscillator and its equation of motion.

Such an oscillating system is approximated by the SMMD design. A flexure pivot or plate fulcra made of spring material both supports and constrains the mass to approximately translational motion as well as provides restoring force when displaced. Timing to

10^{-5} seconds is accomplished by a crystal controlled digital timer with a six place readout. An electrooptical transducer sends a signal to the device's logic circuit each time the tray crosses the midpoint in its oscillating cycle. After two cycles have been completed to allow transients to decay, the total elapsed time for the next three cycles in tens of microseconds appears on the device's digital display.

The displacement and release of the mass is controlled by a single spring-loaded control lever which normally locks the mechanical oscillator and on manual rotation displaces and releases the tray and specimen mass to oscillate. A reset button on the electronic package sets the time to zero. Since these SMMD's were not designed with a zero temperature coefficient, temperature was to be internally measured. The electronics unit has a switch-selected measurement function with a sensor in its base for this purpose. A large flat tray with an elastomeric cover sheet is used to couple specimens into the oscillator system. The complete SMMD includes a series of solid calibration masses.

Operation consisted of turning the device's power on, resetting the electronics readout to zero, placing the specimen to be measured on the tray under the elastic sheet, and rotating and holding the operating lever until the counting cycle is complete. This reading was manually recorded for verbal transmission during a schedule report.

The SMMD was mounted on a replica of a set of Skylab wardroom cabinets vertically oriented in the SMEAT chamber head (Figure 8-2). Actual mounting in the cabinet consisted of supporting the SMMD base plate on the ends of vertical vernier bolts at four corners for leveling. These bolts fitted recesses in the plate, and contact was maintained by the large weight of mounting plate and SMMD. Neither cabinet nor mountings were as rigid as Skylab. A potential error source was the large amount of low frequency vibration in chamber structure generated by the environmental control system blower. This could be expected to increase the random errors. There was virtually no air flow or other potential error sources in the SMMD area.
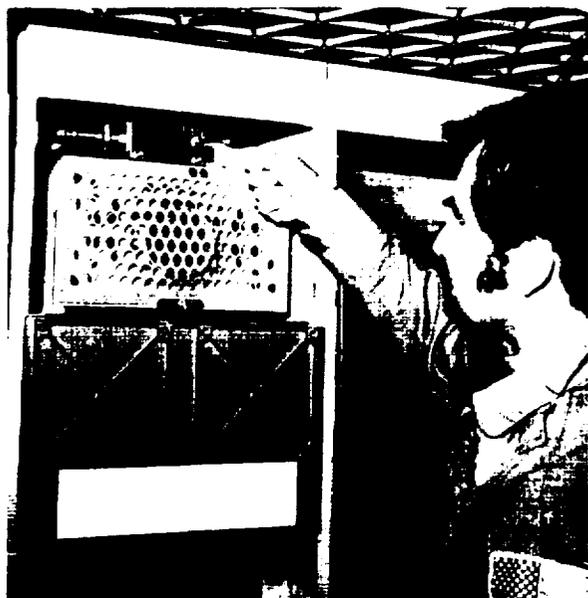
Figure 8-2. Specimen is weighed in the SMMD.

All weights other than the calibration masses were determined with an ordinary laboratory platform/beam balance scale (NASA T00837) placed in a cabinet immediately above the SMMD. The SMMD used in this test was a DVTU (development test unit), part 2837-002-01, Serial DH-1. It was essentially identical to flight hardware.

Data Collection

Since the device is a comparative rather than an absolute unit, calibration is required at least once every ten days both for operation as well as evaluation of the instrument. Briefly, calibration of the SMMD in the SMEAT chamber consisted of: (1) Verifying level by visual inspection of the bubble level; (2) Obtaining a starting temperature reading from the SMMD and independent sensors; (3) Inserting the proper mass in the center of the specimen tray; (4) Zeroing the electronic timer; and (5) Releasing the tray to oscillate.

This procedure was repeated five times for each mass unless unusual crew acceleration or other activity produced a period readout of more than 200 microseconds (20 counts) difference

from the average of the five readings obtained. In this event, the measurement was simply repeated. Calibration masses were: 0, 50, 100, 150, 250, 300, 400, and 500 gm, the range of masses capable of being measured by the SMMD at 1 g versus a maximum of 1,000 gm at 0 g.

At the beginning of the test, it had been planned to use the internal temperature measurement, but its inaccuracies prevented this, and a variety of work-arounds were tried, including use of the air probe sensors and digital thermometer from M487 and using air temperature measured by the environmental control system. Temperatures from these devices were taken from structure as close to spring supports as possible. These data are presented and discussed subsequently in this report. Since chamber temperature was constant and there were no significant heat sources in the associated structure, ambient chamber temperature proved to be the most practical.

It was originally intended to measure all food residue and feces, but no residue was ever available, and only fecal mass measurements were made. Several food residues were simulated. A variety of methods of folding or manipulating fecal bags was tried during the test. Although this has no effect on errors shown, which is gross mass of bag and contents, large errors in fecal masses can result from uncontrolled variations in packaging techniques. Several food residue measurement techniques were also tried. Since fecal mass measurement is interrelated with collection, the methods and probable errors given are discussed later.

It had been planned to pass the calibration and sample period data from the chamber verbally and have all calibration curve generation and mass conversion performed externally. Rough in-chamber conversions were to be made graphically. Gravimetric mass determinations of all samples were made in-chamber and also verbally passed out as were the actual samples which were then to be remeasured with high resolution balances and differences checked. Just prior to entry, a tiny digital computer (HP-35) became available and made mass

conversions using externally generated curve coefficients a simple enough task to be done in-chamber.

Data Reduction

Analysis

Ultimate performance of the SMMD is simply judged by how closely it determines the mass of any unknown sample as compared to the sample's true mass. This difference is designated ΔM. (Equation 1 is an approximation adequate for operational measurements.)

$$\text{Mass} = A + BT^2 \qquad (1)$$

A and B are coefficients determined by calibration with known solid masses using the regression equations 4a and 4b.

For examination of ultimate performance, a series of equations of higher orders are generated to fit the calibration points more closely. They are of the form:

$$\text{Mass} = A + BT + CT^2 + DT^3 \cdots NT^n \qquad (2)$$

Errors in mass M are related to period errors by:

$$\frac{\Delta M}{M} = \frac{2 \Delta T}{T} \qquad (3)$$

where: T is time of period(s), ΔT is error or variation in this time.

Errors, ΔT (hence ΔM), may be considered from several aspects, and the ones examined here are defined as:

Resolution is variation in recorded periods with a given sample in place and with repeated operations of the scale. This value determines the ultimate SMMD performance which may be expected and is a function of all short term errors in the unit such as zero crossing resolution as well as externally induced disturbances such as vibration.

Repeatability is determined by removing a mass, replacing it on the tray, and repeating the measurement immediately.

Drift is error over a longer period of time and is determined by measurements of the same mass separated by days or weeks of time.

Although omitted in the above discussion, temperature is assumed to be constant in the previous measurements. These devices were fabricated with appreciable temperature coefficients, so this error source must also be considered.

Since the primary objectives of M074 are evaluation of its performance as a nongravimetric mass measurement device, MMD (Mass Measurement Device) error source analysis is crucial. Expected sources include:

1. External vibrations which have components close enough to the natural frequency of oscillation to cause an error in period. Since the SMMD oscillation amplitude has been kept small, very low levels of external oscillation may cause appreciable period disturbances.

2. Any nonrigidity, i.e., "slosh," either in specimen mass or in coupling the specimen to the tray may result in secondary oscillations which, if the frequency is near the fundamental frequency, will cause errors. This is the major limitation in the utility of this type of mass measurement.

3. Any lack of rigidity in either the mounting or supporting structure of the device can produce either coupled compliances or resistances which may alter oscillation period.

4. Any mechanical or other disturbance to the tray such as air streams or mechanical interference are fairly obvious error sources.

5. In 1 g use, the plane of oscillation must be normal to gravity, or a pendulum effect with shifts in period will otherwise occur; hence, the need for careful leveling.

6. "Internal" errors determine ultimate accuracy available and include errors of

spring/plate fulcra (which cannot be separated from overall mechanical design) such as spring rate drift, hysteresis, creep, and temperature effects.

7. Accuracy of the counting circuit and the resolution of the zero-crossing detector determine ultimate resolution and accuracy.

8. Not so obvious an error source is the "tare mass" or mass of the specimen tray and associated structure. Overall accuracy is limited by tare mass as follows. The maximum SMMD resolution available is ΔM, a relatively fixed value of M_0 (tare mass). However, the error of interest is the fraction of specimen mass M_x or $\Delta M/M_x$: thus, when M_x is small when compared to M_0 (tare mass), appreciable errors can result as in the case of measurement of small food residues.

9. Second and third order errors include buoyancy generated in gravimetric mass determination and a virtual mass of air which moves with an object at low velocities.

Data were analyzed as follows. Calibration masses were accurate to five significant places and thus assumed to have negligible error and became standards. All other sample masses were determined from the gravimetric balance which was in turn compared to the calibration masses as shown in Table 8-1. Weighed sample masses were corrected to the calibration masses. The gravimetric scale was obviously sensitive to the location of weights on the pan. This was its largest error source and could easily be one-third gm or more without careful centering of small objects. Resolution of .05 gm was possible with this scale, although 0.1 gm would be a more conservative figure. Dis-

Table 8-1

Indicated Weights From Gravimetric Balance₁ vs. Calibration Masses

Calibration Mass Grams	Scale Reading Grams	Date J.D.	Difference %
0.0	0.00	179	0.0
50.00	50.04	179	$8. \times 10^{-2}$
100.00	100.03	179	$3. \times 10^{-2}$
150.00	150.3	179	2×10^{-1}
250.00	250.28	179	1.12×10^{-1}
300.00	300.50	179	1.66×10^{-1}
400.00	400.58	179	1.45×10^{-1}
500.00	500.62	179	1.24×10^{-1}
100.00	100.05₂	203	$5. \times 10^{-2}$
100.00	100.06₃	203	$6. \times 10^{-2}$
100.00	100.35₄	203	3.5×10^{-1}
100.00	100.10	222	1×10^{-1}
90.00₅	90.08	222	8.9×10^{-2}
95.00₅	95.08	222	8.4×10^{-2}

1 - NASA Scale #T00837

2 - X 10 Scale

3 - X 1 Scale

4 - ≈ 6 cm. Off Center

5 - Laboratory Standard Masses

crepancies between the standard and measured weights amounted to some one- to two-tenths of a percent at masses above 100 gm and slightly less than that at lower masses.

The first five readings were always recorded to allow study of maximum period variation. If drift or some overt instability were present, a sequence would be repeated as necessary.

Straight-line calibration curve coefficients were calculated from:

$$\text{a. } B = \frac{\Sigma XY - \bar{X}\Sigma Y}{\Sigma X^2 - \bar{X}\Sigma X} \qquad \text{b. } A = \bar{Y} - B\bar{X} \qquad (4) \text{ a\&b}$$

$X = T \text{ (period)}^2$
$\bar{X} = \text{average } X$
$Y = \text{mass}$
$\bar{Y} = \text{average } Y$

A computer program was used to generate a curve to calculate empirically a series of equations of the form shown in Equation 2 up to the fifth order. Each curve was then used to calculate masses at each calibration point. Best fit was selected by comparing calculated to actual values.

Determination of and subsequent compensation for temperature was a problem. Table 8-2 shows a series of indicated temperature readings by the SMMD versus either measured temperatures on structure near the springs felt to be in equilibrium with them, or else ambient temperature if it had been stable for several days. The first temperature on a given day was taken immediately after the SMMD power had been turned on while the second was just prior to power being turned off.

Until day 240, the SMMD temperature seems to bear a relatively constant, though erroneous, relationship to that which actually existed, but after that there was little relation between the two. A second problem with the SMMD internal thermometer is that the electronics' heat induces errors after a short period of usage.

Calibrations were first made with and without temperature corrections. Such corrections were based on indicated temperatures and a temperature coefficient supplied by the fabricator and apparently derived using the SMMD internal temperature measurement, and, as such, produced errors. The temperature was measured independently at each calibration and data were not "corrected" to some standard temperature but rather the apparent differences in mass were used to generate an accurate temperature coefficient. This latter figure is of interest in defining temperature coefficients but is not required to meet operational sample measurements. Measurements shown here are not temperature corrected.

Table 8-3 is a tabulation of several aspects of all calibrations and includes the average of all periods at zero mass both at the beginning and end (O_1 and O_2) of the calibration period, of the 250 gm calibration sequence, the total variation in period at each sequence (resolution), differences between O_1 and O_2 during a calibration period (short term drift), and differences in the average periods of O_1, O_2, and 250 mass sequence from the initial calibration (long term drift), temperature as measured by independent methods, and the straight-line calibration curve constants A and B. The initial calibrations were separated since on day 240 and after the SMMD had been altered. It would be more accurate to take the mode rather than mean period of oscillation if a sufficiently large number of cycles had been available to select a mode.

Table 8-4 contains values from three representative periods of fecal mass measurement, early, mid and late in the test. Values include date and sample identification, gravimetric mass, gravimetric mass approximately corrected to SMMD standard masses, mass difference, and percentage difference of fecal mass plus bag and wipes and percentage of estimated fecal mass. The latter was obtained by subtracting an estimated 110 gm for bag and wipes from total gross. The SMMD mass is calculated from Equation 1 using the required number of significant figures. No temperature corrections were used since a calibration curve at the stable temperature of each period was available.

Table 8–2

SMMD Indicated vs. Measured Temperature

Date	Time	Indicated Temperature °F.	Measured Temperature °F.	Temperature Error °F.	Indicated Temperature Rise °F.
17 /	1423	70	67	+3	
	1425	73	67	+6	3
182	1346	74	71	+3	
	1405	77	71	+6	3
2.6	1745	73	70.5	+2.5	
	1800	76	70.5	+55	3
727	1503	77	73	+4.	
	1531	80	73	+7.	3
240	1456	82	77	+5	
	1509	83	77	+6	1
246	2307	75	68.5	+6.5	
	2309	77	68.5	+8.5	2
251	1440	77	68	+9	
	1455	78	-	-	-
	1507	79	68	+11	2
25 /	0346	74	68	+6	-

Table 8–3

Some Values of SMMD Calibrations

Mass Date/Grams	Average Period(T) Seconds	Drift Long Sec.x10⁻⁵	Drift Short Sec.x10⁻⁵	Resolution Sec.x10⁻⁵	Measured Temp F°	Calibration Curve Coefficients A	B
	1.34702			55	71	-618.477	161.74
	.44773		-29	9			
	.32707			5			
	1.34405	-47		9	70.5	-618.354	161.022

Table 8–3 (Continued)
Some Values of SMMD Calibrations

Mass Date/Grams	Average Period(T) Seconds	Drift Long Sec.x10^-5	Drift Short Sec.x10^-5	Resolution Sec.x10^-5	Measured Temp F°	Calibration Curve Coefficients	
						A	B
		-40	-22	6			
		-46		7			
		-35				-?18.684	162.944
		-19	-12				
		-9					
		-13		16		-?18.243	162.?31
		-19	23	13			
				13			
	1.?4881	-21		8		-618.190	162.?3?
	1.04258	-15	23	14			
	2.3?74?	-27		10			
	1.94?01	-1?		13	7	-162.961	-618.3?4
	1.9486?	-11	-29	14			
		-13		7			
	1.?4?4?	+2		12		162.915	-618.3??
		+5	-36	19			
		+11		5			
	1.?4??	-21		9		?.?4?	-618.3??
		-30	-38	7			
		-29		1?			
		-30		?	70	162.047	-618.071
		-18	-27	?			
		-2?		8			
	1.?4784	-118		39	73	162.983	-617.874

Table 8–3 (Continued)
Some Values of SMMD Calibrations

Mass Date/Grams	Average Period(T) Seconds	Drift Long Sec.x10⁻⁵	Drift Short Sec.x10⁻⁵	Resolution Sec.x10⁻⁵	Measured Temp F°	Calibration Curve Coefficients	
						A	B
	1.94740	-124	-35	4			
	1.30633	-134		15			
	1.4751			5		174.175	-107.17
	1.4571	-100	-30	9			
		-134		15			
	1.4571			8	77	195.151	
			31	4			
	1.5475			9			
	1.494	+433		14	68.5	127.270	
	1.475	+451	30	6			
	1.45064	+45		21			
	1.38753	+400		20	68	257.154	-71.154
	1.4717	+463	44	9			
753	1.35151	+447		11			
	1.3880	+458		13	68	257.576	
	1.3877	+433		44			
25	1.35741	+537		39			
	1.8861	+439		20	68	157.566	
	1.38733	+399		11			
299	1.35186	+476		8			

In when performing calibration.

   = Cdr.

B = Plt.

= Spt.

Table 8-4

Accuracy of Fecal Sample Mass Determinations

Date	Sample Number	Gravimetric[1] Mass Grams	SMMD Mass Grams	Error Grams	% Gross Error	Net Error %	Period Resolution Sec.x10^{-5}
904	FC 1547	246.84	247.70	+.86	.3	.1	23
	FC 1544	275.41	275.26	-.15	-.054	-.061	11
	FC 1549	212.34	212.75	.26	.12	.25	55
919	FC 1546	254.1	255.2	1.1	.42	.77	03
	FC 1542	187.15	188.87	.72	.39	.74	
921	FC 1541	165.91	169.33	3.42	2.04	4.1	27
	FC 155	277.5	278.28	.77	.27	.4	5
	FC 1512	171.3	172.85	2.55	1.1	4.1	4
922	FC 1527	257.55	257.08	.48	.1	.3	27
	FC 1526	186.15	188.58	-.07	0.037	5.03	23
	FC 1524	207.4	209.2	1.8	.87	1.8	14
929	FD 1782	174.37	178.3	-.16	.14	.19	3½
	FD 17	277.88	278.41	-.47	.17	.17	14
	FD 1777	144.43	143.99	-.44	.31	1.35	1
	FD 1786	183.7	184.05	.45	.29	.61	3
931	FD 1790	206.90	206.79	-.29	.14	.36	21
	FD 1804	198.00	199.16	1.16	.59	1.30	15
	FD 1805	191.43	191.08	-.35	.16	.43	10
960	FD 1753	159.45	160.21	.91	.57	1.86	77
	FC 1517	231.6	233.74	2.14	.92	1.75	42
	FC 1516	173.83	175.58	+1.74	1.00	4.14	19
960		179.83	181.50	1.67	.93	2.38	48

[1] Corrected to SMMD calibration mass

Table 8-5 shows the results from several simulated food residue measurements. Table 8-6 shows the accuracy of fit of various calibration curves from Equations 1 and 2.

Results

The RMS errors for the third and fourth order calibration curves were similar and the practical best accuracy which could be obtained was .0238 percent and .0244 percent RMS error respectively with a range of .009 percent minimum at 500 gm to +.03464 percent at 100 gm. This compares reasonably well to prototype errors on the order of .01 percent. Resolution at 250 gm using calibration masses was typically 3.95×10^{-2} percent or .0089 gm. Drift over a ten-day period averaged 5.329×10^{-2} percent or .1332 gm.

A worst case error over a ten-day period at 250 gm should thus not exceed .256 gm or .102 percent. Short term resolution at small masses was on the order of 100 mg. Temperature coefficient appears to be on the order of 45 counts/°F or .125 percent/°F at 250 gm (.313 gm).

Fecal masses had typical net errors of .5 to .75 percent with normal samples, but occasionally small samples exceeded 2 percent. Gross fecal samples (wipes and bag) were typically less than 0.5 percent with occasional errors on the order of 2 percent.

Table 8-5

Food Residue Determinations

Item	Mass Gravimetric Grams	Mass SMMD Grams	Error Grams	Error Percent
Urine #LW0-7[1]	5.7	41.75	+1.95	5.
Urine #56-377[1]	7.7	47.77	+1.07	2.
Urine #12-347[1]	44.37	45.25	.88	2.
... + ...[2]	45.24	45.72	+ .7	.7
...[2]	5.55	44.75	+1.24	7.7
... 2 ...[2]	45.5	44.41	+1.09	7.5
...	25.5	115.04	+1.54	.4
... A -	155.30	158.74	+3.44	
5 -	163.25	163.58	+ .33	... x ....

1 · Liquid in Skylab drink containers.

2 · Tissues used to constrain liquid.

The food residue measurements shown are not exhaustive and, in fact, a number of additional determinations were made. These, of course, must be supplemented with a great many more runs with the definitive flight procedures prior to flight. Free liquid, i.e., liquid with a large air interface or in a container with large dimensions in the plane of oscillation, will produce large errors. Conversely, the small samples of more viscous materials (corn, sauces, etc.) produced surprisingly large errors on the order of two gm which could never be explained. Larger, more liquid samples with tissue entrapment were measured accurately.

Discussion

The SMMD performed satisfactorily as a non-gravimetric instrument for mass measurement within the accuracies required for support of the associated medical tests. It was reasonably quick and easy to use. The chief operational problem was recording and verbally transmitting considerable amounts of time data which then required translation into mass, i.e., the device was not direct reading as such an operational instrument should have been.

As a tool for rigorously investigating a new method, it had predictable limitations. Lack of a workable temperature-sensing system can probably be worked around, but this is a problem with the instrument's large temperature coefficient. The large tare mass of the specimen tray makes high resolution studies impossible. It performed well as regards drift, but showed moderate sensitivity to mass position, undoubtedly a byproduct of the large specimen tray and plate fulcra design.

Some care will be required in measurement of food residue to prevent slosh and resulting errors. An overbag and enough tissues to soak up liquids will produce acceptable results here. Careful accounting will be required to insure that no errors in adding wipes to fecal and food samples occur.

Table 8-6

SMMD Calibration Curve Errors

Equation:	1		2 2nd Order		2 3rd Order		2 4th Order		2 5th Order	
Calibration Mass Grams	Calc Mass Error Grams	Error Percent	Calc. Mass Error Grams	Error Percent	Calc. Mass Error Grams	Error Percent	Calc. Mass Error Grams	Error Percent	Calc. Mass Error Grams	Error Percent
0	[illegible]		[illegible]	-	[illegible]	-	[illegible]	-	[illegible]	-
[illegible]	.0066	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.03579	-.07346
[illegible]	-.314	[illegible]	[illegible]	[illegible]	.03464	[illegible]	[illegible]	.03887	.04433	.04433
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.01097	.06554	.04368
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

COEFFICIENTS

Curve Order	A_0	A_1	A_2	A_3	A_4	A_5
2nd	[illegible]	[illegible]	[illegible]			
3rd	[illegible]	[illegible]	186.502	[illegible]		
4th	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
5th	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.332

Eqn. 1 – $M = 618.477 + 162.962\ T^2$ (Cal. from Day 208)

Eqn. 2 – $M = A_0 + A_1T + A_2T^2 \times A_3T^3 + A_4T^4 + A_5T^5$

Discrepancies

The temperature measurement system was inaccurate and unreliable.

After some ten days of use, the elastomer specimen hold-down sheet began to pull loose from its lower clamping rail. It pulled completely loose at several points by day 234, and was passed from the chamber where the sheet and clamping rail were replaced. The mechanical portion of the unit was autoclaved twice before being returned which apparently stressed springs or structure such that performance was markedly different from the first portion of the test. After return on day 240, period readings were erratic, and there was a frequent large drift. This is not so readily apparent from the recorded data since they were filtered prior to recording, i.e., the crew would wait until the worst drift was over or not record obviously spurious readings. In addition, the zero-crossing detector was found to be loose after the chamber run. For these reasons, data from day 240 onward are not considered representative.

The replacement clamping rail for the elastic sheet was a heavier, more rigid, element than the original, which was thin and flexible, and did not distribute pressure evenly resulting in stress points on the sheet. This replacement appeared to solve the problem.

Although mass determination is an obvious error source, other much larger errors can easily accrue to make worthless the efforts to obtain a good MMD instrument. Some of these errors in fecal specimen measurement are examined.

Fecal samples are collected in a bag with self-adhesive surfaces which prior to use are

covered with plastic backing. In addition, six wipes are nominally used and placed in the bag but more than this may be required.

Several possibilities of error present themselves. First, the bag weight must be known. Table 8-7a is a typical listing of seventeen bags. It appears that the bags were handled in lots since, as shown by this sampling, there was large variation in accuracy of recorded weights. Some lots were close to marked weights while others showed typical errors recorded.

Table 8-7b shows the consistency of mass of the total amount of adhesive backing tape. Variation from maximum to minimum weight is 0.29 gm. As expected, this die-cut material is very constant, and a fixed average value can be used with negligible error, so long as all of it is consistently accounted for, i.e., the same procedure is used each time. Portions of this backing weigh approximately 2.5 gm each.

The most likely source of error is accounting for the number of wipes used. Table 8-7c shows

Table 8–7a

Measured vs. Recorded Fecal Bag Weight

Bag I.D.#	Measured Weight * Grams	Recorded Weight (on bag) Grams	Weight Error Grams	Error Percent
FD 1790	97.77	99.90	2.13	2.18
88	96.90	97.00	.10	.10
87	96.30	97.30	1.0	1.04
86	96.08	99.70	3.62	3.76
5	95.15	95.65	.50	.53
4	97.68	100.03	2.35	2.41
3	97.18	99.58	2.40	2.47
FD 1858	96.72	97.10	.38	.39
49	99.22	99.48	.26	.26
31	95.22	95.11	-.11	-.12
30	96.36	96.15	-.21	-.22
29	99.44	99.45	.22	.22
28	95.55	95.36	-.19	-.20
27	96.93	96.54	.39	.40
25	96.60	96.55	-.05	-.52
FD 1791	95.32	97.40	2.08	2.18
1792	97.14	100.11	2.97	3.05

* Corrected to cal. weight.

Table 8-7 (Continued)

Measured vs. Recorded Fecal Bag Weight

(b) Fecal Bag I.D.#	Adhesive Tape Backing Total
—	10.52
FD 1848	10.60
1830	10.25
1831	10.47
1838	10.43
1787	10.48
1805	10.42
1806	10.31
—	10.35
—	10.35
1846	10.50
	10.474 Avg.

(c) Weight of Wipes
2.6 gm.
2.5
2.5
2.6
2.65
2.57 Avg.

Average weight of another sample of 63 wipes was

2.798 gm.

some typical wipe weights. As would be expected, they are very consistent in weight from item to item, but there were at least two lots of wipes used in SMEAT. Another sample of 63 wipes averaged 2.798 gm. An error of wipe count is likely and one to two wipes can cause appreciable errors. This, plus errors in bag weights and possible differences in techniques of adhesive backing disposal, can easily produce errors of ten gm or more.

It is recommended for Skylab that:

1. The sources of bag weight error be found and corrected.

2. A fixed procedure for removal of adhesive backing be instituted and followed.

3. Wipe weight determination be made and wipe count rechecked on return.

4. Most importantly, personnel using specimen data become aware of error sources and take appropriate precautions.

Measurement of food residue samples, like fecal sample measurement, will depend very much upon procedures used. At the moment, these have not been delineated. The following is a resume of error sources and recommendations of procedures.

Food packages vary widely including: beverage containers, an accordion-folded plastic cylinder with a push-pull valve; several can arrangements with pull-ring top removal, including small cans of custards, candies and peanuts; a separate larger can with plastic internal container and a water valve for rehydration, and with a plastic diaphragm for large cans of wet-packed foods such as fruits in syrup and applesauce; and large cans with frozen foods such as filets, shellfish in sauce and ice cream. Apparently, a new design for dehydrated foods will be used for flight. It will have a semirigid section to fit the larger cans with a sealable plastic membrane extension.

Regardless of food residue, two requirements must be met for satisfactory mass determination. The object(s) must be secured to the SMMD specimen tray. They must be prevented from sloshing. Of all the schemes tried, the following was the most practical. Small custard cans with or without the lid may be placed directly on the scale. A plastic bag with some form of liquid-tight closure is required for other measurements. Those cans with particulate materials such as candies and peanuts should be emptied into the plastic bag which is then placed on the specimen tray such that all contained particles are under pressure by the elastomer sheet.

Depending upon the final container configuration, the plastic inner containers should be removed from the cans and either sealed or placed in the plastic bag which is sealed. Any homogenous foods can be measured directly since they are viscous enough not to slosh. Most of the wet-packed foods (with the possible exception of applesauce) and the frozen items should be placed in the bag with its can and sufficient wipes to absorb any free liquid and the assembly place l under the specimen restraint. Using these procedures, accuracies sufficient for support of the metabolic analysis should be obtained.

Equally, or even more important than mass measurement technique is the accounting of all objects in the gross mass figure, i.e., type and number of containers and wipes. It is equally important to insure that an accurate known mass is available for all of these items, i.e., can weights and wipe weights should be accurately known. Both cans (and their lids) and wipes have uniform weights to a small fraction of a gram. It is assumed that any plastic bags used will also be uniform or else weighed and stamped.

If such procedures are instituted and followed, accuracies adequate to support the metabolic experiments will be attained.

Body Mass Measurement

Although not directly associated with M074 and the SMMD, there was opportunity to verify a crucial component of M172 (body mass measurement experiment) during the SMEAT test. In this experiment, food trays are to be used as calibration masses. One might reasonably expect some change in these masses either through evaporation of volatiles or through addition of food residue. To determine magnitude of such changes, all four food trays were accurately measured by the NASA calibration lab using[1] balances #41689 and CO 3586 and mass sets #46994 and CO 2731. Results are shown in Table 8-8. In the absence of any consistent trend, no valid conclusions can be drawn.

Table 8–8

Calibration Data for Four Food Trays

Tray Serial Number	Pre-test Mass Kilograms	Post-test Mass Kilograms	Difference Grams	Difference Percent
4904[2]	10.95175	10.94848	-3.27	-2.99×10^{-2}
4910	11.03376	10.97474	-59.02	-5.35×10^{-1}
4911	11.10955	11.10888	-0.67	-6.03×10^{-3}
4912	11.00276	10.99907	-3.71	-3.37×10^{-2}

In the absence of any consistent trend no valid conclusions can be drawn.

One could postulate that both evaporative losses and residue additions had occurred. The magnitude of loss would be negligible except for 4910.

[2]Spare unit

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[1]Three trays were used and one was kept in the chamber as a spare.

One could postulate that both evaporative losses and residue additions had occurred. The magnitude of loss would be negligible except for 4910. This should produce an error well above the resolution of the BMMD (body mass measuring device) for analytical studies; hence, bias them and if such a loss continued for two flights, it would produce a detectable and variable bias in the body weights.

Summary

The Skylab specimen mass measurement device was operated throughout the SMEAT test in close simulation of the 56-day Skylab mission. It performed operational specimen measurements well until it was passed out of the chamber for replacement of the specimen hold-down and was autoclaved prior to return. Performance after this is not considered representative.

Fecal measurements were typically made with less than one percent error with small samples occasionally exceeding this. No food residue was available, but simulations were made. By using a mylar bag for containment and paper wipes to entrap liquids, measurements of less than 2 percent are routine.

Present Skylab procedures are adequate for calibration, but the specimen mass determinations should be reduced to three readings without temperature. Careful documentation of number of wipes, etc., will be required to maintain overall accuracy.

This SMMD performed well as regards to stability and period resolution. It has a large (for rigorous analysis) temperature coefficient and this, coupled with a faulty temperature measurement, requires an independent temperature determination during calibration.

This temperature problem and a very heavy specimen tray limits its utility as an investigative tool. With larger calibration masses it has reasonably good accuracy, on the order of .05 percent. Maximum resolution is on the order of 50 mg at small masses. Stability for ten-day periods was on the order of 175 mg.

CHAPTER 9

BONE MINERAL MEASUREMENT — EXPERIMENT M078

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Gravitational loading and countergravitational muscular effort are thought to play an important part in maintaining skeletal strength. Loss of minerals from the bones is a consistent finding in studies using various analogs of weightlessness, including bedrest, water immersion, and immobilization (Mack et al., 1967; Mack & Vogt, 1971; Vogel & Friedman, 1972).

Space flight findings concerning bone mineral loss have been variable. Bone mineral loss has been seen in some astronauts and not in others, using both the bone densitometric X-ray technique and the more precise gamma-ray absorptiometry method. Bone mineral losses have also varied from site to site in the body, being more evident in the lower extremities, especially in the os calcis (Hulley et al., 1972). If these losses are indeed a consequence of weightless space flight, the issue of whether they are self-limiting or continue unabated over time becomes of paramount importance.

The Skylab Bone Mineral Measurement Experiment (M078) has been designed to clarify the issue of bone mineral loss associated with prolonged periods of residence in the zero gravity environment. There are, however, other variables in the space flight environment which could perhaps mediate bone mineral losses. The SMEAT Program afforded the opportunity to isolate these variables, notably the Skylab atmospheric/pressure environment, from the weightlessness variable. While these two factors may not have played a demonstrable role relative to bone mineral loss in the shorter Apollo missions, they could conceivably be more significant factors in the 28- and 56-day Skylab missions.

A group of control subjects was also studied in conjunction with the SMEAT bone mineral measurement experiment. These individuals were included so that the effects of confinement and cabin environment, if any, could be calculated. With this design, it was expected that the effects of weightlessness could be isolated from other factors which might be operative in bone mineral loss, and that the magnitude of each of the factors involved could be assessed.

The immediate objective of the SMEAT bone mineral measurement experiment was to determine by comparison of pretest and posttest measurements what effect, if any, 56 days of residence in a Skylab-type environment might have on the mineral content of the left os calcis (heel bone) and the right radius and ulna (forearm) of the three SMEAT crewmen and five controls.

Equipment

Bone mineral measurements were made employing the gamma-ray absorption technique, using a rectilinear scanner fitted with a gamma-ray source and a scintillation detector mounted opposite each other. With this method, the heel bone, or any limb being examined, is placed on a stationary platform between the photon source and the detector. The detector and source are designed to move synchronously in order to measure the beam attenuation caused by the bone positioned between them: the higher the count rate, the lower the mineral content.

Bone Mineral Measurement Device — Description

The bone mineral measurement unit is depicted diagrammatically in Figure 9-1a and 9-1b. It consists
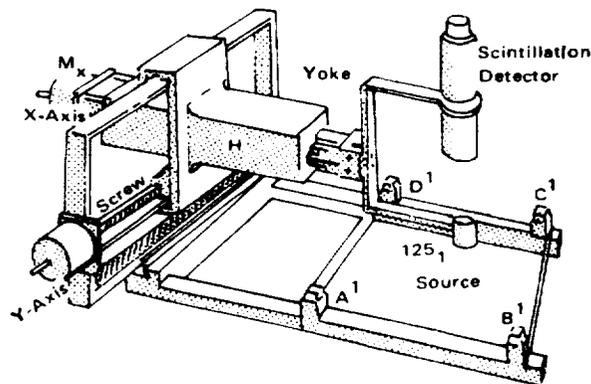
(a) Scanner Diagram
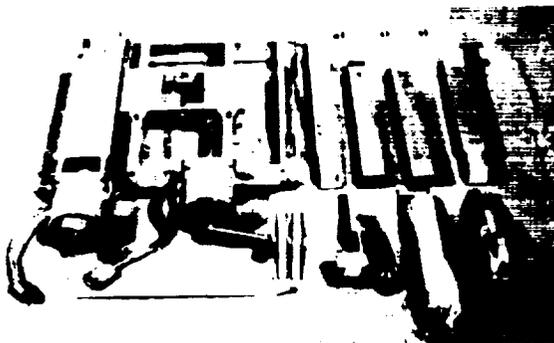
(b) Scanner Disassembled

Figure 9-1. Scanner.

principally of a scanning yoke, which holds the collimated photon source and a collimated detector: an apparatus for moving the yoke: and devices for positioning the limb to be scanned. The photon source is 400 mCi of ^{125}I; the detector is a thin (3 mm) sodium iodide crystal (NAI-th) coupled to a photomultiplier tube: both source and detector are collimated to 3 mm. Since ^{125}I is a low energy source, the thin crystal eliminates noise and high energy background.

The device can operate in two configurations, one for heel scanning (Figure 9-2) and one for arm scanning (Figure 9-3). Scanning is accomplished by movement of the yoke in two separate axes, the x-axis and the y-axis. The conversion of the scanner from one configuration to the other requires a $90°$ rotation of the frame with respect to the base and a $90°$ rotation of the yoke with respect to its mounting stud.
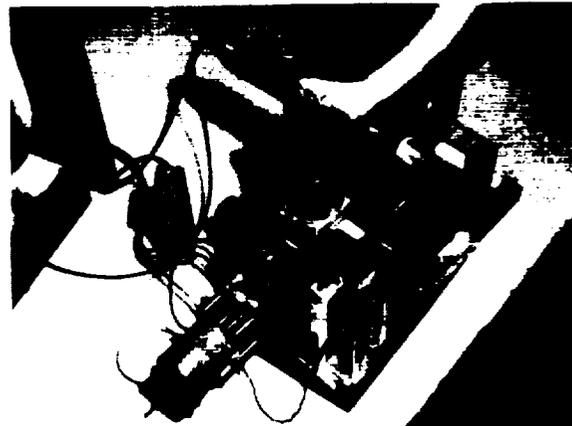
Figure 9-2. Heel scanning configuration.

Positioning. Two interchangeable tables, which mount on a common holder that slides on the scanner base, position the limb for scanning and hold it stable. The base is locked into position by thumbscrews.

Scanner Control. The stepper motors are accurately controlled by a miniaturized, digital scanner control instrument. The scanner control module weighs seven pounds (3.2 kg) and is housed in

an instrument bin with the data collection electronics.
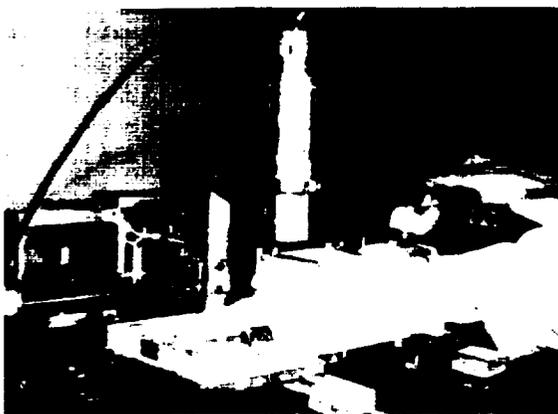
Figure 9-3. Arm scanning configuration.

The motion of the yoke along the x-axis is controlled by a quartz crystal oscillator and digital frequency synthesizer.

The yoke is driven on both axes by means of precision stepping motors. Each stepping impulse turns the motor through $1.8°$ of arc, or 200 steps per revolution. A microswitch on each axis determines an exact reference point for repositioning.

Data Collection Electronics

The signals from the photomultiplier are amplified by a linear amplifier and the photo peak pulses are selected by a single channel analyzer. These pulses are counted for an interval set by the scanner control and then punched on paper tape for subsequent processing by a computer. A linear ratemeter monitors the count-rate in real time.

Calibration

Standards were scanned before and after each subject to calibrate the entire system. The Cameron Standard used consists of a block of plastic containing three chambers filled with dipotassium hydrogen phosphate to stimulate bone mineral attenuation (Witt et al., 1970). A hydroxyapatite step wedge was scanned weekly to calibrate the Cameron Standard in terms of hydroxyapatite attenuation (Heuck & Schmidt, 1960).

Data Reduction

Data on punched paper tape was fed into a computer for calculation. Bone mineral content (BMC) is calculated from the formula:

$$BMC = K \sum_i \ln \frac{I_{o^*}}{I_i}$$

where K is the attenuation coefficient, I_{o^*} the average count rate through soft tissue, and I_i the count rate through bone. The program determines the bone edges and width and calculates I_{o^*} to minimize the effects of fat (Vogel, 1971). For the heel, I_{o^*} is determined on the lean side only. The reported BMC is the average over nine rows in the central os calcis and seven rows of the distal radius and ulna.

Procedures

The scan procedure was essentially the same as used on Apollo 14, 15, and 16 (Vogel, 1971). Simultaneous scans were made of the left os calcis and right forearm of each subject beginning 44 days pretest and ending 20 days posttest. Before the first measurement, an impression was made of each subject's foot and a plastic mold fashioned from this impression.

During scanning of the os calcis, the heel rested in the foot mold which was mounted in a plastic box filled with water, as shown in Figure 9-2, to provide a constant tissue equivalent path.

During arm scanning, the arm lay horizontally between two plastic vertical uprights on the arm tabletop, as pictured in Figure 9-3. A peg in a movable hand rest was positioned to hold the arm with the ulnar styloid opposite a reference in the upright. A constant path length tissue equivalent was obtained in this case by surrounding the arm with Superstuff* covered with a thin plexiglass sheet (see Figure 9-3). Sixteen parallel rows** (3 mm apart) were scanned.

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*WHAM-O Corporation, San Gabriel, California.

**A traverse by the x-axis ram constitutes a row during which data are collected. A second movement, by the y-axis unit, in between rows constitutes an increment, during which no data are collected.

The initial heel positioning was determined in prescan X-rays. Final positioning is provided both by the heel mold and by matching a heel profile made by plotting heel width versus location. A contour display (Figure 9-4) of each scan could be compared with the X-ray to verify positioning.

SMEAT commander, showed a loss of bone minerals posttest which could indicate a statistically significant trend. The commander's loss of 3.1 percent of bone minerals below his baseline measurement on the first day after the test may indicate some os calcis mineral loss. It should be noted, however, that the loss is of borderline significance. The science pilot also had negative percentages of bone mineral after the test, particularly on day 2, but, since his preflight baseline

Figure 9-4. Gamma-ray contour display of foot.

Results/Controls

Table 9-1 shows the percentage change from baseline bone mineral measurements for the heel bone of the crew and controls. These data are shown graphically in Figure 9-5. Only one crewmember, the
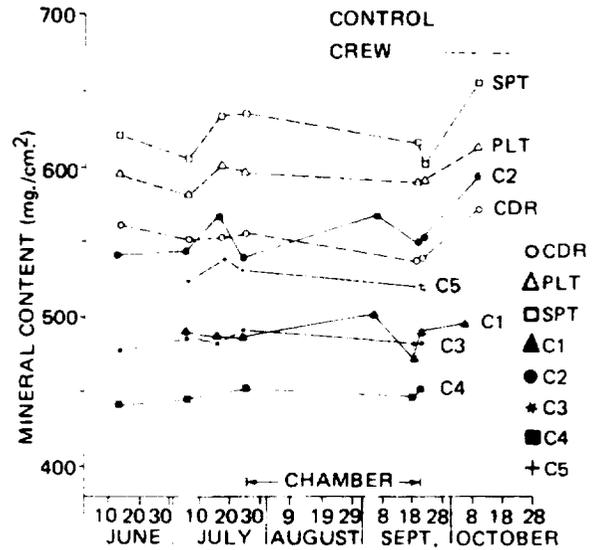
Figure 9-5. Changes from baseline bone mineral measurements in heel bone of SMEAT crew and controls.

Table 9-1

Percent Change From Mean Baseline Bone Mineral Measurements

	Crew			Controls				
	CDR	SPT	PLT	C1	C2	C3	C4	C5
T − 44	+1.0	−0.6	+0.2	−	−1.2	−1.8	−0.9	−
T − 20	−0.7	−2.9	−2.0	+0.5	−0.9	+0.2	−	−1.5
T − 9	−0.4	+1.6	+1.2	−0.4	+3.5	+0.2	−0.5	+1.4
T − 1	+0.1	+1.9	+0.6	−0.2	−1.5	+1.3	+1.3	0.0
R + 0	−3.1	−1.0	−0.4	−	+0.5	−	−	−
R + 1	−	−	−	+0.3	−	−0.3	+1.3	−2.1
R + 2	−2.7	−3.4	−0.2	−	+1.2	−	−	−2.5
R + 16	−	−	−	+1.5	−	−	−	−
R + 20	+3.1	+5.4	+3.6	−	+8.7	−	−	−

also tended to run in the negative direction, this apparent postflight loss cannot be considered significant. The apparent increase in bone mineral content on 10/10/72 indicated in Figure 9-5 must be attributed to instrumental variation since both controls and crews showed substantially higher levels at the time of this measurement.

Percent deviation from baseline for the right radius shows no significant variation in either crew or controls. The posttest ulnar measurements, however, show a substantial increase in bone mineral measurement for the science pilot. No change was evidenced in the remainder of the crew or controls. While ulna measurements typically show a larger variance from baseline than do radius measurements, the gain shown by the science pilot in this experiment indicates a true significant change. These results are shown in Table 9-2.

Equipment Problems

The equipment problems and procedures noted during the SMEAT bone mineral experiment for the most part have been resolved. The SMEAT test led to various refinements in equipment and systems. A drift in calibration was rectified by the use of a precision high voltage power supply in lieu of the previously employed battery powered system. Mechanical problems with the scanner have been resolved by replacing the drive mechanism. (The cause for the apparent R + 20[*] increase in bone mineral content, seen in crew and controls alike, and connected with instrument electronics problems is being investigated so as to prevent its recurrence.)

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[*]Twenty days after recovery.

Table 9-2

Right Ulna Mineral Measurements
(Mean gm/cm)

	Crew			Controls				
	CDR	SPT	PLT	C1	C2	C3	C4	C5
T − 44	0.554	0.699	0.846	−	0.658	0.650	0.563	−
T − 20	0.558	0.705	0.812	0.760	0.665	0.671	−	0.565
T − 9	0.587	0.674	0.835	0.762	0.638	0.674	0.568	0. 77
T − 1	0.567	0.710	0.839	0.772	0.651	0.659	0.573	0. 67
Baseline Av	0.566	0.697	0.833	0.765	0.653	0.663	0.568	0. 70
	±0.015	±0.016	±0.015	±0.007	±0.011	±0.011	±0.005	±0.007
T + 41	−	−	−	0.795	0.635	−	−	−
R − 1	−	−	−	0.778	−	0.664	0.563	−
R + 0	0.581	0.728	0.840	−	0.664	−	−	−
R + 1	−	−	−	0.771	−	0.685	0.578	0.564
R + 2	0.585	0.770	0.841	−	0.666	−	−	0.573
R + 16	−	−	−	0.775	−	−	−	−
R + 20	0.552	0.740	0.840	−	0.651	−	−	−
SMEAT Av				0.773	0.653	0.667	0.569	0.569
				±0.012	±0.012	±0.012	±0.007	±0.006

Conclusions

The SMEAT bone mineral measurement test revealed few deviations from baseline bone mineral measurements after 56 days in a Skylab-type environment. No mineral change was observed in the right radius. One individual, however, showed a possible mineral loss in the left os calcis and another gained mineral in the right ulna. The cause of the gain is unclear but may be attributable to the heavy exercise routines engaged in by the crewmember in question. Equipment problems were identified during the SMEAT experiment and rectified. These results have formed the basis for significantly improved systems for the Skylab bone mineral measurement experiment.

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CHAPTER 10

METABOLIC ACTIVITY — EXPERIMENT M171

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Metabolic measurement during American space flights has been limited to determining the total production of carbon dioxide by analysis of the amount of lithium carbonate formed by the reaction of carbon dioxide with lithium hydroxide in the carbon dioxide removal canisters carried onboard. This method, although valuable in determining the average heat production rate for crewmen during space flight, does not provide insight into transitory (peak) energy expenditures that are associated with performance of work in space.

During the Skylab missions, the first attempts are being made to study metabolic activity in a controlled way. A bicycle ergometer and equipment for measuring respiratory and cardiac function have been included onboard. Crewmembers can thus obtain ongoing readings of their metabolic effectiveness in doing mechanical work as a mission progresses.

The Skylab metabolic activity experiment, Experiment M171, was included in the SMEAT test to determine if man's metabolic effectiveness in doing mechanical work is progressively altered by a simulated Skylab environment, including environmental factors such as slightly increased pCO_2. The data obtained is intended to serve as baseline information against which to compare inflight results. A second purpose of the experiment was to evaluate the bicycle ergometer for crew personal exercise. The SMEAT version of the Skylab metabolic activity experiment also provided an opportunity to test crew procedures and data handling procedures.

It should be noted at the outset that certain hardware anomalies occurred during this exercise. The physiological data collected should, therefore, be viewed in the context of these anomalies. Special tests and procedures to resolve the problems are discussed in the following sections.

Equipment and Methods

The experiment hardware consisted of a metabolic analyzer, an ergometer, and ancillary equipment to measure heart rate, blood pressure, and body temperature.

The metabolic analyzer utilizes a mass spectrometer to determine the partial pressures of oxygen, nitrogen, carbon dioxide, and water in the inspired and expired gases. Rolling-seal, dry spirometers are used to measure separately inspired and expired breath volume. From these inputs, an analog computer derives minute volume, carbon dioxide consumption, carbon dioxide production, and respiratory exchange ratio each minute. These data may be computed using both inspired and expired volume measurements (Mode 1), or using an inspired volume computed from the expired volume and the inspired and expired nitrogen measurements (Mode 2). The latter mode, which is the prime mode for Skylab, was used during the SMEAT test.

Heart rate was computed based on the time required for five ECG R-waves and was displayed each five beats. An automatic blood pressure measurement system performed an inflate/bleed-down cycle each minute and displayed systolic and diastolic pressures each minute based on Korotkoff sounds. Body temperature measurement was made with an oral thermistor before each test run.

Metabolic Analyzer

The metabolic analyzer, used in SMEAT, was a design verification test unit (DVTU) that differed from the flight unit only in the following minor details:

1. The seals on the spirometer dump valves were not flight-type.

2. The mass spectrometer status-light power supply was not flight-type.

3. A breakout cable had been attached to the metabolic analyzer analog computer to permit evaluation of various stages of computation. Figure 10-1 illustrates the metabolic analyzer.

Ergometer

The bicycle ergometer is an electrically braked exercise device that can be operated in either of three modes: set work, set heart rate, or sequenced heart rate steps. All M171 tests utilized the set work mode. The loading of the ergometer is independent of the pedaling rate between 50 to 80 cycles/minute.

The SMEAT ergometer was a flight trainer unit. Figure 10-2 shows a subject engaged in a metabolic test on a similar ergometer. The primary design difference between it and flight units was the orientation of the brush ring. In the SMEAT unit, the brush ring "fingers" pointed against the direction of the rotation of the armature, rather than with it.

During the second day of the SMEAT test, a load module failure occurred. A substitution was made for the defective load module, and the unit was recalibrated. Following repair, the original load module was returned to the chamber, but it failed again. After conclusion of the SMEAT test, it was determined that the load module had a bearing that was defective due to improper installation. It is

presumed that the bearing caused the "growling" noise and torque sensor failures that occurred each time the ergometer failed.
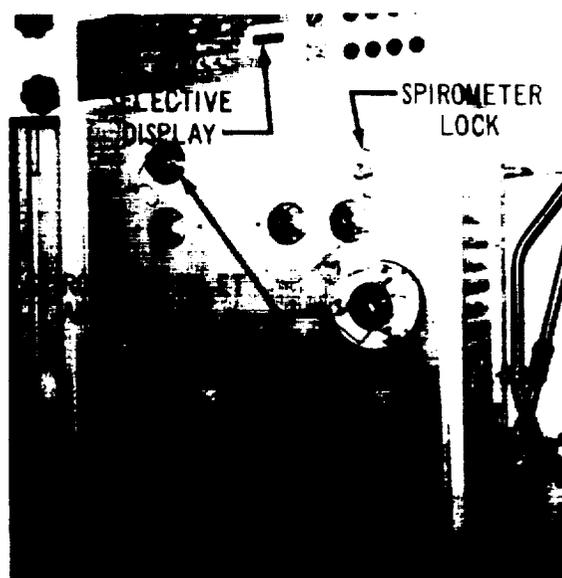
Figure 10-1. The metabolic analyzer.

Figure 10-2. A subject on the ergometer.

Testing

The preparatory phase of each test included adjustment and calibration of the metabolic analyzer, checking electrode isolation, body temperature measurement, and vital capacity measurements.

The test profile was as follows: The event time was set to 26 minutes. The timer was a digital clock that counted down from 26:00 to 0. The subject began breathing on the mouthpiece while remaining at rest, relaxing until the twenty-minute mark, at which time he began pedaling at 50 to 80 rpm. The first work level (approximately 25 percent of the subject's predetermined maximum aerobic capacity) was set for five minutes at 50 watts for the CDR, 100 watts for the SPT, and 60 watts for the PLT. At the fifteen-minute mark, the work level was increased to 50 percent of maximum (100 watts for the CDR, 180 watts for the SPT, and 120 watts for the PLT). At the ten-minute mark, the work level was further increased to 75 percent of maximum (150 watts for the CDR, 260 watts for the SPT, and 180 watts for the PLT). At the five-minute mark, the subject ceased pedaling and began a five-minute recovery period.

Metabolic data were voice recorded at 21, 16, 15, 11, 10, 6, 5, and 0 minutes. Carbon dioxide produced, oxygen consumed, respiratory exchange ratio, minute volume, heart rate, and blood pressure were recorded each time.

Procedural Variations

The pretest protocol was the same as that used during in-chamber testing. This protocol was run in the laboratory in February, March, and April 1972, using DVTU #2. It was repeated in the SMEAT chamber at 14.7 psia prior to the test in July 1972. During the pre-SMEAT testing at 14.7 psia in the chamber, two tests were found unacceptable due to an erroneous ergometer calibration. The data from these tests were eliminated from statistical consideration of baseline data.

The posttest protocol was performed in the chamber at 14.7 psia on each subject following termination of the altitude test using the same protocol previously described for the experiments at 5 psia. The test performed in the laboratory on the following day (R+1) used Douglas bags in lieu of the metabolic analyzer.

Data Handling

Test data were recorded by three methods: (1) Voice recorded in Building 36, where medical experiments were monitored and data review took place; (2) Voice recorded at the test console in Building 7, the building housing the SMEAT chamber; and (3) Telemetered onto magnetic tape.

Manually recorded voice data were filed in the Johnson Space Center's Environmental Physiology Laboratory. Magnetic tapes were processed and summarized on 16 mm microfilm rolls. Minute-by-minute data extracted from hard copies of the microfilm were entered into a PDP-12 digital computer for editing, plotting, and statistical treatment. The same data handling methods were used for prechamber, in-chamber, and postchamber periods.

Population t-statistics were applied to the data and the results formed the basis of the conclusions reached in this report.

Results

Environmental Parameter Data

Table 10-1 summarizes the pertinent environmental conditions monitored during the M171 experiment runs for the pretest, test, and posttest periods. All parameters were within expected limits, and no significant changes occurred during the experiment runs. (The average ambient carbon dioxide level during the test period was 4.8 torr).

Although the test times for each subject were standardized during the SMEAT period (CDR-1100, SPT-1700, PLT-1430), no attempt was made to assure this same temporal relationship during prechamber or postchamber test periods. An attempt will be made to control this factor more precisely during Skylab to eliminate any variability in exercise response that might be caused by circadian variations.

Physiological Data

Vital Capacity. Because of spirometer triggering problems and possible respiratory valve leaks, vital

Table 10-1

Environmental Conditions During M171 Tests

		CDR						SPT						PLT					
		O_2 (%)	CO_2 (%)	N_2 (%)	H_2O (%)	Temp (oC)	Pressure (mm Hg)	O_2 (%)	CO_2 (%)	N_2 (%)	H_2O (%)	Temp (oC)	Pressure (mm Hg)	O_2 (%)	CO_2 (%)	N_2 (%)	H_2O (%)	Temp (oC)	Pressure (mm Hg)
Pretest	X̄	20.82	.24	78.33	1.21	22.7	760	20.71	.25	79.32	1.79	23.1	760	20.43	.19	77.84	1.11	22.7	760
	S.D.	.37	.13	.24	.66	.50	0	.45	.10	.83	.83	.75	0	.55	.06	.64	.91	.50	0
	N	4	4	2	4	4	5	5	5	3	4	4	5	4	4	2	4	4	5
Test	X̄	67.03	1.87	26.51	4.72	21.3	260	66.75	1.84	26.79	4.77	21.3	260	66.83	1.78	26.66	4.87	21.4	260
	S.D.	1.21	.18	1.40	.98	1.54	0	1.57	.24	1.66	1.06	1.69	0	1.62	.19	1.81	1.04	1.88	0
	N	11	11	11	11	11	11	11	11	22	11	11	11	11	11	11	11	11	11
Posttest	X̄	21.62	.23	76.50	—	20.9	760	21.63	.25	76.51	—	21.7	760	20.77	.21	77.13	—	21.4	760
	S.D.	1.74	.01	1.94	—	.07	0	1.65	.01	1.99	—	.42	0	.71	.01	1.14	—	.77	0
	N	2	2	2	—	2	2	2	2	2	—	2	2	2	2	2	—	2	2

capacity measurements exhibited more variability than anticipated. Table 10-2 summarizes the data for each crewman during the various test periods. Data obtained in the Cardiopulmonary Laboratory, Johnson Space Center, for these subjects and data collected by the SPT in the chamber utilizing a vitalometer are included. As can be observed, the baseline data collected in-chamber agree with data collected over several years in the Cardiopulmonary Laboratory. The erroneous spirometer triggering or leakage of the respiratory valves in-chamber resulted in low vital capacity measurements. The vitalometer data also appear low, but they are higher than the metabolic analyzer values. These data indicate an unacceptable degree of variation in this variable, and it will be deleted as a required inflight measurement.

Heat storage was expected due to the high thermal environment anticipated during some orbital conditions. Since this is no longer a concern, body temperature measurement will be used only to screen the subject for fever.

Table 10-3

Body Temperature

		$\bar{X}$	S.D.	N	t	P
CDR	Pretest	97.9	.460	8	0.0	N.S.
	Posttest	97.9	.661	8		
SPT	Pretest	97.3	.255	7	0.433	N.S.
	Posttest	97.4	.554	7		
PLT	Pretest	98.1	.28	8	3.325	p>0.01
	Posttest	97.3	.58	7		

N.S. – Non-significant (p > 0.05)

Table 10-2

Vital Capacity

		C/P Data	Base-line	In-Test (5.0 psia)		Posttest	
				MA	V	MA	C/P
CDR	$\bar{X}$	5.768	5.726	5.298	5.418	–	5.780
	S.D.	0.04	0.11	0.15	0.15	–	–
	N	5	5	11	4		1
SPT	$\bar{X}$	6.282	6.250	5.702	6.100	6.170	6.192
	S.D.	0.07	0.23	0.42	0.05	–	–
	N	4	4	10	4	1	1
PLT	$\bar{X}$	6.140	6.084	5.785	5.841	5.795	6.295
	S.D.	0.14	0.22	0.28	0.09	–	–
	N	4	4	9	4	1	1

Resting and Recovery Heart Rate. Table 10-4 represents the resting and recovery heart rates (two minutes after the termination of exercise) for the three crewmen during the pretest and test periods. As can be seen from these data, there were no significant differences (p <.05). Neither were there trends in the values during the test period.

Table 10-4

Heart Rate (Rest/Recovery)

			X	S.D.	N	t	P
CDR	Rest	Pretest	61.5	8.312	6	.1636	N.S.
		Test	62.1	4.408	10		
	Recovery	Pretest	87.0	13.880	4	2.113	N.S.
		Test	71.5	7.501	10		
SPT	Rest	Pretest	59.2	6.648	5	1.596	N.S.
		Test	54.3	2.540	11		
	Recovery	Pretest	87.0	4.966	4	1.874	N.S.
		Test	79.8	9.724	11		
PLT	Rest	Pretest	76.8	11.548	6	.550	N.S.
		Test	74.1	4.306	10		
	Recovery	Pretest	84.3	7.023	3	.033	N.S.
		Test	84.5	13.794	10		

N.S. – Non-significant (p > 0.05)

Body Temperature. Table 10-3 shows pre- and postexercise oral temperatures for the three crewmen. Because there were no significant differences between the pre- and postexercise values, it was recommended that the postexercise oral temperature be eliminated as a required measurement. The mean preexercise temperatures appeared low, probably as a result of slow probe response time and lack of a definite measurement interval requirement for all tests. A three-minute measurement period should be sufficient to obtain a true reading. The original intent of this measurement was to identify any abnormal thermal state of the subject before or following a run.

Resting and Recovery Blood Pressure. Table 10-5 summarizes the pretest and test systolic and diastolic blood pressure data during rest and recovery periods. The t-values indicate no significant differences. It should be emphasized that the variability of this measurement exceeds that previously observed during exercise studies, although some editing of obviously erroneous values was done. It is felt that a considerable improvement in these data could be realized if crewmen removed their hands from the ergometer handlebars during each blood pressure measurement period.

Table 10—5

Systolic Blood Pressure (Rest/Recovery)

			X̄	S.D.	N	t	P
CDR	Rest	Pretest	112.4	5.54	5	0.000	N.S.
		Test	112.4	7.160	11		
	Recovery	Pretest	142.5	16.36	4	0.308	N.S.
		Test	145.1	6.911	11		
SPT	Rest	Pretest	101.7	10.657	4	0.760	N.S.
		Test	106.0	6.261	11		
	Recovery	Pretest	155.0	22.73	4	0.846	N.S.
		Test	165.3	14.4	11		
PLT	Rest	Pretest	108.8	8.18	6	1.779	N.S.
		Test	117.7	12.345	11		
	Recovery	Pretest	146.0	7.07	2	1.942	N.S.
		Test	159.9	169.73	11		

Diastolic Blood Pressure (Rest/Recovery)

			X̄	S.D.	N	T	P
CDR	Rest	Pretest	73.3	7.09	5	0.503	N.S.
		Test	71.5	6.77	11		
	Recovery	Pretest	71.5	11.09	4	0.034	N.S.
		Test	71.3	6.42	11		
SPT	Rest	Pretest	71.7	2.50	4	0.477	N.S.
		Test	72.8	6.41	11		
	Recovery	Pretest	72.5	6.40	4	0.540	N.S.
		Test	74.5	6.17	11		
PLT	Rest	Pretest	75.0	4.14	6	0.583	N.S.
		Test	77.8	14.91	11		
	Recovery	Pretest	81.6	8.14	3	0.246	N.S.
		Test	80.3	8.01	11		

N.S. — Non-significant (p > 0.05)

Resting Gas Exchange. Table 10-6 represents the summary of the *oxygen consumption* data obtained during rest for the pretest and test periods. None of the crewmen had differences significant at the $p < 0.05$ level of confidence.

Table 10—6

Oxygen Consumption (Rest)

		X̄	S.D.	N	t	P
CDR	Pretest	.293	.039	6	0.620	N.S.
	Test	.276	.074	11		
SPT	Pretest	.331	.032	5	0.599	N.S.
	Test	.316	.018	11		
PLT	Pretest	.295	.022	6	1.928	N.S.
	Test	.247	.077	11		

N.S. — Non-significant (p > 0.05)

Table 10-7 summarizes the resting *carbon dioxide production* data during the pretest and test periods. There were no significant changes observed during any of the periods. However, because of the difficulties and errors observed in carbon dioxide measurement, these data have a low confidence level.

Table 10—7

Carbon Dioxide Production (Rest)

		X̄	S.D.	N	t	P
CDR	Pretest	0.224	0.024	3	−0.589	N.S.
	Test	0.238	0.064	11		
SPT	Pretest	0.267	0.001	2	−0.146	N.S.
	Test	0.270	0.068	11		
PLT	Pretest	0.269	0.028	3	1.872	N.S.
	Test	0.224	0.059	11		

N.S. — Non-significant (p > 0.05)

Table 10-8 summarizes the resting *respiratory exchange ratio* ($\dot{V}_{CO_2}/\dot{V}_{O_2}$) during the pretest and test periods. Although there were no significant changes, the measurement is suspect because of the $\dot{V}_{CO_2}$ problems noted.

Table 10-9 summarizes the resting *minute volume* data during the pretest and test periods. Although all

crewmen exhibited slightly lower values during the test period, none of these changes was significant at the $p < 0.05$ level of confidence.

Table 10–8

Respiratory Exchange Ratio (Rest)

		$\bar{X}$	S.D.	N	t	P
CDR	Pretest	.835	.042	6	0.996	N.S.
	Test	.868	.094	11		
SPT	Pretest	.877	.070	5	0.136	N.S.
	Test	.869	.164	11		
PLT	Pretest	.933	.091	6	0.189	N.S.
	Test	.923	.124	11		

N.S. — Non-significant ($p > 0.05$)

Table 10–9

Minute Volume ($\dot{V}_E$) (Rest)

		$\bar{X}$	S.D.	N	t	P
CDR	Pretest	8.3	1.47	5	1.646	N.S.
	Test	6.9	1.79	11		
SPT	Pretest	12.3	.77	5	1.550	N.S.
	Test	10.4	3.9	11		
PLT	Pretest	10.7	1.83	6	1.957	N.S.
	Test	9.0	1.47	11		

N.S. — Non-significant ($p > 0.05$)

Exercise Data

Heart Rate. Table 10-10 summarizes the heart rate response for all crewmen at each exercise level during the pretest and test periods. Although the CDR exhibited a statistically significant increase during level 3, this was only an average of four beats/minute and is not considered physiologically significant. The SPT did not exhibit any significant changes. The PLT exhibited a significantly increased heart rate in-chamber for the first two exercise levels. The higher heart rate levels were noted during the first chamber test and declined toward baseline levels by the fourth test.

Table 10–10

Heart Rate (Exercise)

			$\bar{X}$	S.D.	N	t	P
	Level 1	Pretest	80.4	8.3	11	0.15	N.S.
		Test	80.0	3.1	29		
CDR	Level 2	Pretest	102.9	10.2	10	1.13	N.S.
		Test	99.2	2.8	28		
	Level 3	Pretest	121.2	3.7	7	−2.73	N.S.
		Test	125.5	3.9	29		
	Level 1	Pretest	89.7	4.4	14	0.0	N.S.
		Test	89.7	3.8	33		
SPT	Level 2	Pretest	116.4	5.9	15	0.95	N.S.
		Test	114.7	5.3	33		
	Level 3	Pretest	138.9	6.1	13	0.79	N.S.
		Test	137.4	4.7	33		
	Level 1	Pretest	89.9	3.8	12	−3.47	p<0.01
		Test	94.7	5.0	32		
PLT	Level 2	Pretest	113.9	7.1	15	−2.57	p<0.02
		Test	120.1	8.8	32		
	Level 3	Pretest	141.5	3.0	13	−1.29	N.S.
		Test	143.8	8.7	32		

N.S. — Non-significant ($p > 0.05$)

Blood Pressure. Table 10-11 summarizes the systolic blood pressure during exercise for the pretest and test periods. Significant increases in indicated blood pressure were observed for the SPT during all levels of exercise during the test period. The PLT showed an increase in systolic blood pressure at levels 1 and 2 of exercise during the test period. These data are difficult to explain and may indicate a technical problem with the measurement. One suggested explanation is that the blood pressure cuff bleed rate at 14.7 psia, which is faster than at 5.0 psia, resulted in lower blood pressure values at 14.7 psia than at 5.0 psia. This could occur because the electronic logic for the blood pressure measurement system permits a rapid cuff bleed down from maximum cuff inflation until the first Korotkoff

sound is detected. The bleed-down rate, or pressure ramp, is slower from systolic blood pressure until diastolic blood pressure is determined.

Table 10-11
Systolic Blood Pressure (Exercise)

	$\bar{X}$	S.D.	N	t	P
Level 1					
Pretest	121.4	13.1	11		
Test	128.5	7.4	26	−1.6873	N.S.
CDR Level 2					
Pretest	153.0	12.1	13		
Test	145.6	8.9	23	1.9297	N.S.
Level 3					
Pretest	172.0	10.5	13		
Test	172.2	13.2	32	−0.0536	N.S.
Level 1					
Pretest	126.1	5.7	11		
Test	135.1	12.1	31	−3.2483	p<0.01
SPT Level 2					
Pretest	154.3	6.0	9		
Test	162.3	13.8	33	−2.5593	p<0.02
Level 3					
Pretest	166.3	9.4	9		
Test	185.3	7.6	33	−5.5863	p<0.001
Level 1					
Pretest	129.0	9.5	15		
Test	147.3	16.9	24	−4.3233	p<0.001
PLT Level 2					
Pretest	152.0	7.2	15		
Test	165.6	9.9	27	−5.1090	p<0.001
Level 3					
Pretest	198.1	14.2	13		
Test	191.3	3.8	33	1.7026	N.S.

N.S. — Non-significant (p > 0.05)

Table 10-12 summarizes the diastolic blood pressure data for the same periods. Significant decreases were observed for the SPT during level 2 and during levels 1 and 2 for the CDR. These changes are of a small absolute magnitude and, in view of their somewhat random occurrence, are probably related to the technical variability of this measurement.

Gas Exchange.

1. *Oxygen Consumption.* Table 10-13 summarizes the oxygen consumption data for the pretest

and test periods for all crewmen. The PLT was the only subject who exhibited a significant change during the test (decrease) from the pretest period. A possible explanation for this was his lack of familiarity with the ergometer prior to the SMEAT test period. These differences were numerically small and represent a slight increase in mechanical efficiency.

Table 10-12
Diastolic Blood Pressure (Exercise)

	$\bar{X}$	S.D.	N	t	P
Level 1					
Pretest	73.2	10.8	14		
Test	66.7	5.8	32	2.1220	p<0.05
CDR Level 2					
Pretest	80.8	10.8	15		
Test	68.1	5.9	31	4.2573	p<0.001
Level 3					
Pretest	75.3	10.9	13		
Test	71.8	4.4	32	1.1212	N.S.
Level 1					
Pretest	67.2	3.5	12		
Test	65.8	6.3	33	0.9389	N.S.
SPT Level 2					
Pretest	72.7	4.7	11		
Test	68.0	6.3	33	2.6229	p<0.02
Level 3					
Pretest	68.2	7.3	11		
Test	65.1	7.1	33	1.2281	N.S.
Level 1					
Pretest	67.2	5.2	16		
Test	69.7	7.7	33	1.3389	N.S.
PLT Level 2					
Pretest	74.3	6.0	16		
Test	76.1	6.9	33	0.9901	N.S.
Level 3					
Pretest	81.5	6.2	14		
Test	78.3	5.9	33	1.6414	N.S.

N.S. — Non-significant (p > 0.05)

2. *Carbon Dioxide Production.* Table 10-14 summarizes the carbon dioxide production exercise data for the pretest and test periods. All these data were collected utilizing a metabolic analyzer. The data show a significantly higher output for the CDR during the test period. Since the baseline data were also collected with the metabolic analyzer, the lack of a significant increase in carbon dioxide production in

the other two crewmen is misleading. The baseline $\dot{V}_{CO_2}$ data collected using the metabolic analyzer were high relative to the Douglas bag data. In other words, all carbon dioxide production data obtained by use of the metabolic analyzer were erroneously high, but this was accentuated at 5 psia in the case of the CDR.

with the mass spectrometer sample inlet system. There is a high probability that some cabin air is trapped within the sample lines and this air dilutes the cal gas flow, resulting in erroneously high carbon dioxide gain settings. Modifications presently being incorporated into the flight hardware should eliminate this problem.

Table 10-13

Oxygen Consumption (Exercise)

		X̄	S.D.	N	t	P
Level 1	Pretest	.856	.071	12	1.459	N.S.
	Test	.898	.116	33		
CDR Level 2	Pretest	1.409	.071	16	0.0	N.S.
	Test	1.409	.147	33		
Level 3	Pretest	2.034	.107	16	0.930	N.S.
	Test	2.000	.143	33		
Level 1	Pretest	1.414	.100	14	0.066	N.S.
	Test	1.416	.077	33		
SPT Level 2	Pretest	2.310	.210	14	1.415	N.S.
	Test	2.223	.144	33		
Level 3	Pretest	3.177	.303	13	0.198	N.S.
	Test	3.195	.190	32		
Level 1	Pretest	.949	.059	16	2.893	p<0.01
	Test	.886	.092	33		
PLT Level 2	Pretest	1.540	.095	16	2.356	p<0.05
	Test	1.463	.127	32		
Level 3	Pretest	2.247	.157	16	3.824	p<0.001
	Test	2.080	.110	33		

N.S. – Non-significant (p > 0.05)

Table 10-14

Carbon Dioxide Production (Exercise)

		X̄	S.D.	N	t	P
Level 1	Pretest	.726	.057	7		
	Test	.852	.140	33	-3.8736	p<0.001
CDR Level 2	Pretest	1.376	.032	7		
	Test	1.478	.161	33	-3.3415	p<0.01
Level 3	Pretest	2.084	.073	7		
	Test	2.219	.213	33	-2.9209	p<0.01
Level 1	Pretest	1.404	.084	4		
	Test	1.316	.122	33	1.8698	N.S.
SPT Level 2	Pretest	2.430	.251	5		
	Test	2.350	.184	33	0.6853	N.S.
Level 3	Pretest	3.665	.308	5		
	Test	3.65	.501	33	0.0920	N.S.
Level 1	Pretest	.863	.043	7		
	Test	.856	.099	33	0.2955	N.S.
PLT Level 2	Pretest	1.460	.088	7		
	Test	1.535	.140	33	1.8189	N.S.
Level 3	Pretest	2.272	.074	7		
	Test	2.290	.156	33	0.4617	N.S.

N.S. – Non-significant (p > 0.05)

The nature of the calibration sequence may explain the greater differential for the CDR. It is presently thought that the lack of sufficient warmup time, which results in an erroneously high gain setting for carbon dioxide, is a contributory factor. The carbon dioxide calibration problem is further complicated by the valving and plumbing associated

3. *Respiratory Exchange Ratio.* Because of the problems in carbon dioxide production determination, the respiratory exchange ratio will not be evaluated since it reflects the same errors. However, the Douglas bag data collected during special tests at altitude confirmed normal RER values during the test period.

4. *Minute Volume*. Table 10-15 summarizes the minute volume data for the pretest and test periods. Except for level 1 for the CDR, statistically significant increases were observed for this variable. Since hand pump calibration data verified the accuracy of the measurement under ambient conditions and the Douglas bag data collected during the special tests confirmed a normal minute volume, these slight increases are attributed to the erroneous water reading by the mass spectrometer. This parameter is fed into the minute volume circuit to correct this signal to BTPS conditions and could account for the magnitude of difference observed.

Table 10-15

Minute Volume (Exercise)

		X̄	S.D.	N	t	P
CDR	Level 1 Pretest	22.0	2.7	9	−0.521	N.S.
	Test	22.5	1.9	33		
	Level 2 Pretest	37.2	2.2	13	3.13	p<0.01
	Test	35.0	2.0	33		
	Level 3 Pretest	54.7	4.1	13	3.08	p<0.01
	Test	50.8	3.2	33		
SPT	Level 1 Pretest	42.5	3.1	14	−2.35	p<0.05
	Test	45.2	4.5	32		
	Level 2 Pretest	73.4	6.3	14	−2.71	p<0.02
	Test	78.8	6.0	32		
	Level 3 Pretest	117.3	13.5	14	−4.03	p<0.001
	Test	133.0	8.2	32		
PLT	Level 1 Pretest	24.8	1.5	16	−4.09	p<0.001
	Test	26.8	1.8	33		
	Level 2 Pretest	39.9	2.6	16	−4.61	p<0.001
	Test	43.7	2.9	33		
	Level 3 Pretest	59.1	6.2	16	−3.22	p<0.02
	Test	64.6	4.1	33		

N.S. — Non-significant (p >0.05)

Variable Pairs.

1. *Oxygen Consumption — Workload (Mechanical Efficiency)*. The relationship between oxygen consumption and workload indicates the mechanical efficiency in accomplishment of physical work. A standard way of calculating this value is to measure the metabolic rate at a known workload and to subtract the resting metabolic rate. Since a multilevel exercise test is used, mechanical efficiency is reported as the slope (cc/watt) of oxygen consumption — workload curve. This relationship is linear, and for the SMEAT subjects, the average correlation coefficient was 0.9785 ± .026 for a total of 50 tests.

Table 10-16 summarizes the slope of the oxygen consumption — workload relationship for the pretest and test periods for the three crewmen. Efficiencies, expressed as percentages, are shown in parentheses. The average for all the Apollo pre- and postflight exercise tests through Apollo 16 was 11.8 cc/watt (25.3 percent efficiency). Both the CDR and SPT indicated small, but significant, changes for this relationship. Since one was an increase and one was a decrease, this is not viewed as an overall significant finding.

Table 10-16

Mechanical Efficiency (cc's O_2 per watt)

		X̄	S.D.	N	t	P
CDR	Pretest	11.4(26.2)	.2	5		
	Test	11.1(26.9)	.1	10	3.162	0.01
SPT	Pretest	9.9(30.2)	.4	4		
	Test	11.1(26.9)	.9	11	3.560	0.01
PLT	Pretest	10.0(29.9)	.8	6		
	Test	9.9(30.2)	.5	10	0.276	N.S.

(% Efficiency)   N. S. - Non-significant

2. $\dot{V}_E$ — $\dot{V}_{O_2}$ *(Respiratory Efficiency)*. The relationship between minute volume and oxygen consumption is the ventilatory equivalent for oxygen and gives indication of pulmonary efficiency (i.e., how much air is required to supply a certain amount of metabolic oxygen). These variables are highly correlated and linear. For all tests on all subjects, the average correlation coefficient was

0.9984 ± 0.014 (N=55). Table 10-17 summarizes the minute volume for an oxygen consumption of 2.0 liters/minute STPD for all these crewmen.

Table 10-17

Minute Volume at 2.0 1/min Oxygen Consumption

$$\dot{V}_E - \dot{V}_{O_2}$$

		X̄	S.D.	N	t	P
CDR	Pretest	53.8	1.4	5		
	Test	50.4	3.3	11	2.892	0.01
SPT	Pretest	64.4	5.4	4		
	Test	72.0	6.5	11	2.278	0.05
PLT	Pretest	51.8	2.1	6		
	Test	59.8	5.8	7	3.398	0.01

The data indicate the CDR had a significantly reduced minute volume and the SPT and PLT had increased minute volumes for the same oxygen consumption. This may indicate individual differences in response to the reduced viscosity of the air and the change in resistance of breathing. However, the most plausible explanation relates to the previously discussed error in measurement of B T P S minute volume due, in turn, to high water measurement by the mass spectrometer.

3. *Oxygen Pulse (Oxygen Consumption/Heart Rate)*. The slope of the relationship between oxygen consumption and heart rate is called the oxygen pulse or the number of cubic centimeters of oxygen carried per heartbeat. This relationship is highly linear with a very significant correlation. The average correlation coefficient for 53 tests was 0.9782 ± .026. Table 10-18 summarizes the slopes of this relationship for the pretest and test periods for each crewman. There were no significant changes observed for this parameter.

4. *Systolic Blood Pressure – Oxygen Consumption*. Another approach in evaluating cardiopulmonary function is to look at changes in the relationship between oxygen consumption and systolic blood pressure. This combination is highly correlated, although not as highly as the previous

variable pairs. The average correlation coefficient for 50 tests was 0.9200 ± .065. Table 10-19 summarizes the systolic blood pressure at 2.0 liters/minute oxygen consumption for each crewman during the pretest and test period. The SPT shows a slightly increased pressure at this exercise level, but again this may be due to previously discussed problems with the blood pressure measurement system.

Table 10-18

Oxygen Pulse ($\dot{V}_{O_2}$ HR)

		X̄	S.D.	N	t	P
CDR	Pretest	21.8	3.8	6		
	Test	24.6	2.3	10	1.634	N.S.
SPT	Pretest	37.1	2.4	4		
	Test	37.2	2.2	11	.073	N.S.
PLT	Pretest	22.4	5.9	6		
	Test	23.9	2.2	11	.600	N.S.

N. S. - Non-significant

Table 10-19

Systolic Blood Pressure at 2.0 1/min

		X̄	S.D.	N	t	P
CDR	Pretest	172.3	10.8	6		
	Test	172.8	9.5	11	.095	N.S.
SPT	Pretest	144.1	5.3	4		
	Test	153.0	7.7	11	2.526	p>0.05
PLT	Pretest	175.2	16.1	6		
	Test	188.1	5.5	7	1.871	N.S.

N. S. - Non-significant

5. *Heart Rate - Systolic Blood Pressure*. The relationship between heart rate and systolic blood pressure was one relationship studied during Apollo pre- and postflight exercise studies. This usually highly significant correlation averaged .9819 ± .098 for 47 SMEAT tests. Table 10-20 summarizes the systolic blood pressure at a projected heart rate of 160 beats/minute for the three crewmen during the pretest and test periods. There were no significant changes during the summarized periods.

Table 10-20

Systolic Blood Pressure
at a Heart Rate of 160 Beats/Min

		$\bar{X}$	S.D.	N	t	P
CDR	Pretest	181.9	27.2	6		
	Test	209.4	15.8	10	2.258	N.S.
SPT	Pretest	194.8	15.9	4		
	Test	209.6	7.6	11	1.789	N.S.
PLT	Pretest	202.9	32.0	6		
	Test	199.7	14.4	7	.226	N.S.

N. S. - Non-significant

Crew Personal Exercise

Regardless of deconditioning trends, the higher the initial fitness (aerobic capacity), the more physiological reserve there is available to do a given amount of work. The missing data point and the one which prevents the enforcing of minimum fitness levels is the lack of obvious correlation between aerobic capacity and nondeteriorating physiological adaptation to space flight as measured by the response to exercise pre- and postflight during Apollo.

Recommendations for an exercise program were formulated by the Principal Investigator of Experiment M171. For SMEAT, the exercise approach used was essentially that planned for Skylab. The SPT was very familiar with fitness programs and desired to structure his own program. Exercise programs considered adequate to maintain fitness levels were recommended to the CDR and PLT.

The recommended exercise programs were not carefully followed by the crew nor were attempts made to determine if recommended levels were acceptable. Post-SMEAT, the crew assessed the recommended programs as inadequate. A review of exercise levels showed that both the CDR and PLT changed to new exercise levels apparently considered by them to be more appropriate.

During SMEAT baseline data analysis, it was necessary to eliminate the first several M171 runs for the CDR and PLT because training resulted in a

changing fitness level. This should be avoided during Skylab where crew time available for exercise is at a premium and the total number of baseline tests will be limited.

Table 10-21 summarizes the crew personal exercise levels and how these compared with caloric intake. From these data it is apparent that activity levels should be more adequately planned and followed in order to be sure that sufficient caloric input is provided.

Another problem area was the failure of the bicycle ergometer load module. It is felt that the bicycle ergometer is the only adequate exercise device available during Skylab and that *it should not have any performance limitations*. To restrict its use could seriously impact the ability of Skylab crews to obtain sufficient cardiopulmonary exercise.

Discussion

The SMEAT version of the M171 study proved to be a very beneficial aspect of development of the experiment for the Skylab Program. The functions evaluated were the following: (1) Baseline data gathering, (2) Crew procedures, (3) Hardware performance, (4) Physiological effects of the Skylab atmosphere, (5) Data handling procedures, and (6) Crew personal exercise on the bicycle ergometer. The following paragraphs summarize these important points in each of these areas.

Baseline Data Gathering

The object of the baseline data activity is to provide a population of numbers from which statistical confidence levels can be determined. Without this confidence interval, it is impossible to determine with any objectivity whether significant changes occur during the inflight period. This proved to be a problem during SMEAT because of equipment anomalies, crew training sessions, and most important, the initial lack of a repeatable response. This latter problem was a training effect, and, because of it, the first two baseline runs for the CDR and PLT had to be eliminated. The SPT was familiar with bicycle ergometry and demonstrated a more stable fitness level with no training effect. However, because

SMEAT provided an opportunity for rescheduling runs, sufficient data could be obtained for adequate statistical considerations. Had this not been possible, the test objectives could not have been met.

Table 10-21

SMEAT Free Time Exercise
Watt-Minutes

Test Day	CDR	SPT	PLT
1	0	0	0
2	2526	10000	0
3	1623	2672	1762
4	2598	8285	3343
5	0	0	0
6	1474	2734	1781
7	4357	0	4352
8	1555	11075	4500
9	297	10293	292
10	458	10500	5004
11	4553	11600	0
12	1518	2703	1811
13	3265	18300	5000
14	4570	15250	5000
15	292	21294	298
16	5225	0	5500
17	0	16125	5000
18	1516	2703	1807
19	5210	16750	5002
20	5313	19175	5500
21	296	11525	291
22	5362	19750	6000
23	5252	17250	6000
24	1543	24851	1803
25	5300	11850	6000
26	5303	0	1799
27	1491	16725	6250
28	0	6620	6500
29	5329	17691	6500
30	1498	2733	1793
31	5330	18375	6780
32	5400	19450	6780
33	0	0	0
34	4812	6655	5500
35	5006	20425	5500
36	1482	8742	1810
37	5205	15200	5500
38	5265	14306	5500
39	0	12933	0
40	5930	0	0
41	6040	9660	6040
42	1514	4455	1807
43	1497	9750	1813
44	2084	11428	5200

Table 10-21 (Continued)

SMEAT Free Time Exercise
Watt-Minutes

Test Day	CDR	SPT	PLT
45	0	10500	5000
46	6000	9000	5000
47	13500	8000	6000
48	6000	15280	6000
49	6000	8500	6000
50	8043	15280	6000
51	0	0	8100
52	1702	9240	6500
53	6000	30000	0
54	1513	2739	7205
55	7511	2689	7000
56	6000	15000	5000
Total Work (watt min.)	189560	594161	210757
Total Work (watt min/day)	3385	10610	3763
Total Work (BTU/day)	192	603	214
Metabolic Expenditure Assuming 25% Efficiency	768	2412	856
BTU/day	768	2412	856
BTU/hr	32	100	36
K cal/day	194	607	215
Energy Expenditure Caloric Intake K cal/day	2902	3527	3102
Caloric Equivalent of Weight Loss Assuming Fat Metabolism K cal/day	188	672	102
Total Energy Expenditure K cal/day	3090	4199	3204
BTU/hr	510	694	530

Crew Procedures

On the basis of the SMEAT experience, crew procedures have been optimized to permit proper setup and execution of Experiment M171 in Skylab. Final hardware modifications may dictate some change, but no serious problems are anticipated.

Hardware Performance

The following comments reflect our most recent understanding of the performance of specific hardware.

Bicycle Ergometer. Posttest analysis of the bicycle ergometer load module failures has indicated

improper assembly procedures were at fault. Otherwise, the unit performed satisfactorily. However, its upper tolerance limit is still in question.

The heart rate control portions of the ergometer malfunctioned in two ways. First, the indicated heart rate was low by approximately ten beats/minute. This has been traced to a potential calibration problem in which the width of the calibration pulse affects the average heart rate value.

The second malfunction was the apparent lack of proper control in the heart rate mode. In posttest evaluations, the unit functioned properly. The in-test difficulties may have been the result of procedural problems.

Metabolic Analyzer. Although minor anomalies were identified and have been corrected, there are still several important items outstanding. Carbon dioxide production is measured significantly high. This problem is thought to be associated with the carbon dioxide sampling, measurement, and/or calibration of the mass spectrometer. Testing performed by the manufacturer disclosed no influence on carbon dioxide measurements by water. Therefore, the high carbon dioxide levels are not attributed to calibration procedures. Design changes have been initiated to provide an improved calibration technique.

The measurement of water vapor pressure is in error and impacts the correction of respiratory volumes to standardized conditions. Testing by the manufacturer verified that a high gain was being set during water calibration.

The vital capacity measurement capability of the metabolic analyzer is suspect due to the low values observed at 5 psia. This results from a spirometer triggering problem and/or respiratory valve leakage identified by the SMEAT crew. This latter anomaly could not be repeated at 14.7 psia and therefore is either a reduced pressure phenomenon or due to the measurement technique utilized at 5 psia.

Blood Pressure Measurement System (BPMS). The performance of this system has been discussed in detail. On first impression it appeared that there were an unacceptably high number of bad

data points. However, even though there was more variability than desired, the postflight analysis of the data has shown that long term trends in systolic pressure should be detectable after obviously erroneous values are edited out. This will be possible because of the large number of data points and the regression techniques used for evaluating the data. It will probably be impossible to evaluate diastolic pressure changes in detail, but this measurement has historically been difficult.

An additional problem was that the same subject showed increasing diastolic pressures one time and decreasing diastolic pressures the next time at the same exercise stress. A considerable improvement in blood pressure data would be realized if the crewman were to remove his arm from the handlebars during the measurement period.

Body Temperature Measuring System (BTMS). This system was originally designed to measure body temperature in the ear canal but, because of fitting problems with some crewmembers, it was changed to an oral measurement. The system appears to function properly except that the response time is longer than desirable. However, for the intended purpose (to detect a fever), it should be adequate.

Vectorcardiogram (VCG). This system was used to measure heart rate only and it functioned satisfactorily.

Physiological Effects of the Skylab Atmosphere

Utilizing primary and/or backup measurement techniques (i.e., Douglas bags), no adverse physiological changes have been observed which could be ascribed to the simulated Skylab atmosphere or conditions.

Data Handling Procedures

A total data flow system was developed and checked. This system, with minor modifications, should be adequate for Skylab.

Personal Exercise

The bicycle ergometer is an excellent device for crew personal exercise, but design constraints may

limit its ultimate usefulness. There was a problem in defining adequate crew personal exercise programs for those crewmen not familiar with bicycle ergometer exercise.

Conclusions and Recommendations

This test identified several hardware/procedural anomalies which had to be satisfied (either through hardware modifications or procedural changes) prior to a successful implementation of the actual inflight activity. The most important of these were: (1) The metabolic analyzer measured carbon dioxide production and expired water too high; (2) The ergometer load module failed under continuous high workload conditions; (3) A higher than desirable number of erroneous blood pressure measurements were recorded; (4) Vital capacity measurements were unreliable; and (5) Anticipated crew personal exercise needs to be more structured.

A review of the results of this experiment prompts the following recommendations:

1. Contingency scheduling should be planned in advance for possible additional baseline runs. These would be utilized only after evaluation of available data proved that an inadequate baseline sample had been obtained.

2. The vital capacity measurement should be eliminated as an inflight requirement.

3. The postexercise body temperature measurement should be eliminated and the preexercise measurement interval standardized at three minutes.

4. Computation of metabolic effectiveness by use of both inspired and expired volume measurements (Mode 1) should be reevaluated.

5. Baseline data should be obtained on the first two Skylab flight crews at 5 psia utilizing the actual flight hardware.

6. The Skylab flight crews should investigate the feasibility of removing the left hand from the handlebar during the blood pressure measurement period.

7. A more definitive estimate of anticipated crew personal exercise parameters should be obtained.

CHAPTER 11

BIOASSAY OF BODY FLUIDS – EXPERIMENT M073

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As a result of medical observations during the U.S. and U.S.S.R. manned space flight programs, it is now known that complex physiological changes have occurred in crews returning from space missions (Berry, 1970; Balakhovskiy et al., 1971). These changes have been associated with severe intellectual demands and exacting mechanical tasks, acceleration, weightlessness, sleep loss, changing circadian rhythms, confinement, relative inactivity at some times and periods of high physical activity at others, and alterations in cabin atmosphere composition. There is an urgent need to study the physiological changes in exact and mechanistic terms. The changes must be precisely documented with respect to magnitude, time-course, and direction. Underlying mechanisms must be ascribed to these changes in order to assess man's ability to withstand long duration space flight and the need for countermeasures.

The Skylab Medical Experiments Altitude Test provided the opportunity to examine the effects of space flight conditions in the presence of gravity. In particular, it allowed the collection of baseline data on men from the same population as the Skylab crews under conditions expected to occur during the Skylab flights.

The experiment reported in this section was designed to measure the biochemical changes in endocrine and metabolic physiology of the SMEAT crewmen in the following areas:

1. Fluid and electrolyte balance.

2. Regulation of calcium metabolism.

3. Adaptation to the environment.

4. Regulation of metabolic processes.

Experimental Protocol and Methods

The study included the collection of urine into daily 24-hour urine pools commencing 28 days before chamber ingress, continuing throughout the chamber confinement, and for 18 days after egress. The urine was cooled during the collection to $4^{\circ}C$. Each morning, the previous day's urine pool was received in the laboratory and stabilized. The in-chamber collections were performed with specially designed urine collection devices. The SPT used a prototype of the actual system designed for inflight Skylab use.

This study encompassed 104 days of urine collection, resulting in 312 separate 24-hour urine pools. Data from eight percent of these samples were

not used in the statistical calculations due to known or suspected urine loss.

Analyses conducted on the 24-hour urine samples included antidiuretic hormone (ADH), aldosterone, hydrocortisone, total 17-hydroxycorticosteroids (17 OHCS), total and fractionated 17-ketosteroids, amino acid excretion patterns, epinephrine and norepinephrine, sodium, potassium, chloride, osmolality, and creatinine.

Fasting blood samples (7 a.m.) were drawn 21, 14, and 7 days before and on the morning of chamber ingress. Similar samples were drawn eight times during the in-chamber phase on days 30, 32, 41, 48, 55, 64, 75, and 83. The postchamber blood samples were drawn immediately after egress, three and fourteen days later. For this experiment, the blood volumes for pre- and postchamber analysis were 25 ml and the in-chamber plasma sample averaged 2.75 ml. Sodium and lithium (EDTA) were used as the anticoagulant.

The plasma samples were analyzed for angiotensin I, aldosterone, adrenocorticotrophin hormone (ACTH), hydrocortisone, insulin, glucose, human growth hormone, thyroid stimulating hormone, thyroxine, osmolality, parathormone (PTH), calcitonin, vitamin D, blood urea nitrogen, creatinine, and the electrolytes: sodium, potassium, chloride, calcium, phosphorus and magnesium.

Radionuclide studies were performed to obtain measurements of the following body compartments: total body water, extracellular fluid, and plasma volume. Total body exchangeable potassium was measured postchamber.

Body mass was measured daily with water and nutrient intake. Deviations in temperature and pressure and changes in the degree of physical activity and the occurrence of provocative cardiovascular testing (LBNP) were examined in relation to changes in plasma and urinary concentrations of the spectrum of chemical parameters of interest to this experiment.

Since large individual variation among crewmen has been a constant finding during the Apollo

program, each man served as his own control by comparing the in-chamber and postchamber data with the prechamber control phase.

The urine data have been grouped into periods of equal duration for analysis of variance (Snedecor, 1956). When significant changes were detected, a Tukey rank test was applied to establish period variation. The prechamber plasma data were compared by an analysis of variance. The mean was obtained from values which did not differ and they were compared to the in-chamber and post-chamber results for percent change.

Results and Discussion

Fluid/Electrolyte Balance

A negative water balance has resulted in some body weight loss of the crews returning from space flight with a rapid regain of a portion of the lost weight within the first 24 hours (Leach et al., 1972). Table 11-1 gives the mean six days weights for each crewman. These data were grouped for six days to coincide with the dietary cycles. There were no significant variations in the PLT, a trend toward slight decreases in the CDR, and significant decreases in the SPT ($p < .001$).

The SPT's weight loss evidently resulted from a caloric deficit accentuated by physical activity and is not related to chamber exposure. The maintenance of weight in two crewmembers, together with relatively constant water intake, lends credence to the belief that weight losses observed on the U.S. and U.S.S.R. space flight crews may be only partially related to caloric deficits.

The hypothesis that electrolytes are lost with fluid changes is substantiated by a detailed examination. The urine and plasma levels, summarized in Tables 11-2 and 11-3, reveal slight variations in blood electrolytes for the pre and post phases of this study. Serum sodium demonstrated variation from -0.1 to +2.8 percent. These are not considered to be significant. Potassium varied significantly during the control period with the variations occurring on days 2 and 9. In the immediate postflight sample, potassium was

Table 11-1

Six Day Mean Body
Weight Kgs.

Man	Prechamber					In-Chamber									Postchamber		
	1-3	4-9	10-15	16-21	22-28	29-34	35-40	41-46	47-52	53-58	59-64	65-70	71-76	79-82	85-90	91-96	97-101
CDR	72.18 ±.17	71.61 ±.15	71.53 ±.12	71.63 ±.12	71.91 ±.14	71.40 ±.14	71.14 ±.14	71.14 ±.08	71.48 ±.07	71.41 ±.07	71.25 ±.14	71.01 ±.11	70.97 ±.07	70.72 ±.08	70.63 ±.14	70.44 ±.06	70.67 ±.0
SPT	94.57 ±.08	93.83 ±.09	93.26 ±.13	93.01 ±.13	92.60 ±.15	92.19 ±.08	92.11 ±.16	91.22 ±.17	90.77 ±.09	89.96 ±.16	89.56 ±.07	89.07 ±.12	88.69 ±.09	88.17 ±.15	87.30 ±.19	87.21 ±.31	87.59 ±.23
PLT	84.86 ±.08	84.25 ±.04	84.39 ±.06	84.46 ±.12	84.22 ±.09	83.96 ±.04	84.02 ±.07	84.15 ±.07	84.47 ±.07	84.56 ±.08	84.46 ±.05	84.31 ±.05	84.39 ±.05	84.24 ±.11	83.77 ±.06	83.71 ±.11	83.74 ±.10

Table 11-2

Serum Electrolyte Results
(meq/l)

Prechamber Means

Sodium	140.4
Potassium	3.8
Chloride	105.5

Postchamber

Date	Sodium	Percent Change	Potassium	Percent Change	Chloride	Percent Change
9-20	141.3	+ 0.6	3.7	− 2.6	106.3	+ 0.8
9-21	140.0	0.3	4.0	+ 5.3	104.7	− 0.8
9-25	144.3	+ 2.8	4.2	+ 10.5	108.7	+ 3.0
10-5	140.3	-0.1	4.0	+ 5.3	108.3	+ 2.7

Table 11-3

Urinary Electrolyte Concentrations
meq/volume

		Sodium			Chloride			Potassium		
		CDR	SPT	PLT	CDR	SPT	PLT	CDR	SPT	PLT
Pre-chamber	1.	128	135	143	108	114	122	72	73	69
	2.	131	148	152	108	123	134	88	75	73
	3.	156	128	140	124	102	132	83	73	84
In-Chamber	4.	157	143	167	132	123	148	82	73	75
	5.	153	128	169	126	114	149	83	75	82
	6.	142	105	154	114	89	139	78	80	76
	7.	148	115	152	115	91	135	80	73	75
	8.	133	118	162	112	96	143	71	73	77
	9.	154	143	156	125	114	137	78	70	72
	10.	151	131	176	105	110	153	81	72	82
	11.	163	135	169	132	106	136	86	79	86
	12.	157	114	157	139	78	134	87	71	75
Post-chamber	13.	123	89	157	98	71	126	68	51	72
	14.	144	110	160	134	93	140	83	65	80
	15.	118	106	146	104	90	129	71	81	75

Sodium { FA = Between Treatments   P = .025   2.4864
       FB = Between Men   P < 001   24.2233

Chloride { FA = Between Treatments   1.8710   P .10
       FB = Between Men   39.4455   P <.001

Potassium { FA = Between Treatments   P = .025   2.5055
       FB = Between Men   P < .005   7.7318

decreased by 2.1 percent from the prechamber mean and then increased for the following blood samples 7.5, 12.0, and 5.9 percent. Serum chloride was increased on days 90 and 99. The greatest increase,

which occurred on day 90, was consistent with the increase in sodium also observed on that day. The urine electrolyte data exhibit significant variation among the crewmen; however, only potassium varied significantly for the group between the in-chamber and postchamber values, with the first postflight period demonstrating the lowest potassium excretion values. This coincides with the decreased serum potassium observed on day 85. This slight but significant potassium change has been noted after other hypobaric studies (Katchman et al., 1967; Gee et al., 1968). It has been attributed to dietary factors by one author but may be more appropriately related to other metabolic and endocrine control mechanisms as discussed in this section.

In order to examine more closely the control of sodium and potassium metabolism, the salt retaining hormone aldosterone was measured in combination with the peptide angiotensin which is responsible for the primary control of aldosterone secretion from the

adrenal cortex. These data are summarized in Table 11-4.

There is a slight trend toward an increase in urinary aldosterone during the periods after chamber ingress with the fifth and sixth periods varying significantly from the pre- and postchamber phases. Angiotensin I, a direct measurement of renin activity, shows overall slight increases from the preflight control period during in- and postchamber sample periods. This increase was noted in all three crewmen. The CDR's data exhibit abnormally elevated values periodically, and the exact reason is not yet apparent.

The two crewmen on Gemini 7 showed increased urinary aldosterone excretion during the flight (Lutwak et al., 1969). Data from crews of the Apollo missions also suggest that aldosterone is elevated during weightlessness (Leach et al., 1972). The results reported herein are probably not related to dietary sodium or potassium since the intake of both of these electrolytes remained constant.

Table 11-4

Sodium Control Mechanism Results

		Urinary Aldosterone µg/tv			Plasma Angiotensin I m/µg/ml/hr		
		CDR	SPT	PLT			
Prechamber	1.	3.9	4.4	5.9	Prechamber Mean = 0.58		
	2.	6.7	4.4	5.0	In-chamber		
	3.	5.2	3.4	4.4			
					Date	Means	Percent Change
	4.	6.5	6.0	8.9	7-29	1.08	+ 86.2
	5.	12.2	5.9	10.4	8-7	2.74	+372.4
	6.	8.9	7.6	10.9	8-14	1.26	+117.2
In-chamber	7.	7.1	5.9	7.4	8-22	1.65	+184.5
	8.	6.2	5.5	6.6	8-31	0.99	+ 70.7
	9.	5.5	4.5	5.9	9-11	4.69	+708.6
	10.	7.6	6.3	8.7	9-18	2.08	+258.6
	11.	3.7	6.8	5.6			
	12.	5.1	4.9	4.3			
					Postchamber		
					9-20	1.90	+227.6
Postchamber	13.	4.1	3.3	4.9	9-21	0.79	+ 36.2
	14.	5.7	3.5	4.5	9-25	1.38	+137.9
	15.	7.5	6.9	7.7	10-5	1.23	+112.1

Aldosterone $\begin{cases} F A = \text{Between Treatments} & 6.8279 \quad P < .001 \\ F B = \text{Between Men} & 6.7518 \quad P \quad .005 \end{cases}$

There are reports of electrolyte changes due to hypobaric chambers exposure (Katchman et al., 1967). However, the magnitude of those changes, as well as the ones in this study, is much less than the magnitude of the changes reported from space flight (Leach et al., 1972). There are several factors which influence the adrenal secretion of aldosterone (Muller, 1971). Among these are potassium ions, related monovalent cations, angiotensin, serotonin, and ACTH. All but the last one acts directly on the production of aldosterone.

It is not possible to discuss changes in electrolyte metabolism without studying the control and disposition of body water. The data pertinent to this area are summarized in Table 11-5. There were significant differences during the eighth and ninth in-chamber periods and the last postchamber period with the remaining periods in urine volume and ADH. Neither urinary nor plasma osmolality varied significantly throughout the study. The in-chamber increases in ADH with concomitant decreases in urine volume occurred at the time the temperature was increased within the chamber.

The reaction of the central nervous system to conserve water during elevated temperature exposure is well documented (Strauss, 1957). The response postchamber is related to the environmental temperature outside the chamber. Table 11-6 shows the body fluid volumes measured during SMEAT. Except for plasma volume, all other volumes were

Table 11-5

Urine Volume Data

		Urine Volume ml			ADH m Units/tv			Osmolality m OSMO		
		CDR	SPT	PLT	CDR	SPT	PLT	CDR	SPT	PLT
Pre-chamber	1.	2546	1967	1497	14.0	10.2	11.0	378	655	516
	2.	2103	1667	1910	10.8	11.9	10.9	392	577	512
	3.	2426	1483	1691	5.0	4.8	8.1	341	569	435
In-chamber	4.	2745	2080	1848	7.9	6.5	9.1	326	428	458
	5.	2874	1904	2024	9.0	10.8	15.7	313	462	457
	6.	2615	1646	1820	12.0	7.9	10.2	331	626	500
	7.	2372	1626	1488	12.1	7.4	12.2	362	590	597
	8.	2162	1251	1394	54.6	28.7	17.8	380	639	579
	9.	2365	1825	1418	21.1	47.5	19.7	368	749	577
	10.	2369	1932	1905	18.2	30.8	14.9	336	429	476
	11.	2756	1929	1757	7.7	5.3	3.4	346	431	490
	12.	2863	1653	1786	29.7	3.9	18.1	348	469	531
Post-chamber	13.	1940	1408	1815	20.1	10.2	9.6	470	547	530
	14.	2526	1578	2039	18.6	7.5	10.3	344	629	456
	15.	1983	1128	1590	15.0	8.2	9.6	403	722	492

Urine Volume	{ FA = Between Treatments	3.7953	P <.005
	FB = Between Men	78.8081	P <.001
ADH	{ FA = Between Treatments	3.2267	P <.005
	FB = Between Men	1.6416	P <.25
Osmolality	{ FA = Between Treatments	P= .025	2.3272
	FB = Between Men	P <.001	48.0314

Serum Osmolality
m OSMO

Prechamber Mean: 286.4

POSTCHAMBER

Date	Means	Percent Change
9-20	286.0	−0.1
9-21	286.0	−0.1
9-25	285.7	−0.2
10-5	282.7	−1.3

Table 11—6

Body Compartment Measurements

Body Fluid Volumes Expressed in Liters

	CDR			SPT			PLT			
	Pre	Post	%Δ	Pre	Post	%Δ	Pre	Post	%Δ	Mean %Δ
Total Body Water	45.9	44.1	− 3.9	59.3	57.5	− 3.0	52.2	51.7	− 0.9	− 2.6
Intracellular Fluid	31.6	29.7	− 6.0	39.3	38.7	− 1.5	34.8	34.8	0.0	− 2.5
Extracellular Fluid	14.3	14.4	+ 0.7	20.0	18.8	− 6.0	17.4	16.9	− 2.9	− 2.7
Plasma Volume	3.4	3.2	− 5.9	4.2	4.4	+ 4.4	3.2	3.5	+ 9.4	+ 2.8
Interstitial Fluid	10.9	11.2	+ 2.8	15.8	14.4	− 8.9	14.2	13.4	− 5.6	− 3.9
Weight in Kg	72.1	70.3	− 2.5	94.9	87.7	− 7.6	85.1	84.2	− 1.0	− 1.0

Body Fluid Volumes Expressed as ml/kg Body Weight

	CDR			SPT			PLT			
	Pre	Post	%Δ	Pre	Post	%Δ	Pre	Post	%Δ	Mean %Δ
Total Body Water	637	627	− 1.6	625	656	+ 5.0	613	614	+ 0.2	+ 1.2
Intracellular Fluid	438	422	− 3.6	414	441	+ 6.5	409	413	+ 1.0	+ 1.3
Extracellular Fluid	198	205	+ 3.5	211	214	+ 1.4	204	201	− 1.5	+ 1.1
Plasma Volume	47	46	− 2.1	44	50	+ 13.6	38	42	+ 10.5	+ 7.3
Interstitial Fluid	151	159	+ 5.3	166	164	− 1.2	167	159	4.8	− 0.2
Lean Body Mass in Kg	62.9	60.4	− 4.0	81.2	78.8	− 3.0	71.5	70.8	− 1.0	− 1.0

decreased during the mission. When the volumes are expressed as milliliters per kilogram of body weight, there is an increase in all volumes except interstitial fluid. This indicates that the decreases in the volumes are a result of the weight decrease of the crewmembers.

Lean body mass decreased in all three crewmembers; however, the decrease in lean body mass was small compared to the loss of lipid containing tissue shown by SPT and the increase shown by CDR.

Total body exchangeable potassium was determined immediately after chamber egress and again fourteen days later (Table 11-7). There was no significant change in the results of this determination. Total body exchangeable potassium represents about 90 percent of the total body potassium.

Table 11-7

Total Body Exchangeable Potassium
meq/K/kg Body Weight

	CDR	SPT	PLT
ASAP	41.8	41.0	47.2
R + 14	42.8	40.3	48.5

Total meq

	CDR	SPT	PLT
ASAP	2938	3596	3974
R + 14	3032	3562	4074

The body fluid changes were small and proportional to the change in body weight experienced by the crewmembers during the mission. Since this was a 1 g environment, the fluid shifts associated with weightlessness would not be expected. The large weight change experienced by the SPT appeared to have been fat (-29.2 percent) with a relative increase in lean body mass (+4.9 percent). This indicates a degree of physical conditioning associated with his weight loss since a weight loss due only to caloric restriction should have produced an equivalent change in percent lean body mass.

Fluid and electrolyte changes have been shown in actual and simulated space flights (Glen & Shannon,

1966). The results indicate that the environmental conditions of this chamber did provoke changes, particularly when the temperature was elevated. However, the changes reported here are not comparable to those reported from the U.S. and U.S.S.R. manned space flights.

Regulation of Calcium Metabolism

One of the more significant threats to the health of space flight crews during long-term exposure to weightlessness flight is regarded to be alterations in calcium metabolism (Hattner & McMillian, 1968). Studies with subjects at bed rest indicate that exposure to reduced gravitational stress would result in an imbalance between bone formation and bone restoration (Deitrick et al., 1948). For this reason, the hormones which affect calcium levels in the blood were analyzed. These were parathormone (PTH), calcitonin, and vitamin D.

The PTH results are shown in Table 11-8. There were no significant changes in the plasma levels of this hormone in any phase of the experiment. All of the calcitonin results remained below 70 pg/ml which is the level of detection of this assay (Deftos, 1971). It can be assumed, therefore, that there were no physiologically significant increases in plasma calcitonin concentration during the study. Vitamin D also demonstrated no changes from baseline.

Although a possible effect on calcium metabolism of the SMEAT environment was a primary motivating factor in the conception of the SMEAT Program, it was not anticipated that this alteration would be large enough to manifest itself in significant and prolonged negative calcium balance. These findings have been verified, and it is believed that the constancy of the calcium/phosphorus balance in this study provides a stable baseline for the interpretation of the Skylab calcium balance experiment.

Adaptation to the Environment

Space flight of long or short duration includes a wide range of types and intensities of stress stimuli. Almost all components of the endocrine system respond to stress. By studying this system, the earliest reaction of man to stress, as well as the intensity of the neuroendocrine response, can be determined. For

Table 11-8

Plasma Parathormone Results

		CDR	SPT	PLT
		— — —	Heparin	— — —
Prechamber	6/29	< 0.42 ± • 0.00	< 0.42 ± • 0.00	< 0.42 ± • 0.00
	7/6	< 0.42 ± • 0.00	< 0.42 ± • 0.00	< 0.42 ± • 0.00
	7/13	0.62 ± • 0.08	0.49 ± • 0.01	0.69 ± • 0.13
	7/25	< 0.42 ± • 0.00	0.54 ± • 0.12	0.54 ± 0.08
		— — —	EDTA	— — —
In-chamber	7/27	N. S.	N. S.	0.96 ± 0.03
	7/29	1.07 ± 0.03	1.37 ± 0.04	1.21 ± 0.12
	8/7	1.57 ± 0.50	1.20 ± 0.22	1.22 ± 0.03
	8/14	N. S.	1.24 ± 0.04	1.00 ± 0.06
	8/22	0.90 ± 0.07	1.05 ± 0.16	1.06 ± 0.24
	8/31	1.58 ± 0.29	1.05 ± 0.02	0.97 ± 0.08
	9/11	< 0.64 ± • 0.00	< 0.64 ± • 0.00	< 0.64 ± • 0.00
	9/18	0.82 ± 0.00	< 0.64 ± • 0.00	< 0.64 ± • 0.00
		— — —	Heparin	— — —
Postchamber	9/20	< 0.64 ± • 0.00	0.77 ± 0.08	0.79 ± 0.15
	9/21	< 0.64 ± • 0.00	0.65 ± 0.01	< 0.64 ± • 0.00
	9/25	0.73 ± 0.08	0.77 ± 0.03	< 0.64 ± • 0.00
	10/5	0.70 ± 0.06	0.67 ± 0.02	< 0.64 ± • 0.00

< — ± means all replicates undetectable

N. S. Indicates no sample

consideration of the physiological cost of maintaining existence in the chamber environment, the sympatho-adrenal medullary and the pituitary-adrenal axis secretions were studied. For this purpose, two groups of hormones were assayed and the results are given in Table 11-9 (a and b).

Plasma ACTH was elevated in the pretest period once. Excluding those data for the analysis, all of the in- and postchamber samples except the first in-chamber sample were significantly decreased (average 50 percent). Plasma free hydrocortisone was slightly elevated during this study. The range for this elevation was from 14 to + 52 percent. These results agree with the concept of a negative feedback control between the adrenal and the anterior pituitary.

The urinary steroid data demonstrated changes in several areas. Hydrocortisone excretion was decreased below control values for the seventh and eighth chamber periods and the postchamber results also differed from the prevalues. The total 17 OHCS showed slight decreases throughout the chamber and post periods. There appear to be two reasons for the decreasing trends in the urinary excretion of the glucocorticoids. First, the prechamber phase urinary steroid levels may have been elevated due to the anticipatory stress of the study. The second reason may be the decreased excretion of these compounds in a hypobaric environment. This was reported on the one flight experiment for which there were urine samples returned for analysis, and similar decreases have been reported in various altitude testing (Ulvedal et al., 1963). It is thought that these changes reflect decreased metabolism of the steroid compounds.

The total and fractional ketosteroid data were grouped on a seven-day basis for statistical treatment. The analysis of variance for these data is shown in Table 11-10. This analysis substantiated the individual variations which have been demonstrated in most other areas. More importantly, etiocholanolone, 11 = 0 etiocholanolone and the total values varied significantly (p< .05) between the pre-weeks and first week in the chamber, with a definite decrease after chamber ingress.

Decrease in total steroid excretion has been linked to hypobaric exposure (Ulvedal et al., 1963). However, the decrease in one particular steroid in the metabolism of the ketosteroids has not been shown before this experiment. This decrease may be of importance in the enzymatic shifts evidently occurring at the glandular level.

Table 11–9a

Pituitary Results

Date	ACTH pg/ml Prechamber Mean: 63.7		Hydrocortisone μg/100 ml Prechamber Mean: 15.3	
	Means	Percent Change	Means	Percent Change
	Chamber		Chamber	
7-29	61.0	− 4.2	15.5	+ 1.3
8-7	32.8	− 48.5	23.2	+ 51.6
8-14	25.5	− 60.0	14.3	− 6.5
8-22	29.3	− 54.0	13.1	− 14.4
8-31	30.4	− 52.3	19.2	+ 25.5
9-11	42.1	− 33.9	21.1	+ 37.9
9-18	32.1	− 49.6	20.3	+ 32.7
	Postchamber		Postchamber	
9-20	30.9	− 51.5	21.9	+ 43.1
9-21	20.1	− 68.4	17.7	+ 15.7
9-25	25.4	− 60.1	17.3	+ 13.1
10-5	33.1	− 48.0	19.8	+ 29.4

Table 11–9b

Urinary Adrenal Cortical Results

		Hydrocortisone μg/tv			Total 17-Hydroxycorticosteroids mg/tv		
		CDR	SPT	PLT	CDR	SPT	PLT
Pre-chamber	1.	73	81	117	8.8	12.4	11.6
	2.	83	139	89	8.7	9.9	12.7
	3.	83	108	79	8.1	10.1	11.5
In-chamber	4.	71	82	81	8.5	9.3	8.6
	5.	85	97	88	8.6	9.9	10.9
	6.	54	61	65	8.4	7.8	9.9
	7.	47	66	37	7.6	7.6	6.6
	8.	42	52	47	5.9	6.5	6.2
	9.	61	91	61	7.6	8.9	6.8
	10.	56	95	78	8.9	9.5	8.9
	11.	79	96	79	10.1	6.8	6.2
	12.	83	77	76	10.5	5.9	8.9
Post-chamber	13.	80	71	75	4.5	6.4	6.5
	14.	52	60	48	5.9	7.0	7.3
	15.	76	75	62	7.0	7.4	10.3

Hydrocortisone { FA = Between Treatments   5.4037 $P < .001$
                { FB = Between Men   6.2775 $P = .005$

Total
17-Hydroxy-   { FA = Between Treatments   3.5910 $P < .005$
corticosteroids { FB = Between Men   1.6622 $P = .25$

Table 11–10

17-Ketosteroids: Two Way Analysis of Variance

	F_A	$F_{0.95}$	F_B	$F_{0.95}$
Pregnanediol	1.24		39.76	•
Androsterone	1.25		22.59	•
Etiocholanolone	4.90	•	141.76	•
Dehydroepiandrosterone	1.27		3.55	•
11=0 Etiocholanolone	5.85	•	20.96	•
Total	3.21	•	42.17	•

The second group of hormones, generically called catecholamines, is represented by the substances epinephrine or norepinephrine which are secreted in response to immediate short-term stress situations.

The results of the analysis of these hormones reveal significant changes among the periods, as shown in Table 11-11.

Both catecholamines were consistently higher in the CDR. His urine also demonstrated frequent decreases in the ratio of norepinephrine to epinephrine. The SPT excreted increased amounts of norepinephrine beginning before the chamber ingress and continuing throughout the exposure. The PLT demonstrated normal excretion of the catecholamines with minor incidence of increases. Studies on the effect of hypobaric chamber exposure on the urinary excretion of epinephrine and norepinephrine and steroids are inconclusive (Ulvedal, et al., 1963). However, it is considered that epinephrine excretion is elevated in mental or emotional strain while

Table 11-11

Urinary Catecholamines

$\mu g/lv$

		Epinephrine			Norepinephrine		
		CDR	SPT	PLT	CDR	SPT	PLT
Prechamber	1.	52.8	14.1	39.8	82.0	70.1	63.1
	2.	42.3	11.5	24.7	68.3	66.9	35.9
	3.	35.1	13.5	25.8	61.6	60.5	42.8
In-chamber	4.	49.5	9.9	25.8	69.3	78.3	57.6
	5.	42.8	25.5	38.4	74.4	82.5	43.0
	6.	53.3	15.3	30.9	84.8	88.0	50.6
	7.	52.1	29.3	29.9	65.6	73.7	44.0
	8.	48.7	22.3	27.7	49.7	58.4	30.5
	9.	46.7	21.5	25.2	53.3	63.6	26.7
	10.	41.8	1.4	21.7	55.1	53.6	41.1
	11.	46.7	12.1	26.5	52.7	66.8	34.4
	12.	47.6	17.6	33.5	56.0	66.6	32.7
Post-chamber	13.	44.9	11.4	23.3	70.0	63.9	46.5
	14.	31.5	11.5	20.0	77.5	64.5	48.5
	15.	42.7	14.1	22.1	87.7	81.2	60.7

Epinephrine	FA = Between Treatments	3.5286	P < .005
	FB = Between Men	154.5620	P < .001
Norepinephrine	FA = Between Treatments	7.9418	P < .001
	FB = Between Men	80.9077	P < .001

increases in norepinephrine excretion are more closely associated with physical strains (Sudoh, 1971).

Regulation of Metabolic Processes

Assessment of overall metabolic response to the SMEAT environment was based on assay of serum levels of glucose, insulin, human growth hormone (HGH) and thyroxine and thyroid stimulating hormone. Urinary levels of nine free amino acids completed the picture of metabolic regulation.

Glucose did not differ significantly from pre- to postchamber; likewise, insulin was not greatly changed. However, it is important to note on day 86 postchamber, the insulin was increased 50 percent and the glucose was decreased from the prechamber mean. Changes in these parameters are considered to

be of primary concern for long duration missions since bed rest, the most used analog to weightlessness, does produce alteration in glucose utilization (Lipman, 1970).

Growth hormone, assessed as an indication of nutrient utilization, did not vary significantly except in the SPT on day 99 postchamber (Table 11-12). Human growth hormone acts to increase blood sugar, increase plasma free fatty acids, and lower plasma amino acids by incorporating them into proteins (Schalch, 1969). The significant rise in the SPT's HGH is related to the increase in dietary protein allotted to him at this particular phase in the chamber test.

Plasma thyroxine and thyroid stimulating hormone results did not show significant changes (Table 11-13). There were, however, trend increases

Table 11-12

Plasma Biochemical Results

	Insulin μU/ml		Glucose mg/100 ml		Human Growth Hormone meq/l	
Prechamber Mean:	15.5		99.2		2.8	
	Postchamber:					
Date	Means	Percent Change	Means	Percent Change	Means	Percent Change
9-20	19.0	+ 23	91.3	− 8	3.9	+ 39
9-21	24.7	+ 59	110.7	+ 12	3.7	+ 32
9-25	21.3	+ 37	96.0	− 3	2.5	− 11
10-5	14.3	−8	92.7	− 7	4.7	+ 68

Table 11-13

Thyroid Parameters

		Thyroid Stimulating Hormone μU/ml	Thyroxine μg/100 ml	
Prechamber Mean:		5.3	6.3	
Date	Means	Percent Change	Means	Percent Change
9-20	4.8	− 9	6.6	+ 5
9-21	4.5	−15	7.1	+13
9-25	7.6	+43	8.5	+35
10-5	4.4	−17	8.7	+38

in thyroxine and decreases in thyroid stimulating hormone. This trend has to be assessed in regard to metabolic requirements of the chamber environment. There is evidence that changes in space flight do diminish metabolic requirements of the flight crews (Johnson et al., in press).

Of the 36 urinary amino acids analyzed, nine free amino acids showed statistically significant changes from the prechamber to the postchamber period. These were as follows: phosphoethanolamine, glutamic acid, alanine, phenylalanine, tyrosine, gamma-amino butyric acid, 1-methyl histidine, and arginine.

Changes in amino acid excretion could result from increased tissue breakdown, overproduction or increased permeability at the cellular level (Searcy, 1969). Furthermore, the catabolic effect of short-term increases in steroid production serves to divert amino acids from protein synthesis and to enhance renal excretion of individual amino acids (Zinneman et al., 1963).

Since this is the first hypobaric chamber study to consider amino acid excretion profiles, the results must be considered in relation to stress, exercise and nutrient balance. Because of the essential role of several trace metals in biochemical reactions, a spectrum of individual elements was examined for changes due to the chamber environment. The results of the analysis by optical emission spectroscopy confirmed earlier reports of individual variations; however, the results from the SMEAT crewmen compare favorably with other published reports (Schroeder et al., 1971). Although certain element excretions were different at certain times, there were no significant trends in all three crewmen.

Summary and Conclusions

Body fluids were assayed in this experiment to demonstrate changes which might have occurred during the 56-day chamber study in fluid and electrolyte balance, in regulation of calcium metabolism, in overall physiological and emotional adaptation to the environment, and in regulation of metabolic processes.

There was a slight but significant decrease in potassium excretion probably related to slight increases in urinary aldosterone and other metabolic mechanisms.

Increases in antidiuretic hormone, when noted during the chamber and postchamber periods, were related to environmental temperatures within and without the chamber. Body fluid losses were generally proportional to body weight losses.

No changes indicative of altered calcium metabolism were found. The constancy of calcium balance in this study provides a stable baseline for interpretation of Skylab results.

Decreases were noted in glucocorticoids. Similar decreases have been reported in altitude testing and in one space flight experiment, and these decreases are believed to reflect decreased metabolism of the steroid compounds in hypobaric environments. Changes in catecholamine levels are marked by a high degree of individual variability.

The enhanced renal excretion of amino acids noted may be related to the catabolic effects of steroid overproduction. This was the first hypobaric chamber study to consider amino acid excretion profiles, and the results must be considered in relation to stress, exercise, and nutrient balance as well.

The results of this experiment provide a stable background for the endocrine experiments being performed in the Skylab missions. The SMEAT version of Experiment M073 will make it possible to separate with more certainty than was previously possible weightlessness effects from other conditions accompanying space flight. Further, the chamber test enabled perfection of the logistics of implementing this very complex experiment in orbital flight.

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CHAPTER 12

SLEEP-MONITORING-EXPERIMENT M133

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The sleep-monitoring experiment proposed for the first two Skylab missions has been designed to allow the first truly objective evaluation of man's ability to sleep during extended space travel. While subjective reports of sleeping difficulty have been made by crews of some previous, shorter-duration flights, (Berry, 1970) objective or quantitative information has been sparse. Such information is obtained only by continuous monitoring of electroencephalographic (EEG) and electrooculographic (EOG) activity during sleep periods, and the technical problems associated with data acquisition and analysis are considerable. The only previous attempt to examine the EEG during U.S. space flights was carried out during the Gemini VII mission in 1965; technical difficulties at that time limited recording to the first two sleep periods, thereby preventing an adequate analysis of adaptation to the weightless environment.

Sleep deprivation is associated with degradation of performance and the severity of the performance decrement generally increases in proportion to the length of the sleep loss (Naitoh, 1969). Because crewmembers are required to perform at a high level throughout their mission, their ability to obtain a sufficient quantity of sleep becomes an important variable in terms of overall mission planning and in the selection of day-to-day work-rest periods.

The apparatus designed for the Skylab sleep-monitoring experiment provides a complete system for automatically analyzing sleep during space flight. It includes data acquisition hardware, onboard analysis circuitry, and real-time telemetry. During Skylab missions, a crewmember's sleep status is monitored throughout selected eight-hour rest periods. Sleep-stage information (provided by an onboard analyzer) is telemetered to Mission Control where a profile of sleep stage versus time is accumulated. Analog data (EEG, EOG and head motion) is also preserved in unprocessed form by onboard magnetic tape recorders to allow detailed postflight analysis by visual and computer methods.

The information provided by the Skylab M133 experiment will clarify whether or not there is a problem in obtaining adequate sleep over a long period in the weightless environment, and it will also help to determine the best corrective measures to be taken so that the effects on performance are minimized.

The SMEAT project provided an opportunity to test the M133 hardware system under operational and environmental conditions closely approximating those expected during a 56-day mission. Simultaneously, it permitted study of the possible effects

upon sleep of certain environmental factors under the influence of gravity, thus providing a more meaningful evaluation of the effect of weightlessness during the actual Skylab flights.

Equipment

Description of Apparatus

The M133 hardware consists of three basic units:

1. The cap assembly, including the recording cap with attached prefilled electrodes;

2. The preamplifier/accelerometer assembly which mounts on the cap and contains amplifiers, electroshock protection circuitry, and dual-axis accelerometers; and

3. The control-panel assembly which contains circuitry for automatic electrode checkout,

final amplification, and EEG and EOG analysis, and which includes dual analog magnetic tape recorders. A block diagram showing the interconnections of these three assemblies is provided in Figure 12-1. A photograph of the actual equipment appears in Figure 12-2.

Cap Assembly. A recording cap assembly is illustrated in Figure 12-3. Electrodes are joined by wires to the miniature electrical connector at the vertex, which permits the crewmember to attach the preamplifier/accelerometer assembly before the cap is donned. The cap contains seven electrodes, thereby providing two EEG channels (C_1O_1 and C_2O_2), one EOG channel (one electrode lateral to and one above the left eye), and one ground. At the end of a sleep
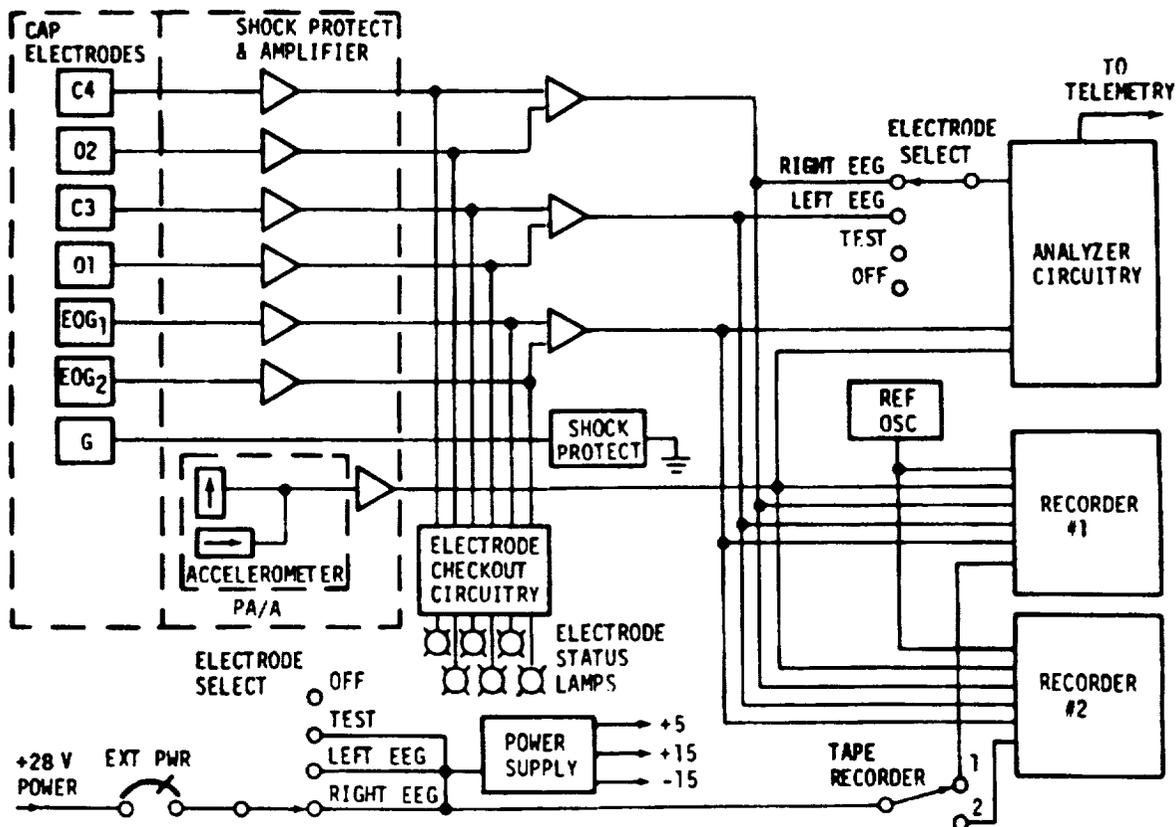

Figure 12-1. M133 automatic sleep analysis hardware block diagram.
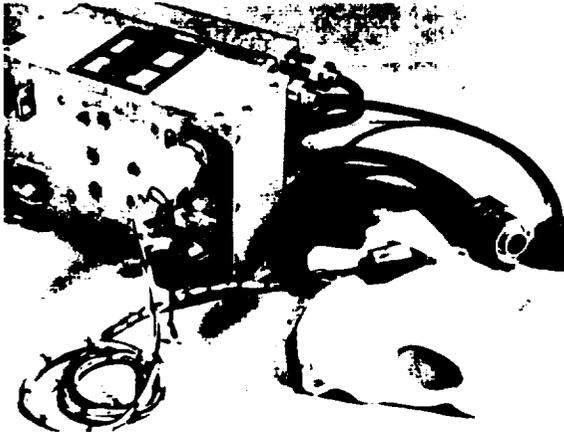
Figure 12-2. M133 sleep-monitoring recording cap and attached preamplifier (lower right); control-panel assembly containing automatic electrode check, final amplification, tape recorders, and EEG-EOG analysis (upper left).
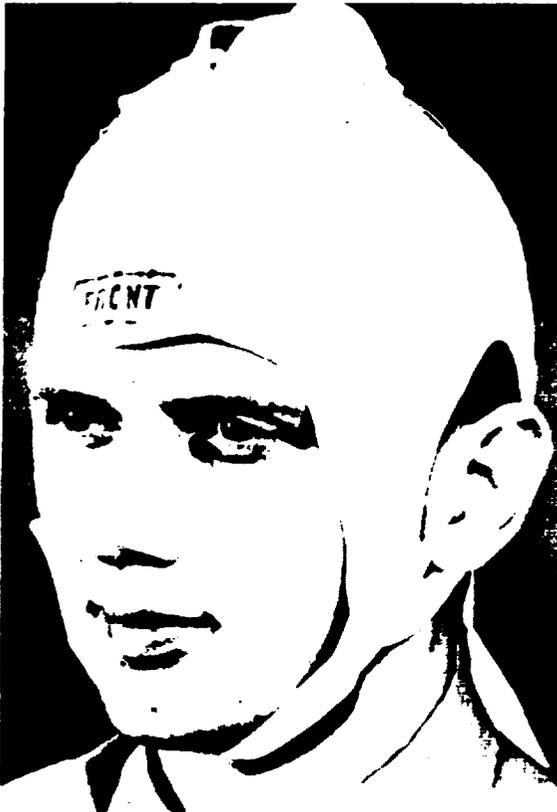
Figure 12-3. Subject wearing the recording cap properly positioned.

period, the preamplifier/accelerometer is disconnected, and the used cap is discarded. A new cap is used for each recording session, eliminating a time-consuming procedure associated with care of used electrodes. A cross section of one recording electrode is shown in Figure 12-4.
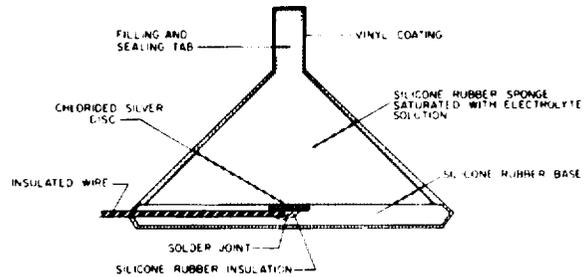

Figure 12-4. Cross section of a prefilled sponge electrode.

As a part of the manufacturing process, an electrically conductive gel is injected through the electrode's tab into the body of the sponge through a hollow needle until the porous structure becomes saturated. The needle is withdrawn and the tip resealed with vinyl. The completed electrode is then attached to the cap, which may be stored indefinitely in a metalized plastic bag.

To prepare for a recording period, the crewman simply removes the cap from its protective bag, attaches the preamplifier unit, and with scissors clips the sealing tabs from the seven electrodes as illustrated in Figure 12-5. The cap is donned, and the exposed portions of the electrodes make contact with the scalp. The cap is held in place during a sleep period by a padded chin strap that is attached with Velcro fasteners.

Preamplifier/Accelerometer Assembly. Matched pairs of field-effect transistors, providing a gain of approximately ten, preamplify EEG and EOG signals within this unit. A dual-axis accelerometer and associated preamplifier are included for detecting head motion in the lateral (side-to-side) and vertical (up-down) axes. The amplified signals pass through a four-foot cable (Figure 12-2) to the control-panel assembly which provides final amplification of the signals.
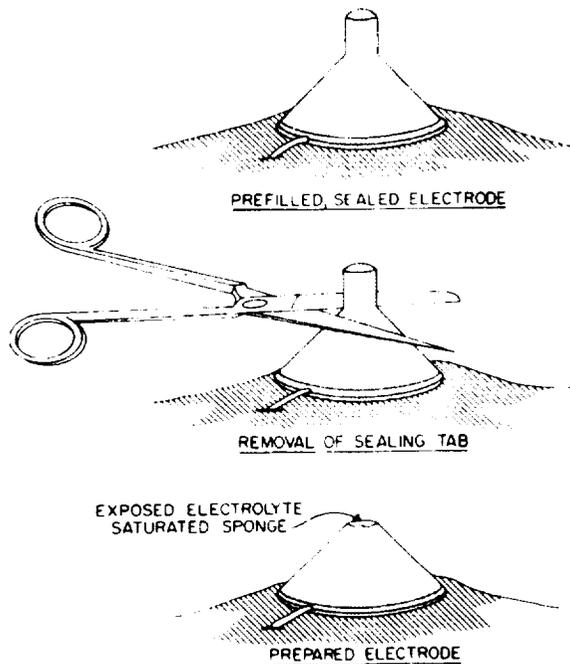
Figure 12-5. Sequence followed in preparing an electrode for recording.

Circuitry within the preamplifier/accelerometer assembly also provides electroshock protection for the subject. Each electrode lead is actively protected against current flow in excess of 200 μA (peak).

Control-Panel Assembly. The control-panel assembly is mounted on the wall of the sleep compartment within easy reach of the subject. Front panel controls include the power switch, a mode-selection switch, tape-recorder selection switch, and a subject gain-factor potentiometer. The circuitry accomplishes automatic signal amplification, electrode testing, and data analysis, and provides outputs to the two attached analog magnetic tape recorders and to the spacecraft telemetry system.

The electrode-check section performs automatic testing of each recording electrode before the sleep period begins. The front panel contains a series of indicator lamps, each representing one sponge-electrode sensor in the cap. The panel lamps are arranged in a configuration simulating their relative position on the head. When the subject dons the cap,

he moves the mode-selection switch from the off to the test position, thereby activating the test circuitry. A small test current (10 μA) passes through the single ground electrode to each of the six recording electrodes, and the amount of current passed by each electrode is sensed to provide an indication of interelectrode resistance. If a given electrode is in proper scalp contact, its resistance will be 50,000 Ω or less, and this condition is indicated by illumination of the corresponding lamp on the panel display. Improper contact, signaled by failure of any lamp to illuminate, usually can be resolved by slightly rocking the involved electrode to position the tip through the hair and against the scalp.

The data-analysis equipment is designed to meet the limitations imposed by space flight. In order to supply sleep-stage information in near real time, while still minimizing telemetry time and bandwidth, most of the data processing is accomplished by the panel-assembly circuitry. Since the unit's output is expressed in terms of sleep stage (i.e., restricted to one of seven possible states) and changes only slowly, the information content can be telemetered adequately by transmitting only three bits at a rate of 1.25 samples/sec (as opposed to approximately 3200 bits/sec which would be required to transmit the unprocessed data).

The established criteria for evaluating sleep are based upon changes in the EEG and EOG patterns which accompany behavioral and physiological changes during the transition from the Awake condition to one of deep sleep. The Awake state is typically characterized electroencephalographically by alpha activity (8-13 Hz) and/or low-amplitude, generally mixed-frequency activity. Stage 1, or very light sleep, is indicated by low-amplitude, irregular EEG signals of a lower frequency (5-7 Hz) than the Awake state. During Stage 2 sleep, the EEG exhibits a somewhat random frequency and low-amplitude background activity upon which is superimposed sporadic bursts of 12-14 Hz activity (sleep spindles) and/or relatively high-voltage transients exceeding 0.5 sec in duration (K complexes).

Stage 3 is identified by the occurrence of high-amplitude (>75 uV) activity of less than 2 Hz which

is present between 20 and 50 percent of the time, while Stage 4 is characterized by the presence of such activity more than 50 percent of the time. The rapid eye movement (REM) sleep stage has been highly associated with dreaming and is characterized by EEG signals similar to Stage 1 in appearance, but it is differentiated by the occurrence of rapid, jerking-type eye movements as detected by the EOG. A seventh category, Stage O, has been included to indicate interruption of data or the loss of physiological signals.

EEG alone is used to determine Stages Awake, 1, 2, 3 and 4 of sleep. EEG and EOG signals differentiate Stage REM, and the EEG and accelerometer outputs delineate periods that are likely to be contaminated by artifactual signals.

The EEG analysis considers activity in the 0.7-13 Hz range which is derived from either of the two channels available (left EEG, C_1O_1, or right EEG, C_2O_2, selectable from front panel control). The circuit functions as an amplitude-weighted frequency meter for the dominant EEG activity. Each of the three comparators is set to detect a different signal amplitude: high, or 100 percent; intermediate, or twenty percent; and low, or one percent. The input EEG signal gain factor is adjusted once for each subject so that the average peak amplitude of the subject's eyes-closed, waking EEG is made to fall midway between levels 2 and 3, or approximately 60 percent. Consequently, the higher voltage activity during sleep frequently will cross the third level, whereas the lower voltage signals of Stage 1 usually will exceed only levels 1 or 2.

The bistable circuit, following the level 1 and level 2 comparators, triggers the negative pulse generator only if level 1 and level 2 are crossed successively in a negative-going direction. The number of standard amplitude pulses produced by the negative-pulse generator is therefore proportional to the dominant frequency of the EEG and is relatively independent of minor inflections. The positive-pulse generator, whose output is one-half the amplitude of the negative-pulse generator, triggers each time the voltage exceeds level 3. The pulses from the two generators enter the mixer amplifier, which supplies a composite pulse train to the integrator circuit. The

integrator has a rise and fall time constant of 10 sec, and consequently its output is a voltage level largely dependent upon the number and polarity of pulses recorded during the preceding 10-sec epoch.

With respect to its effect on the integrator circuit output, an EEG wave of very low voltage, i.e., not exceeding level 2, has zero value; an intermediate-amplitude wave has maximum value (negative pulse); and a high-amplitude wave (exceeding level 3) has a value of 50 percent since it produces a negative pulse *and* a positive pulse of one-half the amplitude. This permits the progressive decline in frequency and the general increase in amplitude, which occur with increasing sleep depth, to be effectively utilized. The individual's EEG state is consequently expressed as a voltage level at the output of the integrator. The Awake state is associated with the highest output voltage, while progressive stages of sleep are accompanied by correspondingly lower output values.

The integrator voltage enters a series of comparator circuits in the output section where it is compared to previously determined voltage ranges, each corresponding to one of the clinical sleep stages. Thus, while the EEG analysis output remains within the range specified for a particular sleep stage, a constant voltage is supplied to the corresponding output line of the analyzer.

The EEG analysis section usually classifies Stage REM sleep as either Stage 1 or 2 due to its similiarity in frequency and amplitude; however, true Stage REM is distinguished by the occurrence of bursts of rapid, jerking eye movements. Although these events are sporadic throughout a REM period, they typically occur with a frequency of at least one recognizable event in each 30-sec epoch. In true Stage 1-2 sleep these events are not present. The REM-detection circuitry detects events in the EOG channel which may be rapid eye movements and indicates Stage REM when such events occur during an EEG period representative of Stage 1 or 2.

EOG activity enters the REM-detection section and is passed through a filter which limits the response to the 2.0-3.75 Hz range, thereby optimally separating true REM's from EEG activity, which is also detected by the EOG electrodes, slow eye

movements, and movement artifacts. The signal then enters the EOG-transient detector which detects the occurrence of rapidly rising EOG wave forms that exceed a value of 250 percent of either the average positive or the average negative peak voltage of the simultaneously occurring EEG signal. Averaging occurs continuously over 15 sec. A change in EEG background-activity level during the sleep period results in an automatic resetting of the EOG-detection reference levels to proper relative values, thereby further minimizing the chance of false triggering by transient EEG wave forms that may also be detected by the EOG electrodes. The remainder of the logic circuitry permits an output indication of Stage REM only if the following criteria are met:

1. An EOG event is detected by the EOG-transient detector,

2. No EEG event is detected by an EEG-transient detector within a time window extending from 1.4 sec before until 1.4 sec after the EOG event, and

3. The EEG analysis section indicates the presence of Stages 1 or 2 sleep. When these conditions are met, a 30-sec output indication of Stage REM occurs and is fed to the output section where its presence supersedes the sleep-stage output of the EEG analysis section. Since each REM resets the 30-sec timer, if REM's are detected with a frequency exceeding one per 30 sec, a continuous output indication of Stage REM will occur.

The excessive-amplitude detector minimizes the occurrence of false sleep-stage determinations by disabling the EEG analysis section and the REM-detection section during and for 1 sec following the occurrence of an excessively high (i.e., non-physiological) EEG signal. This prevents a change in the sleep-stage output section as a result of an artifactual signal (such as those caused by movement of the subject). A dual comparator produces a trigger pulse if either the positive or negative phase of the EEG signal voltage exceeds a value of 600 percent (using the same relative amplitude scale here as in the EEG analysis section), which is considered to be in excess of the physiological range. The resultant pulse triggers a 4-sec artifact-detection timer which in turn operates the disabling relay for the 4-sec period. If

the timer receives trigger pulses at a rate equal to or exceeding one per 4 sec, the disable relay will remain activated continuously.

The accelerometer contained in the preamplifier/accelerometer assembly serves as another means for detecting periods when artifactual contamination is highly probable. Head motion produces an output voltage proportional to the rapidity of the motion. A relatively high-voltage output from this device is therefore more likely to be associated with artifact. The accelerometer comparator in the artifact-detection section is set so that it is triggered by voltages equivalent to changes in acceleration of approximately 0.2 g in either the vertical or lateral axis. When triggered, the accelerometer comparator resets the 4-sec artifact-detection timer, and the disable relay is activated for the duration of and for 4 sec following the movement.

Outputs from the six sleep-stage comparators and the REM indicator are combined in the output section of the analysis circuitry by an analog adder which drives the single output line to the spacecraft telemetry system. Unprocessed analog EEG, EOG and head-motion signals are also preserved on magnetic tape by the recorders included in the M133 panel assembly. Each recorder is capable of storing 150 hr of data; by switching from one recorder to the other it is possible to confine tape changes to the end of the mission.

Data Display

During each sleep-monitoring period throughout a Skylab flight, the telemetered sleep-stage information is relayed from the various ground tracking stations to Mission Control. True real-time data is available for a few minutes only during each pass over a ground station. In the frequent periods when the spacecraft is out of communication range, data is accumulated onboard by the spacecraft telemetry recorders and transmitted to ground at a high rate during the passes over tracking stations. The information recorded in the control center during a sleep period is consequently somewhat sporadic, ranging from real time to delays of up to approximately two hours. Data processing equipment in the control center collates the incoming data and preserves the time relation-

ships so that a complete profile of sleep stage versus elapsed time eventually will evolve.

Video consoles in the control center display the data graphically, permitting an estimate of sleep quantity and quality on a near real-time basis. At the conclusion of a sleep period, hard copies of the complete sleep-stage profile are made available, as are complete statistical evaluations of various sleep parameters (e.g., total sleep time, time to fall asleep, number of arousals, percent stage time, number of sleep cycles, etc.).

During SMEAT, the spacecraft telemetry system was simulated by a hardware interface between the panel assembly output and monitoring apparatus located outside the SMEAT chamber. No attempt was made to duplicate the intermittent nature of actual Skylab data transmission, and consequently the data were recorded in an online, real-time fashion throughout the sleep periods. The role of the Mission Control data-processing equipment was easily simulated in the SMEAT situation by utilizing a specially designed data display console which received the seven discrete sleep-stage output voltages from the panel assemblies. This unit provides the following simultaneous display modes:

1. Visible indication of the subject's current sleep stage by means of panel indicator lamps,

2. Cumulative, numeric digital display (in hours and minutes) of the total amount of time spent in each sleep stage, and

3. Stepwise, graphic recording of the subject's sleep-stage progression versus time.

The display console was readily visible to medical observers throughout the SMEAT series of recordings, and the graphic plots were utilized daily to assess the quality of the previous night's sleep.

Procedures

Of the three SMEAT crewmembers (commander, pilot, and scientist pilot), two, the commander (CDR) and the scientist pilot (SPT), were originally designated to participate in the M133 experiment. Although during the Skylab missions only one crewmember will be involved during each flight, two were

monitored during SMEAT in order to accumulate as much experience with the hardware as possible.

Pre-SMEAT Baseline Testing

Baseline studies were conducted on each of the selected crewmembers (CDR and SPT) and upon the backup subject (PLT) prior to the start of SMEAT.

Initially, a standard clinical electroencephalogram was performed under laboratory conditions. During this procedure precise amplitude determinations were made during the Awake condition for the purpose of calibrating the M133 panel assembly gain potentiometer. Each crewmember was then monitored during three consecutive nights of sleep in his own home, using DVTL hardware identical to that utilized in the SMEAT chamber. Since online telemetry was not used during these recordings in the crewman's home, data were analyzed offline after playback of the analog tape recordings. Finally, one night of recording was carried out on each of the participating crewmembers (CDR and SPT) during the SMEAT dry run (6/30/72) in which SMEAT hardware was utilized and the online telemetry system was tested.

SMEAT Schedule

Although the SMEAT M133 schedule was originally planned to exactly duplicate the timeline of a 56-day Skylab mission (i.e., recording on nights 3-5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44, 47, 50, 52-54), a number of unexpected events necessitated several changes in the plan. Table 12-1 summarizes the actual recording nights and indicates the crewmembers involved.

At the conclusion of each sleep period, the display console timer readings were recorded to provide the first stage in the data analysis procedure. These values indicated the time (in hours and minutes) occupied by the recorded sleep period as well as individual cumulative times for each of the seven stages as distinguished by the automatic analysis circuitry.

The display console readings were later modified by careful interpretation of the strip-chart record (also produced by the display console) which showed

Table 12–1

Summary of Nights on Which
Sleep Data Were Recorded

Date	Mission Day	Crew Member Recorded		
		CDR	SPT	PLT
7/28/72	3	X[1]	X	
7/30/72	4	X	X	
8/2/72	5	X[2]		
8/5/72	8		X	X
8/5/72	11		X	X
8/8/72	14		X	X
8/11/72	17		X	X
8/14/72	20		X	X
8/17/72	23		X	X
8/20/72	26		X	X
8/23/72	29		X	X
8/26/72	32		X	X[9]
8/29/72	35		3	X[9]
9/1/72	38		X	X[9]
9/4/72	41		X	X[9]
9/7/72	44		X	X[9]
9/8/72	45		X[10]	5
9/10/72	47		6	X[9]
9/13/72	50		7	X[9]
9/15/72	52		X[8]	X[9]
9/16/72	53		X	X[9]
9/17/72	54		X	X[9]

[1] One and one half hr only; cap removed due to irritation at electrode sites.

[2] Two hr only; cap removed due to irritation at electrode sites. SPT did not run; no cap available of correct size.

[3] DVTU #2 was out of chamber undergoing tests for possible malfunction of electrode check.

[4] DVTU #2 was out of chamber for repair of power supply.

[5] SPT ran using PLT's unit (qualification unit).

[6] SPT did not run due to skin tests in progress.

[7] SPT did not run; schedule misinterpretation.

[8] Training unit was substituted for DVTU #2 and used for remainder of tests.

[9] Automatic analysis only; recorder malfunction caused loss of data for visual analysis.

[10] No valid data obtained; recorder malfunction caused loss of data for visual analysis. Display console malfunction resulted in loss of automatic analysis results.

the progression of sleep stages over time throughout the sleep period. Such changes often included alteration of the Stage REM time which resulted from smoothing of the REM periods as well as elimination of certain artifactual components (e.g., occasionally the display console was not turned off precisely at the conclusion of the sleep period, resulting in accumulation of excessive amounts of Awake time. This occurred because in the simulated telemetry scheme the true Awake state was represented by zero-volts output, and this situation also occurred in the power-off condition.)

Interpretation of the strip-chart sleep profile also provided determination of the sleep latency (time to attain Stage 2 sleep), the total sleep time (total time in Stages, 1, 2, 3, 4, and REM), total sleep percentage (total sleep time divided by total sleep period time), and the percentage of the total sleep time occupied by each of the sleep stages (1, 2, 3, 4, and REM).

At the conclusion of the 56-day SMEAT mission, the analog magnetic tapes were retrieved and played back to produce continuous polygraphic records (at 3 cm/sec) of the EEG, EOG, and head-motion activity throughout the sleep periods. These data were then visually interpreted by standardized criteria (Rechtschaffen et al., 1968) to provide a final report for each night of sleep. The final report included the following items: total time of rest period, sleep latency (time until first Stage 2 occurs), REM latency (time until first Stage REM occurs), total Awake time, total sleep time, total Awake percent, total sleep percent, Awake time for each third of the night, and number of arousals, REM time for each third of the night, and number of REM periods, absolute time in each stage of sleep, percent of total sleep time occupied by each stage of sleep, and a graphic plot of sleep stage versus time throughout the night.

Post-SMEAT Baseline Testing

After termination of the 56-day SMEAT mission, three consecutive nights of sleep monitoring were carried out in the two crewmembers' homes, following the same procedure as during the pre-SMEAT testing.

Results and Discussion

Operational and Hardware Factors

A number of hardware-related problems arose during the SMEAT run which resulted in a significant number of data-loss periods and in changes made to the Skylab hardware configuration.

Further testing on the CDR was canceled after the third scheduled recording night (day 5). The subject developed a generalized headache shortly after putting on the cap on the first scheduled night (day 3), and he removed the cap after approximately one to one and one-half hours of recording. Swelling and induration at the electrode contact sites was noted, and this condition persisted throughout the next day. A larger cap was tried during the next session (day 4), and recording was successful for the entire night with no problems noted. On day 5, however, the problem recurred and required removal of the cap after two hours. Since the CDR appeared to have an allergic-type response to some component of the electrode assembly, no further recording attempts were made with him. Dermatological patch testing was carried out during the latter portion of the SMEAT mission, and the results appeared to confirm the sensitivity of the CDR to the electrode-electrolyte material.

A somewhat similar problem, but of much lesser degree, was experienced by the SPT, beginning at approximately day 32. He occasionally noted a slight burning, tingling sensation around the EOG electrodes, and during the following day these areas appeared somewhat indurated and slightly swollen. Skin tests on this subject were inconclusive, and recording was continued for the duration of the mission with no increase in severity of the symptoms.

The PLT, who substituted for the CDR after day 5, experienced no undue reactions, and successful recordings were made during all the scheduled periods.

Patch tests were scheduled for all Skylab crewmen participating in M133 in order to ensure that no similar problems would occur.

Although the quality of the recorded data was generally good throughout the SMEAT test, post-SMEAT visual analysis revealed occasional periods of artifactual contamination of the EEG channels and, more rarely, of the EOG. In most instances, one EEG channel or the other remained of acceptable quality, thereby permitting successful postmission visual analysis in terms of sleep characteristics, but if the channel undergoing analysis by the automatic system became of poor quality, the telemetered data were degraded for the duration of the problem. It is possible to switch the EEG channel utilized by the automatic analyzer by means of a front panel control, but when all three crewmembers have simultaneous rest periods, as they did during SMEAT, there is no one available to make the change. Since this situation also exists during Skylab, two changes in the cap electrode configuration have been made to increase the reliability of the data-acquisition scheme and to make it unnecessary to switch EEG channels in order to eliminate the influence of artifacts.

The ground electrode, which was originally located just anterior to the left central (C_1) EEG electrode, was moved to a location on the R forehead. This insured a more reliable contact of the ground electrode with the subject since the forehead is devoid of hair.

The two central EEG electrodes (C_1 and C_2) have been electrically tied together to form one composite electrode. The two occipital EEG electrodes (O_1 and O_2) are similarly tied together to form a second composite. A single EEG derivation is obtained by recording between the two composite electrodes, and this signal is led to both EEG channels. The single EEG channel is highly reliable, since loss of contact of either of the central or either of the occipital electrodes will not degrade the signal.

Laboratory tests carried out since the conclusion of SMEAT have proven the effectiveness of these modifications in over 56 instances of all-night recording.

At the conclusion of the SMEAT mission, the M133 panel assemblies were removed from the test chamber and returned to the laboratory where the

tapes were removed to permit final analysis. At that time it was discovered that the tape reels on the Qualification Unit had been improperly installed at the time of the midmission change of tapes (day 30). As a result, tape motion had been prevented during the entire second half of the test series (days 32, 35, 38, 41, 44, 45, 47, 50, 52, 53, 54). This data loss precluded visual analysis of the PLT's sleep characteristics on those days.

Since it is necessary to make a similar change of tapes between the first and second Skylab missions, the crew checklist was revised to contain a warning of this possible condition.

Sleep Characteristics

In spite of the hardware problems noted above, it was possible to obtain comprehensive data concerning the sleep characteristics of the PLT and SPT. The online, real-time display of the sleep information worked satisfactorily, making it possible to provide a daily status report of the crewman's sleep quantity and quality for the previous night. Post-SMEAT visual analysis of the available data permitted a comprehensive tabulation of sleep characteristics and allowed a retrospective evaluation of the validity of the online results.

The results of post-SMEAT visual analysis of the recorded data for the SPT are presented in Tables 12-2 and 12-3. It is obvious from inspection of the results that the SPT exhibited a considerable alteration in his sleeping patterns during the 56-day SMEAT mission. This is demonstrated graphically by Figure 12-6, in which selected parameters from the results of visual analysis (Tables 12-2 and 12-3) have been plotted versus time. Compared to the pre-SMEAT (B-1, B-2 and B-3) and post-SMEAT (P-1, P-2 and P-3) baseline recording nights, the most noticeable changes occurred in the sleep latency and total sleep time characteristics. The sleep latency, or time to fall asleep, which averaged 23 min (range 18-31 min) during the pre-SMEAT studies and 24 min (range 6-47 min) during the post-SMEAT recordings, averaged 1 hr and 6 min during the SMEAT period with a range of 17 min to 3 hr and 17 min.

Total sleep time for the SPT, which averaged 6 hr, 26 min before, and 7 hr, 4 min after SMEAT, averaged only 5 hr, 6 min during SMEAT. Analysis of variance, comparing test nights with pre- and post-mission values, revealed that total sleep time was significantly reduced during the mission (F = 16.54, p < 0.01). While most of the reduction in total sleep time can be accounted for by the increased sleep latency, a portion, at least on some nights, was also a result of fairly lengthy arousals during the first portion of the night. The SPT thus spent a greater percentage of his time awake during the first third of the night than he did during either the pre- or post-SMEAT baseline studies.

The quantity of sleep during the second and final thirds of the night tended to be fairly typical of the baseline results. During the pre-SMEAT series, the average Awake time during the second and final thirds was 6 and 10 min, respectively. The corresponding values for the post-SMEAT recordings were 6 and 3 min. During the SMEAT mission these figures were 10 and 6 min, respectively, an insignificant change in either case.

In spite of the significant reduction in total sleep time, the sleep quality of the SPT, in terms of the sleep-stage characteristics, was changed relatively less, as indicated in Table 12-4, which shows average values obtained from the tables of visual analysis results.

The average Stage REM time remained unchanged during SMEAT in spite of considerable day-to-day fluctuation. A slight increase of REM time was seen during the post-SMEAT baseline studies. This increase was found to be significant at the 0.05 level of confidence (F = 7.65, for 2 and 18 degrees of freedom).

A reduction of Stage 3 and 4 time during the test nights, as compared to the pre-SMEAT baseline nights, was also evident and was significant at the 0.01 level of confidence (F = 12.91 for 1, 18 d.f.). A further decrease in Stage 3-4 time occurred during the post-SMEAT baseline nights as compared to the

Table 12-2

SMEAT M133 Experiment – Visual Analysis Results – Part 1

(Time in hours and minutes)

Day No.	Total Period	Total Sleep Time	Total Sleep %	Sleep Latency	Total Awake Time	Awake Time (by Thirds)			Total Number of Arousals	No. of Arousals (by Thirds)			Total Stage 0 Time
						1st	2nd	3rd		1st	2nd	3rd	
B1	5:48	5:07	88.3	0:21	0:41	0:32	0:04	0:05	17	9	1	7	0:00
B2	7:57	7:14	90.8	0:18	0:44	0:22	0:04	0:18	23	11	7	5	0:00
B3	7:32	6:57	92.5	0:31	0:34	0:16	0:09	0:08	30	13	9	8	0:00
3	7:23	4:30	77.2	0:52	1:20	1:09	0:00	0:11	8	4	0	4	1:32
4	7:39	6:49	89.2	0:30	0:49	0:42	0:01	0:06	12	4	2	6	0:00
8	6:51	6:05	89.4	0:26	0:44	0:26	0:13	0:05	13	6	1	6	0:03
11	6:51	4:10	60.8	2:33	2:41	2:14	0:15	0:12	10	1	2	7	0:00
14	7:02	6:22	90.4	0:32	0:41	0:30	0:08	0:02	11	3	3	5	0:00
17	7:38	4:18	56.4	3:17	3:20	2:33	0:44	0:03	8	1	3	4	0:00
20	6:51	5:49	84.9	0:36	1:02	0:36	0:02	0:24	17	5	6	6	0:00
23	6:34	3:42	56.4	2:53	2:52	2:10	0:40	0:02	4	1	2	1	0:00
26	6:43	5:21	79.5	0:17	1:23	1:14	0:05	0:03	10	4	1	5	0:00
29	6:21	5:04	79.9	1:18	1:17	1:15	<0:01	0:01	6	3	1	2	0:00
32	6:23	6:01	94.3	0:22	0:22	0:20	<0:01	0:02	8	3	1	4	0:00
38	7:16	5:53	80.9	1:01	1:23	1:09	0:10	0:03	16	6	5	5	0:00
41	3:03	2:28	81.2	0:31	0:34	0:29	0:02	0:04	5	2	2	2	0:00
52	6:40	5:13	78.1	0:57	1:27	1:20	<0:01	0:07	7	3	1	3	0:00
53	5:18	4:30	84.9	0:46	0:48	0:47	0:00	0:02	7	5	0	2	0:00
54	6:29	5:26	84.2	0:49	1:01	0:54	0:07	<0:01	7	2	4	1	0:00
P1	6:24	6:01	94.0	0:18	0:23	0:20	0:00	0:03	3	2	0	1	0:00
P2	9:01	7:56	88.0	0:47	1:05	0:45	0:16	0:03	16	3	3	10	0:00
P3	7:23	7:15	98.2	0:08	0:05	0:03	0:03	0:03	10	2	4	4	0:00

Table 12–3

SMEAT M133 Experiment — Visual Analysis Results — Part 2

(Time in hours and minutes)

| Day No.	Stage 1 Total Time	Stage 1 % Time	Stage 2 Total Time	Stage 2 % Time	Stage 3 Total Time	Stage 3 % Time	Stage 4 Total Time	Stage 4 % Time	Stage REM Total Time	Stage REM % Time	REM Latency	No. REM Periods (by thirds) 1st	2nd	3rd	Total No. REM Periods	Stage REM Total Time (by thirds) 1st	2nd	3rd
B1	0:21	6.8	2:29	48.4	0:41	13.4	0:35	11.2	1:02	20.1	1:38	1	1	4	6	0:08	0:15	0:39
B2	1:10	16.1	2:16	45.3	0:55	12.7	0:06	1.4	1:46	24.5	1:07	3	3	2	8	0:17	0:52	0:37
B3	0:25	5.9	3:28	49.9	1:06	15.7	0:17	4.2	1:42	24.4	1:18	1	3	1	5	0:10	0:53	0:39
3	0:17	6.3	3:26	76.2	0:12	4.6	0:00	0.0	0:35	12.9	2:35	0	1	3	4	0:00	0:05	0:30
4	0:21	5.1	4:15	62.2	0:32	7.7	<0:01	0.1	1:42	24.8	1:50	1	2	3	6	0:14	0:44	0:44
8	0:24	6.6	2:54	47.6	0:53	14.6	0:03	0.8	1:51	30.4	1:00	3	1	3	7	0:28	0:41	0:42
11	0:27	10.8	2:00	47.9	0:32	12.6	<0:01	0.1	1:11	28.6	3:25	0	1	2	3	0:00	0:15	0:57
14	0:31	8.1	3:45	59.0	0:44	11.6	0:01	0.3	1:20	21.0	1:30	2	2	3	7	0:08	0:33	0:39
17	0:22	8.7	2:19	53.8	0:49	19.1	<0:01	0.1	0:47	18.3	4:49	0	1	2	3	0:00	0:13	0:34
20	0:22	6.2	2:58	51.1	0:51	14.6	0:02	0.6	1:36	27.5	1:23	2	2	3	7	0:20	0:35	0:40
23	0:20	8.9	1:51	49.9	0:49	22.0	0:00	0.0	0:43	19.3	3:53	0	2	3	5	0:00	0:16	0:27
	0:24	7.4	2:41	50.2	0:54	16.8	0:01	0.2	1:21	25.4	1:43	1	2	4	7	0:07	0:18	0:57
	0:14	4.7	2:44	53.8	0:58	19.1	<0:01	0.1	1:08	22.4	1:27	1	2	2	5	0:02	0:39	0:27
	0:17	4.7	3:42	61.4	0:33	9.0	0:00	0.0	1:30	24.7	1:11	2	1	1	4	0:11	0:48	0:31
	0:37	10.4	3:33	60.5	0:18	5.1	0:00	0.0	1:25	24.0	1:52	1	2	4	7	0:17	0:31	0:36
41	0:11	7.2	1:44	63.6	0:19	12.9	0:00	0.0	0:24	14.3	1:21	0	2	0		0:00	0:24	0:00
52	0:30	9.7	3:08	60.0	0:21	6.6	0:00	0.0	1:14	23.7	2:09	1	3	2	6	0:05	0:39	0:31
53	0:18	6.5	2:38	58.4	0:35	13.0	0:00	0.0	1:00	22.0	1:40	1	1	3	5	0:06	0:22	0:31
54	0:27	6.3	3:15	59.9	0:03	0.8	0:00	0.0	1:41	31.1	1:49	1	2	3	6	0:07	0:48	0:46
P1	0:23	6.2	3:51	64.0	0:11	3.0	0:00	0.0	1:36	26.8	1:12	1	2	4	7	0:08	0:34	0:54
P2	0:34	7.2	4:44	59.6	0:15	3.2	0:00	0.0	2:23	30.0	1:46	1	3	3	7	0:14	0:57	1:12
P3	0:24	5.4	4:27	61.3	0:20	4.6	0:00	0.0	2:05	28.7	1:06	1	2	4	7	0:26	0:32	1:07
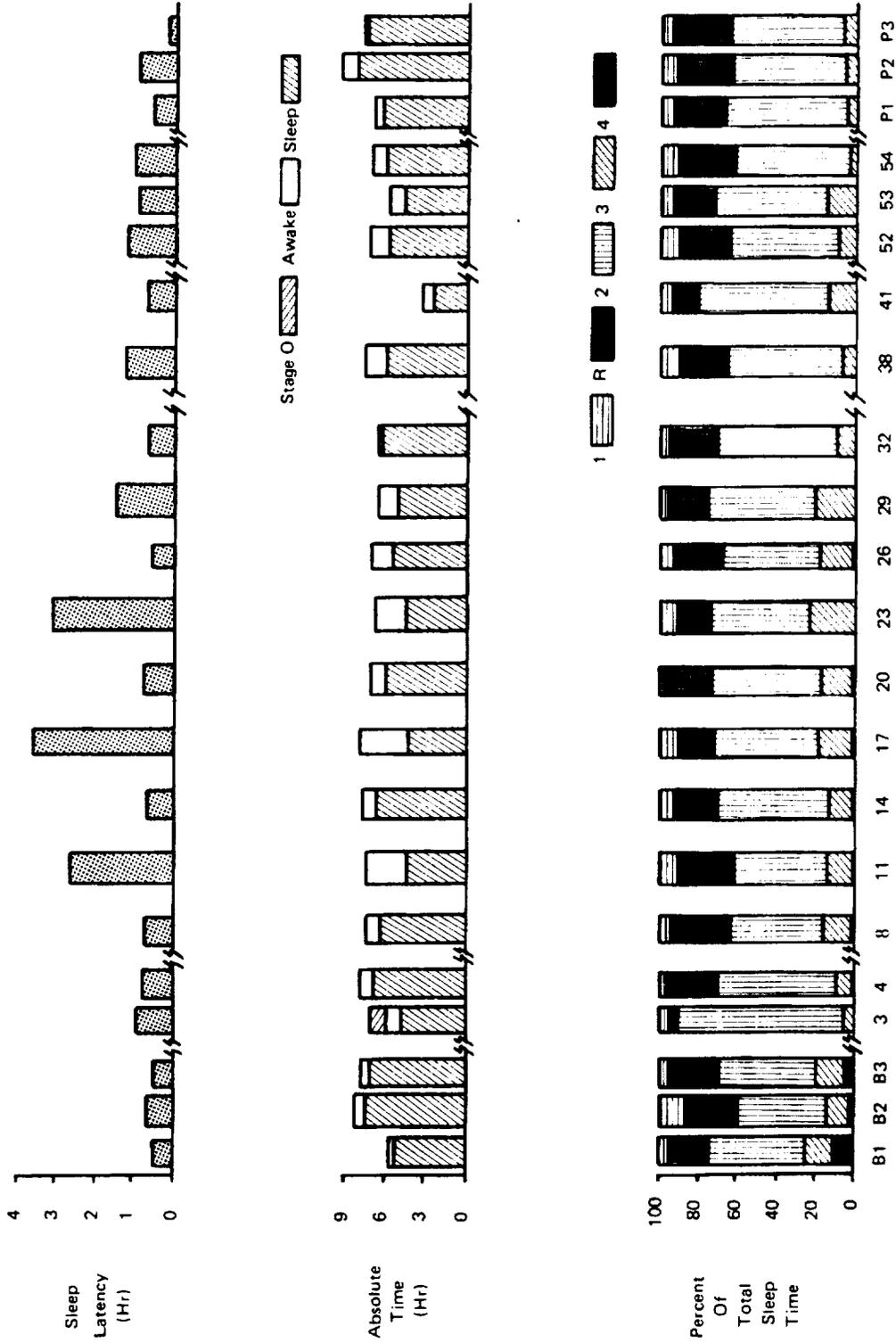
Figure 12-6. Visual analysis results graph for SPT (Thornton) covering entire study.

mission nights, and, while this was significantly different from the pre-SMEAT values (p <0.01), it was not significantly different from the mission period. Since Stages 3 and 4 are known to occur predominantly during the first half of a nightly sleep period, while Stage 2 and REM predominate during the latter half, the decline in Stage 3-4 in this case would logically appear to be a result of the disturbances in sleep quantity during the first third of the night as described previously. This may not be the only factor, however, since the reduced percentage of Stages 3 and 4 persisted throughout the postmission baseline nights in spite of the fact that both sleep latency and first third Awake time had returned to premission levels.

Table 12-4

Sleep Quality for SPT
Before, During, and After SMEAT Exercise

	% Stage 1 Time	% Stage 2 Time	% Stage 3 and 4 Time	% Stage REM Time
Pre-SMEAT Average	10	48	20	12
SMEAT Average	7	57	12	23
Post-SMEAT Average	6	62	4	29

A significant drop in Stage 1 time occurred during the mission compared to the pre-SMEAT nights (p <0.05, F - 5.02 for 1, 18 d.f.). The post-SMEAT Stage 1 time remained depressed compared to the pretest period. Although there was no statistical difference in Stage 2 time between the premission and SMEAT periods, the post-SMEAT Stage 2 time increased significantly (p <0.05, F = 4.1 for 2, 18 d.f.).

It must be concluded that, in the case of the SPT, there was a significant alteration of sleeping characteristics during the period of the SMEAT mission. The causes of these changes are not evident from the results.

The PLT exhibited no obvious change in his sleep quantity characteristics. Figure 12-7 graphically displays many of his visually determined sleep characteristics. Based upon the results of visual analysis, the total sleep time, which averaged 6 hr, 21 min before, and 6 hr, 52 min after the SMEAT mission, averaged 6 hr, 47 min during SMEAT. This difference did not achieve statistical significance. Similarly, the sleep latency during SMEAT averaged 9 min, as compared to a value of 9 min before and 6 min after the mission, again not statistically significant. Although these averages do not include data after day 29 (because of the tape recorder malfunction), the results of automatic analysis, which correspond closely with those of visual analysis for the days on which both sets of data were available, confirm that no change of significance occurred during the latter half of the SMEAT test. (See Tables 12-5, 12-6 and 12-7.)

As illustrated in Table 12-6 and Figure 12-7, the sleep quality also remained relatively constant throughout SMEAT, although some alterations of a relatively minor nature were found. Table 12-8 compares the average percent sleep-time characteristics of the SMEAT period with those of the pre- and posttest baseline nights.

Analysis of variance revealed no significant differences in the Stage 1 time for pre-, test and posttest conditions. Likewise, no statistical differences were obtained for Stage 2 time.

The Stage 3 and 4 time (combined) showed a slight increase during SMEAT, and this change is significant at the 0.01 level of confidence (F = 20.1 for 1, 11 d.f.). This Stage 3-4 increase is in contrast to the results obtained for the SPT, where a reduction of approximately the same magnitude was obtained.

The slight reduction in percent Stage REM during the SMEAT period was not significant. An increase in percent REM time was also seen in this subject during the post-SMEAT recordings but was not of statistical significance.

It is concluded that the PLT was able to obtain sleep of adequate quantity during the SMEAT

Table 12-5

SMEAT M133 Experiment — Visual Analysis Results — Part 1
(Time in hours and minutes)

Day No.	Total Period	Total Sleep Time	Total Sleep %	Sleep Latency	Total Awake Time	Awake Time (by Thirds)			Total Number of Arousals	No. of Arousals (by Thirds)			Total Stage 0 Time
						1st	2nd	3rd		1st	2nd	3rd	
B1	5:56	5:46	97.2	0:12	0:10	0:09	0:01	<0:01	6	4	1	1	0:00
B2	6:38	6:22	94.6	0:06	0:15	0:08	0:03	0:05	15	5	7	3	0:00
B3	7:21	6:56	94.2	0:08	0:26	0:08	0:09	0:08	24	4	8	12	0:00
8	7:39	7:18	95.4	0:05	0:21	0:07	0:06	0:08	23	8	8	7	0:00
11	7:08	6:39	93.3	0:16	0:29	0:14	0:12	0:02	18	5	7	6	0:00
14	7:17	6:41	91.9	0:10	0:36	0:13	0:05	0:18	28	7	8	13	0:00
17	7:34	7:02	93.1	0:09	0:31	0:08	0:20	0:03	24	7	9	8	0:00
20	7:12	6:40	92.6	0:09	0:32	0:16	0:05	0:11	24	9	5	10	0:00
23	6:38	6:22	96.1	0:01	0:16	0:05	0:06	0:05	17	5	6	6	0:00
26	6:46	6:16	92.5	0:17	0:31	0:17	0:06	0:08	17	5	5	7	0:00
29	7:38	7:19	95.2	0:07	0:19	0:11	0:04	0:04	22	9	4	9	0:00
P1	6:30	6:20	97.8	0:08	0:09	0:07	0:02	<0:01	5	2	2	1	0:02
P2	7:27	7:18	98.1	0:02	0:09	0:05	<0:01	0:03	12	5	1	6	0:00
P3	7:51	6:58	97.9	0:07	0:09	0:05	0:02	0:01	9	4	3	2	0:44

Table 12-6

SMEAT M133 Experiment — Visual Analysis Results — Part 2

(Time in hours and minutes)

Day No.	Stage 1 Total Time	Stage 1 % Time	Stage 2 Total Time	Stage 2 % Time	Stage 3 Total Time	Stage 3 % Time	Stage 4 Total Time	Stage 4 % Time	Stage REM Total Time	Stage REM % Time	REM Latency	No. REM Periods (by thirds) 1st	2nd	3rd	Total No. REM Periods	Stage REM Total Time (by thirds) 1st	2nd	3rd
B1	0:19	5.5	3:46	65.5	0:21	6.1	0:00	0.0	1:19	22.8	1:19	1	1	1	3	0:15	0:30	0:34
B2	0:44	11.4	3:28	54.3	0:45	11.7	<0:01	0.1	1:26	22.5	0:59	1	3	3	7	0:12	0:29	0:45
B3	0:56	13.3	3:40	52.9	0:42	10.1	0:00	0.0	1:49	23.7	0:41	2	3	8	13	0:23	0:23	0:53
8	0:34	7.8	4:15	58.2	0:52	12.0	0:02	0.5	1:34	21.5	1:33	1	2	4	7	0:10	0:29	0:55
11	0:40	10.0	3:47	56.9	1:03	15.8	0:01	0.2	1:08	17.1	3:57	0	1	2	3	0:00	0:36	0:32
14	0:34	8.5	4:18	64.4	0:35	8.6	0:18	4.5	0:56	14.0	1:36	1	4	8	13	0:09	0:15	0:33
17	0:32	7.7	4:19	61.3	0:45	10.7	0:22	5.2	1:04	15.1	1:27	5	4	9	18	0:09	0:17	0:38
20	0:24	6.1	3:47	56.8	0:40	10.1	0:37	9.3	1:11	17.8	1:20	2	1	6	9	0:10	0:16	0:45
23	0:17	4.5	3:46	59.3	0:40	10.4	0:36	9.3	1:03	16.6	1:21	1	2	6	9	0:04	0:27	0:32
26	0:14	3.6	3:21	53.5	0:40	10.6	0:39	10.5	1:22	21.7	1:22	2	2	3	7	0:13	0:27	0:41
29	0:22	5.0	4:08	56.5	0:29	6.7	0:38	8.7	1:41	23.1	1:05	4	3	8	15	0:24	0:45	0:33
P1	0:23	6.0	3:48	59.9	0:46	12.0	0:02	0.4	1:23	21.8	1:15	1	2	1	4	0:09	0:37	0:37
P2	0:28	6.4	3:53	53.1	0:36	8.1	0:01	0.3	2:21	32.1	1:43	1	2	4	7	0:08	0:51	1:22
P3	0:20	4.9	4:24	63.1	0:32	7.7	0:07	1.7	1:35	22.6	1:41	2	1	4	7	0:08	0:36	0:51

Table 12-7

Automatic Analysis Results

Modified Values Obtained by Intrepretation of Display Console Strip Chart

(Time in hours and minutes)

Day No.	Total Rest Period Time	Total Sleep Time	Total Sleep %	Sleep Latency	Total Awake Time	Stage 1 Total Time	Stage 1 % Time	Stage 2 Total Time	Stage 2 % Time	Stage 3 Total Time	Stage 3 % Time	Stage 4 Total Time	Stage 4 % Time	Stage REM Total Time	Stage REM % Time	Stage 0 Time
8	7:51	7:38	98	0:07	0:08	0:21	5	3:46	49	0:59	13	0:37	8	1:55	25	0:00
11	7:43	6:54	90	0:18	0:44	0:24	6	3:37	53	0:50	12	0:44	11	1:19	19	0:00
14	7:56	7:09	91	0:10	0:41	0:18	4	3:23	47	0:52	12	0:59	14	1:37	23	0:00
17	7:51	7:27	96	0:11	0:19	0:13	3	3:28	47	0:53	12	0:51	11	1:58	26	0:04
20	7:24	7:15	99	0:04	0:03	0:10	2	3:23	47	0:53	12	0:51	12	1:58	27	0:00
23	7:09	6:58	98	0:06	0:10	0:13	3	3:04	43	1:08	16	0:58	14	1:35	23	0:01
26	6:52	6:45	98	0:15	0:07	0:14	4	2:42	40	0:51	13	0:58	14	2:00	30	0:00
29	7:48	7:43	99	0:06	0:05	0:02	0	3:26	45	0:43	9	1:02	13	2:29	32	0:01
32	7:16	7:03	97	0:12	0:13	0:14	3	2:51	39	1:09	16	1:05	15	1:43	24	0:01
35	7:55	7:23	93	0:07	0:32	0:20	5	3:14	44	0:57	13	0:53	12	1:59	27	0:00
38	8:14	8:06	98	0:07	0:08	0:35	7	3:50	47	1:05	13	0:55	11	1:41	21	0:00
41	7:52	7:27	96	0:18	0:21	0:27	6	3:26	46	1:07	15	1:06	15	1:21	18	0:04
44	8:02	7:24	92	0:15	0:38	0:31	7	3:49	52	0:52	12	0:50	11	1:22	19	0:00
47	7:18	7:08	98	0:10	0:10	0:24	6	2:25	34	1:01	14	0:40	9	2:38	37	0:00
50	7:54	7:40	97	0:21	0:14	0:31	7	3:03	40	0:50	11	0:45	10	2:29	32	0:02
52	7:45	7:40	99	0:04	0:05	0:08	2	3:18	43	1:44	23	1:01	13	1:29	19	0:00
53	7:26	6:35	89	0:36	0:51	0:24	7	2:00	30	0:47	12	0:52	13	2:32	39	0:00
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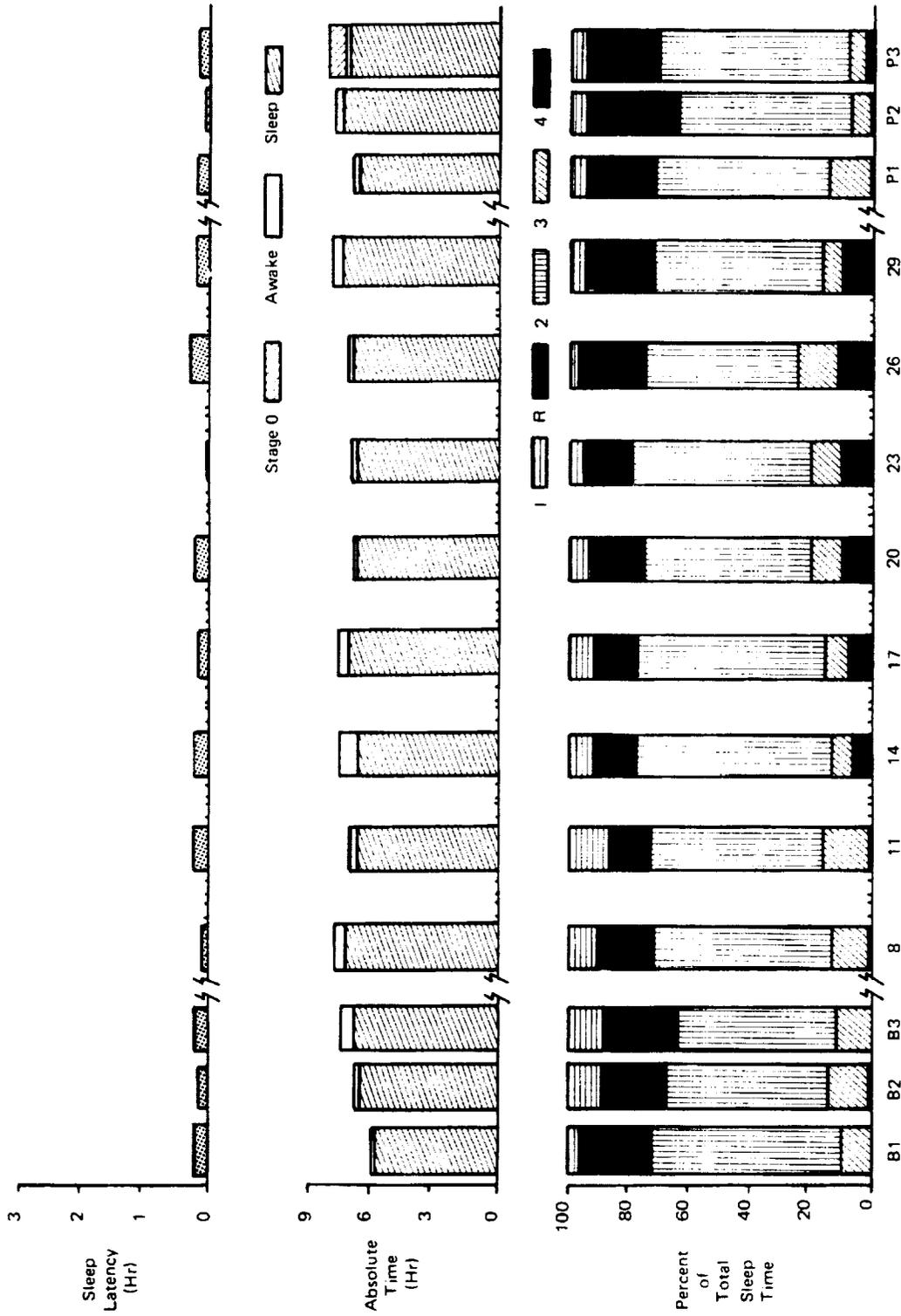
Figure 12-7. Visual analysis results graph for PLT (Bobko) covering entire study.

mission and that the sleep quality, in terms of stage characteristics, was not adversely altered by the experimental circumstances.

Table 12-8

Average Percent
Sleep-time Characteristics of PLT

	% Stage 1	% Stage 2	% Stage 3 and 4	% Stage REM
Pre-SMEAT Average	10	58	9	23
SMEAT Average	7	58	17	18
Post-SMEAT Average	6	59	10	26

Comparison of Automatic and Visual Analysis Results

An important aspect of the SMEAT M133 study was the comparison of the automatic sleep-stage scoring method with that of the visual scoring method. While the practicality of automatic analysis was not in question, it was necessary to gain experience in interpretation of the online analyzer results. These comparisons are illustrated graphically in Figures 12-8 and 12-9, which show information concerning sleep latency and the total sleep time.

Examination of the data reveals, in most instances, a very close correlation between automatic and visual analysis results, and only rarely is there a marked discrepancy (e.g., see sleep latency on day 29 for the SPT).

Table 12-9 presents the results of a t-test comparison between the two methods for the SPT and PLT.

The table reveals that for the SPT the automatic method overestimated total sleep time (T.S.T.) as well as Stages 3 and 4, and underestimated the Stage 1 time. No statistical differences were observed between the two methods in determining sleep latency, Stage 2 time, and REM time.

For the PLT there were no differences between the two methods in determining the T.S.T. and sleep

latency. Stages 1 and 2 were consistently underestimated by the automatic method, while Stages 3, 4 and REM were somewhat overestimated.

In general, the automatic analyzer's performance was satisfactory. Deviations from the visual scoring method were systematic, and the use of the analyzer on future preflight baseline studies will enable a more accurate appraisal during the test nights.

The automatic analysis results were, in some instances, considerably degraded by the presence of artifactual signals in the single EEG channel. As was discussed above, several changes in the electrode cap configuration have been devised and will lead to further improvement in the reliability of the automatic analysis results during Skylab. In spite of these problems during SMEAT, however, the results show conclusively the feasibility of obtaining useful, quantitative, and objective information concerning sleep characteristics in an online fashion. The general conclusions drawn from the results of visual analysis of the data from each of the subjects studied during SMEAT would have been the same if only the automatic analysis results had been available.

Conclusions

The Skylab M133 sleep-monitoring experiment was operationally tested during the Skylab Medical Experiments Altitude Test, which simulated the timelines and environment expected during a 56-day Skylab mission. Two crewmembers utilized the M133 data-acquisition and analysis hardware, and their sleep characteristics were studied in an online fashion during a number of all-night recording sessions.

The feasibility of all aspects of the M133 experiment plan was confirmed, and only minor changes in procedure have been suggested in order to clarify certain points. The M133 hardware utilized during SMEAT (DVTU and Qualification Units) developed several malfunctions throughout the course of the mission. Causes for all of the failures were conclusively determined, and corrective measures have been taken to insure that the Skylab flight hardware is properly configured. The M133 hardware performed functionally as expected, and no conceptual problems were encountered.

Several minor modifications in the configuration of
the data-acquisition apparatus (recording cap) have
been suggested for Skylab in order to further increase
the reliability.

Comparison of the results of online automatic
analysis with those of postmission visual data analysis
was favorable, confirming the feasibility of obtaining

reliable objective information concerning sleep
characteristics during the Skylab missions. One
SMEAT crewmember exhibited definite changes in
certain sleep characteristics (e.g., increased sleep
latency, increased time Awake during first third of
night, and decreased total sleep time) during the
mission. The sleep parameters of the other subject
remained essentially unchanged for the duration of
the project.
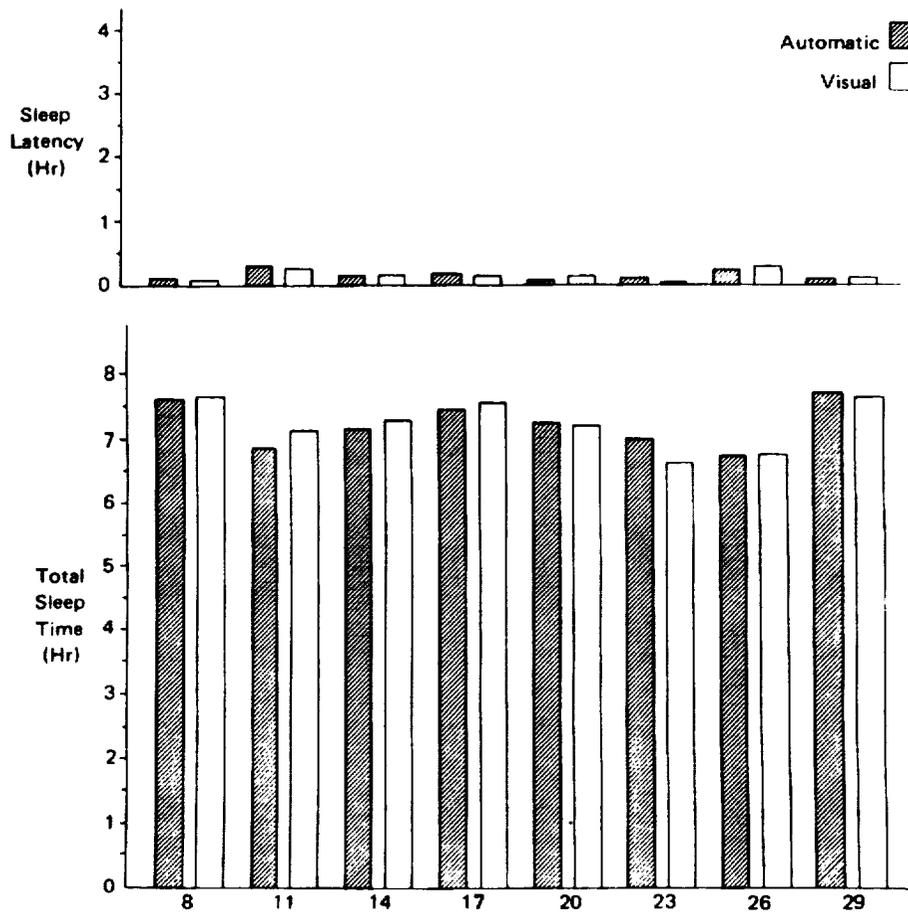
Figure 12-8. Comparison of automatic
and visual analysis results for PLT.
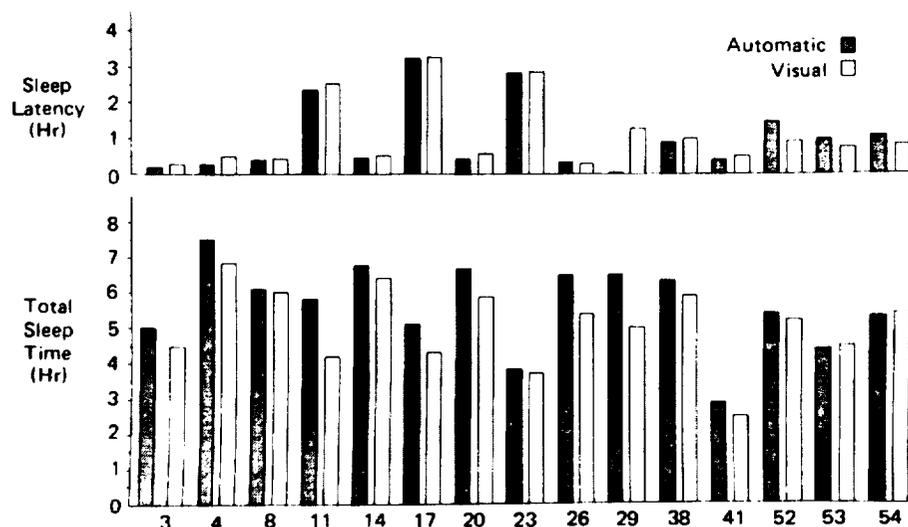
Figure 12-9. Comparison of automatic
and visual analysis results for SPT.

Table 12—9

Automatic and Visual Analysis Results: A t-test Comparison

	T.S.T.	Sleep Latency	1	2	3	4	REM
SPT	3.86*	−1.00	−4.55*	−0.81	3.65*	4.04*	−1.64
PLT	0.10	+0.35	−5.07**	−6.97**	2.60**	7.64**	6.79**

* = p 0.05 (for 14 d.f.)

** = p 0.05 (for 7 d.f.)

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Rechtschaffen, A., and Kales, A. (Eds.), Berger, R. J., Dement, W. C., Jacobson, A., Johnson, L. C., Jouvet, M., Monroe, L. J., Oswald, I., Roffwarg, H. P., Roth, B., & Walter, R. D. A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects. Public Health Service. Washington, D.C.: U.S. Government Printing Office, 1968.

CHAPTER 13

TIME AND MOTION -- EXPERIMENT M151

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Astronaut work performance during the preparation and execution of experiments in SMEAT was analyzed according to time and motion. The objectives of the study were to evaluate the efficiency and consistency of performance (adaptation function) for several different types of activity over the course of the mission; to evaluate the procedures to be used by the same experiment in Skylab; to generate characteristic adaptation functions for later comparison with Skylab data; and to examine astronaut performance for any behavioral stress due to the SMEAT environment.

The time required to perform a given task, subtask or element varies from performance to performance. Time also depends on the method, procedure or motion pattern used to perform the task. Variations are due to a complex set of factors and, where no assignable cause (or causes) can be found, they are characterized as random. However, film analysis frequently reveals identifiable perturbations in task performance which have assignable causes and which cause variations in performance time.

Performance data for the three crewmen were extracted from videotape; real-time observation by analysts outside the SMEAT chamber was used for verification and clarification. Individual and group data were analyzed for task and subtask performance.

Equipment

A significant difference exists between the method and medium used for SMEAT data collection and that planned for Skylab. In Skylab, 16 mm motion pictures will be taken from optimized predetermined locations using wide angle lenses (50-110° field-of-view). The lens chosen to film a particular activity encompasses the entire activity without need for multiple cameras or realignment of the single camera used.

In SMEAT, the M151 experiment made use of the available TV system in which the positions of the cameras were fixed. This meant that several cameras had to be used for an activity which would ordinarily be covered by one camera with a wide angle lens. In some cases, as many as three cameras had to be used to cover the range of activities involved in an experiment.

These complications made it necessary to have an M151 observer in the control room or the Data Acquisitions Recording Systems (DARS) room to program the activities of the three cameras as they were needed. In addition, an observer was stationed at the Medical Data Support Center to monitor in real time the same activity which was being taped. This served to back up the taped information in case equipment problems led to a loss of data.

Procedures

In order to coordinate SMEAT results with Skylab planning, the experimenters decided to study those activities that would be performed in SMEAT in the same way that they would later be studied in Skylab. The medical experiments met this specification. Food preparation, as an operational daily activity, was also considered. It was hoped that some maintenance activities would be available for analysis of manual dexterity. The functional objectives of M151 were as follows:

1. Videotape all crewmen during donning of VCG sensors and harness; lower body negative pressure device (LBNPD) ingress and egress; mounting and dismounting of the ergometer, including the applying and removing of restraints.

2. Videotape crewmen during activities pertinent to food preparation and measurement of food residue.

3. Videotape crewmen during operational activities such as setting up shower, donning, doffing, and exercising with the operational bioinstrumentation system (OBS).

For the most part, adequate data were collected for the activities comprising the first functional objective. The second objective could not be realized; the task of calibrating the SMMD was substituted in its place. Because of a change in SMEAT plans, the third functional objective was never fully exercised.

Real-time observations were also made on a noninterference basis for those M092/M093 performances not scheduled to be taped for M151. This was done to keep abreast of any changes which might occur.

Data Analysis

Over 60,000 feet of kinescope film were acquired by M151 during SMEAT operations. Of this total, approximately 20,000 were taken during the pretest and shakedown runs and the rest during the actual test. Since kinescopes (16 mm) are made and operated at 24 frames per second, a rate four times that planned for Skylab, a great deal of redundant information had to be scanned in toto.

The work of the analyst involved viewing the kinescope film and using the crew's checklist to verify and measure the task and subtask segments. At the same time, he accounted for any anomalous situations which might occur.

Simultaneously with the TV tapes of crewmen activities, M151 personnel analyzed task elements and times from the TV monitors. These data enabled the analysts to fill in gaps in kinescope coverage, and to clarify certain kinescope scenes.

Analysis of the tasks performed in the chamber consisted mainly of recording task time and description using the TV tapes, real-time observations, and crew checklists. In certain cases where significant changes in methodology were introduced by the crewmen, the task activity was further defined by the identification of task aids and motion patterns.

The videotapes provided precise measurements which enabled the analyst to identify such anomalous situations as "foreign elements" (activities which are performed during the task but are unrelated to it, e.g., answering phone call while preparing food), idle and wait times, legitimate intrusions, etc., all of which were deleted from performance time. The identification of task-related anomalies (crew error) was also made possible through this analysis, especially on a subtask level. In the basic analysis of the data, task-related anomalies were not excluded from calculation of task time. In subsidiary analyses, emphasizing regularities in functions, task-related anomalies, when identified as outliers, were removed and estimated values substituted for them.

The information generated by the analysts was coded onto punch cards along with comments further explaining what happened. These were run with the TAMS-1 program which calculates the elapsed time for the task or subtask and also keeps track of anomalous conditions and the times associated with them. From this decoded information, graphs and tables were constructed for a first-order statistical analysis. Subsequent programs for trend analyses and typical tests of significance were developed.

Results

The overall results indicate that the anticipated adaptation function was obtained both for individual and for averaged data. More important, the function also appeared in most of the subtask analyses. These results indicate that the preexperiment training activities were thoroughly performed.

Total Task

Figure 13-1 presents the adaptation function for M092 preparation. The curves represent improvement in performance for the entire task. They are based on the combined data of the crewmen. The upper graph presents the "reality" picture, incorporating everything as it really happened; the lower graph gives a relatively idealized picture of what the results might be if reasonably correctable anomalies could be eliminated.

Two characteristics differentiate the two graphs: elevation, and the scatter of observations about the fitted functions. The first graph shows longer times, and its points do not fit as closely as those in the second graph. The "better" and "smoother" performance in the lower graph results, naturally enough, from the removal of the anomalies and the substitution of estimated values for the omitted activities.

The important feature in both graphs is their essential similarity. They represent simple power functions, show characteristic adaptation features, and tend to approach a limiting value. The gradual decline, or improvement in performance, represents a reduction from about sixteen minutes to ten minutes, a saving of 38 percent of time, over the course of nine trials.

Subtasks

Graphical analyses were completed for the subtasks, for each crewman separately, and for all crewmen combined.

From a diagnostic point of view, it is more important to study the subtask adaptation functions

because they span relatively short periods of time. Such a study reveals that activities differ in rates of adaptation. Some even show no adaptation. With such information, training procedures can be structured to take advantage of these variations.
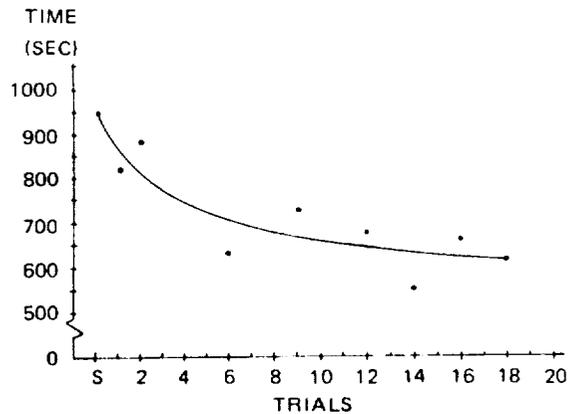
MO92 PREP—WITH ANOMALIES
(PLT AND SPT COMBINED)
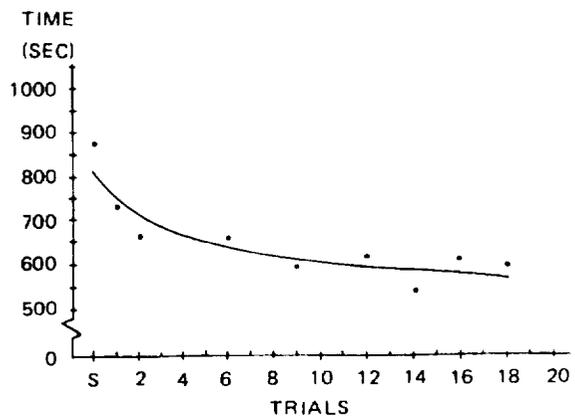
MO92 PREP—ANOMALY FREE
(PLT AND SPT COMBINED)

Figure 13-1. Adaptation function.

Equally important is the easier identification of anomalies within the part or subtasks. Some subtasks are more sensitive than others to environmental, hardware, or motivational changes. Other subtasks are relatively impervious to large changes in the system.

Improvement Over Trials. A typical subtask showing improvement over trials is Leg Measurement, found in Figure 13-2. As may be observed from the scatter of the points, the reality picture (with anomalies) represents pronounced variability in performance. It is important to note, however, that both variability and performance levels decrease as the trials continue.

LEG MEASUREMENT–WITH ANOMALIES
(PLT AND SPT COMBINED)

LEG MEASUREMENT–ANOMALY FREE
(PLT AND SPT COMBINED)
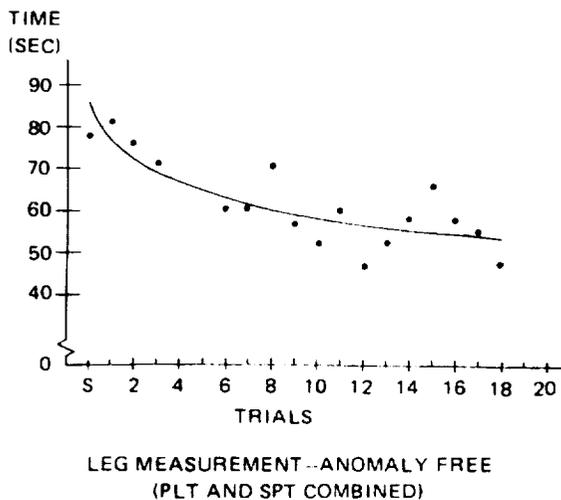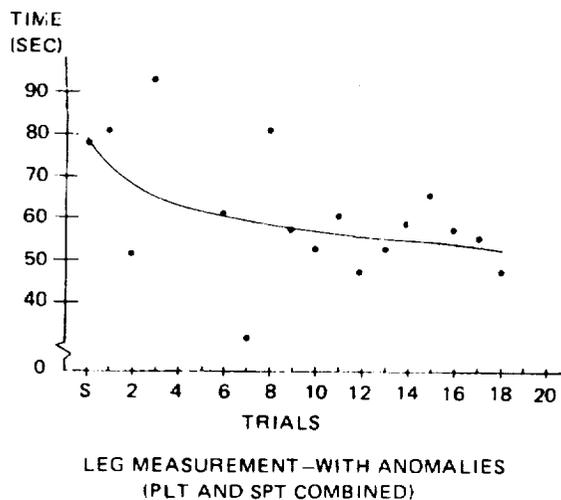
Figure 13-2. Typical subtask showing improvement.

With the removal of correctable anomalies, the variability is greatly reduced. This occurs in situations where many anomalies occur. In these instances, the simple estimation procedure overcorrects the inherent variability. (To introduce a random mechanism into the estimation procedure is a refinement that is neither necessary nor illuminating. There were too few activities which were characterized by too many anomalies.)

Subtask Showing No Improvement. Ingress LBNPD, as shown in Figure 13-3, represents the relatively rare phenomenon of poorer performance toward the latter part of the mission. That this could represent an "end effect" is given some support from the statistical analysis comparing the last six performances and the six immediately preceding them. There is a significant increase in time during the last six performances. The mental attitude of "getting-ready-to-leave" cannot be invoked as an explanation because other subtasks have not demonstrated this phenomenon. No defects in the apparatus were reported. And it is unlikely that physiological deterioration would manifest itself in such a selective fashion, namely in Ingress LBNPD but not in other subtasks.

The lower graph pictures the course of performance over time with the influence of anomalies removed. Their exclusion removes most of the deterioration effect noted in the upper graph. It is likely, then, that the "end effect" suggested by the upper graph is an artifact created by anomalous conditions.

Subtask Performance with Hardware Changes

The results from SMEAT showed the sensitivity of the adaptation function to instrumental changes. With improved hardware, performance was shown to improve; with "problem" hardware, performance deteriorated. Similarly the adaptation function showed the expected effects with change in application of force and possible use of caution.

Prior to mission day 24 (Trial 8), the crewmen experienced difficulty in donning the VCG harness. These difficulties are reflected in the pronounced variations shown in the early trials. On mission day 23, new VCG harnesses with longer electrode leads and requiring only one sponge per electrode

were passed into the SMEAT chamber. The result, as indicated in Figure 13-4, was marked reduction in variability for the next nine trials.

TIME
(SEC)
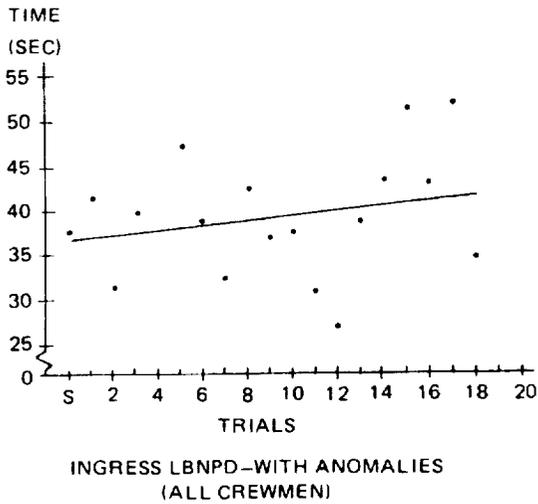
INGRESS LBNPD—WITH ANOMALIES
(ALL CREWMEN)

TIME
(SEC)

INGRESS LBNPD—ANOMALY FREE
(ALL CREWMEN)
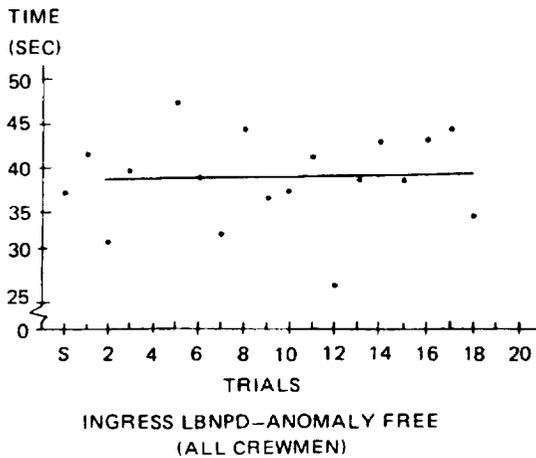
Figure 13-3. Typical subtask showing no improvement.

The crewmen also had problems with the connectors which were to be mated to the SIB. The connectors, which made the VCG/SIB somewhat difficult, became degraded with use. Performance in using the connectors gradually deteriorated over the course of the trials.

TIME
(SEC)

DON VCG HARNESS—WITH ANOMALIES
(ALL CREWMEN)
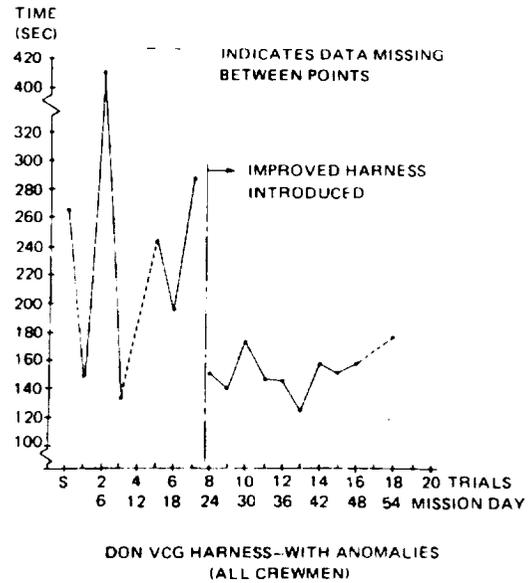
Figure 13-4. Effect of change in hardware.

Additional Analyses

Figure 13-5 presents the graphs of two relatively simple and practically identical operations: closing the LBNPD on prerun and postrun. On prerun, the closing is accomplished with a subject in the LBNPD, on postrun without a subject. The prerun graph is more variable and shows appreciably less improvement over trials than does the postrun graph.

There are two factors which explain the differences. First, there is weight. Since the force required to close the LBNPD is a function of the frictional resistance caused by the interface of the wheels and the floor, more force is required to move the device with a subject in it than when it is empty. Second, there is caution. More caution will almost certainly be exercised in closing the LBNPD with a crewman in it than when it is empty.

Although the general adaptation characteristics were observed in most activities, an unusually variable set of performances deserves special mention. These are the placing of the right and left plethysmograph legbands. Of these, the right legband placement was

the most variable. Both graphs in Figure 13-6 show high variability which indicates that it was not a subject related phenomenon, but may reflect a complex hardware-operation interaction.

readings. Because of this, the crewman may have exercised additional care when placing the legbands.
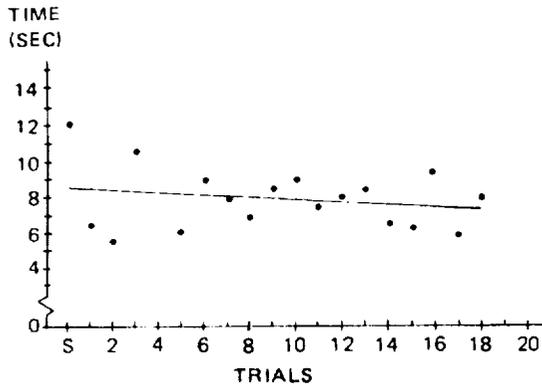
CLOSE LBNPD PRERUN
(SPT AVERAGE)

PLACE RIGHT LEGBAND—WITH ANOMALIES
(CREWMAN X)
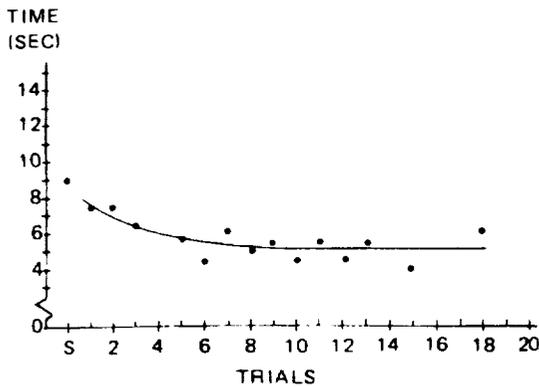
CLOSE LBNPD POSTRUN
(SPT AVERAGE)

Figure 13-5. Possible effect of frictional resistance as well as caution.
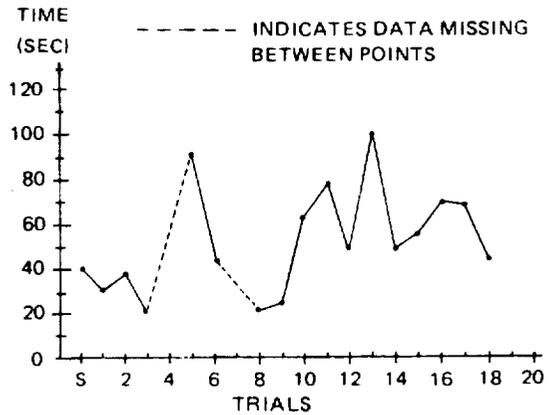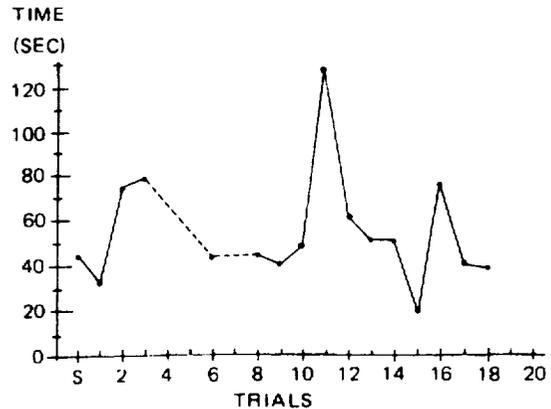
PLACE RIGHT LEGBAND—WITH ANOMALIES
(CREWMAN Y)

Figure 13-6. Subtask showing excessive variation.

Several possible factors may account for the high variability: the time required to perform alignment and the time spent inspecting the configuration of the legband. During the third week of the mission, there was a problem as to the accuracy of the legband

Equipment Problems

The kinescope data ranged from poor to useful quality. The poor overall quality was caused by the low lighting level in the SMEAT chamber and by the loss in resolution in conversion of the TV video to kinescope.

The TV camera has basic limitations. Activities can move outside camera range or be blocked from view. Technical problems with film can produce faulty reproduction. Real-time recording by an analyst is not exact, either. Only total element times can be obtained (about three to five seconds is the shortest element time that can be successfully observed and recorded), and if an element is missed, no opportunity exists for a rerun as in film analysis.

Conclusions

Experiment M-151 demonstrated the value of time and motion procedures to evaluate task performance. During SMEAT, there was a general improvement in both task and subtask performance over time.

The structure of the adaptation function was related to the type of task performed and exhibited sensitivity to changes in hardware. The partitioning of a task into subtasks provided a basis for diagnostic evaluation of difficulties associated with poor or variable performance. The results showed that subtasks which did not improve were those which could not be expected to change for the better or those which required hardware changes for improvement. There was no evidence for deterioration in performance that could be attributed to the stressful experience of the SMEAT program.

The SMEAT adaptation functions obtained for the various subtasks provide a basis for comparison with the corresponding functions to be obtained during Skylab preflight and inflight time and motion studies. In addition, the simulation exercise exhibited the magnitude of the analytic problems to be faced in Skylab. As a result, the M151 data handling procedures were made more efficient.

CHAPTER 14

ENVIRONMENTAL NOISE EXPERIMENT (DTO 71-22)

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Laboratory investigations have demonstrated that exposure to sound can result in a variety of physiological and psychological responses affecting man's performance, safety, and well-being (Broadbent & Burno, 1965; Harris, 1968). High intensity sound can produce temporary (Carder & Miller, 1969; Fletcher, 1969) or permanent (Glorig, Ward, & Nixon, 1961; Kryter et al., 1966) changes in hearing, interfere with communications (Kryter & Williams, 1966; Webster, n.d.), and cause subtle alterations in respiratory and cardiovascular function. Noise can interfere with sleep and be a chronic source of annoyance (Kryter et al., 1971), thereby leading to performance decrement.

SMEAT presented an unparalleled opportunity to obtain data which would permit a greater understanding of the probable effects of the expected Skylab noise environment on the crew, as well as provide data which could be useful in the development of noise standards for future manned spacecraft designs. Heretofore, there has been a lack of valid, empirical data on the effects of continuous, long term exposure to noise on man. Data in the SMEAT environmental noise experiment was collected by measuring ambient and equipment noise, hearing thresholds, and speech intelligibility prechamber, in-chamber, and postchamber. The crewmen also completed a questionnaire on possible psychological effects of continuous noise exposure.

This experiment was designed especially for the SMEAT Program, and no part of it is being conducted onboard actual Skylab missions.

Apparatus

Equipment Noise and Ambient Noise Measurement

One fixed and one portable General Radio ceramic microphone were used in the SMEAT chamber for noise measurements. Power for the microphones was supplied with a Power Designs Power Supply and input voltages were visually monitored with a Triplet voltmeter. Signals from the microphones were led through a chamber interface plate to a microphone junction box. From the junction box, the signals were led to a B&K noise analyzer. Signals from the noise analyzer were fed through a B&K bandpass filter set and automatically recorded in one-third or one octave band widths on a B&K graphic level recorder. The level recorder was equipped with a 50 dB potentiometer.

A line was taken from the B&K noise analyzer's input amplifier through which signals were led from the microphones to one channel of an Ampex AM/FM tape recorder. Signals placed on tape were monitored with a B&K RMS electronic voltmeter and a Tektronix oscilloscope.

Hearing Threshold Measurement

Hearing threshold measurements were made with a Bekesy-type Rudmose recording audiometer and Telephonics 100Ω transducers (TDH-39). For the prechamber and postchamber threshold measurements, the earphones were equipped with MX-41AR ear cushions and enclosed in Rudmose otocups. Nonflammable otocups patterned after the Rudmose design were designed for the in-chamber phase.

Speech Intelligibility Measurement

These measurements were obtained either with a headset as the transducer or in a free field situation with a speaker. The headset was the same as that used for the hearing threshold measurements. The speaker was a LaFayette 8Ω model installed in the Skylab entertainment center. The frequency characteristics of the speaker were somewhat altered as a result of being treated to make it fireproof.

An Ampex recorder was used to deliver the taped word lists and a Grason-Stadler noise generator provided the masking noise. Signals from both the recorder and noise generator were led through two Hewlett-Packard attenuator sets. Mixing and amplification of the noise and speech was achieved with an Altec audio amplifier. Signal levels were monitored with a B&K RMS voltmeter and a dual beam Tektronix oscilloscope.

Speech Intelligibility Word Lists

All speech intelligibility word lists were taken directly from the American Standard Method for Measurement of Monosyllabic Word Intelligibility (American Standards Association, 1960). An Electro-voice microphone was used as the transducer for voice pickup. Signals from the microphone were led into an Altec amplifier. The amplified signals were monitored with a B&K RMS electronic voltmeter and recorded on one channel of an Ampex AM/FM tape recorder.

Noise Questionnaire

A two-part questionnaire was constructed to help in determining the psychological effects that exposure to constant unvarying noise may have. The first part of the questionnaire consisted of twenty paired polar opposite adjectives to be rated on a seven-point rating scale (e.g., heavy light). The pairs of polar opposite adjectives were taken from orthogonal factors isolated by Solomon (1958). The second half of the questionnaire consisted of open ended questions designed to elicit awareness and clear descriptions of the noise present in the altitude chamber from the three crewmen.

Calibration

The microphones used in the equipment noise and ambient noise measurement were calibrated with a B&K pistonphone. Calibration of the audiometer used in the hearing threshold measurement was obtained with a B&K sound level meter, an octave filter set, and an artificial ear. When calibrating with the transducers fitted with MX-41AR ear cushions, an American N.B.S. 9A coupler was employed. For the specially designed in-chamber headset, an ASA type 1 coupler was used. A B&K pistonphone was used to calibrate the sound level meter.

Calibrations of the microphones were completed both at normal (14.7 psia) and reduced (5.0 psia) atmospheric pressures. All calibrations at reduced pressure occurred during "wet runs" before the test actually began. Calibration at normal atmospheric pressure was accomplished before the in-chamber phase began and again after it was completed.

Pretest and posttest audiometric calibrations at the frequencies of .5, 1, 2, 3, 4 and 6k Hz were made according to the ISO 1964 standard. Under these conditions all reported data represent actual thresholds in dB HTL.

Calibration at reduced and normal atmospheric pressures of the audiometer for in-chamber testing at the frequencies of .5, 1, 2, 3, 4 and 6k Hz was only at approximate ISO 1964 standards. Attenuation properties present in the line interfacing the chamber headset with the testing station resulted in lower levels at 4 and 6k Hz. As a result, all in-chamber thresholds are relative only to one another and provide an index of change over time. The actual numerical values obtained should not be regarded as threshold in dB HTL.

Procedures

Noise Measurement and Analysis

Ambient noise measurements were made at six different locations in the SMEAT chamber. Five of the measurements were made with a detachable microphone on a portable tripod in the lower level of the chamber. The sixth was obtained with a permanently attached microphone located in the approximate center of the second level of the chamber. Readings for all locations were for approximately five to eight minutes. The measurements were conducted several times at 14.7 psia and on nine separate occasions during the in-chamber phase.

Equipment noise measurements depended on the scheduled use of the equipment for any particular day. Equipment measured included the specimen mass measurement device (SMMD), the Skylab ergometer, and the charcoal filter blower system in the waste management compartment. The SMMD and the ergometer were measured four times during the 56-day test. The charcoal filter blowers were measured twice.

Noise measurement analysis at each of the six chamber locations and for the three types of Skylab hardware consisted of a minimum of two sweeps through the frequency spectrum of 25 Hz to 20k Hz in one-third octave band widths. Direct noise levels were placed on analog tape and voice annotated as to the specific location or type of equipment being measured.

Hearing Threshold Measurements

Three hearing threshold measurements were made both before and after the 56-day chamber phase. The measurements were conducted at normal atmospheric pressure in an audiometric booth at frequencies of .5, 1, 2, 3, 4, and 6k Hz. The first postchamber measurement was made within a few hours after the crew left the chamber. Each crewman served as his own control.

Threshold measurements were made with each of the crewmen at approximately one-week intervals during the 56-day chamber phase at reduced atmospheric pressures. The measurements were taken in the lock-sleep compartment because it was the area with the lowest level of ambient noise. The frequencies were the same as those in the prechamber and postchamber phases. The right and left ear hearing threshold data at each frequency for each crewman obtained during the crew "wet run" (chamber at 5.0 psia) became the in-chamber baseline for that crewman.

During each hearing threshold test, a microphone was placed close to the crewman and the background noise recorded in one-third and one octave band widths to determine the amount of masking present. The procedure assured that each test day could be equated with any other test day.

Construction of Speech Intelligibility Tapes

The procedures in taping the word lists that were used in determining changes in speech intelligibility were those defined by the American Standard Method for Measurement of Monosyllabic Word Intelligibility. Each word in a list was spoken singly in the following carrier sentence: "Would you write (key word) now." The manner of reading was such as to place no unnatural stress on any word in the sentence.

The distance between reader and microphone was kept constant and voice level was monitored by both the reader and a second party with a vu meter and an RMS voltmeter. Words were read at the rate of one word every four seconds. No one word list was repeated for a single crewman in either the headset or speaker mode of presentation over the entire testing procedure.

Speech Intelligibility Measurements

Speech intelligibility scores were obtained at approximately one-week intervals. The mode of word list presentation was alternated between the headset and the speaker with four measurements obtained with headset and six obtained with the speaker. Baseline scores for both modes were obtained with the crewmen on two occasions at normal atmospheric pressure. One baseline score, speaker mode only, was obtained at reduced pressure.

The signal-to-noise ratio for speech intelligibility levels was determined before the chamber phase began and set at approximately 70 percent correct for both modes.

The crewman being tested sat in a chair three meters in front of the speaker when this mode was used. When the word lists were presented through the headset, the crewman sat in the lock-sleep compartment at the same location employed for determining hearing threshold levels.

The crewman was presented with two word lists of 50 words each. Scoring of word intelligibility was according to the procedure of the American Standards Association. A word was considered incorrect if any one of the sounds in the spelling was incorrectly indicated. Incorrect spellings which resulted in a word that sounded as originally heard were considered correct.

In both the headset and speaker mode of word list presentation, the crewman positioned a microphone approximately .5 meters from his head in order to permit one-third octave and one octave band analysis of background noise during each of the two word lists presented.

Noise Questionnaire

The crewmen completed the questionnaire at ten-day intervals eight times, three times before the chamber phase and five times in-chamber. Primary attention was given to the way the crewmen rated the sound present in the chamber on the seven-point scale comprised of paired polar opposite adjectives and their actual written descriptions of the sound.

Results

Ambient Noise Measurement

Low frequency noise was predominant in the chamber. In every instance there was a progressive drop in noise level toward the high frequency end of the spectrum. Beyond 10k Hz, there was no noise present above 25 dB in either of the two sleep compartments (where noise levels were consistently lowest) or the waste management compartment.

When all measurement locations are compared, it is apparent that there was a slight tendency toward greater variability at the high end of the measured spectrum. The greatest overall variability in noise spectral content occurred in the ward room where the day-to-day noise level varied up to 15 dB over a significant portion of the spectrum.

Overall and A-weighted sound pressure levels plotted as a function of time (pre- and in-chamber) for each measurement location are shown in Figure 14-1. Inspection of this figure indicates that there was little change in the overall sound pressure level in the chamber during the 56 days. If anything, there was a very slight decrease in level at several locations. As would be expected, there is somewhat more variability in the A-weighted sound pressure levels, but even these values remained fairly consistent throughout the 56 days. The highest A-weighted levels occurred approximately midway through the study and were undoubtedly associated with the operation of the Skylab carbon monoxide monitor which was located in the ward room.
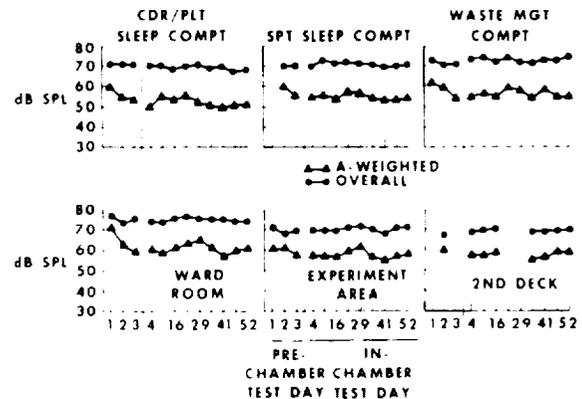

Figure 14-1. Sound pressure levels (re .0002 dyne/cm^2) of ambient noise at each of the six measurement locations.

Although limited data are available to make comparisons, it can be seen from Figure 14-1 that measured noise levels in the chamber decreased approximately 3 to 8 dB when the atmospheric pressure was reduced from 14.7 to 5.0 psi. The decrease in sound level with reduced pressure was frequency dependent and varied with measurement location.

Equipment Noise Measurement

The noise resulting from the use of the ergometer during SMEAT exceeded the Skylab noise specification by approximately 5 dB. The ergometer was operated at a workload of 150 watts at 60 rpm.

Operation of the SMMD did not produce excessive noise. When compared to the noise in the waste management compartment where the device was located, it became apparent that the SMMD noise was no greater than the ambient noise in the area. Use of SMMD did, however, result in high intensity, high frequency peak noise, a whine which was subjectively quite noticeable.

The charcoal filter blowers were significant noise generators and exceeded Skylab noise specifications by approximately 4 dB.

Hearing Threshold Measurement

Figure 14-2 represents the results of in-chamber threshold data obtained for each of the three crewmen. Inspection of these figures indicates that there were no outstanding changes in any of the crewmen's hearing during the actual 56 days of unvarying noise exposure. However, some noticeable threshold shifts are evident. The CDR shows small downward trends at 3 and 4k Hz in the left ear and at 2.3 and 6k Hz in the right ear. The data collected for the SPT indicate negative threshold shifts at 1, 2, 3, and 4k Hz for the left ear and at 2.3 and 4k Hz in the right ear. The in-chamber hearing threshold data obtained for the PLT indicate that, with the exception of some day-to-day variability, this crewman's hearing remained unchanged throughout the 56-day test.

Figure 14-3 illustrates the pre- and postchamber hearing threshold data collected for each of the crewmen. The mean and the range of three measurements made prechamber represent the baseline. Compared against this baseline are data obtained at approximately five hours (R+0) after exit from the chamber. The other two points were obtained two days and twelve days following exit from the chamber.
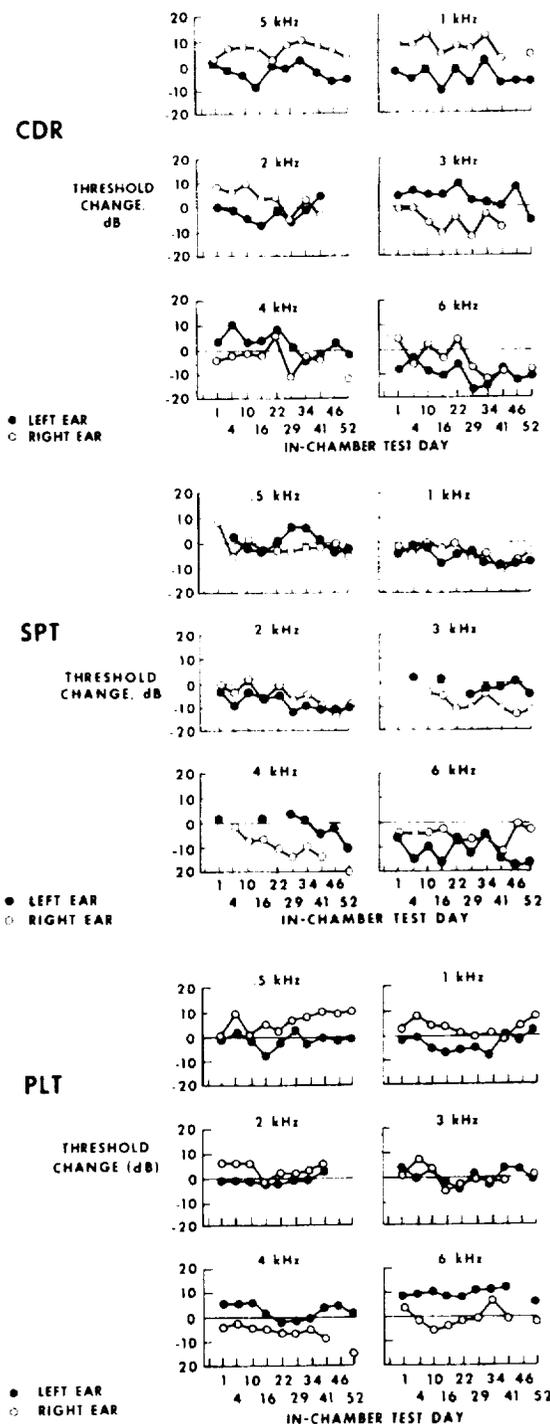

Figure 14-2. Right and left ear hearing threshold changes at each of six test frequencies for the CDR, SPT and PLT. Data are plotted as a function of in-chamber test day.
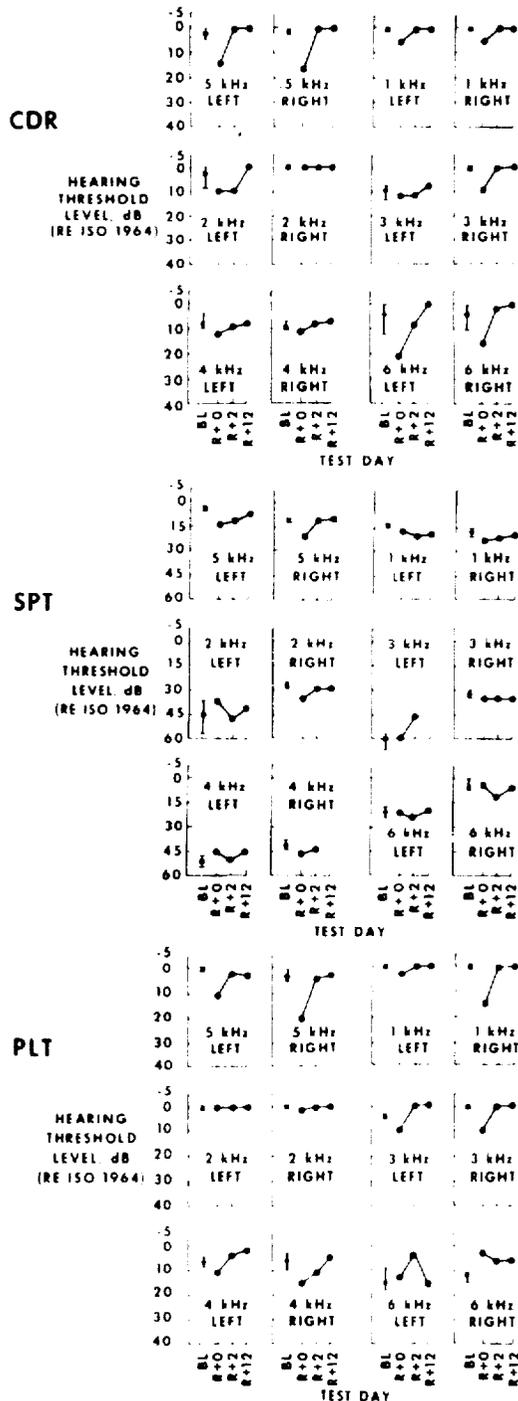
Figure 14-3. Right and left ear hearing threshold levels at six test frequencies for the CDR, SPT and PLT. Three prechamber baseline and three postchamber measurements are shown.

Note that for the CDR rather large threshold shifts occurred at R+0, particularly at 500 Hz and 6k Hz in the left and right ears. The PLT experienced rather substantial negative threshold shifts at R+0 at 500 Hz in the left ear and 500 Hz, 1k Hz, 3k Hz, and 4k Hz in the right ear. Pre- and postchamber threshold data for the SPT indicate relatively large negative threshold shifts at 500 Hz in both the left and right ears at R+0.

Speech Intelligibility

The results of the speech intelligibility measurements are presented in Figure 14-4. The numbers in parenthesis adjacent to each data point are preferred speech interference levels (PSIL) in dB. These values were derived from the one octave band noise measurements made during each speech intelligibility test by averaging the sound pressure levels of the octave bands centered at 500, 1,000, and 2,000 Hz.

An analysis of these data reveals several significant findings. First, intelligibility scores were invariably higher with the headset mode of presentation. The overall average scores were approximately 80 percent and 60 percent correct intelligibility for the headset mode and speaker mode, respectively. With few exceptions, this finding correlated well with the fact that speech interference levels were generally 5 to 10 dB lower at the headset mode test location than at the speaker mode test location. Also, even within modes of presentation, intelligibility scores tended to vary as a function of PSIL. Two of the subjects gave evidence of a gradual deterioration in their ability to accurately comprehend the test words, particularly toward the end of the study. These were the same two subjects who demonstrated increased hearing thresholds during the course of the study. There were no differences in intelligibility scores obtained under normal and reduced atmospheric pressure when the test words were presented via headset. However, a decrease in intelligibility was observed in all three subjects when the speaker mode was used at reduced pressure.

Noise Questionnaire

Information obtained from the special environmental noise questionnaire was generally inconclu-

SPEECH INTELLIGIBILITY

SPEAKER MODE
HEADSET MODE

PERCENT CORRECT INTELLIGIBILITY

CDR

(53.0) (45.4) (42.7) (44.1) (45.8)
(46.8)
(49.0) (49.0) (51.3)
(55.0) (46.0) (54.0) (54.7) (49.7)

PRE-CHAMBER IN-CHAMBER

0 1 2 3 4 10 16 22 29 34 41 46 52 56
TEST DAY

PERCENT CORRECT INTELLIGIBILITY

SPT

(53.0) (45.5) (45.0) (44.0)
(46.1) (45.5)
(54.0)
(49.0) (48.8)
(55.0) (47.0) (51.3)
(54.8)
(49.0)

PRE-CHAMBER IN-CHAMBER

0 1 2 3 4 10 16 22 29 34 41 46 52 56
TEST DAY

PERCENT CORRECT INTELLIGIBILITY

PLT

(53.0) (46.0) (45.3) (44.1)
(51.7) (43.8) (45.5)
(51.3)
(55.0) (48.8)
(46.8) (52.5) (55.0) (49.0)

PRE-CHAMBER IN-CHAMBER

0 1 2 3 4 10 16 22 29 34 41 46 52 56
TEST DAY

Figure 14-4. Speech intelligibility scores for the CDR, SPT, PLT. Date for speaker and headset modes are plotted separately as a function of test day. Numbers in parenthesis represent the preferred speech interference level (PSIL) in dB.

sive. On the word-pair portion of the questionnaire, all crewmen gave a preponderance of neutral responses. The SPT did show some tendency toward polarity on several word pairs. For example, he consistently rated the chamber noise as being more unpleasant and annoying than either of the other crewmen. No outstanding comments were elicited from the crewmen on the open-ended portion of the questionnaire. In general, their subjective observations correlated with the noise data obtained in that they reported the noise to be predominantly low frequency in nature, the ward room as being the loudest area of the chamber, the CDR/PLT sleep compartment the quietest, and the ergometer as being the loudest and most annoying piece of equipment hardware.

Conclusions

The acoustical noise environment in SMEAT was not like that expected for Skylab. SMEAT chamber noise was influenced by the vacuum pumps and other environmental control systems located near the chamber. There are hardware systems on Skylab which produce more mid- to high frequency range noise than was present in SMEAT.

Only general conclusions can be reached on the effect of SMEAT noise on the crewmen. Two crewmen experienced a small hearing decrement in-chamber, but there was no pattern as to the ear and frequency affected. Temporary hearing threshold shifts were observed in all three crewmen postchamber. These postchamber threshold shifts were perhaps the most significant finding of the study. However, exposure to the SMEAT noise environment had no lasting detrimental effects on the crew's hearing.

There are no firm explanations with respect to the apparent gradual deterioration of speech comprehension ability of two of the crewmen. Reduced atmospheric pressure cannot be held responsible since the data indicate that speech interference levels in the headset mode were slightly lower at 5.0 psia and in the speaker mode test area were essentially the same at 14.7 psia as at 5.0 psia. Performance on the speech intelligibility task may have been affected by subtle fatigue factors.

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CHAPTER 15

CREW MICROBIOLOGY (DTO 71-19)

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Man has evolved in intimate and constant association with complex microflora. Some of these produce disease and others generally do not. Pathogens, or disease-producing organisms, are not normally part of man's indigenous body flora. While the modes of transmission of disease by these organisms is well understood, the mechanisms of disease production by the indigenous flora are poorly understood. It is well established, however, that damaging effects of the indigenous microflora become manifest chiefly when individuals are placed under conditions that differ from those under which the normal equilibrium between host and microbes became established.

Spacecraft represent such a new and unique environment. Since the prevention and control of infectious diseases during space missions is directly related to crew safety and mission success, it is important to study man-microbe ecological patterns under the conditions of space flight, especially space flight of long duration.

The Skylab missions are the first to provide the capability for inflight microbiological studies and disease diagnoses. Microbial alterations that occur will be the complex resultant of the combined physical and biological factors that prevail in the space environment.

The purpose of the SMEAT microbiology tests was to obtain data on man-microbe-environment interactions which reflect the effects of ground-based Skylab parameters, such as confinement in a semiclosed ecosystem, diet, restricted activity, and reduced pressure, on crew microbial burdens and on the microbial ecology of the SMEAT chamber. This information has direct bearing on crew health and materials degradation within the actual orbital assembly.

Equipment and Procedures

Specimen collection regimens and processing schema for the SMEAT microbiological studies are summarized in Table 15-1. Sterile phosphate buffered saline (PBS) was used throughout the study as the initial collection medium for bacteriology and mycology. Earle's balanced salt solution containing 0.5 percent gelatin was used as the diluent for specimens for virologic analyses. Gargle samples were obtained by having the crewmembers gargle and "wash" the oral cavity with PBS and return the material to the original container. Skin and nasal sampling was accomplished using premoistened calcium alginate swabs which were placed individually in tubes containing PBS. Midstream urine and fecal samples were collected in sterile containers.

For chamber microbial monitoring, two stainless steel strips were collected weekly from each of eight locations and placed individually in sterile metal screw cap containers. Ten-minute air samples were collected using a standard six-stage Anderson Cascade Air Sampler calibrated for one cubic foot per minute (0.028 m^3 per min) of air at 5.0 psia (35.2 gm per cm^2 absolute). Before a chamber swab sample was taken, the area was first outlined with a template. The area was then scrubbed with a moistened swab and dried with a second swab. Both swabs were placed in a single tube containing PBS.

Table 15—1

SMEAT Microbiology — Sampling Schedule

Julian Date Specimen	Prechamber 131	138	145	152	159	166	173	180[a]	187	194	201	In-chamber 208[b]	215	222	229	236	243	250	257	264[c]	Postchamber 271	278[d]	306
Gargle	XO	X	X	X	XO	X	X	X	X	X	X	XO	X	X	X	X	XO	X	X	XO	X	XO	X
Throat swab	O				O							O					O			O		O	
Nasal swab			X		X		X	X	X			X	+		X	X	X	X		X	X	X	X
Skin swabs	X		X		X		X	X	X			X	+		X			X	X	X	X	X	X
Fecal	ZO			Z	O		Z				Z	O		Z			ZO			ZO		ZO	Z
Urine	XO				XO		X		X			XO			X		XO			XO		XO	X
Strip samples													X	X	X	X	X	X	X	A			
Air samples												B	B	B	M	B	B	B	B	B			
Chamber swab samples																				A			

X — Bacteriology (aerobes, anaerobes) fungi and yeast
+ — Medically significant organisms only
B — Bacteriology medium used
M — Mycology medium used
A — Aerobic bacteria, yeasts and fungi
O — Viruses and mycoplasma
Z — Anaerobic and facultative bacteria, yeasts and fungi

ᵃStart Skylab diet — June 28, 1972
ᵇChamber close — July 26, 1972
ᶜChamber open — September 20, 1972
ᵈEnd Skylab diet — October 7, 1972

Specimens collected during the prechamber period were processed as soon as possible, usually within 30 minutes, after collection. Specimens collected during the chamber run were passed out through the transfer lock as soon as possible after collection. Ordinarily, about one hour elapsed between the time of collection and laboratory processing of intrachamber samples.

Crew Mycology

To permit quantitative isolation of fungi, aliquots of each sample were inoculated onto corn meal/malt-extract/yeast-extract agar with antibiotics (CMMY), Sabouraud's dextrose agar with antibiotics (SAB), and Czapek-Dox agar (CD). After incubation, isolated colonies were counted and recovered from the agar surfaces for identification. To recover fungi present in low numbers, diluents of skin-swab samples and urine were each centrifuged and the sediments inoculated onto the three agars. Species not recovered from the first set of isolation plates were removed for identification.

Crew Bacteriology

Skin samples were inoculated onto blood agar, Staphylococcus-110 agar, and letheen agar to isolate aerobes and onto blood agar containing vitamin K and hemin for anaerobes. Throat-mouth gargle was inoculated onto blood agar, Staphylococcus-110, Mitis-Salivarius agar, and chocolate agar containing bacitracin for aerobes. Rogosa agar, Paromo-mycin-Vancomycin-Menadione agar, and blood agar with vitamin K and hemin were used for anaerobes. Urine aerobe isolation was done with blood agar, Staphylococcus-110 agar, MacConkey agar, and chocolate agar containing bacitracin. Following incubation, isolated colonies were counted and recovered from the agar surfaces for identification.

To recover aerobic bacteria present in low numbers, a standard loop of each sample was inoculated into trypticase soy broth. After incubation, the broth was streaked on the above media and incubated again. Those species not recovered from the first set of isolation plates were removed for identification.

Crew Virology

Twenty percent (w/v) stool suspensions were prepared by homogenizing the specimen with Earle's balanced salt solution in a Sorvall omnimixer. The suspension was centrifuged and the supernatant was adjusted to neutrality and treated with penicillin, streptomycin, and fungizone.

The pharyngeal swab gargle specimens were processed by expressing the medium from the swab and transferring it to the gargle. A portion of the specimen was reserved for mycoplasma analysis and the remainder was centrifuged. The supernatant was adjusted to neutrality. The portion used for tissue culture challenge was treated with streptomycin and fungizone; the portion used for embryonated egg challenge was treated with penicillin and streptomycin. The portion reserved for mycoplasma analysis was treated with staphcillin and penicillin.

The urine specimens were adjusted to neutrality and a portion reserved for mycoplasma analysis. The remainder, which was used for tissue culture challenge, was centrifuged. The antibiotic treatment for the urine specimens was similar to the pharyngeal swab-gargle specimens.

Primary rhesus monkey kidney and diploid semicontinuous human embryonic lung were utilized. Six culture tubes of each cell culture type were inoculated with the treated specimens. The cultures were rolled in roller drums at designated temperatures and were examined daily by microscope. At ten-day intervals, two blind subpassages were made. The final cultures were challenged with vesicular stomatitis virus to detect hidden infection.

Treated stool specimens were also inoculated into suckling mice. The mice were observed daily, and subpassaged after fourteen days.

The treated pharyngeal swab-gargle specimens were also inoculated into the amniotic and allantoic sacs of embryonated chicken eggs. The inoculated eggs were incubated in increased humidity and observed daily for evidences of infection. At four-day

intervals, two blind subpassages were made. Subpassage material from cell cultures, suckling mice, and embryonated eggs was tested for hemagglutinins using chicken, guinea pig, and human O erythrocytes at ambient temperatures and 4°C.

Mycoplasma isolations were attempted from treated pharyngeal swab-gargle and urine specimens. The medium developed by Hayflick and modified by Barile was used as an agar and a broth. Shepard's medium for the primary isolation of small colony mycoplasma (T-strains) was also used. The plates were incubated at 36°C (309°K) in a humidified five percent CO_2-95 percent air environment. The cultures were examined daily for growth and the isolants were identified. The specimens inoculated into Hayflick's broth (pH 7.2) were subpassaged three times at four and seven days into broth and agar. A-3 and U-9 broths and A-6 agar plates of Shepard's medium (pH 6.0) were utilized. The broth cultures were subpassaged into A-6 agar plates after eighteen hours incubation.

Environmental Microbiology

Each stainless steel strip was transferred to a flask containing 0.2 percent Tween 80 solution and insonated. Half the suspension was heat shocked at 80°C for twenty minutes. Serial dilutions of the remaining half were prepared in the Tween 80 solution. Aliquots of each dilution were placed on Trypticase soy agar (TSA) and on blood agar plates. The TSA plates were incubated under aerobic conditions and the blood plates were incubated under anaerobic conditions at 37°C (310°K). The heat shocked portion was handled in the same manner as the nonheat-shocked portion.

Aerobic colonies were counted after 48 hours; anaerobic colonies were counted after 96 hours. Following quantitation, all plates were examined for different colony types and species were identified by standard procedures.

After using the Anderson Air Sampler, the unit was passed out of the chamber and the plates removed. The six plates were incubated 48 hours at 37°C (310°K) and colonies were counted. Each plate

was then examined qualitatively in the same manner as those from the stainless steel strips.

Each swab sample was taken at chamber closeout and vortexed for two minutes. It was deemed not necessary to heat shock or analyze the swab samples for anaerobes.

After vortexing, serial dilutions were made in sterile phosphate buffer. Duplicate blood agar spread plates were prepared for each dilution. All plates were incubated at 37°C (310°K) for 48 hours and then examined quantitatively. Following quantitation, the plates were examined for different colony types and treated in the same manner as the aerobic, nonheat-treated stainless steel strip plates.

Original material from both the strip samples and swab samples were examined for fungi and yeasts using CMMY containing antibiotics. All plates were incubated at room temperature for seven days. All filamentous fungi and yeasts were isolated and identified using standard procedures.

Fecal Anaerobic Flora Studies

Nine samples were taken from each of the crewmembers. The first three samples were on normal diet, the fourth sample was after three weeks on astronaut diet prechamber, the fifth sample after two weeks in-chamber, the sixth sample four weeks in-chamber, the seventh sample at the end of the chamber run, the eighth two weeks after coming out of the chamber (still on astronaut diet), and the ninth after four or more weeks on normal diet.

Specimens were collected and transported to the laboratory where they were placed in polypropylene plastic bags flushed with oxygen-free carbon dioxide. Stool specimens were thoroughly mixed by kneading the plastic bags. Subsamples of feces were then placed in preweighed tubes containing prereduced buffered salts solution. Dilutions of 10^{-8}, 10^{-9}, or 10^{-10} were cultured in triplicate in prereduced rumen fluid-glucose-cellobiose agar roll tubes (a nonselective medium) and incubated. Concurrently, slides for direct microscopic clump counts were made from 10^{-3} or 10^{-4} dilutions in the same dilution series used for culture.

An average of 55 unselected colonies were picked at random from cultures of the highest dilutions. Duplicate lyophilized cultures were prepared and stored on each isolate resulting from the colony picked from the roll tube. The isolates were restreaked and checked for purity by uniformity of colony type and by direct microscopic observation. Triplicate lyophilized vials were then prepared on each isolate resulting from the second streaking. Analyses for biochemical characteristics, metabolic pathways, and morphology – averaging more than 40 tests per strain – were carried out to characterize each isolate and allow speciation.

Results and Discussion

Skin Bacterial Flora Studies

The combined incidence of the predominant bacteria found on seven skin sites from all SMEAT

crewmembers is presented in Table 15-2. The table shows that the gram positive bacilli and the gram negative flavobacteria were not, with one exception, recovered from the skin after the crewmembers were isolated inside the chamber. These organisms, recovered during the prechamber period in approximately equal proportions from all crewmembers, are obviously not part of the indigenous flora and represent contamination of the skin by ubiquitous organisms. The species which were isolated are almost never involved in pathological processes. This represents an example of microflora alteration resulting from isolation in a closed environment.

The largest proportion of the indigenous aerobic skin flora of all crewmembers was found to be comprised of numerous species or subgroups of corynebacteria, micrococci and *Staphylococcus*

Table 15–2

Incidence of Predominant Bacteria on Seven Skin Sites[a]
During the Prechamber, In-chamber, and Postchamber Periods

CDR, SPT, PLT	Prechamber (6)[b] C −77 thru C −0[f]		In-chamber (4) C + 21 thru C + 56		Postchamber R + 14
	No. Isolants	Mean[d]	No. Isolants	Mean	No. Isolants
Bacillus spp. (10)[c]	49	8	1	−[e]	7
Flavobacterium sp.	29	5	0	-	0
Corynebacterium spp. (15)	198	33	133	33	26
Micrococcus spp. (7)	113	19	92	23	12
Staphylococcus epidermis (5)	141	23	73	18	12
Streptococcus spp. (6)	24	4	10	2	2
Mima spp. and Moraxella spp. (5)	15	2	7	2	1
Gram negative enterics[g]	17	3	1	−	1
Anaerobic cocci (7)[h]	41	7	3	−	1
Propionibacterium spp. (5)	100	17	39	10	6

[a]Neck, ear, axilla, hands, umbillicus, groin, toe web

[b]Number of times sampled

[c]Number of species, varieties or subgroups

[d]$\dfrac{\text{No. isolants}}{\text{No. samples}}$ = mean rounded to nearest whole number

[e]Less than 1

[f]Chamber minus 77 days through chamber close

[g]Escherichia, Enterobacter, Klebsiella

[h]Peptococcus and Peptostreptococcus

epidermis. It may be noted that the incidence of these organisms on the skin was not affected by chamber confinement and/or chamber environmental factors.

The incidence of *S. epidermis* types II and VI showed a relative decrease during the period of confinement. *S. epidermis* was isolated in almost pure culture from an acne pustule of one crewmember during the prechamber period. Although the eruptions partially receded following tetracycline therapy, these pustules continued to be present during the chamber run and recurrence of lesions followed return to the normal postchamber environment.

The aerobic, gram positive micrococci from the third major group of indigenous skin flora were common to all three crewmembers.

Various species of streptococci were found with approximately equal frequencies on all crewmembers. During chamber confinement the incidence of *Streptococcus faecalis*, *Streptococcus mitis*, *Streptococcus salivarius*, and the alpha-gamma-hemolytic streptococci showed a decrease in occurrence. Beta-hemolytic, non-Group A, streptococci increased in occurrence.

The significant decrease of gram negative enterics during chamber confinement suggests that their occurrence on the skin may be dependent on continued exposure to the outside environment including varied social contact. Alternatively, one may postulate that chamber environmental factors are not favorable for survival of these organisms once shed from their normal habitat in the oral cavity and intestinal tract. In either case, the fact that these enterics did not increase on skin surfaces during chamber confinement is a suggestion that the personal hygiene regimes were adequate. Any significant buildup of these organisms in the oral cavity or skin would have been indicative of "bacterial flooding" (movement from the gut to the oral cavity and skin) and a cause for serious concern.

It can be noted from Table 15-2 that recovery of anaerobic cocci (*Peptococcus spp.* and *Peptostreptococcus spp.* and *Propionibacterium spp.*) in-chamber

was significantly decreased ($p < 0.01$, Wilcoxon's Rank-Sum Test). This may be attributed to the effects of environmental factors, such as elevated oxygen level, or to personal hygiene regimens, or to both.

The combined quantitative values from all crewmembers of the predominant bacteria recovered from seven skin sites during the prechamber, in-chamber, and postchamber periods are shown in Table 15-3. With respect to the corynebacteria, the micrococci, and *S. epidermis*, the ranges of values during all periods remained fairly constant and this pattern was characteristic of all three crewmembers. The numbers of streptococci recovered from the skin were decreased by approximately one-log during the chamber run with no consistent patterns among the three crewmembers.

Although there was a significant decrease in the incidence of anaerobic cocci, there was not a significant decrease in quantity. Further analyses of the data reveal a slight increase in the Beta-hemolytic, non-Group A streptococci and an overall decrease of one-log in all other streptococci. The total burden of anaerobic cocci recovered from skin surfaces during the chamber run was due to the isolation of *Peptostreptococcus anaerobius* from one crewmember's umbilicus and the isolation of *Peptococcus prevotii* and *P. anaerobius* from the hands of another crewmember. These organisms were recovered only during the fifth week of the chamber run.

While the in-chamber incidence of *Propionibacteria* was reduced approximately 50 percent from the prechamber baseline, this was not accompanied by a large reduction in the average number of *Propionibacteria* (Table 15-3). Although the *Propionibacterium spp.* were isolated from fewer sites during the chamber run, the total numbers remained almost constant due to the continued isolation of *P.acnes* from all three crewmembers.

Analyses of data relating both to the kinds and numbers of bacteria present on skin surfaces suggest that chamber confinement had little, if any, effect on the indigenous aerobic skin flora. However, there was

a significant decrease in both the kinds and numbers of anaerobic skin bacteria during the period of chamber confinement. This decrease was due mainly to the almost complete disappearance of anaerobic cocci and significant reductions in two species of *Propionibacterium*. This may or may not be a reflection of changes occurring in the deep layers of the skin where anaerobic conditions, which favor the survival of these organisms, are maintained. It is entirely possible that the microbial burden is unchanged in the deeper layers of the skin and that the changes noted during the chamber run are only the result of accelerated inactivation of anaerobic bacteria due to the slightly elevated partial pressure of oxygen. Alternatively, it may be suggested that a reduction in whole-body washing resulted in changes in the skin surface environment which mediated towards lower skin surface burdens of viable anaerobic bacteria. Detailed data analyses reveal that decreases in anaerobic skin flora were not accompanied by increases in other genera or species of aerobic bacteria.

Table 15-3

Quantitative Values of Predominant Bacteria on Seven Skin Sites[a]

During the Prechamber, In-chamber and Postchamber Periods

Isolants From CDR, SPT, PLT	Prechamber (6)[b] C−77[c] thru C−0		In-chamber (4) C + 21 thru C + 56		Postchamber	
	Range[d]	Mean	Range	Mean	R + 14 No. Isolants	R + 42 No. Isolants
Corynebacterium spp.	9.5×5^e to 7.3×6	2.2×6	5.0×5 to 7.5×5	6.5×5	1.1×6 1.1×6	
Micrococcus spp.	8.7×4 to 7.2×5	3.6×5	1.5×5 to 3.0×5	2.2×5	8.9×4	
Staphylococcus epidermis	7.3×4 to 4.2×5	1.8×5	4.9×4 to 1.1×5	7.7×4	2.2×5	
Streptococcus spp.	1.0×2 to 4.8×3	2.0×3	1.0×2 to 4.2×2	2.4×2	2.0×2	
Mima spp. and Moraxella spp.	7.2×2 to 5.0×4	1.1×3	6.0×1 to 4.9×2	2.5×2	5.4×2	
Anaerobic cocci[f]	3.7×4 to 1.6×5	6.6×4	0 to 3.9×5	9.7×4	9.0×3	
Propionibacterium spp.	2.3×4 to 1.6×5	9.3×4	9.3×3 to 9.0×4	4.71×4	1.6×3	

[a]Neck, ear, axilla, hands, umbillicus, groin, toe web

[b]Number of times sampled

[c]Chamber minus 77 days through chamber close

[d]Range of total values from all crewmembers

[e]9.5×10^5 viable cells per cm^3 of diluent

[f]Peptostreptococcus and Peptococcus

Nasal and Oral Bacterial Flora Studies

Whereas *Staphylococcus epidermidis* quantitations remained very stable, the number of viable *Staphylococcus aureus* cells recovered increased during the chamber confinement period. The majority of *Staphylococcus aureus* isolations were made from throat-mouth gargle specimens. Analyses of the phage typing data reveal that there was no interchange of *S. aureus* between the CDR and SPT, with each crewmember carrying only his particular phage types on the skin, in the external nares, or in the throat and mouth.

Strains of *S. aureus* were isolated only twice from the PLT during the seventh and eighth weeks of chamber confinement. During the twelve-week prechamber period, *S. aureus* was recovered from the gargle, skin, and nasal area of the CDR a total of nine times. During the eight-week in-chamber period, the incidence of recovery increased to fourteen. Similar totals for the SPT during the prechamber and in-chamber periods were three and eight, respectively.

At the beginning of the chamber study, the number of viable corynebacteria recovered from the nasal samples decreased. Much of this loss was replaced with an increased number of viable *S. aureus* cells up to the third week in-chamber. After that, *S. aureus* maintained a high incidence and the corynebacteria regained their former high quantitation until the end of the chamber confinement.

As with the nasal samples, aerobic bacteria recovered from the gargle samples demonstrated very little variation. *Streptococcus mitis* generally accounted for the high quantitations. Other species which were also present in high numbers were *Streptococcus salivarius, Haemophilus parainfluenzae*, and *Neisseria perflava*. *S. salivarius*, *S. mitis*, *Staphylococcus epidermidis*, *N. perflava*, and *H. parainfluenzae* were always recovered from every sample period. No significant change could be detected in the incidence of these species resulting from test conditions. *Klebsiella pneumoniae* was present in prechamber gargles but was not recovered from in-chamber samples. *Pseudomonas maltophalia* was recovered from one of the last in-chamber samples. Beta-hemolytic streptococci and *Haemophilus influenzae* were nearly always recovered. The quantitation of *Escherichia coli*, which was recovered from most sample periods, remained very constant.

The above data indicate that whereas the astronauts were burdened with several species of medically important micro-organisms in the nasal and oral cavity, no alterations could be detected in their microbial flora which could be directly related to flight food or chamber conditions.

The most commonly isolated anaerobic bacteria were members of the genera *Propionobacterium* which decreased through the seventh week in-chamber. This decrease was not matched by an increase in other anaerobic bacteria but does coincide with the increase in aerobic bacterial quantitation noted earlier.

Unlike the nasal samples, the number of viable anaerobic bacteria recovered from the gargle specimens remained quite constant and no significant alterations in individual species were detected.

Crew Mycological Studies

The total number of yeast and of filamentous fungi recoveries prior to entry into the chamber was quite variable. A similar variability was demonstrated within the chamber. This variability underscores the normal, ephemeral relationship between integumentary fungi and the healthy body. However, even with this wide variability, the incidence of prechamber recovery of filamentous fungi values could be demonstrated to be significantly different ($p < 0.005$) from the in-chamber values, as calculated by the Wilcoxon Rank-Sum Test. This analysis demonstrated a significant in-chamber decrease in the fungal load of crewmembers and a similar, but not statistically significant, depression of the total number of yeasts.

The filamentous fungi data show that of the 52 species recovered during the sampling period, 35 were isolated only once and 42 were isolated no more than twice. The PLT contributed 59.2 percent of the

recovered fungi, whereas the CDR contributed 22.4 percent and the SPT only 18.4 percent. Twenty-eight percent of all reported isolates were recovered from nasal swabs, with about half that many being recovered from the fecal samples, the gargles, and the toe swabs. Twenty-eight percent of all recovered samples were obtained from the remaining seven sites combined.

Aureobasidium pullulans and *Cladosporium cladospoioides* were present in high numbers before chamber closure and remained in the population under chamber conditions. This is the type of pattern expected of species that are not merely transients.

On the other hand, *Epicoccum nigrum, Penicillium corymbiferum, Pithomyces astro-olivaceus,* and *Wallemia ichthyophage* also were present in high numbers before chamber closure, but were entirely absent from specimens collected within the chamber. These species are, therefore, undoubtedly transients.

As with the filamentous fungi, a large portion (72 percent) of the yeast species isolated were transients. Interestingly, the yeasts *Pityrosporum ovale* and *Torulopsis famata,* isolated in large numbers before chamber closure, could not be recovered from the samples collected in the chamber. *Candida albicans* and *C. parapsilosis,* however, were recoverable from within the chamber. These results suggest that the probability of mycotic disturbance may actually be increased in the chamber. The loss of fungi from the body surface can upset the microbial balance of these areas and provide a more favorable environment to those species which remain. For example, the well-known pathogenic yeast, *Candida albicans,* remained throughout the chamber study. In addition, different species of *Candida* began to appear near the middle of the chamber period, signaling a buildup of these species. Likewise, the odious fungus *Aureobasidium pullulans* remained through the end of the chamber study. In fact, *Candida* and *Aureobasidium pullulans* comprised 88 percent of the recovered fungal flora by the end of the chamber study. The number of fungi recovered returned to normal upon removal of the crewmembers from the chamber.

Crew Virological and Mycoplasma Studies

There was no evidence of viral growth in any of the host systems inoculated with specimens obtained from the SMEAT crew before, during, or after chamber exposure. Since the crew remained healthy throughout the duration of the study, these results were expected.

There was a possibility that the environment of SMEAT might induce the appearance of viruses that are not isolated normally, but this did not occur. *Mycoplasma orale 1* was repeatedly isolated from the throats of the SPT and PLT before, during, and after chamber exposure. There were no mycoplasma isolations from urine. The CDR did not carry *M. orale 1* before chamber exposure and was not cross-infected during chamber residence.

Environmental Microbiological Studies

The predominate organisms found on the stainless steel strips located in eight different areas of the chamber are shown in Table 15-4. The total number of organisms recovered did not vary materially from week to week. However, variance did occur in the types of organisms isolated. For example, species of *Bacillus* were in high numbers after the first week, decreased during the next two weeks, and were not recovered again for three weeks. A possible explanation for this is that after closure of the chamber, all items being passed into the chamber through the transfer lock were decontaminated or sterilized. More use was made of the man lock for equipment transfers during the last two weeks. Contamination control for items being passed into the chamber in this manner was more difficult.

It is evident from the data that under the conditions of SMEAT the environmental microbiological burden rapidly became a duplication of the skin and oral flora of the personnel in the environment. This could become significant in transmittal of infectious organisms between crewmembers as well as between crews.

The recovery of yeast and fungi in relatively large numbers throughout the chamber over the eight

Table 15-4

Quantitative Values of Predominant Bacteria Recovered From Stainless Steel Strips

Julian Date	215	222	229	236	243	250	257	264
Bacillus spp.	$8 \times 10^{4*}$	1×10^1	2×10^1	0	0	0	6×10^2	2×10^3
Corynebacterium spp.	2×10^3	2×10^4	3×10^4	3×10^3	3×10^4	9×10^3	1×10^3	9×10^3
Micrococcus spp.	5×10^2	2×10^4	1×10^5	4×10^3	5×10^4	5×10^4	9×10^3	2×10^4
Mima	0	0	0	8×10^2	0	0	0	0
Staphylococcus epidermidis	8×10^3	7×10^3	1×10^4	3×10^3	1×10^4	1×10^4	3×10^3	3×10^4
Staphylococcus aureus	2×10^2	0	8×10^2	8×10^2	4×10^3	0	0	2×10^2
Streptococcus spp.	5×10^1	8×10^2	1×10^4	0	0	0	0	0
Propionebacterium spp.	8×10^2	0	2×10^3	1×10^3	0	0	0	0
Yeast and fungi	2×10^2	4×10^2	2×10^3	9×10^2	5×10^3	7×10^0	3×10^0	2×10^2
Totals	9×10^4	5×10^4	2×10^5	1×10^4	1×10^5	7×10^4	1×10^4	6×10^4

*Sum of 5 strips expressed as organisms per square inch.

weeks could have significant implications. Yeasts such as Candida and Rhodotorula, both of which were recovered from the environment, are recognized as "opportunistic" micro-organisms with significant pathogenic potential. Filamentous fungi like Aspergillus and Penicillium can become medically significant and also may degrade hardware. In a reduced gravity environment where aerosol burdens are expected to be quite high, large quantities of fungal spores could be inhaled and cause infectious and/or allergic reactions in the crewmembers.

Numerous yeasts and fungi were recovered from contingency samples taken around the food chiller. This was an area of high humidity and visible growth was observed on the chamber wall. These types of organisms can be expected to occur in Skylab and to proliferate if areas of high humidity (65 percent or above) are maintained.

The exhalation hose of the metabolic analyzer was examined for microbial contamination during and at the end of the chamber study. Two types of yeast, Candida laurentii and Rhodotorula rubra, were recovered each time. In addition, another yeast Candida albicans and two filamentous fungi,

Penicillium funiculosium and Botrytis cinerea were recovered in the last sample. The inside of the hose is an area of high humidity and gives ideal conditions for growth of yeasts and fungi.

Immediately after the crew left the chamber, 30 chamber areas were sampled using the swab-rinse technique. The results show direct correlation with the skin flora of the SMEAT crewmembers. Yeast or fungi were recovered from 17 of the 30 locations, with eight locations having more than one type.

Levels of organisms obtained from the swabs were lower than those obtained on the stainless steel strips. A possible explanation is that the strips were not disturbed during the eight weeks except for times of sampling, while the majority of the swabbed areas had undergone some form of housekeeping, vacuuming or washing, during the chamber test.

The Anderson Air Sampler, which was run for a ten-minute period each week at a rate of 0.028 m³/min indicated a microbial burden in the chamber atmosphere of eight to ten organisms, predominantly micrococci and staphylococci per 0.028 m³. These counts were quite high when

compared to normal environments where two to four organisms per cubic meter are expected.

Fecal Anaerobic Flora Studies

The cultural procedure allowed recovery of an average of 93 percent of the direct microscopic clump count. This is one-to-two orders of magnitude higher than has been generally reported in the literature with previous techniques. One hundred and forty (140) distinct species or subspecies have been detected in the isolates that have been examined. Although a complete analysis of the data is not yet available, it appears that there was no major change in the total number of organisms present as a result of diet or environment. The data, however, do suggest that there may be some simplification of the flora on the astronaut diet. It is quite possible that this diet was of less varied composition than the uncontrolled normal diet. If such is the case, the simplification of the flora would further confirm previous observations that the relative proportion of major species in the flora is highly sensitive to individual dietary components.

Individual differences in fecal flora persisted during SMEAT. *B. fragilis* ss. *thetaiotaomicron* and *B. fragilis* ss. *vulgatus* were the only species seen in all individuals in each sample examined. These organisms are sometimes associated with soft tissue infections, and they convert bile salts to possibly undesirable intermediate products. *Bacteroides fragilis* ss. *fragilis*, the subspecies of *B. fragilis* most often isolated from infections, was found only twice. The relatively low incidence of this subspecies in fecal flora is commensurate with data from other individuals.

The proportion of *Bacteroides fragilis* ss. *thetaiotaomicron* was increased over the normal level in all three crewmembers after four weeks in the chamber. Chromatographic analyses of fecal specimens, however, showed normal levels of fecal steroids. The significance of the increase in *B. fragilis* ss *thetaiotaomicron* is unknown at present. The levels of the other species obtained thus far were within the ranges observed among "normal" North Americans and Japanese Hawaiians.

The same percentage of resistant strains of *B. fragilis* was maintained for each crewman throughout

the test, which suggests that under these conditions, individuals maintain their own personal flora type. It also indicates that cross-contamination of intestinal flora was not significant.

It appears that the composition of the fecal flora is strongly controlled by the physiology of the host individual, but that the environment and diet tested do affect it.

Conclusions

States of microbial imbalance as a result of the SMEAT chamber confinement occurred, for the most part, only in those genera and species of bacteria, yeast, and fungi which are classified as transients and are not part of the true indigenous flora of the crewmembers.

Inasmuch as no crew illness events occurred and only subtle changes in the indigenous flora were noted, it appears that confinement of 56 days in a Skylab simulated environment does not mediate toward shifts in bacterial populations which have obvious clinical significance.

The lack of buildup of skin flora, particularly gram negative species and enteric bacteria, suggests that the personal hygiene regimens are adequate.

Careful analyses of preflight Skylab data, however, should be performed in order to provide information for therapeutic decisions in case of illness.

It is probable that latent viruses were present among the crewmembers even though this was not demonstrated. The SMEAT environment did not result in the activation of such latent agents. This would suggest that viral infections may be of minimal consequence provided crewmembers are not actually in the incubation phase of a viral disease prior to launch.

The fact that bacteria, yeasts, and fungi existed in high numbers, relative to a normal environment, both on surfaces and in the air, is highly significant. In the zero g situation, the majority of these organisms may exist for long periods as aerosolized particles, making

the atmospheric particle count several orders of magnitude higher than normal. Continued long term exposure and inhalation of the organisms could result in clinical manifestations ranging in severity from frank pneumonia to allergic responses.

The results of SMEAT also clearly demonstrate that a variety of filamentous fungi will survive in the environment. Condensate formation resulting in local areas of high relative humidity will almost certainly create local areas of growth. Organisms from thes areas could then be disseminated throughout Skylab causing degradation of a wide variety of materials.

Control of microbial growth during Skylab depends primarily upon the faithful execution of housekeeping tasks. The results of SMEAT demonstrate that the performance of these tasks with rigor is fully justified.

Comprehensive measurements of the fecal flora of the SMEAT crewmembers on their normal diet, on the Skylab diet, in the test chamber, and following the chamber trial give preliminary indications that the flora was partially simplified as a result of the astronaut diet. Throughout the test period, the individuals maintained their own distinct fecal floras without apparent cross-contamination. In general, the bacterial fecal flora of each person responded independent to the variables tested. However, there was a uniform increase in the levels of *B. fragilis* ss. *thetaiotaomicron* in the flora of the test subjects during the chamber run. The levels of *B. fragilis* ss. *thetaiotaomicron* increased above the values that we have seen in any of 25 other "normal" North Americans and Japanese Hawaiians. The significance of this change is not yet known.

CHAPTER 16

EFFECTS OF SMEAT ON THE ORAL HEALTH OF CREWMEN (DTO 71-2)

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To insure the unqualified success of extended space ventures, all possible health hazards, including dental health problems, must be eliminated. The oral cavity serves as a portal of entry for pathogenic agents, acts as a reservoir for infectious micro-organisms, and plays a prominent role in cross-contamination and disease transmission. Detectable changes in oral microflora usually precede the clinical manifestations of acute and chronic infectious oral diseases. Clinical examinations of the oral tissues can thus identify local and systemic impairments of either microbial or nonmicrobial origin. The objectives of the SMEAT oral health experiment were to compare the microbial population dynamics in the oral micro-environments of the crewmen before, during, and after the 56-day SMEAT trial, and to determine clinically the effects of space simulated environment on oral health, preexisting dental caries and periodontal disease.

Equipment and Procedures

Microbiological Assessments

Specimen Collection. Oral specimens were collected from all three crewmembers weekly or semiweekly during a period which began 25 days prechamber and ended 30 days postchamber. The prechamber and postchamber specimens were collected by the principal investigator, while the in-chamber specimens were collected by two of the crewmembers. All collections took place between 7 a.m. and 8 a.m. before oral hygiene procedures or breakfast.

The specimens included dental plaque, residual saliva (unstimulated saliva), crevicular fluid (exudate absorbed from the gingival sulcus area) and stimulated saliva. These parameters were selected because of their ultimate relation to the development of dental caries, periodontal disease, and alveolar bone loss.

Dental plaque was removed using a modification of the technique described by Jordon et al. (1968) Residual saliva was collected with a calibrated wire loop, and crevicular fluid was obtained by inserting a paper point into the gingival sulcus of an upper bicuspid according to the method of Brown et al. (1971). Each specimen was placed aseptically into a sterile tube containing 2 ml of 0.1 percent peptone and 0.85 percent NaCl. The peptone-saline solution served as both a transport and dilution medium.

To produce stimulated saliva, the crewmembers chewed rubber bands and expectorated into a sterile jar until a 5 ml indicator mark was reached. The time required for each crewman to collect this volume was recorded and used to calculate the saliva flow rate.

In-chamber specimens were received outside the chamber within 30 minutes after collection. All specimens were transported in cracked ice to the University of Texas Dental Science Institute for immediate processing which occurred about one hour after collection.

Specimen Processing. Serial ten-fold dilutions of each specimen were plated onto a variety of bacteriologic media (Rogosa et al., 1951; Rogosa et al., 1958; Omata & Disraely, 1956; Kraus & Gaston, 1956; Richardson & Jones, 1958; Shklair et al., 1962; McCarthy et al., 1965; Ritz, 1967; Gibbons & MacDonald, 1960; Socransky et al., 1963; Sonnenwirth, 1965; Finegold, et al., 1965) for the enumeration of up to seventeen microbial categories. Duplicate platings were incubated at 37°C either aerobically or anaerobically. The bacteriologic media, microbial categories and anaerobic procedures are shown in Figure 16-1.

Specific microbial types from selective and differential media were verified by subculture and by pertinent physiologic reactions when necessary.

In addition to the microbial assessments, stimulated saliva was used to determine total protein, secretory IgA and lysozyme. Salivary protein determinations were made by the Lowry procedure (Lowry et al., 1951). Secretory IgA was assayed by electroimmunodiffusion (Merrill et al., 1967) where the samples are electrophoresed through a medium containing monospecific antisera. Plates were precoated with 0.1 percent agarose in 0.05 percent glycerol and layered with buffered agarose containing antisera. Wells were filled with standards or saliva. Samples were electrophoresed until the point of equivalence of the highest standard was attained. The plates were then processed for staining and the migration distances were measured. Values beyond the standard range required dilution. A plot of log concentration versus log migration distance yielded a linear curve for quantification (Lopez et al., 1969). Lysozyme values were determined by radial quantitative diffusion using heat-killed *Micrococcus lysodeikticus* cells as substrate according to the procedures of Osserman and Lawlor (1966). Plates were layered with a cell suspension in buffered

molten agarose. Wells were cut and filled with standards or saliva. Diffusion was allowed to proceed overnight. Values were determined from a plot of log concentration versus diameter of lysed zone.

The microbiologic enumeration and immunologic data were recorded for appropriate statistical analysis. Both a one-way and a two-way unbalanced analysis of variance were used for multiple comparisons of individual, paired and grouped data (Scheffé, 1959). Primary comparisons were made among four segments of collective data — the prechamber data, the data for the first half of the chamber confinement, the data for the second half of the chamber confinement, and the postchamber data.

Clinical Examinations. Oral examinations of each crewmember were made prior to SMEAT entry and immediately following chamber confinement. The examinations were designed to determine changes in the amount of plaque and calculus that formed on the teeth, gingival response to the SMEAT confinement, and teeth, bone and soft tissue changes resulting from the simulated space environment. Plaque, calculus, and inflammation indices were derived from the findings.

A plaque score for each astronaut was obtained by the use of disclosing wafers which stained the plaque adhering to the tooth surfaces. Calculus scores for each crewmember were obtained by dividing the number of tooth surfaces that had calculus by the number of teeth. The inflammation index was scored according to the method of Loe and Silnes (1963) which graded the gingivae surrounding each tooth.

Dental radiographs and dental casts of each crewmember were made prior to chamber confinement to provide baseline records for subsequent comparisons.

Results

Comparisons of mean counts of total anaerobes, bacteroides, fusobacteria, and veillonella from stimulated saliva and dental plaque revealed no obvious chamber-associated changes. Except for mycoplasma, individual and group fluctuations of

Dental Plaque	Stimulated Saliva	Residual Saliva	Gingival Sulcus Area
Pooled scrapings from teeth to fill a calibrated plastic cup	Collected on volume-time basis by means of chewing rubber bands	Collected with calibrated wire loops from beneath tongue	Collected with endodontic paper points from an upper bicuspid

Plating Media and Microbial Categories Enumerated (Total and Relative Counts of Predominant Isolates)		Anaerobic Procedures
Total Anaerobes	Heart Infusion Agar with 5% defibrinated horse blood	95% N_2 – 5% CO_2 displacement jars containing copper plated steel wool
Total Aerobes Neisseria	5% defibrinated horse blood	N.A.
Total Streptococci sanguis salivarius mutans ML types mitis and misc. species	Mitis Salivarius Agar	95% N_2 – 5% CO_2 displacement

Plating Media and Microbial Categories Enumerated		Anaerobic Procedures
Total Anaerobes	Heart Infusion Agar with 5% defibrinated horse blood	95% N_2 – 5% CO_2 displacement jars containing copper plated steel wool
Total Aerobes Neisseria		N.A.
Total Streptococci sanguis salivarius mutans ML types mitis and misc. species	Mitis Salivarius Agar	95% N_2 – 5% CO_2 displacement
Salt Tolerant Staphylococci	Staphylococcus 110 Agar	N.A.
Lactobacilli	Rogosa SL Agar	N.A.
Yeast	Sabouraud-Dextrose Agar	N.A.
Enterics	Desoxycholate Agar	N.A.
Fusobacteria	Trypticase Soy Agar with Vancomycin and Crystal Violet	Gaspak technique
Veillonella	Veillonella Agar with Tween 80 and Vancomycin	95% N_2 – 5% CO_2 displacement jars containing copper plated steel wool
Bacteroides	Heart Infusion Agar with laked horse blood, menadione, NaHCO₃, Kanamycin and Vancomycin	95% H_2 – 5% CO_2 in brewer jars. Duplicate plates: 95% H_2 – 5% CO_2 displacement plus Gaspak catalyst
Mycoplasma and L-forms	PPLO Agar with yeast autolysate, horse serum, thallium acetate and penicillin	N.A.

Figure 16-1. Chart for sampling and enumerating cultivable oral micro-organisms.

in-chamber counts were of magnitudes comparable to those observed before and after chamber confinement.

Mycoplasma counts from both saliva and plaque appeared to increase slightly with chamber confinement. An analysis of variance revealed that the mycoplasma increases in the saliva of two of the crewmembers were statistically significant.

Counts of total aerobes, neisseria, staphylococci, lactobacilli, and candida from stimulated saliva were relatively constant throughout the study. Conversely, counts of enteric organisms, which were considered above normal prior to chamber entry, declined to low or undetectable levels during chamber confinement and increased toward prechamber values during the postchamber period.

Counts of total aerobes and neisseria in dental plaque followed a pattern similar to those in stimulated saliva, but the counts of lactobacilli and candida were extremely variable. Staphylococci and enteric organisms were observed infrequently and only at very low levels.

Total anaerobes, total aerobes and neisseria counts from residual saliva and crevicular fluid showed little if any change throughout the study. Because of the small volumes of these samples, only the most prominent microflora were assessed.

Except for *Streptococcus mutans*, the change in the streptococcal counts were within the expected range of variation throughout the test period. *S. mutans*, a cariogenic micro-organism which is primarily a resident of dental plaque, was found in unusually high numbers in stimulated saliva before, during, and after chamber confinement.

Counts of *S. mutans* attained a high level in plaque approximately one week before chamber entry, or two weeks after initiation of the space diet, and remained at high levels throughout sampling. As with stimulated saliva, *S. mutans* counts in residual saliva and crevicular fluid were too variable to be meaningful.

Mean saliva flow rates decreased while saliva protein concentrations appeared to increase slightly during chamber confinement. The decrease in saliva flow rates was statistically significant, but the increase in saliva protein concentrations was not.

Salivary lysozyme remained rather constant except for two periods where the mean values were higher than normal. The second elevation, found primarily in two of the crewmembers, was found to be statistically significant.

Mean secretory IgA levels demonstrated a persistent increase with chamber isolation. Two astronauts primarily accounted for the statistically significant increases. A 10X concentration of their respective saliva specimens was used for slide agglutination tests against *S. mutans* and related streptococcal isolates. These tests were negative suggesting that the secretory IgA response may have been caused by either the oral increases of mycoplasma or by a virus or other microbial agent in the chamber environment.

Comparison of clinical evaluations before and after chamber isolation showed slight to moderate changes in the oral health indices. A paired t-test of the data, however, revealed no statistically significant differences.

Discussion

The increased counts of mycoplasma were unexplained and their impact on oral health is presently unknown. Since *S. mutans* reached a prominence in dental plaque two weeks after space diet initiation and one week before chamber entry, the increase was assumed to be diet related. The impact of the emergence of this cariogenic organism on subsequent dental caries awaits clinical confirmation.

The decreased number of enteric bacilli was attributed to conscientious personal hygiene efforts and the decreased saliva flow rates were ascribed to possible stress or other factors affecting normal physiology.

Secretory IgA and salivary lysozyme elevations were considered to be responses to an endogenous or environmental microbial agent. The increased oral health scores were indicative of insufficient oral hygiene practices during chamber confinement.

Conclusions

The oral health status of three astronauts was monitored before, during and after SMEAT, a 56-day simulation of the Skylab missions. Laboratory and clinical parameters which are considered to be ultimately related to dental impairments were evaluated. The most notable changes were observed in increased counts of mycoplasma and *S. mutans*, decreased counts of enteric bacilli, decreased saliva flow rates, increased secretory IgA and salivary lysozyme levels, and increased clinical scores of dental plaque, calculus and inflammation.

The relevance of both the laboratory and clinical findings to dietary change, chamber confinement or the future development of oral disease may be confirmed by subsequent postchamber evaluations.

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CHAPTER 17

HABITABILITY/CREW QUARTERS — EXPERIMENT M487

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A spacecraft represents a unique and, in many respects, a different environment in which to live for any extended period of time. For a long term mission, considerable attention must be given to the habitability characteristics of the vehicle. The difficulties and discomforts endured during Gemini and Apollo flights must be eliminated before interplanetary flight can be undertaken. However, habitability data collected for earthbound stations may not be adequate as a basis for the design of future space vehicles. For example, crewmen have noted that the Apollo Command Module, which is relatively cramped during 1 g tests, assumes a more spacious character in zero gravity when movements can be made freely in three dimensions.

The need for habitability data relating specifically to space vehicles is well recognized and plans have been made to use the Skylab Program to provide a fund of meaningful information on a number of habitability variables. Skylab Experiment M487, Habitability/Crew Quarters, is designed to provide an operational evaluation of the Skylab habitat by gathering data regarding the manner in which crewmen carry out their daily living and working routines during the missions.

The success of the Skylab habitability experiment will depend, in large measure, on the adequacy of the data collection instruments and the manner in which they are used. For this reason, the M487 experiment was included in the SMEAT Program. To gain realistic experience in handling the M487 protocols, the four M487 objectives to be met in SMEAT were:

1. To obtain use-efficiency and use-time information for the environmental measuring instruments.

2. To obtain crew evaluations of the various subjective data formats and the times involved in their use.

3. To evaluate the communications disciplines associated with complete dependence upon voice recorded data.

4. To evaluate flight scheduling and timeline requirements for the experiment.

The evaluation of the SMEAT chamber as a habitat was not an objective of this experiment; however, useful habitability data were collected during the test that are applicable to the Skylab Program.

In keeping with the intent of M487 in SMEAT, only those results which reflect directly on the conduct of the flight experiment are included in this report. SMEAT habitability assessment data, such as the environmental measurements obtained with the M487 instruments, are not presented or discussed.

Test Hardware

The hardware employed by M487 can be categorized into two major groups: environmental measuring instruments and subjective evaluation formats. The instruments are further classified as experiment equipment and supporting equipment. Three different subjective formats were used during SMEAT: a rating form, a debriefing questionnaire, and an environmental evaluation scale.

Instruments

The M487 hardware has become something of a test case in an attempt to procure "off-the-shelf" items, conduct a minimum qualification-test program,

and certify flight readiness. The Development Center
(Marshall Space Flight Center) for the M487 experi-
ment chose to conduct this type of procurement
since the hardware requirement for the experiment
was quite simple and straightforward: to provide a
small assortment of measuring devices useful in
obtaining quantitative data to supplement the crew-
men's subjective impressions of various habitability
related parameters.

Experiment Equipment. The experiment equip-
ment includes:

1. Velometer
2. Sound Level Meter
3. Frequency Analyzer
4. Thermometers (for ambient atmosphere)
5. Thermometers (for surface temperatures)
6. Force Gauge
7. Tape Measure
8. Equipment Container

Supporting Equipment. The instruments con-
tained within the Skylab onboard inventory to be
jointly used by M487 include:

1. CO_2/Dewpoint Monitor
2. One Degree Automatic Spotmeter
3. Photographic Equipment and Accessories

An equipment container was developed to house
the M487 peculiar equipment. This unit, which
resembles the Skylab tool kit, is a compact self-
contained module with three slide-out drawers. The
instruments are shock mounted in cutouts recessed
into closed cell Mozite inserts within each drawer.
The container is designed to fit into a standard
Skylab stowage locker, as depicted in Figure 17-1. In
the SMEAT chamber, the M487 equipment container
was located in stowage locker 703 within the
wardroom.

The experiment equipment used in the SMEAT
Program was the qualification-test hardware. This
hardware was of flight configuration except for two
late changes which were identified at the M487
Critical Design Review held on June 1, 1972. The
first was a redesigned drawer latch (welded instead of
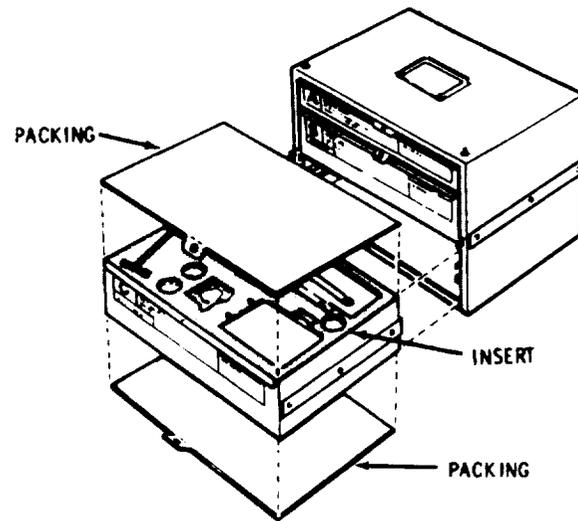
Figure 17-1. M487 Instrument Kit.

bonded) which will be more reliable under multiple
uses, and the second was the incorporation of finger
cutouts in the Mozite to facilitate instrument removal
and replacement.

Subjective Formats

Although not hardware, the subjective formats
are included in this section because a major effort
went into their development and they do represent
separate stowage items requiring unique timeline
scheduling for their use. All the various subjective
formats were flight configured and contained many
zero g related items that were obviously not ratable
by the SMEAT crew. These items were not used
during SMEAT.

Rating Forms. The Subjective Rating Form used
by the SMEAT crew was a "cue card" containing
generalized compartment design information on one
side and equipment adequacy information on the
other side. Figure 17-2 shows the form used for
general compartment evaluations. Items on each side
of the card were alphanumerically coded to facilitate
inflight voice recording of the evaluation data. In
preparing the "cue card," a section was inadvertently
omitted which called for evaluating certain items of
equipment in terms of their frequency of use rather
than in terms of an absolute assessment of their

STATE NAME & DATE

STATE CODE, THEN NUMERICAL RATING FOR EACH ITEM TO BE RATED (either by row or column).

EXPLANATORY COMMENTS ENCOURAGED, ESPECIALLY FOR RATINGS OF 3, 4, OR 5.

SUBJECTIVE RATING SCALE
DEFINITION

RATING

1   EXCELLENT: Improvements matter of individual crewman preference.

2   VERY GOOD: Minor improvements possible, but not really necessary.

3   ADEQUATE: Some shortcomings found and a few improvements would be desirable.

4   POOR: Shortcomings found and improvements are necessary.

5   UNACCEPTABLE: Gross shortcomings found and improvements are mandatory.

PARAMETER TO BE RATED	EXPMT	FWD/DOME*	AIRLOCK	MDA/STS	WARDROOM	HEAD	SLEEP
Compartment general arrangement and orientation	EA	FA	AA	MA	WA	HA	SA
Volume of compartment	EB	FB	AB	MB	WB	HB	SB
Ceiling/floor proximity	EC	///	///	///	WC	HC	SC
Compt ingress/egress provisions	ED	FD	AD	MD	WD	HD	SD
Trash collections provisions	EE	FE	AE	ME	WE	HE	SE
Stowage volume and access	EF	FF	AF	MF	WF	HF	SF
Temporary equipment restraints	EG	FG	AG	MG	WG	HG	SG
Personnel mobility aids	EH	FH	AH	MH	WH	HH	SH
Personnel restraint devices	EI	FI	AI	MI	///	///	///

*Use FWD/DOME column for 2nd Deck evaluation.

Figure 17-2. Subjective rating for general compartment accommodations.

design adequacy. This form was included in the checklist and was used concurrently with the rating scale. Figure 17-3 shows the use frequency rating form.

Debriefing Questionnaires. In order to stimulate group discussion among crewmen concerning various aspects of Skylab habitability, a set of questions was prepared for use as part of the regular off-duty day debriefing. The questions were designed to gather a more comprehensive assessment of certain aspects of habitability which were not readily amenable to the rating scale form of evaluation. The rating scales were designed to elicit individual evaluations, while the

questions were intended to create a discussion atmosphere which would allow a free exchange of ideas between the crewmen and thus possibly prompt a more detailed evaluation of design inadequacies and potential corrective actions. A sample of the questions used is shown in Table 17-1.

Environmental Scales. The environmental scales were designed for use in conjunction with the instrument surveys of the environment. These scales were intended to gather the crewmen's subjective evaluations of the environment for correlation with the quantitative measurements obtained from the instruments. Figure 17-4 shows the environmental scales.

Table 17 1

Inflight Debriefing Questions
Used for Day-9 in SMEAT Mission

1. What particular aspects of the O/A seem well designed
   and arranged for living and working in zero-g?

   What aspects are deficient, and how?

2. Which restraint device offered the most assistance in per-
   forming tasks; which the least? What recommendations
   do you have for improvements?

3. What visibility problems have been created by shadowing
   within the O/A? What areas, or activities, are most
   affected? How practical is portable supplemental
   lighting?

4. How effective is non-equipment-assisted verbal communi-
   cation throughout the O/A?

5. How satisfactory are the food management and dining
   accommodations? How well does the food adhere to the
   utensils when eating? Would a closer tray-to-mouth
   proximity be desirable?

6. In what ways has zero-g been helpful; in what ways a
   hinderance?

Test Methods

Since the prime purpose for incorporating M487
into the SMEAT Program was to gain experience with
all aspects of the experiment protocol, a dedicated
effort was made to follow the anticipated Skylab
flight procedures and schedules.

Instruments

The M487 experiment and supporting equipment
was scheduled for periodic use throughout the
SMEAT Program, with each crewman having at least
two opportunities to operate each instrument. The
instruments are categorized into scheduled use items
and discretionary use items for inflight application,
but all instruments except the tape measure were
scheduled for use during the SMEAT Program.
Scheduled inflight items are the velometer, the sound
level meter and frequency analyzer, and the tem-
perature measuring devices. Discretionary inflight use
items are the force gauge, the spotmeter, and the tape
measure. Environmental surveys were scheduled on
SMEAT mission days 10, 23, 38, and 55, and
required the use of each scheduled instrument in each

compartment within the SMEAT chamber. The in-
struments scheduled for use on these days were
divided among the crewmen in order to share the
workload and to gain opportunities for use ex-
perience. The data were voice recorded in order to
avoid as much onboard logging as possible, although
the crew found it more convenient to log the
instrument measurements as they were made and
then read them into the recorder all at one time.

Subjective Formats

The use of the subjective formats was scheduled
into the timeline in accordance with anticipated
Skylab flight use schedules.

Rating Forms. The initial SMEAT timeline called
for five uses per man of the rating form. Three
objectives defined this schedule: first, to determine
reliably exactly how much time was required to use
the forms; second, to determine whether or not the
form would become more of an irritant than a data
source because of repeated use; and third, to identify
any attitude shifts toward the items being rated as a
function of their prolonged use. Supplementing the
assigned ratings with explanatory comments was
considered essential for proper interpretation of the
ratings, especially for those items rated at midscale or
lower.

Debriefing Questionnaires. The debriefing ques-
tionnaires were designed specifically for the three
off-duty day debriefings scheduled for the SL-2
mission and were used intact for SMEAT. A fourth
set of questions was also developed which addressed
the experimental protocol rather than habitability
assessment per se. The questionnaire uses were
scheduled for mission days 11, 19, 32, and 47.

Environmental Scales. The environmental scales
were included as a page in the M487 checklist which
contained the instrument use procedures. The time-
line called for the use of this form by each crewman
during each scheduled environmental measurement
day.

Ad Hoc Comments. During Skylab flight, Experi-
ment M487 will be limited in its ability to make the
timeline impositions required to fully document crew
responses to all aspects of habitability. Those items

INSTRUCTIONS:

USING THE FOLLOWING 5- POINT SCALE, VOICE RECORD YOUR USE FREQUENCY OF

THE ITEMS LISTED BELOW.

RATING	USE FREQUENCY
1 (very often)	Daily - or every available opportunity
2 (often)	Every day or two
3 (average)	About once a week
4 (seldom)	Infrequently - once every two or three weeks
5 (never)	Not at all - (define whether item is ill designed and difficult to use or found to be unnecessary)

EXPLANATORY COMMENTS ARE ENCOURAGED.

CLOTHING ITEMS   OFF-DUTY ITEMS

A. Jacket   M. Tape player
B. IV boots   N. Headset
C. IV gloves   O. Microphone
D. Bump hat   P. Playing cards   State the
                                        Q. Books - (pleasure)   letter
SLEEP COMPARTMENT ITEMS   R. Hand exerciser   designator
                                        S. Hand balls   of the item
E. Pillow   T. Darts & board   and your
F. Blankets   U. Exer-gym   rating of
G. Light baffle   V. Binoculars   that item.
H. Privacy curtain   W. Windows (W/R - STS)
                                       *X. Chess game
SUPPORT ITEMS   *Y. Course material
                                       *Z. Manual dexterity kit
I. Penlights
J. Scissors
K. Tool caddy
L. Portable fan

NOTE - ASTERISKED ITEMS (*) APPLY ONLY TO SMEAT AND WILL NOT
       APPEAR ON THE FLIGHT FORM.

Figure 17-3. Evaluation form for equipment use frequency.

deemed most important for evaluating Skylab habitability have been included in the various M487 data sources specifically developed to support the experiment. However, it is anticipated that additional data will be available during the missions in the form of ad hoc comments offered by the crew as they conduct their routine communications between the spacecraft and mission control. In order to assess the quantity and quality of data available through this means, the daily SMEAT reports were reviewed and random samples were taken of routine communications, which will be transcribed for Skylab, but were not for the SMEAT Program.

Results and Discussion

The results and discussion presented in this section are limited to only those data obtained during the SMEAT Program which impact the Skylab M487 protocol. Therefore, only representative examples of data actually gathered are presented. Complete transcripts of the debriefing questionnaires and the environmental measurement data are available through the M487 Principal Investigator.

Instruments

The two most significant outputs of the instrument uses were:

INSTRUCTIONS:

VOICE RECORD YOUR IMPRESSIONS OF THE FOLLOWING ENVIRONMENTAL PARAMETERS IN
EACH COMPARTMENT THROUGHOUT THE ORBITAL ASSEMBLY. IDENTIFY YOURSELF, THE
COMPARTMENT, THE DATE, AND THE TIME. ALSO IDENTIFY ANY ITEMS ON WHICH YOU
CHOOSE TO MAKE SURFACE TEMPERATURE MEASUREMENTS. EXPLANATORY COMMENTS
ARE ENCOURAGED.

PARAMETER \ RATING	A	B	C	D	E
1. ILLUMINATION	EXCESSIVELY BRIGHT	BRIGHT	ADEQUATE	DIM	EXCESSIVELY DIM
2. AIR TEMPERATURE	UNCOMFORTABLY HOT	COMFORTABLY WARM	COMFORTABLE, NEITHER WARM NOR COOL	COMFORTABLY COOL	UNCOMFORTABLY COLD
3. HUMIDITY	UNCOMFORTABLY DRY	DRY	COMFORTABLE, NEITHER DRY NOR DAMP	DAMP	UNCOMFORTABLY DAMP
4. AIR FLOW	UNCOMFORTABLY DRAFTY	DRAFTY	COMFORTABLE, NEITHER DRAFTY NOR STILL	STILL	UNCOMFORTABLY STILL
5. NOISE	ANNOYING CONTINUOUS NOISE	ACCEPTABLE CONTINUOUS NOISE	NO DISTURBANCE	ACCEPTABLE INTERMITTENT NOISE	ANNOYING INTERMITTENT NOISE

READ THE NUMBER OF THE PARAMETER FOLLOWED BY THE LETTER RATING
YOU ASSESS FOR THAT PARAMETER.

Figure 17-4 Evaluation form for environmental features.

1. The determination of actual time required to conduct a survey.

2. The verification of operating procedures and reporting formats.

To use any of the units included in the scheduled surveys required about 30 minutes of a crewman's time from instrument unstowage to stowage and voice recording of the data. The one exception was the sound level meter/frequency analyzer combination, which took approximately 45 minutes because of the requirement to step successively through eleven different frequency bands rather than making a single reading per compartment (as was required with the other instruments). The initial use of the sound meter and the velometer required an additional fifteen minutes for battery loading and instrument assembly. Skylab flight timelines for instrument uses will be scheduled for no less than 45 minutes.

The SMEAT crewmen found the M487 instrument surveys to be more efficient if the use times during the day were staggered. This eliminated the potential congestion of two crewmen concurrently taking different measurements in the same area. It also reduced the use constraints on voice recording time by spreading out the data retrieval cycle. The crewmen suggested that instrument use efficiency would be enhanced if they were allowed to specialize in the use of one or two instruments rather than requiring all to be proficient with the entire inventory. Both suggestions will be incorporated in the plans for flight use of the M487 experiment and supporting equipment.

One of the more interesting results of the M487 instruments' presence in the chamber was their discretionary use to supplement subjective impressions and to quantify data items for interested

Table 17-2

Subjective Rating Data for Generalized Compartment Design

Compartment	Day	Crewman	Design Feature/Accommodation								
			A	B	C	D	E	F	G	H	I
EXPT	6	CDR	3	3	3	3	3	3	3	3	3
	4	PLT	3	3	2	2	4	3	2		
	8	SPT	3	3	3	3	3.5	3	4		
WARD-ROOM	6	C	3	4	3	2	4	3	3	3	
	4	P	4	3	2	2	3.5	3			
	8	S	3.6	3.5	3.5	3.5	3.5	3			
WMC	6	C	3	4	3	2	3	3	3	3	
	4	P	3	3	2	2	2				
	8	S	4	4	3	3.5	3.5	4			
SLEEP	6	C	3	3	3	2	3	3	3	3	
	4	P	3	3	2	2	2	2.5			
	8	S	3.5	3.5	3.5	3.5	3.5	4			
SECOND DECK	6	C	4	4	3	3	3	3	3	3	3
	4	P	4	3		3	2	3	3		
	8	S	3.5	3.5		3.5	3.5	3.5			

Note: 1 = Excellent, 5 = Unacceptable; see Figure 2 for complete definition of ratings.

Table 17-3

Frequency of Use for In-chamber Equipment Items

Crewman	Day	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
CDR	6	4							1	3	2	3	2	1	1	5	5	2	5	5	5	3			2	1	1
SPT	8	2	1			1			4	1	2	1	1	2	1	1	5	1	5	5	5	5			5	1	5

Note: See Figure 3 for list of equipment items.

parties who had no onboard hardware for such purposes. An example was the use of both types of temperature sensors to determine the most acceptable water temperature for the shower. Such discretionary uses of the instruments, either at crew option or ground request, will be their primary inflight use mode.

Subjective Formats

Representative results are covered in this section for the various subjective formats used, and the related discussion will address any protocol changes.

Rating Forms. The first use of the rating forms revealed several operational difficulties. First, to complete both sides of the cue card took about fifteen to twenty minutes, which was nearly twice the time that had been anticipated. Second, some problems were encountered in interpreting the voice data. These difficulties were associated with the listener confusing the alphanumeric designations. Finally, and most importantly, there was less than wholehearted crew acceptance of the forms as useful data tools. The major complaint was that the forms were too mechanical and constrained the crew's attempts at subjective evaluation.

Table 17-4

Subjective Rating Data for Equipment Items

Equipment Item	Crewman								
	CDR			PLT			SPT		
	Parameter			Parameter			Parameter		
	A	B	C	A	B	C	A	B	C
OWS fireman's pole				2	3	3			
OWS dome and wall handrail	3	2	3						
Triangular shoes/grid	3	3	2	2		3			
Trash airlock	3	4	3	2	3.5	3.5			
Wardroom table (eating station)	2	2	2	2	2	3	3	3.5	3.5
Wardroom table (non-eating uses)	2	2	2	2	2	3	3	3.5	3.5
Water dispenser (food)	2	2	2	2	2	2	2.5	3.5	2.5
Drinking water dispenser	3	3	3	2	3	3	2.5	3.5	3.5
Food tray	2	2	2	3	3	3	3	3	3.5
Food cans	3	3	3	3	3	2	4.5	3.5	4
Drinking containers	4	4	4	2	2.5	2.5	4	3.5	4
Seasoning dispensers	3	3	3	3	3	2			
Eating utensils	4	3	4	3	3	2	3.5	3.5	3.5
Fecal collection equipment	3	4	3	3	3	2			
Urine collection equipment	3	4	3	2	3	2	4	4	4
Hand washer	3	3	3	3	2	3			
Drying stations	2	2	2						
Whole body shower							3.5	3.5	3.5
Sleep restraint	3	3	3		3	3			

Note: 1 = Excellent, 5 = Unacceptable; see Figure 2 for complete definition of ratings.

A compilation of the data retrieved from the first use of the rating forms is shown in Tables 17-2, 17-3, and 17-4. A short set of comments was offered in support of the actual ratings. They are not presented in this report.

Following the crew's first use of the "cue card," the card was reconfigured in an attempt to increase crew acceptance, since it was still considered to be a worthwhile evaluation instrument. A copy of the revised form was passed into the chamber for crew evaluation. It was evaluated as no better than the first edition and the use of the subjective rating form was discontinued for the remainder of the SMEAT Program.

Subsequent use of the reconfigured form in a recent Skylab crew training exercise which simulated several days of the SL-2 mission revealed rather similar crew reactions, although all parties agreed that the data which the form was designed to retrieve were indeed worthwhile.

As a result of these experiences, the cue card has now been abandoned for Skylab inflight application. However, the individual segments of the revised card

are now being expanded and incorporated into the M487 checklist, with a two-page format being used to present use instructions and evaluation criteria on one page and the items to be evaluated on the facing page. This scheme will be baselined as the SL-2 subjective evaluation format.

The scheduling of the subjective evaluations will also be modified as a result of the SMEAT experience. The equipment evaluations will be made twice, once yearly and once late in the mission; the compartment accommodations will be evaluated once about midmission; and the equipment use frequency will be recorded once, late in the mission.

Debriefing Questionnaires. The debriefing questionnaires had a high degree of crew acceptability. Each scheduled use was completed, and, on occasion, an extra question or two was added to the list to cover some specific item of interest that had arisen since the previous debriefing. A representative excerpt is provided here to indicate the quality of data that this method of retrieval elicited.

"Mission Day 11 Debriefing"

Question #5 - How satisfactory are the food management and dining accommodations? How well does the food adhere to the utensils when eating? Would a closer tray-to-mouth proximity be desirable?

Answers -

SPT - The food system is surprisingly good. The trays heat well--the water dispensers work well--the total activity required to prepare, consume, and clean up after a meal is something of a nuisance but no big problem.

PLT - Trash accumulation associated with dining is the biggest problem. The manipulations of prep and post are a pain, but necessary. Forty to fifty pieces of trash are generated per meal and their constant management is the main drawback to the food system. The utensils are too small to handle comfortably.

CDR - Agree with trash comments. Each guy should handle his own residue rather than constantly passing items to a single trash manager. For SMEAT we are dumping most trash into a large food can

which is placed in the middle of the wardroom table. If this scheme is used for flight, a restraint will be required. The pantry system seems well organized. It takes about 40 minutes to prep-eat-and set up for the next meal. The wardroom table is well laid out to cope with this job. We like the table arrangement of facing each other because it lends itself to a nice social atmosphere in conjunction with eating. Also a good place for group discussion and timeline planning activity. The zero g aspects of this question can't be addressed very well.

Environmental Scales. The environmental rating scales were intended for use each time an instrument survey was made in order to obtain subjective data to correlate with the quantitative data. However, some interpretation problems were associated with their use. Seemingly, all possible combinations of use were found:

1. Rating each parameter for each compartment (as was intended).

2. Rating only the parameter associated with the instrument that particular crewman was using.

3. Announcing an overall chamber rating for each parameter, integrated over all compartments.

Due to the confusion which the scales seemed to generate, and due to the logistic difficulty of acquiring scale ratings in close proximity with instrument readings, the environmental scales will not be used inflight.

To salvage the subjective environmental data during flight two changes will be made in the M487 protocol. First, three environmental parameters (noise level, thermal comfort, and illumination) will be added to the subjective evaluation form under the compartment accommodations section. Second, there will be an environmental assessment question added to each debriefing session.

Ad Hoc Comments

One of the most beneficial data sources was the communication interchanges between the crew and the capcom. Numerous items of interest to M487 were either specifically discussed in response to questions or unsolicitedly offered during the

debriefing. Since most of this type of information was problem oriented, it is discussed in more detail in the following section. This type of data source is expected to provide a major source of habitability assessment data during the Skylab flights.

Problems

The items covered in this section relate primarily to the Discrepancy Reports (DR's) initiated against M487 during the course of the SMEAT Program. Those difficulties that M487 encountered with respect to protocol have been addressed in previous sections.

M487 Discrepancy Reports

The DR's initiated against M487 are listed in numerical order with a statement of the problem and the solution.

Problem - The probe portion of the M487 digital thermometer became inoperative.

Solution - The inoperative probe was removed from the chamber and a replacement unit was passed into the crew. The replacement unit was a new configuration which corrected an electronic open circuit inherent in the manufacturing process for the probe sensor tip. The new configuration will be used onboard Skylab.

Problem - One of the ambient thermometers (S/N 002) appeared to be reading 10°F low.

Solution - The defective instrument was removed from the chamber and a calibration test was conducted. The test revealed that the unit was indeed reading from 8 to 10° low throughout its entire range. No visible damage could be detected and no obvious reason could be found for the anomaly, although it was suspected that a lateral impact to the stem caused the problem. The thermometer was put into bonded storage until the end of the SMEAT Program and then returned for failure analysis. No results are available as of the writing of this report. However, the M487 checklist will include a note on precautions to be followed when handling and transporting the ambient thermometers.

Problem - Exactly the same as the previous item.

Solution - The same procedure was followed for the second ambient thermometer failure, and the outcome was precisely the same. Pending some reassurance from the failure analysis that this anomaly can be corrected in the flight units, the prime instrument for inflight ambient temperature measurements will be the onboard CO_2 dewpoint monitor.

Problem - The M487 instruments are stowed in Mozite inserts (configured to instrument dimensions) within the equipment container, and the fit is tight enough to make instrument retrieval difficult.

Solution - The Mozite problem is one of universal application to Skylab since numerous stowage areas onboard make use of this material for shock mounting. The material has been tested under a variety of pressures and seems to contract markedly during the 26 psi launch environment and expand when the pressure falls to the 5.0 psi seen in orbit. The M487 stowage scheme has been modified to include finger cutouts around the instruments to facilitate their removal and replacement in the kit. This modification was independent of the difficulties induced by the spacecraft pressure environment since the M487 Mozite was evaluated as too tight a fit even at ambient sea level pressure.

Problem - The one-degree spotmeter is not an incident light-reading device and needs a reflective surface to be used as an ambient illumination survey device.

Solution - A standard 89.5 percent reflective card was stowed in the chamber for use with the spotmeter during the SMEAT Program, and a similar card will be included as a blank page (approximately identified) in the M487 checklist for use during Skylab flights.

Habitability Related Items

In support of the M487 request to receive transcripts of all Skylab inflight communications, and to support the earlier remarks regarding the value of the ad hoc comments during the SMEAT Program,

the following examples of significant habitability related items (retrieved via this means) are provided:

Urine spills

Wipes — quantity and quality

Housekeeping procedures

Beverage container leaks

Vacuum cleaner difficulties

Can crusher procedures and problems

Fecal bag handling and sealing

Hygiene period rescheduling

Use of Command Module spoon as Orbital Workshop eating utensil

Lint and dust collection

Clothing preferences

Detailed discussion of the items in this list can be found in other sections of this report.

One last comment is offered in support of habitability as an entity as opposed to habitability when constrained by outside influences, such as biomedical data considerations. Were it not for the requirements to collect urine and fecal samples, the waste management facilities could have been designed to avoid many of the problems observed in SMEAT and anticipated in Skylab by simply treating these items as disposable. A systematic review of the entire habitat might reveal other areas where habitability has been compromised because of experimental or operational constraints.

Flight Impact

Three major areas of flight impact emerged from the M487 experience in the SMEAT Program:

1. Reconfiguration of portions of the subjective data package.

2. Scheduling implications.

3. Instrument use philosophy.

As previously discussed, the "cue card" rating format has been abandoned in favor of a less rigid evaluation scheme with greater emphasis on supporting commentary and less emphasis on the assignment of unique scalar values. The subjective approach to the environmental data has been reoriented to allow more freedom for the crewmen to discuss their impressions rather than forcing scalar choices.

Based upon the SMEAT experience in scheduling unique timeline periods to accomplish the various portions of M487, and the actual times required for performance, inflight use of all data sources except the debriefing questionnaires has been reduced. More freedom has also been granted the flight planners in scheduling the various M487 data sessions into the timeline. Since many of the M487 data acquisition items have minimal time requirements, and are not uniquely constrained by orbital position or time of day, they may be conveniently scheduled as timeline activities when a small time period is available.

The periodic instrument surveys are time-consuming and somewhat redundant in purpose unless there has been a change of some significance in the onboard environment. The current philosophy is to obtain an early survey for baseline purposes and rely upon the crewmen to detect and report changes in their impressions of the various Skylab environmental elements. The measuring instruments will serve as discretionary devices available to verify subjective impressions, quantify anomalies, or assist mission control in troubleshooting as necessary.
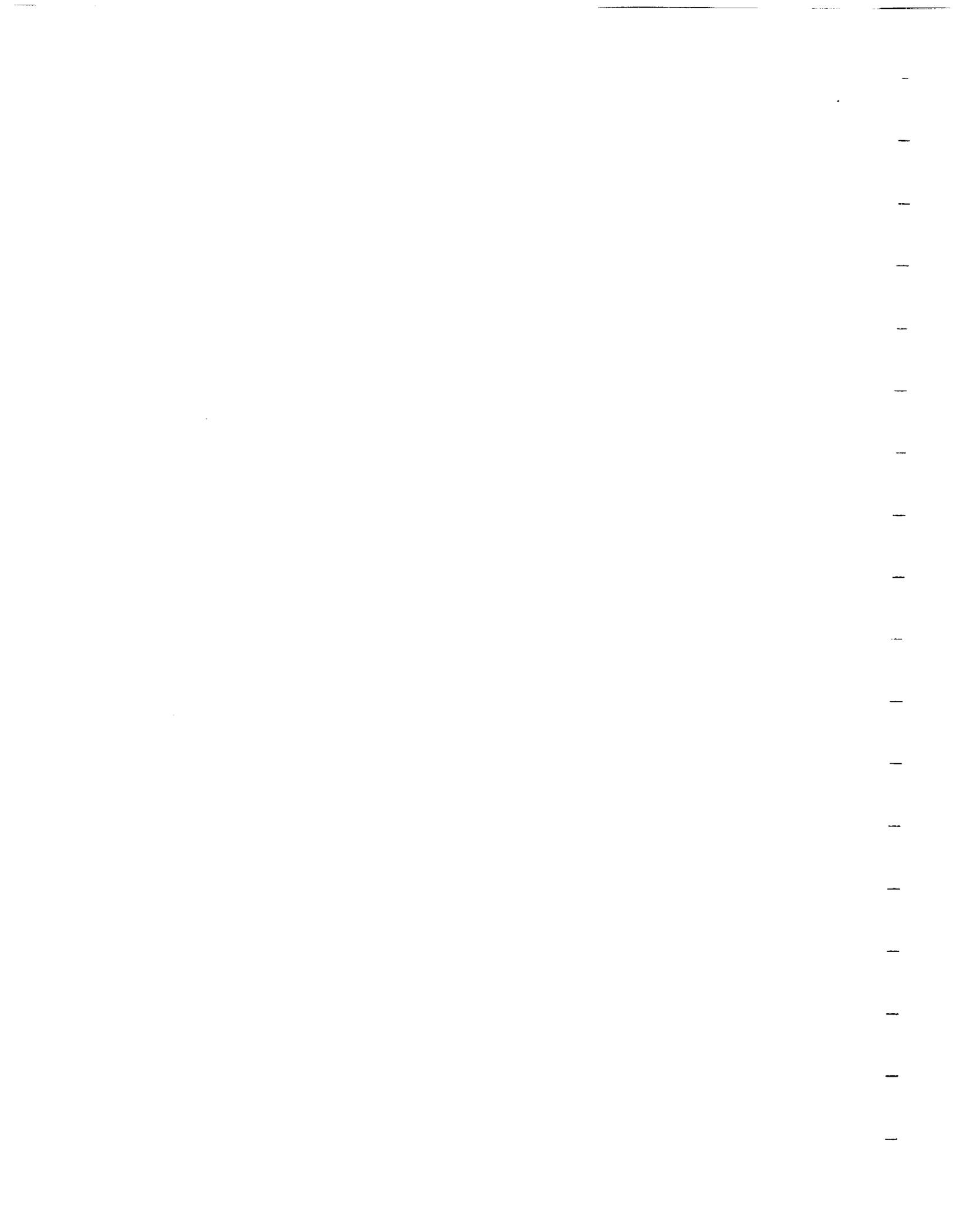
CHAPTER 18

BIOMEDICAL SUPPORT SYSTEMS

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Biomedical support hardware for SMEAT consisted basically of two systems, the Inflight Medical Support System, known by the acronym IMMU, and the Operational Bioinstrumentation System, or OBS. The former is essentially a diagnostic and therapeutic kit; the latter is a belt equipped with sensors worn by the crewman to permit monitoring of his vital signs. Special attention was given during SMEAT to the use and verification of the items in the IMMU so that changes required in the equipment could be pinpointed and effected prior to the Skylab mission. During the in-chamber testing, evaluations were made of the effectiveness of the proposed microbiology procedures, techniques, equipment, and the stability of media and reagents over the extended period of storage. These evaluations are described in this chapter and, in more detail, in Chapter 21.

Inflight Medical Support System

The Skylab Inflight Medical Support System provides a diagnostic and therapeutic capability in space. With the aid of preflight training and direction from the mission Flight Surgeon on the ground, a crewman can use the IMSS to diagnose illness and treat illness or injury in earth orbit. For diagnostic purposes, standard clinical tools such as a stethoscope, sphygmomanometer, and thermometer are provided. The unit also contains medical laboratory equipment for blood analysis, urinalysis, and microbiological work. The IMSS therapeutic equipment consists of bandages, drugs, both oral and injectable, and a minor surgery kit outfitted for the care of wounds and broken bones. The drug assortment is large enough to allow for the treatment and prevention of infection, disease, or allergy. Also supplied are catheterization and dental care kits. Figure 18-1 (a, b) illustrates the components of the IMSS and its use.

The chief difficulties associated with using the IMSS were inadequate lighting and insufficient work space. Shortcomings were also noted in connection with the slide stainer and the microscope. These problems have been corrected for Skylab.

The clinical tools in the diagnostic kit were used several times in routine physical examinations and proved to be adequate with the exception of the tongue depressor and the Politzer bag. The tongue depressor was uncomfortable to use and difficult to sterilize, while the lower ambient pressure made it impossible to develop useful pressures with the Politzer bag.

The reduced sound transmission at 5 psia had to be taken into account during sound-dependent

The IMSS diagnostic kit in use.
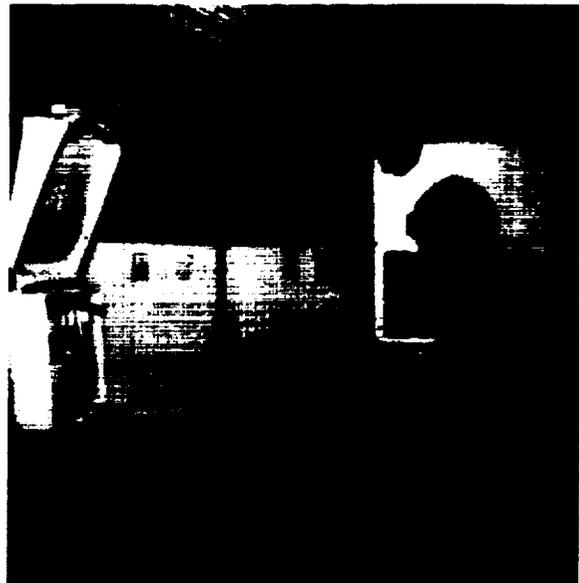
The IMSS microscope kit and worktable.

The IMSS kit with microscope.

Figure 18-1(a). Skylab inflight medical support system.
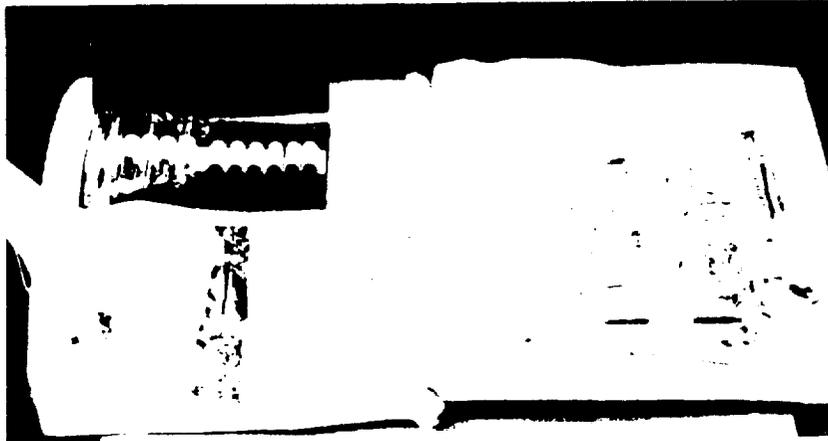
The IMSS minor surgery and dental kit.
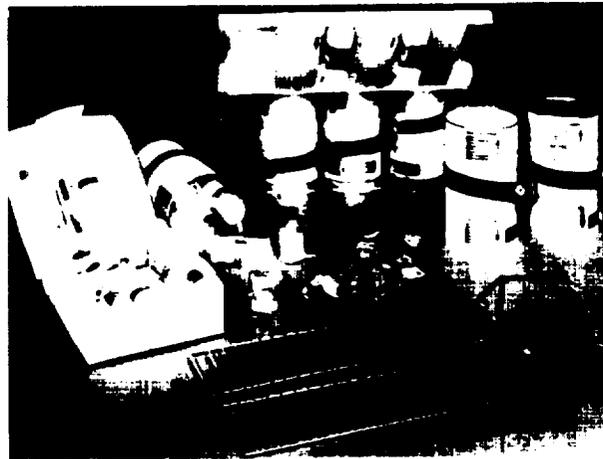
The drug supply kit of the IMSS.

Figure 18-1(b). Skylab inflight medical support system.

clinical procedures, such as mediate percussion and use of the stethoscope.

The drug kit received little use, except for such everyday items as nasal emollient, Phisohex, Tinactin, and bandaids. There was no occasion to test the other elements of the IMSS concerned with therapy. The crew considered the dental kit to be particularly well thought-out and suggested the surgical kit be similarly streamlined.

Testing IMMU Microbiological Capability

The basic diagnostic microbiology capabilities of the IMMU were tested in SMEAT. This aspect of the kit provides for antibiotic sensitivity tests, preparation of gram stains, and routine laboratory tests to determine the pathogenicity of micro-organisms isolated from the respiratory and urinary tracts. The unit is also designed to take regular microbiological samples from the crew, the

chamber equipment, and the surrounding atmosphere for postmission analysis.

The equipment used in microbiological studies included an incubator, microscope, gram staining apparatus, swabs, and streaking loops items. Crewmen did laboratory work on the door to the IMMU module which forms a work table when open.

Media preparation and packaging procedures were identical to those planned for Skylab. All microbiological test media were prepared under a nitrogen atmosphere in sterile conditions. Blood agar plates were sealed in plastic bags before removal from the cabinet and subsequent canning.

Procedures. Skylab timelines and procedures were used in order to test IMMU microbiological components as thoroughly as possible. Many of the test procedures were observed on closed-circuit television.

Diagnostic Microbiology. Mock-illness samples were obtained and tested on days 7, 14, 28, and 49. Throat samples were processed on days 7 and 28. A skin sample was tested on day 14, and a urine sample on day 49. Calcium alginate swabs were used to obtain the throat and skin samples and to inoculate blood agar plates. Urine specimens were collected from a urine sample bag with a syringe which was then used to inoculate blood agar plates. Urine samples were streaked for both quantitation and isolation, while all other samples were streaked for isolation only.

During SMEAT, the only deviation from Skylab procedures involved control sampling. At each sampling period, the SPT was supplied with two freshly prepared blood agar plates for use as control plates. These and test plates were inoculated and streaked in the same manner. One control was removed from the chamber immediately for incubation and analysis. The second control plate was incubated in the chamber with the test plates and was then passed out of the chamber for analysis.

After incubation, colonies were transferred to additional blood agar test media for antibiotic sensitivity testing. After sensitivity results were obtained, these cultures were used for gram staining and for oxidase, catalase, and coagulase testing. When all data had been obtained, a sample from each sensitivity plate was collected on a swab and placed into a test transport media vial containing Stewart media base. All sample vials were stored in the food chiller for the remainder of SMEAT.

Test results obtained in-chamber were compared to the results obtained from the controls, and the stability of the diagnostic test reagents and antibiotic sensitivity discs were determined.

Crew and Environmental Monitoring. Crew and environmental swab samples were taken (see Chapter 15 for details). Again, control media were used. Each site was sampled with two calcium alginate swabs. One swab was placed into a test transport media vial and the other into a control transport media vial. Twelve crew sites and fifteen hardware sites were sampled and stored in the SMEAT environment for eighteen days. Each set of control samples was transferred out of the chamber for immediate processing. Following storage, the test samples were analyzed and comparisons were made to determine the loss in number and type of microorganisms during storage. Chapter 15 provides a complete discussion of the microbiologic populations found during SMEAT.

Air Sampling. The Skylab air sampler was tested once each week throughout the SMEAT program. Freshly prepared blood agar plates were transferred into the chamber and used for tests.

Additional information was obtained on the performance of the Skylab air sampler by using the Anderson air sampler as a control. Both samplers were run simultaneously for ten minutes at each test period. In addition, one minute and five minute samples were taken with the Skylab air sampler during each test to comply with the Skylab protocol. The sample plates were passed

out of the chamber and incubated in the laboratory. Counts and identifications were obtained for each colony type present. Results from the two air samplers were then compared.

On days 49 and 56, an additional air sample was taken using the blood agar test plates in the Skylab air sampler. The plates were stored in the chiller for the remainder of the chamber confinement. The sample plates were then incubated and analyzed. The results were compared to the regular Skylab air sample obtained on days 49 and 56 in order to determine the effects of storage.

Results and Discussion.

Diagnostic Microbiology. A comparison of the in-chamber test results and the laboratory control results is shown in Table 18-1. Only the results obtained from microorganisms isolated from both the test and control plates are considered. Although the diagnostic tests are important for the detection of a possible pathogen, the antibiotic sensitivity test is considered to be of prime importance since it suggests possible therapy. Of 55 sensitivity tests performed, 92 percent were

recorded as sensitive, or resistant, when compared to the laboratory controls, a very good correlation.

Unsatisfactory results were obtained, however, with the gram stain, catalase, and coagulase tests. The gram stain problem became apparent during the second test when air pockets could be observed inside the reagent syringes of the slide stainer. The incorrect stains obtained were in part due to trapped air which prevented the passage of sufficient reagents to the staining reservoir. With the correction of this mechanical problem, staining results should be as good as results produced by routine laboratory methods. Low correlation between test and control results for the catalase and coagulase tests were found to be due to inadequate procedures and methods. Modifications have been made that should improve the test results.

The A and P disc results were adequate, but can be improved by providing additional examples for examination during training. The remaining test results shown in Table 18-1 are considered to be exceptionally good.

Table 18-1

Comparison of Results Between In-chamber Diagnostic Tests and Laboratory Controls

Test	Mock Illness Exercise (percent correlation)				Total Test Performed	Average Percent Correlation
	1	2	3	4		.
Colony Morphology	66	86	100	81	43	83
Cellular Morphology	88	80	100	99	27	92
Antibiotic Sensitivity	93	100	90	100	55	96
Gram Stain	75	0	100	75	12	63
Oxidase	100	100	100	75	11	94
Catalase	75	0	100	75	12	63
A Disc	100	100	100	50	11	88
P Disc	25	100	100	100	11	81
Hemolysis	100	100	100	100	11	100
Coagulase	100	Not Done	50	75	9	75

Postchamber recovery of illness isolates stored in test transport vials could only be made from the tests performed on days 28 and 49. No isolates were recovered from specimens stored on days 7 and 14. Survival of stored microorganisms depends on the type of microorganism, the numbers initially present, the nature of the storage medium, and the conditions of storage. These factors can never be optimal for all microorganisms. However, in an attempt to maximize the recovery of isolates, Skylab procedures have been altered to increase the number of microorganisms placed in storage, and a study is in progress to determine whether the transport medium can be altered chemically to provide improved recovery.

Postchamber stability tests of the reagents and antibiotic discs did not show a loss in reactivity. All reagents and antibiotic discs maintained their effectiveness throughout the seven week chamber storage period when compared to controls.

A pre-SMEAT study of the stored blood agar along with observations made during SMEAT have shown the medium to be useful for supporting microbial growth throughout the storage period. On test days 28 and 49, the red blood cells were more fragile and some darkening of the media had occurred. Pre-SMEAT studies indicated that increased hemolysis of microorganisms occurs during this period of storage, but this is not expected to present a problem in Skylab. The moisture content was maintained, microbial growth was supported, and the diagnostic tests were demonstrated to be feasible throughout the entire storage period.

Crew and Environmental Sampling. The transport media remained moist with no apparent change throughout the sixteen-day storage period. Difficulty with the media was encountered, however, in the laboratory preparation of the samples for dilution and plating. Suspensions were difficult to obtain because of the semisolid nature of the media. Other methods are currently being tested in order to improve the dilution and plating techniques.

The survival of microorganisms isolated from the crew ranged from no change in number to a 10^3 loss during the storage period. *Corynebacterium, staphylococcus,* and *streptococcus* were the principal surviving genera. Evidence for the survival of the gram negative enterics is indicated by the presence of *Escherichia coli* in the stored media. Only one anaerobic species, *Propionibacterium acnes,* survived the sixteen-day storage period but was not found in the control vial. In a number of cases, microorganisms, especially anaerobes, were isolated from the control samples but were not reisolated from the test vial. Many of these organisms undoubtedly did not survive storage in the test vial, but their loss could not be estimated since the initial presence of the organisms could not be determined. Sampling error accounts for some of the observed loss in species. Evidence of sampling error was seen in cases where microorganisms were isolated in the test but not in the control samples.

With the exception of one micrococcus species found in a concentration of 10^4, all species from the environmental samples were recovered in concentrations of 10^3 or less at each sampling site.

No significant loss in the number of each species was indicated. In fact, one species had a higher concentration in the test vial. The increase is most likely due to sampling error, possibly compounded by a limited amount of growth during the storage period. As with the crew samples, a given species was usually not isolated in both the control and test vials.

When microorganisms are present in such low numbers, it can be expected that two swabs, even though taken simultaneously, will contain equal samples of the microflora present. Approximately one-fourth of all isolations were made only from the test samples indicating error due to unequal sampling of the population present. Since sampling error can be reduced by increasing the number of samples, the sum of all the environmental samples presents a fairly accurate evaluation of the SMEAT aerobic microbial flora. Only five aerobic species present in either the test or control vials were not recovered from the test vials.

Air Sampling. The ten minute counts obtained with the Skylab air sampler were generally consistent with the counts obtained with the Anderson air sampler. Of the three Skylab air sampler plates, the counts obtained from the five and ten minute plates were more consistently alike. The one minute plate counts were considerably higher. This difference is probably due to contamination of the air in the sampling area by the individual obtaining the sample. For such a short sampling period, the individual must remain in the area while the sampler is in operation, increasing the possibility for contamination of the plate.

A valid comparison of the species isolated from the two sets of air samples cannot be made. The selection of colonies from the plates for identification was made by different technicians using different methods. The species of microorganisms isolated from the Skylab air sampler plates were, however, representative of the microorganisms found in the SMEAT chamber by the Anderson air sampler and the other chamber sampling methods.

Comparison of the regular Skylab air samples taken on days 49 and 56 with the additional samples taken at the same time and stored in-chamber revealed that two-day storage has little effect on the microorganisms, while seven-day storage results in significant differences. This suggests that samples should be obtained as late in each Skylab mission as possible to reduce the storage time required.

Conclusions. Some problems were experienced with the procedures and equipment used in conjunction with microbiological studies. These are discussed in detail in Chapter 21. As a result of the difficulties encountered, an extensive revision of procedures was undertaken. The revision should improve the flow of work and provide more efficient use of time and work space. Efficient use of the work surface is being emphasized in crew training.

The SMEAT tests of the IMMU have shown that the unit is capable of providing useful information to the ground level medical support group for assistance in diagnosis and treatment of inflight illness. The IMMU can also be used effectively for monitoring the microbiologic populations of the crew, the environment, and the surrounding areas.

Operational Bioinstrumentation System

The other major item for biomedical support tested in SMEAT was the Skylab Operational Bioinstrumentation System. The OBS is designed primarily for obtaining physiological data during launch, extravehicular activity, and return mission phases. It is also available for full-time monitoring of an ill crewman.

The operational bioinstrumentation hardware is designed as an individually adjustable biobelt worn on the body. The biobelt assembly, which can be worn in either of two modes, suited or unsuited, is an electronic system that includes sensors, signal conditioners, and telemetry interfaces. The electrical harness assembly into which the signal conditioners are placed and which is worn by each crewman is included as part of the system. The OBS is capable of transmitting electrocardiograms, heart rate, impedance pneumograms, and subject identification. (Figure 18-2)

Testing of the OBS

The SMEAT Program provided an opportunity to test the OBS prior to Skylab. The system was used during specified exercise periods. Data were obtained three times for the CDR and once each for the SPT and PLT. The crewmen exercised on a bicycle ergometer for approximately one hour during each recording session.

A special test was conducted during the last week of the SMEAT Program to compare flush electrodes with the sponge type. Flush electrodes have the conductive pellet at the surface. The crewman applies a small drop of electrode paste to the pellet and attaches it to the body. With the sponge type electrodes, an electrolyte sponge is placed in the electrode housing and then attached to the body.

Figure 18-2. Operational biomstrumentation electrodes
in use in the suited mode.

The ORS performed well during all test periods, but data handling problems caused the impedance pneumogram to be lost for one of the test runs. Post-SMEAT checkout of the system indicated that all components were functioning properly.

The flush electrodes provided data of equal quality to the sponge electrodes. The SMEAT crewmen indicated, however, that they preferred to use the sponge electrodes for the sake of consistency since sponge electrodes were in use for the vectorcardiogram tests.

CHAPTER 19

MEDICAL OPERATIONS

Crew Surgeon's Report

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Primary medical and health responsibilities for SMEAT were delegated to the Health Services Division, as shown in Figure 19-1, with a two-man team appointed to implement programs which included health care of the test crew and their families, occupational medical services for chamber operating personnel, clinical laboratory support and hypobaric and other emergency support. This team consisted of Dr. C. E. Ross, Crew Surgeon and team leader, and Mr. G. H. Pittman, Safety Officer.

The Safety Officer was responsible for physiological training, scheduling and implementation of the SMEAT safety plan. The Crew Surgeon was responsible for all other medical aspects including: pre- and posttest crew physicals and care, testing, and a crew health stabilization plan, crew family health care, insurance of in-chamber water, atmospheric gas and food quality, monitoring of chamber tests and laboratory results, preparation of IMSS training and coordination with investigators, the management committee, test director and in-chamber physician.

Participation in SMEAT activities began several months prior to test and included organizing and attending the initial IMSS academic training at Sheppard Air Force Base. Full-time assignment began approximately one month prior to the test. This period was occupied with organization of various supporting functions, implementation of the health stabilization plan, and crew testing and examination.

A crew health stabilization period was started 21 days prior to the test (this became 28 days with a starting slip of one week), and continued for 18 days following the test. The crew slept at home and usually had evening and weekend meals there while other meals were provided onsite. Guidelines for this period included:

Verification of family member immunity

Awareness and reporting of illness or potential illness by crew and family

Crewman limited contact and activities to family and work-related individuals

Crew and family avoided all contact with individuals known to be ill and avoided all other children.

In the event of family illness, the crewmember would sleep and live elsewhere.

During the pretest period, all medical data gathered by experimenters which might be relevant to crew health were carefully screened. During the actual chamber run, the experiment data became a major source for medical surveillance and, just as in Skylab, was an essential source for health monitoring. In addition, as in Skylab, it was agreed to send certain portions of these data to
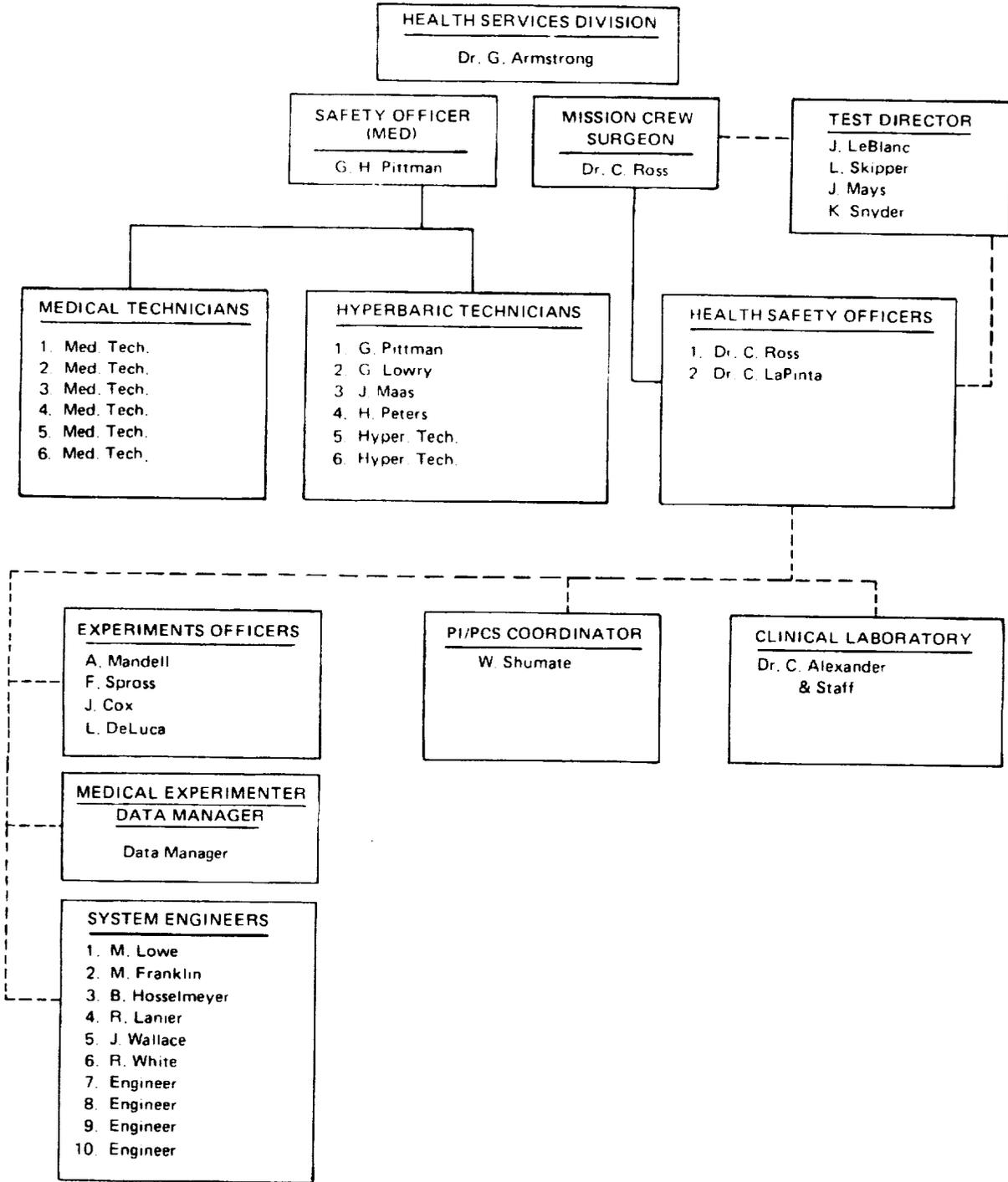
Figure 19-1. Medical operations management organization.

the crew and to make any portion available on request. During this period, the dental and optometric exams were made. Also, some special orthopedic and dermatological consultations were obtained for the CDR's fracture and acne and an otolaryngology consultation for the SPT's hearing loss and cervical adenopathy. All crew physicals were performed with Dr. Thornton, the SPT.

During the test, except for a period exactly simulating Skylab communication schedules, all LBNP (M092), vectorcardiography (M093), and ergometry (M171) experiment runs were monitored by a physician in a room adjacent to the chamber by TV and chart recorders. Monitoring of atmospheric gases and water was accomplished by standard NASA procedures and standards which were augmented by making one individual in each area responsible for testing, having him present when reservoir connections were made or broken and having him report directly to the Crew Surgeon. All gas cylinder changes were made with the crew awake. Standards had to be established for purchased carbon dioxide which had not been previously used as an atmospheric gas. Normal food quality control was accepted except that additional studies were made of pea soup samples implicated in a series of GI upsets. Results were negative.

It had been mutually agreed that the crew and crewmember surgeons would act in concert in all questions of crew health. Test results were to be supplied to the crewmember surgeon in-chamber, a series of phone conversations were to be held to discuss results of in-chamber exams or any problems that occurred, and all medications and treatment in-chamber were to be mutually agreed upon.

A regular evening report was made by the crew including any anomalies, weights, and food and water consumed. Several times a day, a scheduled walk-around TV safety surveillance was made by the crew. All of the above data were used in preparation of a daily medical report presented each morning to the SMEAT Management Committee who made any decisions required on items outside the normally planned schedule.

Results

Other than for a few routine incidents mentioned in the examination report, the preflight period was routine. It was very rushed, with long crew hours and frequent changes in plans and procedures. A weight loss was established in the SPT and it was assumed this would continue unless the diet was modified, a move deemed undesirable by the experiment investigators. Therefore, it was agreed with him that he would continue unchanged until a ten-pound loss had been sustained, at which time the situation would be evaluated.

During the test, there were no real medical problems. Establishing a data flow with a reasonable response time was a problem and prevented timely presentation of data to the crew until near the end of the test. A slight atmospheric irritant appeared intermittently and was never identified positively. The SPT's weight loss continued until he reached 196 pounds at day 40. At this time, contingency electrolytes were drawn. (Blood work was normally unavailable since the SL simulation of storage was made.) This was normal and it was agreed with him to let him continue for another five pound loss at which time the diet would be changed or dropped completely. All other in-chamber medical events were incidents of no import. A full reporting of these was made by the in-chamber physician and will not be reported.

Postchamber there were no real changes and the period was routine. All crewmen were at their prechamber performance levels on the various experiments at time of exit.

At 190 pounds, a nineteen pound loss, the SPT was taken off the previously formulated diet and allowed to eat Skylab food ad libitum with a prompt weight gain.

In summary, there were no significant changes in the crew, other than SPT weight loss, which could be attributed to the chamber stay. This atmosphere and regimen produced no changes even where small ones might have been anticipated, in blood or microbiology for example. As a result of this experience, it

would appear that the only effects which must be dealt with in Skylab will be from weightlessness.

Some Medical Aspects of SMEAT As Observed By The Crewmember Physician

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Pretest

In addition to IMSS training, medically relevant activities during this period were participation in design reviews and surveillance of test aspects which would affect crew health. These included environmental control system, food and water, waste, safety, and medical coverage. No involvement in clinical aspects of crew health was attempted until a Mission Flight Surgeon was assigned approximately one month prior to test start. At that time, all health aspects external to the chamber were also primarily relegated to him. Items in chamber design pertinent to this surveillance included general physical layout, construction of items with injury potential such as sharp corners and edges, obstructions, protruding elements, and ECS system, especially regarding quality control of gases. In some cases, standards had to be modified for nitrogen and carbon dioxide for human use. An overall quality assurance program for which one man was responsible was instituted. Other rules established insured that all gases were connected during the day shift and were installed only under the supervision of that individual responsible for quality assurance. This person reported directly to the Mission Surgeon on ECS performance and safety.

Water System. Establishment of a quality assurance program with one man having responsibility which included his being present at all filling and transfers. Again, this individual reported to the Mission Surgeon.

Wiring, Fire Detection, and Suppression. Surveillance to insure that insofar as possible standard chamber practices were followed.

Ancillary Medical Personnel and Facilities. There were several periods of emergency training in which all elements of the rescue and medical emergency facilities were exercised with resulting modifications and personnel additions and changes.

Coordination of many medical aspects of equipment and experimental procedures with the PI's and PCS's was attempted. After Dr. Ross's assignment as Mission Surgeon various aspects of crew health were coordinated and mutually agreed upon, including: presence of SPT at all remaining pretest physicals; a schedule of regular telephonic communication schedules to discuss in-chamber examinations and observations which were held every three to four days for the first week or so and approximately every week after that; coordination in event of medical contingencies; establishment of test data to be transmitted to the crew.

Significant prechamber findings are included in the Mission Surgeon's report. The only clinical items worthy of comment at the time of entrance were a resolving acne of the CDR and an established and continuing weight loss by the SPT.

In-Test

Complete physicals were performed on days 213, 221, 226, 235, 250, and 263 by the SPT on the CDR and PLT. In addition, several attenuated exams were performed as well as examinations of any reported complaints, or of any observed signs. These complete physicals were made attempting to simulate Skylab facilities and using IMSS instruments and are further described in the crew report. All systems were covered except anal and genital areas which were omitted in the absence of complaints.

Physical Findings – (CDR)

Oral temperature ranged from 98.2 to 98.4°F.

Blood pressure seated, right arm 120/80 with no significant change.

Heart rate (HR) mean – 59 – there was a slight increase from approximately 55 to 60 BPM during the test with a range of 50 to 65 BPM.

Positive findings were limited to integument, lymph nodes, and throat and nasal areas. On entry,

there was a clearing acne rosacea between the eyebrows, a few small discrete pustules scattered over the upper back and shoulder areas, and injected nasal mucosa with moderately swollen turbinates.

On day 213, there had been clearing of both acne and pustules with decreased nasal congestion. Bilateral small, swollen posterior submandibular nodes were present. A beard was growing at this time.

Day 221 saw further clearing except for the right submandibular nodes. There was an injected, eroded 1 cm diameter area around a follicle on the left submandibular area. By day 226 the acne had cleared and only four to five discrete pustules with red bases were present in the left scapular area. A "beard" folliculitis was present on the right lateral maxillary area which had formed a confluent indurated base while the previously involved area had enlarged slightly. Phisohex washes were started and the patient admonished to avoid "picking" it. There was remarkable clearing overnight and plans for cultures were dropped. The patient stated that this folliculitis was an intermittent condition of long standing with spontaneous resolution. On day 250 lips were chapped with both upper and lower lips showing areas of erosion of mucosa.

By day 263, several infected follicles were resolving on the right upper lip. A few scattered pustules were usually present over the scapular and shoulder areas.

It was noted that the CDR displayed peripheral vascular hyper-reactivity including a flushed mottling of the upper back during exercise, marked flushing of pressure areas after leaning against a chair back, and a rather striking dermatographia over the entire back which would persist for several minutes. There were no symptoms or signs associated with this and no vascular abnormalities could be demonstrated. This was first noted one to two days after entry into the chamber. It persisted two to three weeks and cleared slowly though not completely by chamber exit. There was no evidence of this at normal atmospheric pressure.

Physical Findings – (PLT)

Oral temperature ranged from 97.5 to 98.2°F.

Heart rate (HR)   72 BPM   average   seated remained unchanged throughout test.

Blood pressure   120/75 right arm, seated.

Positive findings on physical were limited to ENT and integument. On entry, the PLT had a number of discrete two to three mm pustules scattered over the upper back and shoulders which cleared almost completely over the next two physicals. There was marked whitish-gray "furring" of the tongue which slowly cleared and by day 45 this had virtually disappeared. On entry, nasal mucosa and turbinates were moderately swollen and injected with slight amounts of whitish discharge, especially on the left. This congestion and discharge slowly cleared and by day 250, only a slight clear discharge was present.

Personal Observations of SPT

Oral temperature ranged from 97.1 to 97.4°F.

Blood pressure seated, left arm 110/75 to 105/70.

Heart rate (HR)   seated – 53 – 56 average 55.

Oral. On day 10, symptoms of a pulpitis in the upper left anterior molar developed with slight to moderate pain not requiring analgesics but with sensitivity to pressure and temperature changes. Chewing on the left side was avoided and the symptoms largely cleared over the next few days but would recur whenever that area was used. These symptoms cleared completely in approximately six weeks after leaving the chamber. A full crown had been replaced on the tooth approximately one year prior to the test.

Integument. Six days prior to the end of test, a number of broad-based white pustules two to four mm in diameter developed over the left face and forehead. The distribution suggested infection from the pillow. Cultures were made of the infected area, pillow, and nares. All copiously grew a pure culture

of a slightly pleomorphic gram positive cocci. Cultures were passed from the chamber with requests for more definitive identification. The pillow cover was changed and Phisohex was used in washing. There was gradual disappearance of the lesions over the next ten days which are assumed to have arisen from nasal crustings shed on the pillow which in turn were rubbed into the face.

At the end of the elevated temperature period, there was a marked recurrence of old athlete's foot infection with fissures and erosion of the lateral and anterior plantar area of the right foot. This was probably exacerbated by going barefoot for comfort during the elevated temperature period. It was washed more frequently and Tinactin used twice daily with very slow clearing by the fourth week posttest.

Medication and Drugs

Only the following items were used. Nasal emollient was employed for complaints of nasal drying and irritation in the PLT with improvement. It was of no use for relief of the CDR's chapped lips nor was Alph-Keri. Tinactin was used for a longstanding fungal infection with reasonably good result. The most used item was Phisohex which appeared to be useful in two skin infections as well as a general disinfectant. An effective emollient for chapped lips should be included for this condition is likely to recur. Description of the drugs in the check list was felt to be adequate.

Laboratory and Tests

Results are reported under their respective experiment sections. A major problem was obtaining results of analyses performed outside the chamber in spite of a previously established transmission protocol.

Psychological

No specific studies of this aspect were performed. It is always risky for the subject to attempt psychological evaluation of a situation in which he is subjectively involved, but the following observations are felt to be valid.

There was no perceptible evidence of serious stress at any point during the test. Interpersonal relationships remained excellent. There were differences of opinion on a variety of subjects but some working consensus was always obtained and followed. At no time was an angry or irritable word exchanged between crewmembers.

There was slight consternation after it seemed the test would be terminated early and was then extended. The most obviously stressful aspects of the test were those times when it appeared that data were being lost after considerable effort on the part of the crew to gather it, especially if it had involved difficulty on their part. Examples of this were: continued runs with faulty gear which was apparently not being repaired; obviously erroneous lab data such as the polyethylene glycol when many hours were expended counting pills to check that the material was correctly consumed at each meal (a nuisance in itself); or seeing incorrect data repeating that had been previously corrected by the subjects. Also stressful was the impression that arose from some situations that the crew were being used as experimental animals rather than participating investigators in an experiment. Some investigators were never able to accept or tolerate any view of the situation other than investigator subject.

There was unquestionably some polarization of "we" (the crew) against "them" (the outside world) which probably served as a useful protective device against isolation. No feeling of spatial isolation was felt at any time by any crewmember. There may have been some release mechanism involved in the leg pulling of exterior personnel by the crew.

In addition to the surprising absence of stress, there was an unexpected dedication to the SMEAT mission and not just as a job to be done. It was striking to observe the way two individuals who had been trained primarily as military pilots could conscientiously apply themselves not only to going through medical investigative routine but also to making every personal effort to understand and gain the maximum from all aspects of the test. This was deeper than military professionalism. Not one deliberate deviation from a diet, collection procedure or protocol, no matter how onerous, was observed.

Indeed, the rare mistake or lapse always brought real consternation and renewed efforts.

Medical Incidents

The EKG electrode adhesive discs have produced more or less severe sensitivity reactions in some crewmembers since Project Mercury. This sensitivity continued on SMEAT. Differing batches of this tape have widely varying irritant capacity, but apparently it has not been possible to discover or correct manufacturing variations. For example, the initial batches produced reactions only on the CDR but later the PLT developed reactions to different tape. In the chamber, the discs produced reactions on all three crewmen at first. Later, we were instructed to delete scrubbing the area with Zerphrarin[R] wipes. This produced an improvement and only the SPT and PLT were having moderate reactions by the end of the test. However, reactions were still present and this cannot be considered a "fix." especially in view of the marked reactions of some Skylab crewmembers to this tape.

The most marked reactions typically occur at the axillary and sternal sites with minimal reaction on the back and neck. It is a typical contact dermatitis and consists of an erythema, slight edema and, in marked cases, tiny blebs, limited to the immediate area of contact beneath the discs. In severe cases, there will be denuding of the epidermis, marked injection, and sometimes secondary infections. Milder cases have only reddening of the area with increased pigmentation. These reactions can occur in 30 minutes' time and produce no symptoms other than itching or, in cases with damaged skin, burning on application. After approximately two weeks in the chamber, it was necessary to relocate the electrodes for one or two runs on the PLT to allow healing. Reaction to the electrode paste was never seen.

Another sensitivity reaction occurred with the M133 electrode paste itself. The CDR and SPT used this equipment, which has paste impregnated sponge electrodes mounted in an elastic cap, for three times without difficulty. On the fourth usage, the CDR, after two to three hours exposure, experienced an increasingly severe generalized headache which cleared in approximately one hour after removal of the cap. The following morning, there appeared to be some diffuse induration around the frontal electrode sites. These symptoms and signs recurred on repeated attempts to use the equipment in-chamber and forced the substitution of the PLT as a subject. Definite diffuse induration, several centimeters in diameter, was present around the frontal and parietal sites with an indentation under the electrode proper without reddening or other signs. No itching or pain was related to the immediate site.

The SPT had similar symptoms, though mild enough to continue the experiment. The PLT developed no symptoms. Patch tests were conducted by taping split electrodes to the forehead of all three crewmembers. Unfortunately, the tape provided had a heavy elastic component whose pressure effects made other results equivocal.

Atmospheric Irritants

Approximately twelve days after test start, the SPT noted a sense of vague irritation in the posterior naso-pharynx which was sometimes accompanied by an occasional cough. This continued in an intermittent fashion with development of nasal "stuffiness," a slight clear discharge and conjunctival irritation and itching. The CDR developed similar symptoms several days later. These continued in an intermittent and variable fashion throughout the test and could not be related to any other event, time, or location. The PLT was never affected. Although it was assumed that LiOH dust was responsible for this and changes were made in canister processing, there was no real improvement. The cause was, in fact, never positively identified.

Virtually no physical trauma occurred during the test in spite of frequent near misses or glancing blows from improperly fitted cabinet doors falling open as one passed. One finger was lightly scraped during a climb to the second deck and numerous small nicks about the thumb and index fingers accrued from opening the extremely tough outer covering of the drink containers with a sharp knife. None of these showed any indication of infection. The SPT also occasionally suffered small nicks in attempts to clean the urine volume measuring system and, in spite of the filth of this machine, there was never any reaction.

A number of changes in phonation, transmission, and reception related to atmospheric pressure occurred. The first change to be noted at 5 psi is the quietness and consequent impression of distance from sound sources. A slight hoarseness is noticeable by external as well as internal chamber personnel and becomes more pronounced with prolonged or moderately loud speaking. In an effort to quantitate these effects, records were made and will be analyzed for spectral content. No difficulty in communication was encountered from either reduced amplitude or changed frequency components. An interesting psycho-acoustic phenomenon occurred in that after several weeks, the reduced sound level was perceived as normal. This was obviously a central phenomenon since no audiometric threshold shift occurred. On chamber exit, sounds were not perceived as abnormally loud as might have been expected. Another aspect of this is that all crewmen were unable to whistle. After several weeks, two of the crewmen could make feeble whistling noises but, even at the test end, this did not approach normal ability.

Medical examination was affected in that auscultatory sounds were markedly reduced with possibly some reduction in low frequencies. It was impossible to appreciate sounds from mediate percussion at normal distances and required much closer approach of the examiner's ear to the struck finger. Except the possibly reduced low frequency content and reduced amplitude, no changes in the quality of normal breath and heart sounds could be appreciated. Standard diagnostic maneuvers such as vocal fremitus and "E" sounds remained normal.

Changes Associated With The Diet

On beginning the diet some 30 days prior to chamber entry, two changes were noticed in all three subjects. Flatulence was markedly increased and the stools became soft and unformed but not liquid. The loose stools were simply a personal hygiene problem. Stool quantity, both total and individual defecation, was markedly reduced. Outside the chamber, this flatulence was simply a social hazard but inside, as the day passed, it became an increasing nuisance until it reached a peak after the evening meal. Some idea of the magnitude of the normal problem may be judged from the PLT who used a hand counter to document

some 64 passages during one typical twelve-hour period. Another time, the SPT recorded 38 such passages offensive both to the subject and associates in one three-hour period. Occasionally, some food item would produce gas and abdominal discomfort to a degree that interfered with duties. Soups and pea soup in particular seemed to be involved in this, though the offenders were never identified with certainty. Pea soup was associated with several bouts of cramps, gas, and slight nausea in the SPT before it was dropped from his menu. Two such occasions proceeded to bouts of rather violent diarrhea. The particular cans of food which caused this upset were not studied; however, duplicate items were examined and proved to be well within the allowed microbiological limit. This did not allow for the normal heating time which would provide an incubation period for any organisms present. Postchamber, there was marked decrease in gas formation, but it still remained in an episodic form. One had an impression that some adaptation to the food had occurred but had been a very slow process with a time constant of months.

The most marked physiological change in SMEAT was the nineteen-pound weight loss incurred by the SPT during some 90 days of eating the recommended SMEAT diet. Table 19-1 presents a detailed description of this process.

Table 19-1

Crew Weights

	Start Diet	Enter Chamber	Exit Chamber	End Diet
CDR	159	157 1/2	154 3/4	156
SPT	209	204	193 1/4	190*
PLT	185 3/4	185 1/2	185 1/2	184 1/2

*Diet was terminated one week prior to end of planned termination

The SPT's normal weight was 207 pounds, unchanged from that at which he had played collegiate football. He was in reasonably good condition at the time of starting the diet with maximum oxygen uptakes above 50 ml/kg/min, capable of sustaining

400 watts/min for three minutes on a bicycle ergometer, and with jogging mile times of 7:30 to 7:40 min/mile to 7:50 to 8:00 min/mile for three to four mile runs. This status required eight to ten miles/week jogging interspersed with two to three runs/week on a bicycle ergometer for 45 minutes to more than an hour at 300 to 275 watts/min loads, and some weight lifting and handball. His diet was high in protein with relatively little carbohydrate.

His in-chamber exercise plan was to maintain ergometer performance and cardiovascular status with whatever loads and times were required. This was discussed with pertinent investigators and no objections were raised.

Pretest, repeated attempts were made at every level to point out the inadequacy of the proposed diet especially after marked losses and acute hunger during the two trial periods. At that time, no interest was evidenced by investigators in exercise, previous diets, or physical condition. Weight was 209 pounds when beginning the diet with the two pounds above normal accumulated by numerous dietary excesses during the last week before the diet began. After the first week on the diet, a more or less stable loss of approximately one and one-half pounds/week was established. During this period, prior to chamber entry, time for normal amounts of exercise was simply not available; otherwise, the pretest loss would have been much greater.

Body composition was determined by radioisotope studies just prior to chamber entry and is given in Table 19-2 of the M073 report. No other measurements[1] of body size, configuration, or composition were made except some extremely crude trunk and extremity girth measurements by the SPT. During this prechamber period, the basic diet was frequently augmented with up to four cans per day of nonrestricted "sugar cookies." Hunger was constant. No modifications were offered or introduced by the experiment investigators.

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[1]One valid girth measurement is that of the maximum calf diameter which was recorded for each M092 run.

In the chamber, the SPT set the exercise at approximately 15×10^3 watts/min/day, a level estimated to be roughly equivalent to the total work energy expenditure immediately pre-SMEAT, not at the much higher level before the diet was begun. Rate of weight loss, except for a period of one week when no ergometer was available for exercise, remained constant at the prechamber level. After two weeks in the chamber, original work level could only be sustained by reducing work loads and increasing duration, i.e., performance levels dropped. Shortly after this time, there was cramping of the lower legs associated with flexion of the feet. This was a phenomenon never previously experienced, even transiently, but which persisted for some three weeks after ending the diet. There has been no recurrence. Electrolyte levels were unavailable since a protocol for determination procedures had not been agreed upon by the investigators.

On day 21, the SPT was requested for the first time to increase his caloric intake at least 300 calories/day utilizing the "free" food items. At that time, the only such high carbohydrate items which could be tolerated were sugar cookies and mints but the diet was augmented approximately 375 calories/day with these items (see Table 19-2), except for one week when they became intolerable. In spite of acute hunger, it became a problem of force feeding to ingest and retain this material as well as a diet formed in large part by vanilla wafers, puddings, crackers, jams, lemon drops, and imitation fruit beverages. This relatively small caloric increment did little to arrest the weight loss. At approximately 196 pounds, all factors were considered with the Mission Surgeon and a contingency electrolyte sample run. The Mission Surgeon agreed to allow continuation of the diet until reaching 192 to 193 pounds.

Immediately postchamber, large quantities of butter were added in every conceivable (and some inconceivable to the SPT) food item. If the item were rendered inedible, for example, rehydrated barbecue floating in butter, then it became a matter of eat it or else do without the food and take mineral capsules. Some items were impossible to consume. At this time, maximum oxygen uptakes were down to 47 ml/kg. Maximum ergometer workloads were six

Table 19-2

Average Daily Intake of Calories
Above Base Line by SPT in Chamber

Week	Total Sugar Cookies Cans	Total Mints Cans	Total Calories	Daily Average Calories
1 - 7	15		1500	214
8 - 14	9		1350	192
15 - 21	3		450	64
22 - 28 *	1	12	2742	392
29 - 35	11	9	2919	419
36 - 42	5	19	2529	361
43 - 49	1	19	1560	223
50 - 56	2	14	2274	358
	38	84		

*Subject was instructed to increase intake to 300 calories above base line at
that time

to seven percent down. At chamber exit, repeat radioisotope studies of body composition revealed an in-chamber loss of 2.4 kg lean body mass and 4.8 kg loss of fat with a body fat percentage of about ten percent or reduction of about four percent. An independent specific gravity lean body mass determination by the Cooper Clinic confirmed the ten percent body fat figure to a small fraction of a percent. It should be noted that these were end of chamber and not end of diet determinations which would have shown even greater losses. Weight loss continued and the SPT consented to the Mission Surgeon's termination of the diet at 190 pounds. Additional food was found and the diet became ad libitum Skylab food. Although large quantities of lobster, beef, fruit, and vegetables produced a weight gain of two pounds in seven days and the first hunger-free day in three months, there was no improvement in physical performance for approximately two weeks after beginning normal foods. Leg cramps took even longer to clear.

After final Skylab diet termination, weight gain was one to two pounds/week on a meat, fresh fruit, and vegetable diet (even with running five to eight miles/day). The diet was deliberately restricted in quantity to avoid replacement of lost lean body mass with fat. Carbohydrates were initially intolerable to taste. After approximately six weeks, pre-Skylab diet performance indices were exceeded.

Comments

It was obvious that the diet was inadequate to maintain weight and avoid severe hunger from the two trial diet periods. The nineteen-pound weight loss only further confirmed this.

The loss has been interpreted as simply excess fat. The first six to seven pounds may well have been in this category; however, such an interpretation beyond this amount is contradicted by the radioisotope and specific gravity studies. A simple fat loss should have resulted in at least a ten percent improvement in maximum oxygen uptake when, in fact, there was an approximately five percent decrement. The creatinine data did not support a negative nitrogen balance but, unfortunately, there are aspects of this data which make the values questionable. The loss of 2.4 kg lean body mass as shown by the radioisotope studies was completely consistent with the entire picture.

The real significance of this is its relation to Skylab. There are prime crewmembers as large, who require quantities of food as great and maintain physical condition as well or better than the SPT. An operational mission is not the place to perform a weight reduction program nor especially can any induced reduction in condition be tolerated. The diet as constituted for SMEAT with fixed and inviolable

mineral and protein levels is probably adequate for individuals requiring no more than 2,800 to 2,900 calories/day. Beyond that, increasing quantities of "free"[1] carbohydrates are required. There are limits to which such items can be tolerated, even with force feeding. It is understood that rectification of these problems is in progress for Skylab.

Impressions

There were no medical problems of consequence induced by the atmosphere, confinement, or other test conditions. The total absence of physical as well as psychological problems was unexpected and striking.

CDR

There was a recurrent beard folliculitis which responded to simple external measures. One had the feeling that a slight cardiovascular deconditioning trend may have been present but this is speculative. This subject was in excellent condition at the beginning of the test and large amounts of work are required to maintain such a state. The CDR limited himself to the exercise time available in Skylab. A slight weight loss occurred.

SPT

There was a superficial fungal and bacterial infection, both responding to simple treatment. A pulpitis resolved spontaneously. There was a major weight loss and some deconditioning, primarily somatic, apparently from the diet.

PLT

There were no changes of significance.

[1] i.e. free of all food value except calories.

Changes in Vision Parameters During SMEAT

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No statistically significant variation was found in comparisons of pretest to posttest data on the vision parameters listed in Table 19-3, with the exception of far visual acuity, refractive error, visual fields, and retinal vessel sizes. These four functions are more fully discussed below.

Far Visual Acuity

A statistically valid decrease in visual acuity was noted during this test which is consistent with available data for the Gemini and Apollo missions. This decrease in acuity is the result of the limited confines of the SMEAT chamber. The Gemini and Apollo flight crewmembers returned to preflight levels as rapidly as did the SMEAT crew.

Refractive Error

A statistically valid change in the refractive state of the eyes was noted during this test which is in the opposite direction of that noted in the eyes of the two Apollo crews that were examined. The Apollo crews showed a slight decrease in hyperopia (transient "space myopia") at a nonsignificant level and the SMEAT crew showed an increase in hyperopia. It is unknown why the SMEAT crew showed an increase because it would be expected that the limited confines should have resulted in a decrease if a change was present at all.

Visual Fields

A statistically valid decrease in visual fields was noted during this test, even though only two crewmembers manifested marked constrictions. This decrease was anticipated due to the high trend that is

Table 19-3

Comparison of Preflight to Postflight Vision Parameters

Parameter	CDR	SPT	PLT
Distance Visual acuity	Decrease	Decrease	Decrease
Refractive error	More hyperopic	More hyperopic	More hyperopic
Amplitude of accommodation	No change	No change	Increase
Introcular tension	No change	No change	No change
Depth perception a) Error	Increase	Decrease	Decrease
b) Standard deviation	Increase	Decrease	No change
Horizontal phoria a) Far	Decrease Exo	Increase Exo	No change
b) Near	Decrease Exo	Increase Exo	Increase Exo
Near point of convergence	Further	Further	Neared
Daction a) Base in	Decrease	Increase	Increase
b) Base out	No change		Decrease
Color perception	Towards dautor-anomolous	No change	No change
Peripheral fields	Increase	Decrease	Decrease
Retinal vessels a) Arteries	Increase	Decrease	Increase
b) Veins	Decrease	Decrease	Increase

noted in the Apollo data. The trend noted in Apollo, however, was not at a significant level. Although there is no known reason why these extreme fields constrict during missions, two theories might be proposed: (1) Fields constrict when there is a decrease in blood oxygen, and (2) Nonuse of the cues received from the extreme fields during the flight might temporarily "dull" the responses from these areas.

Retinal Vessel Size

On Apollo 15, retinal photography was used to determine whether the high energy particles noted during previous flights might cause retinal damage. These photographs were taken on low contrast Polaroid film, and although no damage was indicated, it appeared that the postflight photographs revealed a decrease in vessel size. This experiment was dupli-

cated on Apollo 16, but Kodachrome 35 mm film was used. The LMP showed no statistical change in the size of either the veins or arteries at approximately three hours postflight. The CMP showed a statistical decrease in the size of both the veins and arteries at approximately three and one-half hours after splashdown, and the CDR showed a statistical decrease in the size of just the veins after approximately four hours.

A subsequent in-house experiment showed that high oxygen intake alone causes a very marked decrease in retinal vein and artery sizes, but the arteries returned to normal in five minutes at ambient oxygen and the veins were back to normal in less than 30 minutes. It was the belief that some other factor caused the decrease in vessel size because of the time that the vessels remained constricted. It was not proposed what this factor might be.

The SMEAT test showed statistical size changes, but not those that would have been anticipated from past experimentation. Because time was one of the factors noted in previous experimentation, it was decided to conduct postflight photographs at three different times after the crew's removal from the chamber. The pilot was examined three and one-half hours postflight and it was found that both his veins and arteries were statistically *increased*; the commander was examined at five and one-half hours postflight and although his arteries showed a statistical *increase* in size, his veins showed no statistical variation; the scientist pilot was examined at eight and one-half hours postflight and no statistical changes were noted in the size of either his veins or arteries.

A time factor seems to be present in both the Apollo and SMEAT studies, but the alteration in vessel size is in the opposite direction during these two studies, i.e., a decrease in Apollo and an increase in SMEAT. It is unknown what has caused these differences, but the differences in confinement and the variation in oxygen levels during the Apollo mission might be predisposing factors.

SMEAT Medical Safety Plan

To assure the safety and well-being of the SMEAT crewmembers it was necessary to develop a Medical Safety Plan with emergency procedures. All medical and nonmedical test and operations personnel, except those specifically exempted, were required to meet the MSC Medical Standards and proficiency levels as established by the Health Services Division.

Health Services Division

The function of the Health Services Division in support of SMEAT was to provide medical surveillance and emergency support to the manned testing including health care of test subjects and their families, provision of hypobaric chamber support, and occupational clinical medical services for test personnel engaged in the test operation of the chamber. In addition, clinical laboratory capability to support all biochemical, microbiological, and pathological analyses was provided.

To implement the above requirements, the Health Services Division appointed a two-man team consisting of the Crew Surgeon and a Safety Officer (medical). The Crew Surgeon was team chief and was responsible for all medical aspects of the Program; the Safety Officer was responsible for physiological training, implementation of the safety program and scheduling participation of all Health Services Division personnel.

After assignment, the two-man team had responsibility for all prechamber operations including medical surveillance, physical exams, accomplishment of pretest checklist, and participation in dry runs and shake-down test. In addition, they were responsible for interfacing with the Life Sciences Directorate test project manager and the SMEAT Steering Committee and for coordination of intradivision activities associated with SMEAT.

Medical Manning Plan

The manning levels for the SMEAT Program varied with the test timeline based upon the probability of occurrence of a medical anomaly, the crewmembers' health status, and the medical data-gathering activity. The maximum manning level was expected to occur during the initial 48 hours of testing, during a medical anomaly, a possible emergency, and when experiments were conducted on the crewmembers. During other periods of this test program, the manning requirement level would be less. The medical manning plan was as follows.

Mission Crew Surgeon. Dr. Charles E. Ross was appointed to this position and his assistant was Dr. Charles K. La Pinta. Dr. Ross scheduled the Health Safety Officers who provided medical surveillance.

During the initial 48 hours, the test was monitored by the Mission Crew Surgeon and two other physicians. They worked eight-hour shifts on a rotational basis. They were at the test chamber for medical surveillance and had a dedicated line of communication with the Building 36 Medical Experiments Data Center where the biomedical data was received.

Following the initial 48 hours of testing and for the remainder of the test program, medical coverage was provided by the Health Safety Officer. Physicians were scheduled on a rotational basis for this tour of duty: During the performance of Experiments M092, M093, and M171; for daily crew status reports and SMEAT Team meetings; in the event of a medical anomaly; and in the event of an emergency.

Health Safety Officer. Three physicians were assigned to serve in this capacity. The tour of duty was for a daily period of from two to five hours, except for the first 48 hours, and scheduling was on a rotational basis. For the remainder of the 24 hours, the Medical Duty Officer performed the function of Health Safety Officer on an "on-call" basis.

Medical Technicians. This position was manned full time to assist the Health Safety Officer and to furnish relief from medical surveillance when the physician was not present. Should a medical contingency condition develop when the Health Safety Officer was absent, the technician was to immediately notify the Medical Duty Officer by telephone. Each medical technician worked an eight-hour shift. There were two teams of six men each that rotated on a weekly basis.

Hyperbaric Chamber Technicians. During the initial 48 hours of the test, the Building 32 hyperbaric chamber was manned by two chamber technicians. If a requirement existed for hyperbaric chamber therapy, they were to notify two other crewmembers who were "on-call" either at their office or residence. For the remainder of the SMEAT operation, a roster was maintained for an "on-call" chamber team, who could respond within twenty minutes after notification.

Operational Consultants. A group of specialists (toxicology, microbiology, clinical laboratory) were on call to evaluate the aspects of the operation as they relate to test subject health. In the experiments area, the consultants were the PCS/PI team. The latter were available during conduct of their respective experiments and on call to lend expertise when required in matters affecting operational health.

In the event of an off-nominal health situation, such as the occurrence of an illness or an accident among the test subjects or a physiological deterioration causing a temporary suspension of experimentation, a full-time mode of medical operation manning was planned. This mode was to exist until a decision was reached to resume normal operation or a test abort was declared. The medical manning requirement for such a contingency was identical to the initial 48 Hour Test Phase.

Prechamber Health Protection Guides

During the prechamber phase there was a health protection plan that was implemented. The following guidelines were given to the crewmen to minimize the probability of exposure to infectious disease during the last three weeks prior to test initiation.

1. Verify that immunizations for family members are current.

2. Be alert for signs of potential illness in self and family.

3. Report to Flight Crew Health Section if any change in health status of self or family is noted.

4. Limit personal contact to household members and normal work-related individuals.

5. Avoid contact by all family members with known ill individuals.

6. Avoid meetings, training sessions, etc. that include individuals other than normal work-related population.

7. Live apart from family in the event of family illness.

8. Avoid activities producing excessive fatigue or stress.

Medical Surveillance

In order to assess in real time medical data which impacted crew performance and function and provided for postflight interpretation of medical findings, medical observations on the crew health status were solicited from the in-chamber physician via the private communication line. In the event of medical problems or illness, the

crewmembers had the option to communicate directly and privately with the Crew Surgeon or Health Safety Officer.

Medical surveillance via television was maintained by the Health Safety Officer and medical technicians located in Building 7. In order to assess the crewmen physiological status in real time, medical surveillance monitoring of all M092/M093 and M092/M171 experiment runs was accomplished via television. In addition, contact was maintained with the PI/PCS team in Building 36 by means of dedicated communications line. Additional TV surveillance was maintained during three daily scans of 30 minutes duration with all cameras including the portable one. The latter camera was used to view inaccessible areas. One run was shortly after breakfast, one in midafternoon, and the other shortly before the crew retired for the evening. Contingency TV monitoring was to be accomplished any time there was a threat to the crew or test. A record of the event was to be kept in this case by the Health Safety Officer.

A number of SMEAT functional objectives were of particular interest to the medical officers. Therefore, particularly close surveillance was maintained over the following:

1. Inflight medical support system (IMSS)

2. CO_2 monitor

3. CO monitor

4. Oral hygiene

5. Microbiology

6. Chamber Environmental Microbial Monitoring

7. Operational Bioinstrumentation System

8. Body weight

9. SMEAT shower

10. Aerosol analyses

In reference to the Clinical Laboratory, certain data relative to the cellular elements of the blood, chemical constituents of the blood and urine, the hemeral and cellular factors involved with immunity, and intercompartmental fluid volumes were monitored to evaluate crew physical status. Reporting was accomplished on a daily basis and pertinent information was summarized either at the daily SMEAT Team meeting or the Test Operations Management Committee (TOMC).

Emergency Procedures

In the event of an emergency, the Health Safety Officer or his medical assistant were to enter the anteroom to render medical assistance and supervise the removal of the crewmember (or members) to a treatment facility. Two ambulances, each capable of carrying two patients in SMEAT Gurneys, were on standby at the Fire Department 24 hours each day throughout the entire test period. In the event of illness experienced by a crewmember (or members), the Health Safety Officer was to determine what medical treatment or procedure was required. During his absence, the Medical Technician on duty would, if necessary, consult by telephone with the physician "on-call." The severity or nature of the illness will dictate whether the "on-call" physician was to report immediately to the test site area to administer assistance or if it was feasible to give appropriate treatment instructions to the Medical Technician on duty.

To assist the attending physician with his diagnosis of any crewmember illness that might occur, pertinent biomedical data was to be made available to him by the Principal Investigators and Medical Experiments Data Manager.

CHAPTER 20

CREW BACKGROUND, TRAINING, AND ACTIVITIES

Crew Selection

During the early stages of planning for the SMEAT mission, it was decided that crewmembers would be selected from astronauts in training at the Johnson Space Center. Use of astronauts was considered desirable since this would insure a general comparability of background, skills, and motivation between the SMEAT crew and subsequent Skylab crews. Within the SMEAT crew, of course, there was individual variation in terms of aspects such as physical characteristics, educational and military service backgrounds, personal tastes in off-duty activities, and emotional and personality characteristics. Following is a brief resume for each of the SMEAT crewmembers.

Lieutenant Commander Robert L. Crippen, USN, was selected as *Commander*. LCDR Crippen received a Bachelor of Science degree in Aerospace Engineering from the University of Texas in 1960. He was subsequently commissioned as a Naval Aviator and served as an attack pilot aboard the aircraft carrier *USS Independence*. He then attended the USAF Aerospace Research Pilot School at Edwards Air Force Base, remaining there as an instructor until his selection in October, 1966, to the USAF Manned Orbiting Laboratory Program. LCDR Crippen became a NASA astronaut in September, 1969.

William E. Thornton, M.D., was selected as *Scientist Pilot*. Dr. Thornton received his Bachelor of Science degree in Physics from the University of North Carolina in 1952. He then served as Officer-in-Charge of the Instrumentation Laboratory at the Flight Test Air Proving Ground. He later worked as Chief Engineer of the Electronics Division of the Del Mar Engineering Labs at Los Angeles. He returned to the University of North Carolina Medical School in 1959, graduated in 1963, and completed internship training at the Wilford Hall USAF Hospital in 1964. Following this, he returned to active duty and was assigned to the USAF Aerospace Medical Division at Brooks Air Force Base, where he became involved in space medicine research. The principal interest of Dr. Thornton is in biomedical engineering. Dr. Thornton was selected as a scientist-astronaut by NASA in August, 1967.

Lieutenant Colonel Karol J. Bobko, USAF, was selected as *Pilot*. Lt Col Bobko received a Bachelor of Science degree from the Air Force Academy in 1959 and a Master of Science degree in Aerospace Engineering from the University of Southern California in 1970. He completed flight training with the Air Force and received his wings in 1960, following which he served with Tactical Fighter Squadrons. He attended the Aerospace Research Pilot School at Edwards Air Force Base and subsequently was assigned to the USAF Manned Orbiting Laboratory Program. Lt Col Bobko became a NASA astronaut in September, 1969.

Crew Training

Astronauts scheduled to participate as SMEAT crewmembers underwent an extensive period of scheduled training, similar in many respects to that required for Skylab missions. Training began in November, 1971, with initial briefings on several of the medical experiments. The training became more intensive in March, 1972, when training exercises

ROBERT L. CRIPPEN

WILLIAM E. THORNTON
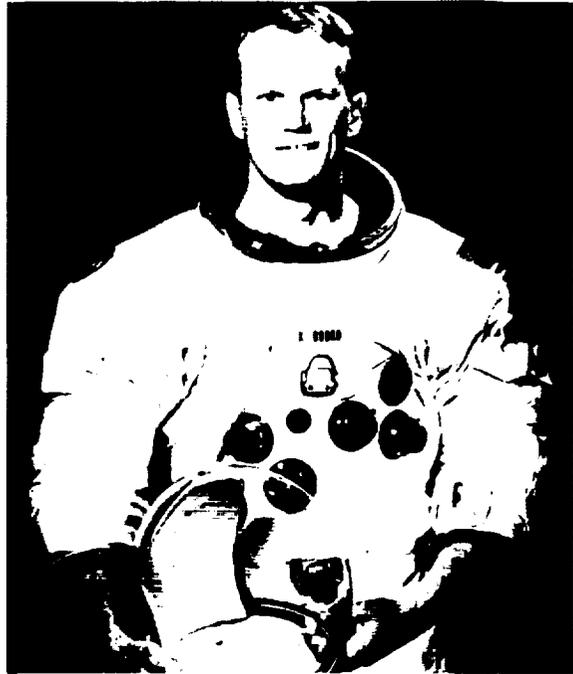
KAROL J. BOBKO

began for operational SMEAT procedures, and continued until the actual start of the mission.

SMEAT training included medical experiments briefings and hardware operation practice, chamber briefings and systems operations, storage bench checks, crew compartment fit and functional checks, maintenance briefings, test procedure and flight data file briefings, diagnostic and therapeutic briefings, microbiological training, and emergency procedures training. Table 20-1 shows the organization of the

formally scheduled training, the hours planned for each topic, and the actual time devoted by each of the three astronauts to that topic. In initial planning, 412 hours were alloted to all topics. In practice, each crewmember exceeded 500 hours of training time. However, as noted below, much of this time was not devoted to training in its usual sense.

The training schedule called for initial classroom training, followed by benchtop briefings and equipment demonstrations. Finally, the crew were to

Table 20-1

Planned and Actual Training Times
for Crew Activities in SMEAT

Item	Planned Hours	CDR	SPT	PLT
EXPERIMENTS				
M092/M093/M171	62	88 + 30	100 + 30	94 + 15
M074	2	1 + 00	1 + 00	1 + 00
M111-115	3	4 + 30	6 + 00	6 + 00
M133	30	31 + 00	31 + 00	31 + 00
M078A	2	1 + 00	1 + 00	1 + 00
M071/M073	2		3 + 30	3 + 30
Diet Management	7	15 + 00	15 + 00	19 + 00
Waste Managmt	7	11 + 00	11 + 00	11 + 00
M487	3	3 + 30	2 + 30	3 + 30
T003	3	4 + 00	3 + 00	4 + 00
Environmental Noise	5	6 + 00	6 + 00	6 + 00
CHAMBER				
ECS/EPS, COMM	6	10 + 00	10 + 00	10 + 00
Crew Systems	6	12 + 30	11 + 00	11 + 00
Emergency	12	24 + 00	24 + 00	24 + 00
CCFF/Bench Check	8	24 + 00	24 + 00	24 + 00
Mission Rules	6	3 + 00	3 + 00	3 + 00
ORI/TRRB	10	44 + 00	4 + 00	4 + 00
Dry Run Test	48	43 + 00	43 + 00	43 + 00
Alt. Shakedown Test	72	64 + 00	56 + 00	56 + 00
MEDICAL				
Physiol/Psychol	4	3 + 00	3 + 00	3 + 00
Medical Data System	2	1 + 45	1 + 45	1 + 45
Physical Exam	10	12 + 00	12 + 00	12 + 00
Microbiology	4	27 + 30	27 + 30	27 + 30
Inflt Med Spt Sys	74	77 + 00	77 + 00	77 + 00
Oral Hygiene	3	4 + 00	4 + 00	4 + 00
Personal Hygiene	1	1 + 00	1 + 00	1 + 00
MISCELLANEOUS				
Data Acquisition Cam	4	2 + 00	2 + 00	2 + 00
Timeline	4	18 + 30	15 + 00	18 + 30
Flight Data File	4	2 + 30	2 + 30	4 + 00
Paper Simulation	8	8 + 00	8 + 00	8 + 00
TOTAL	412	547 + 15	509 + 15	514 + 00

perform the actual tasks in accordance with appropriate checklist procedures in the 1 g trainer or the SMEAT chamber. In fact, the exigencies of preparing for the overall SMEAT program caused any number of alterations in the training schedule and procedures. Since much of the SMEAT equipment remained in a development stage even as training was scheduled, no firm checklists for the operation of these equipment items were available. In some instances, procedures fo, equipment operation still were being revised even toward the end of the 56-day mission. For this reason, what normally would have been routine training sessions instead became periods devoted to trouble-shooting the equipment and to the development of checklist procedures. This not only imposed a heavy workload on SMEAT crewmembers but obviously prevented training in its conventional sense. As a result of these additional requirements, the training schedule, particularly during the four-week period prior to start of the mission, was heavy with twelve-hour days and six- and seven-day weeks. At its conclusion, however, crewmembers considered the training program to have been adequate even though frequently compromised by procedural and equipment difficulties.

The SMEAT crew, following the same program planned for Skylab astronauts, received supplementary medical training off the Johnson Space Center base. They participated in a three-day course at the USAF Regional Hospital, Sheppard AFB, Texas. The course included limited observation of symptoms and a discussion of diseases of the eye, head, cardiovascular, pulmonary, abdominal and musculoskeletal systems, and dermatology. The SMEAT crew also participated in a 10-hour course conducted at the Air Force School of Health Care Sciences, Wichita Falls, Texas. Medical subjects and emergency care were treated in this course also. The purpose of these courses was to prepare crewmembers, under dire emergencies, to attempt such treatments as catheterization of the urinary bladder, nasal gastric intubation, tracheotomy (with a tracheotome), bandaging, splinting, and administration of medication.

Apart from the training in conduct of medical experiments and in emergency medical procedures, a comprehensive course of training, consisting of briefings and operational walk-throughs, was provided to acclimate the crew to living in the test chamber. These study periods covered topics such as communications, housekeeping practices, sanitation management, use of hygiene equipment, diet management, and safety measures and emergency procedures.

Final training for SMEAT crewmen was given during a sixteen-hour wet run and a three-day shakedown altitude run prior to initiation of the 56-mission. The sixteen hour wet run was performed to operate equipment that could not be operated at site pressure or without a crewman in the chamber. During this run, noise measurements were made with various equipment components running to verify that the background noise level was within the Skylab specifications. In the three-day shakedown run, the SMEAT crew used the same operational protocol as used for the 56-day test. This run enabled a preliminary evaluation of procedures, medical experiments, and off-nominal modes of operation.

Crew Activities

Flight Data File

Crew activities in the SMEAT chamber were conducted according to a flight data file located in the chamber. The flight data file included a timeline book, medical experiments checklists, malfunction procedures, systems data book, stowage book, crew supplementary activities, experiment emergency procedures, and chamber test procedure extractions for crew activity. The flight data file served not only to provide the crew with information but was used by the crew to record information in the form of various records and logs. Physically, the flight data file was in book form. The ring bindings permitted change or removal of the contents. The crew contributed to the preparation of the flight data file.

During the test, the flight data file was updated both verbally and by simulated teleprinter message, e.g., typewritten and passed through the lock. Of these two methods, the simulated teleprinter message was most effective in that it assured accuracy, saved copying time, and did not require the crew to

interrupt an experiment during the available station passages.

Prior to the SMEAT test, the in-chamber physician (SPT) and the Crew Surgeon had mutually agreed on a list and format for medical information obtained from outside-chamber analyses of medical experiments to be passed in on a regular basis. There were frequent delays and difficulties in obtaining these data until near the end of the test when a good deal of additional data, plus data collected in the chamber, were combined into a second record book. The crew felt that this record could have been even more valuable had it been begun before the test so that it could include baseline medical information.

The most frequently used item in the flight data file was the chamber log. It included sections for logging chamber parameters and other items recorded on a daily basis and was used as the basis for daily and weekly reports.

A variety of clipboards and holders was provided to hold books and logs during experiments. The crew felt these holding devices served their intended functions well.

A bulletin board in the center of the chamber for posting of constantly needed items was found convenient. The daily flight plan, communications plan, transfer lock schedule, and similar items were posted there.

Schedules (Timelines)

The crew day was conducted according to mission timelines shown in Figure 20-1, which approximated those planned for Skylab as closely as possible. One variation was that the day began at 0700 Houston time rather than the 0600 time planned for Skylab for the convenience of the operation team. Also, because the SMEAT mission was concerned with medical experiments only, whereas the Skylab mission included earth resources experiments and Apollo telescope mount activities in addition to the medical experiments, certain supplementary activities were added to the SMEAT mission.

The first 30 minutes to one hour of the day were allotted for personal hygiene and prebreakfast experiments. Blood drawings, crew microbial samplings, and crew oral samples might be scheduled during this time period.

Preparation of breakfast, consuming the meal, cleaning up, and making initial preparations for the next meal generally required about the next 40 minutes of the day. All of the crew participated in these activities. The 40-minute time requirement and involvement of the entire crew was typical of the lunch and dinner meals also.

Following breakfast, one crewmember was generally assigned kitchen and housekeeping duties followed by a television safety scan of the chamber. The other two crewmembers accomplished tasks outlined in the timeline. On a major medical day, the bulk of the interval between breakfast and lunch (approximately 1300) and between lunch and dinner (approximately 1900) was occupied by the performance of medical experiments. Two crewmembers at a time usually were occupied with these experiments with the Scientist Pilot participating both in the morning and in the afternoon. Either the Commander or Pilot was also involved.

During the time when a crewmember was not involved in the medical experiments, he was scheduled for supplementary activities such as courses, pantry restocking, system housekeeping, and television safety monitoring duties or other items. On days when major medical experiments were not scheduled, SMEAT experiments and supplementary activities were specified for all crewmembers by the time line.

After dinner, the chamber was cleaned for the evening, the daily report was prepared, and the television safety scan was accomplished. Preparation for the next day's activities would be accomplished also. Postdinner tasks generally required one hour or longer depending upon the complexity of the next day's activities.
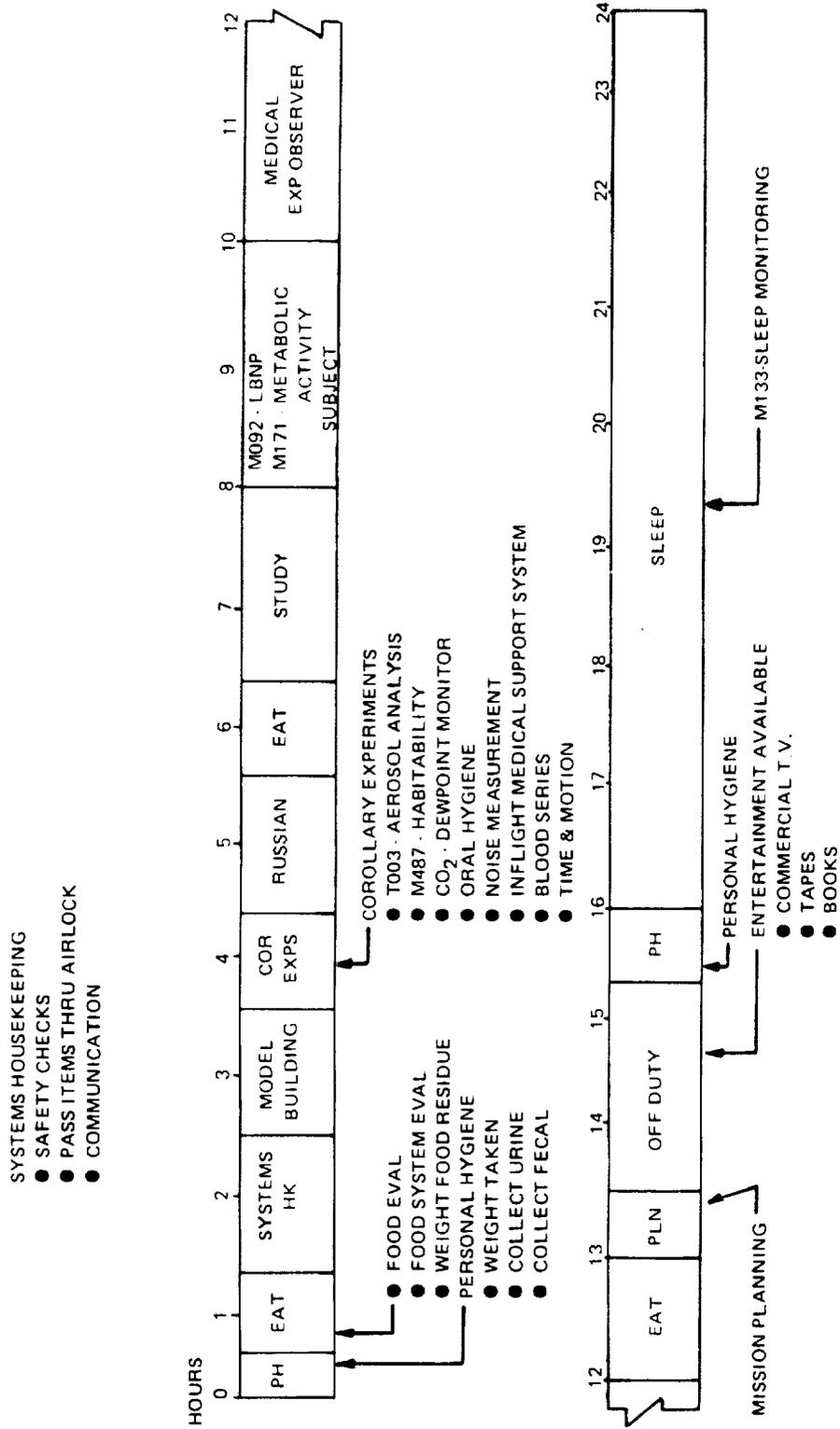
Figure 20-1. SMEAT typical crewman day.

A rest and relaxation period began around 2100. Television, the off-duty activities equipment, or the phone might be used at this time.

The planning cycle for a day was begun the morning before that day with the premission plan serving as a basis. Frequently, changes were made in the premission plan. Transfer of information with regard to these changes between the chamber and the outside was made in accord with the schedule of simulated station passes and usually occurred near meal times. Because the timeline activities were in convenient time blocks, rearrangement of activities was facilitated. The times allotted for various activities by the premission plan was generally accurate. An exception was the Inflight Medical Support System microbiological experiment which required significantly more time than was allotted.

One day a week was scheduled as an off-duty day. It was usually either Saturday or Sunday of each week, depending on test requirements. Preparation of a weekly report was one of the major unscheduled items to be completed during this day. This normally required about five hours of crew time.

Data Recording

SMEAT data recording practices simulated the Skylab mission. Five types of reports were prepared and all were found useful. One or two of the reporting types were generally found to be most appropriate for each particular task. The five reporting methods were:

1. Speaking into interphone boxes. This simulated the Skylab voice recording capabilities and was used, for example, to record calf girth and leg band calibration numbers during an M092 experiment run.

2. Logging a number of items over a time period and then repeating the group of items into the interphone boxes. An example is the recording of environmental measurements taken at various points in the chamber and reporting all values at one time.

3. The daily report prepared by a crewmember which was then read into the interphone system. Here, the chamber log was heavily used to record items to be included in the daily report, and the log also served as a record of the reports. Ten to twenty minutes were normally required for delivery of this type of report.

4. The weekly report. This summary report was prepared during the off-duty day in written or outline form and delivered using the simulated Skylab voice record capability. About one-half hour was required for delivery.

5. Direct contact with the CAPCOM. This was used primarily to discuss immediate problems. Direct contact was found difficult at times in the simulated Skylab environment because of the restricted contact with the ground. Simulated teleprinter and voice record rather than attempting to copy and answer questions in real time was more effective. A procedure which was found useful was to have the CAPCOM advise the crew when there was a simulated radio contact. This obviated the necessity for keeping a schedule of station contact.

Supplementary Activities

Scheduled SMEAT activities included Skylab medical experiments, SMEAT-specific experiments, and supplementary activities. The supplementary activities occupied timeline periods which in Skylab might be used for earth resources program experiments, Apollo telescope mount activities, and other Skylab-specific activities. The supplementary activities were selected by the individual crewmen and included a Russian course, Command Module course, astrodynamics course, solar physics course, electronics course, medical research, model building, and commercial pilot license study.

CHAPTER 21

CREW REPORT

Karol J. Bobko, Lt Col, USAF
Robert L. Crippen, LCDR, USN
William E. Thornton, M.D.

Lyndon B. Johnson Space Center

Three members of the NASA Astronaut Office participated as crewmembers in the Skylab Medical Experiments Altitude Test. This is their report on that test. The crew assignments were: Robert L. Crippen, LCDR, USN, Commander; William E. Thornton, M.D., Scientist Pilot; Karol J. Bobko, Lt Col., USAF, Pilot.

A detailed description of this test and the hardware used therein has been provided in earlier sections of this document and can also be found in the SMEAT Program Plan, Revision A, dated March 20, 1972.

The objectives of the test were:

Primary

1. To obtain and evaluate baseline medical data for those Skylab experiments which reflect the Skylab gaseous environment.

Secondary

1. Evaluate selected hardware.
2. Evaluate data handling and reduction.
3. Evaluate pre- and postflight medical support operations, procedures and equipment.
4. Evaluate inflight experiment operating procedures.
5. Train Skylab medical operations team.

Most of the Skylab major medical experiments were conducted in the course of the SMEAT test. In addition, some Skylab systems and equipment such as food, waste management, entertainment, clothing, etc. were exercised. Scheduling, communication, and procedural changes were also handled in a manner similar to that planned for Skylab.

Since the Skylab activities included in this test would not occupy our entire day, additional items such as Russian lessons, Command Module courses, medical research, and model building were added and scheduled as timeline activities.

Our participation in SMEAT began on July 20, 1971, about a year before the test actually started. The early crew participation was in the area of design and operational planning. Actual training began in November 1971. Crew training in the chamber with the test equipment began in the spring of 1972. After the completion of the test the crew continued with follow-on portions of the medical experiments until October 9, 1972.

Medical Experiments Discussion

M092 – Lower Body Negative Pressure

The M092 pretest protocol generally followed that outlined for the Skylab mission. Most training sessions were also baseline data gathering sessions to make the most of all available time. Hardware

problems noted during the test had usually been noted during the pretest activities.

During training and baseline runs, pain in the abdomen was noted by two of us at the higher delta pressures caused by the skin being pulled up around the sharp inner lip of the iris plate. Our unit was radiused, which solved the problem. We would recommend this as a change to the flight hardware.

The LBNPD had excessive leak rates during most of the test runs in spite of all crew efforts. A new waist seal was passed in and installed during the test. A zipper failed on the first new seal; this illustrated a probable single point failure. Consideration should be given to flying a backup waist seal.

The new seal was somewhat more difficult to get into since it was more closely contoured to the body. Subjectively, we did not notice a great deal of difference between the new and old seal. They should be judged on their capability to reduce leakage.

The device has a restraint strap for the legs, located at the knees, that would not remain properly positioned. Some type of restraint is probably required, but this strap is not adequate in that it would not hold the legs. Also, the Velcro on the strap tended to catch the hair on the subject's legs and cause some discomfort. If restraint of the legs at the knees is required for flight, then the strap must be improved.

A failure of the automatic blood pressure cuff occurred during the test. The unit was passed out, repaired, and returned to the chamber. The failure was caused when a wire on the accelerometer was cut by a piece of metal tubing. The same problem was encountered on a pretest failure. It appears to be a design problem and should be corrected for flight.

The Blood Pressure Measuring System (BPMS) gave values of systolic and diastolic pressure that differed substantially from those we measured using the manual blood pressure cuff from the Inflight Medical Support System. This was observed during the pretest activities, and the differences seemed more significant while the chamber was at 5 psia. This difference varied each time it was displayed, so it was impossible to just add a delta to get the correct blood

pressure. The difference was normally larger than 10 mm Hg and periodically increased to more than 30 mm Hg. The largest errors were in diastolic pressure.

During a special test run at the request of the "outside world," the BPMS decisions were compared with those of a crewman. It was found the systolic decision usually varied at least plus or minus one beat. Whether the BPMS system made the decision high or low seemed to vary with the subject and with the blood pressure. The diastolic decision was normally one to more than three beats late. Quite often there was a significant pause after the light signifying K sounds stopped flashing, and then the pressure indicated would be in the 50's. The BPMS also randomly displayed "001" systolic pressure, and sometimes "001" diastolic pressure.

There seemed to be some question by the outside as to whether the unit was in error. From our standpoint the BPMS unit used in SMEAT was obviously in error and was unsatisfactory for monitoring the health and well being of the test subjects. When monitoring a subject, just one unusual reading can cause concern. The requirement to take manual blood pressures is an undesirable task for the observor, but is certainly a task for which he should be trained. This problem of erratic blood pressure indications should be investigated to determine the cause and correction required for flight.

The heart rate display periodically hung up, normally on the calibration number. However, toward the end of SMEAT it hung on other values also. This was also noted pretest. Its frequency of occurrence increased as the test progressed. There was also no easy way to release what appeared to be a relay hang up. This failure is especially serious because both the crew and ground control lose real-time heart rate. This failure has been said to have occurred in the 1g trainer unit as well. This problem should be investigated, and any applicable correction should be made to the flight unit.

It should be noted here that the observer could normally handle the backup procedures for a single failure. When two failures were encountered, the third crewman had to conduct the experiment.

CREW REPORT

21-3

The Leg Volume Measuring System (LVMS) worked very well after some hardware problems encountered pretest were overcome. Some problems were encountered in getting good contact for a ground return from the reference band on one subject. This was solved by using electrode sponges from the Vectorcardiogram kit and some mosite wedges to hold the reference band against the leg. This procedure was then used on all crewmen and worked very well. Neither wedges nor extra sponges are baselined for Skylab. We recommend that these or similar hardware be provided for flight.

There was a problem of making crew procedures compatible with the software program used to reduce the experiment data. This was primarily associated with tagging the data in some manner such that the program knew where it was. This was never satisfactorily worked out during SMEAT. We considered the procedures used in this area unsatisfactory for flight.

This comment is applicable also to data handling for M093 and M171. Appropriate action should be taken immediately if the problem is to be solved. The appropriate action should be a software change and not a procedural one.

The shock isolation did not work. This apparently caused no problems because we always pressed on without it. If it is not important enough to fix, it should be eliminated from the procedures. There were a series of subject-to-ground shorts, all of which had been demonstrated in training, including sweat dampening the blood pressure cuff, "insulated" areas on the LBNP, portions of the temperature probe and many areas of the bicycle after sweating.

M093 — Vectorcardiogram

The Vectorcardiogram (VCG) harness used with this experiment was also used with M092 and M171. Most of the comments in this section apply to the harness and occurred during the performance of all three major medical experiments.

We were tattooed in March 1972, to mark the electrode sites, and the marks were adequate but not conspicuous.

Several pretest problems plagued us through the test. Stomaseal tapes used to stick the electrodes to the skin caused irritation to all of us at one time or another. The irritation varied between batches of Stomaseal and subjects. The irritation left scars but was never painful. We received a procedural change to reduce the amount of wiping of the area prior to applying the electrode. This cured the problem for one subject and reduced it for another. We recommend the Skylab crews try seals from the flight batch early to insure there is not a similar problem.

Some of the electrode sponges were too thin for the depth of the electrode cup with resulting high impedance. We handled this initially by using two sponges in each electrode. Any requirement to change an electrode is often a very time consuming process because it was usually necessary for the subject to get out of the LBNPD after the LVMS bands had been attached and calibrated. During the test we received VCG harnesses with electrode cup depths that were compatible with the sponges. We recommend these as the type that should be flown.

The initial VCG harnesses were too small for the SPT and PLT. This caused electrodes to be pulled off, and time was lost during electrode replacement. The problem was corrected by passing personally fitted VCG harnesses into the chamber after the test had started. We recommend that flight harnesses either be personally fitted or that several sizes be available to cover the range of crewmen.

Connectors on the modified VCG harnesses developed a binding problem after they were used for several weeks. They became increasingly difficult to connect and disconnect from the SIB. It is doubtful these could have been used for the full eight weeks. We were not able to apply Cryotox to the necessary areas to relieve what appeared to be a galling problem. We recommend investigation of this problem to determine its cause and correction for the flight items.

We often found electrode sponges that were too dry. In certain cases it was obvious they were too dry, and in others this was not discovered until electrodes

were applied and the impedance check was being performed. There was a great deal of variability between packages of sponges. This problem should be investigated and action taken to insure the sponges flown have an adequate amount of electrolyte. Consideration should also be given to increasing the number of sponges available in view of the use rate in SMEAT.

The VCG electrode kit should provide enough Zephrin wet wipes to allow for two to be used on each application (before and after), plus a reasonable number for spares.

M110 Series – Hematology

Training for this experiment commenced prior to training at Sheppard Air Force Base in the use of the Inflight Medical Support Systems. After a 1.5 hour session at Johnson Space Center, the CDR and PLT performed their first needle sticks. Blood drawing training was repeated at Sheppard AFB. During each pretest session in which we were required to give blood, we were allowed to draw blood from someone else. The training was good. We suggest, however, that flight-type needles and syringes be used with blood transferred to the Automatic Sample Processor (ASP) in Skylab training sessions as this is where problems arose during the test.

During the SMEAT test we drew blood samples of 11 to 26 ml each week. The larger amount was required on three sessions for a chamber-peculiar microbiology study. Venipuncture was not a problem, even for the amateurs among us. However, even with proper penetration of superficial veins, there were cases of spasm which made it difficult to get the blood out. There was no difficulty with deeper veins (antecubital) and we would recommend these be used even though they are not the most obvious target for a beginner.

Some blood drawing problems were caused by air leakage at the needle/syringe interface. Needle hubs and syringe fitting were obviously distorted. This leak also allowed air to get into the ASP when it was being filled. A leak at this interface is unsatisfactory, and steps should be taken to insure it does not occur during flight.

We encountered some difficulty in evacuating the ASP with the vacuum source available. A larger pump was added during the test, but it still did not seem adequate. The last 5 ml of each sample had to be forced in under pressure. This meant that a small blood spill occurred each time the syringe was withdrawn from the ASP. Steps should be taken to insure the ASP is adequately evacuated inflight, for both experimental and operational considerations.

The centrifuge was simple to operate with the exception of insuring the cover was centered. The cover was easily misaligned and even when care was taken to insure proper alignment the device still vibrated excessively in the separation mode. Steps should be taken to minimize vibration, for example, providing a centering fixture to allow easy cover alignment.

We set the centrifuge on the mosite portion of the LBNPD upper torso restraint to stop the vibration from being transmitted throughout the chamber. Consideration should be given to shock mounting the device on Skylab. Provisions should also be made for capturing the cover restraining nut and providing in-use stowage for the dummy weights to simplify zero g operation.

M074 – Specimen Mass Measurement Device

The stated purpose of this experiment was evaluation of the man-machine interface and hardware performance of the Specimen Mass Measurement Device (SMMD) in a simulated space environment. Naturally the most significant aspect of the environment, i.e. weightlessness, could not be simulated.

A prototype SMMD was available approximately a month prior to the test. The SPT and Project Engineer evaluated its performance and attempted to work out procedures for measurement of food residue prior to chamber installation. During this period of prechamber tests, several characteristics of the instrument became obvious. The temperature measuring system was incorrect by several degrees

even prior to electronics warm-up. The device was sensitive to location on the specimen tray of the mass to be measured.

Several restraint methods were tried with a variety of food residues. The most promising seemed to be placement of any residue in an elastomer (Mylar) bag which was folded to prevent spillage. Total mass of all items such as the Mylar bag, number of wipes, and the type of cans that were used in the measurement was recorded. A standard tare weight would then be used for the bag, food container, and wipes.

After installation in the chamber, runs were made at 14.7 and 5 psi. Many calibration runs were made during the test along with simulated food residue measurements. As has been noted, no food residue measurements were required during SMEAT. This had not been predicted, but we feel it reflects a realistic state of affairs. On the basis of these results, the requirement for food residue measurement should be minimal – on the order of not more than ten measurements per mission or fewer. This, of course, has potentially favorable impact on timeline and on the quantity of accessories needed for making the residue measurement.

When making residue mass measurements, two requirements must be met. The first of these is to contain the liquid and semisolid food; the second is to prevent any sloshing of this food during the measurement process. After experimenting with a large number of potential methods, it is our recommendation that a Mylar bag be provided with a small malleable metal clip to allow complete closure. The food can be placed in this along with the requisite number of wipes to prevent slosh; that is, to soak up the liquid. The number of wipes and the type of food container used should be recorded. Although other time-saving methods might be devised, the predicted infrequency of the need to make food residue measurements suggests the method described is a reasonable approach to follow.

During the chamber run, as expected, the internal thermometer readings bore little relationship (except for being constantly higher) to either ambient

temperature or the temperature of the structure as measured by independent methods. This, of course, was further confused after the instrument had been running for a few minutes and local temperatures increased while there was no increase in the support and spring temperatures. The device also continued to be sensitive to mass location.

During the test the elastomer sheet used to restrain specimens came loose since considerable local tension is applied, and the hold-down strip is very flexible. This should be modified on the flight unit.

Calibration proceeded normally and the timeline seemed realistic. The largest difficulty was experienced in voice recording the data.

Average fecal measurement errors were on the order of less than 1 percent, but some were occasionally greater than 2 percent. Some care is required to place large fecal bags in the unit since difficulty can be encountered in locating and containing these on the tray. In order to determine the minimum number of cycles required to make accurate mass determinations, each cycle was recorded without preliminary "seating in" runs. It should be possible to reduce the number of counts for ordinary measurements from five to three.

The device was performing reasonably well until the time of the elastomer hold-down separation. Prior to passback into the chamber, the unit was autoclaved twice which apparently disturbed the springs, for the device always had excessive drift after this time. Some measurements that had been planned to investigate other characteristics of operation were not possible because of this.

M171 – Metabolic Activities

The metabolic activity balance, the lower body negative pressure experiment, and the calcium balance study form an interrelated triad of experiments and are the major Skylab medical experiments.

The stated objective of M171 in SMEAT was to "determine if man's metabolic effectiveness in doing mechanical work is progressively altered by the

simulated space environment." Actually this experiment concerns itself with only one measure of work metabolism, i.e., effectiveness in pedaling a bicycle ergometer. Although not stated, some additional factors besides bicycle ergometry would seem essential to reasonably meet the stated objective. These items should include body size; composition; the strength and endurance of the upper and lower extremities; and the quality and type of pretest, in-test, and posttest exercise.

Baseline testing for bicycle ergometry plus metabolic gas analysis was scheduled to begin some six months prior to the test, but hardware problems effectively prevented any baseline data collection until a "minimum baseline" was rescheduled approximately six weeks prior to the test which included some five data gathering sessions.

The CDR experienced a large training effect such that his full work capacity was not tested, nor was the protocol revised to even approximate his 25, 50, and 75 percent of maximum load. Conversely machine limitations required test loads to be set for the SPT well below his 50 and 75 percent of maximum. Vital capacities obtained on the metabolic analyzer varied widely from values obtained on a laboratory spirometer.

As prechamber runs continued, we became convinced that the metabolic analyzer was unworkable. This was reinforced by a test of the SMEAT metabolic analyzer at 5 psi where the unit gave even worse performance. A test of the Skylab flight hardware was also made at 5 psi with results even worse than the SMEAT unit. It appeared that the metabolic analyzer had never been tested under realistic conditions at 5 psi with subjects over a wide range.

Following the completion of these tests, the decision was made to begin the test to obtain more data on the metabolic analyzer. This meant that initially the test was to be used to trouble shoot the metabolic analyzer since there was no reliable crew baseline data and the instrument was not giving valid results. This was a continuation of what had been done during the baseline period where no baseline

data, standardized training, or fixed procedures had been accomplished.

To obtain some valid baseline data we all performed tests using Douglas bags, a Collins ergometer, and a spirometer. The SPT had previously collected additional data using this equipment. For the other two of us one previous run represented our baseline data. At this time an alternate plan for inchamber data gathering was requested by us, but not implemented.

The chamber test went very much as expected with the metabolic analyzer giving variable and obviously erroneous data which typically followed the pattern of impossibly high carbon dioxide readings and carbon dioxide/oxygen readings with somewhat variable oxygen values. Vital capacities varied from 0.5 to 8.5 liters for a given individual, and on certain days expired volumes were in comparable error.

The metabolic analyzer had been wired at a number of data points, and these signals were passed outside for troubleshooting records. Raw data from the mass spectrometer, spirometer, and other points were fed into an online digital computer which paralleled the internal analog unit, and outputs are reported to be essentially the same.

In response to our requests for some valid measurements in the chamber, some Douglas bags and a turbine spirometer were passed in late in the test. The turbine spirometer proved to be useless at 5 psi, but some apparently valid results were obtained with the bags. A Collins water-sealed spirometer was passed in and a series of consistent readings of vital capacity were made each week until the end of the test. Douglas bags were run only three times for two valid determinations on each crewmember. Some of the runs gave excellent results while others were erratic for no apparent reason. It is possible that alcohol used in cleaning the bags interfered with the mass spectrometer used in analysis.

The final weeks in test were spent in a series of troubleshooting maneuvers involving some seven

special procedures, some of which were run repeatedly. One special procedure applied "fudge factors" to the calibrations in an effort to make the measurements "look right." Even after this, many of the measurements were not credible.

The respiration valves had several problems. Apparently the springs on the valves were not strong enough to hold them closed without the aid of gravity. There was a tendency for the valves to stick when there was an accumulation of moisture. The inspiration valves also opened at the end of large, rapid expirations, adding up to 250 ml of gas to the expired volume. These valves became dirty, and we used a gravity-peculiar procedure for washing them. Some technique should be developed to clean the valves in zero g for Skylab.

The expiration hoses accumulated so much liquid that a small bucket was used to drain it. Although we were reassured this was condensate, it had the appearance of saliva. Several samples were sent out for a determination of the type of liquid, but this determination was apparently never done. Posttest microbiology found a large number and variety of organisms and fungi in this hose. A way is needed to clean this hose in Skylab. It would also seem advisable to use a new expiration hose for each mission.

Other problems affecting M171 were erratic operation of the Blood Pressure Measuring System and hangup of the cardiotachometer (discussed in connection with M092). When either manual blood pressure or heart rate is required for data purposes, an additional crewman is necessary to cope with the amount of data gathered. Further, some training is required to make valid heart rate and blood pressure measurements under exercise.

The bicycle ergometer is essential not only to this experiment but to the crew's exercise program. The SPT had extensive experience with the ergometer prototypes prior to the chamber run. Except for some pedal failures it had been a reliable device, tolerating long runs at maximum workload. It is a comfortable ergometer to use.

In the chamber the ergometer failed initially on the second day, after approximately 40 minutes at 280 watts. The failure was reported to be in the load unit brushes. The ergometer was passed out of the chamber, the load module was replaced with a Development Verification Test Unit, and the ergometer was passed back into the chamber with restrictions placed on its maximum load. Even with this derating, some binding was felt at the end of a 30 minute run, and even more stringent restrictions, 150 watts maximum for 40 minutes, were placed on its use. The failed load module was repaired and placed back on the ergometer. The new operational restriction was 300 watts maximum with a maximum time of 30 minutes for exercise. The unit failed again after five days use with a loud mechanical grinding and binding followed by free wheeling. This time the failure analysis was reported to have revealed a defective strain gage. This is not consistent with the mechanical noise that accompanied the failure.

The seat on the ergometer showed a significant amount of wear considering the restricted use this device received during SMEAT.

Just prior to the end of the test, the right pedal began to bind. It was also necessary to tape the triangle portions of the pedals out of the way when the device was used in the hand mode since latches for this purpose were not adequate.

A Monark mechanical ergometer was passed in following the initial failure. This machine performed in its usual reliable fashion, after the front wheel and tachometer take-off were properly reassembled in chamber.

The PLT was the only crewman who wore the zero-g restraint assembly. The over-the-shoulder straps were too long to allow proper adjustment, especially for smaller individuals. The parachute cone tore loose after approximately one week's usage. This harness caused a heat buildup with an initial marked increase in heart rate. It also restricted motion and caused complaints of posterior tenderness from localized pressure points. There was initially a marked

difference in heart rate at a given workload with and without the harness.

A shirt was always worn with the restraint assembly but the assembly normally became wet and required drying. The harness dried without difficulty when hung from the ceiling grid for three or four hours. If three Skylab assemblies are to be provided for use by different crewmembers, a place for each to dry must also be provided. The restraint assembly was used for approximately five weeks of the test and no noticeable problem was noted with dirt, odor, or apparent bacterial growth.

The ergometer was repeatedly tried early in the test in its heart-rate controlled exercise mode. The unit's response in this mode resulted in alternating a load too great for the average man to handle with virtually no load. A recommended fitness program of ten minutes of heart rate greater then 140 beats per minute seemed inadequate prior to the test and this proved to be the case during the test. Posttest, we tried to duplicate the "heart rate" mode problem but the unit worked properly.

The earpiece for determining heart rate could be made to work at certain heart rates, if the correct heart rate were known. This was done by adjusting it until the proper rate was indicated. It read dangerously low at very high rates. The combination of stiff lead wire and no suitable ear support made it both hard to use and probably add to its inaccuracy through movement artifact. These deficiencies had been pointed out many times before the test began.

Prior to the test, a number of efforts were made to get some functional measure of muscle strength and performance as well as measurement of body composition. Several NASA units capable of such muscle measurements were found in San Francisco. These were shipped to Houston, but arrived in an unworkable condition. This was not rectified prior to chamber entry or exit.

M151 — Time and Motion

Skylab experiment M151 was conducted in SMEAT using available television cameras instead of the 16 mm data acquisition camera. Activities covered included meal preparation, food residue mass measurement, and the major medical experiments (M092/093/171).

Crew involvement was limited to positioning the television cameras and insuring that our activities were within the field of view. This constraint tends to inhibit natural motions of the subjects. We feel the camera position should be selected to cover the general area with no additional constraints being placed on the crew.

One activity to be recorded was the weighing of leftover food. However, we never had a legitimate requirement to weigh leftover food and feel this will be the case in Skylab. Thus, we suggest that a different activity be selected for this experiment, such as SMMD calibration. Food pantry restocking would also be an appropriate activity for a time and motion study. Because crew participation was limited in this experiment, no significant problems were encountered.

M133 — Sleep Monitoring

The M133 Sleep Monitoring Experiment was performed by two of the crewmembers during SMEAT. All members collected baseline data during three nights sleep pretest, but this was unsatisfactory for two of the crew and another set of three nights' data was required.

Two crewmembers began the test using the M133 instrumentation, but one developed an allergic reaction to the electrodes and their electrolyte. There was a generalized headache and some general swelling over the subject's head. After two attempts, that crewmember stopped his participation in the experiment, and the remaining crewmember replaced him for the rest of the test.

There were two failures (a power circuit breaker opened) of one of the M133 units. One of the failures occurred before the test, and the same unit failed during the test. Two preamplifiers failed during the test.

Test electrodes had more electrolyte than pretest. Test electrodes tended to leak paste, formed blobs in the crew's hair and ran down the sides of the head. Showering was the only effective way of cleaning this dried electrolyte from one's hair, but our showers were normally scheduled just before M133 data collection periods. A reverse of this scheduling would have been more appropriate.

For safety reasons, the caps for the M133 experiment were made of polybenzamedizole (PBI) instead of the previously baselined Spandex material. We found no significant comfort difference between the PBI and the Spandex caps. However, PBI caps did not have a strap over the accelerometer, which resulted in the displacement of the accelerometer from the cap of one crewman on four or five occasions.

Wearing the M133 instrumentation, with either the Spandex or the PBI cap, tends to make sleep less comfortable and seems to affect sleep level and quantity. The eight electrodes used are quite detectable when one is between your head and the pillow.

Halfway through the test the tapes in the unit were changed. One tape unit was not installed properly, and all data from it was lost. Insuring the tape is properly installed is a problem since there is no way to detect tape movement once the unit has been reassembled. We recommend some method, probably procedural, be developed to alleviate this problem.

Environmental Noise

The Detailed Test Objective concerning environmental noise required only that environmental chamber noise and possible effects on crewmen be studied. Of more importance and inherent in these measurements were the effects of atmosphere on sound production transmission and changed atmospheres perception.

There was a great deal of difficulty in getting the test wiring installed, but it was completed just prior to test start and in time for a 14.7 psi baseline run. Headphone and threshold switch lines were too short to allow optimum placement of audiometric testing

in the quietest area of the chamber, that is, the lock area.

After solving some problems of inadequately controlled hot microphones by procedural methods, the operation became more or less routine. Questionnaires supplied seemed irrelevant and repetitious. There were relatively frequent problems with the audiometer which was a screening rather than a diagnostic unit. These included spurious tones in the opposite ear and difficulty in controlling the level by the threshold switch.

In addition to the tests made at our request, spectral transmission measurements were made on the stethoscope. Voice readings were also made at 5 psi and posttest at 14.7 psi to allow later spectrometric measurements.

Crew Microbiology

The crew microbiology sampling was similar to that used for pre- and post-Apollo and that planned for Skylab. The in-test sampling was a SMEAT-peculiar test and in no way reflects any plans for Skylab.

The protocol consisted of a full set of samples every other week and a gargle each week. We performed the sampling pre- and posttest and in the chamber to reduce sampling variability. This also allowed for a considerable amount of practice under the observation of the experimenters. Because of this practice and the planning by the experimenters no problems were encountered during the test.

The only problems involved with this experiment were experienced pre- and posttest. These were remembering that we were to be sampled and trying to generate a fecal sample within the constraints of working hours, midweek, diet, and collection facilities.

Environmental Microbiology

This was a SMEAT-peculiar test that involved periodic collection of metal strips in the chamber, and operating an Anderson air sampler for ten minutes.

There were vertical strips at various locations on the walls and horizontal strips located under the air grids in the plenum area to collect bacterial fallout. We feel the horizontal strips did not properly reflect the chamber environment. Since all air circulated through the grids, a large amount of trash was deposited on the plates including urine and waste water spills in the waste management compartment. Procedurally we were not supposed to touch the plates except with sterile forceps when we were collecting them, which resulted in their becoming filthy. It is difficult to imagine any area becoming this dirty without the crew taking some action to clean it. In view of this we felt that any conclusions regarding the data on these strips should consider they were the filthiest thing in the chamber only because of the procedural restriction on cleaning. There were no operational problems with the strip collection and air sampling tasks.

Inflight Medical Support System (IMSS)

The stated purpose of this experiment was to fully exercise the IMSS equipment and obtain simulated diagnostic microbiological samples using the equipment and procedures checklist inchamber. There were two aspects of the equipment, one a physical diagnostic and treatment capability and the other a microbiological and hematological diagnostic capability.

Training on this equipment started with a trip to Sheppard AFB. These efforts were somewhat poorly organized, too much detail was covered in too short a period of time, and many practical aspects of equipment use were neglected. Pretest training was provided locally with available hardware. Unfortunately the actual hardware was frequently not available or only available in separated bits and pieces and not as a kit.

The dental area of the IMSS deserves special mention. Although this was a simpler effort, if for no other reason than the restricted anatomical area it treats, the training and kit were thought out and executed in an exemplary fashion. Only the essentials which were likely to be encountered were considered, that is, extractions and other emergency procedures. The more esoteric aspects of dental care were not

belabored. Practical training was excellent with good exposure to clinical material at the USAF Dental Clinic at Wilford Hall in San Antonio. The dental officer was always present and had first-hand knowledge of just what each member of the crew was capable of performing.

It is felt that the amount of time allocated for the IMSS training is at best minimal. This is particularly true of the microbiological and microhematological procedures.

During the training period a working slide stainer was never seen in conjunction with all the rest of the equipment nor were the complete examination and treatment kits seen together. Some weeks before the beginning of the test, it was decided that the IMSS diagnostic and treatment kits were required for development of Skylab procedures. These were, therefore, removed from the SMEAT chamber. After considerable scrambling a scratch kit was put together utilizing Development/Verification/Test Unit cases and other components which could be acquired. We saw this gear for the first time when we carried it into the test.

The diagnostic kit was used several times in routine physical examinations and is considered generally adequate with one or two exceptions. The tongue depressor cannot be adequately sterilized from one patient to the next, nor could we devise a really humane way of using it. This item was not included in the chamber kit. Fortunately we had a few wooden tongue blades in sterile packages. These are recommended for Skylab.

Our kit was packed without electric bulbs in any of the equipment requiring them. The bulbs were poorly marked. This resulted in at least one error with a consequent burnout. Bulbs should be marked plainly for the respective equipment.

Two blood pressure inflation bulbs failed, and a backup should be considered.

The chief difficulty in performing a physical, and in most of the IMSS work, was the lack of adequate lighting and adequate work space. While there was no

problem in using the small pieces of IMSS equipment in 1 g, there must be some method of restraining all the small pieces in Skylab.

Another difficulty was the reduction in sound transmission with some change in frequency characteristics caused by the 5 psi atmosphere. Mediate percussion was very difficult, and was probably made more so by the increased low frequency noise in the chamber. It could only be accomplished if the ear were about ten centimeters from the finger. Under these circumstances more or less routine percussion could be carried out, and such items as heart margins, descent of the diaphragm, and liver margins could be delineated consistently. The volume produced by the stethoscope was markedly reduced, and there was some change in frequency response which made breath sounds in particular more difficult to evaluate. In order to document this, a stethoscope response characteristic was run at 14.7 and 5 psi as an adjunct to the noise measurement test.

The Politzer bag was also rendered useless by the 5 psi atmosphere, for useful pressures could not be developed. The nasal 'olive' on the unit was also too small. A few medications supplied in the IMSS were used. Nasal emollient was used by the PLT for drying of the external nares. It was considered to be effective here, but useless on the CDR's chapped lips. Alphakeri was also tried with no success. One of the most widely used items was Phisohex, which appeared to give excellent control of a beard folliculitis on the CDR as well as provide some reassurance in cleanup of urine spills and general chamber hygiene. Tinactin was used in an attempt to control the SPT's athlete's foot. This was the total extent of the drug usage.

Bandaids were frequently used to cover minor wounds, the most common of which were inflicted by knives used to open beverage container tops. No real evaluation could be made of many of the items such as catheters, surgical supplies, and the like.

The microbiology/hematology portions of the kit involved the most frustrating procedures to be performed in the chamber run, with the possible exception of urine spill cleanup. The first difficulty

was experienced in unpacking the Command Module Resupply Kit. The mechanical manipulations involved in opening it were a major problem, immediately followed by more difficulty in attempts to remove the internal racks. Closing was another major ordeal. The rack is too tight in the container and does not have adequate removal facilities. We pulled off the tabs that were apparently provided for removal. This was followed by a fight with all manner of tools. The Resupply Kit took up a great deal of room in the chiller and was difficult to get in and out.

Another great difficulty associated with use of the Resupply Kit was of collecting the many pieces for a procedure and then tying them together in some orderly fashion. The checklist, while more or less complete, did not help greatly in simplifying this; however, it did make possible the completion of the task. The bits and pieces required to complete the typical day's procedure were scattered in several lockers and in several containers in each of the several lockers. These items were used at various times throughout the procedures, and some of them needed refrigeration until the time of or immediately after usage.

There was insufficient light to handle and identify cultures and inadequate working space on the foldout locker work surface in front of the incubator. This was not sufficiently sized or correctly arranged to allow any reasonable procedures to be carried out. The additional IMSS work table was usually required while the portable light, which was never really sufficient, was placed above it. Even then there was frequent spill-over to other portions of the chamber.

The cleanup and prophylactic procedures for handling cultures of microorganisms was also considered inadequate. Betadine pads by themselves were felt to be inadequate, especially in crevices or in attempting to deal with Velcro pile and hooks.

In terms of equipment, the first difficulties were encountered with the poured plates. The SPT felt these were poorly controlled. Although they were sterile on opening they certainly did not give that appearance. They were very uneven and the surface was extremely friable. It was impossible throughout

the test to use the loop to adequately spread the organisms without digging into the surface.

Vertical positioning of the Petri dishes in the incubator allowed condensate to drain to the bottom with cross-contamination of the dishes. This was corrected by placing the dishes horizontally.

The first day of an IMSS "illness event" usually went reasonably well. Increased difficulties were encountered the second day and quite often the timeline was overrun by approximately one-half hour. Trouble always developed on the second day with the dispensers for the sensitivity disks. Initially approximately one hour was spent trying to make the dispensers work properly. Some of them could never be properly bent into shape. These dispensers should be corrected prior to flight.

The third day always required at least one hour more than the timeline allowed. One problem which caused this delay was the slide stainer which obviously had air in much of its plumbing. At the request of the project engineer, about halfway through the test the slide stainer was closely examined by removal of the baseplate. There apparently is some extremely volatile material in the decolorizer and Wright fixitive alcohol which produces a large amount of vapor. This not only produced vapor in the lines but also must have forced much of the liquid out of the reservoirs for they were practically empty when examined. After removing all air possible from the reservoirs by means of needle and syringe and reinstalling them, the problem of air in the lines up to the point of the selector valve was eliminated. The problem of vapor in the alcohol lines, however, persisted.

There were air leaks in the selector valves, evidenced by the fact that air was frequently present in the line going to the staining chamber itself. Further, there was a good deal of backflow into the various staining lines unless the selector switch was moved to the S position. This later became standard practice.

Once some of these problems were resolved, the stainer produced reasonable results.

After a slide was finally stained (the smears themselves were always fragile and felt to be improperly fixed), there were problems in observing it under the microscope. Focusing was repeatedly difficult. This problem seemed to be caused by leakage of oil into the microscope objectives. The stage, which was nothing more than a pair of rubber rollers, was almost impossible to use in examination of bacterial slides. The optics left a great deal to be desired and had gross color defects, as well as marked aberrations, such that it was difficult to differentiate between cocci and short rods. A second modified stage with mechanical adjustment was passed in, and this was a marked improvement. It is recommended this type stage be included with the flight equipment.

After gram-staining, one was usually well behind the timeline, and then had to proceed with collecting another handful of bottles and reagents for further identification of the organisms. The catalase reaction, for example, was never successful until near the end of the test when the peroxide was simply poured over the material rather than allowing it to wick up through filter paper per c/l. This, of course, will not work in orbit.

The hematology portion of the kit also presented many small problems. We were not notified that the dilution bottles and counting chamber were in fact not going to be used on Skylab and many frustrating hours were spent in attempting to use these devices. It was indeed a wise decision to delete them from Skylab.

The hemaglobinometer gave some trouble through the entanglement of the small steel cables tying the pieces of the chamber together.

Wright staining could never be satisfactorily done. It was felt that the use of the slides to manually smear the blood may have caused some trouble. Indeed it is hard to see any reason why a proposed simple plastic smear-spreading device cannot be incorporated for Skylab. After literally dozens of efforts the following conclusions were reached about the Wright staining procedures. Apparently some factor, probably atmospheric, causes disruption of the white cells and shrinkage, as shown by crenellation, of the

red cells in thin smears. The existing red cells stained beautifully. In thick smears where there was inadequate staining of the red cells, the white cells would stain beautifully, although there was some question as to the adequacy of staining eosinophils and basophils. This may have been another defect of the microscope optics.

The urine-specific gravity refractometer appeared to work well. There was difficulty with the urine collection bag in that apparently a portion had been omitted. There is real doubt as to how clean the catch will be using this arrangement.

Operational Bioinstrumentation System

The Operational Bioinstrumentation System (OBS) was donned and used by the crew during certain preplanned exercise periods. Instead of using the constant wear garment (CWG), we used a belt designed and fabricated by the Johnson Space Center Crew Systems Division. We believe the belt would be easier to place on a crewmember than would the CWG and recommend one should be carried on Skylab for that purpose. The Stomaseal tapes included in the OBS were superficially similar, but obviously different, from those in the vectorcardiogram kit. These tapes caused irritation on one crewmember who had minimal irritation with the VCG Stomaseal tapes. The OBS was not uncomfortable while exercising on the ergometer.

During use of the OBS there were two EKG signal failures: an external recorder failed and the run was aborted. The second signal failure was caused by an electrode/skin contact problem. This was solved by electrode manipulation. The last few runs were made using paste squeezed from a bottle whose top failed at least once. We feel the paste-soaked sponge is a better arrangement.

Habitability/Crew Quarters

The SMEAT chamber was quite livable for the 56-day test. During the buildup of SMEAT, the crew requested a number of changes be made related directly to habitability. These included making the upper deck available for crew activities, adding two desks, and controling machinery noise in the chamber. All proved to be important. The desks on the

upper deck gave us a place to work undisturbed on a work surface that was of reasonable size and well illuminated. The noise level was tolerable.

The carbon monoxide monitor installed in the wardroom had been intolerably noisy and attempts to quiet it were only partially successful. The noise it generated was irritating and interfered with internal and external communication.

The chamber was of adequate size to be reasonably comfortable, but more room in a few areas would have been welcomed. The size of the wardroom was such that moving items in and out of the transfer airlock was a chore, and it was nearly impossible for one crewmember to move around another who was seated at the food pedestal. The Skylab wardroom is larger that the SMEAT wardroom and does not have the transfer lock, so this problem should not be present. The waste management compartment was small, and this made it difficult to change the urine system and clean around and under some of the items.

The lighting within the chamber was adequate for normal activity, but inadequate for any very close work. Some of the tasks that required bright light could be done at the second level desks with their desk lamps, but other tasks did not lend themselves to being performed on the second deck. There was a portable lamp within the chamber, but it proved not to be as portable as we would have liked. Hence, there was often a deficiency of light when close work was being performed.

We and the chamber stayed cleaner than we had expected, but cleanliness required rather constant attention.

The furnishings were rather spartan, but were adequate for the mission being performed. The large amount of exposed metal made one think of a ship and probably added to the noisy environment. All parts of the chamber received noise generated anywhere in the chamber.

Three SMEAT-peculiar items made the chamber more habitable. These were a television, a telephone,

and lawn chairs. The television was used in the course work that supplemented our Skylab activities, but it was also used each evening for entertainment. Generally two crewmembers watched television one and one-half to two hours per day. We watched movies provided by the Navy motion picture service. Unfortunately the frequency of good movies from this source was rare.

The access we had to commercial telephone system was also important as it gave us an opportunity to keep in touch with our families and friends. We limited these calls to personal matters and used the normal communications loops for SMEAT operational communications. Problems with this system are discussed in the *Chamber Systems* section.

The change in the environment because of the atmosphere being 70 percent O_2 and 30 percent N_2 at 5 psi was practically unnoticeable. One found that speech seemed to shift down in frequency, and noise in general was down a bit; but we soon became unaware of these changes. It was almost impossible to whistle when we first entered the chamber, and a sneeze did not have nearly the force it did at 14.7 psi. There was significantly more abdominal gas during the entire time at 5 psi.

The chamber was comfortable at 69° F. Before the test, one of the crew complained of his feet being cold on the aluminum floor, but this was alleviated by shoes with heavier soles. These shoes also made standing on the metal floor much more comfortable. We seldom used the fan when the temperature was at 69° F. We had the subjective feeling that the 5 psi atmosphere carried less heat away from the body than a normal atmosphere. This meant a cooler temperature was more comfortable. The low humidity level of the chamber made perspiration more effective and balanced the capability of the atmosphere to carry away heat during exercise.

There was a period of approximately four days when the temperature was raised to a maximum of 77° F, and the humidity was allowed to rise to about 60 percent. It was not as comfortable at this temperature and humidity but it certainly was livable. We found there was much more condensation in the chamber. We felt the heat more, particularly during exercise, and clothes and towels took longer to dry. During this period the Skylab fan was normally used during exercise.

Less clothing was worn during the high temperature period. The SPT removed his shoes and socks. The PLT removed his undershirt and the legs of his trousers; and the CDR removed his shirt and trouser legs.

There was a habitability experiment, M487, that had questionnaires concerning habitability and some measuring instruments. The questionnaires were of two forms — tabular and discussion type. We found that for many of the more subjective items the tabular form was quite inadequate and really did not stimulate the crew to identify why they felt the way they did. The discussion items stimulated some conversation between the crew and appeared to bring out salient habitability features of the chamber.

The measurement instruments proved useful to us, and we envision they will be useful in Skylab. The packing of the instruments makes them difficult to get in and out of the drawer, and this may have contributed to the failures of the "meat type" thermometers. The digital thermometer was slow to respond, probably because of the size of the probe. The accuracy of this instrument is questionable, probably because of heat transfer to the large hand-held probe.

T003-Aerosol Analysis

This is a Skylab experiment designed to look at particulate matter concentration and size distribution. We used the Skylab protocol as defined prior to SMEAT.

The aerosol analysis unit is small and simple to use. The only operational problem involved missing some of the displayed numbers. There are three sets of numbers displayed sequentially after a fixed time period. It is then the job of the crewman to log three numbers as they are displayed. There were several occasions when something would happen to distract us from the instrument, and the readings would be

missed. If this happened we simply reinitiated the cycle. It was assumed this would not have an adverse effect on the experimental data.

The instrument displayed questionable data. Particulate count proceeded at some relatively low number, and then for no apparent reason it increased tremendously. The cycle could be immediately reinitiated, and the numbers would return to what they normally read. We began to question the validity of the data. There is no inflight provision for checking this instrument. We tried covering the intake port and discovered the readings were still about the same. When this was reported, the T003 device was passed out of the chamber for calibration and was not returned.

We recommend a check be made to determine if the device is working properly. If possible some means should be devised to check the device in flight.

Chamber Systems

The chamber systems, which were peculiar to this test were, in general, excellent.

We had some problems with the communication system in trying to work out the proper gain settings such that there would be no feedback through the various intercom boxes. The gain had to be increased when the chamber was at 5 psia to use the box mounted microphones. Most problems were worked out pretest. This is probably worthy of consideration for Skylab since the on orbit gain settings will probably be different than for ground test.

There was also some crosstalk on various channels of the communication system which was disconcerting at some times and irritating at others. Part of our communication system was a telephone capability. The initial system was very poor and the party outside could rarely hear us. During the test this was changed to a hard wire system that was a great improvement over the old system, but the incoming volume was low for off site calls. The concept of the telephone is a good one and it proved to be quite useful from the standpoint of work and entertainment.

The environmental control system performed its job satisfactorily throughout the test except that it was unable to control humidity at elevated temperatures. An irritant periodically appeared in the chamber air. This caused a scratchy throat, watery eyes, and runny nose in two of us. It was most noticeable when working with the LiOH canisters, hence, we connected it with them, but never actually determined the specific cause. Some of the symptoms were quite similar to those individuals have experienced in orbit and attributed zero g.

The gas monitors had to be calibrated twice a day and this produced the possibility of false alarms because our alarms came off the recorders rather than the transducers. This proved to be annoying.

There never was an in-chamber fire alarm, false or otherwise, on the fire detector system.

The lighting and electrical system performed well throughout the test. The reading lamps flashed when they were off for no explained reason, but this presented no real problem.

The water system worked well. A decision was made prior to test start to reduce the iodine content from 6 to 4 ppm, which improved the taste considerably. The waste management compartment water collection tank overflowed a few times and produced a foul, sulfurous odor. This was cleaned up with no significant problems. The drain from the sink into this tank was also stopped up, and we felt that some object might have been lodged in the line.

The odor removal filters in the waste management compartment performed superbly.

The entertainment system, which consisted of television as well as AM and FM radio, worked well and was a tremendous asset to the chamber.

Hygiene and Housekeeping

The personal hygiene facilities within the chamber were insofar as possible, similar to those in Skylab. Included was a small test-peculiar sink for wetting washcloths, Skylab personal hygiene kit

articles such as washcloths, soap, razor, clipper, and a shower which functionally approximated the Skylab system, including water quantity and temperature. Not included in SMEAT was the Skylab washcloth squeezer, and Skylab towels.

Showering. We found that the personal hygiene facilities within the chamber were adequate to enable us to feel relatively clean. We always looked forward to the weekly showers and believe they will be one of the most welcome Skylab habitability features. The six pounds of water was adequate for a quick shower, but certainly should not be decreased. Water temperature was acceptable, but hotter water was desirable. We did try showering at the highest test temperature available, 125°F, and found this to be preferable. Skylab miranol soap in the shower proved adequate though the quantity was minimal.

The setup and use of the SMEAT shower was smooth and the spray nozzle worked well with the amount of water available. The SMEAT shower was drained by gravity, and a pan of shower water was passed out of the chamber after each use. Drying of the shower was accomplished by wiping the base with a towel and allowing the sides to dry in the setup position while we were having dinner. On a few occasions, the Skylab fan was set up to blow air to dry the shower, but with or without the fan the shower appeared to adequately dry in two or three hours. At no time did we ever find evidence of any filth or growth in the shower, and at no time did we ever use betadine or any other preparation to clean the shower.

Daily Personal Cleansing. The day-to-day personal hygiene procedures used the contents of the Skylab personal hygiene kit. These were acceptable but we believe the kit would be more effective if each individual could tailor it more to his needs. In one case the kit proved not to have enough toothpaste, and there were unused items.

Skylab Neutragena soap was the only cleaning agent in the test and was adequate. We used about half the soap provided.

We tried three different types of washcloths which included the Skylab washcloths, polybenzamidizole (PBI) washcloths, and a cotton-type procured especially for SMEAT. Of the three types supplied, the Skylab and PBI washcloths were felt to be the best and were about equally effective. The cotton washcloth had little body and was more like a dish cloth. We used approximately one and one-half washcloths per man per day as opposed to the two washcloths per day assigned on Skylab. Since the washcloths are useful for many applications besides personal hygiene, we recommend the Skylab quantity be kept the same.

Two types of towels were supplied for our use, PBI and cotton. We preferred the PBI since the cotton towels, like the cotton washcloths, appeared more like dish cloths than towels. There was one towel per man per day, and we used approximately six towels per week.

Two types of razors were also supplied. One was a windup razor that was adequate for two of the crew pre- and posttest. For the other crewman it dulled consistently after two weeks use on a heavy beard. The other was a standard safety razor that was used with a brushless shaving cream.

The procedure that developed among us was to wash in the morning and evening and, every day or two, to take a body sponge bath after our exercise periods. At this time we would try to wash completely using the small sink and washcloths. This was probably more convenient in SMEAT than it will be on Skylab due to the test-peculiar sink. This method of cleansing was not as effective as taking a shower, but it did clean off much of the perspiration generated by exercise. During this period also, we changed any of our clothes that could be changed for the day. It is our recommendation that a personal hygiene period adequate for rather complete washing be scheduled after each exercise period.

A pair of hair cutting scissors were provided for the chamber stay that are not included in the Skylab stowage list. No extensive hair cutting was done, but we found the scissors a useful item.

Housekeeping. Housekeeping procedures for the chamber were developed by the crew during a number of pretest training exercises. Most of the original procedures called for cleaning the chamber with wipes and betadine pads. Wipes were adequate, and we used washcloths and towels that had been used for personal hygiene, dried, and saved for housecleaning. These washcloths and towels were used with the Skylab soap to clean floors and cabinets as required.

Subjectively the chamber seemed clean. We had three major housekeeping periods of approximately a half hour after each meal. The morning period was used to change the lithium hydroxide (CO_2 scrubbers) canisters and to generally get the chamber ready for the day's activities. The afternoon period was the main housekeeping period of the day, and at that time we did major tasks, such as washing floors and vacuuming. The compartments to be cleaned and many of the items to be accomplished were indicated on the teleprinter timeline by an appropriate code.

The floor was the most difficult item to keep clean. The waste management area floor required wiping on a daily basis since some water from condensation was often present. Also, test-peculiar shoe soles marked the floor badly.

In cleaning the waste management compartment betadine pads were used on items such as the fecal collector seat, and urine cup holders but were not generally used throughout the compartment. It would probably facilitate cleaning if some cleaning agent were provided to clean surfaces such as walls and floors that would remove dirt and grease better than the personal hygiene soap or the betadine pads. The last housekeeping period was in the evening. At that time, all trash and fecal cans were gathered together and sent out through the airlock and the chamber was checked for combustible materials that may have been left out from the day's activities.

A surprising amount of lint collected in the chamber. It appeared to come from the X-420 material from which clothes and bed linen were made. This lint gathered in corners, under bunks, and in other closed areas and was routinely collected and passed out of the chamber for analysis.

Both the Skylab vacuum and the Apollo vacuum cleaner were available for our use. When the test started only the Skylab vacuum was in the chamber; but this proved ineffective, and the Apollo vacuum was requested. The Skylab vacuum did not have adequate power to pick up debris on the floor. In our experience, the Apollo cleaner was two or three times as effective in picking up things than was the Skylab cleaner.

A disadvantage of the Apollo cleaner was that all items were sucked against a screen at the brush and had to be removed by hand and placed in a collection bag. Also, enough items apparently passed through the screen to clog the vacuum cleaner. This caused it to cease to function, and it had to be passed out of the chamber for cleaning.

During the test, modifications were made of the Skylab vacuum cleaner pick-up brush. These modifications made the vacuum slightly more effective, and we judged it minimally satisfactory.

We were concerned about collecting liquid with the vacuum cleaner. We tried collecting a small amount of water with the Skylab vacuum and found it deposited in the hose, and none of it was collected in the collection bag. If the liquid had been such that it turned foul with time, the vacuum would have undoubtedly smelled terribly. For this reason we believe that water is the only liquid that can be picked up with the vacuum cleaner, and water may more effectively be wiped up with a cloth.

One particular problem encountered in the chamber was urine spills. These were cleaned with washcloths, towels, undershirts, and anything else that would absorb liquid. After the urine was absorbed the area was cleaned with betadine. To improve this cleaning procedure, gloves of some sort should be included so that one's hands would not be exposed to the urine.

Trash accumulation in the chamber was less than we had expected. We used one trash bag in the

wardroom for both wet and dry trash: one trash bag in the waste management compartment; and one large trash bag in the experiment area. Trash bags were emptied each evening. The second trash bag in the wardroom was taped shut and never used, and the trash bags in the sleep compartments and experiment area were seldom used and seldom emptied. The large trash bag in the experiment area collected most of the chamber trash and was especially handy for large items such as clothing and bed linens.

Tissues and Wipes. Tissues and wipes were used for many purposes in the chamber, including housekeeping and personal hygiene. When the test started we had approximately the number of tissues and wipes programmed for a 56-day Skylab mission. After less than two weeks of use, we realized that inadequate numbers had been stowed. From that time, we conserved wipes as much as possible and alerted Control that we might run out of wipes before the test was complete.

We ultimately ran out of wipes on day 52, and, therefore, recommend one additional box of wipes be placed aboard Skylab for each month a crew is aboard. This represents a total of five additional boxes, depending on the number of wipes in a box. The wipes originally included in SMEAT were different from those later passed in to us, and the count per box differed. With fewer than 196 wipes per box, one additional box per month would be insufficient. The six wipes per day per man provided were often not adequate. More than six wipes per defecation were required due to stool consistency. There were also multiple defecations on a single day. Tissues were used whenever they could be substituted for a wipe. We recommend the number of tissues be kept the same.

Inventory of items such as tissues and wipes caused some problem. To alleviate this, we suggest Skylab crews use tissues and wipes from as few boxes at a time as possible. One open wipe box in the wardroom and one in the waste management compartment should be adequate. In this manner, as a box is emptied there would be a good inventory point.

Waste Collection

As part of the M070 series experiments we were required to collect all body wastes during the pretest and posttest periods. The pretest period of collection began with a rather loosely defined plan, and the results that were reported to us indicated it was inadequate. During the test, the method of control of these items was improved, and the posttest collections appear to have progressed more smoothly. During the posttest period a system of positive control was implemented: all containers were coded to prevent any mixing of samples.

It was our experience that collecting samples was a rather alien and unpleasant task. It should be made as easy and unconfusing as possible. This was especially felt in the pretest period when we were expected to perform our normal activities, including flying and a large number of other tasks in preparation for the test. It seemed that during the pretest period one had to think of every action, however basic and simple, because information related to these actions were required for the test.

To make specimen collection easier while away from the normal work areas, a carrying case was developed which would keep urine and water chilled. This was made available to us posttest as a result of our pretest experience which pointed to the need for an inconspicuous, small, lightweight, easily carried case, capable of being flown aboard an aircraft. Four stations were available at the Johnson Space Center equipped with refrigerators and specimen collection containers for our use, but no pretest provisions were made for off-site specimen collection. Our posttest experience indicates the carrying case is adequate, and we recommend it be available for the Skylab crews.

Another procedure instituted posttest was a daily briefing on the wastes collected during the previous day. If all goes according to plan this briefing is superfluous, but if there are problems the briefing allows the subjects and the experimenters to discuss what happened and hopefully resolve the problem. We recommend this be done for Skylab since there are bound to be unexpected occurrences in the hundreds of man-days of collection.

Skylab Urine Volume Measuring System

A single complete Skylab Urine Volume Measuring System (UVMS) was placed in SMEAT to be used by the SPT to determine crew acceptability and timelines and to verify that the system worked properly. This was a prototype unit which differed in some ways from the flight unit: for example, it had a number of sharp corners and a special centrifuge outlet nipple to allow for 1-g operation. An early version of urine bags and collection hoses/funnel assemblies were initially supplied for use with the unit.

Prior to SMEAT several problems were encountered including excessive condensation inside the drawer on the cold plates and in other cold areas, an ammoniacal stench whenever the urine blower was on, and failure of the test-peculiar centrifuge output nipple. It was discovered pretest that with the door properly sealed the condensation on the cold plates ceased to be a problem. Also it was discovered that the blower had a good deal of sound deadening material which had absorbed odors. Removal of this soundproofing material and installation of a new charcoal canister solved the odor problem. A new centrifuge with another test-peculiar outlet nipple was installed prior to test start. There was some difficulty with urine regurgitation from the collection hose, apparently due to inadequate airflow.

During the test the UVMS was used in the same fashion as planned on Skylab with the collection hose/funnel assembly kept at the level of the centrifuge. On scheduled days, all urinations were measured and 10 percent aliquots were removed from a measuring cylinder, pooled, and passed out separately to allow volume and chemical comparisons with the UVMS system.

On many days, the SPT kept a record of each micturition volume by catching it in a volumetric cylinder and recording this. Also a crude check was made of each crewmember's daily urine volume by weight.

One of the most significant problems, which was noted even before the chamber run began, was inadequate bag size for a 24-hour pool. The SPT and

PLT exceeded the 2000 ml limit on occasions, and the CDR would typically produce approximately 3000 ml.

Another major problem encountered was urine spills. Even before the test began there was one large urine spill when the previously mentioned centrifuge outlet nipple separated. During the test on days 208 and 209, there were small spills apparently from leakage at the outlet of the centrifuge. There were six major (approximately one liter or more) urine spills from this system during the 56-day test. On day 210 there was a spill due to a repeat failure on the centrifuge outlet nipple. On days 233, 236, 244, 250, and 258 there were major spills due to failures such as tears in the urine bags. One of these failed bags was of flight configuration. These spills required a minimum of an hour to clean, and it was impossible to ever completely clean the unit and surrounding area. This resulted in a significant odor especially in the urine drawer itself.

One of the major difficulties after a spill was inadequate materials and procedures to clean it. The UVMS drawer was filled with small items with sharp corners and bends. This not only held the urine but made any attempt to clean it a hazardous job. The centrifuge had to be removed as the initial step. This and subsequent cleaning usually resulted in nicked hands from surfaces coated with urine.

The UVMS cleaning tool proved to be of little use. We tried two versions in the chamber, neither of which was adequate. For proper cleaning one always went back to using washcloths, towels, undershirts, and the like, held directly in the hand. Another useful item was the "mechanical fingers" in the tool kit. These served the purpose for which the cleaning tool seemed to be intended, i.e. for cleaning hard to reach areas.

Another significant problem encountered was the inability to obtain a proper sample from the system. Most of the sample bags had not been properly evacuated. Hence, when the chamber pressure was reduced, they exploded. It was then necessary for the SPT to evacuate and refold most of the sample bags prior to using. These bags would never fill properly in the compartment made to hold them. If they were

removed from the compartment, they tended to overfill which might cause problems in the refrigerator tray.

There was a problem with low airflow through the collection hose with the first two centrifuges. This caused pooling of urine in the collection hose with spillage. The third centrifuge had adequate airflow, and spillage from the collection hose funnel was markedly reduced.

In an effort to investigate this airflow problem a flowmeter was passed into the chamber. This meter indicated extremely low flow values. Flow was later correctly measured by means of a Collins spirometer which had been passed in for respiratory studies. The flow on the last centrifuge used, post day 235, was approximately 85 percent of specification, which was adequate.

An attempt was made to change the centrifuge filter on day 235. It was impossible to manually remove the filter assembly from the centrifuge. The food overcan lid removal tool was "lashed up" to remove the filter. Some type of appropriate tool should be considered for Skylab to accomplish this task.

On the day following the filter replacement the unit began to drag, apparently because of interference between the filter assembly and the case. Subsequent investigation proved the filter had not been properly latched in place. Apparently 30 to 40 pounds of thumb pressure is required to seat the filter, and this is not practical. Some practical means of installing a filter should be devised along with a means of checking its proper installation.

Each investigation of the several centrifuges revealed white "growths" which appeared to be some rapidly evolving corrosion. This always occurred along the breaklines of the unit. On the unit in which the filter was replaced, the interior was rather foul and discolored. There was also some apparent corrosion.

Another recurring problem with the system was obviously poor quality control on the collection hose/funnel assemblies. It was almost impossible to attach the nonflight version we had at the beginning of the test most of the time, and completely impossible in approximately 10 percent of the cases. The flight-type collection hose/funnel assemblies also had quality control problems. It was virtually impossible to take some of these assemblies off the centrifuge inlet, and others would separate at the nozzle/hose level.

Also the recirculation port on the hoses was often not perforated. Lack of recirculation was a continuing problem. Frequently the cause could not be found, although the plugged port was often the problem.

The volume determination readout began to hang up approximately halfway through the test. On the instruction of appropriate engineers the linkage was examined, and the follower arm appeared to be free. It appeared the meter itself or possibly the flex shaft from the meter to the follower was hanging.

One relatively minor problem was the tendency of the plastic in the urine receiver funnel to retain the creases where it was folded. These creases would retain sizable amounts of urine such that the funnel was always dirty and messy to fold and stow.

The spring clips which were to hold the cover over the folded funnel frequently came off. There were small springs on the inlet boot of the flight urine bags. These would also come off. While this was no great problem to us it would be in Skylab in weightlessness.

The drawer latch was workable throughout the test, but it was always a source of irritation. Considerable fiddling was required to insure that it worked. The latch for the recirculation hose door was very difficult to work. It required high pressures and a little sleight of hand to close.

A great deal of time was spent on the SMEAT UVMS due to the large number of problems encountered. It was obvious that at least one hour per day should be planned to handle the system if improvements are not effected. Hopefully, the Skylab system will have fewer problems and require less time.

Condensation from the cooling lines leading to the cold plates was a continuing problem. Such large accumulations of water could prove to be a significant problem on Skylab considering the proximity of electrical lines and connectors.

This system should not be seriously considered for Skylab in its present state. It is time consuming and a nuisance to use. It has inadequate capacity and poses a potential health hazard. Furthermore, it will not provide the required measurement and sampling functions.

The Skylab Contingency Urine System was used near the end of the test for a period of five days. This test was originally scheduled for ten days, but was reduced by a shortage of the latest configuration of urine bladders. This system consists of a cuff assembly which mates to the recirculation line of the urine bladder. Urination is performed directly through this line and mixing is done by hand.

Many operational problems were also encountered with the contingency system. They were as follows:

1. As with the primary system, the capacity was inadequate and two bladders were required each day.

2. There was excessive back pressure on the system with about 75 percent of the voids. The amount and cause seemed to vary. One major cause was test-peculiar in that the pressure plate would not stay in the full release position. However, removing the bladder from beneath the pressure plate did not solve the problem. Some pressure, enough to cause the cuff to bulge significantly, seems to be flow-related. The back pressure also was independent of height above the bladder.

3. One old style bladder leaked in the vicinity of the bond to the plate. A switch was made to the new bladders when this occurred. There were no leaks with the new style bladders.

4. Several cuff assemblies had small leaks. This combined with the back pressure problem produced a sizable stream of urine.

5. Sampling was totally unsuccessful. The recirculation hose pulled out of the sample bag several times and resulted in urine being sprayed about the waste management compartment. Neither the pressure plate nor hand pressure was adequate to fill the sample bags. Gravity was normally relied upon, and, even then, a sizeable amount of air got into the bag. Another technique that worked, but still had the air problem, was to use the roller to pump urine into the sample container.

6. The roller assembly has a latch that makes it difficult to release when it is on the hose. This becomes a two-handed operation. The latch should be capable of being released with one hand.

7. The large number of operations required to use this system insures that something will be done wrong when it is used in the early morning hours by a sleepy crewman.

The number and magnitude of the problems associated with the urine system make it unsatisfactory for use. Bladder size must be increased to handle 24-hour urine pools. Back pressure must be reduced for medical and comfort reasons. If experiment data is to be obtained the sampling problems need to be corrected.

Fecal Collection System

The SMEAT fecal collection system consisted of a fixture that originally had been scheduled to fly on an Apollo flight and the Skylab fecal collection bags. The SMEAT chamber was equipped with a refrigerator for the stowage of the fecal samples; these were not processed as they will be on Skylab. Instead, the samples were passed through the airlock each evening.

The fecal collection system used the same principles as the Skylab system and was representative of it. In the 1-g environment the system worked well, and the filters effectively eliminated odors. In zero g, however, there may be one problem. When consuming the Skylab diet the stool is not well formed, and, in the absence of gravity, this may create a separation problem.

The Skylab fecal collection bags worked well except for the complicated closing procedure. This procedure is accomplished by stripping off some tape,

exposing sticky surfaces, and then folding and sealing the bag. As a result of the closure problems, we were instructed to throw the tape away and not do the complicated fold. We agree completely with the revised procedures and recommend them for Skylab.

The time required for defecation averaged about 15 minutes with the system we had. This included the weighing of the sample and placing a new bag in the fixture. We strongly recommend that the system be configured so that a bag is in place at the end of each use to eliminate delays if use of the fecal collector is required on short notice.

Carbon Monoxide Monitor

This instrument, a state-of-the-art spectrofourometer, was evaluated for possible Skylab use. It was permanently mounted to continuously measure atmospheric carbon monoxide and provide a visible and audible alarm if the reading exceeded a value of 17 micrograms per cubic meter.

When the unit was operated during training it produced an intolerable noise. It was returned to the manufacturer to cure the noise problem and was passed into us during the test. We found the noise had been reduced to a tolerable level, but it interfered with speech. Unfortunately, the device was located in the wardroom where we tended to gather for meetings and conference calls. At such times it had to be turned off in order to hear. If this device is flown on Skylab, attempts should be made to make it quieter if feasible, and it should be located in an area of the vehicle where the crew would not normally be working.

We found that interpretation of the readings (which were usually negative) was not operationally satisfactory. There was no way to check the unit to verify that readings were correct. The test switch only checked a portion of the electronics. Some way of checking the instrument or verifying unusual readings is required before faith can be placed in its indications. Our unit failed completely during the test and was passed out of the chamber and not returned.

Carbon Dioxide Monitor

The carbon dioxide monitor was a small,

portable, battery-powered device that was being tested for the Skylab Program to provide carbon dioxide levels and ambient and dewpoint temperatures. The carbon dioxide scale is logarithmic, and we found it difficult to read with any degree of accuracy.

During the initial portion of the test, the device was giving carbon dioxide indications of 7 to 8 mm Hg when the actual was approximately 5 mm Hg. It was passed out of the chamber for calibration. The indications agreed with the chamber instrumentation with reading limits.

The response time of the unit for carbon dioxide indications was supposed to be two minutes, but observation of the device when it was passed into the chamber indicated this to be greater than five. This makes it operationally difficult to make a scan of the vehicle with the instrument.

The ambient temperature indication was two to three degrees above that indicated by chamber instrumentation. The dewpoint temperature resulted in a relative humidity value that agreed with chamber instrumentation.

The only means of checking this instrument was by comparison with other instrumentation. This other instrumentation is available on Skylab as a part of the environmental control system. We never developed any faith in the carbon dioxide monitor and doubt the value of flying it on Skylab.

Food

Our introduction to Skylab foods began many months before SMEAT. We sampled and rated individual items, and this served as one criterion for our menu selections. Although dieticians spoke of formulating diets in view of typical individual food intakes, and some crewmembers kept detailed records for this purpose, no use was ever made of such data. The preparation of the SMEAT menus was not just a selection of foods since the daily menu had to satisfy very tight constraints on calories, protein, and five minerals. As a result, we had to revamp the menus numerous times before they were satisfactory to two crewmen and met the constraints of the experiments.

The diets were not modified in face of marked weight losses (3 1/2 pounds and 4 pounds) by one crewmember during two weekly trials periods. In the case of this crewmember, a menu satisfactory to him was never realized, and he entered the pretest period with what he considered an inadequate menu but the best he could obtain.

Menu selection became increasingly more difficult as the amount of food became larger, since the general constraints remained the same no matter what the size of the diet. An individual with 2500 calories in his diet has a much easier task in menu selection than one with 3200 calories in his diet. Food selection was further complicated by the absence of many of the actual food items during testing sessions. Some of the items found unacceptable were improved during manufacture such that they would have been acceptable. The converse was also true. Although 70 plus items were said to be available, only a fraction of this number was actually available when mineral and other constraints were imposed.

We began to eat Skylab food exclusively 28 days before the test began. During that period the weights of two of the crewmembers remained essentially constant, and the third crewmember lost approximately 4 1/2 pound. This was considered acceptable by the experimenters, and the test was begun with these menus.

During the pretest and posttest periods diets were altered to a very limited extent by the substitution of a number of items for the Skylab food. These included items such as baked potatoes, lettuce, tomatoes, cokes, salad dressing, and chocolate ice cream. The inclusion of these items made the diet much more acceptable since they were a welcome change from the Skylab food.

Generally, the pretest breakfasts and lunches were consumed in the Lunar Receiving Laboratory and were prepared for us there. These eating facilities were very basic. A table was set up in the middle of an office, and the kitchen was used by many of the people in the building for a general kitchen. This surprised us since serious thought had been given to having us live away from our homes in a health stabilization plan designed to minimize our exposure

to sickness. In addition, we believe as do some restaurant owners, that dining surroundings affect how one thinks of the food being consumed. Every effort should be made to make the unenjoyable experience of eating a completely controlled diet as pleasant as possible.

The dinner meal and all weekend meals and all the water to be drunk were delivered to our homes where a refrigerator was kept for their stowage. There were three additional stations at the Johnson Space Center where controlled water was kept for our consumption.

Unlike the Skylab Orbital Workshop, the SMEAT chamber did not provide sufficient room to stow the entire 56 days of food. We started with five bales of food in the chamber and then were resupplied with food to keep approximately four bales of food in the chamber. A bale did not provide adequate space to contain all the beverage overcans that were in our six-day diets, and there was always some mixing of menu cycles within at least one of the food bales. A system of color codings was adopted for each six-day cycle's overcans. In our opinion, this system was much easier to use than a complicated numbering system. The beverage trays in the pantry were inadequately large for a six-day cycle, so they had to be restocked every two to three days. Three lockers set aside for stowing the empty overcans were inadequate for the number of overcans in our six-day diet.

Food preparation within the chamber was done on a Skylab food pedestal which worked well. The concept of having individual dishes reconstituted and heated in the heating tray appeared satisfactory. It was necessary to lubricate the reconstitution water selector to prevent binding.

The time required to prepare a meal, consume it, clean up, and then make initial preparations for the next meal took about 40 minutes. At the completion of a meal, we got out the items that were to be prepared for the next meal. If the items were to be heated, they were placed in the trays and the timers set to automatically turn them on; if they were to be chilled, they were placed in the refrigerator.

One class of food items that created a problem was the reconstituted foods that required 15 or 20 minutes reconstitution time for good taste. We were informed not to reconstitute these items at the previous meal to prevent bacterial growth, and reconstituting them at the time of the meal did not give adequate time for rehydration. The problem was often overcome by one of us reconstituting these items 15 or 20 minutes prior to a meal if time could be taken from the performance of another scheduled task. Foods were reconstituted with the amounts of water called out on the menu. This did not always agree with values printed on the cans and resulted in confusion.

In food preparation a number of containers failed. These included the following:

1. Valves on the beverage containers, especially those on the coffee and grape drink containers, leaked. Each time a coffee was to be reconstituted, a tissue was wrapped around the valve to limit the spill that otherwise would result.

2. Seams on a number of the bags failed during the reconstitution. This was especially troublesome when a bag was kneaded for mixing.

3. Membranes on frozen food items failed when the items were heated. We tried heating the food a number of different ways to minimize the mess that would result when a membrane failed, but none helped. Procedures called for the lids of the cans to be removed before heating but opening frozen items often resulted in the tabs breaking requiring lid removal with a screwdriver. If the lid was removed before heating, the membrane usually split during heating, and any liquid in the can would get into the tray wells and on the tray lid. Opening the lids and puncturing the membrane before heating usually resulted in the same spills during heating. The third method was to leave the lid on and open the lid only after heating. This often resulted in the membrane failing when the lid was opened, but one could catch the liquid with a tissue and minimize the mess. We recommend removing lids after heating.

4. A few valves were missing from beverage containers.

5. A few beverage containers were empty.

6. Some beverage containers were missing O-rings.

7. A few items, particularly soups, were very difficult to reconstitute to a smooth consistency.

8. Some foods, such as filets, contained a lot of thin liquids which might prove to be a problem in zero g.

9. If an item failed to be opened by the tab, the use of the can opener resulted in the rim of the can being cut off leaving a dangerously sharp edge. We recommend using a screwdriver to remove the tear-back lid.

The taste of the food was tolerable over the period of the test. One crewmember had difficulty with the diet since he was being fed large quantities of candies and cookies to try to maintain his weight without changing the core diet. This continuing loss of weight in one crewmember and the inability of the system to cope with the problem was our major concern with the food system. During the pretest period this crew member lost 5 pounds, and no change was made in the diet. During the test he lost 9 1/4 pounds, and no change was made in the basic diet except for the addition of almost pure carbohydrate items. During the posttest period, the basic diet was maintained until the total weight loss was 19 pounds. At that time he was allowed to choose and eat additional items from the Skylab food list, and his loss of weight was arrested.

The weight of two crewmembers remained essentially constant during the test while that of the third decreased significantly.

All three of the crewmembers exercised at a level they felt was roughly equivalent to their activity during the pretest menu consumption period.

The problems encountered with the mechanical failures and the problems with the diet indicate to us that more flexibility is required within the food system. Certainly, spares should be available inflight to cover contingencies such as a food item disagreeing

with an astronaut; food package failure; astronaut weight gain or loss, or an illness that prevents an astronaut from eating the prescribed diet. Also a method of easily accessing these spares for particular food items should be developed.

We ate all of our foods with the exception of the pea soup and lemon drops. Pea soup was eliminated from one crewman's diet, because of significant production of abdominal gas, nausea, and diarrhea. Potato soup and biscuits were substituted in its place. The lemon drops became intolerable to one member in the face of the large amount of carbohydrates he was consuming.

Pea soup produced gas that often resulted in abdominal pain. We, therefore, recommend it not be included in Skylab diets. We generally had more abdominal gas on the Skylab diet than on our normal diets, and we all had significantly more abdominal gas in the chamber than in a sea level atmosphere. We adjusted somewhat to the abdominal gas in that after a few weeks in the chamber it seemed to pass easily, but we all had significant gas throughout the test.

The diet produced stools that were soft and not well formed. This, of course, can be expected to add to what is already a difficult waste management problem.

Accounting required to keep track of the food and water intakes was rather minimal since all these matters were fairly well organized. Color coding and bold markings on the food packages indicating the day and the crewmember for whom the item was intended were a help since they kept the items from being mixed inadvertently.

One polyethylene glycol pill was required before each meal for each crewmember. These were stored in cans in a cabinet in the wardroom, and it was very difficult to determine if the proper number had been consumed. If the pills are required on Skylab, they should be packaged so that the pills for any meal are uniquely identifiable and located. Such a method as placing the pills on a card with all the pills for a meal together is highly recommended. Color coding should be used to differentiate mineral pills and polyethylene glycol pills by type. The pills we took in

the greatest number were the polyethylene glycol pills. We recommended that these pills be deleted for the Skylab mission considering their nuisance value.

Eating utensils consisted of a small knife, fork, and spoon that are magnetized to stay on the Skylab tray. These were found to be too small. We used the Apollo Command Module spoon. This spoon is not magnetized and should be made so if it is to be used in Skylab.

The reconstitution bags were opened with the Skylab knife. Tops were also removed from the beverage container with the knife. This was difficult to do without an occasional slip, and each of us stuck himself a half dozen or more times with the knife over the course of the test.

Utensils, trays, and the food pedestal were satisfactorily cleaned with a wet wipe.

Trash generated by the food was stored in the food overcans and passed out through the airlock. Many small pieces of trash were generated at each meal, including food can lids, the tops to beverage containers, pill wrappings, salt packages, napkins, and wet wipes. The trash receptacle was conveniently close to only one person, and all the small trash had to be passed to him for disposal. A small trash bag convenient to the other two crewmembers would have saved much trash handling.

A Skylab "can crusher" furnished by the Marshall Space Flight Center was mounted on the second deck of the chamber. This was to be used in flight to compress food cans to reduce trash volume in the event of a trash lock failure. We used the "can crusher" for one six-day menu cycle for disposing of all food cans. The operational mode in which the trash was to be handled in the event of a trash lock failure was rather sketchy, so we made a few basic assumptions and proceeded from there.

The assumptions were: (1) that all wet food trash was to be compressed as much as possible and placed in the freezer to prevent spoilage. Wet trash was anything that might spoil, such as beverages, frozen items, thermostabilized items, and rehydratable bags; and (2) that all dry food trash was to be compressed,

but not mixed with the wet trash, to save overcans for other trash such as tissues, wipes, towels, etc.

Since freezer space in SMEAT was limited, normally wet and dry food trash were passed from the chamber when an overcan was full. No attempt was made to store other trash items in overcans.

Our mode of operation for "can crusher" utilization was:

1. The pantry waste food area was divided as follows:

   a. One small overcan with innerliner for small wet food cans.

   b. One small overcan without innerliner for beverage containers.

   c. One small overcan with innerliner for small dry cans.

   d. One large overcan with innerliner for large wet food cans.

   e. One large overcan without innerliner for reconstitution food bags.

   f. One large overcan with innerliner for large dry food cans.

2. Beverage containers and reconstitution bags were simply stuffed into the appropriate overcans which were capped when they were full. These might be frozen on Skylab; however, we normally passed them from the chamber.

3. Dry and wet, large and small cans were placed in the appropriate overcans with the innerliners, so they could be easily retrieved for crushing. A tissue was placed in wet cans when visible liquid was present. The necessity for this was proved by a rather messy spill of tomato juice.

4. The cans were crushed approximately once a day doing first the dry cans and then the wet ones. Two separate large and two small overcans were required to hold the appropriate crushed cans until an overcan was filled and was passed from the chamber. A rather large mess usually resulted from crushing the wet cans, and we used a towel to catch droppings and to clean the *crusher* afterwards.

A food utensil wet wipe was normally used to complete cleaning.

5. It was speculated that it might not be necessary to freeze the wet trash. This was investigated by keeping three overcans of wet trash in the chamber. There was one beverage overcan and one each of small and large wet overcans. These overcans were sealed tightly using the overcan *can opening* tools.

The *findings* from SMEAT exercising the Skylab can crusher are:

1. An additional period of approximately 45 to 60 minutes was required each day to allow for handling the trash after meals and crushing the cans.

2. The operational division of trash used worked satisfactorily.

3. Tissues were required to handle any existing liquid in wet cans.

4. The mechanical action of the can crusher worked satisfactorily.

5. There was usually a good sized mess on and around the crusher after crushing wet cans. This was somewhat difficult to clean.

6. The food consumed during this six-day cycle came in 15 large overcans and 31 small overcans. This resulted in the following trash: seven large wet overcans; one large dry overcan, fifteen small wet overcans (two cans/thirteen beverage); one small dry overcan.

Recommendations from this exercise are:

1. Have knowledgeable people examine the wet food trash overcans left in the chamber to determine if this method of trash stowage rather than freezing is satisfactory for Skylab.

2. Modify the "can crusher" to allow for easier cleaning. This should include the following:
   a. Make the four fasteners that hold the unit to the base of the hand release-type to allow the top to be removed to get at the messy area beneath the plunger.

   b. Cover the hole in the center of the base to prevent food waste from escaping below the grid.

e. Radius the interior of the can depressions in the base such that food particles can be easily wiped out.

Clothing

The clothing supplied for the SMEAT test was the same type as planned for Skylab, but in our types of materials. These materials were 42G, X420, Durette 400, and polybezamedizole (PBI). The presently planned material for Skylab is Durette 400. We preferred the 42G material, but found all the material acceptable and subjectively very similar.

The clothing was comfortable and adequate for the SMEAT test. One crewmember developed a problem with fit because he lost almost twenty pounds during the test. During the test we noticed a significant amount of lint in the chamber which required frequent vacuuming. The material that was vacuumed was passed out of the chamber for analysis which showed most of the lint to be generated by X420 cloth. The clothing was sturdy enough for the test. Only one rip occurred in all the clothing items that were worn. The knees of one of the crewmember's trousers ripped after the two weeks of wear.

The suggestions we have concern the selection of clothing items more than the type or fit. We used the jackets provided on only a few occasions, and for the SMEAT test four jackets were certainly too many. Two of the crew used a clothing module with only two sets of trousers which was inadequate for the 28-day period. Normally the trousers were worn until a change, and then they were used for exercise until the next change. With only two sets of trousers for 28 days it meant the trousers were worn for two weeks and were used as an exercise garment for two more weeks. Two of the SMEAT crew never wore undershirts during the test and those items were used for cleaning rags. If any additional items can be included in the clothing selection, we recommend including additional socks and shorts.

The trousers have legs that are attached by zippers and can be removed or put back on. We found this to be a very desirable feature. It provided a great deal of flexibility for hot cycles in the chamber and made the trousers better exercise garments.

The modules are not labeled adequately to enable a crewmember to keep track of what fresh clothing remains. A checklist of some sort should be provided on the module so the crewman can check off the items he has used and know what remains.

The shoes provided for SMEAT required replacement during the test since the soles separated from the shoes. The replacement shoes were better, but by the end of the test the soles on those shoes were also separating from the shoes. These soles were 1 g peculiar and are not applicable to the flight item.

Sleep Restraint

The Skylab sleep restraint was used during SMEAT by the CDR for the entire 56 days. Provisions were made to allow for gravity by laying the sleep restraint horizontally on a bunk over a thin mattress. This sleeping bag type arrangement was comfortable, and having the material of the restraint next to the skin caused no discomfort or irritation. The Skylab linen changeout cycle was used.

Temperature in the chamber was normally maintained at 69°F. At this temperature, only the bottom blanket was used and, with no other sleeping apparel, this proved to be thermally quite comfortable. For five days the temperature was elevated to 77°F requiring removal of the bottom blanket. The sleep restraint was versatile enough to handle the thermal excursions experienced in SMEAT and should be adequate for Skylab.

The restraint straps were used for a period of one week to evaluate them for comfort. No significant problem was noted with these items. There is some type of stiff material sewn into these straps on one end which was positioned over the body when the straps were snugged down. This caused some minor discomfort. The straps should be readjusted to position the ends off to one side, or the stiff material should be cushioned.

The neck hole on the comfort restraint used to enter and exit the unit was so small that it was difficult to do so. This was especially so at the beginning of a two-week cycle on a comfort restraint before the neckhole stretched. We would recommend evaluation of the size of the neck hole by one of the larger Skylab crewmembers.

Tool Kit

We did not have a Skylab tool kit, but we had a kit made up with items to functionally represent most of the Skylab tools. In addition, we had a separate tool kit with tools necessary for chamber peculiar items.

We found the Cryotox lubricant to be very useful. It was used extensively on items that began to bind during the test such as the food pedestal water valves and the SIB dovetail interface. We each carried the pocket knives provided on our person. These were used many times each day for purposes as diverse as opening food cans with ring failure to disassembling the Skylab Urine System. The tool kit seems well equipped.

There were times when a volt-ohm meter would have been handy to check out possible electrical problems such as isolation problems on the VCG and a loading problem on the Skylab urine centrifuge.

We also had to have tubing passed in to make an adapter for a special M171 test. A selection of various sized tubing would have proved useful.

The mission could not have been completed without tape provided in the kit. It should be assured that Skylab has adequate quantities.

The "mechanical fingers" device was used as the UVMS cleaning tool of choice.

Cameras

Flight type camera equipment was provided in the chamber for documentation purposes. This included a 35 mm NIKON camera, a 16 mm data acquisition camera (DAC), 140 ft magazines, a pistol grip handle for the 16 mm camera, and a photometer. The equipment worked well, and there were no significant operational problems.

The wire for the 16 mm DAC 28 volt power cable entangled easily and was difficult to handle. This is the same type of wire used on the ODAE tape recorders where a similar problem was encountered.

On one occasion a 16 mm magazine did not drive and the film tore at the drive holes. The magazine was replaced as per procedures.

Special care was required to insure the film speed mode was not accidently changed when using the pistol grip handle. The wheel dial for the selection moved easily, and the selection was inadvertently changed several times.

The 16 mm camera had no field of view indication on the viewfinder, which produced some errors.

Logging of the 35 mm camera photographs was difficult. When the 35 mm camera was used for unanticipated picture taking, for example of an equipment problem, it was often not convenient to obtain the log from the flight data file and make an appropriate entry. A log card attached to the camera would be preferable.

Reports

The crew reported items in five basic ways during the course of the test. Most tasks lent themselves to one or two of these types of reports and we found all methods useful.

The first method of reporting was to simulate the Skylab voice recording capability and speak into our interphone boxes during the course of an experiment, prefacing our call with "record." An example of this would be the call out of impedence, calf girth, leg band calibration numbers, and other items during an M092 run.

The second type of recording was similar to the first in that the Skylab voice record capability was simulated, but in this report the items were written in a log over some period and then read at one time. An example was the recording of environmental measurements in an M487 experiment where 50 measurements might be taken at various points in the chamber and then all the values would be reported at one time.

The third type of report was the daily report that was prepared by one of the crewmembers and given in a simulated Skylab voice record manner. Here,

items that had been jotted down during the day were collected together in a report along with items that required reporting on a daily basis, such as food consumption and carbon dioxide measurements. We found a chamber log very useful for writing items down that we felt should be included in the daily report, and the log also served as a record of the daily reports. This report normally required between ten to twenty minutes delivery time.

The fourth type of report was the weekly report. This report was prepared during our off day and was a summary of the important items that had taken place during the preceding week. Not only did we again relate some of the facts, but we placed the facts in the context we believed appropriate, which was not always done when an episode occurred. The preparation of this report gave us the opportunity to discuss the week's activities between ourselves and flag those items we believed to be important. It also gave us a chance to discuss possible solutions to the problems and relate them to the rest of the test team. This report was prepared in either written or outline form and was delivered using the simulated Skylab voice record capability. The preparation of this report typically required four hours of the crew's time and another half hour for delivery. Although we believe the report to be very important, it did take away a significant part of our off-duty day. Perhaps some other time should be set aside to allow the crew to review the week's activities.

The last method of reporting was direct contact with the Capsule Communicator (CAPCOM). This was used mainly to discuss immediate problems. We found that direct contact with the CAPCOM was at times difficult in the simulated Skylab communications environment since the Skylab will only be in contact with the ground a small part of the time. It generally was more effective to use simulated teleprinter and voice record rather than to try to copy and answer questions in real time. When discussion of complicated procedures or problems was required, it was more effective if a teleprinter message with the facts had preceded the discussion.

During the course of the test we implemented a procedure whereby the CAPCOM advised the crew when there was simulated radio contact. This was

convenient since we did not have to keep a schedule of the station contacts.

Information passage was a major operational problem encountered in the test. Often the information we thought we had passed out was not that which was received by the appropriate individuals. For example, we tried a modified Skylab vacuum cleaner brush and found that with it the vacuum was marginally satisfactory. This was reported as being very satisfactory which changed the intent of the statement. It appeared that in the passage of information, items were sometimes changed and the entire sense of the transmission was being altered. Fortunately nothing that happened in the chamber was irrevocable. However, consideration should be given to streamlining Skylab communications channels as much as possible to optimize data return.

Unless they occurred during an experiment or during a scheduled period, most voice recordings were 'lost' one way or another.

The reporting procedures we devised were our way of trying to have people accurately understand what we were trying to convey.

An obvious problem was having several echelons of individuals relaying information with which they were unfamiliar. Frequently, too, individuals with little or no expertise attempted to resolve technical problems. These individuals could provide little assistance beyond "did you read the check list?" or the "the C/L says." Skylab astronauts should have the most direct link possible to the most knowledgeable person available with the minimum number of official interpreters.

Flight Data File

The flight data file was an invaluable part of the chamber equipment. The period of time that elapsed between the conduct of training and test startup, and the short period allotted to SMEAT training necessitated that we rely heavily on the flight data file to accomplish tasks. The preparation of the flight data file proved to be a rather difficult task since the chamber was not ready for crew training until just before the test. This often meant the training session

was also the procedures development session, and often occurred after the procedures should have been formulated.

During the test the flight data file was updated both verbally and via teleprinter message. We found that new procedures were much more conveniently passed via a simulated teleprinter message. Many other items were also passed via a simulated teleprinter message and this improved operations by insuring the crew got messages accurately, by saving crew time in copying messages, and by not requiring the crew to interrupt some experiment during the available station passages.

An item that was not part of the SMEAT flight data file, and which was fabricated by the crew during the test, was a record book of medical information as passed to us via simulated teleprinter messages. This would have been a better record had it been started before the test because the medical experiments begin in a baseline period. The information we collected was that top level medical data which would give us information as to important trends during the test.

The fact that we put together various books within the chamber indicates that flexibility should be provided in the flight data file for long duration tests or flights. We found that our day-to-day activities were more like those in an office than an aircraft. We needed additional dividers for our books, binding rings, files, and scotch tape. Paper clips and a staple machine would have been useful. Most of this equipment was used because procedures and information passed to us was not the type of thing one should throw away. As an example, for the M171 experiment we performed seven special procedures at various times during the test. One of these procedures was performed at least four times and we wanted to keep the procedure for future reference.

The chamber log, a looseleaf book with metal cover, was used most. It had sections for logging of chamber parameters on a regular basis, as well as all day-to-day incidents and failures.

The record books and their covers held up adequately during the 56 days except for the rings in the books, which tended to open. We had various clipboards and holders to hold the books and logs

during experiments. These were adequate, and certain ones were preferable for specific applications. A bulletin board was used at a convenient place in the center of the chamber to post various items of continuing interest. This included the daily flight plan, communications plan, transfer lock schedule, and other similar items.

The preparation of reports in the chamber was a bit more difficult because there was no place to conveniently refer to, and voice record, from up to six books. This typically would occur at the evening report when recordings were made from the individual food logs, the specimen mass measurement log, the chamber log, the experiments log, and the debriefing guide.

Timeline and Mission Planning

The crew day was planned to be as close to the Skylab plan as possible. One variation was that we began our day at 7 a.m. Houston time, instead of the planned 6 a.m. Houston time for Skylab, for the convenience of the operations team. Our day began with a period of personal hygiene and experiments that were required before breakfast. These included items such as blood drawings, crew microbial samplings, and crew oral samples when they were scheduled. This period varied from approximately 30 minutes to an hour, depending on how many of these experiments were scheduled. Immediately following this, we prepared and ate breakfast. The time for preparation, consuming the meal, cleaning up, and making initial preparations for the next meal averaged about 40 minutes. All of the crew participated in these activities and generally as much preparation was accomplished for the next meal as conveniently could be done. This time and procedure was closely followed for the remainder of meals of the day.

Following breakfast, two of the crewmembers accomplished tasks as outlined in the timeline, and the third crewmember normally was assigned system and housekeeping duties followed by a television safety scan of the chamber. On a major medical day the M092 experiment was begun by the CDR and SPT approximately two hours after breakfast. This task and the M171 experiment required approximately two hours and fifteen minutes of time and

occupied them until lunch. The PLT was scheduled for other activities during this time, which typically could be a class via closed circuit television in Russian or in the Skylab command module. The PLT ate an early lunch on days when M171 was scheduled so that he would meet the constraints placed by the experiment concerning eating and doing the M092 experiment.

Following lunch the PLT and SPT each served as both subject and observer for the M092/M171 series of experiments. These two experiments took approximately five hours to complete and ran until dinner. During the period when the PLT and SPT were involved with the M092/M171 series of experiments, the CDR was scheduled for activities such as a language course, command module course, pantry restocking or any number of other items. He was the one scheduled for system, housekeeping, and TV safety monitoring duties since the PLT and SPT were otherwise occupied.

Dinner was done in the same manner as breakfast and lunch and took about 40 minutes to complete. After dinner the chamber was cleaned up for the evening, the daily report was prepared, and the TV safety scan was accomplished. These tasks took approximately one hour to complete, but if the next day's activities were complicated or unusual, they ran into a longer period of time.

The last item of the day was a rest and relaxation period. During this period we used the television, the off-duty activities equipment, the phone, and the supplementary activities for their rest and relaxation.

The activities for other than a major medical experiments day consisted of SMEAT experiments and supplementary activities. These were scheduled by the timeline, as were any other tasks.

The planning cycle for a day was begun the morning before the day's activities commenced. The premission plan served as a basis for this plan, but items were often changed to fit the situation. We were informed of proposed major changes at a convenient simulated station pass near 1 p.m. and comments were requested. The plan was then further refined, and a simulated teleprinter message was passed to us during dinner. After dinner this plan served as the basis for the planning for the following day. If any changes were required, they were passed to us via a simulated teleprinter message in the morning.

The timeline was composed of activities that were in convenient time blocks and, although there were significant constraints, these activities could be arranged in many ways to fill the day. This capability meant that each day normally was completely filled with activity and there was no unscheduled time from 7 a.m. to approximately 9 p.m. This method of timeline generation worked well and we had confidence in the timeline that we used each day.

On the basis of in-chamber experience some changes were made in the pretest schedules. For example, postexercise was the proper time for personal hygiene. By and large, the prechamber schedules were maintained with some notable exceptions, such as the IMSS microbiology experiment which was always late.

We had only a small number of experiments to perform, as compared to Skylab crewmembers, yet found ourselves extremely busy. We feel Skylab will be working a very crowded timeline.

One day each week was scheduled as an off-duty day, usually Saturday or Sunday, but not necessarily because of test requirements. One of the major unscheduled items on the off-duty day was the preparation of a weekly report. The flight data file section discussed this fully.

Data

Since data gathering was involved in both primary and secondary objectives of this test we feel comments in this area are pertinent. Because of its importance and because of the nature of this test, we tried to involve ourselves in the data loop more than an actual flight crew has time for. We felt such involvement would improve the data since we were the subjects and directly involved in its gathering. Also by such involvement we could improve its timelines and help determine the kinds of items that should be available to the Skylab crews.

The most disturbing aspect of the data collection and dissemination was the apparent attitude that (1) data were just another part of the test to be eventually sorted out, and (2) data were only the business of the investigators.

Several factors should be recognized. Loss of data is tantamount to loss of the test. Data which are delayed or allowed to pile up are frequently lost through some minor deficiency which could have been discovered by timely analysis. The individuals generating and collecting data, especially if they are the subjects, have a primary responsibility for the ultimate validity of the data. Of necessity, they must be an integral part of the team.

The attitude conveyed to us by several of the experimenters was that we should not be concerned about the data, and that we were interfering when we showed an interest in data collection or validity. Many of our efforts to correct obviously erroneous data were frustrating, but, in several instances, were successful.

In general, no data in the pretest period were made available to us until just prior to starting the test. For Skylab, certain data should be made available on a periodic basis preflight to eliminate possible error sources in data collection and to provide background information for conducting experiments in orbit.

The M070 series data dealing with intake and output should be available to the crews both pre- and postflight to minimize error in data collection. This should be done on a daily basis if possible. A capability for rapid data reduction and dissemination is going to be necessary to handle the between flight periods when a lot of data is brought back from flight and data are being collected on a postflight crew as well as a prime and backup crew for the next flight. The system appeared to be saturated with the one SMEAT crew.

The major medical experiment data on M092 and M171 should be available during the training and baseline data-gathering sessions to aid in the training. We recommend having selected preflight data published as part of the flight data file for each flight

giving the observers a reference and allowing them to do a better job. Selected data should also be fed back to the crew on these experiments during flight via the teleprinter. This should occur prior to repeating the experiment if at all possible. This calls for a rapid data reduction and dissemination capability. Initially during SMEAT this was not possible, but by the end of the test this capability was being exercised in a reasonable timely manner.

Exercise

As on previous missions, exercise programs were the responsibility of the individual. This is a reasonable approach since it would be unwise to change a crewmember's exercise activities shortly before a mission. However, the type and amounts of exercise normally performed by the crew should be documented and understood. This was not done for SMEAT.

We maintained a more or less regular exercise program for the six months prior to the test. The CDR ran two miles per day about six days per week. The SPT ran an average of twenty miles per week averaging about seven and one-half minute miles, used a bicycle ergometer with some alternation of running with workouts on the bicycle ergometer and lifted weights. The PLT ran approximately one and one-half miles per day four times per week and used the bicycle ergometer after each run for approximately 1,500 watt minutes.

This exercise protocol was fairly consistent until the three weeks preceding the test, when the press of events was great, and the SPT and PLT curtailed their exercise significantly.

Prior to the test we suggested that, in addition to the bicycle ergometer, some measurements of the crew's physical capability be recorded. We attempted to make some very simple and crude measurements of muscle capability and recorded a few gross anthropometric measurements. These were the only attempts at documenting this area.

The crew's exercise is obviously an important part of their physical maintenance, but as far as we know none of the experiments has considered exercise except as it may apply to the metabolic activity

experiment, M171 (using bicycle ergometry). One of the consequences of not following the crew's pretest exercise was that the CDR showed a large training effect during the pretest period, and his assigned levels on the bicycle ergometer were much less than the desired 25, 50, and 75 percent of maximum.

Shortly before the test began, it was requested that during the test we record the daily exercise we performed. At this time, an exercise protocol for the test was also suggested. This consisted of using the ergometer heart rate mode and maintaining a heart rate of over 140 beats per minute for at least ten minutes per period. This was to be accomplished three times per week. The "heart rate" mode did not work and we found a great deal more exercise was required.

At the beginning of the chamber residence period, the CDR and PLT began the exercise test at low levels of exercise, but quickly increased their daily exercise to between 5,000 and 6,000 watt minutes per day. The SPT exercised on the bicycle ergometer at a rate he believed would maintain his pretest cardiovascular condition. This normally was about 15,000 watt minutes of exercise. This amount of exercise surprised many of the concerned individuals on the SMEAT team but was very consistent with the SPT's pretest exercise program. The fact that this exercise was sufficient only to maintain his cardiovascular condition is confirmed by the absence of any conditioning effects from exercise.

The exercise program used by us was dependent on, and restricted by, the bicycle ergometer. The early failure of the ergometer quickly showed how dependent we were on this device. After this failure a limit of 150 watts was placed on it, which restricted exercise by all of us. Another commercially available purely mechanical ergometer was passed in and this exclusively was used by the SPT and frequently by the PLT because the Skylab ergometer was restricted to the low loads.

In addition to the normal Skylab ergometer pedaling mode the ergometer arm mode was used by the SPT near the end of the test because of upper limb deconditioning. He found this mode rather unpleasant and very time-consuming. The arm work-

loads are not sufficient to cause any appreciable cardiovascular conditioning. This, however, subjectively appeared to help the function of the arms but did not affect shoulder muscles.

The Exer-Gym was used by us when the ergometer was unavailable. We found its use to be restricted because there was no way to attach it to anything. Normally we found it most useful as a substitute for lifting weights and not effective for cardiovascular conditioning.

The exercise routine within the chamber required about one hour and fifteen minutes for the CDR and PLT. This included a setup time for the ergometer, the actual exercise period which was normally 30 to 40 minutes in duration, the return of the ergometer to its nonuse state, and a period of personal hygiene. The time required for the SPT to exercise was longer, up to two hours.

Posttest, no exercise measurements were made except for the few crude measurements we did ourselves and those concerned with bicycle ergometry for M171.

Shortly after the test ended we went back to our previous exercise programs and found a reduction in performance from our pretest levels. As an example, the SPT suffered approximately 5 ml/kg drop in maximum oxygen uptake, in spite of losing some 4.8 kg of fat which should have produced a favorable increase in oxygen uptake per kilogram. This loss in fat was probably more than offset by the 2.4 kg loss of lean mass.

The upper body strength of all crewmen suffered no real decrement, except in the case of the SPT where there was a loss in shoulder girdle/pectoral strength in spite of the fairly vigorous use of the arm mode of the ergometer.

Supplementary Activities

The Skylab medical experiments and the SMEAT-peculiar experiments were not enough to occupy each day in the chamber. It was desired to have enough scheduleable activities to fill a Skylab timeline and to prevent boredom. The choice of activities

to fill these gaps were left to the individual crewmen. Activities selected included:

Russian course

Command Module course

Astrodynamics course

Solar physics course

Electronics course

Medical research

Model building

Commercial pilot license study

Some of the courses were taught by an instructor via closed circuit television. This proved to be very effective. The Russian course, in particular, was interesting and demanding.

The supplementary activities selected did an excellent job of utilizing the time in the chamber. At no time did we have an opportunity to feel bored from a lack of things to do. In fact the opposite was the case. Often we were so busy we did not have enough time to spend on certain things.

Considering that SMEAT exercised principally Skylab medical experiments and that Skylab crews will have these to perform, plus the Apollo telescopic mount, the earth resources experiments, and many others, we believe there is no need to be concerned about Skylab crews becoming bored over 56 days.

Off-Duty Activity Equipment

A full set of Skylab Off-Duty Activity Equipment (ODAE), with the exception of binoculars, was provided in SMEAT. The equipment worked well and was satisfactory as a source of diversion during our off-duty time. It should be noted that we also had items other than those in the ODAE, such as television and additional books, to occupy our off-duty hours.

The primary items that we used were the books and the tapes and tape players. One Exer-Gym was used, but for only a short time since, with only straps, the Exer-Gym is very limited in the modes of exercise accommodated.

Reading occupied much off-duty time. The number of books was reasonable, and we had no problems using the fireproof book covers. A piece of Velcro on the covers might be a handy item inflight.

Our book selection process was somewhat confusing. First, we went to bookstores, selected titles, and brought the titles back to the people responsible for the ODAE for ordering. They, in turn, had difficulty obtaining the same books. We recommend flight crews be allowed to purchase books directly.

There was a similar problem in selecting the tapes. There were basically three types in the chamber. Some were locally recorded with no modifications. Others, referred to as SMEAT tapes, were locally recorded and had been done in a special manner to sound better when played at 5 psia. The third group was made up of commercial tapes purchased off the shelf. Many of the locally recorded tapes were distorted and 5 psi seemed to increase this distortion. The concensus was that the commercial tapes were the best. We recommend using commerical tapes and allowing the Skylab flight crews to purchase their tapes directly as recommended for the books.

Our tapes had been labeled with the crewman's name and not with the selection on the tape. The Flight Data File personnel generated a cue card to allow us to determine what was on each tape. This was a very confusing system. We recommend labeling tapes according to the selections they contain. We see no need to differentiate them by crewmen.

The wire used on the recorder headsets and the power cord tangles badly. The same wire is used for the 16 mm data acquisition camera and has the same problem.

One recorder had a channel failure and another did not hold the batteries properly to maintain contact at all times. We had one pretest episode of tape being wrapped around a recorder head, but this was not repeated during the test.

The stereo speakers on the ODAE door worked well at 5 psia but were too close together for any stereo effect.

Training

SMEAT crew training formally began in November 1971. Actual crew participation extended back to July 1971, with involvement in test equipment design. Concentrated training began in March 1972. With the exception of the major medical experiments training, training on systems and experiments was generally limited to a briefing on the subject and one walkthrough in the chamber. Where possible, we combined baseline data gathering with training.

Since our training hardware was also the hardware used in SMEAT, we were quite often restricted on access due to availability. Hence, most of the training was crammed into a four-week period just prior to test start. This period was actually much too busy. Twelve-hour days with six-and seven-day weeks were normal.

A total of 412 training hours had been planned, and we each exceeded 500 hours. This, of course, only includes the formal training. Many hours that were not documented were spent in design meetings and extra study.

Health Stabilization Program

There was considerable debate prior to SMEAT on what type of Crew Health Stabilization Program should be imposed. Reasons proposed for isolation of the crew included:

1. Protection of the crew from infection prior to the test.

2. Protection of the crew after the test when a lowered resistance might be postulated.

3. Simplification of crew feeding and sample collection.

The original proposals called for semiquarantine in the Lunar Receiving Laboratory building for a 21-day period before the test and 18 days after the test.

It was our opinion that these early proposals were not adequately consistent to warrant their imple-

mentation. Many of our normal working relationships, as well as our family relationships, would have been altered, and yet it appeared to us that the proposed new environment was no more healthful. For example, no health screening of isolation support personnel was planned, nor was it planned to decontaminate our sleeping rooms which had been used as bacteriology offices for some years. There was direct atmospheric connection to several large labs containing a number of infectious agents in high concentration. When the proposals were more closely examined, a combination of factors such as facilities, personnel, money, and common sense caused the plan to be significantly changed. The final program was basically left to the crew to implement and consisted of having the crew avoid crowds, strangers, and anyone who was ill.

It is our opinion that, if a simple procedure of avoiding illness is abandoned in favor of positive control for health stabilization, significant restrictions and inconveniences are placed on the crew. To justify this complication, the procedure must be capable of consistently avoiding possible illness exposure.

We recommend the Skylab crews be allowed the same freedom of access to required places on the Johnson Space Center complex so they may accomplish their flight preparations. However, we do recommend that certain areas be reserved exclusively for Skylab crews. This would include the Skylab food preparation and eating areas.

Conclusions and Recommendations

This section itemizes our conclusions and recommendations on the subject discussed in the body of this report. All recommendations are based on the conclusions; however, a recommendation does not necessarily accompany each conclusion.

The conclusions presented here represent our opinion based on our experiences pre- and post-test, as well as during the test.

Each recommendation is made based on our knowledge of the status of Skylab as of this writing.* We realize that it is difficult to incorporate changes at this time, but consideration should be given to the recommendations to enhance the chances of a successful Skylab mission.

Lower Body Negative Pressure (M092)

Conclusions

1. The LBNPD iris plate SMEAT modification to radius the internal edge eliminated the abdomen pain we experienced prior to its incorporation.

2. The knee restraint strap is inadequate to hold the legs and causes some discomfort.

3. The SMEAT blood pressure measuring system was inaccurate enough to be unsatisfactory for monitoring a crewman's well-being while in the LBNPD.

4. The heart rate display on the ESS would hang up causing it to be unsatisfactory for monitoring the well-being of a crewman in the LBNPD.

5. The LVMS worked well when used with the mosite wedges and electrode sponges to insure good electrical contact on the reference adapter.

6. There were too many procedural voice calls required in the performance of this experiment for data reduction purposes.

7. The shock isolation system did not work.

Recommendations

1. The flight LBNPD iris plate should be radiused in the same manner as the SMEAT unit to eliminate the sharp edge.

2. Improve the knee restraint strap to insure it will hold the legs and not be uncomfortable.

3. Investigate the large errors in the blood pressure measuring system to determine the cause and correction required for flight.

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*A number of changes suggested herein have served as a basis for equipment redesign and refinement in Skylab.

4. Investigate the ESS heart rate display hang-up to determine cause and correction required for flight.

5. Incorporate the mosite wedges and electrode sponges or similar equipment into the flight LVMS.

6. Make the required ground software changes required to insure adequate data reduction capability without special voice recordings by the crew.

7. The shock isolation system should be made to work properly, or the procedures involved with it should be eliminated.

Vectorcardiogram (M093)

Conclusions

1. Stomaseal tapes from particular lots caused a marked degree of irritation.

2. The final VCG harness configuration which was personally sized and had shallow electrode cups worked satisfactorily.

3. The VCG harness connectors have a binding problem.

4. Some electrode sponges are too dry to work satisfactorily.

Recommendations

1. Skylab crews should test stomaseal tapes from the flight lot to determine if there is any problem with irritation.

2. The Skylab VCG harness should include the SMEAT modification of shallow electrode cups and a personalized fit.

3. Determine the cause of the VCG connector binding problem and correct it.

4. Action should be taken to insure an adequate amount of electrolyte is contained in the flight sponges.

Hematology Program (M110 Series)

Conclusions

1. There were some problems in drawing blood from superficial veins because they appeared to be subject to spasm.

2. The needle/syringe interface leaked air due

to a poor fit.

3. It was necessary to force the last few milliliters of blood into the ASP which produced spills and might harm some of the cells.

4. The centrifuge cover was easily misaligned, and the unit vibrated excessively even when it was aligned.

Recommendations

1. Crewmen should draw blood from the deeper (antecubital) veins.

2. Insure a proper fit of needle and syringes to eliminate any leaks.

3. Investigate the need to force blood into the ASP to determine the cause and corrections required for flight.

4. Provide a means of easily centering the centrifuge cover, and take other steps required to minimize vibration.

Specimen Mass Measurement (M074)

Conclusions

1. A container was required for food residue measurements, and the mylar bags used during the test were satisfactory if a closing method is provided.

2. The initial elastomer sheet tore loose from its hold-down strip.

3. The temperature measurement is inaccurate.

4. The SMMD appears to be workable to the point of providing adequate residue data, although possibly not the two percent specification. Fecal data had typically less than one percent error.

Recommendations

1. A quantity of mylar bags with a malleable metal clip should be provided for food residue measurements on Skylab.

2. The flight elastomer sheet hold-down should be modified to eliminate the tearing problem.

3. An alternate means of measuring the temperature should be devised.

Metabolic Activity (M171)

Conclusions

1. The M171 experiment only measured a part of the crew's capability to do work, and did not document many areas of possible changes in the body.

2. From the crew's standpoint no metabolic analyzer ever demonstrated the capability to give consistent, believable data, at 5 psia on human test subjects.

3. Since the metabolic analyzer did not work, flight procedures, crew training, and data handling procedures could not be considered to have been exercised by the chamber test.

4. The failures experienced by the bicycle ergometer would have made it incapable of supporting M171 and any crew exercise program.

5. A reasonable crew exercise program requires a functional bicycle ergometer with no use restrictions.

6. The harness worked adequately with the exception that the cone separated, and this would have made the harness useless.

7. The harness requires a place to dry.

8. The heart rate mode was not operational during the chamber test.

9. The earpiece often gives incorrect heart rates and can be adjusted only if one knows the correct rate.

10. The data collected pre-, during, and post-test using the Douglas bags appears to be the only reasonable data from the test.

11. The oral thermometer is slow to respond.

12. Oral temperatures tend to be low and variable after prolonged mouth breathing.

Recommendations

1. Consideration should be given to measuring items which may show changes in strength, endurance, and size of the body pre- and postmission.

2. Fix the metabolic analyzer and thoroughly test it under mission conditions.

3. Insure the bicycle ergometer will support a vigorous crew exercise program.

4. Provide places for harnesses to dry.

5. Delete using the heart rate mode, and substitute an exercise protocol using the set work mode.

6. Develop an accurate earpiece thermometer or delete measurements after metabolic analyzer measurements.

Time and Motion (M151)

Conclusions

1. Crew concern over being within the field of view of the camera tended to inhibit the natural movements in accomplishing a task.

2. There could not be any coverage of food residue mass measurement since there normally was no food residue.

3. The crew had little involvement with the experiment, hence complications were minimal.

Recommendations

1. Establish camera positions and lens such that the crew need not be concerned regarding their position.

2. The experiment should cover an event other than food residue mass measurement.

Sleep Monitoring (M133)

Conclusions

1. Two of the crew experienced reactions to the M133 experiment that appeared to be caused by the electrode paste.

2. The electrodes used in the chamber had more electrolyte than those used pre- and posttest.

3. The electrode paste was difficult to clean from one's hair in the chamber.

4. The PBI caps were just as comfortable as the Spandex material.

5. It is easy to improperly install the M133 tape.

Recommendations

1. The Skylab crewmembers should be tested with the M133 experiment to determine if there is any allergic reaction.

2. The minimum amount of paste should be placed in the electrodes.

3. The M133 experiment should be scheduled the night before a shower if possible.

4. A procedure should be developed to insure the proper installation of the M133 tapes.

Experiments Peculiar to SMEAT

Environmental Noise

Conclusion

1. This test ran smoothly with only minor equipment problems.

Crew Microbiology

Conclusion

1. The experiment ran smoothly with the exception of collecting fecal samples within the constraints of processing times and overtime restrictions.

Recommendation

1. Schedule sample collections at a time which will allow some variation in delivery.

Chamber Microbiology

Conclusions

1. The test ran smoothly.

2. The horizontal strips located in the air returns on the floors were not representative of the chamber environment.

Recommendation

1. Don't consider the data from the horizontal strip as being representative of the chamber environment.

Inflight Medical Support System (IMSS)

Conclusions

1. The diagnostic and therapeutic kits are probably adequate, but some items such as the Politzer bag and tongue depressor are useless and should be eliminated. There was an inadequate opportunity to make use of the surgical items and some other items; however, it is felt that the IMSS training should stress the ordinary and not the heroic procedures. The drug kit was not really exercised; however, again it is the small everyday items that will find usage and such items as an effective emollient for lip chapping and the like should be considered.

2. The IMSS resupply kit was frustrating because of the difficulty in identifying item locations and the difficulty in obtaining items.

3. Although it was possible to use the microbiological techniques, the procedures were found to be extremely frustrating and time-consuming and the microscope is still felt to be inadequate. It probably will be possible to do a white blood differential, but further work is needed in this area.

4. SMEAT purposely proceeded with inadequately developed IMSS procedures, especially in microbiology due to the early time of the test. These procedures are fragmented and extremely hard to integrate and even harder to put into any sort of reasonable practice.

5. The time allowed for the microbiology procedures is inadequate and may be more in error in the absence of gravity.

6. There are problems of gas leakage and evolution in the stainer.

7. It is difficult to properly smear and dry blood smears. This problem may be associated with reduced atmospheric pressures.

Recommendations

1. Eliminate the Politzer bag and replace the metal tongue depressor with standard disposable units. Review the surgical kit in view of training received and proficiency attained with view of possible elimination of such items as intracardiac needles. Stress procedures that are likely to be required such as manual blood pressure readings and heart rate during exercise.

2. The IMSS resupply container rack should be reworked for easy removal. Only the racks should be stowed in the chiller.

3. If possible, replace the microscope with one with adequate optics and lighting. Provide a mechanical stage.

4. Some effort should be made to better integrate the many bits and procedures in operations to allow something more realistic in terms of training and timeline.

5. A hard look should be taken at the value to be obtained from some of the more detailed aspects of the microbiological procedures. Then a decision should be made whether it is worth the effort to keep these in the program as compared to the amount of training that will be required as well as the time in orbit should it be used. We would strongly recommend against using these microbiology procedures on any but actual illness events.

6. The stainer should be examined under 5 psia especially as to the alcohol reagents and a fix attempted on the vapor production and other gas leakage.

7. The blood smear fixture should be included and Wright staining procedures should also be further examined under 5 psia.

Operational Bioinstrumentation System (OBS)

Conclusions

1. The OBS experienced a couple of failures and the total number of uses was not adequate for us to make a conclusion on its adequacy.

2. We tried an electrode "knurdle" as well as the electrode sponges and prefer the sponges.

3. We used the OBS belt and prefer it over the CWG.

Recommendation

1. Include an OBS belt on Skylab.

Habitability

Conclusions

1. The SMEAT chamber was adequate for a 56-day habitation.

2. The 5 psia atmosphere had an almost insignificant effect on our daily activities.

3. The temperature was most comfortable at 69°F and acceptable at 77°F.

4. The habitability measurement instruments were useful but probably not optimum.

5. The habitability questions varied from thought provoking to tedious with the multiple choice appearing the least desirable.

Recommendations

1. Eliminate most of the tabular type habitability questions.

2. Increase reliability of temperature measuring equipment.

Aerosol Analysis (T003)

Conclusions

1. The T003 instrument was simple and easy to use but at times displayed questionable data.

2. There was some confusion as to what to do if a reading was not recorded.

Recommendations

1. If possible, devise a way to grossly check the T003 instrument in flight.

2. Define what to do if a reading is not recorded.

Chamber Systems and Equipment

Chamber Systems

Conclusion

1. The Chamber Systems worked well with only minor problems indicating that the

work by the individuals concerned was worthwhile.

Personal and Hygiene

Conclusions

1. The shower is very desirable, but the water quantities are minimal.

2. Shampoo could not be used with the shower.

3. All materials tested for washcloths and towels were satisfactory, but PBI and the Skylab materials were the best. The quantity of washcloths and towels was slightly excessive, but they were also useful for cleaning the chamber.

4. Personal hygiene kits contained unused items and an inadequate amount of others.

5. It is desirable to have a rather thorough washup after exercise.

6. The wipes were not adequate for cleaning.

7. An excessive amount of lint and debris was generated in the chamber. X-420 material was the biggest offender.

8. The Skylab vacuum cleaner was minimally satisfactory in picking up debris with the Apollo-type brush. It was unsatisfactory with the Skylab brush. It would not pull liquid into the collection bag, but allowed it to collect in the hose convolutes.

9. Three men living for two months are bound to have a urine spill, sickness, or other occasion that will require cleaning a distasteful mess.

10. There was an inadequate number of wipes in SMEAT for a 56-day mission.

Recommendations

1. There should be no decrease in water or temperature on the shower.

2. The shampoo should be deleted if it cannot be used with the shower.

3. The current number and type of towels and washcloths should remain the same.

4. Each Skylab crewman should examine the kit to insure adequate quantities of items.

5. Schedule a personal hygiene period following each exercise session.

6. Towels and washcloths should be used for spacecraft cleaning.

7. Minimize any planned use of X420 material and investigate any potential flight problem with ECS filters being clogged by lint.

8. The Apollo-type vacuum cleaner brush should be used on Skylab, and the vacuum should not be used to pick up liquid spills.

9. There should be several pairs of some disposable rubber gloves onboard Skylab for cleaning.

10. Increase the number of wipes on Skylab by five boxes, and only use two dispensers at one time in the wardroom and waste management compartment.

Waste Sample Collection

Conclusions

1. A system of positive control including coding of containers by day and crewman is required to insure that samples are not lost or mixed.

2. A portable container for water and urine is required pre- and postflight. This container must be capable of being carried in the T-38 pod. The container developed during SMEAT is satisfactory.

3. A daily debriefing to the crew on wastes collected from the previous day was required to minimize errors.

4. Personnel were not trained and the collection system was not tested prior to when actual collection began. This produced many problems while the "bugs" were worked out of the system. Now all but one of the individuals who performed the collection (as well as food and water delivery) have been released.

Recommendations

1. The system of sample control developed during SMEAT should be used for Skylab.

2. The portable water and urine container developed for SMEAT should be available to the Skylab crews.

3. The Skylab crews should receive a short debriefing on the previous day's waste collection each day during the pre- and postflight periods.

4. Insure that personnel performing collection have adequate training in a realistic collection situation.

Skylab Urine Volume Measuring System (UVMS)

Conclusions

1. The Skylab UVMS was too small for the crew's daily urine output.

2. Failures in the Skylab UVMS or the urine bags resulted in frequent large urine spills.

3. The design of the UVMS and the tools available made cleaning the UVMS a difficult, hazardous, and time consuming task.

4. It was impossible to obtain consistent urine samples.

5. The volume measurement system hung up during the latter part of the test.

6. Three centrifuges were replaced during the pretest and test period in attempts to obtain adequate airflows.

7. The filter was replaced with extreme difficulty.

8. The urine collection hose/funnel assemblies frequently were ineffective because of quality control problems.

9. The urine system drawer and drawer latch were difficult to operate.

10. There was significant condensation from the cooling lines which led to the cold plates.

11. At least an hour a day should be planned for system operation.

12. The capacity of the contingency system is inadequate.

13. There is back pressure in the contingency system.

14. Several cuff assemblies leaked.

15. Contingency system sampling was unsuccessful.

16. The contingency system procedure is complicated.

Recommendation

1. A major effort should be made to provide a urine system that will collect, measure, and sample the crew's daily urine output without excessive crew time or inconvenience. Any spill not only negates the experiment but requires significant crew time for cleanup and presents potential operational and health hazards.

Fecal Collection System

Conclusions

1. The stools were not well formed while we were on the Skylab diet which may cause a separation problem in zero g.

2. The green sticky-back tape on the fecal bags is too difficult to handle in any manner other than disposal.

3. The second seal on the fecal bag is clumsy and crude if made in the originally designed manner, but the newly proposed method of sticking a sticky surface to the bag is satisfactory.

4. Keeping the fecal system prepared with a bag is advisable in case a need to use the system suddenly arises.

Recommendations

1. Investigate the cause of the soft stools while on the Skylab diet, and correct if possible.

2. The green sticky-back tape on the fecal bags should be thrown away when it is removed.

3. Use the new procedure for making the second seal on the fecal bags.

4. The system should be configured with a bag after each use.

Carbon Monoxide Monitor

Conclusion

1. The unit was noisy, difficult to interpret, had an inadequate means of being checked, and failed during the test.

Recommendation

1. This unit has a significant number of problems that need to be corrected prior to considering it for flight.

Carbon Dioxide Monitor

Conclusion

1. The unit has a slow response time for carbon dioxide measurements, and the ambient temperature gauge was in error by several degrees.

Recommendation

1. Procedures and timeline should account for the slow response time in the use of this instrument, and the temperature error should be corrected.

Food System

Conclusions

1. Dietary requirements imposed by the M070 series experiments did not adequately consider individual variations which made selection of a satisfactory diet for the SPT impossible.

2. Food preparation and eating facilities in Building 37 were inadequate in that the kitchen was available to too many individuals, and the surroundings were not conducive to pleasant dining.

3. There were a large number of food container failures which primarily included beverage container valves leaking, reconstitution bags splitting, and frozen food membranes bursting. The packaging with these failures was unsatisfactory for flight.

4. The large number of food failures and the dietary problems encountered indicate there is need for spare food items.

5. The large number of pills that must be consumed with the diet have a high nuisance value and are easily confused and forgotten. The polyethylene glycol pills were the biggest offenders, and the data presented did not substantiate their use.

6. The Command Module spoon is required for most items that need to be eaten with a spoon, and it is made of a nonmagnetic material.

7. The "can crushing" mode is a very messy operation.

Recommendation

1. Dietary requirements for the M070 series experiments should be revised to allow enough flexibility to include individual variations as well as varying operational conditions. Individual diets should be thoroughly tested prior to beginning the preflight phase, and any problems encountered should be corrected and retested.

2. The food preparation area for pre- and posttest should be restricted to involved personnel, and the dining facility should be isolated and configured to make it as pleasant as possible.

3. The food packaging needs to be redesigned to eliminate the identified failures.

4. Spare food should be provided on Skylab to handle contingencies, and a means of easily accessing these spares should be developed.

5. The polyethylene glycol pills should be eliminated if the data obtained by their use does not substantiate their continuance. Also, all pills should be color coded and packaged so that pills for a particular meal are uniquely identifiable and located.

6. The Command Module spoon should be available in Skylab, and it should be made of a magnetic material.

7. Modify the can crusher to minimize the mess and to allow for easier cleaning.

Clothing

Conclusions

1. All of the clothing materials used were acceptable from a clothing viewpoint, but the X420 material generated a great deal of lint.

2. The clothing was comfortable, wearable, and sturdy with enough changes for reasonable cleanliness.

3. Some clothing items were not worn because of personal preference.

4. The detachable trouser legs were a desirable feature.

5. The clothing module was not labeled adequately to help a crewmember keep track of what fresh items remained in his module.

Recommendations

1. Do not use X420 on Skylab unless the lint problem can be minimized.

2. Allow the crews more freedom to substitute items so that the module will reflect their clothing wearing habits.

3. Label the clothing modules with a list of the items that are included in a manner which would allow their check-off as they were removed.

Sleep Restraint

Conclusions

1. The sleep restraint provided a comfortable place for sleeping.

2. The neck hole was small enough to make entry and exit difficult on a new restraint.

Recommendation

1. Evaluate the sleep restraint neck hole to make sure it is large enough for entry by the largest Skylab crewmember.

Tool Kit

Conclusion

1. The Skylab tool kit seems well equipped.

Cameras

Conclusions

1. The cameras worked well with only minor problems.

2. The logging of the 35 mm pictures was difficult since it usually was not convenient to obtain the appropriate book at the time a picture was taken.

Recommendation

1. A means should be considered for attaching a convenient log to the 35 mm camera.

Crew Related Activities

Reports

Conclusions

1. The crew reported their actions by means of five types of reports. These reports consumed significant crew time, but we believe they were required.

2. The procedure of having CAPCOM advise the crew of station contact worked well.

3. The information passed out by us was often misunderstood. This problem was probably made worse by several layers of individuals relaying information.

4. Much of the tape recorded information was lost.

Recommendations

1. Adequate time should be made available to the crew to allow them to relay to the ground what they believe is important.

2. Skylab should consider having the CAPCOM advise the crew of station contacts.

3. Skylab should try to streamline their communications procedures as much as possible.

4. Adequate voice recording procedures should be implemented.

Flight Data File

Conclusions

1. The flight data file was an invaluable part of the chamber equipment.

2. The teleprinter is the preferred way to pass many messages.

3. Flexibility should be allowed to change the flight data file while it is being used.

4. We found it convenient to log many items in one master log.

5. The stowage of new procedures and information required office-type items.

Recommendations

1. Supply office-type items, such as dividers, binding rings, files, tape, and per clips, to facilitate the handling of new procedures and information, and the changing of the various books in the FDF.

Timeline and Mission Planning

Conclusions

1. The Skylab mission planning and scheduling worked well for SMEAT.

2. Each day was filled with either experiments or other activities and we were constantly busy. We believe the Skylab crews will be kept extremely busy during the entire 56 days.

3. We found that reports consumed a rather significant amount of time yet we can think of no good alternative to the daily and weekly reports.

Data

Conclusions

1. We believe that for best results the crew should be kept aware of the results of the experiment.

2. Timely examination of the experimental data can uncover many items that can be

corrected if recognized while the test is "fresh" in everyone's minds.

3. Procedures should be devised to advise the crew of the experiments' progress at regular intervals pre-, during and then postflight.

Recommendations

1. The experimental data should be sufficiently reduced to allow timely examination of the progress of the experiment.

2. The crew should be advised at frequent, regular intervals of the progress of the experiments preflight, during flight, and postflight.

Exercise

Conclusions

1. There was no program to document and understand each crewman's exercise protocol pre- or posttest. That used during the test was minimal. This left a gap in the total medical experiments and hampered some experiments directly.

2. The bicycle ergometer is critical to the Skylab crews' exercise and we found exercise a very necessary activity in the chamber.

3. Exercise is an essential feature of prolonged stays in such a closed environment.

Recommendations

1. Establish a program to document each crewman's exercise pre- and postflight as well as during flight, and take the required action to insure that the effect of this exercise is factored into each medical experiment.

2. Take steps to insure the ergometer will be available for exercise in Skylab and that limitations of its use be minimized.

3. Allow for adequate exercise time.

Supplementary Activities

Conclusion

1. The supplementary activities did an excellent job of allowing us to utilize our time in the chamber.

Off-Duty Activity Equipment (ODAE)

Conclusions

1. The Skylab ODAE equipment was used often and generally was adequate. The items most used were the books and tapes.

2. The book and tape procurement process was complicated and probably unnecessary. In the case of tapes, we believe normal commercial tapes to be the best.

3. Labeling the tapes with the crewmember's name and not the tape selection was confusing.

Recommendations

1. Allow the crew the option of purchasing books and tapes for Skylab and then of being reimbursed.

2. Label all tapes, and tape containers, with the major selections on the tape.

Training

Conclusion

1. The SMEAT training was adequate but crammed because of hardware availability.

Health Stabilization

Conclusion

1. The health stabilization plan implemented for SMEAT where the crew avoided crowds, strangers, and anyone who was ill worked.

Recommendation

1. A plan similar to the SMEAT plan should be seriously considered for Skylab. If a more positive health stabilization plan is chosen, it should be defined early, so that it can be studied for consistency.

Summary

A 56-day chamber simulation of Skylab was successfully completed. The atmosphere (5 psi. 70 percent oxygen, 30 percent nitrogen, 5 mm carbon dioxide) and medical features including a 21-day pre- and 18-day posttest medical protocols were closely simulated. No apparent crew health problems were induced by the atmosphere, semi-closed environment, or other test features; and no appreciable crew degradation appeared over this period. The chamber and associated systems performed without major problems.

Although only medical experiments were scheduled, crew time was well occupied.

Major and fundamental problems were encountered with medical equipment including Urine Volume Measuring System, and metabolic analyzer and ergometer. Hardware problems were also encountered with the Blood Pressure Measuring System and Experiment Support System/Cardiotachometer. Another major problem was the rigidity of the food system which produced a nineteen pound weight loss in one crewman.

It was concluded that virtually no baseline data was gathered from the metabolic studies, and that UVMS, diet, and metabolic analyzer must be revised and tested before flying on Skylab.

CHAPTER 22

SUMMARY

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Lyndon B. Johnson Space Center

The Skylab Medical Experiments Altitude Test was a simulation of the 56-day Skylab mission. This test, conducted at the Lyndon B. Johnson Space Center, included all significant features of the Skylab flight environment with the exception of weightlessness. The atmosphere was identical to that of Skylab, consisting of a 70 percent oxygen/30 percent nitrogen breathing mixture at 5 psi; the physical facility was quite similar; crew activities were fully representative; the timeline of events was that of an operational mission; and full mission support was provided, just as would be the case in Skylab. Finally, to insure fidelity throughout, three members of the astronaut corps served as subjects.

The objectives of the SMEAT program were several. Of paramount importance was the collection of baseline biomedical data which might be used later in attempting to isolate the effects of weightlessness per se on Skylab crewmembers. A second objective was to evaluate Skylab crew procedures and equipment operations and to train both crewmen and support personnel in the procedures and operations. A third major objective was to test all medical experiment equipment and all life support systems for functional adequacy, reliability, and acceptability so that appropriate redesign might be accomplished prior to Skylab.

The SMEAT mission consisted of a prechamber phase, beginning six months prior to the chamber test; a 56-day chamber test, begun on 26 July, 1972; and an 18-day postchamber test period. The test was conducted in a cylindrical, 20-foot diameter vacuum chamber configured to resemble the part of the Skylab Orbital Workshop (OWS) referred to as the Crew Quarters. The test, conducted effectively as a separate space mission, was judged to be quite successful and produced the following results.

Development of Skylab Program Team

One of the principal outcomes of the SMEAT Program was the molding of a Skylab mission control and support team. A number of new management concepts were used in SMEAT under which a diversified life sciences group, consisting of engineers, physicians, physiologists, biologists, psychologists, and others, became a cohesive program team. A format for regular meetings of key personnel was established and new procedures for information dissemination were used to keep both project personnel and NASA management apprised of significant problems and accomplishments.

During the course of SMEAT, virtually all of the logistics issues which would be found in Skylab were addressed. Such obvious matters as feeding the crewmen, collecting waste samples, and providing exercise facilities, all fairly routine items, required extensive planning for proper accomplishment in the mission environment. The establishment and implementation of logistics programs for issues such

as these brought together people from various NASA Directorates and different disciplines, allowed them to work together and to develop an appreciation of the responsibilities and dimensions by which different organizations involved in mission control work. The result was a team which acquired a mission identity and a confidence concerning its capabilities for mission control and support. This had a profound effect on the ability of the NASA manned space flight organization to fly the most complex medical flight that the United States has set out to accomplish, the Skylab mission.

Baseline Biomedical Data

One of the major objectives of the SMEAT program was to obtain and evaluate baseline medical data for up to 56 days for those medical experiments which might be affected by the Skylab environment. These data then would provide an excellent base from which to isolate and evaluate the effects of weightlessness on Skylab crewmen.

Usable information was obtained from virtually all of the SMEAT medical experiments. These data, coupled with the clinical observations of the medical monitoring team, provided a comprehensive picture of the day-to-day health of the SMEAT crewmembers. No significant changes were noted, and none had really been anticipated, in the results for the medical experiments. There also were no apparent crew health problems induced by living in the semiclosed environment, the altered atmosphere, or other test features of SMEAT. There was no appreciable degradation in crew performance over the period of the test.

The relative constancy of the baseline data obtained during SMEAT is quite important for later Skylab data analysis programs. From the fact that no changes of consequence were found in studies dealing with such variables as mineral balance, metabolic factors, and bone mineral measurements, one can conclude that there will be no bias in the Skylab medical data due to the atmosphere, work, or social conditions.

Data Recording and Handling

A tremendous number of measurements were obtained for medical experiments, systems tests,

environmental tests, and in-chamber monitoring of SMEAT. The acquisition of biomedical data went smoothly, but the processing of the data through computer systems providing automatic computations and plots of the data lagged during the initial stages of the test. These problems were corrected and, by the conclusion of the test, data flow was quite satisfactory.

An initial problem in the SMEAT Program dealt with procedures for handling massive data from the variety of experiments and presenting this information by some system which would allow monitors to follow on a daily basis any trend that might be of significance from a crew health or operational viewpoint. A series of trend charts were developed for each of the major experiments, with daily charting of pertinent data. These trend charts proved quite useful and provided a kind of clinical health chart on the crew using experiment data a different approach to handling medical data from that used in prior space missions.

Equipment and Systems Evaluation

Much of the hardware used in SMEAT was new, particularly that associated with the medical experiments. One of the objectives of the test was to evaluate the functional adequacy and acceptability of the various equipment items and to provide guidelines for needed redesign or improved construction. This effort proved to be of great importance since a large number of potentially serious problems were discovered. In some cases, major redesign of equipment was necessary; in others, additional qualification or life cycle testing was warranted. By the end of the program, however, most problems had been solved and Skylab could be approached with increased confidence concerning hardware adequacy.

The principal equipment problems occurring during the SMEAT test were:

1. *Urine Collection System.* This system was designed to allow the pooled collection of urine samples from Skylab crewmen on a daily basis. The original system was designed to handle 2,000 ml per day. Early in SMEAT, it was discovered that crewmen exceeded this volume on a daily basis quite frequently. Because of this, and other problems associated with use of the system, a major redesign was

undertaken resulting in what is now considered to be a very functional urine collection system for use in flight.

2. *Metabolic Analyzer.* A number of problems were discovered with this unit. For one, a higher oxygen consumption (15 to 25 percent) was observed at altitude than at ground pressure level. Vital capacity and minute volume measures were intermittently as much as 40 to 60 percent higher than should have been the case. In addition, drift was noted in some of the data plots. As a result, a number of the electronic circuits were redesigned and additional mechanical changes made in this system. The metabolic analyzer now provides consistent data and is considered adequate for Skylab use.

3. *Bicycle Ergometer.* A major problem was encountered with the bicycle ergometer. This device is very important since it serves two purposes. First, the ergometer supports the metabolic activities experiment (M171) to determine if man's metabolic effectiveness in doing mechanical work is altered in the space environment. Second, the ergometer is the basic device used by the crew for obtaining daily physical exercise. This is very important if they are to maintain physiological condition throughout the flight.

Failures with the ergometer during SMEAT were such that it was necessary to transfer the device out of the chamber through the airlock during the test, subject it to failure analysis, reassemble the unit, and pass it back in for further use. A number of design deficiencies were noted and additional qualification tests on redesigned units were conducted to insure that the ergometer used during Skylab should be

appropriate for the full 56-day mission. Also, on the basis of the SMEAT results, a spare ergometer load module, housing the pedals and drive motor, was added to the Skylab equipment package.

4. *Lower Body Negative Pressure Device.* A seal in the LBNP device encloses the lower extremities of the body so that a negative pressure can be applied. This seal suffered serious leakage. A redesign of the waist seal was accomplished, and changes were made in both SMEAT and Skylab systems. Further, a decision was made to carry a spare waist seal during the flight program.

Because it gave high readings, the blood pressure measuring system also was deemed unsatisfactory. A failure analysis pointed to a calibration problem with the blood pressure cuffs. This was corrected, and a series of tests were conducted at Dallas County Hospital which verified system adequacy on the basis of correlation between an in-dwelling blood pressure catheter and the experiment blood pressure cuff system.

5. *Vectorcardiogram.* In this experiment, problems were encountered with skin irritation produced by the electrode cement. Special patch tests were instituted to verify that the electrode cement and the electrode paste used would not produce skin irritation in the Skylab crewmen.

6. *Blood Sampling Techniques.* Problems were encountered, in the first blood samples, with coagulation that interfered with the separation of plasma and serum. Additional anticoagulants were added to later samples, and the problem was alleviated. There also was some difficulty with vibration of the blood separation centrifuge. Again, results were used to correct equipment scheduled for later Skylab missions.

APPENDIX TO CHAPTER 10

METABOLIC ACTIVITY -- EXPERIMENT M171

A. *Breakout Cable/PDP 8-e Operation*

An initial SMEAT 5 psia we. run occurred on July 10, 1972. Data from this test were difficult to interpret and raised questions regarding the performance of the metabolic analyzer. It became apparent that knowledge of metabolic analyzer transducer outputs was required to quantitatively describe performance of the metabolic analyzer. A breakout cable was installed on the SMEAT metabolic analyzer before the second 5 psia wet run. Table A-1 lists the variables that were then available to be monitored.

The breakout cable was connected to an electrical feedthrough in the chamber wall. The cable extended from outside the chamber to a platform immediately above the chamber. At this point the cable interfaced with a 24-channel calibration/buffer box. Each signal was buffered by feeding it through a high input, low output impedance unity gain amplifier. Twelve analog outputs were monitored on Brush 260 stripchart recorders. Additional analog signals were patched to a PDP 8-e digital computer.

The digital minicomputer (PDP 8-e) was used to check the computational accuracy of the Metabolic Analyzer (MA) analog computer. The use of a digital computer sampling analog signals allowed simultaneous calculation of gas exchange parameters using four different sets of equations describing mass balance. Two of these sets of equations were identical with the equations implemented in the MA for Mode 1 and Mode 2. The other two sets of equations were Mode 1 and Mode 2 calculations but did not use the gas fraction of water measured by the mass spectrometer. Instead, the temperature of the exhalation spirometer was monitored, and the water fraction was calculated by assuming the spirometer gas was saturated at that temperature. The calculated gas volume at standard temperature and pressure (STP) was then reduced to dry conditions by multiplying the STP volume by $(1-F_{H_2O})$. The Mode 1 and Mode 2 calculations were performed using dry gas volumes and dry gas fractions.

The accuracy and repeatability of the digital calculations were checked by monitoring the MA during an end-to-end calibration run using a known gas mixture and hand pump.

Simultaneous calculation of the four sets of equations using MA transducer data quantitated several sources of errors in the MA. The excessively high fraction of water measured by the mass spectrometer caused MA Mode 2 calculations of O_2 consumption and CO_2 production to be 4-5 percent low. This same error in water fraction caused Mode 1 O_2 consumption to be measured 10-20 percent high. In addition, correct Mode 1 operation was shown to be dependent on exact volume matching of inspired and expired volume spirometers.

B. *Major Problem Areas*

1. Quantitative Carbon Dioxide and Water Measurement

The temperature of the exhalation spirometer was monitored concurrently with Mass Spectrometer (MS) water signal and no consistent relationship was demonstrated. Because partial pressure of water vapor is a function of temperature, a specific relationship between exhalation spirometer temperature and MS water signal was expected. We continually observed higher water readings than anticipated according to indicated spirometer temperature. Either the thermistor in the exhalation spirometer did not indicate true exhaled air temperature or the mass spectrometer was measuring water too high. Test run on DVTU #2 verified that the spirometer thermistor was sufficiently accurate. Therefore, we concluded that the mass spectrometer measured water too high, possibly due to an error in the water gain.

Carbon dioxide quantitation initially appeared to be interlocked with water measurement. MA data compared with Douglas bag data indicated that carbon dioxide was measured higher by the metabolic analyzer than by Douglas bags. In the laboratory, we have been unable to demonstrate a "loss" of carbon dioxide by the Douglas bags. This discrepancy between the MA and the laboratory standard is attributed to operation of the mass spectrometer in the SMEAT MA. Whether or not this problem is one of calibration or malfunction remains to be determined. However, data from the laboratory DVTU MA at sea level show carbon dioxide values similar to Douglas bag data.

Extensive post-SMEAT evaluation of the mass spectrometer is planned at Perkin-Elmer, Pomona, California.

Table A-1

Variables Monitored by PDP-8e

CHANNEL SMEAT	DVTU-2	VARIABLE	BOARD	PIN #	GROUND
1		$\dot{V}$ min (T M)	XA-14		13, 20
		Temp (E)	XA-14		17, 20
		Pressure	XA-14		15,
		Temp (I)	XA-		14,
		$\dot{V}_1$ (Pot)	XA-		0, K
		$\dot{V}_E$ (Pot)	XA-		0, K
		$\dot{V}$ (BR) Mode II	XA-		0, K
		(BR)	XA-		
		(BR)	XA-		
		(BR)	XA-		
		(BR)	XA-		
		(Cabin)	XA-		0, K
		(Cabin)	XA-		
	1		XA-		0, K
	2		XA-		0, K
		(Cabin)	XA-4		0, K
		(Cabin)	XA-4	2, E	0, K
		CO_2	XA-		0, K
		RH	XA-		0, K
		$\dot{V}_1$ (BR) Mode I	XA-	1	14, 20
	1	$\dot{V}_E$ STP	XA-	1,	0, K
		$\dot{V}_1$ STP	XA-	1, E	0, E

Resolution of the water/carbon dioxide measurement problem awaits completion of these tests.

2. Variability in Hand Pump Calibration.

Initial hand pump calibrations showed large variability in computed data. The respiratory valves were suspect because they allowed blow-by due to their low cracking pressure. A study was performed in our laboratory to determine if the flight configuration crew valves were acceptable for end-to-end calibration of the MA. The report titled, *The Effect Of Different Valves On Calibration Of The Metabolic Analyzer*, by A. Paul Schachter, dated August 18, 1972, has been circulated to MSFC and DE4 personnel. Briefly, it was concluded that crew valves were satisfactory for delivering known gas volumes to the MA if the pump was stroked slowly rather than rapidly.

Monitoring SMEAT hand pump calibrations demonstrated two additional sources of error: performance of sample and hold circuits for STP volumes and the trigger concept. STP sample and hold data were shown to correlate poorly with the raw spirometer volumes, e.g., 0.93 instead of the anticipated 1.0 correlation. Further investigation indicated that this problem was unique to the SMEAT MA test setup and was caused by "filter" capacitors used in the calibration voltage follower box. MA DVTU #2 consistently has shown a high correlation between STP and raw volumes.

3. Trigger Circuits.

The trigger circuit design was problematic for two reasons: (1) The trigger signal occurs at or near zero air flow, and (2) There was no requirement that the second half of a breath cycle be initiated before the volume data from the preceding half were used for computation. Mode I operation was hindered by normal human respiratory patterns such as coughs and slow air flow rates because such maneuvers resulted in computation before completion of that exhalation.

A new trigger concept was studied briefly. It would make Mode I functional but lower the overall reliability of the MA by making the dump of each spirometer dependent

upon the other spirometer. Therefore, failure of any portion of the inspiration spirometer circuit or associated hardware would result in total loss of the MA data.

4. Ear Plethysmograph.

Ear plethysmograph performance was the subject of extensive debate. At present we believe that the ear plethysmograph measured heart rate reasonably well within the 60 - 120 beats/minute range. However, most data indicated that the plethysmograph heart rate was low relative to the VCG heart rate above the 120 beats/minute level. Performance of this unit will be rechecked during post-SMEAT testing.

5. Dump Valve.

On SMEAT day 18, significant problems were encountered with the inspiration spirometer dump valve. Stripchart data indicated that the spirometer dump valve hung open during the run on SPT. The exact failure was uncertain, but it most likely resulted from either a temporarily clogged N_2 gas orifice or a too tight ball valve seal that caused the ball valve to stick open. The problem could not be duplicated during post-SMEAT testing.

6. Vital Capacity and Minute Volume Circuitry.

Starting with the SPT test on SMEAT day 27, the vital capacity and minute volume data as recorded were approximately 60 percent high. On SMEAT day 30, the MA data were credible for the CDR at 1230 hours but by 1600 hours, when PLT was run, the data were again 40 - 60 percent high. SPT was run at 1745 hours and these data were still high. However, all data for SMEAT day 36 appeared "normal." The next obvious failure occurred during PLT's special test on SMEAT day 43 at 1545 hours. Data for SPT on that date were also high by the 40 - 60 percent figure seen previously. For the remainder of SMEAT, the MA data for vital capacity and minute volume were credible.

In summary, an intermittent failure was observed which produced high measurements for vital capacity and minute volume. It appeared to be related to MA temperature. Fortunately STP volume, required for computation of oxygen consumption and carbon dioxide production, was not affected by this anomaly. Post-SMEAT the failure was identified in a multiplier required to go from V_{ESTP} to V_{ESTPD}. The problem was isolated to a defective integrated circuit (IC) amplifier. The DVTU metabolic analyzer contained IC's, including the one which failed, from a lot which had previously failed in flight hardware. All such IC's are no longer used in the flight hardware.

7. Ergometer Failure.

The original SMEAT ergometer failed during a personal exercise period with SPT as subject. Examination

indicated that 7 of 12 brushes had separated from the brush ring and the torque sensor had failed. Apparently the only significant difference between the SMEAT ergometer and the flight hardware was in the type of brush ring, and in the fact that the brush ring configuration used causes the armature to turn "into" the brush ring rather than "away from" the brushes.

A flight configuration brush ring was installed in the SMEAT ergometer and the unit was recalibrated and returned to the chamber. Within approximately one week, the ergometer failed again. The characteristics noted were a loud grinding noise and a very high load after 29 minutes at 300 watts. Inspection of the ergometer following its removal from the chamber failed to demonstrate the problem. A subsequent 36 minute run at 300 watts on a calibrator resulted in failure of the unit. Again, the failure was characterized by excessively high loads rather than unloading. In both cases, the failure was the torque sensor. Subsequent investigation at MSFC disclosed a bearing misalignment on the armature shaft caused by improper assembly. At high work levels the armature would expand and, due to the misalignment, eventually contact the stator thus inducing high force spikes into the torque sensor thereby causing its failure.

8. Douglas Bags.

Douglas bag collections were planned for SMEAT using the following protocol for each subject:

Bag #	Sample
1	20 pumps (3.5 l stroke) of cabin air
2	10-minute rest sample
3	Final 3 minutes at first work level
4	Final 3 minutes at second work level
5	Final 2 minutes at third work level

At least three sets of bags were obtained for each subject during the five inflight Douglas bag collections. The test dates were August 25 (238) and August 26 (239), 1972, and September 7 (251), September 13 (257) and September 18 (262), 1972. Twelve bags were available to the crew for each two-subject run. The extra bags were generally used to obtain an additional sample at each subject's last work level. During each run, the Crew Systems Division personnel were requested to hold chamber nitrogen level as stable as possible. This was necessary because of the sensitivity of the metabolic calculations to nitrogen levels. The data from the Douglas bag collections are summarized in Table A-2. The mean oxygen consumption values for each crewman fell near the middle of the 95 percent C.I. of his baseline data. The respiratory exchange ratio data were within normal limits, indicating that the high values noted from the SMEAT MA were incorrect.

Table A-2

Summary of Physiological Data Obtained From SMEAT 5 psia Douglas Bag Collections

EXERCISE LEVEL	CDR				PLT				CPT			
	$\dot{V}_{O_2}$	$\dot{V}_{CO_2}$	R.E.R.	$\dot{V}_E$	$\dot{V}_{O_2}$	$\dot{V}_{CO_2}$	R.E.R.	$\dot{V}_E$	$\dot{V}_{O_2}$	$\dot{V}_{CO_2}$	R.E.R.	$\dot{V}_E$
1	.971	.724	.745	23.4	1.063	.850	.744		1.177	1.111	.741	39.3
	.862	.680	.786	21.3	1.097	.833	.754		1.170	1.143	.834	43.6
					.979	.847			1.447	1.409	.956	48.8
									2.174	1.155	.954	43.9
MEAN	.916	.702	.766	22.4	1.046	.850	.814		1.191	1.148	.884	43.7
±SD	.077	.031	0	1.5	.054	0	.070		.063	.162	.077	3.4
2	1.424	1.242	.872	33.1	1.638	1.367	.835		2.094	1.966	.947	70.5
	1.309	1.196	.913	35.0	1.598	1.383	.865		2.325	2.198	.945	81.8
					1.465	1.452	.991		2.195	2.206	1.003	70.8
									2.195	2.075	.945	68.6
MEAN	1.366	1.219	.892	33.1	1.567	1.401	.897	43.5	2.204	2.116	.960	72.4
±SD	.077	.031	0	.07	.089	.031	.083	1.7	.089	.100	0	6.4
3	1.974	1.763	.893	47.7	2.214	1.937	.844		2.712	3.034	1.119	114.4
	1.786	1.765	.988	43.4	2.068	2.049	.99	89.3	3.025	2.686	.887	99.3
	1.924	1.905	.990	46.0	2.092	2.087	.997	71.4	3.539	3.145	.888	125.3
									2.914	3.258	1.118	111.0
									3.077	3.168	1.031	113.0
									2.700	3.079	1.140	103.3
MEAN	1.894	1.811	.957	45.7	2.151	2.024	.943		2.993	3.061	1.030	111.2
±SD	.094	.077	.054	2.1	.132	.070	.083		.34	.170	.124	9.1

9. Silica Gel Drier Test.

Early in the development of the MA a silica gel drier was incorporated into the system to lower the dewpoint of the exhaled air. However, a negative aspect of silica gel was that it apparently adsorbed CO_2 on the trapped water. The CO_2 adsorption was expected to produce MA data that had low respiratory exchange ratios. With the exception of the rest data from the first subject (CDR), the respiratory exchange ratios were higher than previously noted. Therefore, the canister appeared to saturate with CO_2 long before it lost its capability to adsorb moisture. The data are summarized in Table A-3.

Table A-3

MA Silica Gel Drier Test Data

EXERCISE LEVEL	EVENT TIME	CDR			PLT			CPT		
		$\dot{V}_{O_2}$	$\dot{V}_{CO_2}$	R.E.R.	$\dot{V}_{O_2}$	$\dot{V}_{CO_2}$	R.E.R.	$\dot{V}_{O_2}$	$\dot{V}_{CO_2}$	R.E.R.
1	10	.807	.762	.944	.866	.942	1.08	1.312	1.415	1.031
	15	.911	.932	1.010	.771	.872	1.131	1.421	1.465	1.101
2	11	1.271	1.454	1.143	1.462	1.766	1.13	2.285	1.651	1.17
	17	1.212	1.585	1.307	1.336	1.636	1.225	2.070	.611	1.11
3	11	1.800	2.318	1.283	1.940	2.530	1.204	3.003	3.077	1.175
	5	1.000	2.258	1.113	2.000	2.980	1.377	3.000	3.193	1.276

Water levels remained stable at 1.5 percent during the CDR's test, 1.8 percent during the PLT's test, and began to rise from 2.4 to 4.0 percent during the SPT's test. Therefore, in spite of the low water levels, CO_2 was still being measured higher than anticipated according to the Douglas bag technique. The implication is that the mass spectrometer CO_2 gain was being set too high. This may have been the summation of two separate problems: (1) The mass spectrometer CO_2 gain was adjusted for a gas thought to contain 14.3 percent CO_2 when, in fact, it contained only 14.0 percent CO_2, and (2) The CO_2 gain is adjusted while some cabin air dilution is present in the gas being sampled.

10. Effect of Short Term Changes in Cabin Atmosphere on MA Measurement of Metabolic Rate.

Initial M171 runs at altitude indicated oxygen consumption data were very sensitive to small changes in the quantity (fraction) of nitrogen in the chamber atmosphere. This computational sensitivity results from two facts: (1) The MA analog computer stores cabin air composition at the onset of each test. The implied assumption is that the cabin gaseous composition remains constant during the run; (2) The computation of inspired volume is highly sensitive to small F_{IN_2} changes, thus an increase in F_{IN_2} during an M171 run will produce an apparent increase in $\dot{V}_{O_2}$. Conversely, a decrease in F_{IN_2} during an M171 run will produce a decrease in MA oxygen consumption. Two special SMEAT tests were run to document this point. In both tests, the subject (SPT) performed steady-state exercise at 180 watts as judged by no significant increase in heart rate during the 45 minute exercise period. In the first test, five minutes of $\dot{V}_{O_2}$ data were obtained with a stable cabin gas composition, followed by 30 minutes of $\dot{V}_{O_2}$ data during which time the F_{IN_2} was increased 0.005 per 10 minutes. At total F_{IN_2} increase of 0.015 resulted in an apparent $\dot{V}_{O_2}$ increase from 2.1 to 3.6 liters/minute. On the second special test day a corollary test was performed wherein the F_{IO_2} was raised 0.015 while the same subject repeated the 45 minute ride at 180 watts. Because cabin CO_2 and H_2O levels remained relatively stable at 2.0 percent and 5.0 percent respectively, the increase in

F_{IO_2} was reflected in a like decrease in F_{IN_2}. M171 oxygen consumption data fell from 2.1 to 1.5 liters/minute.

These tests proved the necessity of maintaining cabin atmospheric composition as stable as possible during M171 tests.

The data from the two tests are tabulated in Tables A-4 and A-5.

11. Evaluation of MA Mass Spectrometer Gas Analysis.

All preceding tests indicated the MA mass spectrometer was measuring carbon dioxide too high. This test was designed to provide a series of saturated gas samples to be introduced to the mass spectrometer at 5 psia. The mixed gas samples were analyzed by the MA mass spectrometer using both the cabin air and the exhaled sample inlet ports. At the completion of this portion of testing, the Douglas bags were passed out of the SMEAT chamber and brought to the environmental Physiology Branch for analysis using a S.R.I. MEDSPECT respiratory mass spectrometer. The data are shown in Table A-6.

The results of these analyses indicated that the SMEAT mass spectrometer was measuring CO_2 approximately 25 percent high and O_2 five percent low. Analyses made via the cabin air and exhaled sample ports showed no appreciable differences.

12. Mass Spectrometer Calibration Gain Adjust.

The final regularly scheduled M171 test was used to check the impact of mass spectrometer gain adjusts on MA data. The CO_2 gain was set at 11.4 percent, instead of a nominal 14.3 percent, and water gain was similarly reduced from 24 to 18 percent. Otherwise, the protocol for M171 was that normally employed. The data obtained are shown in Table A-7. Essentially, the $\dot{V}_{O_2}$ data appear normal, but $\dot{V}_{CO_2}$ are somewhat low relative to the Douglas bag data. This indicates that the CO_2 gain may have been reduced too much. The R.E.R. data reflect the CO_2 gain adjust by having numerical values somewhat less than expected.

Table A-4

Nitrogen Injection into Cabin Atmosphere
M171 Special Test #7
Subject: Thornton (180 Watts)

EVENT TIME	MA CO2	VA	VA RQ	VA MV	CABIN AIR			
					F_{O_2} .694			
					F_{N_2} .244			
					F_{CO_2} .0193			
					F_{H_2O} .0452			
						CABIN AIR FRACTIONS		
44	1.310	1.040	1.044	42.6	F_{O_2}	F_{N_2}	F_{CO_2}	DEWPOINT
43	2.500	.147	1.345	78.0				
42	2.450	.150	1.280	76.5				
41	2.400	.113	1.213	73.2				
40	2.400	.093	1.184	76.7				
39	2.44	.117	.193	65.4	.709	.220	.0163	50°F
38	2.41	.040	1....	74.2				
37	2.430	.060	1....	74.2				
36	2.40	.185	1.180	74.6				
35	2.730	2.350	1.205	80.3	.704	.222	.0164	50.5°F
34	2.68	2.416	1.157	80.2				
33	2.65	2.443	1.130	82.5				
32	2.49	2.500	1.112	80.4				
31	2.70	.401	3.105	80.0	.702	.225	.0166	51°F
30	2.60	.541	1.058	83.3				
29	2.57	.621	1.063	78.5				
28	2.70	.670	1.045	82.1				
27	2.66	....	1.035	81.0				
26	2.63	2.740	1.017	80.0	.699	.227	.0160	51.5°F
25	2.60	....	....	77.7				
24	2.72	.850	....	71.5				
23	2.54	....	.407	78.3				
22	2.50	2.691	.965	75.9				
21	2.79	.944	.950	81.9	.697	.229	.0191	52°F
20	2.66	2.956	.946	81.7				
19	2.77	3.028	.945	83.7				
18	2.39	2.74	.908	74.5				
17	2.65	2.030	.920	78.2				
16	2.51	2.850	.904	72.4	.694	.231	.0195	52°F
15	1.80	3.100	.854	57.3				
14	2.74	3.11	.867	80.0				
13	2.61	3.154	.861	79.7				
12	2.58	3.16	.860	76.1				
11	2.71	3.254	.854	76.4	.690	.233	.0198	52°F
10	2.72	2.370	.842	77.6				
9	2.75	3.375	.853	82.7				
8	2.74	3.435	.826	78.0				
7	2.71	3.450	.816	80.1				
6	2.69	3.550	.810	77.7	.688	.234	.0202	52°F
5	2.64	3.507	.802	78.4				
4	2.51	3.544	.800	83.4				
3	2.50	3.30	.797	75.2				
2	2.54	3.446	.701	75.8	.689	.234	.0205	52.5
1	2.60	3.450	....	79.3	.689	.234	.0207	52.5
0	2.77	3.440	.75	84.7	.689	.233	.0208	52.5

Table A-5

Oxygen Injection into Cabin Atmosphere
M171 Special Test #7
Subject: Thornton (180 Watts)

H.R.	EXER. RIDE	PA CO₂	PA O₂	PA H₂	PA HV	INITIAL CABIN AIR				
						F$_{O2}$ .6631				
						F$_{N2}$ .2405				
						F$_{CO2}$ .0224				
						F$_{H2O}$ .0460				
						CABIN AIR FRACTION				
						F$_{N2}$	F$_{O2}$	F$_{CO2}$	C.P. °F	TIME
11	44	1.06	.968	1.113	36.0	.2550	.697	.0203	50	1735
110	43	2.490	2.250	1.124	77.5					
105	4	2.390	2.130	1.143	73.6					
110	41	2.460	2.255	1.190	68.7	.2550	.696	.0307	52	1
100	40	2.340	2.060	1.189	64.8					
106	39	2.460	2.253	1.136	67.1					
105	38	2.410	2.175	1.153	67.9					
104	37	2.52	2.192	1.193	69.6					
104	36	2.57	2.230	1.200	71.0					
105	35	2.46	2.085	1.225	70.0	.253	.700	.0230	52	1
105	34	2.35	2.127	1.218	63.1					
	33	2.34	1.993	1.245	69.3					
107	32	2.64	2.181	1.260	71.8					
1		2.56	2.099	1.26	71.6	.250	.702	.0010	50	1 1
1	30	2.40	1.965	1.267	70.8					
	29	2.49	1.990	1.302	71.2					
1		2.56	2.035	1.306	7					
1		2.73	2.164	1.309	73.6	.249	.703	.0017	50	1 17
1 7		2.510	1.973	1.320	72.9					
	26	2.53	1.949	1.349	75.9					
103	24	2.55	2.031	1.304	71.1					
107	23	2.53	1.970	1.331	72.7					
1	26	2.72	2.044	1.361	73.4	.247	.704	.0010	50	1
1	2	2.57	1.959	1.361	70.3					
1		2.57	1.951	1.366	70.3					
10	19	2.63	1.944	1.400	77.5					
10	18	2.48	1.851	1.357	70.3					
1	17	2.66	1.954	1.392	74.3					
1	16	2.64	1.983	1.407	74.8					
1	15	2.78	2.088	1.445	73.5					
1	14	2.57	1.936	1.451	73.6	.243	.707	.0017	52	14.9
	1	2.70	1.851	1.530	76.5					
1	1	2.58	1.901	1.535	75.9					
1	12	2.94	1.963	1.498	70.1					
1	10	2.64	1.847	1.490	71.5					
10		2.74	2.007	1.556	75.4					
1		2.96	1.915	1.559	74.1	.242	.710	.0015	50	1 35
1		2.65	1.766	1.545	70.8					
10		2.93	1.959	1.568	75.7					
1	5	2.64	1.717	1.597	74.3					
1	4	2.60	1.717	1.569	72.3					
1	3	2.80	1.772	1.607	74.9					
11	2		2.96	1.615	76.5					
11		2.63	1.896	1.600	76.					

Table A - 6

Douglas Bag Gas Analysis at 5 psia

SAMPLE BAG	SPLIT MASS SPEC						SRJ		
	CABIN AIR PORT			EXHALED SAMPLE PORT			INSPECT		
	F_{O_2}	F_{CO_2}	F_{N_2}	F_{O_2}	F_{CO_2}	F_{N_2}	F_{O_2}	F_{CO_2}	F_{N_2}
1			.2635	.5270	.2083			.1632	
2		.1598		.6032	.1355	.2613		.1039	.2763
3	.6170			.6354	.1022	.2624	.6567	.0816	.2613
4				.6686	.0750	.2564		.0608	.2545
5		.0552	.2901	.6808	.0596	.2595		.0470	.2533

Table A - 7

SMEAT MA Metabolic Data Summary
Cal Adjust Test

EXERCISE LEVEL	CDR				PLT				SPT			
	$\dot{V}_{O_2}$	$\dot{V}_{CO_2}$	R.E.R.	$\dot{V}_E$	$\dot{V}_{O_2}$	$\dot{V}_{CO_2}$	R.E.R.	$\dot{V}_E$	$\dot{V}_{O_2}$	$\dot{V}_{CO_2}$	R.E.R.	$\dot{V}_E$
LEVEL 1	.801	.990	.832	20.7	.810	.691	.853	36.9	1.405	1.083	.771	45.4
	.895	.762	.851	22.3	.793	.691	.871	37.4	1.328	1.083	.816	46.6
LEVEL 2	1.480	1.324	.895	31.6	1.290	1.153	.917	46.0	2.286	1.947	.852	78.6
	1.506	1.344	.892	33.1	1.329	1.224	.921	44.1	2.247	1.917	.853	77.9
LEVEL 3	2.067	1.947	.984	46.6	2.017	1.887	.936	63.2	3.164	2.942	.930	123.3
	1.978	1.877	.949	46.2	2.007	1.867	.930	63.9	3.185	2.892	.908	121.7

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15. Supplementary Notes

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16. Abstract

The Skylab Medical Experiments Altitude Test (SMEAT) was a simulation of a 56-day Skylab mission. All significant features of the Skylab flight environment were included, with the exception of weightlessness. The atmosphere was identical; the physical facility was quite similar; crew activities were representative; and three astronauts served as subjects. A number of objectives were achieved. Baseline biomedical data were obtained for most of the medical experiments to be included in Skylab. Data from these experiments are presented. Problems identified in the operation of life support systems and medical experiments equipment are described, together with suggestions for needed redesign or improved construction. Results of evaluations of Skylab operating procedures and data handling techniques also are presented.

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