NASA SP-411

The Apollo-Soyuz Test Project

Medical Report

National Aeronautics
and Space Administration

THE APOLLO-SOYUZ TEST PROJECT MEDICAL REPORT

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Compiled by
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FOREWORD

The Apollo-Soyuz Test Project (ASTP) was both an end and a beginning.

It was the final flight of the highly successful Apollo program. It was the last time that three U.S. astronauts, tightly packed into a command module, would launch from an expendable booster, elbow their way through space, and then return gracefully to a salty splashdown.

But it was the first time that an international purpose to manned flight was demonstrated. Joint docking and the sharing of quarters, experiments, and provisions have all symbolized the feasibility and the will of cooperative space exploration.

As we summarize the Life Sciences findings of this mission, we look forward to the future. We are confident that international manned missions will continue in ever increasing frequency and duration. We are also confident that we will be able to support these missions and to insure the health and well-being of all space travelers.

DAVID L. WINTER, M.D.
NASA Director for Life Sciences

January 1977

PREFACE

The Apollo-Soyuz mission was the first space flight to be conducted jointly by the two leading nations in space exploration, the United States and the U.S.S.R. The primary purpose of this mission was to test systems for rendezvous and docking of manned spacecraft as might occur in standard international space rescue missions and, consequently, to demonstrate the ability to effect crew transfer between spacecraft. The secondary purpose of the mission was to conduct a program of science experiments and technology applications. Except for minor modification, the Apollo and Soyuz spacecraft were identical with those flown on previous missions. A specially constructed docking module was used in flight for crew transfer and also served as the structural base for the docking mechanism that interfaced with a similar mechanism on the Soyuz spacecraft.

This mission, officially known as the Apollo-Soyuz Test Project (ASTP), brought the Apollo Program to a successful conclusion. While marking the end of an era, it also heralded the beginning of increased international cooperation in the space age. The rescue of man in space as a feasible operation on an international basis, should the need arise, was demonstrated.

This report details the results of the clinical aspects as well as the preflight and postflight research studies that were performed on the astronauts. Because of the compromised postflight crew health status, not all postflight research procedures could be accomplished. This compromise was the result of the anomalous entrance of toxic gas into the spacecraft cabin during the Earth landing sequence. Despite the exposure, the medical data collected are of sufficient interest to warrant inclusion in this official ASTP Medical Report.

Only two joint U.S.-U.S.S.R. life sciences experiments were included in this mission: Microbial Exchange and Zone-Forming Fungi. The medical microbiological analysis of the U.S. crewmembers is reported in chapter 13 of this report. The Microbial Exchange experiment, which includes the data from the U.S.S.R. cosmonauts, and the other six (U.S.) science experiments – Quantitative Observation of Light Flash Sensation, Biostack III, Zone-Forming Fungi, Cellular Immune Response, The Effects of Space Flight on Polymorphonuclear Leukocyte Response, and Killifish Hatching and Orientation – are reported elsewhere (see Bibliography).

A most impelling portion of this report is concerned with the entry phase of the mission, when the crew was exposed to toxic nitrogen tetroxide gas, and with their subsequent clinical course and uneventful convalescence. The problem was managed expeditiously and expertly by the crew's flight surgeons and team of medical consultants, both onboard ship and at the Tripler Army Medical Center, Honolulu, Hawaii.

The Apollo era has ended with the ASTP flight. Thus, a remarkable series of space missions – prelunar and lunar Apollo, Skylab, and ASTP – has been concluded. These ventures are now history, and the Space Shuttle era will further the understanding of man in the space environment he has come to know and respect.

LAWRENCE F. DIETLEIN
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CONTENTS

SECTION I

BACKGROUND

1. U.S. AND U.S.S.R. MEDICAL NEGOTIATIONS AND AGREEMENTS

Arnauld E. Nicogossian[a] and Willard R. Hawkins[a]

This discussion of medical negotiations and agreements between representatives of the United States and the U.S.S.R. is presented chronologically.

1972

Joint U.S. and U.S.S.R. negotiations for the Apollo-Soyuz Test Project (ASTP) were conducted at regular intervals by the U.S. and U.S.S.R. specialists at the NASA Lyndon B. Johnson Space Center (JSC) in the United States and, under the auspices of the U.S.S.R. Academy of Sciences, in the U.S.S.R. Preliminary discussions were held October 9 to 19, 1972, in Moscow, U.S.S.R. During this meeting, medical specialists of Working Group III discussed in-flight crew safety, crew transfers, and an in-flight medical support system. In addition, they exchanged several preliminary life sciences documents relating to the proposed joint venture.

1973

The heavy schedules imposed by the Skylab orbital missions limited medical negotiations in 1973 to the two joint life sciences experiments, Microbial Exchange and Zone-Forming Fungi.

1974 and 1975

After completion of the Skylab space flights in 1974, negotiations relating to the medical requirements were renewed, and a joint session was held at JSC from January 14 to February 1, 1974. Appointed representatives of the two countries exchanged general information about the preflight, in-flight, and postflight medical evaluations; schedules; and a flight crew health stabilization program. The negotiations and the intent to follow up with appropriate documentation and preparation of a U.S.-U.S.S.R. working group reference document for medical requirements are recorded in the official minutes of the meeting by Working Group I. The next meeting, April 8 to May 3, 1974, was held again at JSC. Before this meeting, both countries exchanged documents regarding their respective medical requirements. At this meeting, discussion included flight crew health stabilization programs (21 days before flight for the United States and 10 days for the U.S.S.R.), in-flight bioinstrumentation, possible drug kit exchange, drug testing, schedules, and protocols for in-flight crew transfers. Since the internal life sciences ASTP medical requirements document was not completed, only preliminary plans for the preflight and postflight medical examination time lines were discussed at the time of this meeting. The preflight and postflight medical requirements for both countries were finalized during the

[a]NASA Lyndon B. Johnson Space Center.

succeeding meeting, held in Moscow, between August 26 and September 13, 1974. The in-flight medical requirements were completed and added to the overall medical requirements documents during a meeting held January 30 to February 13, 1975, at JSC.

Before ASTP, life sciences programs to be implemented in manned space flights were independently tailored by each country. Though the main objectives of both programs are identical (i.e., the study of man's physiology in space and optimum in-flight crew health maintenance), the methods of accomplishing these objectives are dissimilar and generally reflect each country's respective medical philosophies. At the start of the ASTP medical negotiations, experimental procedures for only two types of medical protocol (i.e., lower body negative pressure and blood biochemical evaluations) had been agreed to under the auspices of the U.S.-U.S.S.R. Joint Working Group on Space Biology and Medicine. Thus, the major portion of the medical evaluations and the respective time lines had to be discussed and unified during the available time apportioned for the meetings of ASTP working groups. The small number of medical representatives participating at any time in the negotiations and the increased secretarial and translator support that was needed accounted for a delay in completion of the joint phase of the biomedical program.

For historical purposes, the final English language version of the ASTP U.S.-U.S.S.R. medical requirements document will be published separately at a later date.

Because each country was allowed to proceed with its respective program, no official contact between medical personnel of the two countries had been established for the ASTP in-flight portion of the mission. It was decided that, in case of need, communications between medical staffs would be routed through the Joint Flight Directors Loop. Also, the final medical findings from this mission would be presented during a regular session of the joint U.S.-U.S.S.R. Working Group on Space Biology and Medicine.

SECTION II

CREW HEALTH AND FLIGHT MONITORING

2. GENERAL BIOMEDICAL EVALUATION

Arnauld E. Nicogossian,[a] Eduard C. Burchard,[a] and Jerry R. Hordinsky[a]

Four areas of importance in health preventive maintenance became apparent from previous Apollo and Skylab space missions. These four areas are:

1. The flight medicine support system and drug testing
2. The work/rest cycle
3. In-flight exercise and bioinstrumentation
4. Food and nutrition.

Comprehensive preflight physical examinations were conducted 30, 15, and 5 days before launch. Additional abbreviated physical examinations were conducted daily starting 3 days before launch. The individual tolerance drug testing was done 3 months before the space flight, and no significant problems were encountered in either prime or backup crewmen.

In the entry phase of the mission, the crew was exposed to the toxic fumes of nitrogen tetroxide and subsequently hospitalized at the Tripler Army Medical Center, Honolulu, Hawaii. Consequently, most preplanned postflight medical activities not directly related to crew health were canceled.

For mission completion, a modified Apollo in-flight medical support system (IMSS), which provided for in-flight diagnosis and treatment of a possible illness, was considered practical for a short, 9-day flight. Two cardiovascular drugs, quinidine sulfate and dipyridamole, were added to the IMSS medication list in deference to the past medical history of one crewmember. The short duration of the mission and inadequate medical training of the crew precluded the addition of such diagnostic equipment as a stethoscope or a blood pressure measuring system into the IMSS. The overall medical IMSS training, limited to a 2-hour general discussion with the command module pilot, covered indications for usage of the available drugs. In addition to the IMSS, data from the operational bioinstrumentation system would also be used, as indicated, as a diagnostic aid to assist in the recommendation for treatment.

It was agreed before the actual flight that the crewmembers, because of their limited training, would consult with the crew surgeon and/or Mission Operations Control Room (MOCR) surgeon over the open loop of the air-to-ground communication system, should the need arise. The private medical communication loop would be reserved for use on the crew's request only and with the flight director's approval.

It should be mentioned that in the very early phase of preflight preparations, each U.S.S.R. prime and backup crewman received a briefing regarding drugs contained in the U.S. medical kit. Further attempts to formally translate U.S. drugs and modes of utilization into written Russian were not successful. By the start of the mission, a list of the Soyuz drugs was available. It was translated into English by the efforts of U.S.S.R. medical personnel, and it included some indication of drug utilization, mode, and dosages. Although crude, this list served as a reference for the MOCR medical personnel.

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[a]NASA Lyndon B. Johnson Space Center.

During the 21-day preflight crew health stabilization program, the crew was maintained on a nominal work/rest schedule. This schedule permitted the crewmembers to have a daily exercise period and at least 7 hours of good night rest. It also included scheduled work and some time for recreation each week.

During the flight period, changes to the flight plan occasionally interrupted the periods of planned crew sleep. The estimate of sleep duration made by ground personnel was in general agreement with the subjective evaluation of the crew. The difference in the launch and zone times of both countries and the scheduled time lines for in-flight joint activities inevitably led to operational circadian shifts for both crews. The resulting in-flight circadian shifts for the U.S. crewmen are depicted in Figures 2-1 and 2-2, where F - 2 is 2 days before lift-off, F - 1 is 1 day before lift-off, and R + 0 is recovery day. The duration of sleep, sleep interruptions, and the magnitude of circadian shifts required for the successful completion of in-flight joint activities are shown in the figures. In summary, a total of three major sleep/wake cycle shifts occurred during this short-duration mission; the most significant shift of approximately 4.5 hours occurred on mission day 2.

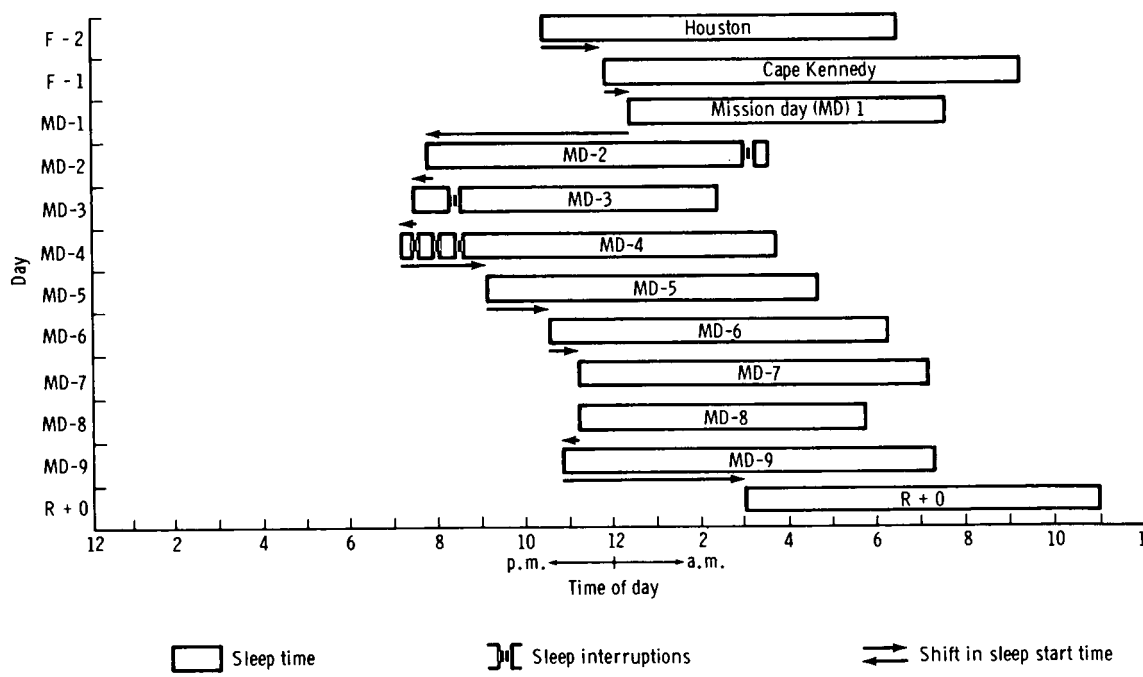

Figure 2-1. Apollo-Soyuz Test Project Sleep Time and Circadian Shift (U.S. Crew)

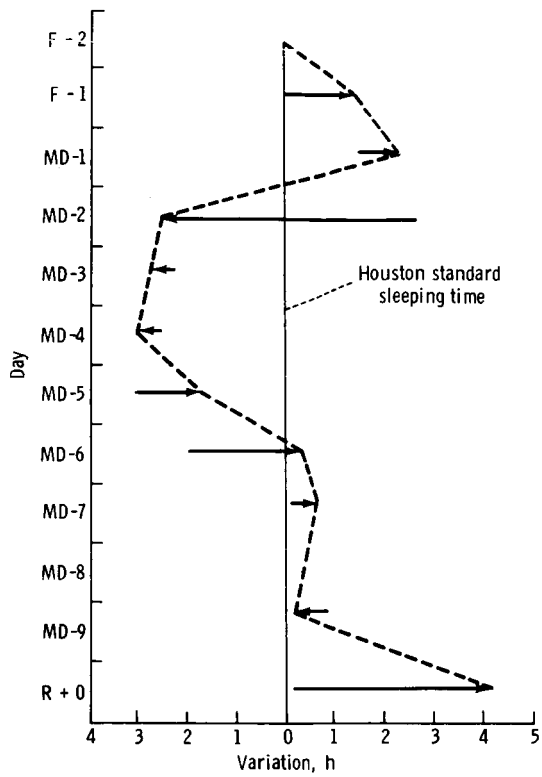

Figure 2-2. Apollo-Soyuz Test Project Circadian Shift (U.S. Crew)

The sporadic increase in the command module ambient temperature (to as high as 299.8 k (26.6° C) (80° F)) during the latter part of the mission did not significantly affect the overall in-flight work/rest cycle.

Flight menus were designed to meet individual energy requirements under normal gravity conditions. The total daily caloric intake requirement was computed before the flight from lean body mass measurements. This topic is discussed in detail in Chapter 6.

3. CREW HEALTH

Arnauld E. Nicogossian,[a] Charles K. LaPinta,[a] Eduard C. Burchard,[a]
G. Wyckliffe Hoffler,[a] and Peter J. Bartelloni[b]

SUMMARY OF CLINICAL FINDINGS

Preflight Crew Health Status

Medical examinations were performed on the three crewmembers at specific intervals during the 30-day preflight period. In anticipation of a long and busy launch day, each crewman attempted to establish a more operationally desirable sleep/work cycle 2 days before lift-off (F - 2) and 1 day before lift-off (F - 1) by going to sleep at approximately 03:00 G.m.t. (11:00 p.m. e.d.t.) and waking up at 13:00 G.m.t. (9:00 a.m. e.d.t.); no hypnotic medications were used during this period. On day F - 4, all crewmembers were on a low-residue diet. To further reduce the fecal content in his bowels, each crewman used a Travad enema and two Pericolace tablets on F - 1. During the preflight physical examinations, no significant medical problems were detected in the prime and backup crewmembers. There were no changes in their health status, and their health remained good throughout the preflight phase of the mission. The Apollo commander (ACDR) was not subjected to studies involving radiation procedures because of a past history of exposure to high radiation levels.

In-Flight Crew Health Status

The physical status of the ACDR, the command module pilot (CMP), and the docking module pilot (DMP) was monitored during flight. The results are presented in the following paragraphs.

Biomedical instrumentation and physiological data.—All physiological measurements remained within the expected limits. Electrocardiographic and respiratory rate data were obtained through the bioinstrumentation data system during launch and on mission days 2, 7, and 8 in conjunction with the exercise periods; additional data were obtained during the entry phase of the mission. Table 3-I is a summary of the physiological data obtained from the biomedical instrumentation.

On mission day 2, interference of the DMP's exercise harness with his bioinstrumentation electrodes resulted in poor quality data not suitable for analysis. Because of ground-support technical difficulties on mission day 6, no biomedical data were received in the Mission Control Center (MCC). Although 5 minutes of instrumented periods of rest, exercise, and postexercise data were formally requested before flight, the lack of knowledge in real time of the exercise start and end times prevented correlation of the biomedical data with the actual activity periods.

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[a]NASA Lyndon B. Johnson Space Center.

[b]Tripler Army Medical Center, Honolulu, Hawaii.

TABLE 3-I.–*PHYSIOLOGICAL DATA SUMMARY*

Mission phase	Heart rate, beats/min						Respiration rate, breaths/min		
	ACDR		DMP		CMP		ACDR	DMP	CMP
	Av	Peak	Av	Peak	Av	Peak			
Launch	105	130	95	123	82	117	14	14	9
[a]Orbital flight									
Mission day 2	74	90	(b)	(b)	66	91	10	(b)	21
[c]Mission day 6	–	–	–	–	–	–	–	–	–
Mission day 7	70	117	–	–	94	137	22	–	26
Mission day 8	–	–	74	140	–	–	–	16	–
Entry	96	150	67	91	76	124	24	16	13

[a]Values obtained during exercise.

[b]Poor data.

[c]No biomedical data received.

No medically significant arrhythmias were detected during this mission. Isolated premature heartbeats were observed in all three crewmembers. The fact that the frequency and character of these prematurities remained consistent with data obtained previously during ground-based studies indicated that they were not related to space flight.

Adaptation to weightlessness.–All three crewmembers experienced the now classical fullness-of-the-head sensation immediately after Earth-orbital insertion. This symptom was mild and did not interfere with the crew's performance. The crewmembers commented that they did not experience sensations of nasal stuffiness or sinus congestion. Head movements and moving around the spacecraft did not intensify the fullness-of-the-head feeling and did not provoke symptoms of motion sickness. There were no instances of nausea, vomiting, disorientation, or loss of appetite.

Crew transfers.–No significant problems with the in-flight docking module (DM) compression and decompression profiles were encountered during the mission. The DM control and life support system performances were normal. During transfers, the DM pressure was raised with nitrogen from 3.32 to 6.56 N/cm^2. During transfers 1, 2, and 4, the Soyuz crewmen requested that nitrogen be added to the atmosphere in the DM to decrease the percentage of oxygen (0_2) seeping into the Soyuz spacecraft; thus the DM-Soyuz combined volume total pressure was increased by 0.27, 0.40, and 0.13 N/cm^2, respectively. No corrective actions were required

during manual or automatic crew transfer operations. During the transfer operations, 8.57 kg of oxygen were used compared to 7.60 kg predicted, and 6.21 kg of nitrogen were used compared to 6.38 kg predicted.

At 52 hours 11 minutes ground elapsed time (GET), after reopening hatch 1, which had been closed for docking, the crew reported a strong acetone-like odor in the DM but could not find the source. The crew performed standard procedures to verify the acceptability of the DM atmosphere, then initiated mixing of the two atmospheres to allow removal of the odor by the environmental control system in the command module (CM). After extensive ground-based studies, it was postulated that the odor was probably caused by methyl ethyl ketone, methyl isobutyl ketone, or both. These compounds are components in the glue used for lining the DM with Velcro material. There was no evidence of adverse effects to crew health from exposure to the compounds or further reports of this odor.

Medication.—Table 3-II is a list of the medications taken by each crewman during flight.

TABLE 3-II.—*MEDICATIONS TAKEN DURING FLIGHT*

Medication	ACDR	DMP	CMP
Actifed (decongestant)	2	0	0
Lomotil (antiperistalsis)	7	2	2
Scopolamine-dextroamphetamine sulfate (anti-motion-sickness drug)	0	0	2
Aspirin	[a]2	0	0

[a]Number not definitely established.

On mission day 3, the ACDR notified MCC that he took three Lomotil tablets prophylactically in an attempt to decrease the frequency of in-flight bowel movements. He took another two tablets on mission day 4 because of a loose bowel movement and again took two Lomotil tablets prophylactically on mission day 8 before DM jettison. The DMP and the CMP took two Lomotil tablets each, prophylactically, on mission day 3. The CMP took one scopolamine-dextroamphetamine sulfate tablet prophylactically immediately after orbital insertion and repeated the same dose approximately 5 hours later.

On entry day, approximately 1 hour after the sleep period, the ACDR took two Actifed tablets prophylactically to prevent possible ear blockage during the entry phase. Since no significant medical problems requiring specific treatment occurred during flight, the medications used by each crewmember were minimal when compared to those used on the majority of previous space flights. No medications for sleep were taken at any time during the in-flight period.

Postflight Crew Health Status

The following discussion of crew health status after flight includes an analysis of the effects of spacecraft atmosphere contamination.

Recovery.–The U.S. crew was exposed to toxic gases (mostly nitrogen tetroxide (N_2O_4)) from inadvertent reaction control system (RCS) firings during the descent phase, 30 seconds after drogue deployment and at approximately 21:15:07 G.m.t. (11:15:07 a.m. Hawaii time) on July 24, 1975. The N_2O_4 entered the CM through the cabin pressure relief valve, which was opened during the landing sequence.

During the postlanding medical debriefing, the ACDR reported, "There was a yellowish-brown colored smoke which smelled like RCS. The smoke was so thick that I had a hard time seeing the other crewmembers or the dials in front of me. The smoke cleared very fast." Neither the DMP nor the CMP reported observing the yellow-brown smoke.

Once the crew disabled the RCS, and following initial peak exposure, uncontaminated air was drawn into the cabin until landing occurred. Simultaneously, the lithium hydroxide (LiOH) scrubbers continued to absorb the nitrogen oxide mixture.

At 21:18:24 G.m.t., the spacecraft landed. While the spacecraft was still in stable II (inverted) position, the ACDR unstrapped and fell down into the CM tunnel, hurting his right shoulder and elbow. He unstowed the oxygen masks and proceeded to provide oxygen to the crewmembers. Not until the spacecraft assumed stable I (upright) position, approximately 3 minutes 30 seconds after landing, did the ACDR notice that the CMP's mask was hanging on the side of his face and that he was unconscious. From the available history, it appears that the CMP was unconscious for approximately 50 seconds. In retrospect, it is thought that the exposure to toxic fumes possibly combined with effects of the feet being positioned lower than the head while in stable II position could have contributed to this fainting episode. The CMP recovered promptly when his face mask was positioned properly and the oxygen flow was increased.

Once in stable I position, the postlanding ventilation was activated, the flotation gear was positioned, and the CM hatch was opened. This action contributed to further improvement of the ventilation and removal of the noxious gases from the cabin.

Approximately 40 minutes 50 seconds later (21:58:44 G.m.t.), the spacecraft was hoisted aboard the recovery vessel U.S.S. *New Orleans,* and the crew exited the CM at 22:05:04 G.m.t. When the hatch was opened, a humid and moldy smell emanated from the CM; there was no detectable odor of the irritant gas. All the crewmembers appeared steady, slightly pale, and profusely diaphoretic. The first indication of exposure to the gas came later during the hangar-deck ceremony when the ACDR requested oxygen for smoke inhalation; the exposure event was detailed during the postflight debriefing sessions also. These facts were further ascertained by playback of onboard voice and data tapes.

Spacecraft atmosphere toxicology.–Total time of crew exposure to the oxidizer vapors was 4 minutes 40 seconds, from the closure of the RCS isolation valves until the crew donned oxygen masks after landing. The peak cabin concentration after the RCS was electrically disabled was estimated to be approximately 700 parts per million (p/m) of N_2O_4 at a pressure of 101.3 kPa (1 atm) (Figure 3-1). The average oxidizer concentration from the outside inlet to the cabin pressure relief valve was 2000 p/m, or 4100 mg/m^3. The peak cabin concentration resulted in an estimated average crew exposure of approximately 510 mg/m^3,

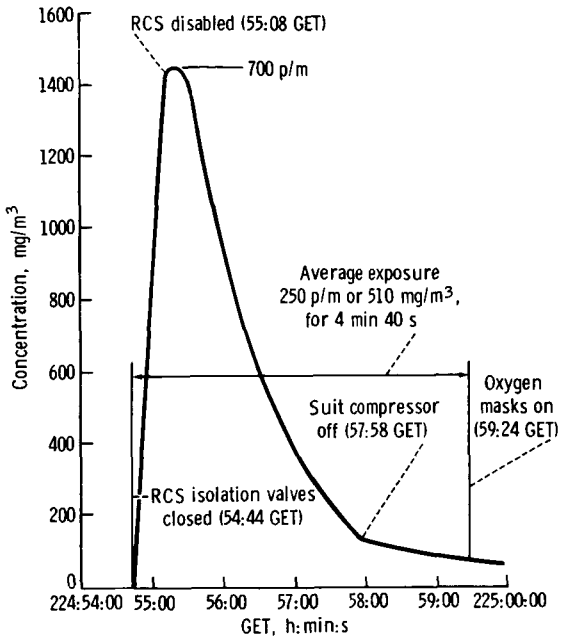

Figure 3-1. Cabin Oxidizer Concentration Expressed as Parts per Million of Nitrogen Tetroxide at a Pressure of 101.3 kPa (1 atm)

which is equivalent to approximately 250 p/m of N_2O_4 at 101.3 kPa (1 atm). These toxicological estimates were not available at the time of exposure. The final estimates of the actual toxic levels of N_2O_4 were based on the analyses of the spacecraft LiOH canisters and the visual comparison of different color shades of N_2O_4 and air mixtures (Figure 3-2).

Initial recovery day physical findings.—Once in the Mobile Laboratories (MOLAB) aboard the primary recovery ship (PRS), the medical team proceeded with the medical debriefing. Oxygen was administered to all three crewmen for approximately 10 minutes. The vital signs that were recorded from the three crewmembers in supine position at approximately 22:40 G.m.t. (12:40 p.m. Hawaii time) are as follows.

Crewmember	Heart rate, beats/min	Blood pressure, systolic/diastolic, mm Hg	Respiration rate, breaths/min
ACDR	90	118/70	16
DMP	60	125/70	20
CMP	56	130/80	14

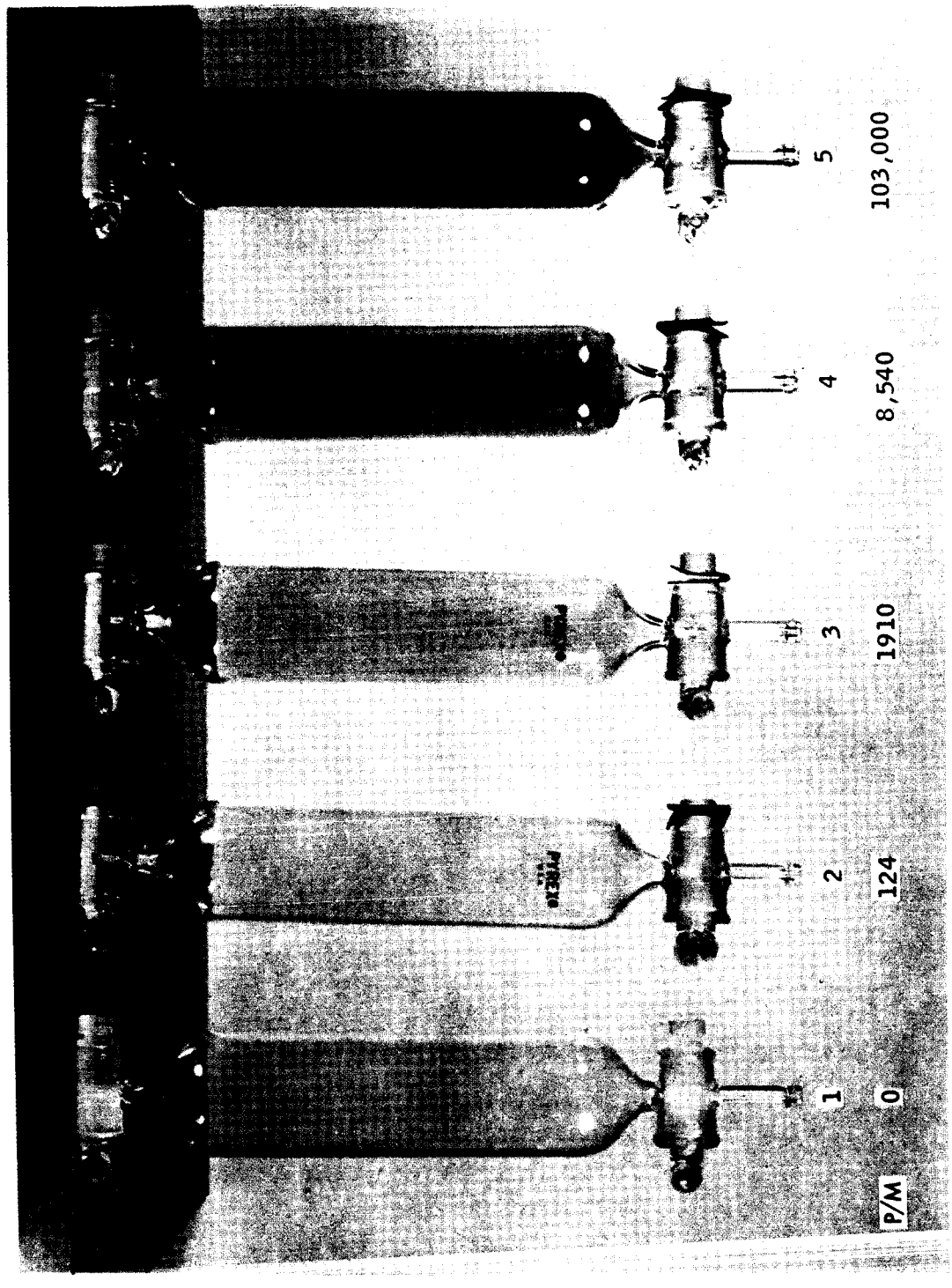

Figure 3-2. N_2O_4-Air Mixtures in 2" Diameter Tubes

Because of time constraints, while the history of exposure to toxic fumes was being reconstructed, the medical team proceeded with the routine recovery day (R + 0) protocols. The ACDR, who had only a short blood drawing and no radioisotope studies, underwent the full lower body negative pressure (LBNP) protocol, which was terminated 3 minutes early in the minus 50 mm Hg period because of a drop in his systolic blood pressure.

At approximately 23:20 G.m.t. (1:20 p.m. Hawaii time), the full history of exposure was completed and, after a preliminary conference with the MCC surgeons at the NASA Lyndon B. Johnson Space Center (JSC), it was decided to stop all of the preplanned medical experiments with the exception of the clinical examinations as dictated by the circumstances. Table 3-III contains details of the modified recovery day schedules.

In general, the chief complaints consisted of burning of the eyes with profuse tearing, burning sensation and itching of the exposed skin surfaces which subsided shortly after the entry into the MOLAB, tightness of the chest, retrosternal burning sensation, and inability to inhale deeply which led to a nonproductive and nonspasmodic cough. The review of systems was noncontributory. The three astronauts were in no acute distress and all were oriented to time, persons, and place. The examination of the skin and mucosa was within normal limits. Slight plantar hyperkeratosis and fissuring were present. Examination of the eyes revealed the pupils to be round, regular, and equal in size; their reaction to light was within normal limits. Extraocular movements were intact, full, and equal. Visual fields and fundi were well within normal limits. Examination of the ears, nasal mucosa, and pharynx was unremarkable. The tracheas were midline and mobile. The shape and size of the thyroid glands were within normal limits. No cervical vein engorgement was noted; carotid arterial pulsations were equal, without bruit, and within normal limits. The chests were symmetrical with good expansion. Deep inspiration produced coughing. The lungs were clear to percussion and auscultation. Examination of the cardiovascular system revealed normal sinus rhythm. There were no murmurs, thrills, clicks, or evidence of cardiomegaly. There was no abdominal tenderness or organomegaly, and the bowel sounds were within normal limits. Abdominal and lumbar paravertebral auscultation failed to reveal abnormal bruits or murmurs. Genitalia and rectal examinations were unremarkable. Detailed neurological examination showed only slight fine tremor of the fingers. Slight hyperreflexia of the deep tendon reflexes was noted. Physical examination of the endocrine system was normal. The peripheral vascular system was intact. No peripheral lymphadenopathies were detected. Generally, the musculoskeletal system was within normal limits.

The examination of the ACDR's right shoulder and elbow showed slight tenderness on palpation; there were no ecchymoses or limitations to motion. The DMP exhibited a slight restriction of mobility of the lumbar spine and straightening of the lordosis. This condition was caused by a strain sustained while exercising during flight. He also had minor bruises over the right temporal region and the right patella. The recorded postlight vital signs, weights, heights,[1] and oral temperatures are shown in Table 3-IV.

During the physical examination, following 5 minutes in the standing position, it was noticed that the CMP's systolic blood pressure dropped to 50 mm Hg with no audible readouts for the diastolic pressure. He was pale and complained of generalized weakness. The CMP was immediately returned to a supine position, and recovery from the orthostatic episode was uneventful. After 3 minutes in the supine position with elevation of the legs, his vital signs were: blood pressure, 122/68 mm Hg; heart rate, 60 beats/min; and respiration rate, 15 breaths/min.

[1]Importance of crew height measurements are detailed in Chapter 16.

TABLE 3-III.–*MODIFIED MEDICAL SCHEDULES ON RECOVERY DAY*

Time, h:min		Event		
G.m.t.	Hawaii	ACDR	DMP	CMP
22:24	12:24 p.m.	MOLAB + O_2	MOLAB + O_2	MOLAB + O_2
22:35	12:35 p.m.	Microbiology samples, exposure history, and vital signs obtained	Exposure history and vital signs obtained	Exposure history, vital signs, and microbiology samples obtained
22:40	12:40 p.m.	Blood drawing initiated	Microbiology samples started	–
22:45	12:45 p.m.	Leg measurements	–	–
22:55	12:55 p.m.	Height and weight measurement obtained	–	–
23:02	1:02 p.m.	Into CV[a]	Blood drawing initiated	Blood drawing initiated
23:10	1:10 p.m.	Leg volume and EKG[b]	–	–
23:15	1:15 p.m.	–	Leg measurements	Leg measurements
[c]23:20	1:20 p.m.	–	–	–
23:25	1:25 p.m.	–	PFT[d]	–
23:30	1:30 p.m.	–	–	PFT
23:32	1:32 p.m.	Resting echocardiography	–	–
23:40	1:40 p.m.	LBNP[e]	–	–
24:00	2:00 p.m.	Early dump hypotension 50/? mm Hg, no subjective symptoms reported	Shower	Shower
00:09	2:09 p.m.	EMG[f]	–	–
00:24	2:24 p.m.	Release from CV	–	–
00:35	2:35 p.m.	Shower	Chest X-rays, physical exam, and EKG initiated	–
00:50	2:50 p.m.	Chest X-rays, physical exam, EKG, and PFT initiated	–	–
02:20	4:20 p.m.	–	–	Chest X-rays, physical exam, and EKG initiated
02:50	4:50 p.m.	Rest in crew quarters and supper	Rest in crew quarters and supper	Rest in crew quarters and supper
08:00	10:00 p.m.	To PRS sickbay for sleep and observation	To PRS sickbay for sleep and observation	To PRS sickbay for sleep and observation

[a]CV = cardiovascular laboratory.

[b]EKG = electrocardiogram.

[c]JSC conference with MCC surgeons regarding history of exposure to N_2O_4 and monomethyl hydrazine. Decision made to stop all postflight medical protocols.

[d]PFT = pulmonary function test.

[e]Terminated 3 minutes early.

[f]EMG = electromyograph.

TABLE 3-IV.–*POSTFLIGHT PHYSIOLOGICAL PARAMETERS*

	Heart rate, beats/min	Blood pressure, systolic/diastolic, mm Hg	Respiration rate, breaths/min	Weight, kg	Height, cm	Temperature, °C (°F)
			ACDR			
Supine	88	112/70	14	–	–	–
Sitting	100	111/72	14	–	–	35.7 (96.4)
Standing	100	102/68	16	77.7	182.6	–
			DMP			
Supine	60	112/70	–	–	–	–
Sitting	60	110/80	–	–	–	35.4 (95.8)
Standing	66	110/70	20	72.8	180.5	–
			CMP			
Supine	60	122/68	16	–	–	–
Sitting	80	108/78	16	–	–	36.0 (96.8)
Standing	88	100/78	16	77.6	180.5	–

Chest roentgenograms done on all three crewmembers failed to reveal any signs of pulmonary involvement (Figure 3-3). Electrocardiographic tracings were within normal limits and identical with baseline data.

Subsequent Course of Events

For the remainder of the evening of July 24, 1975, the crewmembers did not exhibit any significant change in general symptomatology. The feeling of chest tightness, retrosternal burning sensation, and cough on deep inspiration persisted without worsening. Following showers and supper, the astronauts were transferred, at 08:00 G.m.t. July 25, 1975 (10:00 p.m. Hawaii time July 24, 1975) to the sickbay of the ship for rest and further observation. Although they spent a relatively quiet night, sleep was interrupted by occasional episodes of coughing. None of the crewmembers complained of shortness of breath.

On July 25, 1975 (day R + 1), at 16:10 G.m.t. (6:10 a.m. Hawaii time), the astronauts were awakened for further clinical evaluation, consisting of blood draws and chest roentgenograms. The general physical examinations were unremarkable. When questioned about symptoms, all crewmembers complained of slight tightness of the chest and more pronounced inability to breathe deeply without coughing. In fact, they were unable to breath-hold and perform forced expiratory maneuvers required for repeat pulmonary function tests. The following table represents the vital signs as obtained in the supine position.

Followup chest roentgenograms were obtained at 18:00 G.m.t. (8:00 a.m. Hawaii time). Shortly after the chest X-rays were taken and while brushing his teeth, the DMP experienced slight shortness of breath, developed giddiness, and fainted. He was unconscious for about 1 minute. There was slight twitching of the eyelids without evidence of seizure activity, and he recovered quickly when placed in the supine position. This episode was attributed to orthostatic intolerance.

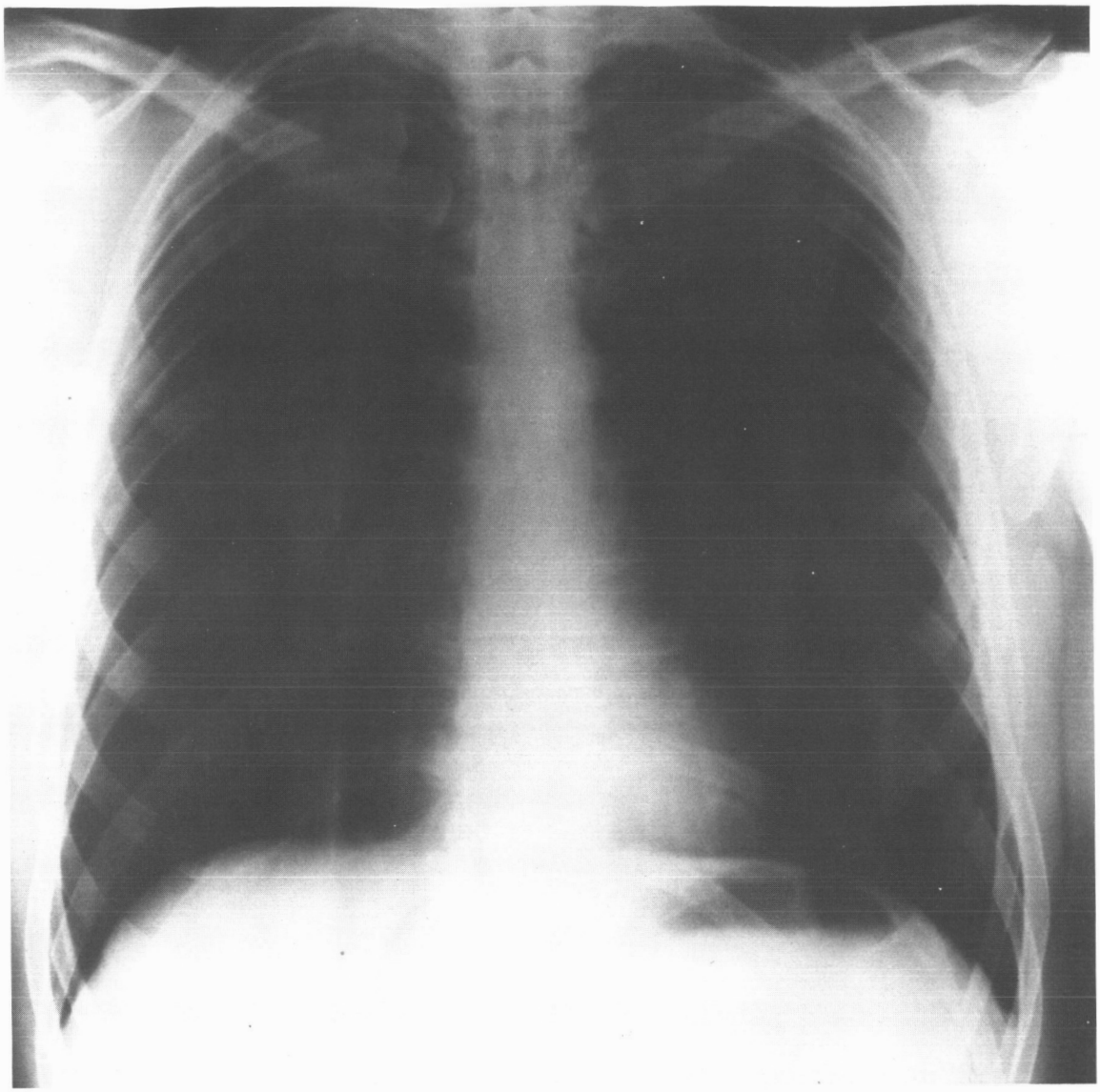

Figure 3-3. Chest Roentgenogram Showing No Pulmonary Involvement

Crewmember	Heart rate, beats/min	Blood pressure, systolic/diastolic, mm Hg	Respiration rate, breaths/min
ACDR	90	108/70	16
DMP	64	122/58	20
CMP	68	118/72	20

The repeat chest roentgenograms on all three crewmembers revealed the presence of diffuse, nodular-type infiltrates throughout both lung fields. A rosette-type pattern with occasional confluence of the infiltrates was present. Both costodiaphragmatic angles were clear with no evidence of pleural effusion, Kerley B lines, or increased pulmonary vasculature. There was no prominence of the pulmonary artery and no signs indicative of the left or right heart involvement. These findings were suggestive of alveolar exudative fillings, characteristic of a diffuse chemical pneumonitis; an example is shown in Figure 3-4 of the same astronaut detailed in Figure 3-3.

At 18:30 G.m.t. (8:30 a.m. Hawaii time), each astronaut was given 16 mg of dexamethasone intravenously and then transferred to Tripler Army Medical Center in Honolulu, Hawaii, for further medical care.

Additional bedside chest X-rays, obtained at 20:45 G.m.t. (10:45 a.m. Hawaii time), confirmed the diagnosis made aboard the recovery vessel. Arterial blood gases were sampled at room air at 21:00 G.m.t. (11:00 a.m. Hawaii time). The results are tabulated as follows, for partial pressure of oxygen (pO_2), partial pressure of carbon dioxide (pCO_2), and hydrogen-ion concentration (pH).

Measurement	ACDR	DMP	CMP
pO_2, mm Hg	76	90	70
pCO_2, mm Hg	37	28	43
pH	7.41	7.48	7.43

Repeated chest X-rays obtained at 01:00 G.m.t. July 26, 1975 (3:00 p.m. Hawaii time July 25, 1975) showed an increase of the infiltrates, more pronounced on the DMP's X-ray. Followup room-air arterial blood gas studies performed at 01:30 G.m.t. (3:30 p.m. Hawaii time) are tabulated as follows. The blood gas findings were indicative of mild respiratory alkalosis with hyperventilation and hypoxemia.

It was decided to switch to oral steroid therapy, consisting of daily doses of 80 mg of Prednisone. Because of the lack of symptomatology and the absence of cyanosis and/or signs of severe anoxia, oxygen was not administered. Vital signs remained stable, and there was no evidence of cardiac rhythm disturbances.

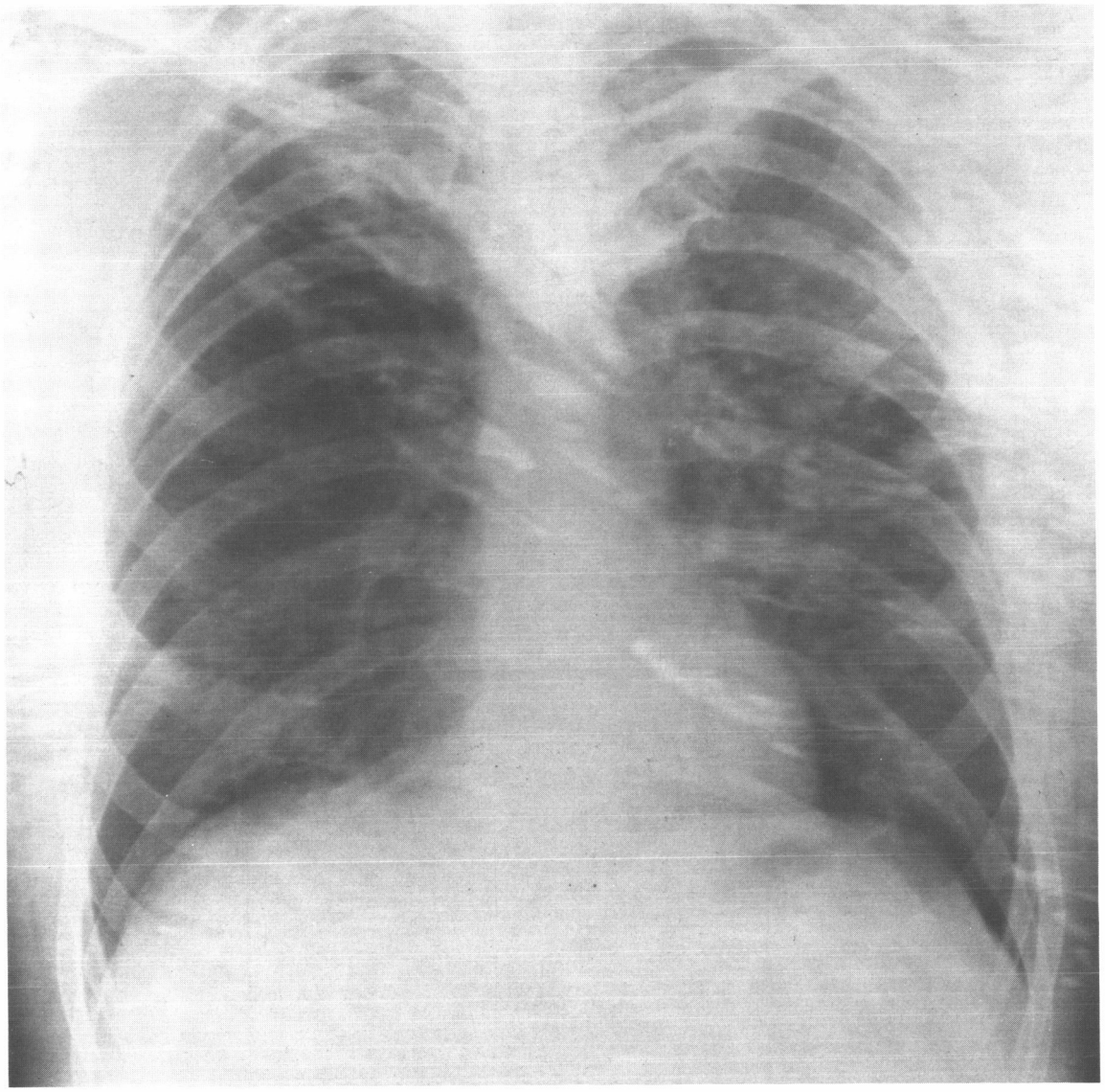

Figure 3-4. Chest Roentgenogram Suggestive of Alveolar Exudative Fillings

Measurement	ACDR	DMP	CMP
pO_2, mm Hg	84	86	84
pCO_2, mm Hg	29	33	35
pH	7.43	7.51	7.44

Hospital Course and Followup

The astronauts were afebrile on admission and remained so throughout their hospitalization period. Vital signs remained generally within normal limits. No significant changes in postflight weights were observed (Table 3-V).

TABLE 3-V.–*PREFLIGHT AND POSTFLIGHT WEIGHT VARIATION*

Day	Body weight, kg		
	ACDR	DMP	CMP
F - 30	78.2	75.3	81.0
F - 15	78.8	76.0	80.4
F - 5	77.0	76.7	79.8
F - 1	78.2	75.7	80.1
F - 0	76.9	74.8	80.2
R + 0	77.6	72.8	77.6
R + 1	79.5	76.4	81.0
R + 2	78.9	76.5	80.6
R + 3	77.3	78.5	74.8
R + 4	77.3	80.0	76.9
R + 5	76.8	76.4	78.6
R + 13	79.5	78.2	82.2
$\bar{x} \pm SD$[a]	77.8 ± 0.83	75.7 ± 0.71	80.3 ± 0.45

[a]Mean plus or minus standard deviation.

The crewmembers continued to have mild discomfort with deep inspiration. The discomfort gradually lessened. They became asymptomatic on July 27, 1975 (day R + 3). The chest X-rays returned to normal on July 29, 1975 (day R + 5). The corticosteroids were gradually tapered and finally discontinued on August 2, 1975 (day R + 9).

The crewmembers were discharged from the hospital on July 30, 1975 (day R + 6). A period of rest, reconditioning, and observation in Hawaii followed. Daily medical evaluations remained within normal limits. All the crewmembers participated in mild exercise, such as jogging, under medical supervision; they exhibited a gradual improvement in physical endurance. The crewmembers left Hawaii on August 7, 1975, and were returned to their regular duties.

Followup detailed medical evaluations were performed 4 weeks after the initial exposure to N_2O_4 vapors. It was established that there were no obvious residual aftereffects from the exposure to toxic fumes.

Clinical Laboratory Data

Extensive laboratory studies were conducted to determine the presence of N_2O_4 and/or monomethyl hydrazine exposure. The laboratory findings are discussed in Chapters 14 and 15. Because the nature of these toxic fumes was not completely known, it was decided to perform several specific tests to isolate the compounds mentioned. These tests included the search for Heinz bodies and for elevation of serum triglycerides, cholesterol, methemoglobin, and hydrazine levels.

There was an initial elevation in the methemoglobin level (mean = 4.2 percent) at R + 0 compared to the preflight levels. By day R + 1, the methemoglobin level had dropped to a mean value of 2.0 percent, not significantly different from preflight values. This finding is compatible with, but not pathognomonic of, exposure to N_2O_4. There was no increase in the serum cholesterol and triglyceride levels or the presence of hydrazine or Heinz bodies which would be indicative of monomethyl hydrazine inhalation.

4. RESULTS OF PULMONARY FUNCTION TESTS

Arnauld E. Nicogossian,[a] Charles F. Sawin,[a] and Peter J. Bartelloni[b]

Preflight pulmonary function tests were performed in conjunction with other medical evaluations 45, 30, and 15 days before lift-off (F - 45, F - 30, and F - 15, respectively). Because of hardware malfunction on day F - 45, data were not amenable to analysis and only two sets of data were used for baseline purposes. Following exposure to nitrogen tetroxide and 10 minutes prebreathing of 100-percent oxygen, pulmonary function screening tests were obtained on all three crewmembers on recovery day aboard the prime recovery vessel. The quality of recovery day (R + 0) data was satisfactory, and no significant changes were observed when compared to the preflight means. Followup evaluations were performed 1, 2, and 13 days after recovery (R + 1, R + 2, and R + 13, respectively) at Tripler Army Medical Center and repeated on day R + 29 at the NASA Lyndon B. Johnson Space Center and at Saint Luke's Episcopal Hospital in Houston, Texas. Because of the discomfort associated with deep inspiration and breath holding on days R + 1 and R + 2, no satisfactory data could be obtained. In general, because of different types of hardware and techniques employed in these pulmonary function measurements, the obtained data were variable and interpretation was difficult. A slight decrease of timed expiratory flows was observed 1 day following recovery (day R + 1). Besides the already mentioned mild hypoxia and respiratory alkalosis (Chapter 3), the only significant finding was a decrease in the single-breath carbon monoxide diffusing capacity ($DLCO_{SB}$). These findings were in agreement with the observed roentgenological abnormalities. The decrease in the diffusion capacity was more pronounced in the Apollo commander: less than 50 percent of the predicted value based on his age, weight, and height. This decrease in $DLCO_{SB}$ persisted until test day R + 13. The R + 29 data obtained from the three crewmembers showed that the measured pulmonary function parameters, including $DLCO_{SB}$ and repeat blood gas determinations (breathing room air and 100-percent oxygen), were within normal limits. These data are summarized in Tables 4-I, 4-II, and 4-III.

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[a]NASA Lyndon B. Johnson Space Center.

[b]Tripler Army Medical Center, Honolulu, Hawaii.

TABLE 4-I.—*APOLLO COMMANDER PULMONARY FUNCTIONS*

Parameter	Preflight $\bar{x} \pm SD$[a]	R + 0	R + 1	R + 2	R + 5	R + 13	R + 29
RV (liters)	2.53 ± 0.12	2.0	(b)	2.10		2.14	2.23
CV (liters)	0.59 ± 0.24	0.64					0.93
VC (liters)	5.38 ± 0.10	5.45	3.72	5.10		5.60	5.35
TLC (liters)	7.90 ± 0.17	7.50		7.22		7.82	7.55
FVC (liters)	5.39 ± 0.04	5.13	3.67	4.80	5.55	5.56	5.20
FEV-1 (liters)	3.83 ± 0.08	3.72	2.78	3.70	4.17	4.26	3.75
$\frac{\text{FEV-1}}{\text{FVC}}$ %	71.1 ± 1.07	72.40	75	76	75	76	72
$\frac{\text{FVC}}{\text{VC}}$ %	100.2 ± 2.16	101.60	98	72		99	97.3
MEFR (l/sec)	5.93 ± 0.25	5.70	5.41	5.91	8.41	9.50	5.3
MMFR (l/sec)	2.83 ± 0.12	2.90	2.36	3.40	3.63	3.66	3.0
$\frac{\text{CV}}{\text{VC}}$ %	10.8 ± 4.26	11.70	(b)	7.5			17.4
$\frac{\text{CC}}{\text{TLC}}$ %	39.3 ± 2.61	35.20	(b)	33			41.9
$DLCO_{SB}$ (mlCO/min/mm Hg)			(b)	8.35[b]	14.58	14.48	31.33

[a]Mean plus or minus standard deviation.

[b]Crewman unable to perform maneuver.

RV = residual volume
CV = closing volume
VC = vital capacity

TLC = total lung capacity
FVC = forced vital capacity
FEV-1 = forced expiratory volume in one second

MEFR = maximum expiratory flow rate
MMFR = maximum midexpiratory flow rate
CC = closing capacity

$DLCO_{SB}$ = single breath carbon monoxide diffusing capacity

TABLE 4-II.–*COMMAND MODULE PILOT PULMONARY FUNCTIONS*

Parameter	Preflight $\bar{x} \pm SD$[a]	R + 0	R + 1	R + 2	R + 5	R + 13	R + 29
RV (liters)	2.11 ± 0.34	2.87	(b)	2.28		2.07	1.98
CV (liters)	0.53 ± 0.05	0.93					0.85
VC (liters)	5.11 ± 0.10	5.06	3.70	5.02		5.20	5.28
TLC (liters)	7.23 ± 0.35	7.90		7.30		7.23	7.26
FVC (liters)	4.98 ± 0.04	5.23	2.82	4.57	5.28	5.16	4.86
FEV-1 (liters)	3.91 ± 0.31	3.69	2.10	3.41	4.12	4.09	3.95
$\frac{\text{FEV-1}}{\text{FVC}}$ %	78.5 ± 6.16	70.40	75	74	78	79	81.2
$\frac{\text{FVC}}{\text{VC}}$ %	97.8 ± 3.50	103.4	76	91		99	92.8
MEFR (l/sec)	7.10 ± 1.14	5.70	4.25	6.81	8.33	9.23	7.8
MMFR (l/sec)	3.93 ± 0.38	4.20	1.61	2.81	4.21	4.43	3.7
$\frac{\text{CV}}{\text{VC}}$ %	10.33 ± 0.76	18.40		13			16.1
$\frac{\text{CC}}{\text{TLC}}$ %	36.43 ± 3.17	48.10		38			39
$DLCO_{SB}$ (mlCO/min/mm Hg)				15.09	24.87	29.55	41.13

[a]Mean plus or minus standard deviation.

[b]Crewman unable to perform maneuver.

TABLE 4-III.—*DOCKING MODULE PILOT PULMONARY FUNCTIONS*

Parameter	Preflight $\bar{x} \pm SD$[a]	R + 0	R + 1	R + 2	R + 5	R + 13	R + 29
RV (liters)	2.47 ± 0.42	2.96	(b)	2.35		2.57	2.46
CV (liters)	0.78 ± 0.33	0.39					0.55
VC (liters)	5.51 ± 0.02	5.50	5.11	5.25		5.83	5.58
TLC (liters)	7.97 ± 0.4	8.50		7.87		8.41	8.04
FVC (liters)	5.41 ± 0.05	5.42	4.56	5.25	5.69	5.83	5.64
FEV-1 (liters)	4.01 ± 0.02	3.92	3.58	3.32	4.48	4.40	4.15
$\frac{\text{FEV-1}}{\text{FVC}}$ %	74.1 ± 1.01	72.20	78	63	79	75	73
$\frac{\text{FVC}}{\text{VC}}$ %	98.2 ± 1.35	98.70	89	100		100	100
MEFR (l/sec)	8.33 ± 0.38	8.00	9.13	8.51	11.45	7.63	8.7
MMFR (l/sec)	3.07 ± 0.06	2.80	3.21	1.51	4.03	3.51	3.0
$\frac{\text{CV}}{\text{VC}}$ %	14.1 ± 5.86	7.00		9			9.9
$\frac{\text{CC}}{\text{TLC}}$ %	40.7 ± 3.78	39.60		34			37.4
$DLCO_{SB}$ (mlCO/min/mm Hg)				16.37	20.15	28.22	29.23

[a]Mean plus or minus standard deviation.

[b]Crewman unable to perform maneuver.

5. IN-FLIGHT RADIATION DETECTION

J. Vernon Bailey[a]

RADIATION DOSIMETRY

One personal radiation dosimeter (PRD) and one passive dosimeter (PD) each were assigned to and were worn at launch by the Apollo commander (ACDR), command module pilot (CMP), and docking module pilot (DMP). During the mission, the PD's assigned to the ACDR and the DMP were worn in the left leg pocket of the in-flight coveralls, and the PD assigned to the CMP was worn in the left thigh pocket. All flight dosimeters were recovered and returned to the NASA Lyndon B. Johnson Space Center (JSC) for evaluation.

PASSIVE DOSIMETERS

The flight PD's were disassembled, and the component detectors were forwarded to the cognizant analysts. The thermoluminescent dosimeters were analyzed in the Lockheed Radiation Laboratory, and the results are reported following this paragraph. The nuclear emulsions were forwarded to Dr. H. J. Schaefer at the Naval Aerospace Research Laboratory, and preliminary results are reported following the next paragraph. The neutron resonance foils and the Lexan track detectors were forwarded to Dr. J. S. Clark, JSC, and Dr. E. V. Benton, University of San Francisco, respectively. The control PD confirmed that no extraneous prelaunch radiation occurred. No evidence of contamination or component damage was observed during disassembly of the dosimeter. The PD results from the thermoluminescent dosimeters are as follows.

Serial no.	Assignment	Mission dose, mrad
1077	ACDR	110 ± 11
1078	CMP	108 ± 11
1079	DMP	100 ± 10
1087	Control	< 1

[a]NASA Lyndon B. Johnson Space Center.

A preliminary analysis of the nuclear emulsions based on photodensitometer measurements and ratios of those measurements to proton doses determined from the previous Apollo Earth-orbit mission agreed well with the thermoluminescent dosimeter data. These results are as follows.

Serial no.	Emulsion pack no.	Assignment	Proton dose (estimated), mrad
1077	1B	ACDR	102
1078	2B	CMP	99
1079	3B	DMP	90

The track and grain count analyses are being continued to provide a more accurate measurement of the Apollo-Soyuz Test Project (ASTP) crew dose from the trapped radiation environment.

PERSONAL RADIATION DOSIMETERS

Personal radiation dosimeter (PRD) postmission response testing was performed at JSC. The PRD battery voltages were measured before this testing was begun. Battery voltages on all three PRD's exceeded 10.70 V dc; 9.0 V dc was the required minimum for satisfactory operation. Premission and postmission responses were compared and are essentially identical. At a dose level of 0.93 mrad/h, personal radiation dosimeter 1022HRE and 1037HRE responses were minus 6 percent, and PRD 1025HRE response was minus 12 percent. At all data points above 2.0 mrad/h, the response deviations for all three instruments were zero percent. Therefore, the following mission doses reported are splashdown values with no response corrections. The tolerance shown represents the one-register-count (0.01 rad) uncertainty inherent to digital readouts.

Crewman	Serial no.	Mission dose, rad
ACDR	1022HRE	0.15 ± 0.01
CMP	1025HRE	5.58
DMP	1037HRE	.12 ± .01

The in-flight malfunction observed on PRD 1025HRE was not reproduced during the postmission testing. One register count (0.01 rad) was accumulated during the 4.5 days between splashdown and initiation of postmission testing. However, this deviation is normal

and within design specifications. The 30 to 40 counts per day accumulated during the mission indicated either a gate-to-drain leakage of the electrometer (MOSFET) or loose conductive particles in the ion chamber. However, neither condition would account for the 144 counts registered between the last in-flight reading and the splashdown reading. An intermittently open circuit could, during entry buffeting, register counts at a very high rate and might also account for the day-to-day counting observed. Since this PRD operated normally during the Apollo 10, Apollo 15, and Skylab 3 missions, the condition resulting in the ASTP malfunction probably occurred just before, or during, launch. Two dents in the aluminum housing (on one corner and one edge), not present during preinstallation acceptance testing, were observed when the dosimeter was returned to JSC. The dents indicated that the instrument had been dropped and/or struck.

SUMMARY

The three PD's and two of the PRD's operated satisfactorily throughout the mission. Because no future mission support is anticipated for these PRD's, failure analysis of the PRD malfunctioning during the zero-g portion of this mission is not planned currently. The 10 to 15 mrad/day crew exposures reported for the ASTP PRD's and PD's are among the lowest reported for any Apollo mission and approach the minimum response sensitivity of the PRD's. The total space radiation exposure of the ASTP crewmen is insignificant from a medical standpoint.

6. FOOD AND NUTRITION

Malcolm C. Smith[a] and Rita M. Rapp[a]

NUTRIENT ENERGY REQUIREMENTS DETERMINATION

As a result of Apollo and Skylab experimentation, data now exist showing relationships between ground-based and in-flight energy requirements. It is recognized that the best estimates of ground-based energy requirements are made on the basis of lean body mass (LBM); i.e., muscle mass. Accurate determination of LBM may be obtained from a total body count of gamma radiation emitted by the body's natural burden of potassium-40 (^{40}K).

The whole-body counter method of determining LBM is based on the assumption that the potassium content of LBM is nearly constant and that body fat is essentially free of potassium. In this context, the body is considered to be composed of two compartments, the fat compartment and the fat-free LBM compartment.

Since 0.0119 percent of all naturally occurring K is the radioactive isotope ^{40}K, a measure of this isotope is an indirect measure of the total K. The whole-body counter measures ^{40}K. Total K is calculated and LBM is determined by use of appropriate constants.

It was anticipated that the average daily in-flight energy intake in the Apollo-Soyuz Test Project (ASTP) would fall short of Skylab intakes and would more closely approximate the averages observed during Apollo flights (i.e., approximately 29 kcal/kg/day) because of the brevity of the mission and the failure to achieve metabolic stabilization. For this reason, certain nutrients, in particular sodium (Na) and K, were concentrated in those foods for which the crew displayed the highest preference and which were deemed most likely to be consumed. As much as possible of the minimum nutrient requirements were included in a basic diet of approximately 1800-2000 kilocalories (kcal). Despite these measures, an awareness of the true energy demands should be kept in mind for understanding the degree of metabolic deficiency that was incurred.

Lean body mass was determined by measurement of total body ^{40}K in the low-background radiation counting facility at the NASA Lyndon B. Johnson Space Center after appropriate calibration with similar counting facilities at U.S. Air Force School of Aviation Medicine and at Battelle N.W. Laboratories. Additional calibration in the technique was accomplished using ^{42}K. Potassium-42 has a 12.36-hour half-life and emits beta rays having a maximum energy of 3.52 MeV and a gamma ray having an energy of 1.525 MeV. The gamma ray energy is close enough to that of ^{40}K (1.46 MeV) to enable direct comparison of the photopeak areas for calibration purposes. For calibration, the same amount of ^{42}K ingested by the volunteer is placed in a 500-ml bottle, and the bottle is filled with water. A weighed quantity of potassium nitrate (KNO_3) is placed in the same size bottle and dissolved in water, and the solution is diluted to the same volume as the ^{42}K solution. Counting

[a]NASA Lyndon B. Johnson Space Center.

measurements are made with the whole-body counter on each of the bottles and the volunteer using the following relationship.

$$\frac{\text{counts per gram K in body}}{\text{counts per gram K in bottle}} = \frac{\text{counts of } {}^{42}\text{K in body}}{\text{counts of } {}^{42}\text{K in bottle}}$$

The calibration factor can be derived using the following equation. The equation is independent of the exact quantity of ^{42}K but dependent on the weight of K in the bottle, which can be determined very accurately.

Counts per gram K in the body = Counts per gram K in bottle

$$X = \frac{\text{counts of } {}^{42}\text{K in body}}{\text{counts of } {}^{42}\text{K in bottle}}$$

A 30-minute count was made on each subject. Before and immediately after counting each subject, a 5-minute count of background and a 5-minute count of a 2.3-kg (5 lb) bottle of crystalline potassium chloride (KCl) were made. The periodic count of KCl, a reference source, was used to correct any variation in overall counter efficiency. Averages were obtained for these counts, corrected for background, and the counts were then reduced to counts per second.

It has been demonstrated that the calibration factors for all whole-body counter techniques depend on the weight of the subject. The single mathematical expression $\log_{10}(g) = A + B(W_{kg})$ will fit the curve of calibration factors obtained for subjects whose weights range from 43.88 kg to 157 kg. The actual calibration factor found for a particular subject may differ by as much as 10 percent from the value predicted by the regression line. The exchangeable K content of the body, as measured by the isotope-dilution technique, is very close to 92 percent of the total body K for all active subjects, including those who have starved for several weeks and lost considerable weight. The results of LBM determinations performed on the prime crewmembers are as follows.

Subject	Body weight, kg	K, g	LBM, kg
Apollo commander (ACDR)	78.30	142.33	61.78
Docking module pilot (DMP)	76.05	166.43	65.14
Command module pilot (CMP)	81.00	190.54	70.95

The measurements were made on December 2 and 3, 1974. For comparison, the total exchangeable K estimated by the ^{42}K exchange technique for the Skylab crewmembers is

given in Table 6-I.[1,2] Lean body mass measurements, derived from data on total exchangeable K, have been used as a basis for expressing caloric expenditure in Skylab crewmembers. The results of these computations are shown in Table 6-II. It can be seen, therefore, that the Skylab crewmembers had a caloric intake at a level of 45.68 ± 4.50 kcal/kg/day. Based on in-flight changes in total body weight, muscle mass, and body volume, it appears that an average daily energy intake of 49.0 ± 3.5 kcal/kg/day would have resulted in negligible body weight loss in Skylab crewmembers.

On the basis of Skylab energy consumption data and ASTP total body K measurements, the energy required to maintain LBM during the ASTP mission was predicted. The results of this prediction are shown in the following table together with estimated energy based on subjective evaluation by the individual of his menus. (Changes in crew body weights are also included.)

Subject	Predicted energy consumption based on –		Average in-flight energy intake, kcal/day	In-flight body wt change, kg
	Body mass ^{40}K, kcal/day	Menu test, kcal/day		
ACDR	2822	2790	2900	-0.45
CMP	3241	2913	3000	-2.52
DMP	2975	3245	2867	-2.90

IN-FLIGHT FOOD

Flight menus were designed to meet comparable individual energy requirements under normal gravity conditions, specified nutrient levels, and crew-selected preferred foods. Energy requirements calculated for each crewman were 2815, 2760, and 2554 kcal/day for the ACDR, the CMP, and the DMP, respectively. Based on crew menu acceptance, evaluations, and compatibility tests, an average daily caloric intake of 2820 kcal was provided for the ACDR and the CMP, and 3165 kcal was provided for the DMP. Estimates of in-flight food consumption based on daily reports indicate that averages of 2900, 3000, and 2867 kcal/day were consumed by the ACDR, the CMP, and the DMP, respectively.

To meet the specified daily nutrient levels, some of the beverages were fortified with either calcium lactate or potassium gluconate. Calcium (Ca) fortified beverages were limited to two per man per day, whereas only one K-fortified beverage was required for each 4-day menu cycle.

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[1]Carolyn S. Leach and Paul C. Rambaut: Biochemical Responses of the Skylab Crewmen: An Overview. Ch. 23 of *Biomedical Results from Skylab,* NASA SP-377, in press.

[2]Philip C. Johnson, Theda B. Driscoll, and Adrian D. LeBlanc: Blood Volume Changes. Ch. 26 of *Biomedical Results from Skylab,* NASA SP-377, in press.

TABLE 6-I.–*TOTAL EXCHANGEABLE POTASSIUM IN SKYLAB CREWMEMBERS*

Subject	Potassium, mg (a)
1	3208 ± 114
2	3870 ± 105
3	3782 ± 133
4	3245 ± 133
5	3045 ± 23
6	4565 ± 114
7	3195 ± 56
8	3569 ± 165
9	3517 ± 200

[a] Mean plus or minus standard deviation.

TABLE 6-II.–*SKYLAB IN-FLIGHT ENERGY INTAKE*

Subject	LBM, kg	Energy intake	
		kcal/day	kcal/kg/day
1	57.0	2616	45.89
2	66.9	2746	41.05
3	71.4	2606	36.50
4	58.2	2636	45.29
5	53.6	2581	48.15
6	73.4	3543	48.30
7	57.3	2959	51.64
8	62.2	2850	45.82
9	62.5	3031	48.50
			[a]45.68 ± 4.50

[a] Mean plus or minus standard deviation.

The crew selected a 4-day menu cycle as used previously on Apollo missions rather than the 6-day cycle used during Skylab missions. The average daily nutrient intakes for the proposed and estimated in-flight food consumption for each crewman are shown in Table 6-III.

TABLE 6-III.–*AVERAGE DAILY NUTRITIONAL INTAKE*

Crewman	Energy, kcal	Protein, g	Calcium, mg	Phosphorus, mg	Sodium, mg	Potassium, mg	Magnesium, mg
				Proposed intake			
ACDR	2820	99.7	1076	1832	4983	2942	313
CMP	2820	98.1	1458	1996	4724	2984	288
DMP	3165	112.2	1375	2113	6402	3745	355
				Estimated actual intake[a]			
ACDR	2900	98.0	1295	1830	4970	2983	299
CMP	3000	101.9	1661	2071	5318	2975	290
DMP	2867	107.7	1422	1964	6079	3748	322

[a] Average of 7 nominal days; incomplete days have been omitted.

In addition to the scheduled meals, a pantry containing beverages and snack foods was supplied. These foods could be used to substitute or supplement the normal meal items.

New food for this mission included dehydrated compressed pea bars and spinach bars; irradiated breakfast rolls; thermostabilized/irradiated turkey, corned beef, and charcoal broiled steak; thermostabilized cranberry sauce; tuna and salmon in cans which required a can opener; commercial cookies and graham crackers; dehydrated beef patty, pears, and potato patty; intermediate moisture almonds and cheese slices; and dried beef jerky.

In general, the crew was satisfied with the quality and quantity of flight food provided. No gastrointestinal problems were encountered during the mission. Appetites during flight were reported to be the same as during the preflight period. The CMP reported changes in the taste of foods during flight and indicated that salty foods tasted best to him. As on previous Apollo missions, the crew reported gas in the hot water supply which interfered with complete rehydration of the food. Throughout the mission, high-priority activities and work schedules frequently precluded adequate time for meal preparation and food consumption.

7. POTABLE WATER

Richard L. Sauer[a]

Postflight comments from the crew indicated that the potable water was of good quality. No out-of-specification conditions were noted in the microbiological and chemical analyses conducted.

Preflight chlorination was accomplished 19 hours before launch. The level of chlorine measured 2 hours later was sufficient for microbial control.

In-flight chlorinations were accomplished approximately on schedule, and no in-flight problems were experienced. As in previous flights, some gas was present, particularly in the hot water.

Postflight analyses indicated a lack of residual chlorine in the potable water. This deficiency remains unexplained since the records indicate that the last in-flight chlorination was accomplished 17 hours before landing. Chemical analyses of postflight samples showed all levels within specification limits. Microbiological results were positive for Flavobacterium species at levels of 10^5 microorganisms/ml.

[a]NASA Lyndon B. Johnson Space Center.

8. FLIGHT CREW HEALTH STABILIZATION PROGRAM

James K. Ferguson[a]

The Flight Crew Health Stabilization Program (FCHSP) was activated for the Apollo Soyuz Test Project (ASTP) as outlined in the program document. Prime and back-up crewmen were held under conditions of semi-isolation from 21 days before flight until launch. Living quarters were established onsite at the NASA Lyndon B. Johnson Space Center (JSC) for both the prime and backup crewmen. The existing crew quarters at the NASA John F. Kennedy Space Center (KSC) were used while the crewmen were at that facility.

An identification list of primary contacts was made available to the Medical Surveillance Office 90 days before lift-off. All physical examinations for persons on this list were completed on schedule. Surveillance of the health status of primary contacts began on June 2, 1975, and continued through July 24, 1975, for a total of 53 days. The total number of primary contacts under surveillance reached 381. The number and location of the primary contacts are as follows.

JSC	KSC	Other	Total
313	32	36	381

Active surveillance was provided at the primary work areas during the times when crewmen were present in the areas. Throat examinations and temperature checks were made once daily on each primary contact entering the primary work area. The results of this active surveillance are shown in Table 8-I.

TABLE 8-I.–*ACTIVE SURVEILLANCE OF PRIMARY CONTACTS*

Category	JSC	KSC
Contacts examined (total)	1169	203
Examining days	16	12
Average daily examinations	73	16.9
Contacts referred to clinic	5	1

[a]NASA Lyndon B. Johnson Space Center.

The primary contacts reported their illnesses and exposure to illnesses to the Medical Surveillance Office. All reporting was made on a voluntary basis. The number and location of the primary contact reports were as follows.

Reports	JSC	KSC	Other	Total
Illness	28	8	0	36
Contacts to illness	7	1	0	8

The rate of illnesses reported by the primary contacts was 12.4 illnesses per 1000 persons per week. The rate of contacts to illness reported was 3 per 1000 persons per week. The types of illness and exposures to illness reported by the primary contacts are shown in Tables 8-II and 8-III, respectively.

TABLE 8-II.–*TYPES OF ILLNESSES REPORTED BY PRIMARY CONTACT*

Symptom complex[a]	JSC	KSC	Percent total
Upper respiratory infection (URI)	23	6	81
Bronchitis	3	0	8
Pneumonia	0	0	0
Upper enteric illness	1	0	3
Lower enteric illness	0	0	0
Fever present	2	0	6
Headache present	4	0	11
Skin infection present	0	1	3
Other infectious illness	1	1	6

[a] One illness may contain more than one symptom complex.

The FCHSP was successfully completed with the recovery of the crewmen at the close of the mission. No infectious illness occurred in any of the crewmen during the period of time they were covered by the program.

It was necessary for the crewmen to enter a nonprimary work area during the preflight period for the purpose of obtaining additional suit-fit checks, for tests, and for the use of medical test equipment. In each case, however, the contingency plans were followed and no problems were encountered.

TABLE 8-III.–*EXPOSURES TO ILLNESS REPORTED BY PRIMARY CONTACTS*

Illness contacted	JSC	KSC	Percent total
URI	1	0	13
Chicken pox	1	0	13
Mumps	2	0	25
Impetigo	0	1	13
Typhoid fever	1	0	13
Infectious hepatitis	2	0	25

The rate of primary contact reporting of illnesses appeared to be improved over past missions. For example, the ASTP summer mission had a greater number of illness reports (12.4 per 1000 per week) than was observed in the fall and winter missions of the Skylab Program (average 8.2 per 1000 per week). However, the reporting of the contacts to illness remained approximately the same as on past missions; the upper respiratory illness was predominant and represented 81 percent of the total illnesses reported.

SECTION III

PREFLIGHT, IN-FLIGHT, AND POSTFLIGHT MEDICAL TESTING

9. ACHILLES TENDON REFLEX

Eduard C. Burchard[a] and Arnauld E. Nicogossian[a]

Generalized hyperreflexia was reported following long-duration Skylab orbital missions. Because it was expected that changes in the neuromuscular function would occur even after a short-duration space flight, a decision was made to measure the Achilles tendon reflex duration in conjunction with the Apollo-Soyuz Test Project (ASTP) mission.

METHOD AND MATERIAL

The measurement of the Achilles tendon reflex time was performed during the physical examination on all three prime astronauts 30 days before lift-off (F - 30), 15 days before lift-off (F - 15), and on recovery day (R + 0) using a Burdick FM-1 photomotograph. A technique using a photoelectric cell is employed to time the Achilles tendon reflex by measuring the displacement of the foot. A lamp and condensing lens in one side of the U-shaped housing directs a beam of light onto a photovoltaic cell on the opposite side of the housing (Figure 9-1(a)). With the subject kneeling comfortably on a specially designed chair, the unit is positioned so that the light beam is partially intercepted by the metatarsal region of the foot (Figure 9-1(b)).

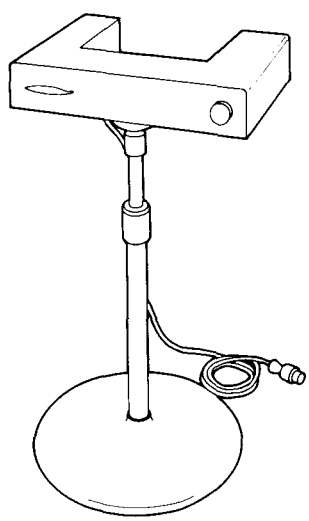

Figure 9-1(a). Photomotograph. Sketch of the Device

[a]NASA Lyndon B. Johnson Space Center.

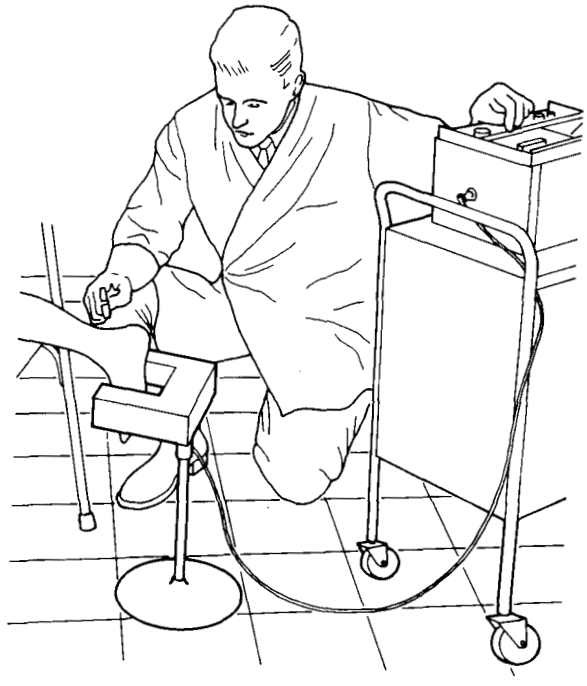

Figure 9-1(b). Photomotograph. Positioning of the Device

A tap on the Achilles tendon with a percussion hammer causes the foot to move in the light beam and thereby to generate a change in photocell voltage. The change in voltage is recorded on electrocardiograph paper to give a time-position plot of reflex action. For each test, an average number of 10 complexes on a strip chart is analyzed using a photomotogram scale (Figure 9-2). To determine the duration of the reflex response, measurements are made from the beginning of the hammer tap to one-half the relaxation period.

RESULTS

Table 9-I and Figures 9-3 and 9-4 contain the Achilles tendon reflex data for the Apollo commander (ACDR) and the docking module pilot (DMP) from tests performed on days F - 30, F - 15, and R + 0. Four preflight baseline sets of data were obtained on the command module pilot (CMP) because he had had previous tests on July 24 and October 10, 1973, while performing as backup crewman for Skylab missions 3 and 4 (Figure 9-5).

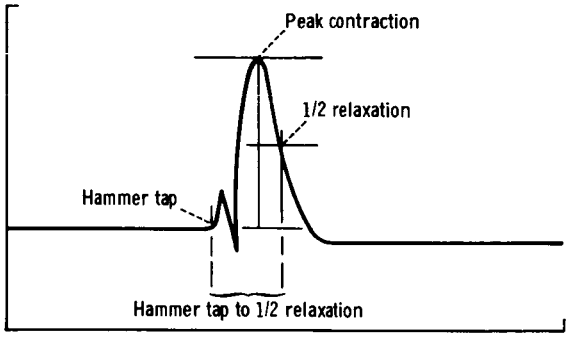

Figure 9-2. Photomotogram Tracing. The Horizontal Distance from Hammer Tap to One-Half Relaxation is Measured in Milliseconds

TABLE 9-1.–*ACHILLES TENDON REFLEX DATA*

	Reflex time, ms				
	Skylab		ASTP		
Crewmember	July 24, 1973	Oct. 10, 1973	F - 30	F - 15	R + 0
ACDR	–	–	298	304	280
DMP	–	–	399	354	312
CMP	317	340	303	291	299

The Achilles tendon reflex was measured within 2 hours after recovery and after the ASTP astronauts had entered the operational Mobile Laboratory (Figure 9-6). The ACDR and the DMP exhibited a shortening in the reflex duration time (Table 9-I), whereas the CMP showed an increased reflex time when his datum was compared with his last preflight results. In addition to the noted changes in reflex time, all three crewmembers showed significant fine tremor, as documented by tracings (Figure 9-5), which could reflect the effects of the inhaled vapor of nitrogen tetroxide. This tremor which was recorded on the baseline tracings of the Achilles tendon reflex was also clinically observed in the fingers for a short time on R + 0.

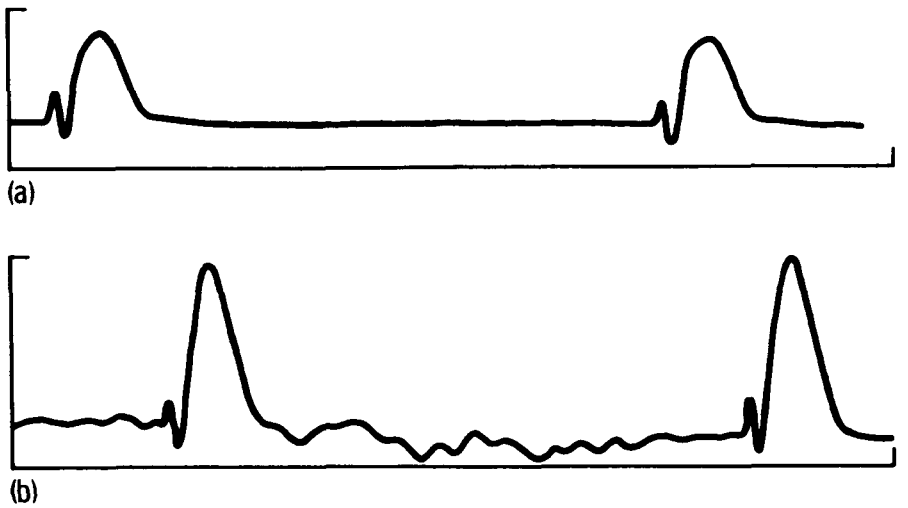

Figure 9-3. Achilles Tendon Reflex Time, Apollo Commander
(a) Preflight, F - 30
(b) Postflight, R + 0

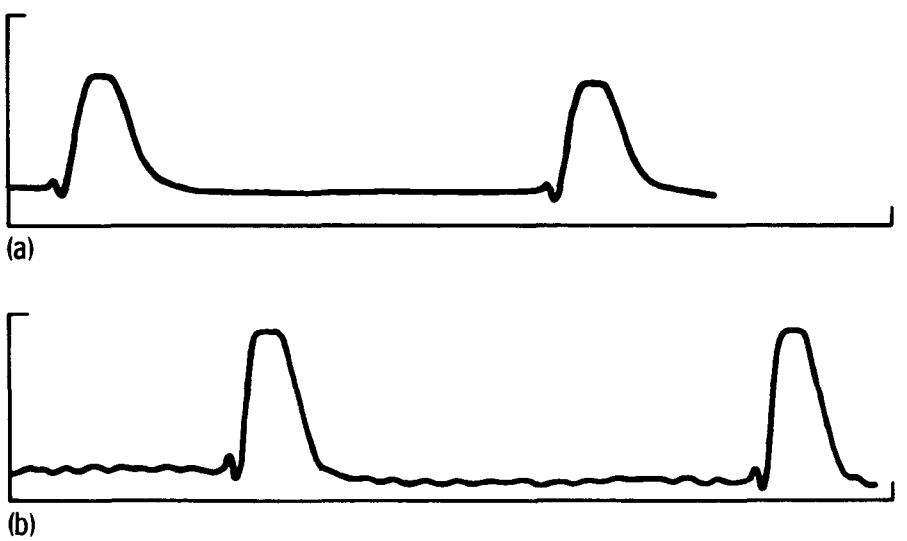

Figure 9-4. Achilles Tendon Reflex Time, Docking Module Pilot
(a) Preflight, F - 30
(b) Postflight, R + 0

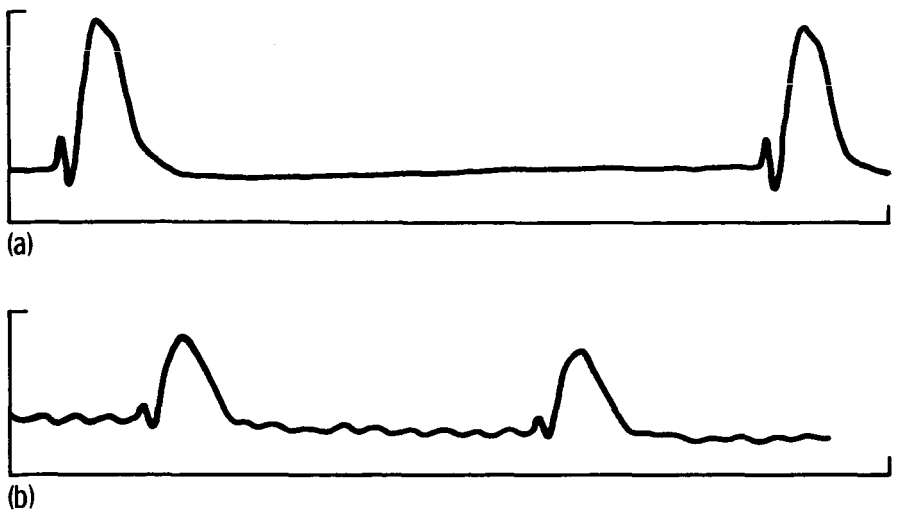

Figure 9-5. Achilles Tendon Reflex Time, Command Module Pilot
(a) Preflight, F - 15
(b) Postflight, R + 0

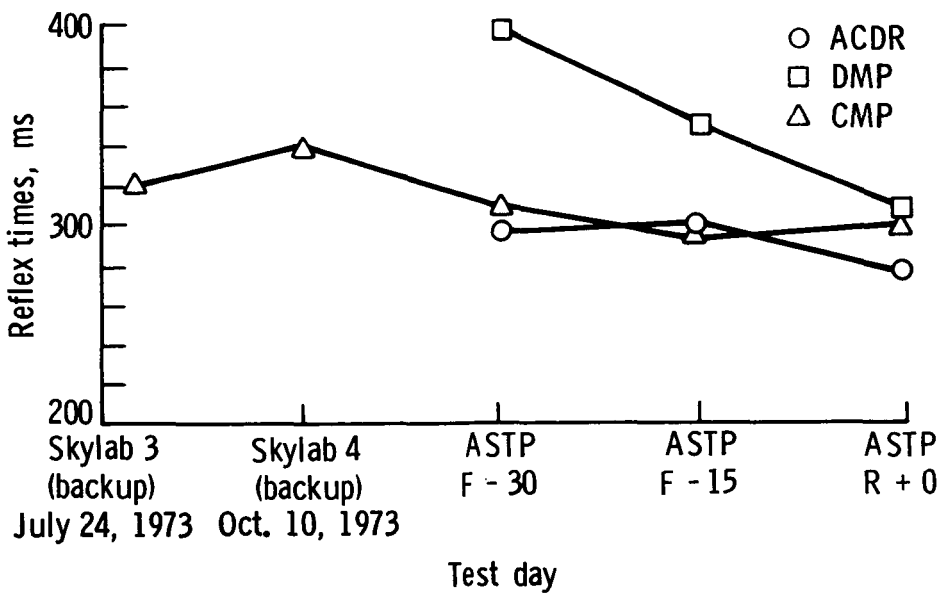

Figure 9-6. Achilles Tendon Reflex Measurements of ASTP U.S. Crewmen

CONCLUSION

The data show the predicted postflight change in the Achilles tendon reflex time; also, for the first time since the tendon reflex measurement was introduced, postflight tremor was documented. Further clinical studies will be required to determine whether the occurrence of such tremors is related to exposure to toxic material.

10. ELECTROMYOGRAPHIC ANALYSIS OF SKELETAL MUSCLE

Earl V. LaFevers,[a] Arnauld E. Nicogossian,[a]
William N. Hursta,[b] and Joseph T. Baker[b]

The first opportunity to study the effects of long-duration weightlessness on human skeletal muscle function occurred during the Skylab missions. The results of the Skylab assessments provided ample evidence that normal muscle function is altered by periods of weightlessness of 59 days or more. This conclusion is supported by a number of physiological and biochemical changes that occurred during Skylab missions (ref. 10-1). The results of ground-based studies have shown that these changes are related to abnormal muscle function (refs. 10-2 to 10-7). For example, in the Skylab crewmen, tension capability was decreased after flight. The electromyogram (EMG) spectral characteristics showed states of muscle superexcitability and increased fatigability with gradual return to baseline states (ref. 10-8).

The purpose of this study was to investigate changes in skeletal muscle electrical activity that occur after exposure to short-term weightlessness; i.e., less than 10 days. The following changes were hypothesized.

1. Heightened excitability as evidenced by a significant shifting of the spectral power into higher frequencies
2. Reduced muscle electrical efficiency
3. Increased muscle fatigability when the muscles are subjected to a moderate fatigue-inducing stress.

METHOD AND MATERIALS

Instrumentation

A skeletal muscle stress apparatus was designed and built to enable controlled isometric muscle testing and measurements. A two-channel EMG detector was built to record the EMG. All data were recorded at a rate of 9.52 cm/s (3.75 in/s) on magnetic tape by a four-channel recorder. A four-channel strip-chart recorder was used to monitor the data playback from the magnetic tape during the experiment.

Protocol

Data were obtained on 3 preflight days: 45, 30, and 15 days before lift-off. Surface electrodes were placed on the lower leg muscles (gastrocnemius and soleus) and on the arm muscles (biceps brachii and brachioradialis). Seated in the muscle stress apparatus, the crewman was instructed to exert a series of graded efforts as follows.

[a]NASA Lyndon B. Johnson Space Center.

[b]Technology Incorporated, Houston, Texas.

1. 10 seconds at 10-percent maximum voluntary contraction (MVC), 20 seconds rest
2. 10 seconds at 20-percent MVC, 20 seconds rest
3. 10 seconds at 30-percent MVC, 20 seconds rest
4. 60 seconds at 50-percent MVC (leg) and 40-percent MVC (arm).

Leg measurements and arm measurements were collected sequentially. Postflight only (recovery day) data on one astronaut were obtained.

Data Processing

A computer program, EMGAN, was written to process the force and EMG data.[1] Force data were calibrated into pounds and averaged over 1-second intervals. The EMG signals were analyzed in 4-second segments. The data were calibrated into microvolts, and the integrated value for each segment was found. The discrete Fourier transform was used to calculate the magnitude of the power spectral density.

Muscle Excitability

Skeletal muscle disuse attributable to 9 days of space-flight weightlessness resulted in increased excitability of the instrumented muscles of this study. Stressed at 30 percent of MVC, the gastrocnemius and biceps brachii muscles showed a postflight increase in their predominant frequency of 30 Hz (25 percent) and 20 Hz (40 percent), respectively. Before the flight, the soleus muscle showed an increase in predominant frequency amounting to 30 Hz (25 percent). The brachioradialis muscle showed the least excitability effect from weightlessness.

Muscle Electrical Efficiency

The ratios of integrated electromyogram (IEMG) to force for both the gastrocnemius and brachioradialis muscles showed a decreased level of electrical efficiency as a result of the 9 days in weightlessness; the data for the biceps and brachioradialis muscles show a tendency for increased electrical efficiency. All of the muscles, with the exception of the gastrocnemius, showed a decrease in the level of the IEMG after flight, and all of the muscles showed a progressive increase in electrical activity with increasing contraction force both before and after flight. The IEMG-to-force ratios for the 1-minute fatigue-inducing stress showed the tendency for all the muscles to decrease in efficiency as the stress was maintained. The soleus muscle showed the greatest change in efficiency as a result of the 9 days in weightlessness.

Muscle Fatigability

Analyses of variance were conducted on the power spectral data of the four muscles used in this study. Three main effects were considered in the analyses.

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[1] W. N. Hursta: EMGAN: A Computer Program for Time and Frequency Domain Reduction of Electromyographic Data. Special report, *Technology Inc.*, Sept. 1975.

1. Conditions, preflight compared to postflight
2. Time increments; i.e., the four equally spaced time intervals within the 1-minute continuous isometric hold for which the EMG was spectrally analyzed
3. Frequency bands used for the data analysis
   a. Leg muscles, 10 to 60 Hz in 10-Hz increments
   b. Arm muscles, 10 to 30 Hz in 10-Hz increments

Significant shifting of the power spectra into lower frequencies was considered evidence of muscle fatigability. In the leg muscle, there was a significant difference between preflight and postflight spectral power levels; the postflight data showed a significantly greater progressive power shift into the lower frequencies as a result of the 1-minute isometric stress. The arm muscles did not exhibit significant differences between conditions.

CONCLUSIONS

The present investigation of skeletal muscle function involving both leg extensor and arm flexor muscles in a shorter period of exposure to weightlessness (9 days) has shown that the muscle dysfunction characteristics prominent after 59 days of exposure in weightlessness (the Skylab 2 mission) are also evident after only 9 days of exposure in weightlessness.

Both upper and lower extremity muscles showed changes in excitability which suggest that skeletal muscles are susceptible to functional changes associated with the reduced muscle activity in weightlessness. Since all changes showed increased sensitivity, the probable site for this effect is the muscle fibers, for the following reason: Previous clinical studies have shown that random loss or reduced activity in muscle fibers, as in myopathy, result in higher firing frequencies of the muscle, whereas dysfunctions of neural loci result in lower firing frequencies (refs. 10-9 to 10-13).

Several studies have provided evidence that the electrical activity of muscles increases as a function of tension (refs. 10-14 to 10-18). Also, previous studies have shown that, after a period of immobilization, or, as in myopathy, the EMG amplitudes are depressed when compared with unaffected muscles (refs. 10-13 and 10-19). The results of this study are in agreement with those findings.

The greater EMG amplitudes of the gastrocnemius in response to disuse are not readily understood. However, Liberson et al. (ref. 10-20) have provided indirect evidence that the IEMG of the gastrocnemius may show an inverse relationship to contraction force; that is, the highest tensions show the lowest levels of electrogenesis.

Muscle Electrical Efficiency

The ratio of IEMG to force appears to have considerable merit for describing the efficiency or quality of muscle activity under normal gravity conditions. However, the interpretation of muscle electrical efficiency after disuse is less clear than before disuse. For example, the increased postflight electrical efficiency shown in the arm muscles was not expected since it was anticipated that all muscles would show a decrease.

A possible explanation for this disparity could be the quantity and quality of in-flight exercise of upper extremities. This possibility, coupled with the short mission duration,

the greater use of arms than legs in normal mission operations, and the added possibility that the arm muscles are less affected by the absence of gravity than the antigravity muscles, could account for postflight enhancement of efficiency.

Another possible explanation for the observed results, however, is that the increased muscle efficiency is an artifact resulting from differences between postflight and preflight IEMG levels. Both the biceps and brachioradialis had depressed IEMG levels after flight. Thus, smaller postflight EMG amplitudes for comparable preflight and postflight force levels would produce smaller IEMG per unit force ratios for postflight data and, therefore, reflect a seemingly better efficiency.

Muscle Fatigability

That short-term exposure to weightlessness heightens fatigability in skeletal muscle was readily demonstrated in the antigravity muscles by the results of this study. Greater amounts of spectral power were observed to develop in the lower frequencies after weightlessness than before in response to the fatigue-inducing stress. These results suggest that the disuse associated with whole-body weightlessness temporarily facilitated certain muscle conditions, as evidenced by a degree of supersensitivity, which led to a quickened fatigability and the earlier incidence of synchronous discharges and recruitment of higher threshold motor units.

ACKNOWLEDGMENTS

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REFERENCES

10-1. The *Proceedings of the Skylab Life Sciences Symposium,* vols. I and II. NASA TM X-58154, 1974.

10-2. Eccles, J. C.: Disuse Atrophy of Skeletal Muscle. *Med. J. Australia,* vol. 2, 1941, pp. 160-164.

10-3. Eccles, J. C.: Investigations on Muscle Atrophies Arising From Disuse and Tenotomy. *J. Physiol.,* vol. 103, 1944, pp. 253-266.

10-4. Fischbach, Gerald D.; and Robbins, Norman: Changes in Contractile Properties of Disused Soleus Muscles. *J. Physiol.,* vol. 201, 1969, pp. 305-320.

10-5. Jewell, P. A.; and Zaimis, E.: Changes at the Neuromuscular Junction of Red and White Muscle Fibres in the Cat Induced by Disuse Atrophy and by Hypertrophy. *J. Physiol.* (London), vol. 124, June 1954, pp. 429-442.

10-6. Nelson, P. G.: Functional Consequences of Tenotomy in Hind Limb Muscle of the Cat. *J. Physiol.,* vol. 201, 1969, pp. 321-333.

10-7. Wells, J. B.: Functional Integrity of Rat Muscle After Isometric Immobilization. *Exptl. Neurol.,* vol. 24, 1969, pp. 514-522.

10-8. LaFevers, E. V.; Nicogossian, A. E.; et al.: Spectral Analysis of Skeletal Muscle Changes Resulting From 59 Days of Weightlessness in Skylab 2. NASA TM X-58171, 1975.

10-9. Gersten, J. W.; Cenkovich, F. S.; and Jones, G. D.: Harmonic Analysis of Normal and Abnormal Electromyograms. *American J. Phys. Med.*, vol. 44, Oct. 1965, pp. 235-240.

10-10. Humphrey, John G.; and Shy, M. G.: Diagnostic Electromyography. *Arch. Neurol.*, vol. 6, May 1962, pp. 339-352.

10-11. Kugelberg, E.: Electromyograms in Muscular Disorders. *J. Neuro., Neurosurg., Psychiat.*, vol. 10, 1947, pp. 122-133.

10-12. Pinelli, P.; and Buchthal, F.: Muscle Action Potentials in Myopathies With Special Regard to Progressive Muscular Dystrophy. *Neurology*, vol. 3, no. 4, 1953, pp. 347-359.

10-13. Walton, J. N.: The EMG of Myopathy: Analysis With Audio Frequency Spectrometer. *J. Neuro., Neurosurg., Psychiat.*, vol. 15, 1952, pp. 219-226.

10-14. Bigland, Brenda; and Lippold, O. C. J.: The Relationship Between Integrated Action Potentials in Human Muscle and Its Isometric Tension. *J. Physiol.*, vol. 123, 1954, p. 214.

10-15. Edwards, R. G.; and Lippold, O. C. J.: The Relation Between Force and Integrated Electrical Activity in Fatigued Muscle. *J. Physiol.*, vol. 132, 1956, pp. 677-681.

10-16. Kuroda, E.; Klissouras, V.; and Milsum, J. H.: Electrical and Metabolic Activities and Fatigue in Human Isometric Contraction. *J. Appl. Physiol.*, vol. 29, no. 3, Sept. 1970, pp. 358-367.

10-17. Lippold, O. C. J.: The Relation Between Integrated Action Potentials in a Human Muscle and Its Isometric Tension. *J. Physiol.* (London), vol. 117, 1952, pp. 492-499.

10-18. Lippold, O. C. J.; Redfearn, J. W. T.; and Vuco, J.: The Electromyography of Experimentally Immobilized Skeletal Muscles in Cats. *American J. Physiol.*, vol. 200, no. 5, 1961, pp. 963-967.

10-19. Fudema, J. J.; Fizzell, J. A.; and Nelson, E. M.: Electromyography of Experimentally Immobilized Skeletal Muscles in Cats. *American J. Physiol.*, vol. 200 no. 5, 1961, pp. 963-967.

10-20. Liberson, W. T.; Dondey, M.; and Asa, M. M.: Brief Repeated Isometric Maximal Exercises. An Evaluation by Integrative Electromyography. *American J. Phys. Med.*, vol. 41, Feb. 1962, pp. 3-14.

11. CARDIOVASCULAR EVALUATIONS

G. Wyckliffe Hoffler,[a] Arnauld E. Nicogossian,[a]
Stuart A. Bergman, Jr.,[a] and Robert L. Johnson[a]

Because of the noxious gas episode during the Apollo-Soyuz Test Project (ASTP) command module entry and recovery, most planned postflight evaluations were curtailed, altered, or deleted. Preflight baseline data, to all intents and purposes, were essentially normal throughout and will be detailed only in summary form. Definitive data analyses and conclusions are not possible after the manner of previous Apollo vehicle recoveries.

METHOD AND MATERIALS

On three preflight test dates, 45, 30, and 15 days before lift-off (F - 45, F - 30, and F - 15, respectively), the following cardiovascular evaluations were performed on each crewman.

1. Orthostatic tolerance by lower body negative pressure (LBNP)
   a. Apollo/Skylab stress protocol
      (1) Heart rate
      (2) Systolic blood pressure
      (3) Diastolic blood pressure
      (4) Percentage change in calf volume
      (5) Systolic time intervals
      (6) Vectorcardiograms
2. Heart size by posterior-anterior chest X-rays (F - 15 only)
3. Resting (supine) leg volume
4. Echocardiogram

The only postflight data obtained were

1. One LBNP test on the Apollo commander (ACDR) on recovery day (R + 0)
2. Chest X-rays
3. Leg volumes

RESULTS

Preflight mean (plus or minus standard deviation) LBNP responses are given in Table 11-I. Circumstances surrounding each preflight test, time of day, ambient and LBNP temperature, time since last meal, and amount of sleep were all nominal and within desired

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[a]NASA Lyndon B. Johnson Space Center.

TABLE 11-I.–*PREFLIGHT LBNP RESPONSES OF ASTP CREWMEN*

[Mean plus or minus standard deviation]

Measurement	Apollo commander	Command module pilot	Docking module pilot	Crew mean
Heart rate, beats/min				
Resting	62 ± 5	53 ± 5	48 ± 5	54 ± 7
LBNP[a]	80 ± 8	60 ± 14	51 ± 9	66 ± 21
Blood pressure, mm Hg				
Systolic				
Resting	106 ± 7	116 ± 4	104	109 ± 6
LBNP[a]	102 ± 7	112 ± 4	103 ± 4	106 ± 6
Diastolic				
Resting	66 ± 7	68 ± 1	61 ± 5	65 ± 4
LBNP[a]	68 ± 5	67 ± 3	63 ± 3	66 ± 3
Maximal left calf circumference, cm	35.9 ± 0.3	38.8 ± 0.2	35.7 ± 0.5	36.8 ± 1.8
LBNP[a] calf volume change, percent	1.9 ± 1.0	2.5 ± 0.2	3.5 ± 0.6	2.6 ± 0.8

[a] Minus 50 mm Hg.

limits of experimental control. No results could be considered unusually aberrational; only a single episode of presyncope occurred, in the command module pilot (CMP) late in the minus 40 mm Hg level of LBNP during the F - 15 test. He had just previously participated in vestibular function testing to the point of symptoms.

Mean responses of the ACDR during the only postflight LBNP test, performed at 23:40 G.m.t. (1:40 p.m. Hawaii time), approximately 2 hours 20 minutes after splashdown but before the major decision to delete all nondiagnostic and nonclinical testing, are detailed in Table 11-II. It should be emphasized that LBNP was stopped at approximately 2 minutes into the minus 50 mm Hg level of LBNP because of progressively declining blood pressure. The crewman vehemently denied any associated symptomatology.

Because LBNP recordings made immediately after flight were deleted, no useful information was obtained from systolic time intervals, vectorcardiograms, or echocardiograms. Strictly resting vectorcardiograms were taken on recovery day in conjunction with clinical electrocardiograms. All tracings were considered to be within normal limits. Those of the docking module pilot (DMP) showed occasional premature supraventricular beats not unlike those observed before flight.

TABLE 11-II.–*MEAN RESPONSES OF APOLLO COMMANDER DURING POSTFLIGHT LBNP*

[Plus or minus standard deviation]

Heart rate, beats/min	
Resting	70 ± 2
LBNP[a]	100 ± 5
Blood pressure, mm Hg	
Systolic	
Resting	104 ± 7
LBNP[a]	74 ± 12
Diastolic	
Resting	62 ± 2
LBNP[a]	–
Maximum left calf circumference (resting), cm	35.0
LBNP[a] calf volume change, percent	+2.0

[a]Minus 50 mm Hg.

Chest X-rays provided heart size determinations by the cardiothoracic (C/T) ratios. No notable or consistent findings developed, but these data must be considered in the light of significant postflight pulmonary involvement. Cardiothoracic ratio data obtained in systole and diastole are summarized in Table 11-III.

Lower limb volume measurements were obtained during flight by the crewmen and serially after flight according to the applicable detailed test procedure. The report of these data is the subject of chapter 12.

CONCLUSIONS

Apart from the noxious gas event associated with the recovery of the ASTP crewmen and their ensuing pulmonary consequences, no findings would lead to conclusions different from that reached with all previous U.S. manned space missions: a modest postflight decrement in orthostatic tolerance without operational significance was demonstrated. Data are mainly documented here for completeness and reference. The in-flight leg volumes augment those from the Skylab 4 mission and actually elaborate further on the early in-flight period.

TABLE 11-III.–*CARDIOTHORACIC RATIO DATA OBTAINED IN SYSTOLE AND DIASTOLE*

Crewmember	Preflight, F - 15 (June 28, 1975)		Postflight R + 0 (July 24, 1975)		Postflight R + 1 (July 25, 1975)	
	Dimensions, cm	C/T ratio	Dimensions, cm	C/T ratio	Dimensions, cm	C/T ratio
			Systole			
ACDR	12.8/30.3	0.422	12.9/30.4	0.424	12.8/29.7	0.430
CMP	13.1/32.7	0.400	12.7/32.3	0.393	13.7/32.2	0.425
DMP	13.0/32.3	0.402	13.0/32.1	0.404	12.5/31.6	0.395
			Diastole			
ACDR	–	–	–	–	–	–
CMP	13.2/32.8	0.402	12.7/32.6	0.389	–	–
DMP	13.6/32.3	0.422	14.7/32.5	0.452	–	–

ACKNOWLEDGMENTS

The authors appreciate the assistance of J. T. Baker, D. Carr, D. Carroll, J. Donaldson, R. Gowen, J. Griffith, W. Henry, P. Hogan, W. Hursta, R. Kessinger, R. Nolte, K. Tamer, M. Taylor, and M. Ward.

12. IN-FLIGHT LOWER LIMB VOLUME MEASUREMENT

G. Wyckliffe Hoffler,[a] Stuart A. Bergman, Jr.,[a]
and Arnauld E. Nicogossian[a]

Major headward fluid shifts during flight have been seen during multiple observations and confirmed in data collected from Apollo and Skylab crews. Dominant among these documented data are the preflight and postflight leg volume determinations that were calculated from multiple circumferential leg measurements. First measured during flight on the Skylab 4 crewmembers, leg volume decrements of a full liter (10 to 15 percent of preflight values) occurred as early as mission day 3, when the earliest in-flight measurements were programed (Figure 12-1). In-flight leg volume measurements were programed on Apollo-Soyuz Test Project (ASTP) crewmembers for the following reasons.

1. To substantiate with further data this rather notable finding
2. To obtain earlier in-flight volume determinations
3. To document the time course of headward fluid shifts by frequent serial leg volume measurements.

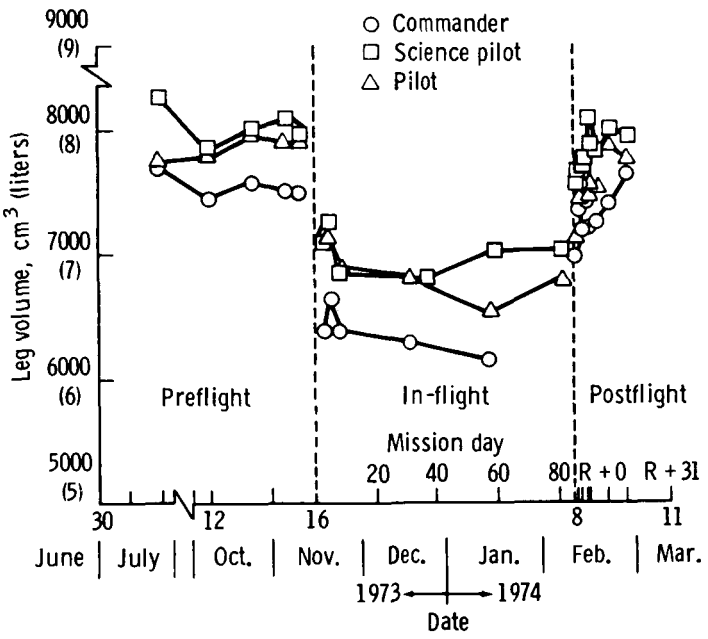

Figure 12-1. Left Leg Volume Measurements of Skylab 4 Crewmen

[a]NASA Lyndon B. Johnson Space Center.

METHOD AND MATERIALS

A simple jig template with an accompanying flexible measuring tape similar to the Skylab 4 limb volume measuring kit was provided (Figure 12-2). The single difference from the Skylab 4 kit design was reduction of the number of circumferential position measurements from 25 to 12, chiefly as a concession to crew time constraints. To preserve the 1- to 2-percent resolution of the method, these 12 template positions were optimized by preflight crew adaptations.

During the period from 45 days before lift-off (F - 45) to 1 day before lift-off (F - 1), five independent determinations of the left leg volume were made. Crewmembers were instructed and trained in the procedure and actually conducted the F - 1 measurements on themselves to ensure adequate familiarization for their seven in-flight measurement sessions. Right leg measurements were obtained three times before flight and once on recovery day (R + 0) by medical team personnel. Because of circumstances associated with the toxic nitrogen tetroxide gas event during the recovery period, leg volumes were not obtained beyond the fourth postflight day (R + 4).

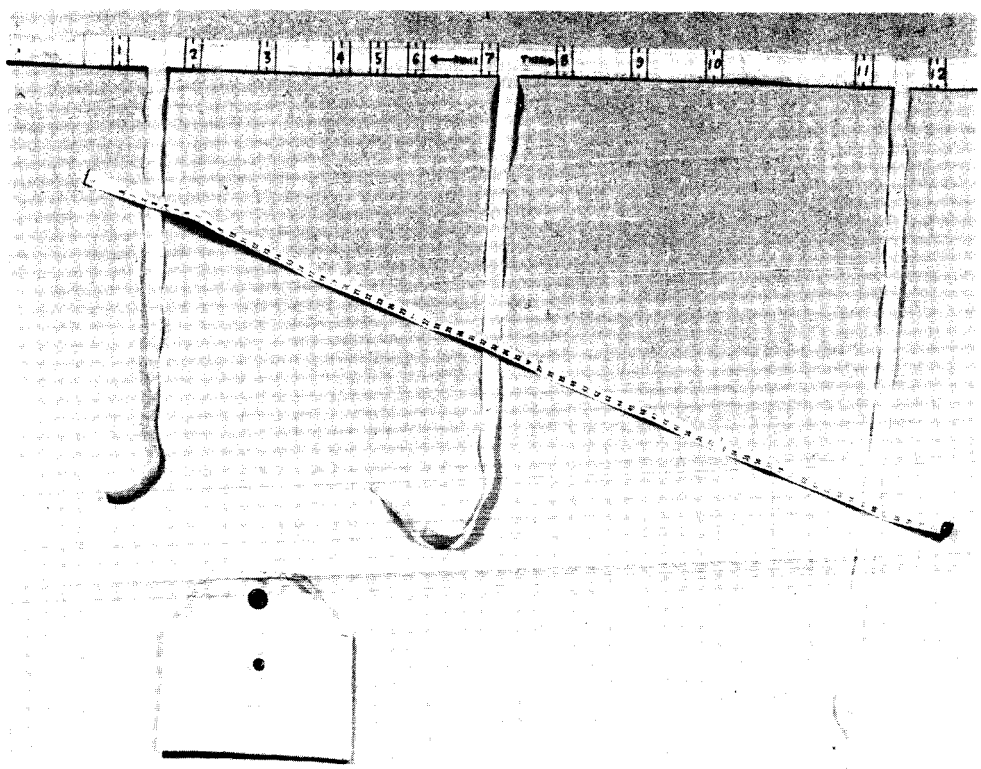

Figure 12-2. The ASTP In-Flight Leg Volume Measuring Kit Including Template, Tape Measure, and Stowage Pouch

RESULTS

In chronological sequence, all leg volume determinations are tabulated from all three flight phases (Table 12-I). Decreasing leg size as the launch period approached is in accordance with preflight findings from previous flight crews. Mean preflight volumes with standard deviations and their 95-percent confidence ranges are included.

The earliest in-flight determination (Figure 12-3) was obtained at approximately 06:00 ground elapsed time (GET) on the command module pilot (CMP). This value fell only 260 cm^3 (0.26 liter) below his F - 1 volume but was still a statistically significant ($P < 0.05$) volume reduction. By 32:00 GET, all three crewmen had evidenced substantially greater in-flight decrements (5 to 10 percent). All four of these values were observed earlier during flight than in the previous earliest in-flight leg volume measurements obtained on Skylab 4 mission day 3. Subsequent determinations showed moderate variability with a definite continuing downward trend, except for the last value at 205:00 GET on the CMP. Most variations were parallel in all three crewmen despite the fact that different crewmembers contributed to measurement variance. All in-flight volumes dropped below the lower 95-percent confidence limit established by preflight volumes determined over a 45-day period.

Earliest postflight determinations were taken between 1.5 and 2 hours after splashdown, about as early as any such data have been acquired on U.S. space crews. Even so, leg volumes on all three crewmen had already increased well above their last in-flight values. Second measurements on recovery day, some 2 to 5 hours after splashdown, evidenced even greater leg volumes, in accord with the reversing effects of readaption in normal gravity. Leg volumes taken on July 25, 1975 (day R + 1), were achieved before arising that morning and show clearly the established diurnal pattern of minimal volume at the end of the sleep period in a horizontal position. The last postflight values, taken on July 28, 1975 (day R + 4), exhibit distinctly increasing trends toward preflight values.

CONCLUSIONS

When considered in conjunction with the earlier Skylab 4 in-flight data on mission days 3, 5, and 8, the comparable flight period, several of the oscillatory variations observed in ASTP flight crewmembers may be judged to be actual physiologic damping responses. In any case, in-flight data from the Skylab 4 and ASTP missions are quite complementary and consistent.

With a single datum for inference, it appears that the major shift of fluid volume from the legs does not occur in the first few hours of orbital exposure. The course seems more likely to assume an exponential form with maximal rate of decrement within the first 24 hours. A distant plateau is evident by 3 to 5 days with little significant additional decrease occurring after the first week in weightlessness. These fluid volume shifts coincide with the occurrence of major crew symptomatology and the plateau with relative adaptive stability. More elaborate studies for clarification of the events observed here must await the Space Shuttle era.

TABLE 12-I.–*LEG VOLUME MEASUREMENTS OF ASTP CREWMEN*

(a) Preflight

Crewmember	Leg volume, liters, on day –					Mean plus or minus standard deviation, liters	95-percent confidence range, liters
	F - 43 (June 2, 1975)	F - 29 (June 16, 1975)	F - 17 (June 28, 1975)	F - 5 (July 10, 1975)	F - 1 (July 14, 1975)		
			Left leg				
Apollo commander (ACDR)	7.88	7.76	7.84	7.76	7.78	7.80 ± 0.06	7.73 to 7.78
Docking module pilot (DMP)	7.72	7.92	7.74	7.68	7.52	7.71 ± .16	7.51 to 7.91
Command module pilot (CMP)	8.42	8.66	8.41	8.24	8.12	8.36 ± .22	8.09 to 8.63
			Right leg				
ACDR	7.50	7.51	7.48	–	–	7.50 ± 0.02	7.45 to 7.55
DMP	7.84	8.00	7.64	–	–	7.83 ± .18	7.38 to 8.28
CMP	8.62	8.68	8.24	–	–	8.51 ± .24	7.91 to 9.11

(b) In-flight, left leg

Crewmember	Leg volume, liters, at GET, h:min, of –						
	06:00	32:00	105:00	129:00	148:00	173:00	205:00
ACDR	–	7.43	7.54	7.34	7.44	6.75	6.88
DMP	–	7.16	7.14	6.67	7.06	7.00	6.75
CMP	7.86	7.26	7.30	7.12	7.20	7.21	7.56

TABLE 12-I.–*CONCLUDED*

(c) Postflight

Crewmember	R + 0 (July 24, 1975)		R + 0 (July 24, 1975)		R + 1 (July 25, 1975)		R + 2 (July 26, 1975)		R + 4 (July 28, 1975)	
	Leg vol., liters	G.m.t., h:min	Leg vol., liters	G.m.t., h:min	Leg vol., liters	G.m.t., h:min	Leg vol., liters	G.m.t., h:min	Leg vol., liters	G.m.t., h:min
					Left leg					
ACDR	7.59	22:45	7.72	23:12	7.43	16:45	7.35	19:52	7.43	18:39
DMP	7.18	23:15	7.38	[a]00:41	7.25	16:40	7.50	19:45	7.54	18:50
CMP	7.67	23:15	7.94	[a]02:49	7.74	16:35	7.70	19:49	7.85	18:44
					Right leg					
ACDR	–	–	7.24	–	–	–	–	–	–	–
DMP	–	–	7.41	–	–	–	–	–	–	–
CMP	–	–	7.92	–	–	–	–	–	–	–

[a] July 25, 1975.

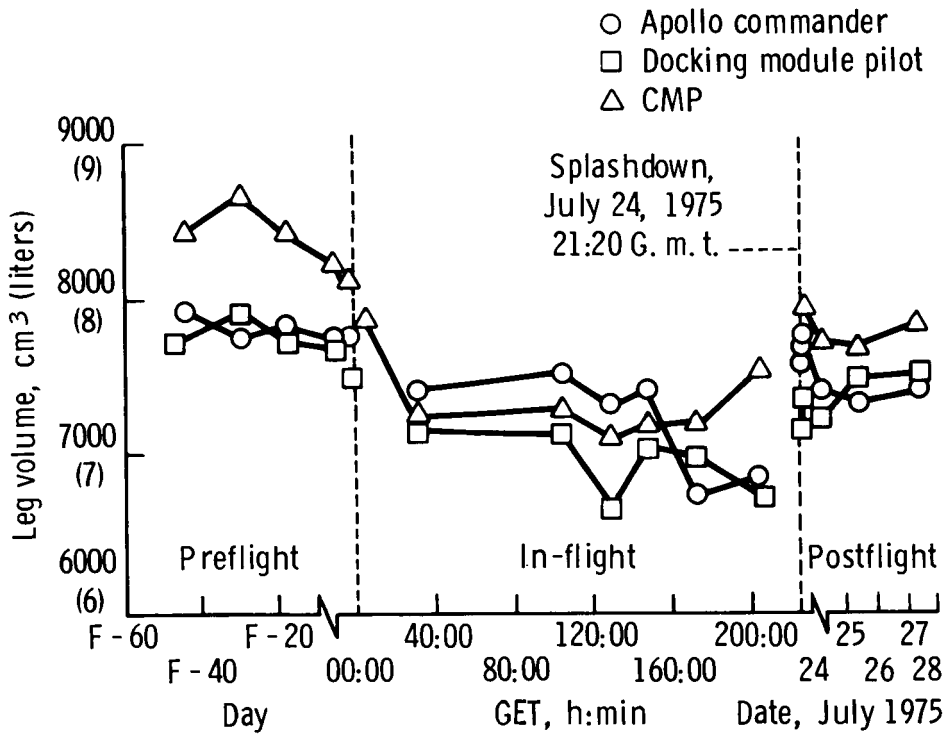

Figure 12-3. Left Leg Volume Measurements of ASTP U.S. Crewmen

ACKNOWLEDGMENTS

The engineering and production of the in-flight limb volume measuring kit was assured by R. Nolte. The ASTP crewmen cooperated magnificently in learning the technique and providing all in-flight data. This detailed test objective doubled the existing data on in-flight leg volume changes and is a credit to the many who have pioneered simple methods for attaining important achievements.

13. MEDICAL MICROBIOLOGICAL ANALYSIS OF U.S. CREWMEMBERS

Gerald R. Taylor[a]

On early Apollo missions before strict protective measures were instituted, in-flight infections were not unusual (ref. 13-1). In-flight illness of microbial origin was, however, completely absent from the Apollo 14 to 17 missions (ref. 13-2). There is no doubt that implementation of extensive preventive measures (ref. 13-3) following the clinically significant Apollo 13 mission was a contributing factor. Preflight monitoring of pathogenic and potentially pathogenic microbial species identified certain potential problems so that appropriate prophylaxis or treatment could be administered before the flight or could be provided during flight. This procedure was highly effective and was recommended for all future U.S. manned space flights (ref. 13-2). Although similar analyses conducted during the three Skylab flights demonstrated the occurrence of several in-flight disease events and evidence of gross contamination of the orbital workshop, such events were not shown to be limiting hazards for long-duration space flights.[1]

The Apollo-Soyuz Test Project (ASTP) was a unique space flight in which two teams of crewmembers from different geographical areas joined their respective spacecraft in space; this mission presented an unusual opportunity for microbial cross-contamination. Accordingly, it was necessary to identify and trace all microorganisms of potential medical importance present in this population. This report covers such an analysis of the three flight and three backup Apollo astronauts that was conducted as part of the Microbial Exchange Experiment. A report of the joint experiment, including analyses of data from the two flight and two backup U.S.S.R. cosmonauts, is presented in the ASTP Preliminary Science Report (ref. 13-4).

METHOD AND MATERIALS

Baseline Microbial Specimen Collection

Nine sets of specimens were collected from the three prime Apollo crewmembers as follows: 45, 30, 15, and 7 days before lift-off (days F - 45, F - 30, F - 15, and F - 7, respectively) and on launch day (F - 0); once during flight; and on recovery day (R + 0) and 15 and 30 days after recovery (R + 15 and R + 30, respectively). Additionally, six sets of control specimens were collected from the three backup Apollo crewmembers before flight on days F - 45, F - 30, F - 15, F - 7, and F - 0, and immediately after the flight.

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[a]NASA Lyndon B. Johnson Space Center.

[1]Gerald R. Taylor, et al.: Skylab Environmental and Crew Microbiology Studies. *Biomedical Results from Skylab*, NASA SP-377, in press.

During each preflight and postflight sample period, microbial specimens were collected from 10 sampling sites on each crewmember (Table 13-I). Calcium alginate swabs wetted in 0.3-mM phosphate buffer were used to sample each of the seven body surface areas. This swab technique was chosen as the only collection method compatible with the flight program. Although it is recognized that subsurface microbes may be overlooked by this method, procedures for sampling subsurface areas were not acceptable. Dry calcium alginate swabs were used to sample the surfaces of the tonsils and the posterior pharyngeal vault before collection of the gargle specimen. For this latter sample, the subject gargled with 0.3-mM phosphate buffer followed by a repeated rinse of the teeth with the same solution. The swabs were placed in 5 cm^3 of 0.3-mM phosphate buffer for transport to the laboratory. Analysis of all samples was initiated within 1 hour of specimen collection.

TABLE 13-I.—*CREW SAMPLE COLLECTION SITES*

Sample no.	Sample designation	Area sampled
1	Hair	20-cm^2 area of hair (and scalp) on top of head
2	Ears	Right and left external auditory canals with 2 revolutions of each swab in each ear canal
3	Neck	20-cm^2 area below hairline at base of neck
4	Nares	Internal area of both nostrils
5	Throat swab	Surfaces of tonsils and posterior pharyngeal vault
6	Hands	20-cm^2 area on right and left palms
7	Axillae	20-cm^2 area below hair on each side
8	Groin	5-cm strip from rear to front on right and left inguinal area between legs
9	Toes	Area between the 2 smallest toes of each foot
10	Gargle	10 cm^3 of phosphate buffer used as gargle and washed through oral cavity 3 times

In-Flight Microbial Specimen Collection

In addition to the baseline samples described previously, in-flight samples were obtained from all five flight crewmembers and both spacecraft between 77:40 and 78:30 Soyuz ground elapsed time. The in-flight samples were made from swabs of the first six areas listed in Table 13-I. For this set of samples, a specially developed sample collection device was employed (Figure 13-1). This device consisted of a cotton-tipped Teflon swab on a capillary

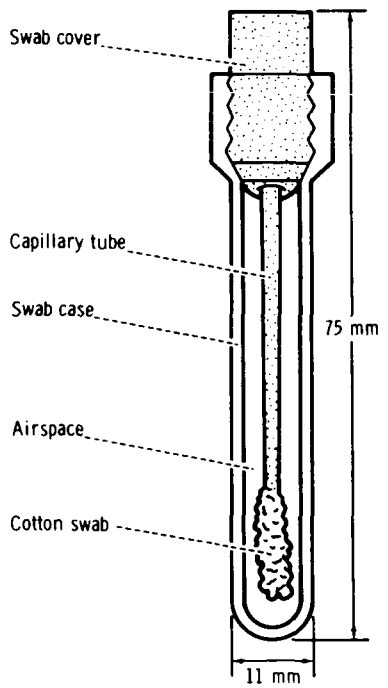

Figure 13-1. In-Flight Microbial Sample Collection Device

tube which contained conservation fluid to keep the microorganisms alive. Each swab was housed within an airtight case to prevent desiccation. Groups of swabs were organized in Beta-cloth retaining bags, an example of which is shown in Figure 13-2.

The contents of each swab and gargle sample were serially diluted under aseptic conditions and subsequently inoculated onto the surface of the nutrient media (Table 13-II). The variety of media, the number of plates inoculated, and the dilution range were selected on the basis of what was required to isolate and quantitate the autoflora components present in each sample area. Sabouraud's dextrose agar (SAB) plates were incubated at 303 K (30° C) for 5 days. Cornmeal, malt-extract, yeast extract (CMMY) agar plates were incubated at 298 K (25° C) for 7 days, and all others were incubated at 310 K (37° C) for 48 hours.

Following incubation under the appropriate conditions, all resulting colonies were categorized and counted on every culture plate. Subsequently, one sample of each morphologically different colony type was transferred from each dilution series to the appropriate nutrient media and was stained according to the method of Gram. Species were identified as previously outlined (refs. 13-5 and 13-6).

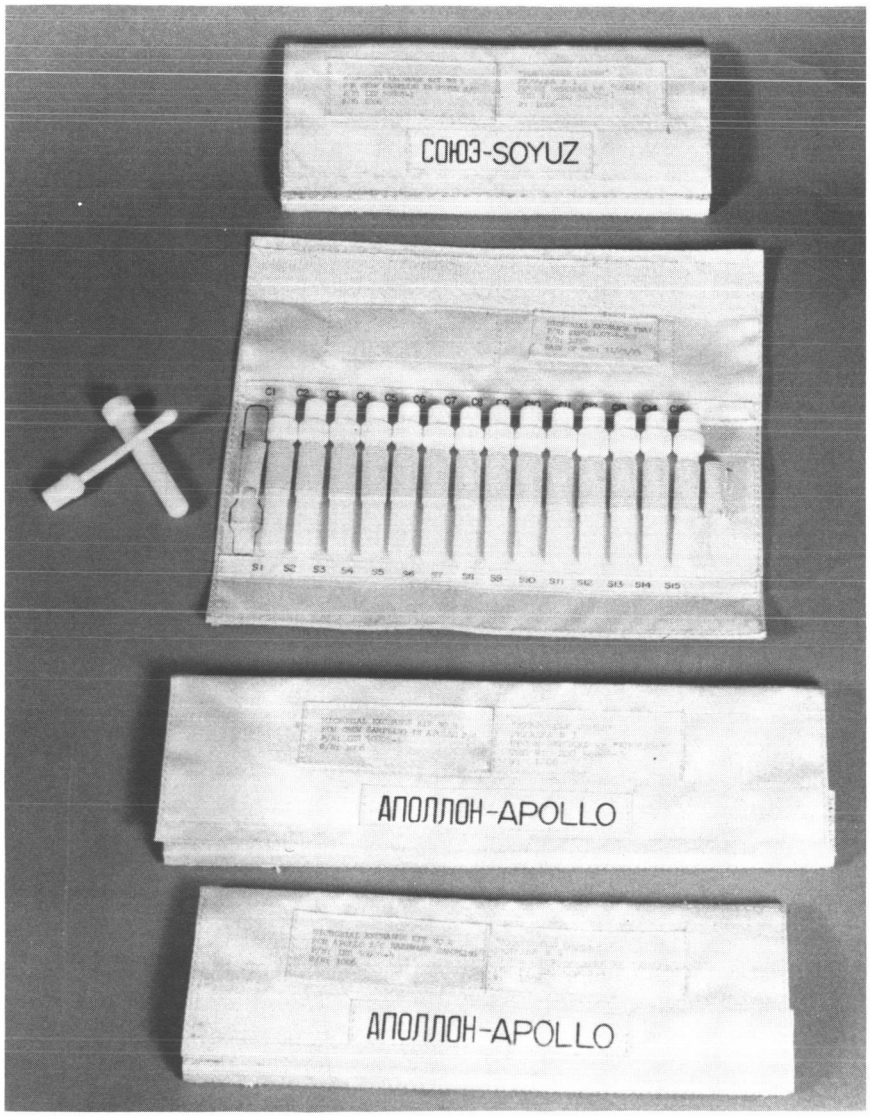

Figure 13-2. Beta-Cloth Sample Collection Kit Used to Sample Crewmembers in Apollo Spacecraft. Open Kit Shows Sample Collection Devices in Place

TABLE 13-II.–*ISOLATION MEDIA USED*

Sample type	Media	Number of plates	Dilution range
Back of neck, Hair, Hands, Axillae, Auditory canals	Blood[a]	2	[b]10^0 to 10^4
	Mannitol[c]	3	10^0 to 10^1
	CMMY[d]	4	10^0
	SAB[e]	5	10^0
Gargle (natural)	Blood	2	10^0 to 10^5
	Mannitol	3	10^0 to 10^1
	CMMY	4	10^0 to 10^2
	Rogosa[f]	3	10^0 to 10^3
	Choc[g]	3	10^0 to 10^5
Gargle (centrifuge)	CMMY	4	10^0
	SAB	5	10^0
Nostrils	Blood	2	10^0 to 10^4
	Mannitol	3	10^0 to 10^3
	CMMY	4	10^0
	SAB	5	10^0
	Choc	3	10^0 to 10^1
Toe webs, Groin	Blood	2	10^0 to 10^5
	Mannitol	3	10^0 to 10^1
	CMMY	4	10^0
	SAB	5	10^0
Throat swab	Blood	2	10^0 to 10^5
	Mannitol	3	10^0 to 10^1
	CMMY	4	10^0 to 10^2
	SAB	5	10^0
	Choc	3	10^0 to 10^5
	Rogosa	3	10^0 to 10^3

[a] Blood = blood agar.

[b] 10^0 = sample in 5 cm^3 of phosphate buffer.

[c] Mannitol = mannitol salts agar.

[d] CMMY = cornmeal, malt-extract, yeast-extract agar.

[e] SAB = Sabouraud's dextrose agar.

[f] Rogosa = Rogosa agar.

[g] Choc = chocolate bacitracin agar.

RESULTS

Enteric Microorganisms

A number of different microbes that occur normally in the intestinal tract or that are associated with intestinal infection are placed in the enteric group of bacilli. The normally occurring members of this group are generally considered to be of potential medical importance when they are recovered repeatedly, or in large numbers, from sites other than the lower digestive tract. The following members of this group were recovered from areas on the ASTP crewmembers other than the lower digestive tract. An outline of the total recovery pattern for the Apollo crewmembers is presented in Tables 13-III to 13-VI.

Escherichia coli species.—The presence of Escherichia coli species is generally accepted as the most reliable evidence of fecal contamination. Outside the intestinal tract, under certain conditions, it often produces diseases such as the following: urinary tract infections (cystitis and pyelitis), peritonitis, gallbladder infection, wound infection, septicemia, and enteritis. This species was repeatedly recovered from the groin of the flight command module pilot (CMP) and occasionally from the upper respiratory tract of the other two flight crewmembers. In all cases, neither the recovery pattern nor the quantitation indicated medical significance.

Enterobacter aerogenes species.—The microorganism Enterobacter aerogenes often occurs in the large intestine of man, although the number present is considerably smaller than that of Escherichia coli. Its pathogenic significance is similar to that of Escherichia coli. As indicated in Tables 13-III and 13-IV, this species was always carried in the nasal and buccal cavities of the flight CMP and docking module pilot (DMP) and was frequently isolated from the backup Apollo commander (ACDR) and DMP. Although this is an uncommon occurrence, it should be noted that this species was not shown to spread to the flight ACDR or to more sites on the carriers during the flight. Also, there were no postflight increases in quantitation. Although carried by two flight crewmembers, this potential pathogen apparently was unaffected by the conditions of space flight.

Proteus mirabilis species.—Species of the genus Proteus may cause infection of the urinary tract and abscesses. Additionally, these microbes have been incriminated in outbreaks of enteric infection, particularly gastroenteritis. More often, they are secondary invaders in infections of the middle ear, the mastoid, meninges, wounds, and the urinary tract. The most frequent species of this genus found in human clinical material, P. mirabilis was carried in low numbers in the nasal passage of the flight ACDR throughout the monitoring period. As in the case of E. aerogenes described previously, this unusual mission provided a good model system for analyzing the response of Gram-negative rods to spaceflight conditions. The ASTP mission had no effect on the qualitative or quantitative presence of this microorganism.

TABLE 13-III.–*RECOVERY OF GRAM-NEGATIVE RODS FROM ASTP APOLLO FLIGHT CREWMEMBERS*
[Genera other than Haemophilus]

Genus and species	Crew-member	Location and quantity of bacteria, $\log_{10}$ colony-forming units/cm^3 of gargle or swab diluent, for day –							
		F - 45	F - 30	F - 15	F - 5	F - 0	R + 0	R + 15	R + 30
Enterobacter aerogenes	ACDR[a]	0	0	0	0	0	0	0	0
	CMP[b]	Axilla 1.95 Nose 2.00 Mouth 1.60	Nose 1.95 Mouth 1.84	Nose 2.23 Mouth 4.00	Nose 1.47 Mouth 3.00	Nose 3.30 Mouth 2.20	Nose 2.78 Mouth 2.60	Nose 2.48 Mouth 2.00	Axilla 1.00 Nose 1.30
	DMP[c]	Nose 1.69 Mouth 1.30	Nose 2.00 Mouth 1.48	Mouth 2.07	Nose 1.47 Mouth 1.47	Nose 2.78 Mouth 2.00	Nose 1.0 Mouth 1.00	Nose 2.40	Mouth 1.95
Escherichia coli	ACDR	0	Mouth 2.00	0	0	0	0	Nose 1.30	0
	CMP	Groin 2.00	Groin 2.60	Groin 1.60	0	Groin 2.30	0	0	0
	DMP	0	0	Nose 2.07	0	0	0	Nose 1.78	Nose 1.00
Moraxella species	ACDR	Hands 1.00	0	0	0	0	0	0	0
	CMP	Mouth 5.00	Ear 1.30	0	Mouth 6.47	0	0	0	0
	DMP	Mouth 2.43	0	Mouth 3.77	Mouth 2.68	Mouth 2.30	Mouth 2.00	0	0
Proteus mirabilis	ACDR	Nose 2.85	Nose 2.00	Nose 2.84	Nose 2.56	Nose 1.30	Nose 1.30	Nose 1.00	Nose 3.04
	CMP	0	0	0	0	0	0	0	0
	DMP	0	0	0	0	0	0	0	0
Acinetobacter calcoaceticus	ACDR	0	0	0	0	0	0	0	0
	CMP	0	Neck 2.00 Hand 2.60	0	0	0	0	0	Hair 1.30 Neck 3.00 Mouth 2.60
	DMP	0	0	0	0	0	0	0	0

[a]ACDR = Apollo commander.

[b]CMP = command module pilot.

[c]DMP = docking module pilot.

TABLE 13-IV.–*RECOVERY OF GRAM-NEGATIVE RODS FROM ASTP APOLLO BACKUP CREWMEMBERS*
[Genera other than Haemophilus]

Genus and species	Crew-member	Location and quantity of bacteria, $\log_{10}$ colony-forming units/cm^3 of gargle or swab diluent, for day –					
		F - 45	F - 30	F - 15	F - 5	F - 0	R + 0
Enterobacter aerogenes	ACDR	Nose 1.00	Nose 1.00	Nose 1.00	0	0	Nose 1.60
	CMP	0	0	0	0	0	0
	DMP	Nose 2.00 Mouth 2.47 Neck 1.00 Groin 1.69	Mouth 2.69 Groin 3.69	0	Mouth 2.00	0	Axilla 1.78
Escherichia coli	ACDR	0	0	0	0	0	0
	CMP	0	0	0	0	0	0
	DMP	0	0	0	0	0	0
Moraxella species	ACDR	Hair 2.11 Neck 3.17 Axilla 2.86 Hands 2.17	0	Neck 1.00	0	0	Nose 2.00 Axilla 1.00
	CMP	0	0	0	0	0	0
	DMP	0	0	0	0	0	Toes 2.00
Proteus mirabilis	ACDR	0	0	0	0	0	0
	CMP	0	0	0	0	0	0
	DMP	0	0	0	0	0	0
Acinetobacter calcoaceticus	ACDR	0	0	0	0	Groin 3.00	Ear 3.00
	CMP	0	0	0	0	0	Neck 2.00 Axilla 1.60
	DMP	Axilla 1.30 Hands 1.60	0	0	0	Nose 2.30 Axilla 1.30 Hands 1.70	0
Klebsiella pneumoniae	ACDR	0	0	0	0	0	0
	CMP	0	0	0	0	0	0
	DMP	0	0	Mouth 3.00 Groin 3.38 Hands 1.30	Mouth 3.48 Groin 3.38 Hands 1.00	Mouth 3.78 Groin 4.00	Mouth 1.48 Groin 3.30

Other Gram-Negative Rods

Nonenteric Gram-negative rods discussed include species of the Moraxella genus, Acinetobacter calcoaceticus organisms, and four species of Haemophilus.

Moraxella species.—Species of the genus Moraxella are parasites found in the mucous membranes of man and are frequently involved in pathogenic activity such as conjunctivitis. Although carried in the oral cavity of the flight DMP for 45 days before the flight, no discernible microbial alteration was demonstrated following the mission.

Acinetobacter calcoaceticus species.—Acinetobacter calcoaceticus (synonym: Mima polymorpha) is a species of minor potential medical importance. Isolated infrequently from multiple sites on the flight CMP, it did not contribute significantly to the load of Gram-negative rods recovered from ASTP flight crewmembers.

Haemophilus species.—Four species of Haemophilus were isolated from the oral cavity of each ASTP astronaut (Tables 13-V and 13-VI). Although each of these species is to some degree a common inhabitant of the human mouth, each is a strict parasite, requiring certain growth factors present in blood. The potential medical importance of each is noted as follows.

Haemophilus influenzae is found in lesions and in the upper respiratory tract of carriers. It may be either a primary or a secondary invader. As a primary incitant of disease, it is responsible for meningitis, septicemia, conjunctivitis, and upper respiratory tract infections. It is commonly a secondary invader in cases of influenza and pertussis. This species was isolated from each of the crewmembers before flight in quantitations ranging from 10 000 to 600 000 viable cells/cm^3 of gargle. The postflight loss from two crewmembers and the quantitative reduction in contamination of the ACDR is contraindicative of a space-flight-mediated increase in infective potential.

Haemophilus haemolyticus and H. parahaemolyticus are often associated with acute pharyngitis when present in high numbers. As with the H. influenzae, the overall quantitation and incidence decreased following the ASTP flight.

Haemophilus parainfluenzae is the most benign of the four species recovered and is used largely as a marker organism because of its almost ubiquitous appearance.

Candida albicans

Candida albicans (ref. 13-7), a well-recognized component of the indigenous autoflora of man, has been recovered from astronaut specimens collected in association with each of the Apollo and Skylab missions (refs. 13-2 and 13-8).[2] Because C. albicans has been identified as the causative agent for serious oral cavity diseases (refs. 13-7 and 13-9), the presence of this microorganism in the mouth of astronauts was carefully monitored. As previously reported (ref. 13-5), C. albicans was recovered from crewmembers following the Apollo 14 and 15 missions, whereas other fungal species, present before flight, were absent from samples obtained immediately after recovery. Analysis of the ASTP data presented in Table 13-VII indicates an in-flight transfer of this species to the ACDR. No such transfer occurred

[2]Ibid.

TABLE 13-V.–*RECOVERY OF GRAM-NEGATIVE RODS FROM ASTP APOLLO FLIGHT CREWMEMBERS*
[Genus Haemophilus]

Crew-member	Species of Haemophilus	Quantity of bacteria, $\log_{10}$ colony-forming units/cm^3 of gargle or swab diluent, for day –							
		F - 45	F - 30	F - 15	F - 5	F - 0	R + 0	R + 15	R + 30
		Throat swab							
ACDR	H. haemolyticus	0	0	4.47	0	0	0	0	0
	H. influenzae	0	0	4.90	0	0	3.34	0	0
	H. parahaemolyticus	0	0	0	0	0	0	0	0
	H. parainfluenzae	4.50	5.04	5.36	5.17	5.20	3.49	4.62	2.18
CMP	H. haemolyticus	5.60	5.47	0	0	0	3.30	0	0
	H. influenzae	5.77	0	0	0	0	0	0	0
	H. parahaemolyticus	0	0	4.00	5.90	0	0	0	0
	H. parainfluenzae	5.69	6.04	5.14	5.90	5.36	3.84	5.87	5.49
DMP	H. haemolyticus	0	0	4.47	0	0	0	0	0
	H. influenzae	0	0	0	0	4.00	0	0	0
	H. parahaemolyticus	0	0	0	0	0	0	5.11	0
	H. parainfluenzae	5.41	5.23	4.84	6.46	5.45	4.77	4.90	4.00
		Gargle							
ACDR	H. haemolyticus	0	0	6.49	0	0	5.30	0	0
	H. influenzae	0	4.90	5.77	0	0	0	0	1.48
	H. parahaemolyticus	0	0	0	0	0	5.00	0	0
	H. parainfluenzae	5.54	5.99	6.77	6.53	6.53	5.95	5.08	4.18
CMP	H. haemolyticus	0	6.30	0	6.90	0	0	0	0
	H. influenzae	5.69	0	0	0	0	0	0	0
	H. parahaemolyticus	0	0	6.30	7.11	0	0	0	0
	H. parainfluenzae	6.23	7.08	7.20	7.39	6.48	5.15	6.48	7.00
DMP	H. haemolyticus	0	0	5.77	0	0	0	5.78	0
	H. influenzae	0	0	0	0	0	0	0	0
	H. parahaemolyticus	4.69	0	0	5.30	0	5.30	5.00	0
	H. parainfluenzae	5.44	6.04	6.43	6.80	6.28	5.52	6.15	5.46

TABLE 13-VI.–*RECOVERY OF GRAM-NEGATIVE RODS FROM ASTP APOLLO BACKUP CREWMEMBERS*
[Genus Haemophilus]

Crew-member	Species of Haemophilus	Quantity of bacteria, $\log_{10}$ colony-forming units/cm^3 of gargle or swab diluent, for day –					
		F - 45	F - 30	F - 15	F - 5	F - 0	R + 0
		Throat swab					
ACDR	H. haemolyticus	0	4.60	0	0	0	0
	H. influenzae	0	0	0	0	0	0
	H. parahaemolyticus	4.30	0	4.11	0	0	0
	H. parainfluenzae	5.32	4.95	7.95	5.81	6.05	5.38
CMP	H. haemolyticus	0	0	0	0	0	0
	H. influenzae	0	0	0	0	0	0
	H. parahaemolyticus	0	0	4.65	4.65	4.57	0
	H. parainfluenzae	4.34	2.30	3.95	3.60	4.48	4.57
DMP	H. haemolyticus	0	0	0	5.04	0	0
	H. influenzae	0	4.00	0	3.00	3.00	0
	H. parahaemolyticus	0	0	0	0	0	0
	H. parainfluenzae	2.44	5.20	4.41	4.69	4.04	4.15
		Gargle					
ACDR	H. haemolyticus	5.47	0	0	0	0	5.00
	H. influenzae	0	0	0	0	0	0
	H. parahaemolyticus	0	0	0	0	0	0
	H. parainfluenzae	5.95	6.54	6.60	0	6.49	6.36
CMP	H. haemolyticus	0	0	0	0	0	0
	H. influenzae	0	0	0	0	0	0
	H. parahaemolyticus	0	0	6.00	6.77	0	5.30
	H. parainfluenzae	4.70	0	6.43	6.36	5.86	6.41
DMP	H. haemolyticus	0	0	0	0	0	0
	H. influenzae	3.00	0	0	0	0	0
	H. parahaemolyticus	4.25	0	0	0	4.00	4.30
	H. parainfluenzae	0	6.73	7.43	7.43	5.81	5.00

TABLE 13-VII.–*RECOVERY OF* Candida albicans *FROM THE MOUTHS OF APOLLO CREWMEMBERS*

Crewmember	Days before or during flight					Days after flight			
	F - 45	F - 30	F - 15	F - 5	F - 0	F + 5	R + 0	R + 15	R + 30
				Flight					
ACDR	A[a]	A	A	A	A	A	P[b]	A	A
CMP	P	P	P	P	P	P	P	P	P
DMP	A	P	P	P	P	A	P	P	P
				Backup					
ACDR	A	A	A	A	A	NS[c]	A	NS	NS
CMP	P	P	P	P	P	NS	P	NS	NS
DMP	A	A	A	A	A	NS	A	NS	NS

[a]Absence of C. albicans.

[b]Presence of C. albicans.

[c]No sample taken.

with the backup controls, although C. albicans was carried in the oral cavity of the backup CMP. All of these events demonstrate the importance of this species in space flight. It could become even more important during in-flight use of antibiotics since this could provide the opportunity for a loss of competing bacterial species and eventual overgrowth with C. albicans (refs. 13-9 to 13-11).

Staphylococcus aureus

Although Staphylococcus aureus microorganisms are not uncommon skin and nasal contaminants, all strains are potential pathogens. They have been shown to be the causative agent of a wide range of infections and intoxications including abscesses, meningitis, furunculosis, pyemia, osteomyelitis, suppuration of wounds, and food poisoning (ref. 13-12). Several space-flight simulation studies have indicated increases in the toxicogenic activity, virulence, or pathogenicity of this species with stressful confinement of the human host (refs. 13-13 to 13-15). If these events were to be duplicated during space flight, the resulting lesions could be especially important because of their interference with close-contact

surfaces, such as the tight-fitting and abrasive pressure suits. Accordingly, the presence and the activity of this species were monitored before and after each of the recent U.S. space flights. Data from the Apollo 13, 14, and 15 missions and from the Skylab missions confirm in-flight cross-contaminations with S. aureus (ref. 13-2).[3]

The recovery of S. aureus from ASTP crewmembers in connection with previous space flights is presented in Table 13-VIII. The ASTP flight DMP had not been assigned to a previous space-flight mission; therefore, such data were nonapplicable. Strains of S. aureus were recovered from all the other five ASTP crewmembers in connection with at least one previous space-flight mission.

The recovery of strains of S. aureus during the ASTP monitoring period is presented in Table 13-IX. These strains are expressed as numbered bacteriophage types. The data show that each of the flight and backup crewmembers carried a different strain of S. aureus. One type (52, 52A, 80, 81) was carried by the DMP and transferred to the ACDR during flight. Apparently, colonization did not ensue because this strain was not again recovered from the flight ACDR.

A postflight increase in the incidence of S. aureus isolation has been reported previously (ref. 13-2).[3] In the ASTP mission, this postflight increase did not occur among the astronaut population. Contrary to some previous missions,[3] no disease events resulted from the ubiquitous presence of S. aureus before and during the flight.

Total Load of Potential Pathogens

Several authors have warned that returning space travelers may experience a "microbial shock" and may respond negatively to renewed contact with potentially pathogenic microorganisms which are absent in the space-flight environment (refs. 13-1 and 13-16 to 13-18). These warnings were based on the assumption that contact with potential pathogens during space flight would be very limited and would thus result in a reduction of immunocompetence. However, there was no demonstrable decrease in the incidence of medically important microorganisms recovered from the astronauts on recovery day. This finding supports earlier reported results (refs. 13-6, and 13-19). Therefore, any reduction in total immunocompetence during the ASTP mission could not have been in response to decreased contact with medically important components of the resident microflora.

CONCLUSION

This analysis of medically important microorganisms was conducted as a part of the ASTP Microbial Exchange experiment. Although several potential pathogens were recovered from each of the flight and backup crewmembers before and after flight, no disease events were reported. Candida albicans and staphylococcus aureus (52, 52A, 80, 81) were shown to have been transferred from one crewmember to another during flight. No other medically significant changes in the microbial population were observed.

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[3] Ibid.

TABLE 13-VIII.—Staphylococcus aureus *RECOVERY FOR U.S. CREWMEMBERS COLLECTED BEFORE ASTP FLIGHT*

Crewmember	Flight	Sampling day	Sample area	Phage type
		Flight ASTP crew		
ACDR	Apollo 10	F - 30	Hands	NA[a]
CMP	Apollo 15	F - 30	Scalp	NT[b]
			Nose	85
		F - 5	Nose	85
			Mouth	NT
	Skylab 3	F - 30	Groin	NT
			Nose	75/85
		F - 14	Groin	NT
		F - 5	Mouth	75/85
			Nose	NT
	Skylab 4	F - 30	Groin	NT
			Nose	75/85
		F - 14	Nose, Groin	NT
			Mouth	75/85
		F - 5	Ear, groin	NT
			Nose	29/75
			Mouth, scalp	29/47/75
DMP	Clinic	–	Mouth	83A
		Backup ASTP crew		
ACDR	Apollo 12	F - 30	Scalp, ears, axilla, hands, nose, groin	NA
		F - 14	Nose	NA
		F - 0	Toes, nose	NA
		R + 0	Nose	NA
	Skylab 3	F - 45	Nose, mouth	3A
		F - 14	Scalp, navel, nose, groin	3A
		F - 5	Nose	3A
		F - 0	Nose	3A
		R + 0	Hands	3A
			Nose	3A/3C
		R + 8	Nose, hands, navel	3A
			Groin	3A/3C
		R + 15	Scalp	3A/3C
			Nose, axilla, hands	3A
			Navel	3C
CMP	Apollo 14	F - 14	Nose, hands	6/47/53/54/77/79/80/81
DMP	Skylab 3	F - 45	Scalp	29/79
			Groin	29/79/80
			Nose	29/53/54/79/80
		F - 14	Nose	29/53/54/79/80
		F - 5	Hands	29/79
			Nose	NT
		R + 0	Mouth, scalp, feces	29/79
			Hands	3A
			Nose	29/53/54/79/80
		R + 8	Mouth	29/53/79/80
		R + 18	Nose	29/79
			Mouth	29/53/79/80

[a]Not applicable (typing not done).
[b]Nontypable.

TABLE 13-IX.–*RECOVERY OF* Staphylococcus aureus *BACTERIOPHAGE TYPES FROM ASTP APOLLO CREWMEN*

Crew-member	Sample collection period								
	Days before flight					Days after flight			Carrier status
	F - 45	F - 30	F - 15	F - 5	F - 0	R + 0	R + 15	R + 30	
					Flight crew				
ACDR	0	Mouth (NT[a])	Mouth (NT) Mouth (6)	Mouth (NT) Toes (85)	Mouth (NT) Hand (42E)	Mouth (52, 52A, 80, 81)	Mouth (NT)	Mouth (NT)	(NT)
CMP	Mouth 85 (83A)	Mouth 85 (53, 83A)	Mouth 83A, 85 (6, 42E, 53, 79, 80, 81) Nose 71 (6, 75, 80, 81)	Mouth 85 (53, 79, 83A)	Mouth 85 (53, 83A)	0	Mouth (83A, 85)	Mouth (85)	53, 83A, 85
DMP	0	Mouth 52, 52A, 80, 81 Mouth 29 (42E, 53, 75, 81, 83A	0	Mouth 52, 52A, 80, 81	Mouth 52, 52A, 80, 81 Nose (6, 42D, 42E, 47, 53, 75, 81)	Mouth (52, 52A, 80, 81)	0	0	52, 52A, 80, 81
					Backup crew				
ACDR	Mouth 3A (3C)	Mouth 3A (3C)	Mouth 3A (3C)	0	0	0	NS[b]	NS	3A, 3C
CMP	Hands (NT) Nose 71 (55)	Nose (55, 71) Hair (55, 71)	0	0	Nose (55, 71)	Nose (54, 55, 71) Hand (NT) Nose (NT) Hair (81)	NS	NS	55, 71
DMP	Nose (75, 79, 84)	Mouth 29 (53, 54, 75, 79, 80, 81) Nose (29, 53, 54, 75, 79, 80)	Mouth 29, 75, 79 (42E, 53) Nose 29, 75, 79 (6, 42E, 53, 80) Neck 29, 75, 79 (42E, 53, 54, 80, 81)	Mouth (29, 42E, 53, 75, 79, 80) Nose 29 (42E, 53, 75, 79, 80, 81, 85)	Mouth (29, 53, 75, 79, 80) Nose (29, 53, 75, 79)	Mouth (29, 53, 54, 75) Nose (29, 53, 75, 80)	NS	NS	29, 53, 54, 75, 79, 80

[a]Nontypable.

[b]No sample taken.

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REFERENCES

13-1. Berry, Charles A.: Summary of Medical Experiences in the Apollo 7 Through 11 Manned Spaceflights. *Aerosp. Med.*, vol. 41, no. 5, May 1970, pp. 500-519.

13-2. Taylor, Gerald R.: Recovery of Medically Important Microorganisms from Apollo Astronauts. *Aerosp. Med.*, vol. 45, no. 8, Aug. 1974, pp. 824-828.

13-3. Wooley, Bennie C.: Apollo Experience Report – Protection of Life and Health. NASA TN D-6856, 1972.

13-4. Taylor, G. R.; Kropp, K. D.; et al.: Microbial Exchange – Experiment AR-002. *Apollo-Soyuz Test Project Preliminary Science Report.* NASA TM X-58173, 1976, pp. 16-1 to 16-31.

13-5. Taylor, Gerald R.; Henney, Mary R.; and Ellis, Walter L.: Changes in the Fungal Autoflora of Apollo Astronauts. *Appl. Microbiol.*, vol. 26, no. 5, Nov. 1973, pp. 804-813.

13-6. Taylor, Gerald R.: Apollo 14 Microbial Analysis. NASA TM X-58094, 1972.

13-7. Rosebury, T.: *Microorganisms Indigenous to Man.* Blackiston Division, McGraw-Hill (New York), 1962.

13-8. Taylor, Gerald R.: Space Microbiology. *Ann. Rev. Microbiol.*, vol. 401, 1974, pp. 23-40.

13-9. Marwin, R. M.: Relative Incidence of Candida albicans on the Skin of Persons With and Without Skin Disease. *J. Investigative Dermatology*, vol. 1, 1949, pp. 229-241.

13-10. Ginsberg, H. S.: Immune States in Long-Term Space Flights. *Life Sciences and Space Research*, IX, COSPAR, Akademie-Verlag (Berlin), May 1971, pp. 1-9.

13-11. Huppert, M.; Cazin, J., Jr.; and Smith, H., Jr.: Pathogenesis of Candida albicans Infections Following Antibiotic Therapy. *J. Bacteriol.*, vol. 70, no. 1, July 1955, pp. 440-447.

13-12. Buchanan, Robert E.; and Gibbons, Norman E.: *Bergey's Manual of Determinative Bacteriology.* Eighth ed., Williams & Wilkins Co. (Baltimore), 1974.

13-13. Chukhlovin, B. A.; Ostrovmov, P. B.; and Ivanova, S. P.: Development of Staphylococcal Infections in Human Subjects Under the Influence of Some Spaceflight Factors. *Space Biol. & Med.*, vol. 5, no. 6, 1971, pp. 91-98. (Primary source – *Kosmicheskaia Biologiia i Meditsina*, vol. 5, 1971, pp. 61-65 (in Russian).)

13-14. Nefedov, Yu. G.; Shilov, V. M.; Konstantinova, I. V.; and Zaloguyev, S. N.: Microbiological and Immunological Aspects of Extended Manned Space Flights. *Life Sciences and Space Research*, IX, COSPAR, Akademie-Verlag (Berlin), May 1971, pp. 11-16.

13-15. Shilov, V. M.; Lizko, N. N.; Borisova, O. K.; and Prokhorov, V. Ya.: Changes in the Microflora of Man During Long-Term Confinement. *Life Sciences and Space Research,* IX, COSPAR, Akademie-Verlag Berlin, May 1971, pp. 43-49.

13-16. Luckey, T. D.: Potential Microbic Shock in Manned Aerospace Systems. *Aerosp. Med.*, vol. 37, no. 12, Dec. 1966, pp. 1223-1228.

13-17. Spizizen, J.: Microbiological Problems of Manned Space Flight. *Life Sciences and Space Research,* IX, COSPAR, Akademie-Verlag (Berlin), May 1971, pp. 65-68.

13-18. Wilkins, Judd R.: Man, His Environment, and Microbiological Problems of Long-Term Spaceflight. *Biotechnology*, NASA SP-205, 1967, pp. 133-143.

13-19. Zaloguyev, S. N.; Skinkareva, N. M.; and Utkina, T. G.: State of the Automicroflora of Skin Tissues and Certain Natural Immunity Indices in the Astronauts A. G. Nikolaev and V. I. Sevast'ianov Before and After Flight. *Kosmicheskaia Biologiia i Meditsina*, vol. 4, no. 6, 1970, pp. 54-59. (Translation available from Joint Publications Research Service, Washington, D.C.)

14. BIOCHEMISTRY AND ENDOCRINOLOGY RESULTS

Carolyn S. Leach[a]

The biochemistry and endocrinology studies were conducted to provide data which, when integrated with information from other medical disciplines, permit an objective assessment of the individual crewman's health. Additionally, the data collected during the preflight phase of the Apollo-Soyuz Test Project (ASTP) mission provided baseline information for the medical team in detecting and identifying postflight physiological changes which may have resulted from exposure to the space-flight environment. The results of these tests not only helped in the diagnosis of abnormalities but also provided rationale for accurate remedial procedures.[1]

METHODS

Analyses were performed on venous blood three times before the mission: 30, 15, and 5 days before lift-off (days F-30, F-15, and F-5, respectively). Postflight blood was drawn as soon as possible (ASAP) after recovery (day R + 0) and 28 days later (day R + 28). All preflight blood samples were obtained fasting. On the same day that blood was drawn, 24-hour urine samples were collected from each crewman.

During the preflight and postflight periods, the crew consumed the diet of their choosing but followed the provided ASTP diet during flight. Fluids were available when desired.

Analyses on the blood (plasma or serum) samples included: glucose (Glu), cholesterol (Chol), serum glutamic oxaloacetic transaminase (SGOT), serum glutamic pyruvic transaminase (SGPT), blood urea nitrogen (BUN), uric acid, alkaline phosphatase (Alk Phos), calcium (Ca), magnesium (Mg), inorganic phosphate (PO_4), bilirubin total (Bili T), creatinine (Creat), creatine phosphokinase (CPK), lactic dehydrogenase (LDH), osmolality (Osmol), sodium (Na), potassium (K), chloride (Cl), triglycerides (Trigly), adrenocorticotrophic hormone (ACTH), angiotensin I (ANGIO I), aldosterone (ALDO), and cortisol. The 24-hour urine samples were analyzed for: specific gravity (sp. gr.), Osmol, Na, K, Cl, Ca, Mg, inorganic phosphate, uric acid, Creat, ALDO, antidiuretic hormone (ADH), cortisol, epinephrine (Epi), norepinephrine (Nor), and amino acids.

Body compartments were determined on two of the crewmen, the docking module pilot (DMP) and the command module pilot (CMP), 15 days before the flight and immediately after flight. These compartments included plasma volume (iodine-125 (^{125}I)), total body water (tritium (^{3}H)), extracellular fluid (sulfur-35 (^{35}S)), and total body exchangeable potassium (^{42}K). The analytical procedures used have been described previously.[2]

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[a]NASA Lyndon B. Johnson Space Center.

[1]Life Sciences Directorate, Lyndon B. Johnson Space Center: Medical Requirements, Apollo-Soyuz Test Project. JSC-09242, Oct. 1974.

[2]Lyndon B. Johnson Space Center: Skylab Biomedical Analytical Laboratory Procedure. JSC-07795, 1973.

The data are given for each crewman. Where possible, the preflight mean (PM) and standard deviation (SD) are shown after the preflight values, and each postflight value obtained is given. Because of the concern for crew health, the originally approved schedule was not followed after flight. Blood samples for complete analyses were drawn on days R + 0 and R + 28. Limited plasma was available from the immunology studies on days R + 1, R + 8, and R + 13. These samples were analyzed for cortisol and ALDO.

RESULTS

Blood (plasma or serum) biochemistry findings are shown in Tables 14-I and 14-II. The results show postflight decreases below preflight values for glucose in the CMP and the DMP, for cholesterol in the Apollo commander (ACDR) and the CMP, and for uric acid in the ACDR and the DMP. Increases above preflight values are observed in SGOT, SGPT, BUN, Alk Phos, Creat, LDH, and ANGIO I. The LDH isoenzyme values are given in Table 14-III. These results show nearly equal distribution of the total LDH increase through all five bands on R + 0. By day R + 28, the elevation was shifted more toward LDH isoenzyme 1 for the ACDR and the CMP. The DMP's results were still more generally elevated in bands 2, 4, and 5.

The 24-hour urine results are given in Tables 14-IV and 14-V. There is a postflight decrease in Na, K, and Cl in all three crewmen. Increases after flight are seen in hydrogen ion (H+), cortisol, and ALDO.

The body compartment results are given in Table 14-VI. Only two crewmen participated in these tests. Postflight decreases were measured in plasma volume, total body water, extracellular fluid, and total body exchangeable K.

Immediately upon entry, the three astronauts excreted significantly higher amounts of total hydroxylysine ($p < 0.05$) and total hydroxylysine glycoside (Tables 14-VII and 14-VIII). The latter increase was caused entirely by galactosyl hydroxylysine in the DMP ($p < 0.01$), and to both glycosides in the CMP ($p < 0.01$). Consequently, the ratio glucosyl-galactosyl hydroxylysine (GLU-GAL)/galactosyl hydroxylysine (GAL), normally having an average value of 1.50, decreased in the ACDR but increased in the other two crewmembers. The changes in the urinary excretion of free hydroxylysine were significant only in one crewmember (DMP, $p < 0.05$). All the increased values had returned to normal 28 days after entry.

DISCUSSION

The test results of U.S. crewmen on the 9-day ASTP flight were similar to the findings on recovery of previous space-flight crews from missions of comparable duration (ref. 14-1). Weight loss has been a nearly universal finding after exposure to weightlessness. The weight loss on this flight was variable; the ACDR actually gaining 0.5 kg (1 lb). The postflight urine results and the body compartment results indicate that body fluids and electrolytes were decreased on return to normal gravity and that a process of conservation by the body had been initiated at R + 0. This process is shown in particular by the ANGIO I and ALDO results.

TABLE 14-I.–*PLASMA ENDOCRINE RESULTS*

Sample day	ANGIO I, mμg/ml/h	Cortisol, μg/100 ml	ALDO, pg/ml	Insulin, [a]μU/ml	DBH[b] activity, IU[c]	[d]T_3, percent uptake	[e]T_4, μg/100 ml	[f]TSH, μU/ml	[g]HGH, ng/ml
					ACDR				
F - 30	0.78	13.4	282	11	29.9	31.5	9.6	2.8	1.2
F - 15	1.95	15.2	91	15	23.3	33.5	6.0	–[h]	–
F - 5	1.58	15.5	432	12	28.1	–	8.8	2.7	1.2
PM ± SD[i]	1.44 ± 0.6	14.7 ± 1.1	268 ± 171	13 ± 2	27 ± 3.4	32.5 ± 1.4	8.1 ± 1.9	2.75 ± 0.1	1.2 ± 0
R + 0	2.82	15.0	257	61	26.2	–	–	2.7	0.9
R + 1	–	12.7	368	–	27.0	–	–	–	–
R + 8	–	10.1	200	–	–	–	–	–	–
R + 13	–	19.5	368	–	–	–	–	–	–
R + 28	.92	15.5	202	15	–	25.4	7.0	2.9	0.9
					CMP				
F - 30	1.19	13.0	211	8	41.8	32.7	10.6	1.6	1.2
F - 15	.31	16.3	209	10	34.6	36.5	12.6	1.6	–
F - 5	.40	10.1	215	10	34.6	–	10.0	1.3	1.5
PM ± SD	.63 ± 0.48	13.1 ± 3.1	212 ± 3	9 ± 1	37.0 ± 4.2	34.6 ± 2.7	11.1 ± 1.4	1.5 ± 0.2	1.4 ± 0.2
R + 0	.82	21.0	287	9	39.1	–	–	1.5	1.8
R + 1	–	11.4	368	–	34.7	–	–	–	–
R + 8	–	5.5	206	–	–	–	–	–	–
R + 13	–	14.7	309	–	–	–	–	–	–
R + 28	.52	10.7	403	15	–	30.0	5.6	1.7	1.2
					DMP				
F - 30	0.21	16.3	157	8	18.8	34.6	7.3	1.6	1.5
F - 15	.37	11.0	191	8	13.4	36.5	6.1	1.9	1.5
F - 5	.13	18.5	255	12	15.4	34.2	5.6	2.1	1.5
PM ± SD	.24 ± 0.12	15.3 ± 3.9	201 ± 50	9 ± 2	15.9 ± 2.7	35.1 ± 1.2	6.3 ± 0.9	1.9 ± 0.3	1.5 ± 0
R + 0	1.53	14.9	216	19	15.0	–	–	2.0	1.8
R + 1	–	14.2	368	–	14.7	–	–	–	–
R + 8	–	3.8	147	–	–	–	–	–	–
R + 13	–	18.5	309	–	–	–	–	–	–
R + 28	.49	11.0	280	18	–	39.2	6.9	1.8	1.2

[a]U = standard unit.

[b]DBH = diabetogenic hormone.

[c]IU = international unit.

[d]T_3 = triiodothyronine.

[e]T_4 = thyroxine.

[f]TSH = thyroid stimulating hormone.

[g]HGH = human growth hormone.

[h]Dashes indicate no data.

[i]Preflight mean plus or minus standard deviation.

TABLE 14-II.–*SERUM BIOCHEMISTRY RESULTS*

Sample day	GLU, mg/100 ml	[a]Chol, mg/100 ml	[b]SGOT, mU/ml	[c]SGPT, mU/ml	[d]BUN, mg/100 ml	Uric acid, mg/100 ml	[e]Alk Phos, IU	[f]Ca, mg/100 ml	[g]Mg, mg/100 ml	[h]PO_4, mg/100 ml	[i]Bili T, mg/100 ml	[j]Creat, mg	[k]CPK, mU/ml	[l]LDH, mU/ml	Osmol, mOsmol	[m]Na, meq/liter	[n]K, meq/liter	[o]Cl, meq/liter	[p]TRIGLY, mg/100 ml
										ACDR									
F - 30	116	256	14	9	13	7.1	11	9.2	2.0	3.6	0.5	1.2	67	163	288	140	4.0	101	146
F - 15	110	250	11	8	17	7.7	8	9.2	2.1	3.6	.2	1.2	69	151	290	139	4.1	104	265
F - 5	116	237	14	7	16	8.4	13	8.7	2.1	4.0	.9	1.3	62	159	283	140	3.8	102	122
PM ± SD	114 ± 3	248 ± 10	13 ± 2	7 ± 2	15 ± 2	7.7 ± 0.7	11 ± 3	9.0 ± 0.3	2.1 ± 0.1	3.7 ± 0.2	.5 ± 0.4	1.2 ± 0.1	62 ± 5	158 ± 6	287 ± 4	140 ± 1.4	4.0 ± 0.2	102 ± 2	178 ± 77
R + 0	124	210	21	32	18	6.3	15	8.6	1.9	2.8	.2	1.5	69	254	282	139	3.6	104	147
R + 28	114	271	14	9	16	8.5	16	9.2	2.1	4.0	.3	1.3	55	230	287	139	4.1	102	81
										CMP									
F - 30	101	219	13	11	23	6.7	18	9.2	1.7	3.2	0.7	1.2	129	185	287	139	4.2	100	141
F - 15	102	209	15	6	19	7.9	15	9.0	1.7	3.0	.3	1.4	124	163	291	142	4.5	108	67
F - 5	104	211	17	16	19	8.7	21	8.5	1.8	3.4	1.4	1.4	58	163	286	142	4.1	106	136
PM ± SD	102 ± 2	213 ± 5	15 ± 2	11 ± 5	20 ± 2	7.8 ± 1.0	18 ± 3	8.9 ± 0.4	1.7 ± 0.1	3.2 ± 0.2	.8 ± 0.6	1.3 ± 0.1	104 ± 40	170 ± 13	288 ± 3	141 ± 2	4.3 ± 0.2	105 ± 4	115 ± 42
R + 0	100	210	19	20	25	7.8	21	9.2	1.7	4.5	.3	1.6	68	268	286	140	4.4	97	112
R + 28	112	291	23	23	16	8.8	18	9.3	1.8	2.9	.4	1.8	148	243	286	139	4.6	103	77
										DMP									
F - 30	96	216	9	9	17	6.5	10	8.8	1.9	3.1	0.4	1.1	44	159	286	140	4.6	99	83
F - 15	100	207	10	5	15	6.4	8	8.6	2.0	3.2	.3	1.1	71	146	290	142	4.2	107	36
F - 5	104	234	13	7	16	6.8	15	8.6	2.1	3.3	.5	1.2	64	172	283	141	3.9	103	86
PM ± SD	100 ± 4	219 ± 14	11 ± 2	6 ± 1	16 ± 1	6.6 ± 0.2	11 ± 4	8.7 ± 0.1	2.0 ± 0.1	3.2 ± 0.1	.4 ± 0.1	1.1 ± 0.1	60 ± 14	159 ± 13	286 ± 4	141 ± 1	4.2 ± 0.4	103 ± 4	68 ± 28
R + 0	92	218	12	10	23	6.0	13	9.0	2.0	3.2	.3	1.3	46	202	287	140	4.3	104	89
R + 28	116	221	13	6	18	6.8	12	9.0	1.9	3.1	.4	1.2	54	196	287	141	4.0	104	21

[a]Chol = cholesterol.
[b]SGOT = serum glutamic oxaloacetic transaminase.
[c]SGPT = serum glutamic pyruvic transaminase.
[d]BUN = blood urea nitrogen.
[e]Alk Phos = alkaline phosphatase.
[f]Ca = calcium.
[g]Mg = magnesium.
[h]PO_4 = inorganic phosphate.
[i]Bili T = bilirubin total.
[j]Creat = creatinine.
[k]CPK = creatine phospho kinase.
[l]LDH = lactic dehydrogenase.
[m]Na = sodium.
[n]K = potassium.
[o]Cl = chloride.
[p]TRIGLY = triglycerides.

TABLE 14-III.–*LACTIC DEHYDROGENASE ISOENZYME*

Sample day	Band 1		Band 2		Band 3		Band 4		Band 5	
	Percent	IU	Percent	IU	Percent	IU	Percent	IU	Percent	IU
					ACDR					
F - 30	27	44	30	49	15	24	9	15	19	31
F - 15	28	42	28	42	16	24	9	14	19	39
F - 5	30	48	30	48	15	24	6	10	19	30
R + 0	23	58	26	66	16	41	12	30	23	58
R + 1	21	–	35	–	16	–	8	–	16	–
R + 4	22	–	31	–	18	–	10	–	19	–
R + 8	22	42	27	51	18	34	13	25	20	38
R + 13	24	52	26	56	19	41	13	28	18	39
R + 28	42	97	29	67	21	48	4	9	4	9
					CMP					
F - 30	31	57	33	61	12	22	9	17	15	28
F - 15	29	47	30	49	14	23	9	15	18	29
F - 5	26	42	26	42	15	24	12	20	21	34
R + 0	24	64	26	70	16	43	11	29	23	62
R + 1	29	–	27	–	17	–	10	–	17	–
R + 3	24	–	26	–	19	–	10	–	21	–
R + 4	25	–	27	–	18	–	11	–	19	–
R + 8	26	60	29	67	19	44	10	23	16	37
R + 13	26	66	28	71	19	48	10	25	17	43
R + 28	39	95	24	58	11	27	8	19	18	44
					DMP					
F - 30	33	52	35	56	12	19	6	10	14	22
F - 15	26	38	28	41	15	22	10	14	21	31
F - 5	28	48	25	43	17	29	10	17	20	34
R + 0	28	57	25	51	15	30	11	22	21	42
R + 1	24	–	26	–	16	–	11	–	23	–
R + 3	26	–	24	–	19	–	12	–	19	–
R + 4	26	–	25	–	18	–	11	–	20	–
R + 8	25	50	28	55	18	36	10	20	19	38
R + 13	27	52	31	60	16	31	10	19	16	31
R + 28	24	47	31	61	15	29	10	20	20	39

TABLE 14-IV.–*URINE ENDOCRINE RESULTS*

Sample day	24-h volume, ml	Cortisol, μg/TV[a]	[b]Epi, μg/TV	[c]Nor, μg/TV	[d]ALDO, μg/TV	[e]ADH, mU/TV
			ACDR			
F - 30	2560	84.5	5.2	66.1	11.2	22.6
F - 15	1960	66.6	67.4	50.8	11.9	178.2
F - 5	2390	33.5	LTD[f]	104.6	23.6	30.5
PM ± SD	2303 ± 309	61.5 ± 25.9	36.3 ± 44.0	73.8 ± 27.7	15.6 ± 7.0	77.1 ± 87.6
R + 0	2630	84.2	2.8	74.1	32.8	70.0
R + 28	750	24.0	9.7	28.2	5.1	11.5
			CMP			
[g]F - 30	1550	77.5	34.1	93.5	4.9	29.9
F - 15	1040	100.4	21.1	74.2	8.8	93.8
[g]F - 5	1940	27.2	2.9	80.4	11.1	27.1
PM ± SD	1510 ± 451	68.4 ± 37.4	19.4 ± 15.7	82.7 ± 9.9	8.3 ± 3.1	50.3 ± 37.7
R + 0	1495	109.9	21.2	40.3	34.3	58.0
R + 28	1840	50.6	6.0	69.1	6.3	8.4
			DMP			
F - 30	2250	56.3	LTD	108.9	11.4	108.0
F - 15	750	105.0	LTD	118.1	8.2	72.0
[g]F - 5	1350	19.6	LTD	65.7	7.1	147.6
PM ± SD	1450 ± 755	60.3 ± 42.8	–	97.6 ± 28.0	8.9 ± 2.2	109.2 ± 37.8
R + 0	830	81.8	7.8	61.3	32.8	21.5
R + 28	1180	20.7	56.6	19.7	9.3	77.4

[a]TV = total volume.
[b]Epi = epinephrine.
[c]Nor = norepinephrine.
[d]ALDO= aldosterone.
[e]ADH = antidiuretic harmone.
[f]LTD = less than detectable.
[g]Sample unsatisfactory.

TABLE 14-V.–*URINE CHEMISTRY*

Sample day	24-h volume, ml	Sp. gr.	Osmol, mOsmol	Na, meq/TV	K, meq/TV	Cl, meq/TV	Ca, meq/TV	Mg, meq/TV	PO_4, mg/TV	Uric acid, mg/TV	Creat, mg/TV	Hydroxyproline, mg/TV	H^+
						ACDR							
F - 30	2560	1.007	299	147	92	143	6.7	4.4	819	1024	1843	31	12
F - 15	1960	1.008	372	123	101	121	4.7	1.8	666	980	1725	35	9
F - 5	2390	1.009	364	124	93	124	23.2	11.6	860	1004	2056	43	17
PM ± SD	2303 ± 309	1.008 ± 0.001	345 ± 40	131 ± 14	95 ± 5	129 ± 12	11.5 ± 10	5.9 ± 5	782 ± 102	1003 ± 22	1875 ± 168	36 ± 6	13 ± 4
R + 0	2630	1.006	242	76	42	79	11.6	4.0	579	894	1420	39	75
[a]R + 28	750	1.014	546	72	36	62	8.2	5.0	495	420	810	40	192
						CMP							
[a]F - 30	1550	1.023	930	213	128	178	7.4	4.0	2837	1519	3503	68	217
F - 15	1040	1.020	808	157	94	164	7.1	3.8	978	1019	1955	42	154
[a]F - 5	1940	1.009	381	132	83	120	6.0	10.0	660	854	1513	49	35
(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
R + 0	1495	1.018	705	90	70	67	12.4	7.3	1555	1196	2123	71	270
R + 28	1840	1.012	468	167	114	158	13.1	8.1	1030	883	1950	65	40
						DMP							
F - 30	2550	1.011	465	223	121	207	8.6	1.7	1395	1305	2565	51	0
F - 15	750	1.022	901	109	81	141	5.8	2.2	885	900	1680	28	212
[a]F - 5	1350	1.013	559	165	61	146	16.8	5.4	702	729	1485	42	23
PM ± SD	1650 ± 1273	1.017 ± 0.008	683 ± 308	166 ± 28	101 ± 81	174 ± 47	7.2 ± 2	2.0 ± 0.4	1140 ± 361	1493 ± 265	2123 ± 626	40 ± 12	106 ± 150
R + 0	830	1.025	962	70	74	75	11.8	4.6	979	830	1776	48	349
R + 28	1180	1.016	624	84	83	97	15.1	6.1	1109	826	1959	32	229

[a]Sample unsatisfactory.

[b]No mean possible.

TABLE 14-VI.–*BODY COMPARTMENT RESULTS*

Sample day	Plasma		Total body water		Extracellular fluid		Total body exchangeable K	
	Vol., ml	Change, percent	Vol., liters	Change, percent	Vol., liters	Change, percent	Qty., meq	Change, percent
				CMP				
F - 15	4112	-1	52.8	-2	19.7	-3	4396 2753	-5 +5
R + 0 ASAP	3496		51.6		19.2		4181	
				DMP				
F - 15	3972	-7	48.4	-2	19.8	-3	3372	-2
R + 0 ASAP	3708		47.3		19.2		2781	

TABLE 14-VII.–*URINARY, FREE, AND PEPTIDE-BOUND HYDROXYLYSINE*

[μmoles/g creatinine]

Sample day	ACDR			CMP			DMP		
	Total	Free	Peptide-bound	Total	Free	Peptide-bound	Total	Free	Peptide-bound
F - 30	59.88	6.97	21.91	110.71	12.79	51.94	53.20	7.08	14.30
F - 15	65.98	18.31	10.66	69.82	18.39	22.13	43.46	9.52	2.10
F - 5	79.38	9.71	36.56	90.68	9.55	40.09	76.81	19.28	20.97
PM ± SD	68.41 ± 9.98	11.66 ± 5.92	23.04 ± 12.99	90.40 ± 20.45	13.58 ± 4.47	38.05 ± 15.01	57.82± 17.15	11.98 ± 6.46	12.46 ± 9.57
R + 0	[a]97.48	13.89	44.39	[a]172.58	17.99	54.42	[a]100.62	[a]24.99	22.30
R + 28	41.79	10.38	2.92	54.71	13.14	15.16	55.64	14.92	7.17

[a]$p < 0.05$.

TABLE 14-VIII.–*URINARY GLUCOSYL-GALACTOSYL HYDROXYLYSINE AND GALACTOSYL HYDROXYLYSINE*

[μmoles/g creatinine]

Sample day	ACDR			CMP			DMP		
	GLU-GAL	GAL	Ratio	GLU-GAL	GAL	Ratio	GLU-GAL	GAL	Ratio
F - 30	17.72	13.28	1.33	30.03	15.95	1.88	18.46	13.36	1.38
F - 15	22.34	14.67	1.52	19.58	9.72	2.01	21.76	10.08	2.16
F - 5	22.41	10.70	2.09	25.84	15.20	1.70	23.09	13.47	1.70
PM ± SD	20.82 ± 2.69	12.88 ± 2.01	1.65 ± 0.40	25.15 ± 5.26	13.62 ± 3.40	1.86 ± 0.16	21.10 ± 2.39	12.30 ± 1.93	1.75 ± 0.39
R + 0	18.57	[a]20.63	.90	[a]79.96	[a]23.21	3.32	[a]37.52	15.81	2.37
R + 28	16.62	11.87	1.40	16.14	10.27	1.57	21.64	11.91	1.82

[a] $p < 0.01$.

Because of the problems after entry, the complete postflight protocol was not followed; however, several findings do merit discussion in relation to the toxic fumes inhaled by the crewmen after flight.

Because enzymes are responsible for biological regulation, the change of activity should appear early, and should precede many of the structural indications of tissue degradation after toxic inhalation and offer a sensitive method for detection before actual irreversible damage. In an assessment of the effects of the inhaled nitrogen tetroxide (N_2O_4) on the returning Apollo crewmen, the serum enzymes values are very useful. At sublethal concentration, oxidants such as those present in the rocket fuel may alter, impair, or otherwise interfere with normal physiological systems. The physiological and pathological effects of the oxidant gases have been studied, whereas the biochemical effects resulting from short-term and prolonged exposure to these gases have not yet been completely defined. It has been proposed that the gas may act by way of enzyme systems or directly on the structural components of the lung (ref. 14-2). Previous studies of alteration in enzyme activity levels following exposure to irritants have revealed that changes occur early, even before clinical signs of the tissue damage. The results on the ASTP crewmen show elevations in several serum enzymes as soon as blood was drawn after recovery.

At recovery, increases in SGOT, SGPT, Alk Phos, and LDH were seen in most cases. Serum glutamic oxaloacetate transaminase is an enzyme that catalyzes the reversible transfer of the amino group from glutamic to oxaloacetic acid. In man, it is found in cardiac, hepatic, skeletal muscle, renal, and cerebral tissue in decreasing concentrations (ref. 14-3).

Glutamic pyruvic transaminase catalyzes the reversible transfer of an amino group from glutamic to pyruvic acid. It also has been found to be widely distributed in humans. The high hepatic content compared to the relatively low concentration in myocardial and other tissues has led to the application of SGPT determination to the study of hepatic disease (ref. 14-4).

Alkaline phosphatase, the first serum enzyme to be studied in hepatic disease, has been extensively applied to the differential diagnosis of liver involvement (ref. 14-5). Lactic dehydrogenase is the naturally occurring enzyme which readily catalyzes the reversible oxidation of lactic to pyruvic acid (ref. 14-6). The defined distribution in the five LDH isoenzymes suggests organ source of the particular isoenzyme fraction. The component isoenzymes of LDH were examined to ascertain the effect of the N_2O_4 inhalation on the normal isoenzyme distribution. However, it must be made clear that the changes observed in the LDH isoenzyme patterns of the ASTP crewmen do not reflect damage in tissue other than lung. Buckley and Balchum (ref. 14-7) found that LDH enzyme activity was grossly elevated in lung, liver, and kidney tissue homogenates, whereas the isoenzyme pattern was significantly altered only in the lung tissue. Their findings suggest that nitrogen dioxide favors conditions which inhibit aerobic and stimulate anaerobic oxidation in lung tissue (ref. 14-7).

In an attempt to identify components of the inhaled gas which might have affected the crewmen, the postflight blood samples were analyzed for hydrazine (H) and 1-methylhydrazine (MMH). The results of the analyses were negative. The absence of these compounds was also confirmed by the lack of consistent change in serum cholesterol and triglycerides. The next section contains the findings from the H and MMH study.

The 24-hour urine samples obtained after recovery were analyzed to evaluate the possible effects of weightlessness on collagen degradation. The average values obtained from the preflight specimens for glucosyl-galactosyl hydroxylysine, for galactosyl hydroxylysine, and for the GLU-GAL/GAL ratio agree well with those given by Askenasi (ref. 14-8) and by Kakimoto and Akazawa (ref. 14-9) for normal subjects. The values for total hydroxylysine, free hydroxylysine, and peptide-bound hydroxylysine, however, are consistently higher in the ASTP series.

The work of Cunningham et al., (ref. 14-10), Kakimoto and Akazawa (ref. 14-9), Lou and Hamilton (ref. 14-11), and more recently of Askenasi (refs. 14-8 and 14-12) suggests that the urinary excretion of hydroxylysine metabolites may represent an index of collagen breakdown. Little is known of the metabolic significance of the urinary free hydroxylysine apart from the fact that this is usually the least abundant metabolite and its excretion seems to vary in different species (ref. 14-8). The excretion of the hydroxylysine glycosides is fairly constant in normal individuals, and it is considered to be quite independent of dietary variations (ref. 14-12).

An increased excretion of glycosides has been demonstrated in various diseases; it is reported that the excretion of the disaccharides is more abundant in the course of skin diseases, whereas the excretion of the monosaccharides is more abundant in the course of bone diseases (refs. 14-8 and 14-12). The urinary peptide-bound hydroxylysine represents relatively large polypeptides with a composition similar to that of collagen. Because polypeptides are considered to be related to collagen synthesis rather than to collagen degradation, their metabolic significance is not yet clear (ref. 14-13).

The available information does not suggest that an increased urinary excretion of hydroxylysine metabolites might occur as a result of acute lesions of the pulmonary parenchyma. However, such a possibility is not unlikely when one considers that 60 to 80 percent

of the dry weight of normal lungs is represented by collagen (refs. 14-14 and 14-15), which must be spread on an extremely large surface. The knowledge that the three U.S. astronauts inhaled toxic fumes after entry into the Earth's atmosphere and subsequently developed symptoms of chemical pneumonitis suggests that the increased urinary excretion of hydroxylysine metabolites might have been related to the acute destruction and/or increased permeability of lung parenchyma (ref. 14-16). It is unfortunate that additional urine specimens were prohibited, because such specimens could have revealed even more meaningful changes, especially in relation to the clinical and radiological course of the lesions. However, the occurrence of situations in which toxic fumes may be inhaled accidentally should provide abundant material for the assessment of biochemical parameters of potential value for determining the prognosis of acute pulmonary lesions.

ADDITIONAL DATA ON BLOOD HYDRAZINE AND 1-METHYLHYDRAZINE

Blood drawn from the ASTP crewmen approximately 2 hours after recovery and in the morning of the day after recovery was analyzed for H and MMH according to the procedure described by Reynolds and Thomas (ref. 14-17). Table 14-IX contains the results of the study conducted in preparation for analysis of the crew samples. Blood was drawn from six normal controls and analyzed for H and MMH. Recovery studies were conducted by adding 0.1 and 2.5 μg of H and MMH to each control sample. Comparisons were made between 0.5 ml and 1 ml of serum samples and between plasma from blood treated with ethylenediaminetetraacetate (EDTA) as an anticoagulant and serum. The results of the study on normal controls show that neither H nor MMH was detected. The recovery study demonstrated that both H and MMH were detectable in ranges of 0.1 and 2.5 μg. It was also shown that no significant difference was apparent between serum and EDTA plasma samples. Table 14-X contains the results on EDTA plasma for the three ASTP crewmen for recovery day and the morning of the day after recovery. The results show no detectable H or MMH at either time.

Studies conducted by Reynolds and Thomas (ref. 14-17) showed a rapid clearance from the blood by the male Sprague-Dawley rats given large doses of intraperitoneal injections of H and MMH ranging from 0.5 to 60 mg/kg and 1.0 to 15.0 mg/4 g, respectively. The absolute blood concentrations increased with increasing dosage and decreased with time after exposure. Blood levels were detectable when injected doses were 0.6 mg/kg and 3.0 mg/kg for H and MMH, respectively.

TABLE 14-IX.–*DETERMINATION OF HYDRAZINE AND 1-METHYLHYDRAZINE IN BLOOD SERUM*

(a) Initial analyses

Control subject	Sample type	Sample size, ml	Qty found, μg
		H	
1	Serum and plasma	1.0	0.0
2	Serum and plasma	1.0	.0
3	Serum and plasma	1.0	.0
4	Serum and plasma	1.0	.0
5	Serum and plasma	1.0	.0
6	Serum and plasma	1.0	.0
		MMH	
1	Serum and plasma	1.0	0.0
2	Serum and plasma	1.0	.0
3	Serum and plasma	1.0	.0
4	Serum and plasma	1.0	.0
5	Serum and plasma	1.0	.0
6	Serum and plasma	1.0	.0

(b) Recovery studies

Control sample			Quantity added, μg	Quantity recovered, μg
No.	Type	Size, ml		
			H	
1	Serum	1.0	0.1	1.1
2	Serum	1.0	.2	.2
3	Serum	1.0	.3	.4
1	Plasma	1.0	.1	.1
2	Plasma	1.0	.2	.125
3	Plasma	1.0	.3	.25
1	Serum	.5	.4	.4
3	Serum	.5	.5	.5
5	Serum	.5	1.0	1.0
6	Plasma	1.0	2.5	2.7
			MMH	
4	Plasma	1.0	0.1	0.0
5	Plasma	1.0	.2	.2
6	Plasma	1.0	.3	.5
4	Serum	1.0	.1	.0
5	Serum	1.0	.2	.15
6	Serum	1.0	.3	.3
2	Serum	.5	.4	.5
4	Serum	.5	.5	.6
6	Serum	.5	1.0	1.5
6	Serum	1.0	2.5	3.2

TABLE 14-X.–*RESULTS OF EDTA PLASMA ANALYSES*

Subject	Sample day	EDTA sample (plasma), ml	H, μg	MMH, μg
ACDR	R + 0	0.5	0.0	0.0
CMP	R + 0	.5	.0	.0
DMP	R + 0	.5	.0	.0
ACDR	R + 0	.5	.0	.0
CMP	R + 1	.5	.0	.0
DMP	R + 1	.5	.0	.0
Control 1	–	.5	.0	.0
Control 2	–	.5	.0	.0
Control 3	–	.5	.0	.0
Control 4	–	.5	.0	.0
Control 5	–	.5	.0	.0
Control 6	–	.5	.0	.0
[a]Control 3	–	.5	2.7	3.2

[a]Control 3, 2.5 μg H and MMH added. Recovery was the same as that for control 6.

REFERENCES

14-1. Alexander, W. C.; Leach, C. S.; and Fischer, C. L.: Clinical Biochemistry. *Biomedical Results of Apollo.* NASA SP-368, 1975, pp. 185-196.

14-2. Hueter, F. Gordon; and Fritzhand, Martin: Oxidants and Lung Biochemistry. *Arch. Intern. Med.*, vol. 128, 1971, pp. 48-53.

14-3. Karmen, A.; Wróblewski, F.; and LaDue, J. S.: Transaminase Activity in Human Blood. *J. Clin. Invest.*, vol. 34, 1955, p. 126.

14-4. Page, L. B.; and Culver, P. J., eds.: *A Syllabus of Laboratory Examinations in Clinical Diagnosis.* Revised ed., Harvard University Press, 1960, pp. 423-424.

14-5. Gutman, A. B.: Serum Alkaline Phosphatase Activity in Diseases of Skeletal and Hepatobiliary Systems. *American J. Med.*, vol. 27, 1959, p. 875.

14-6. Frankel, S.; Reitman, S.; and Sonnenwirth, A. C., eds.: *Gradwhol's Clinical Laboratory Methods and Diagnosis.* C. V. Mosby Co. (St. Louis), 1970, p. 130.

14-7. Buckley, R. D.; and Balchum, O. J.: Effects of Nitrogen Dioxide on Lactic Dehydrogenase Isoenzymes. *Arch. Environmental Health,* vol. 14, 1967, pp. 424-428.

14-8. Askenasi, R.: Urinary Hydroxylysine and Hydroxylysyl Glycoside Excretions in Normal and Pathological States. *J. Lab. Clin. Med.*, vol. 83, 1974, pp. 673-679.

14-9. Kakimoto, Y.; and Akazawa, S.: Isolation and Identification of N^G; N^G, and N'^G Dimethylarginine; N^G-mono, Di-, and Trimethyllysine; and Glucosylgalactosyl- and Galactosyl-δ-hydroxylysine From Human Urine. *J. Biol. Chem.*, vol. 245, 1970, pp. 5751-5758.

14-10. Cunningham, L. W.; Ford, J. D.; and Segrest, J. P.: The Isolation of Identical Hydroxylysyl Glycosides from Hydrolysates of Soluble Collagen and from Human Urine. *J. Biol. Chem.*, vol. 242, 1971, pp. 2570-2571.

14-11. Lou, M. F.; and Hamilton, P. B.: Hydroxylysine Glycosides in Human Urine. *Clin. Chem.*, 1971, pp. 782-788.

14-12. Askenasi, R.: A New Rapid Method of Measuring Hydroxylysine and Its Glycosides in Hydrolysates and Physiological Fluids. *Biochem. Biophys. Acta,* vol. 304, 1973, pp. 375-383.

14-13. Krane, S. M.; Muñoz, A. J.; and Harris, E. D., Jr.: Urinary Polypeptides Related to Collagen Synthesis. *J. Clin. Invest.*, vol. 49, 1970, pp. 716-729.

14-14. Pierce, J. A.: Biochemistry of Aging in the Lung. *Aging of the Lung.* L. Cander, ed., J. B. Lippincott (Philadelphia), 1964.

14-15. Pierce, J. A.; and Ebert, R. V.: Fibrous Network of the Lung and Its Change With Age. *Thorax,* vol. 20, 1965, pp. 469-476.

14-16. Segrest, J. P.; and Cunningham, L. W.: Variations in Human Urinary O-Hydroxylysyl Glycoside Levels and Their Relationship to Collagen Metabolism. *J. Clin. Invest.*, vol. 49, 1970, pp. 1497-1509.

14-17. Reynolds, Barbara A.; and Thomas, Anthony A., M.D.: Determination of Hydrazine and 1-Methylhydrazine In Blood Serum. AMRL-TDR-64-24, April 1964.

15. HEMATOLOGICAL AND IMMUNOLOGICAL STUDIES

Stephen L. Kimzey[a] and Phillip C. Johnson[b]

The primary purpose of the hematological and immunological studies was to provide hematologic and immunologic data to the Apollo-Soyuz Test Project (ASTP) crew surgeon necessary for the objective assessment of the crew's health status before launch and during the period immediately after flight. A secondary objective was to evaluate the influence of space flight on the circulating blood volume. Supporting data and sample logistics were also provided for ASTP Experiment MA-031, Cellular Immune Response (ref. 15-1), and Experiment MA-032, The Effects of Space Flight on Polymorphonuclear Leukocyte Response (ref. 15-2).

BLOOD SAMPLE COLLECTION

Blood samples were collected by venipuncture from the prime U.S. crewmen three times during the preflight period (approximately 30, 15, and 5 days before lift-off (days F - 30, F - 15, and F - 5, respectively) and during the 4 weeks following recovery (days R + 0 to R + 29). In addition, identical samples were collected from the backup crewmen during the preflight phase and from three ground-based control subjects during the mission. Radioisotope studies (for the determination of red cell mass and plasma volume) were conducted on days F - 15, R + 0, and R + 29. The Apollo commander (ACDR) did not participate in these studies. The blood volumes and distributions are detailed in Table 15-I.

ROUTINE HEMATOLOGY

The routine hematology data, including preflight mean (PM) and standard deviation (SD), are summarized in Tables 15-II(a) and 15-II(b). Varying degrees of hemodilution were evident in all three crewmen after the flight (Figures 15-1 to 15-3). These changes in red blood cell (RBC) count, hemoglobin concentration (Hb), and hematocrit (HCT) are similar to those observed following previous manned space flights and reflect the changes in plasma volume and red cell mass. The decline in plasma volume and red cell mass of comparable magnitudes in the command module pilot (CMP) and the docking module pilot (DMP) are responsible for the lack of a significant change at R + 0 (except in the ACDR). (These values are depicted in the subsection entitled "Radioactive Hematological Studies.") The recovery of plasma volume at a rate faster than that for the red cell mass results in an apparent hemodilution during the first few days following recovery.

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TABLE 15-I.–*BLOOD SAMPLE SCHEDULE*

Sample day	Sample volume, ml	Comment
F - 30	90	–
F - 15	90	Radioisotope studies
F - 14	15	Type and cross-match
F - 5	70	–
R + 0	90	Radioisotope studies
R + 1	45	–
R + 1	42	Drawn at Tripler[a]
R + 2	32	Drawn at Tripler
R + 4	32	Drawn at Tripler
R + 8	40	Drawn at Tripler
R + 13	35	Drawn at Tripler
R + 29	35	Radioisotope studies

[a]Tripler Army Medical Center, Honolulu, Hawaii.

An elevation in methemoglobin occurred at R + 0 (mean = 4.2 percent) compared to preflight values (mean = 1.3 ± 0.4 percent). By day R + 1, the methemoglobin levels had dropped to a mean value of 2.0 percent. This transient rise in the methemoglobin levels was most likely caused by exposure of the crew to nitrogen tetroxide (N_2O_4) vapors during entry.

A significant elevation in the white blood cell (WBC) count after flight was due to an increase in the absolute neutrophil number (Table 15-II(b), Figures 15-4 and 15-5). Although there was a decrease in the percentage of lymphocytes, the absolute lymphocyte count did not change after flight (Figure 15-6). A similar neutrophil elevation was observed following the Skylab flights but was typically back within preflight limits by day R + 1. In contrast, the elevated neutrophil levels persisted in the ASTP crewmen and even showed a further increase in two of the men. This continued elevation was possibly related to the resultant pulmonary damage and subsequent steroid therapy during the postflight period.

The reticulocyte counts were unchanged immediately after flight. There are no data on reticulocyte counts during the subsequent 2-week period, when the red cell mass was being replaced. However, based on previous data, only a modest response would be expected. Classification of reticulocytes, based on density of the residual intracellular ribosomal network, indicated no significant shift in the age distribution of the reticulocytes on day R + 0 or day R + 1 (Table 15-III).

IMMUNOLOGY STUDIES

Total serum protein levels showed some postflight variation which was probably due to the changing plasma volume during this time. Serum protein electrophoretic patterns were normal, with the exception of a low value to albumin on day R + 28 in the DMP (Table 15-IV).

TABLE 15-II.–*HEMATOLOGY DATA ON ASTP CREWMEN*

(a) Red cell

Sample day	RBC, $x10^{12}$/liter	[a]RETIC, percent	Hb, g/dl	HCT, percent	[b]METHB, percent	MCV, fl[c]	MCH, pg	MCHC, g/dl	Platelet count, mm^3
				ACDR					
F - 30	4.97	0.9	15.1	44	1.5	89	30	34	337 000
F - 15	4.97	1.0	15.5	44	1.2	88	31	35	363 000
F - 5	4.96	.6	15.0	43	1.0	89	30	35	308 000
PM[d]	4.97	.83	15.2	43.7	1.23	88.7	30.3	34.3	336 000
SD[e]	.01	.21	.26	.6	.25	.58	.6	.6	27 500
R + 0	4.50	.7	13.7	39.5	2.8	88	30	35	304 000
R + 1	4.77	.5	14.2	42	2.7	88	30	34	ND[f]
R + 8	4.36	ND	12.9	37.8	ND	87	29.7	34.2	294 000
R + 13	4.45	ND	13.3	38.7	ND	87	30	34.3	165 000
R + 29	4.67	1.0	14	43	1.1	92	30	33	252 000
				CMP					
F - 30	4.72	1.2	14.7	42.5	2.1	90	31	35	353 000
F - 15	4.69	1.3	14.6	43.0	.8	92	31	34	371 000
F - 5	5.07	.9	15.7	45.0	1.3	89	31	35	353 000
PM	4.83	1.13	15.0	43.5	1.4	90.3	31	34.6	352 333
SD	.21	.2	.6	1.3	.7	1.5	0	.5	19 008
R + 0	4.88	.8	15.3	44.5	5.1	91	31	34	364 000
R + 1	4.86	1.0	15	44.0	2.1	91	31	34	ND
R + 8	4.42	ND	13.3	38.5	ND	87	30	34.3	282 000
R + 13	4.32	ND	13.3	37.9	ND	88	30.8	34.9	269 000
R + 29	4.81	.8	14.5	44	1.6	91	30	33	282 000
				DMP					
F - 30	4.53	0.9	13.8	40.5	1.1	89	30	34	267 000
F - 15	4.32	1.0	13.1	39.0	1.5	90	30	34	290 000
F - 5	4.32	.9	13.8	41.0	.9	95	32	34	263 000
PM	4.39	.93	13.6	40.2	1.2	91.3	30.7	33.7	273 000
SD	.12	.06	.4	1.0	.3	3.2	1.1	.58	14 572
R + 0	4.46	.7	13.5	40.0	4.6	90	30	34	2 380 000
R + 1	4.84	ND	14.4	43.0	1.1	89	30	33	ND
R + 2	4.35	.5	13.0	39.0	ND	89	29.9	33.4	ND
R + 8	4.19	ND	12.6	36.4	ND	87	30.1	34.4	192 000
R + 13	4.14	ND	12.4	35.9	ND	87	30	34.5	194 000
R + 29	4.22	1.1	13.2	37.0	.6	88	31	35	242 000

[a]RETIC = reticulocyte.

[b]METHB = methemoglobin.

[c]fl = femtoliter (10^{-16}/l).

[d]PM = preflight mean.

[e]SD = standard deviation.

[f]ND = not determined.

TABLE 15-II.—*CONCLUDED*

(b) White cell

Sample day	[g]WBC, mm^3	[h]NEUT, percent	NEUT, mm^3	[i]LYMPH, percent	LYMPH, no., mm^3	[j]MONO, percent	[k]EOS, percent	[l]BASO, percent	BANDS, percent
				ACDR					
F - 30	6 700	56	3752	42	2814	2	0	0	0
F - 15	7 200	60	4320	37	2264	1	2	0	0
F - 5	6 400	61	3904	37	1388	1	1	0	0
PM	6 766	59	2992	28.7	2282	ND	ND	ND	ND
SD	404	2.7	294	2.9	779	ND	ND	ND	ND
R + 0	6 900	63	4347	36	2484	1	0	0	0
R + 1	11 700	77	9009	21	2457	2	0	0	0
R + 8	7 200	59	4258	39	2808	7	4	0	1
R + 13	6 400	61	3904	32	2048	5	0	0	3
R + 29	6 000	56	3360	41	2460	0	3	0	0
				CMP					
F - 30	5 400	49	2 646	45	2340	0	6	0	0
F - 15	4 500	43	1 935	54	2430	2	1	0	0
F - 5	6 200	59	3 658	34	1388	6	1	0	0
PM	5 366	50.3	2 746	44.3	2083	ND	ND	ND	ND
SD	850	8.1	866	10.0	602	ND	ND	ND	ND
R + 0	12 500	88	11 000	11	1375	1	0	0	0
R + 1	10 900	73	7 957	25	2725	2	0	0	0
R + 8	10 000	44	4 400	40	4000	7	9	0	0
R + 13	7 800	66	5 148	32	2496	0	2	0	0
R + 29	4 200	58	2 436	35	1470	1	6	0	0
				DMP					
F - 30	4 700	37	1739	61	2867	0	2	0	0
F - 15	3 700	32	1184	64	2368	0	4	0	0
F - 5	5 200	37	1424	57	2059	2	2	0	2
PM	4 533	35.3	1449	60.7	2431	ND	ND	ND	ND
SD	764	2.9	278	3.5	408	ND	ND	ND	ND
R + 0	8 100	73	5913	25	2025	2	0	0	0
R + 1	11 000	75	8250	23	2530	1	1	0	0
R + 2	7 700	56	4312	35	2695	8	1	0	0
R + 8	8 300	48	3984	42	3486	3	4	1	2
R + 13	3 900	43	1677	47	1833	2	8	0	0
R + 28	3 700	38	1406	54	1998	2	6	0	0

[g]WBC = white blood cell.

[h]NEUT = neutrophil.

[i]LYMPH = lymphocyte.

[j]MONO = monocyte.

[k]EOS = eosinophil.

[l]BASO = basophil.

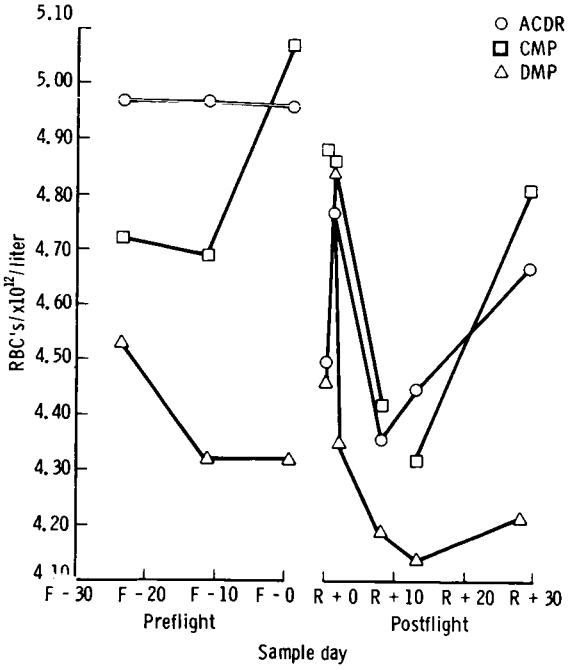

Figure 15-1. Red Blood Cell Count, ASTP U.S. Crewmen

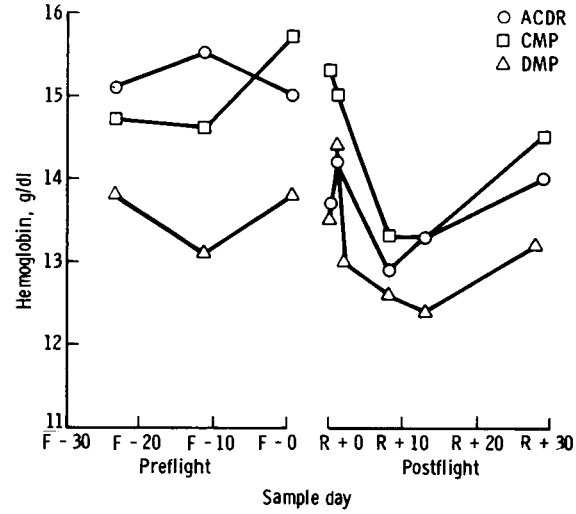

Figure 15-2. Hemoglobin, ASTP U.S. Crewmen

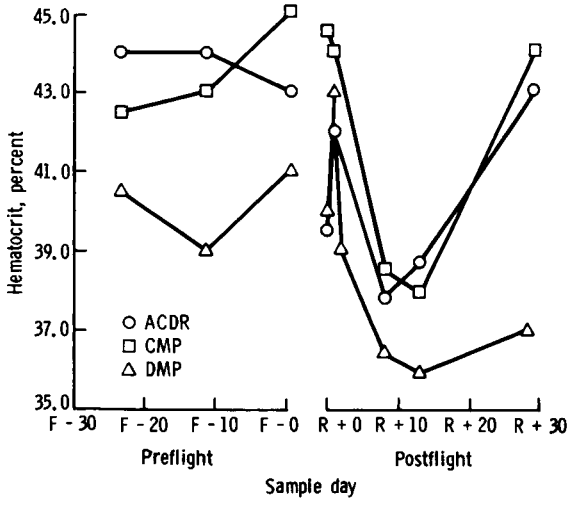

Figure 15-3. Hematocrit, ASTP U.S. Crewmen

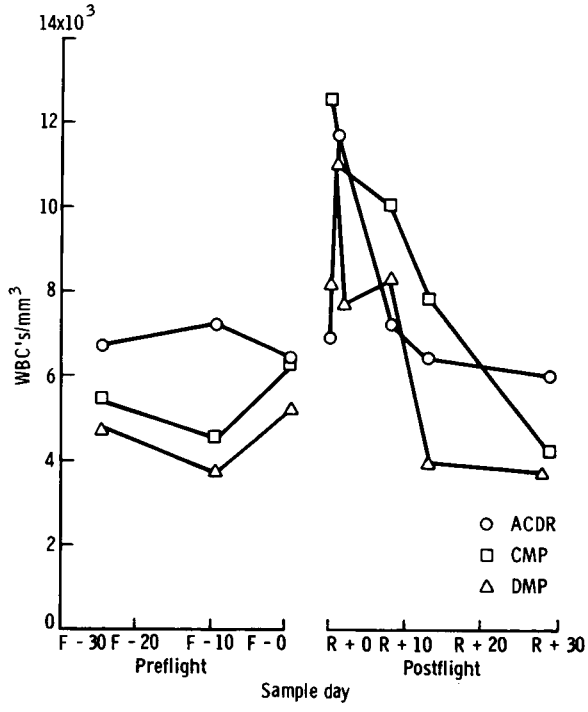

Figure 15-4. White Blood Cell Count, ASTP U.S. Crewmen

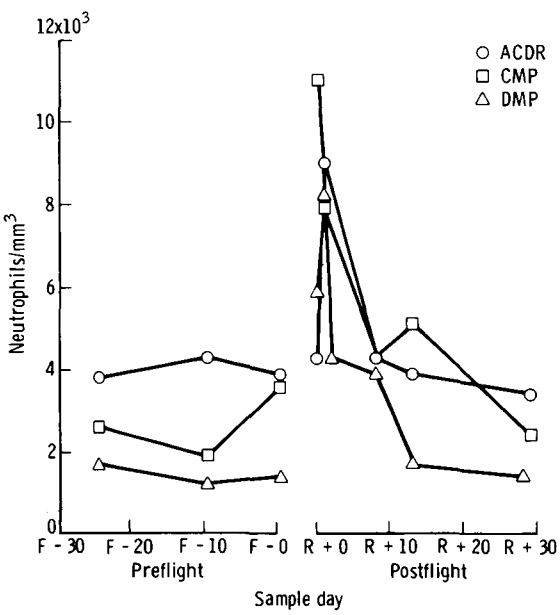

Figure 15-5. Neutrophil Count, ASTP U.S. Crewmen

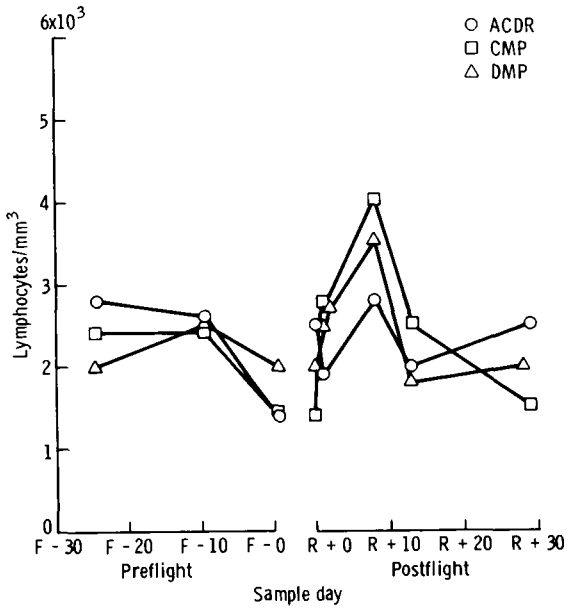

Figure 15-6. Lymphocyte Count, ASTP U.S. Crewmen

Although there was a 48-percent elevation in lactic dehydrogenase (LDH) levels on R + 0 (R + 0 mean = 241 mg percent; preflight mean = 162 mg percent), the distribution of the LDH isoenzymes did not change drastically, but there were slight elevations in the fifth band (Table 15-V). The diagnostic significance of this small elevation in the fifth band is undetermined at this time. Lipoprotein fractions were normal (Table 15-V).

The most significant alteration in serum protein quantitation (Table 15-VI) was a postflight elevation in the haptoglobin concentration on all three crewmen (Figure 15-7). This change was observed frequently in crewmen returning from the Apollo space flights. It may reflect an acute phase protein response, perhaps caused by tissue destruction. Because of the toxic exposure of the ASTP crew during recovery and the subsequent lung tissue damage, it is impossible to identify the specific effects of space flight on the haptoglobin levels in the crew. The fact that the maximum values are observed 3 to 4 days after recovery is also suggestive of a response to the toxic gas rather than to weightlessness.

No changes in immunoglobulins (IgG, IgA, IgM, IgD) were observed in any of the crewmen (Table 15-VII), with the exception of a reduction in the IgG levels in the ACDR. The postflight (days R + 0 and R + 1) concentration of 909 mg/100 ml of serum is still within the normal range but is 34 percent below his preflight mean.

The C-reactive protein was negative at R + 0 but strongly positive on day R + 1. This change probably reflects the tissue destruction observed in the crew on day R + 1.

TABLE 15-III.–*RETICULOCYTE CLASSIFICATION*

Crewman	Sample day	Reticulocyte count, percent		
		Class I	Class II	Class III
ACDR	F - 30	1.9	41.6	64.6
	F - 15	2.0	44.0	54.0
	F - 5	1.6	46.2	52.2
CMP	F - 30	1.8	34.6	63.6
	F - 15	1.4	38.8	59.8
	F - 5	3.6	43.2	53.2
DMP	F - 20	1.0	37.0	62.0
	F - 15	1.5	29.3	69.2
	F - 5	4.8	48.6	46.6
	PM	2.1	40.3	58.3
	SD	1.2	6.0	7.2
ACDR	R + 0	3.4	33.6	63.0
	R + 1	3.7	35.9	60.2
CMP	R + 0	2.8	33.8	63.3
	R + 1	1.9	50.9	47.0
DMP	R + 0	1.5	27.7	70.7
	R + 1	1.0	28.8	70.2
	R + 0 mean	2.5	31.7	65.6
	SD	0.9	3.4	4.3
	R + 1 mean	2.2	38.5	59.1
	SD	1.3	11.2	11.6

TABLE 15-IV.–*SERUM PROTEIN ELECTROPHORESIS*

[Grams per 100 ml]

Sample day	Total protein	Albumin	Globulins			
			A1	A2	B	G
		ACDR				
HM[a]	7.3	4.7	0.2	0.5	0.8	1.0
SD	.4	.4	.1	.1	.1	.2
F - 30	7.5	4.4	.3	.7	.9	1.2
F - 15	7.4	4.2	.3	.7	.9	1.3
F - 5	7.2	4.2	.2	.6	.8	1.4
PM	7.4	4.3	.3	.7	.9	1.3
SD	.2	.1	.05	.06	.1	.1
R + 0	6.7	4.1	.3	.5	.7	1.1
R + 1	6.7	4.1	.2	.5	.8	1.1
R + 4	6.9	3.8	.3	.8	.8	1.2
R + 8	7.1	4.1	.3	.7	.8	1.2
R + 13	6.9	4.0	.3	.6	.8	1.2
R + 29	7.3	5.0	.2	.4	.8	.9
		CMP				
HM	7.4	4.6	0.2	0.6	0.8	1.3
SD	.3	.4	.1	.2	.2	.1
F - 30	7.2	4.3	.2	.6	.8	1.3
F - 15	6.6	3.8	.2	.6	.9	1.1
F - 5	6.8	4.0	.2	.6	.8	1.2
PM	6.9	4.0	.2	.6	.8	1.2
SD	.2	.3	.0	.0	.1	.1
R + 0	7.2	4.1	.2	.7	.8	1.4
R + 1	6.7	3.8	.2	.7	.8	1.3
R + 2	6.5	3.6	.2	.7	.7	1.3
R + 3	7.0	4.0	.3	.7	.7	1.3
R + 8	6.5	3.6	.2	.7	.7	1.3
R + 13	6.4	3.5	.2	.7	.7	1.3
R + 29	7.1	4.7	.2	.5	.8	.9
		DMP				
HM	6.9	4.6	0.2	0.5	0.8	0.9
SD	.4	.2	.0	.1	.1	.1
F - 30	6.8	4.3	.2	.5	.9	.9
F - 15	6.3	3.5	.3	.6	.8	1.1
F - 5	6.6	4.1	.2	.5	.8	1.1
PM	6.5	4.0	.2	.5	.8	1.0
SD	.2	.4	.1	.1	.1	.1
R + 0	7.0	4.3	.2	.6	.9	1.0
R + 1	6.8	4.2	.2	.6	.8	1.0
R + 3	6.8	3.7	.4	.8	.6	1.3
R + 4	6.7	3.6	.4	.9	.6	1.2
R + 8	6.8	3.9	.2	.7	.9	1.1
R + 13	6.5	3.6	.3	.7	.8	1.2
R + 28	6.4	[b]2.7	.4	.7	1.0	1.6

[a]HM = history mean (Definition – pooled value from previous annual physical examinations).

[b]Outside normal range.

TABLE 15-V.—*LACTIC DEHYDROGENASE ISOENZYMES AND LIPOPROTEINS*

[Percent]

Sample day	LDH bands					Lipoproteins		
	1	2	3	4	5	A	PREB[a]	B
				ACDR				
HM	28	28	19	9	16	22	20	57
SD	5	5	3	3	3	7	8	11
F - 30	27	30	15	9	19	26	22	52
F - 15	28	28	16	9	19	29	23	48
F - 5	30	30	15	6	19	37	22	41
PM	28	29	15	8	19	31	22	47
SD	2	1	1	2	0	6	1	6
R + 0	23	26	16	12	23	31	17	52
R + 1	21	35	16	8	16	35	17	48
R + 4	22	31	18	10	19	21	22	57
R + 8	22	27	18	13	20	40	16	44
R + 13	24	26	19	13	18	35	20	45
R + 29	42	29	21	4	4	18	14	68
				CMP				
HM	33	31	17	8	12	27	19	51
SD	3	5	3	4	4	9	9	9
F - 30	31	33	12	9	15	25	20	55
F - 15	29	30	14	9	18	37	13	56
F - 5	26	26	15	12	21	30	21	49
PM	29	30	14	10	18	31	18	53
SD	3	4	2	2	3	6	4	4
R + 0	24	26	16	11	23	34	16	50
R + 1	29	27	17	10	17	26	20	54
R + 3	24	26	19	10	21	36	26	38
R + 4	25	27	18	11	19	31	25	43
R + 8	26	29	19	10	16	35	25	40
R + 13	26	28	19	10	17	35	25	40
R + 29	39	24	11	8	18	13	8	79
				DMP				
HM	24	33	17	11	12	45	3	51
SD	8	6	6	4	5	5	4	8
F - 30	33	35	12	6	14	36	12	52
F - 15	26	28	15	10	21	36	13	51
F - 5	28	25	17	10	20	37	20	43
PM	29	29	15	9	18	36	15	49
SD	4	5	3	2	4	1	5	5
R + 0	28	25	15	11	21	33	23	44
R + 1	24	26	16	11	23	30	24	46
R + 2	26	24	19	12	19	27	17	56
R + 4	26	25	18	11	20	35	19	46
R + 8	25	28	18	10	19	34	26	40
R + 13	27	31	16	10	16	34	22	44
R + 28	24	31	15	10	20	26	11	63

[a]PREB = prebeta.

TABLE 15-VI.–*SERUM PROTEINS*

[milligrams per 100 ml]

Sample day	TRANS[a]	HAPTO[b]	CERULO[c]	A2 MACRO[d]	A1 GLYCO[e]	A1 ANTI[f]	C3[g]
			ACDR				
HM	215	84	33	183	75	294	98
SD	17	15	7	57	16	67	16
F - 30	296	143	33	93	67	187	109
F - 15	258	152	28	115	64	234	112
F - 5	250	155	32	118	66	236	98
PM	268	150	31	109	66	219	106
SD	24	6	2	14	2	28	8
R + 0	258	135	33	106	48	190	104
R + 1	220	131	29	114	51	177	118
R + 4	296	248	37	100	85	261	121
R + 8	258	212	38	101	92	177	117
R + 13	288	146	35	101	111	226	112
R + 29	301	98	30	111	80	161	112
			CMP				
HM	190	94	29	225	61	234	93
SD	22	30	4	40	13	54	32
F - 30	296	153	30	134	48	191	98
F - 15	312	132	29	118	48	234	98
F - 5	290	144	27	121	52	206	108
PM	299	143	28	124	49	156	101
SD	11	10	2	9	3	70	6
R + 0	190	192	32	133	67	166	112
R + 1	190	216	27	116	56	177	116
R + 3	251	306	40	132	83	227	114
R + 4	258	322	40	127	83	227	109
R + 8	210	244	28	130	95	185	108
R + 15	220	199	31	139	92	186	112
R + 29	204	136	24	194	91	165	116
			DMP				
HM	253	184	28	141	58	228	95
SD	47	66	5	23	24	42	38
F - 30	323	135	33	97	48	214	88
F - 15	258	142	27	125	50	193	91
F - 5	264	148	28	121	66	191	90
PM	281	141	29	114	54	199	90
SD	36	7	3	15	10	13	2
R + 0	243	220	27	125	48	198	108
R + 1	220	261	27	128	42	185	114
R + 3	281	408	39	107	88	251	108
R + 4	273	399	40	107	85	247	108
R + 8	197	326	33	113	101	239	98
R + 13	220	322	40	113	96	193	106
R + 28	334	199	27	146	95	199	117

[a]TRANS = transaminase.
[b]HAPTO = haptoglobin.
[c]CERULO = ceruloplasmin.
[d]A2 MACRO = A2 macroglobulin.
[e]A1 GLYCO = A1 glycoprotein.
[f]A1 ANTI = A1 antitrypsin.
[g]C3 = complement factor 3.

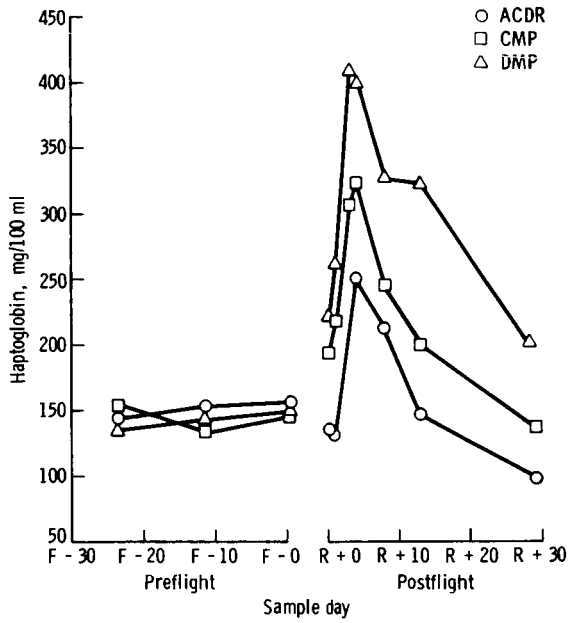

Figure 15-7. Haptoglobin, ASTP U.S. Crewmen

TABLE 15-VII.–*IMMUNOGLOBULINS*

[Milligrams per 100 ml]

Sample day	IgG	IgA	IgM	IgD
		ACDR		
HM	1269	163	87	8
SD	222	28	23	3
F - 30	1419	146	97	9
F - 15	1419	156	99	8
F - 5	1309	166	101	8
PM	1382	156	99	8
SD	64	10	2	.5
R + 0	909	159	92	9
R + 1	909	166	90	8
R + 4	1186	182	112	6
R + 8	931	162	113	6
R + 13	1086	174	113	5
R + 29	1064	136	68	9

TABLE 15-VII.–*CONCLUDED*

Sample day	IgG	IgA	IgM	IgD
		CMP		
HM	1297	165	161	5
SD	258	20	40	1
F - 30	1064	222	121	6
F - 15	1197	166	96	5
F - 5	998	174	121	5
PM	1086	187	113	5
SD	101	30	14	.5
R + 0	1065	156	90	5
R + 1	1087	166	104	5
R + 3	1352	185	117	4
R + 4	1364	185	121	4
R + 8	1375	157	101	5
R + 13	1330	157	106	5
R + 29	1153	156	106	4
		DMP		
HM	947	229	137	6
SD	157	43	37	3
F - 30	798	205	97	5
F - 15	886	172	109	5
F - 5	887	189	116	5
PM	857	188	107	5
SD	51	17	10	0
R + 0	954	232	97	6
R + 1	932	236	99	5
R + 3	1230	270	102	5
R + 4	1230	265	97	5
R + 8	931	229	96	6
R + 13	998	232	96	6
R + 28	842	229	121	ND[a]

[a]ND = not determined.

SPECIAL HEMATOLOGY

A significant shift occurred in the red cell shape classification after flight (Tables 15-VIII(a) and 15-VIII(b)). The percentage of discocytes (normal, biconcave red cells) dropped by 28 percent from a preflight mean of 79.8 to an R + 0 mean of 57.4. There were significantly more stomatocytes, spherocytes, and knizocytes after flight. There was also evidence of cell fragmentation and increased echinocytes (crenated cells). The percentage of discocytes in the postflight samples remained below the preflight mean throughout the postflight examination period. The implications of these data are not clear at this time, but it would appear that the red cell shape classification was perturbed by the exposure to space flight and/or N_2O_4 (Figure 15-8).

TABLE 15-VIII.–*RED CELL SHAPE CLASSIFICATION*

[Percent]

(a) Preflight and postflight to day R + 1

Crewman	Sample day	Discocyte	Stomatocyte	Spherocyte	Echinocyte	Knizocyte	Other
			Preflight				
ACDR	F - 30	68.6	2.2	9.0	3.6	8.8	7.8
	F - 15	76.8	2.0	9.8	2.4	5.2	3.8
	F - 5	86.8	1.2	5.0	4.4	1.6	1.0
CMP	F - 30	77.4	2.0	5.0	2.8	6.2	6.6
	F - 15	78.6	4.2	6.2	2.2	5.2	3.6
	F - 5	83.2	1.8	6.4	4.2	2.6	1.8
DMP	F - 30	76.6	3.2	7.4	4.6	3.8	4.4
	F - 15	85.4	2.6	7.0	.6	1.4	3.0
	F - 5	85.0	1.8	3.2	3.8	1.2	5.0
	PM	79.8	2.3	6.6	3.2	4.0	4.1
	SD	5.8	.9	2.1	1.3	2.6	2.2
			Postflight				
ACDR	R + 0	51.2	14.8	10.0	9.0	11.7	3.3
	R + 1	56.0	11.4	19.0	2.0	10.8	0.8
CMP	R + 0	61.2	8.2	10.4	3.6	12.0	4.6
	R + 1	65.8	2.8	5.4	10.8	7.4	4.2
DMP	R + 0	59.8	13.6	15.6	2.4	5.4	3.2
	R + 1	60.2	4.8	4.2	7.4	9.8	13.6
	R + 0 mean	57.4	12.2	11.9	5.0	9.6	3.7
	R + 1 mean	60.7	6.3	9.5	6.7	9.3	6.2

TABLE 15-VIII.–*CONCLUDED*

(b) Postflight to day R + 29

Crewman	Sample day	Discocyte	Stomatocyte	Spherocyte	Echinocyte	Knizocyte	Other
ACDR	R + 0	51.2	14.8	10.0	9.0	11.7	3.3
	R + 1	56.0	11.4	19.0	2.0	10.8	0.8
	R + 2	65.4	2.6	13.2	5.6	6.4	6.8
	R + 8	57.2	8.6	16.4	6.2	3.4	8.2
	R + 13	75.4	3.8	21.2	13.0	2.0	5.0
	R + 29	75.4	1.0	16.2	3.2	1.8	2.4
CMP	R + 0	61.2	8.2	10.4	3.6	12.0	4.6
	R + 1	65.8	2.8	5.4	10.8	7.4	4.2
	R + 2	67.4	8.6	9.0	8.4	3.8	2.8
	R + 8	71.6	4.6	12.0	7.4	1.0	3.4
	R + 13	65.6	4.6	8.0	13.4	3.6	4.8.
	R + 29	62.4	1.0	14.8	4.8	10.0	7.0
DMP	R + 0	59.8	13.6	15.6	2.4	5.4	3.2
	R + 1	60.2	4.8	4.2	7.4	9.8	13.6
	R + 2	70.4	3.0	11.6	7.4	3.0	4.6
	R + 8	56.6	6.8	12.4	4.6	4.6	15.0
	R + 13	65.6	5.0	11.6	9.6	3.0	5.2
	R + 29	61.6	.4	11.4	9.2	5.4	12.0
	Mean	62.6	5.9	12.3	7.1	5.8	5.9
	SD	6.3	4.2	4.4	3.4	3.6	3.9

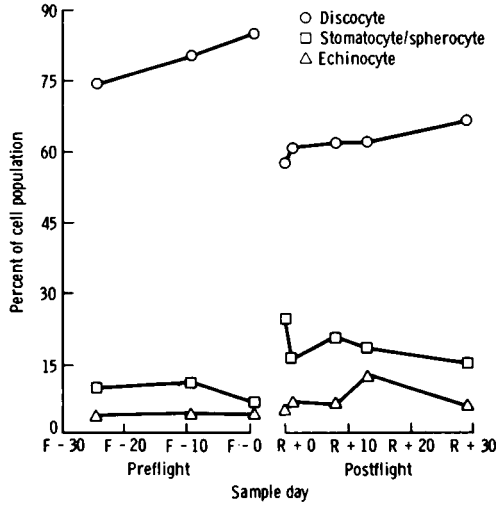

Figure 15-8. Red Cell Shape Classification, ASTP U.S. Crewmen

SUMMARY

Most of the changes observed in the hematologic and immunologic functions of the ASTP crewmen as a result of their exposure to space flight were subtle and/or transient. The changes in RBC, Hb, and HCT were the result of shifts in plasma volume during the flight and immediately after flight. The exposure of the crew to a toxic gas during entry complicates the interpretation of those changes observed. This exposure may have particular significance with respect to the altered red cell shape profile after flight and its slow rate of recovery.

RADIOACTIVE HEMATOLOGICAL STUDIES

Red cell mass decreases were found in the two crewmembers tested at recovery. The mean decrease of 8 percent was less than the -10.1 ± 1.3-percent mean of the crewmen who took part in the Apollo lunar landing missions. The change noted in the CMP was two and one-half times that of the DMP. On day R + 28, the loss in red cell mass of the CMP had been made up with both crewmembers showing a 3-percent decrease over the premission value. A decreased chromium-51 (^{51}Cr) red cell survival was found in the DMP's results but not in the CMP's results. The 11-percent mean decrease in plasma volume was larger than the 4.4 ± 1.7-percent mean decrease of the Apollo 14 to 17 crewmen. It is possible that the exposure to the chemical irritant may partly account for the greater decrease in plasma volume after this mission than after Apollo missions. The plasma volume of both crewmembers had essentially returned to the preflight value by day R + 28. The increased plasma volume loss of these two crewmembers produced higher peripheral HCT's obtained as soon as possible (ASAP) after recovery (41) than were obtained before flight (44). This deviation is different from Apollo missions, for which mean HCT did not change (0.1 ± 0.9 percent) between preflight and ASAP values. The decreased plasma volume caused an increase in the total body hematocrit for one crewmember and no change for the other crewmember. A 3.0 ± 1.3-percent decrease in total body hematocrit was seen in Apollo ASAP measurements. Total body HCT values did vary on the three occasions it was measured.

Radioactive iron was injected for determination of iron turnover at recovery. Because of crew medical problems, the 2-hour samples were not drawn; therefore, the value cannot be calculated.

During ASTP, measurements of spleen-liver ratios were performed. The ratio did not rise in the crewmembers, but it did in the controls. This result is evidence against splenic trapping having been the cause of the decreased red cell mass of the crewmembers. The radioactive hematological data are summarized in Tables 15-IX(a) and 15-IX(b).

TABLE 15-IX.–*RADIOACTIVE HEMATOLOGICAL RESULTS*

(a) Baseline data

Sample day	Crewman		Control subject		
	DMP	CMP	1	2	3
			Total red cell mass, ml		
F - 15	2109	2560	1990	2158	2320
ASAP	2017	2300	2036	2143	2358
R + 28	2037	2480	–	–	–
			Total plasma volume, ml		
F - 15	3972	4112	3442	3294	3364
ASAP	3708	3496	3467	3541	3659
R + 28	3948	3874	–	–	–
			Red cell mass, ml/kg		
F - 15	27.8	31.7	29.2	29.1	32.7
ASAP	27.7	29.6	29.7	28.8	33.0
			Plasma volume, ml/kg		
F - 15	52.3	50.9	50.5	44.5	47.4
ASAP	50.9	45.0	50.5	47.6	51.2
			Peripheral hematocrit		
F - 15	39	43	41	44	44
ASAP	41	46	41	43	44
R + 28	39	44	–	–	–
			Total body hematocrit[a]		
F - 15	35	38	37	40	41
ASAP	35	40	37	38	39
R + 28	34	39	–	–	–
			Total body hematocrit to peripheral hematocrit ratio		
F - 15	0.90	0.88	0.90	0.91	9.93
ASAP	.85	.87	.90	.88	.89
R + 28	.87	.89	–	–	–

[a]Calculated from RBC mass and plasma volume determinations.

TABLE 15-IX.–*CONCLUDED*

(a) Baseline data (continued)

Sample day	Crewman		Control subject		
	DMP	CMP	1	2	3
		^{51}Cr red cell survival, days			
Preflight	28	24	29	25	24
In-flight	21	23	28	24	26
		Spleen to liver ratio			
Preflight	0.89	0.93	1.03	1.35	–
Postflight	.86	.91	1.68	1.99	–

(b) Percent of preflight value

Sample day	Crewman		Control subject		
	DMP	CMP	1	2	3
		Total red cell mass			
ASAP	96	90	102	99	102
R + 28	97	97	–	–	–
		Red cell mass, ml/kg			
ASAP	100	93	102	99	101
		Total plasma volume			
ASAP	93	85	101	107	109
R + 28	99	97	–	–	–
		Plasma volume, ml/kg			
ASAP	97	88	100	107	108

REFERENCES

15-1. Criswell, B. S.: Cellular Immune Response – Experiment MA-031. *Apollo-Soyuz Test Project Preliminary Science Report.* NASA TM X-58173, 1976, pp. 17-1 to 17-7.

15-2. Martin, R. R.: The Effects of Space Flight on Polymorphonuclear Leukocyte Response – Experiment MA-032. *Apollo-Soyuz Test Project Preliminary Science Report.* NASA TM X-58173, 1976, pp. 18-1 to 18-29.

16. CREW HEIGHT MEASUREMENT

Jeri W. Brown[a]

Gross effects of zero g on man's anthropometry were observed during and after extended orbital flight periods of the Skylab Program. In the weightless state, the crewmen "grew taller" and the one-g erect body posture was altered at several skeletal joints, namely, the neck, shoulder, elbow, hip, knee, and ankle.

Quantification of these effects is important for optimizing the physical interfaces between the crewman and his work station equipment and flight clothing, particularly the space suit. The Apollo-Soyuz Test Project (ASTP) mission provided this opportunity to quantify the effects of zero g on crewman height and to determine the change as a function of time over a mission length comparable to the projected initial Space Shuttle flights.

MEASUREMENT DATA

Approved data requirements for human engineering preflight, in-flight, and postflight measurements consisted of maximum stature, sitting height, and eye-level height. The preflight data on the ASTP crewmen were obtained during the routine physical examinations conducted 45, 30, and 15 days before lift-off (F - 45, F - 30, and F - 15, respectively). In-flight data measurements were completed during three mission phases:

1. After launch, in the command module (CM) before docking module (DM) transfer – Sitting height and eye-level height were measured as soon as possible after weightlessness was attained.
2. After DM entry and before DM jettison – Stature and eye-level height were measured periodically in the DM.
3. After DM jettison and before entry – Sitting height and eye-level height were measured in the CM as late as possible before entry.

Because of scheduling problems and the limited number of data points completed, only the stature measurements from the second phase will be discussed in this report. Because of crew health concerns, a minimal number of postflight measurements were made.

RESULTS AND DISCUSSION

The anticipated increase in stature was noted in each of the ASTP crewmen (Table 16-I). This increase can probably be attributed to the absence of g-loading on the spine which resulted in loss of normal spinal curvature and in expansion of the intervertebral disks.

[a]NASA Lyndon B. Johnson Space Center.

TABLE 16-I.–*CREW HEIGHT MEASUREMENTS*

Crewman	Preflight			In-flight			Postflight		
	Day	Measurement, cm	(in)	Day	Measurement, cm	(in)	Day	Measurement, cm	(in)
Apollo commander	F - 45	181.3	(71.4)	6	180.6	(71.1)	R + 0	182.6	(71.9)
	F - 30	181.5	(71.5)	8	185.4	(73.0)			
	F - 15	181.1	(71.3)	9	188.0	(74.0)			
Docking module pilot	F - 45	178.8	(70.4)	6	181.1	(71.3)	R + 0	180.5	(71.1)
	F - 30	179.1	(70.5)	8	182.9	(72.0)			
	F - 15	179.0	(70.5)	9	180.1	(70.9)			
Command module pilot	F - 45	179.4	(70.6)	6	181.9	(71.6)	R + 0	180.5	(71.1)
	F - 30	180.2	(71.0)	8	181.9	(71.6)			
	F - 15	180.4	(71.0)	9	186.4	(73.4)			

These data, in conjunction with Skylab height data, indicate a two-step "growth." Only a small change (less than 1.3 cm (0.5 in.) average) occurred between launch and mission day 6, which was the first measurement opportunity in the DM. The major change, as much as 6.6 cm (2.6 in.) total, occurred between mission days 6 and 9.

Although various hypotheses accounting for this time/stature relationship are being considered, the following seems most probable. The smaller initial change may result from removing g-loads on the body and thus permitting loss of spinal curvature. A similar expansion is observed on Earth when stature is compared between standing and supine body positions. The second larger "growth" may be accounted for from the expansion of the now unloaded intervertebral disks; this expansion may be further affected by the body fluid shifts in zero g (ref. 16-1). Application of these data is being made in future man-machine interface designs.

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REFERENCE

16-1. Thornton, William E.; Hoffler, G. W.; and Rummel, J. A.: Anthropometric Changes and Fluid Shifts. *The Proceedings of the Skylab Life Sciences Symposium,* vol. II. NASA TM X-58154, 1974, pp. 637-658.

BIBLIOGRAPHY

BUDINGER, T.F.; TOBIAS, C. A.; ET AL.: Quantitative Observation of Light Flash Sensations – Experiment MA-106. *Apollo-Soyuz Test Project Preliminary Science Report.* NASA TM X-58173, 1976, pp. 13-1 to 13-16.

BÜCKER, H.; FACIUS, R.; ET AL.: Biostack III – Experiment MA-107. *Apollo-Soyuz Test Project Preliminary Science Report.* NASA TM X-58173, 1976, pp. 14-1 to 14-28.

ROGERS, T. D.; TAYLOR, G. R.; AND BROWER, M. E.: Zone-Forming Fungi – Experiment MA-147. *Apollo-Soyuz Test Project Preliminary Science Report.* NASA TM X-58173, 1976, pp. 15-1 to 15-12.

TAYLOR, G. R.; KROPP, K. D.; ET AL.: Microbial Exchange – Experiment AR-002. *Apollo-Soyuz Test Project Preliminary Science Report.* NASA TM X-58173, 1976, pp. 16-1 to 16-31.

CRISWELL, B. S.: Cellular Immune Response – Experiment MA-031. *Apollo-Soyuz Test Project Preliminary Science Report.* NASA TM X-58173, 1976, pp. 17-1 to 17-7.

MARTIN, R. R.: The Effects of Space Flight on Polymorphonuclear Leukocyte Response – Experiment MA-032. *Apollo-Soyuz Test Project Preliminary Science Report.* NASA TM X-58173, 1976, pp. 18-1 to 18-29.

SCHELD, H. W.; BOYD, J. F.; ET AL.: Killifish Hatching and Orientation – Experiment MA-161. *Apollo-Soyuz Test Project Preliminary Science Report.* NASA TM X-58173, 1976, pp. 19-1 to 19-14.

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