NASA Technical Memorandum 58252

Shuttle OFT Medical Report

Summary of Medical Results from STS-1, STS-2, STS-3, and STS-4

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Summary of Medical Results from STS-1, STS-2, STS-3, and STS-4

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INTRODUCTION

The first four flights of the Space Transportation System (STS) were known as the Orbital Flight Tests (OFT). Verification of the engineering systems and the safety of the world's first reusable spacecraft were tested during this period. The Space and Life Sciences Directorate at the Johnson Space Center supported OFT crews through extensive preflight, inflight and postflight training, and monitoring in a variety of specialized areas which will be addressed in this report. All of the OFT flights were made in the spacecraft Columbia and launched from the Kennedy Space Center (KSC).

Columbia's inaugural flight began on April 12, 1981, at 7:00 A.M. Eastern Standard Time (EST). Since this was the first time that an American spacecraft had been put into orbit without prior unmanned flight orbital testing, the mission was conservatively planned in the interest of safety. During the flight, a series of tests and checkouts were accomplished. After 2 days, 6 hours, 20 minutes and 52 seconds, the Columbia landed on runway 23 of Rogers Dry Lake at Edwards Air Force Base in the Mojave Desert of California. John W. Young served as Commander and Robert L. Crippen was the Pilot.

On November 12, 1981, at 10:10 A.M. EST STS-2 was launched. The launch was initially scheduled for November 4, 1981; however, a hold at T-minus 31 seconds for out-of-tolerance measurements could not be resolved to support the scheduled launch time. Subsequent evaluation of the lubrication oil pressure of the auxiliary power units (APU) 1 and 3 resulted in a decision to delay the launch until the APU's 1 and 3 could be flushed and the filters replaced. On November 11, the revised flight schedule of November 12 was placed in some jeopardy by the malfunction of one of Columbia's multiplexer units. A unit from Challenger, the second Shuttle Orbiter then under construction, was flown to KSC and launch occurred at the revised time. When the refurbished Columbia made its second flight it carried a space application payload and a remote manipulator. Due to a fuel cell failure, the planned five-day mission was shortened to about 54 hours. The Columbia landed at the Edwards Air Force Base runway 23, 2 days, 6 hours, and 13 minutes into the mission. The Commander of the mission was Joe H. Engle, and the Pilot was Richard H. Truly.

The crew for STS-3 consisted of Jack R. Lousma, Commander, and C. Gordon Fullerton, Pilot. Launch took place on March 22, 1982, at 10:59 A.M. EST for a planned duration of seven days. The mission was originally planned for a landing at Edwards Air Force Base, California, but due to adverse (wet) lake bed runway conditions, the primary landing site was moved to White Sands, New Mexico. Again, adverse weather conditions changed the plan. The Orbiter landed safely on the eighth day at 11:05 A.M. EST, March 30, 1982. The major activities of the STS-3 flight were the thermal testing as well as opening and closing of the payload bay doors. The thermal testing consisted of placing the Orbiter in four attitudes for extended periods of time to determine the thermal responses of specific areas. All payload bay door closures during the various attitudes were successful except during the thermal test tail-to-Sun attitude. This situation was cleared after reorienting the Orbiter to the top-to-Sun attitude for approximately 15 minutes followed by a short period of passive thermal control.

STS-4 was flown as planned with the launch on June 27, 1982, at 10:00 A.M. EST. It landed on July 4, 1982, at 11:11 A.M. EST on the runway at Edwards Air Force Base. The nominal landing on the Edwards runway (not lake bed) occurred on the 206th birthday of the United States and was attended by President Reagan and the First Lady. The major activities during the fourth OFT included remote manipulator system operations with a 90 pound payload (Induced Environment Contamination Monitor). This flight also included the first Department of Defense payload. All of the Orbiter Services required were payload supplied as planned, with one exception. The carrying harness between the crew cabin area and the Get-Away Special (GAS) experiment was not satisfactory, but the crew was successful in working around this problem and activating the GAS experiment. All spacecraft systems operated satisfactorily throughout the STS-4 mission with only minor problems that did not impact the results of the mission. The fourth OFT crew consisted of T.K. Mattingly, Commander, and Henry W. Hartsfield, Jr., Pilot.

The OFT missions provided medical information on the eight Shuttle crewmembers. Although the sample numbers are small and the astronauts spent varing amounts of time in microgravity, an attempt is made to give a summary of the various aspects of medical support.

Additional information about the medical results of STS missions may be obtained by reviewing the following NASA Technical Memoranda:

58240	STS-1 Medical Report	December 1981
58245	STS-2 Medical Report	May 1982
58247	STS-3 Medical Report	August 1982

There is no medical report for STS-4; the information covering this mission is included in this summary OFT report.

EVALUATION OF CREW HEALTH

CHAPTER 1

Sam L. Pool, M.D.

NASA medical personnel are responsible for the health of all persons flying in NASA spacecraft. This includes the application of principles of preventive medicine, as well as the treatment of any illnesses or injuries occurring as a result of space flight. All personnel who fly on NASA spacecraft must hold a current medical certification. The classifications currently in use are Class I for pilot astronauts, Class II for mission specialist astronauts, and Class III for payload specialists. During OFT, each crewman underwent four preflight medical evaluations which began 30 days prior to the flight and were concluded on launch morning. Included in these evaluations were general examinations, a dental examination, plus clinical laboratory and stress tests.

Crew health status was evaluated in accordance with the schedule shown in Table 1-1. All eight OFT crewmen were found to be in excellent health prior to flight. One backup flight crewmember developed an upper respiratory infection and was removed from routine contact with other crewmembers in the preflight period.

Several postflight medical evaluations were conducted on each crewmember. The first examination was done within one hour after landing and included a medical debriefing, a physical and laboratory examination. All crewmen were returned to flight status three to five days later.

Physiological changes observed as a result of the OFT missions have been similar in nature to those observed in Apollo and Skylab programs. Cephalic fluid shifts have invariably occurred. Accelerated heart rates on launch and reentry were similar in magnitude to those recorded in previous flights. Space adaptation syndrome was symptomatic in approximately 50 percent of crewmembers flown. Orthostatic intolerance was observed among those crewmembers who had not received countermeasures. Hormonal, electrolyte, and immunological responses specific to space flight were again observed upon return to the Earth's environment. Most of these immediate postflight changes occurred from a few hours to one day postflight and returned to preflight baseline by the third to fifth day postflight.

Unlike previous space flights, OFT crewmembers actively participated in the piloting of the spacecraft during entry. Comments by the crews dealing with proprioceptive experiences in this phase of the mission have been noted elsewhere in this report. It has been postulated that these sensations are the results of the workload distribution and/or the neuro-sensory realignments exhibited as a result of exposure to reentry gravitational forces. Additional studies are underway.

No significant residual physiological decrements have been elicited postflight. As a result of the confidence gained from the practice of space medicine in the OFT period, a less conservative medical approach has been taken toward the flight certification of space crews. For example, all crewmembers were returned to regular duties at least five days after return from space flight. Since the STS may function as an orbiting research laboratory, especially when carrying the pressurized Spacelab module, a more sophisticated scientific approach toward the study of physiological adaptation and testing of countermeasures is planned.

TABLE 1-1 MEDICAL EVALUATIONS SCHEDULE-ORBITAL FLIGHT TESTS

Exam Schedule	Annual Flight Exam	Flight -30 Days	Flight -10 Days	Flight -2 Days	Flight -0	Inflight Each Day	Landing +0 Days	Landing 3 to 6 Days
Location	JSC	JSC	JSC	JSC	KSC	MCC to space-craft	Land	JSC
Approxi-mate Time (hours)	4:00	1:30	0:45	0:10	0:10	about 0:05***	0:30	1:30
Exam Compon-ents	PX L A V T CST* D	PX L A V D CST80	PX(ab) L M CVE HS**	L M	PX(ab)	PMC	PX(ab) L M A V CVE	PX L A V D CVE

* Annual 100% treadmill unless under age 35. Then 100% every 3 years.

** Flight-10 day exam qualifies crew for start of HS program.

***Duration variable at crew discretion and time available during pass over monitoring station.

PX - Complete Physical
PXC(ab) - Abbreviated Physical
L - Laboratory
M - Microbiology
A - Audiometry
V - Visual Acuity
T - Tonometry
CST - Cardiovascular Stress Test 80% of predicted max
D - Dental
CVE - Cardiovascular Evaluation (Stand Test-Echocardiogram)
PMC - Private Medical Conference MCC Surgeon and crew
HS - Health Stabilization Program

CREW MEDICAL TRAINING

CHAPTER 2

James M. Vanderploeg, M.D.

INTRODUCTION

The objective of the crew medical training for the Orbital Flight Test (OFT) portion of the Space Transportation System (STS) program was to provide each astronaut with the knowledge and skills necessary to respond to inflight illnesses and injuries in an appropriate and expedient manner. An additional feature of this medical training was the education of the crewmembers in the various physiological changes which occur during space flight and the appropriate countermeasures to these changes. This objective was met through both the general medical training which is part of each astronaut's initial training and mission-specific training in preparation for each of the OFT missions.

DISCUSSION

Each astronaut's initial medical training involves 16 hours of instruction during the first year following selection. The curriculum of this training is listed in Table 2-1. Also included during the first year of training is a two day course in altitude physiology. The course content is listed in Table 2-2. This material is reviewed every three years in a one day refresher course.

Mission specific medical training for the OFT astronauts was consistent in content for each of the flight crews, but the organization of the materials varied to accommodate individual training schedules. The inital portion of this training involved completion of the self-study workbook, MED EQ 2102. Topics covered in the Medical Equipment Workbook were the following:

a. Shuttle Orbiter Medical System (SOMS)
   (1) contents
   (2) uses
   (3) location and stowage

b. Operational Bioinstrumentation System (OBS)
   (1) components
   (2) donned configuration
   (3) on-orbit contingency use

c. Anti-Gravity Suit (AGS)
   (1) components
   (2) pressure controller operations

d. Radiation Equipment
   (1) components
   (2) locations
   (3) on-orbit contingency use

After completion of the workbook, the training was conducted in classroom sessions. For the STS-1 through STS-3 flight crews, this training was presented in three courses of three hours each plus an F-30 premission review and medical briefing. These courses were entitled Medical Procedures 2101, 2201 and 2301. The premission briefing was entitled Medical Procedures 4101. The overall organization of the medical training was streamlined for the STS-4 flight crew in order to eliminate the redundancy of the three classroom courses and to make the training more time efficient. Consequently, the materials of Medical Procedures 2101, 2201 and 2301 were consolidated into one course of three and one-half hours duration entitled Medical Procedures 2101A. In conjunction with this, Medical Procedures 4101 was expanded to two and one-half hours and included a more extensive review of the

material from Medical Procedures 2101A.

The curriculum of Medical Procedures 2101A is outlined in Table 2-3. In this course, the crewmembers were taught the techniques of measuring vital signs, examining the eyes, ears, throat, neck, chest and abdomen; diagnosing and treating various illnesses and injuries; as well as obtaining microbiological cultures. Throughout this training the SOMS medical kits and checklist were used extensively. Thus, the crewmembers learned the organization and uses of the SOMS while the examination and treatment techniques were being practiced. Several emergency procedures were demonstrated and practiced. These included one-man cardiopulmonary resuscitation (CPR), the Heimlich maneuver, cricothyrotomy, and splinting and bandaging techniques.

Areas covered in Medical Procedures 4101 are listed in Table 2-4. This session was attended by the crew physician, deputy crew physician, Mission Operations Control Room (MOCR) surgeons and the flight crew for each flight. During this training, the physicians and flight crew were able to discuss the physiologic changes of zero-gravity and appropriate countermeasures as well as review medical procedures and treatment techniques.

CONCLUSION

Each flight crew for STS-1 through STS-4 completed the required medical training. For STS-1 through STS-3 a backup crew was designated who subsequently became the prime crew for a later mission. Those individuals received additional medical training since they participated in training sessions both as backup and prime crewmembers. The use of the SOMS inflight during OFT demonstrated that the objective for crew medical training was accomplished. When use of the medical kits was required inflight, the crewmembers were able to respond to the MOCR surgeon's instructions promptly and without difficulty.

TABLE 2-1

CURRICULUM OF INITIAL MEDICAL TRAINING

Central and Peripheral Nervous System
Visual System
Auditory and Vestibular Systems
Dental Health
Cardiovascular System
Pulmonary System
Gastrointestinal System
Genitourinary System
Musculoskeletal System

TABLE 2-2

ALTITUDE PHYSIOLOGY TRAINING

Composition of the Atmosphere
Gas Laws
Hypoxia: Signs, Symptoms, Treatment
Life Support Equipment Operation
Effects of Increased G Loading
L-1 and M-1 Anti-G Maneuvers
Anti-G Suit Use
Altitude Chamber Ride

TABLE 2-3

MEDICAL PROCEDURES TRAINING 2101A

SOMS Medical Kits and Medical Checklist
Microbiology: Techniques for Cultures
Vital Signs Determination
Physical Examination Techniques
Treatment Techniques

TABLE 2-4

MEDICAL PROCEDURES TRAINING 4101

Anti-G Suit
Biomedical Electrodes
Dehydration
Exercise
EVA and Aspirin Use
Health Stabilization Program
Medical Mission Rules
Physical Exam Schedule: Preflight and Postflight
Private Medical Communication
Radiation Dosimeter
Review of Medical Kits and Procedures
Space Adaptation Syndrome

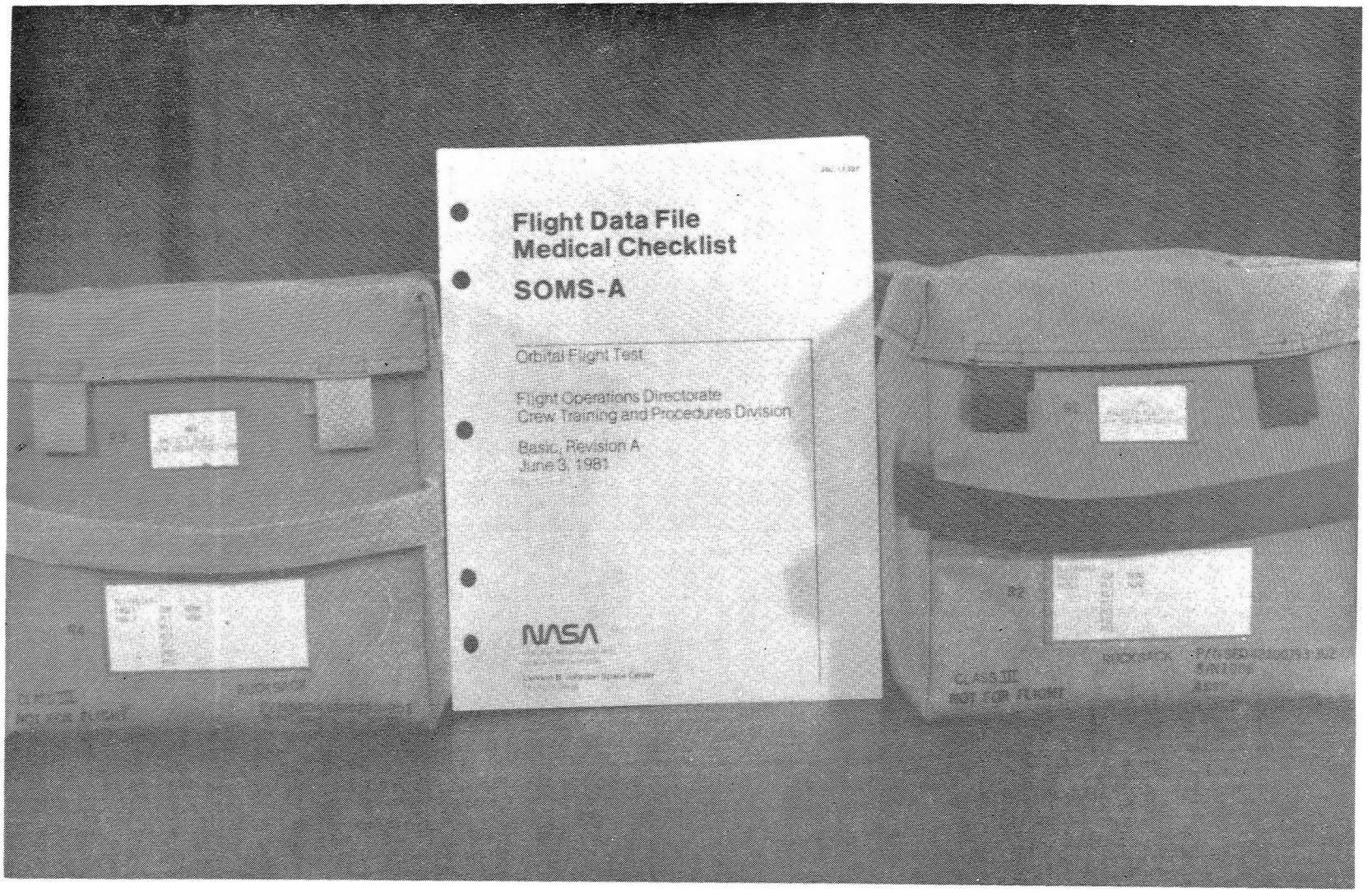
Flight Data File
Medical Checklist
SOMS-A
Orbital Flight Test
Flight Operations Directorate
Crew Training and Procedures Division
Basic, Revision A
June 3, 1981
NASA

FIGURE 3-1

SHUTTLE ORBITER MEDICAL SYSTEM CHAPTER 3

James M. Vanderploeg, M.D.

INTRODUCTION

The Shuttle Orbiter Medical System (SOMS) is a product of the development of onboard medical kits which have been in use throughout the history of U.S. manned space flight. Designed for use during the Orbital Flight Tests (OFT), the "A" version of the SOMS provides treatment capability for life-threatening emergencies and permits diagnosis and treatment of many less severe illnesses and injuries. The inventory of the SOMS-A is intended to sustain the medical needs of a two-man crew for up to 14 days.

DISCUSSION

The total system is composed of the Medicine and Bandage Kit (MBK), the Emergency Medical Kit (EMK), and the Medical Checklist as well as other Orbiter systems such as the Portable Oxygen System (POS). In the EMK are four pallets with items stowed on both sides. Included in the pallets are injectable medications, IV supplies, most diagnostic equipment, the suturing equipment, and the microbiological culturing supplies. The MBK contains three pallets with items stowed on both sides of each pallet. All oral, topical and suppository medications; most bandage items and some diagnostic equipment are in the MBK.

The Medical Checklist is composed of two parts. The first is a generic document (JSI-17327) which contains checklist instructions for medical emergencies, laboratory procedures, and supplementary illustrations. The second part is issued as a Flight Supplement and is composed of an alphabetical and a usage listing of the medical kit contents. By issuing this as a flight supplement, medications can be modified from flight to flight to accommodate specific crew requirements. The SOMS-A is shown in Figure 3-1.

Throughout the history of the space program, part of the premission preparation has been the evaluation of an individual astronaut's sensitivity to any of the drugs contained in the medical kit. Knowledge of any allergic reaction or undesirable side effect to the medical kit contents is imperative for effective health care by the Mission Operations Control Room (MOCR) surgeons and crew physicians.

A drug sensitivity evaluation was conducted prior to each OFT mission. This was carried out in two segments. First, each crewmember's health record was reviewed and every medication he had received either for a clinical indication or for previous drug sensitivity testing was recorded. Any reported reactions or side effects were also recorded.

The second segment of this evaluation involved testing each crewmember with those medications which were felt to have a high likelihood for use in flight. This testing was scheduled such that no flying was undertaken for 24 hours following the ingestion of any medication. Most of the tests were done in conjunction with flight simulation exercises. Sedatives were taken at home in the evening to evaluate sleep induction as well as alertness the following day. Prior to being issued any medication the crewmember was briefed on possible side effects and allergic manifestations as well as the procedure to

follow to obtain emergency medical attention.

The information gained from the drug sensitivity evaluation was checked against the contents of the SOMS-A. Thus, the physicians made certain that no medication was carried on board to which a crewman was unusually sensitive. Table 3-1 lists the medications considered to have a probability of use.

CONCLUSION

Use was made of the SOMS-A during the OFT missions for the treatment of medical conditions. Table 3-2 lists the various items and medications utilized in flight. In each instance in which use of the medical kits was required, the appropriate items were present and readily located by the crewmember.

TABLE 3-1

MEDICATIONS HAVING A HIGH PROBABILITY OF USE

Actifed	Lomotil
Afrin Nasal Spray	Mycolog Cream
Amoxicillin	Mylanta
Aspirin	Parafon Forte
Benadryl, 25 mg	Phenergan, 25 mg
Betadine (Povidone-Iodine)	Polysporin
Codeine, 15 mg	Pyridium, 200 mg
Compazine, 10 mg	Scopolamine/Dexedrine, 0.4/5 mg
Cortisporin Otic Suspension	Sulfacetamide Ophthalmic
Dalmane, 30 mg	Tetracycline, 250 mg
Dexedrine, 5 mg	Tylenol
Keflex, 250 mg	

TABLE 3-2

SOMS ITEMS USED DURING OFT MISSION

Ascriptin Tablets
Flurazepam Hydrochloride Capsules
Mylanta Tablets
Scopolamine/Dexedrine Capsules
Scopolamine Skin Patch
Tempadot Disposable Thermometer

VALIDATION OF PREDICTIVE TESTS AND COUNTERMEASURES FOR SPACE MOTION SICKNESS

CHAPTER 4

Jerry L. Homick, Ph.D.

INTRODUCTION

Space motion sickness has been characterized as a maladaptation phenomenon that is experienced by some individuals during the first few days of exposure to microgravity. The syndrome may include such symptoms as depressed appetite, a nonspecific malaise, performance decrements, gastrointestinal disturbances, nausea and vomiting. The precise mechanisms underlying space motion sickness are not fully understood; however, investigators generally agree that the syndrome has its origin in the vestibular system. Neither techniques for the a priori identification of persons susceptible to this syndrome, nor effective and operationally acceptable countermeasures have been fully developed.

Experience from previous flights indicates that the space sickness syndrome represents a potential threat to the operational efficacy and physical well-being of future crewmembers. Although none of the Mercury or Gemini flight crews reported space sickness, 33% of the Apollo crewmen experienced symptoms and 54% of the Skylab crewmen had symptoms. Reports from the USSR indicate that about 40% of the Soviet cosmonauts have experienced space motion sickness. These combined data suggest that if no corrective actions are taken, up to 40% of Shuttle crewmembers could experience some degree of space sickness during the first few days of flight. Because of its complexity and uniqueness, this biomedical problem cannot be resolved solely with ground-based research. It is essential that data be collected systematically on individuals who fly Shuttle missions in order to obtain final and valid solutions.

A Flight Supplementary Objective (FSO) was developed to initiate this data collection with the first four Shuttle missions. A primary purpose of this FSO was to conduct inflight observations, supported by a series of preflight and postflight data collection procedures, in an effort to begin validating ground-based tests which may be predictive of susceptibility to the space motion sickness syndrome. An additional objective was to implement crew testing procedures which would enable acquisition of data to be used in validating countermeasures.

MATERIALS AND METHODS

Preflight

Part of the required crew preflight activity was based on guidelines set forth in NASA's medical operations policy for the prophylaxis and treatment of space motion sickness with anti-motion sickness drugs. This policy states that astronauts with a positive history of space sickness or with no space flight experience will be premedicated with a previously selected anti-motion sickness drug. Premedication is operationally defined as taking the prescribed drug prior to launch or immediately after the inflight Orbital Manuevering Subsystem (OMS 1) correction maneuver. The OMS 1 occurs about 10 minutes after orbital insertion. The policy further states that astronauts who have flown in space with no symptom of space sickness are not required to

be premedicated. Any individual who experiences space motion sickness will be administered appropriate inflight treatment with anti-motion sickness drugs. The policy requires preflight side effects screening and efficacy testing with one or more anti-motion sickness medications.

During the early preflight period the eight crewmembers completed a questionnaire designed to elicit information regarding past experiences with various motion environments and responses to those environments.

Approximately three to six months before flight each of the crewmembers were tested at least one time for susceptibility to experimentally induced motion sickness in the Johnson Space Center (JSC) Neurophysiology Laboratory. The standard Coriolis Sickness Susceptibility Index (CSSI) test was used. This procedure requires the performance of head movements while rotating at a constant velocity in a servo-controlled chair. The test was terminated when the crewmember reached the Malaise III level (8 symptom points) of motion sickness or performed 150 head movements, whichever occurred first. This test served two purposes. First, it provided a ground based susceptibility data point against which inflight susceptibility could be compared. Second, it provided a baseline for subsequent evaluations of anti-motion sickness drug efficacy. During this test session the crewmembers were instructed on the self-recognition and reporting of motion sickness symptoms. They were also instructed on the use of a microcassette recorder and symptom checklist which were to be used inflight for symptom reporting.

In accordance with the medical operations policy, all of the crewmembers were screened for side effects with one or more medications. This screening was typically done under operational conditions. For example, the crewman would use a medication while working in the Shuttle simulator. Verbal reports of any side effects experienced were given to the crew physician and documented. The medication most frequently evaluated (and most preferred) was oral Scopolamine (0.4 milligrams) plus Dexedrine (5.0 milligrams). A recently developed transdermal (skin patch) method of administering Scopolamine was evaluated by a few crewmen.

Crewmen who were required to be premedicated for flight were tested in the Neurophysiology Laboratory to evaluate the efficacy of the preferred medication in preventing or minimizing motion sickness. The CSSI test procedures described above were used. In a few cases where the initially preferred medication produced questionable results, the test was repeated with the same medication or a different medication. A minimum of two weeks was maintained between the rotating chair tests to minimize adaptation effects.

Inflight

A microcassette tape recorder and symptom checklist were stowed onboard. The flight crewmen were required to use the recorder and checklist during a designated pre-sleep period each Mission Day to debrief on any symptoms or sensations that had been experienced.

Postflight

Questions pertaining to motion sickness and vestibular sensations were asked of each crewman on the day of landing and during the postflight medical debriefing. Two additional motion sickness susceptibility tests were also required postflight. These were the off-vertical rotation test and the sudden-stop test, both of which were to be performed one time

for each crewman within three months following the mission. The purpose of these postflight tests was to acquire additional ground-based susceptibility data against which inflight susceptibility could be compared. These tests were intentionally scheduled for the postflight period because inadequate crew time existed preflight.

RESULTS

The motion experience questionnaire indicated that all of the crewmembers had a minimal history of susceptibility to terrestrial forms of motion sickness. The questionnaire revealed that a few crewmen had experienced some motion sickness symptoms during past exposures to aerobatic flight, parabolic flight and heavy sea conditions. The questionnaire results did not correlate with the actual incidence of space sickness reported by this group of eight crewmen.

The preflight CSSI test results, anti-motion sickness drugs used inflight and occurrences of space motion sickness are summarized in Table 4-1. The mean preflight CSSI score for the eight crewmen was 41.4 (S.D. = 27.9) on a scale of 0-100 where a CSSI score of 100 means extreme resistance to motion sickness.

By way of contrast, the mean CSSI score for a normative population of 225 non-astronaut individuals at JSC is 12.2 (S.D. = 9.3).

As indicated by Table 4-1, four out of eight crewmen reported symptoms that were interpreted as being space motion sickness. The predominant symptoms reported were decreased appetite, epigastric discomfort of varying degrees and general malaise. Three crewmen experienced a single episode of emesis. The emesis usually occurred abruptly and resulted in a rapid diminution of symptoms. The work efficacy of more severely affected crewmen was temporarily impaired to a minor degree, but at no time were they unable to perform their required tasks. Complete recovery from symptoms always occurred within 36 to 72 hours of onset.

The mean preflight CSSI scores for the four crewmen who experienced inflight symptoms and the four who did not report inflight symptoms were 31.5 and 51.2, respectively. Because of the high variance in the data and the small sample size, this difference was not statistically significant.

Five of the eight crewmen utilized oral Scopolamine plus Dexedrine as a prophylactic medication. In all of these cases the medication was taken after the OMS 1 maneuver. Four of these same crewmen experienced some degree of space motion sickness. One crewman used the transdermal Scopolamine skin patch (applied 12 hours pre-launch) and reported no inflight symptoms. As indicated by Table 4-1, several crewmen used an additional dose or doses of anti-motion sickness medication on Mission Days 1, 2, or 3.

None of the eight crewmen experienced any motion sickness or other unusual vestibular sensations post-landing. With one exception, no vestibular disturbance is experienced as a result of exposure to gravito-internal forces during reentry and landing. One crewmen did experience a transient vertigo during reentry.

DISCUSSION

The incidence of space motion sickness experienced during the first four Space Shuttle flights was not unexpected when considering past space flight results. The severity of symptoms was never extreme and the affected crewmen's performance was at no time compromised.

TABLE 4-1

SUMMARY OF SPACE MOTION SICKNESS RELATED DATA ON STS FLIGHTS 1-4

	Preflight				Inflight	
Crewman*	Chair RPM	Head Movements	Symptom Points	CSSI Scores	Drug Used	Symptoms Reported
1	25	150	0	64.5	Scop/Dex (1)	No
2	15	110	9	18.15	Scop/Dex (2)	Yes
3	20	45	9	12.6	Scop/Dex (3,2,1)	Yes
4	25	150	0	64.5	Scop/Dex (1,1)	Yes
5	20	110	9	30.8	Scop/Dex (3,2,1)	Yes
6	20	85	8	23.8	None	No
7	20	95	12	26.6	TTS Scop (1,1)	No
8	30	150	2	90.0	None	No
			$\bar{X}$ =	41.1		
			S.D.=	27.9		

Scop/Dex - Scopolamine (.4 mg) + Dexedrine (5 mg)
TTS Scop - Transdermal Scopolamine

Note: Values in parenthesis indicate number of doses per day, e.g. (1,1) would indicate one dose on Mission Day 1 and one dose on Mission Day 2.

*Crewman listed in random order

In assessing the effectiveness of medications utilized, it must be recognized that the medications were taken after the OMS 1 maneuver and may have had insufficient time to reach a therapeutic level before the crewmen were stressed. Orally administered Scopolamine normally requires 60-90 minutes to reach its peak effectiveness. Some crewmen were already beginning to move about the vehicle within that period of time. On the basis of available data, it cannot be determined whether or not the crewmen would have had more severe symptoms if they had not used anti-motion sickness medications. Verbal reports from the crewmen suggest that the medication was having some positive effect.

The preflight CSSI data for this population showed a moderate amount of inter-subject variability. However, as a group this population was considerably more resistant to terrestrial motion sickness, including the CSSI test, than the average non-astronaut population. The data showed a tendency for lower ground based CSSI scores to be related to higher inflight susceptibility to motion sickness, although exceptions occurred. One crewman with a higher than average CSSI score experienced symptoms inflight and two with lower than average scores did not experience symptoms inflight. The prophylactic medication used by one of these latter individuals may have effectively suppressed symptoms. These data and previous data underscore the difficulty in predicting susceptibility to space motion sickness on the basis of a single test procedure. Furthermore, the small sample size obtained to date does not allow conclusions to be drawn at this time. Additional data must be collected on flight crewmen, not only with the CSSI test procedure, but also with other methods in order to establish a composite index or susceptibility profile. Only in this fashion can the goal of establishing reliable methods of predicting susceptibility to space motion sickness be realized. Activities are underway to acquire such data both for the validation of predictors and countermeasures.

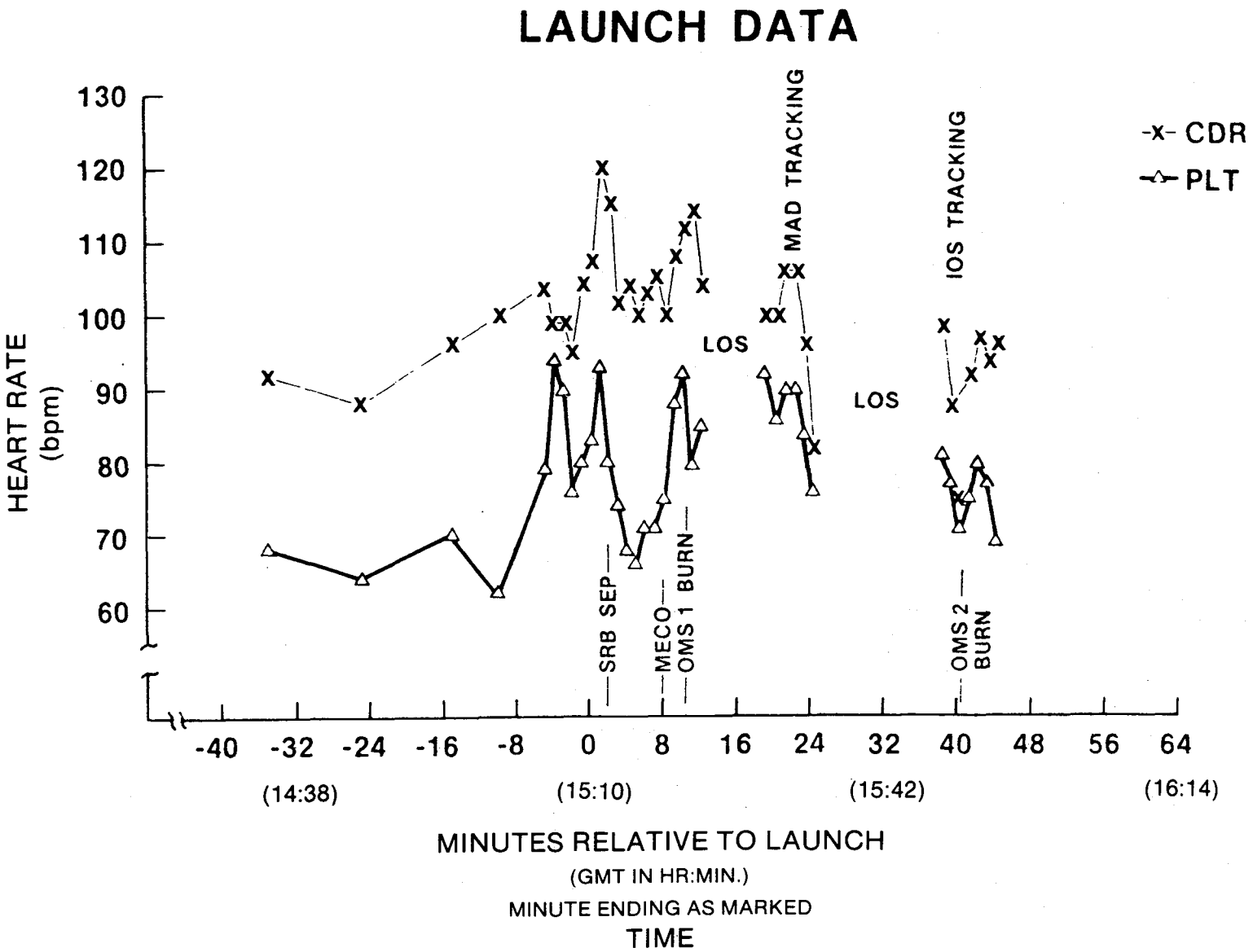
LAUNCH DATA
HEART RATE (bpm)
130
120
110
100
90
80
70
60
CDR
PLT
MAD TRACKING
IOS TRACKING
LOS
LOS
SRB SEP
MECO
OMS 1 BURN
OMS 2 BURN
-40
-32
-24
-16
-8
0
8
16
24
32
40
48
56
64
(14:38)
(15:10)
(15:42)
(16:14)
MINUTES RELATIVE TO LAUNCH
(GMT IN HR:MIN.)
MINUTE ENDING AS MARKED
TIME

FIGURE 5-1

CARDIOVASCULAR EXAMINATIONS AND OBSERVATIONS

CHAPTER 5

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ABSTRACT

During the first four flights of the Space Shuttle, cardiovascular data were obtained on each crewmember as part of the operational medicine requirements for crew health and safety. From monitoring blood pressure and electrocardiographic data, it was possible to estimate the degree of deconditioning imposed by exposure to the microgravity environment. A quantitative Cardiovascular Index of Deconditioning was derived to aid the clinician in his assessment. Isotonic saline was investigated as a countermeasure against orthostatic intolerance. It was observed that the space flight environment might potentially be arrhythmogenic.

INTRODUCTION

The first four flights of the Space Transportation System (STS) were considered Orbital Flight Tests (OFT). The primary purpose of these flights was to test the engineering capabilities of the Orbiter. It had previously been established that humans are capable of withstanding the physiologic stresses of weightlessness (1). The Shuttle was unique in that crewmembers experienced the reentry force of gravity close to the head-to-toe axis, G_z, as opposed to all previous U.S. and U.S.S.R. flights during which reentry gravitational acceleration was experienced from front-to-back, G_x.

METHODS

A stand test was performed pre- and postflight to assess the astronaut's tolerance to orthostatic provocation. This test consisted of measuring the subject's heart rate continuously using a standard three lead electrocardiographic signal (the negative lead being placed at the manubrium, the positive lead in the left fourth intercostal space at the mid-clavicular line, and the ground lead on the right lateral chest wall) and measuring the blood pressure every minute using a clinical sphygmomanometer and stethoscope.

The protocol consisted of recording heart rate and blood pressure for five minutes while the crewmember was in the supine position; followed immediately by five additional minutes of recording while the crewmember was standing with his feet six inches apart and nine inches from a wall with his upper back leaning slightly against the wall for support. Although not providing the fine increments of orthostatic stress that a tilt table or lower body negative pressure device might generate, this method produced reproducible provocation that was clinically simple to use and easy to evaluate.

In addition, each crewmember was instrumented with electrocardiographic monitoring as described above during the launch and landing phases. No additional onboard cardiovascular data were acquired.

RESULTS

The electrocardiographic data from the ECG monitoring during ascents were unremarkable. A typical heart rate profile from one of the missions is presented in Figure 5-1. Gravitational forces of acceleration are

being absorbed in the x-axis, front-to-back, and peak G loads do not exceed 3.0 G. The most pronounced influence on heart rate is reflected by psychological inputs which occur at lift-off, solid rocket booster separation, and orbital insertion. Responses were similar between flights and crewpersons so that these data can be considered typical.

During entry, heart rates were more significantly influenced by the force of gravity, which was experienced head-to-toe, and by the effects that weightlessness had on cardiovascular deconditioning. The biomedical harness carrying ECG data on the pilots for STS-2 and STS-3 failed due to malthreading of the connector; therefore, no entry data were obtained on these two crewmen. Summary data for the commanders of all four OFT missions for comparison are presented in Figure 5-2. As can be seen, it was not uncommon for a crewman to experience heart rates of 90 percent of his prior excercise determined maximum heart rate.

During preflight examinations as well as during prior testing, one crewmember was noted to have occasional premature ventricular contractions (PVC's) occurring as isolated unifocal ventricular ectopic activity which never exceeded two to three ectopics per minute and was usually abolished with higher heart rates. During entry this same crewman exhibited unifocal PVC's during nearly every minute after the onset of gravitational loading. PVC's occurred at rates up to 16 ectopics per minute and averaged four beats per minute. A second crewmember exhibited a rare PVC during the entry phase. He had no significant prior history of ventricular ectopy. Serum electrolytes were not abnormal in either crewman.

The results of orthostatic provocation by means of the stand test are presented in Table 5-1. The crewpersons are identified only by an arbitrarily assigned number and the order in which they are presented does not follow any pattern in order to preserve the confidentiality of personal medical data. It is readily seen that heart rate elevation is the major response to orthostatic stress and that crewmen universally increase their heart rate in response to stress and also increase the magnitude of this response in the deconditioned state. The one exception to the latter statement occurred in crewman 7 whose postflight delta heart rate, lying to standing, was similar to that observed preflight. This resulted in an inadequate blood pressure and evidence of inadequate cerebral perfusion. The average heart rate increase preflight due to orthostatic provocation was 13 ± 6.3 beats/min. Postflight this value was 33.3 ± 13.4 beats/min. Yet the resting supine heart rate postflight was 16.9 ± 7.4 beats/min greater than preflight.

In a like manner, systolic blood pressure postflight universally decreased with orthostatic stress, but diastolic pressure responded variably with no change or with upward or downward changes. In nearly all crewmen, however, these changes resulted in a decrease in the pulse pressure (systolic B.P. minus diastolic B.P.) when the crewman was in the upright posture.

As a consequence, we have derived a formula for estimating the degree of cardiovascular deconditioning due to space flight and have standardized this value to the individual preflight response to testing. The Cardiovascular Index of Deconditioning (CID) is defined as the change in heart rate standing postflight compared to preflight minus the change in systolic blood pressure standing postflight compared to preflight plus the change in diastolic blood pres-

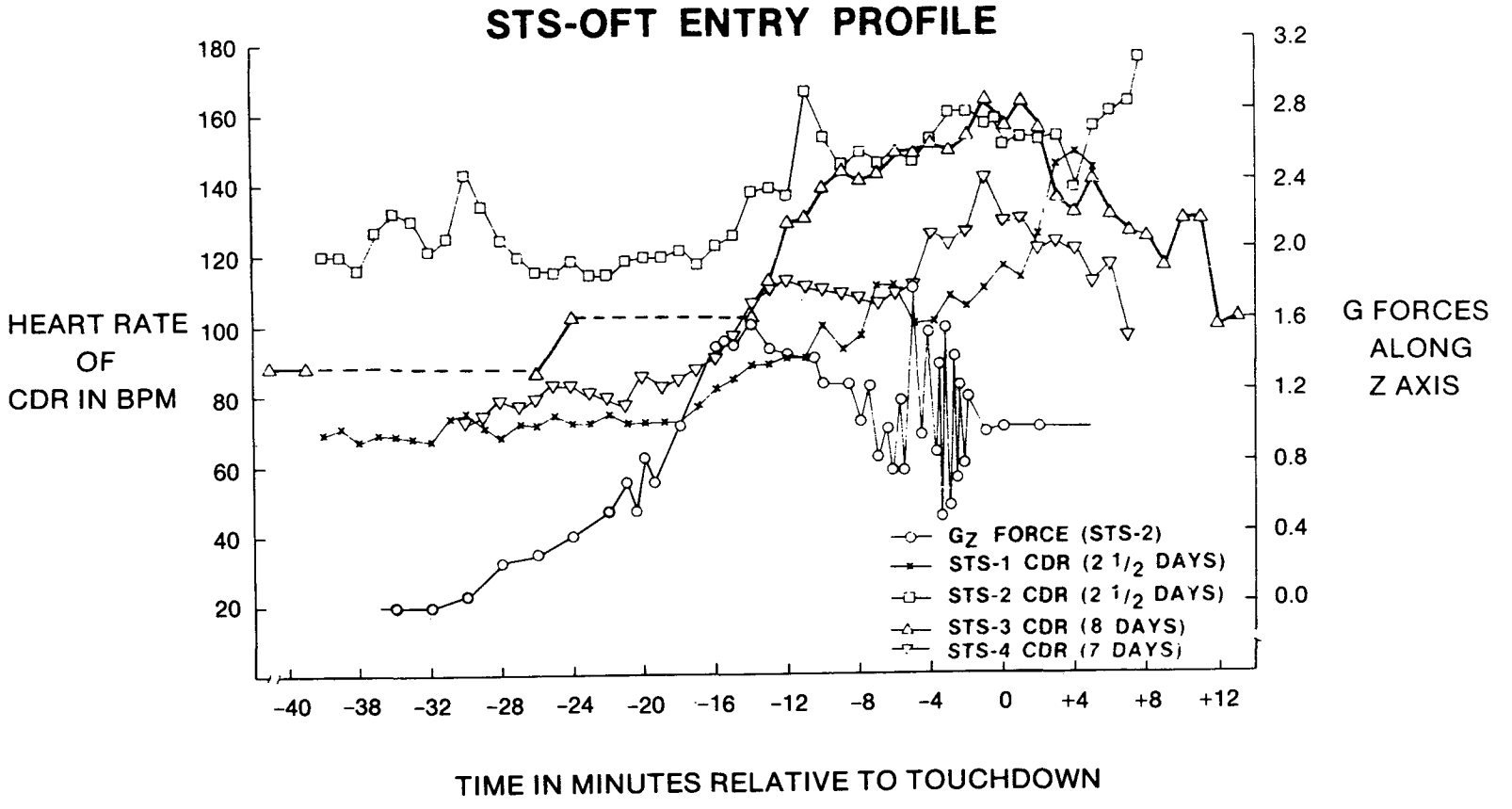
STS-OFT ENTRY PROFILE
HEART RATE OF CDR IN BPM
180
160
140
120
100
80
60
40
20
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
G FORCES ALONG Z AXIS
-40 -38 -32 -28 -24 -20 -16 -12 -8 -4 0 +4 +8 +12
TIME IN MINUTES RELATIVE TO TOUCHDOWN
GZ FORCE (STS-2)
STS-1 CDR (2 1/2 DAYS)
STS-2 CDR (2 1/2 DAYS)
STS-3 CDR (8 DAYS)
STS-4 CDR (7 DAYS)

FIGURE 5-2

TABLE 5-1 - OFT STAND TEST RESULTS

Crewmember	Duration of Spaceflight in days	Preflight Heart Rate*/Blood Pressure**		Postflight Heart Rate*/Blood Pressure**	
		Supine	Standing	Supine	Standing
1	2.5	54 110/70	71 105/68	80 118/62	111 118/86
2	8	53 100/70	65 100/72	77 118/82	127 104/70
3	2.5	61 127/88	73 145/92	61 120/80	99 110/80
4	8	52 118/80	70 105/80	77 140/84	120 120/98
5	7	53 130/80	60 118/78	69 128/84	97 126/82
6	2.5	59 129/76	65 137/86	66 140/110	85 135/110
7	2.5	78 118/76	102 118/76	103 117/75	126*** 90/62
8	7	57 110/68	65 98/66	69 108/78	93 100/68

*Heart Rate (beats/min)
**Systolic Blood Pressure/Diastolic Blood Pressure (mmHg)
***Indicates early termination of stand test because of clinical evidence of presyncope

TABLE 5-2 - CARDIOVASCULAR INDEX OF DECONDITIONING

Crewmember	CID
1	45
2	66
3	49
4	53
5	33
6	46
7	38
8	28

sure standing postflight compared to preflight. Simply stated, this reduces to the following:

CID = delta HR - delta SBP + delta DBP

where delta HR = heart rate standing postflight minus heart rate standing preflight

delta SBP = systolic blood pressure standing postflight minus systolic blood pressure standing preflight

delta DBP = diastolic blood pressure standing postflight minus diastolic blood pressure standing preflight

Inherent in this index is that deconditioning produces an increase in heart rate, a drop in systolic blood pressure, and a decrease in pulse pressure, although the effect on diastolic pressure might be variable. Therefore, as the value of CID increases, one would assume that the response of the cardiovascular system is greater and the level of deconditioning, i.e., orthostatic susceptibility, more profound. The data for the OFT crewmembers are presented in Table 5-2. The authors believe that this approach to such a complex, and unresolved, clinical problem will be a helpful guide to those responsible for making operational judgements with minimal facilities for data acquisition.

DISCUSSION

The four missions of the OFT series were heterogeneous from a medical as well as an engineering standpoint. STS-1 and STS-2 were short flights when compared to STS-3 and STS-4. Vestibular disturbances, known also as space sickness, were experienced by the crews of the three later flights to varying degrees (2). These disturbances altered crew fluid and food intake in addition to altering their activity levels. The flight duration of STS-3 and STS-4 were long enough, however, for the crew to recuperate from the potentially deleterious effects of space sickness.

The CID values for crewmembers undergoing 2.5 days of spaceflight were 45, 49, 46 and 38. The CID of 38 in crewman 7 failed to predict his presyncopal episode largely because of an inadequate heart rate response to falling blood pressure. This situation occurred in the context of significant inflight vestibular disturbances and decreased fluid intake. The CID would have to be considered useful only when the cardiovascular system is still within the limits of its compensatory factors. Crewman 7 lost seven pounds of body weight during the flight. If one considers this a single compartment loss, then he lost approximately 19 percent of his extracellular fluid. Values for other astronauts with similar flight durations (2.5 days) are less than half this amount; weight losses of three pounds which correspond to a nine percent extracellular fluid loss (3).

Crewmen 5 and 8 had the lowest CID, 33 and 28, respectively, and certainly much lower than the CID of crewmen with similar duration of weightlessness, 2:CID=66 and 4:CID=53. Crewmen 5 and 8 participated in an operational medicine study to investigate the effects of saline loading on orthostatic tolerance. Each of these two subjects consumed one liter of isotonic saline orally in the hour before entry interface as part of an experimental protocol (4). Their CID values and heart rate profile (Figure 5-2) appear to reflect this beneficial effect. More data, however, will be accumulated on upcoming Shuttle flights before conclusions are formalized.

In summary, the OFT series has provided evidence of cardiovascular de-

conditioning reflected in changes in heart rate and blood pressure both at rest and in response to orthostatic provocation. Universally, crewmembers react with higher heart rate responses after deconditioning. Nevertheless, there appears to be two categories of blood pressure response. One group responds as a rigid pipe with decreases in systolic and diastolic pressure upon orthostatic stress. A second group responds with increases in diastolic pressure, and in at least one instance, to hypertensive levels. These vascular hyper-responders appear to have had their cardiovascular controlling mechanisms reset during the weightless period as well as having experienced the usual inflight diuresis and volume depletion (5).

Additionally, in one astronaut previously noted ventricular ectopic activity was exacerbated. Whether this was a result of the release of catecholamine stimulation from intense psychological input (6), or the result of decreased coronary perfusion due to orthostatic stress, can only be a matter of speculation with the data available.

Continued research into the volume shifts and neural-hormonal control of cardiovascular function should provide the knowledge needed to counter the deleterious effects of space flight deconditioning and to understand its physiology; along with understanding its Earth-based analog, bedrest. Eventually, investigation into the primary structure of the myocardium and microvascular tissue pressures as they relate to the weightless state will be necessary to understand the long-term consequences of space travel.

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BIOCHEMISTRY AND ENDOCRINOLOGY

CHAPTER 6

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ABSTRACT

Venous blood was drawn from the eight crewmembers of STS-1 through STS-4 three times before lift-off, and twice after landing. A number of parameters in serum or plasma were measured, including electrolytes, enzymes and hormones. Twenty-four-hour urine pools were collected 30 days before flight and on Landing Day or day four after landing; some of the same parameters were measured. Statistically significant increases over preflight levels of serum calcium, glucose, thyroxine and insulin and of plasma and urinary aldosterone were recorded on Landing Day. Significant decreases in serum sodium and potassium and urinary calcium, chloride and uric acid occurred on the same day. The results were similar in many respects to those from other series of space flights and were interpreted to indicate that although fluid and electrolyte loss occur during space flight, conservation of these substances is begun almost immediately upon cessation of weightlessness. Enzyme and hormone measurements indicated that landing may have caused some stress on crewmembers, especially when compared with results from the Apollo missions. The difference in length of flight (54, 169 or 192 hours) did not appear to affect the results. Several days after landing, most parameters had returned to preflight levels, but some effects of space flight were more exaggerated or had "overshot" preflight levels.

INTRODUCTION

Biochemistry and endocrinology studies were conducted on crewmembers of STS-1 through STS-4 to provide data to assist in objective assessment of the health of each crewmen. Data collected during the preflight phase of the mission provided baseline information to compare to postflight results for detection and identification of any physiological changes which may have resulted from exposure to the space flight environment. The first two STS flights provided detailed data not previously acquired in the U.S. space program on men returning from two days in space.

Physiological changes for which evidence has been found in the blood and urine of crewmembers on other space flight series include loss of fluids and electrolytes, demineralization of bone and changes in metabolism of protein and carbohydrates. Measurement of concentrations of electrolytes, tissue enzymes, hormones and other components were undertaken to better understand alterations in homeostatic mechanisms resulting from space flight.

METHODS

During the preflight and postflight periods, the crew consumed the ground control diet of their choosing. In-flight they followed the provided Shuttle diet. Fluids were available when desired. In addition to their varied intakes during each mission, crewmembers of STS-2 each drank two to three liters of fluid after landing, but before the blood samples were drawn; the crew of STS-3 drank Gatorade just before landing; and the crew of STS-4 each took eight salt tablets and drank about a liter of water in the hours just before landing.

Venous blood was drawn three times before the mission, generally 30, 10, and 2 days before lift-off (F-30, -10, -2). After landing, blood was drawn as soon as possible (L+0) and three to five days later (L+3, +4, +5). Table 7-1 in "Hematological and Immunological Analysis" shows the sampling schedule for each flight. All blood samples were fasting samples (14 hours) and were collected as early in the morning as possible, except for the one at L+0. Alcoholic beverages were not consumed for at least 14 hours before blood collection.

Quantitative analyses of the following blood components (plasma or serum) were done: osmolality, sodium, potassium, chloride, total calcium, magnesium, inorganic phosphate (IPO_4), uric acid, blood urea nitrogen (BUN), creatinine, glucose, triglycerides, cholesterol, high density lipoprotein (HDL), low density lipoprotein (LDL), very low density lipoprotein (VLDL), total bilirubin, alanine aminotransferase (glutamic oxaloacetic transaminase) (ALT), aspartate aminotransferase (glutamic pyruvic transaminase) (AST), alkaline phosphatase, total creatine phosphokinase (CPK) and isoenzymes, -glutamyl (GGTP), total lactate dehydrogenase (LDH) and isoenzymes, triiodothyroxine (T3), thyroxine (T4), thyroid stimulating hormone (TSH), insulin, human growth hormone (HGH), angiotensin I, aldosterone, cortisol and adrenocorticotrophic hormone (ACTH).

For STS-1, -2, -3 and -4, twenty-four-hour urine pools were collected 30 days before flight (F-30). They were also collected on Landing Day (L+0) (STS-1, -2 and -3) or on day four after landing (L+4) (STS-4). The samples were analyzed for volume, specific gravity, osmolality, sodium, potassium, chloride, calcium, magnesium, phosphate, uric acid, creatinine, cortisol, aldosterone, antidiuretic hormone (ADH), epinephrine and norepinephrine.

For each crewman, the mean and standard deviation for the three preflight days were calculated for each parameter and used as the best preflight control value to compare with postflight findings. The percent change was calculated for each crewman for L+0 and L+3, +4 or +5, and the mean percent change was determined for L+0 and for L+3, +4 and +5. The student test was used to identify significant differences.

RESULTS

Significant changes in blood and urine chemistry, biochemistry and endocrinology are listed on Table 6-1 by an asterisk.

Serum Biochemistry - L+0

In five out of eight crewmembers, serum osmolality had decreased from the preflight control value a maximum of 2% upon landing (Table 6-1); however, in two crewmembers from the shorter flights it increased by 4 or 5%. The concentration of sodium decreased a maximum of 3% in all but two crewmembers; the mean decrease was significant. Decreases in potassium concentration were generally greater (up to 15%) and serum potassium decreased significantly in all crewmen. Chloride concentration increased slightly in most crewmen.

Serum calcium increased a maximum of 9% in all crewmen, a significant change. Inorganic phosphate increased by 6-28% in five crewmen out of eight (Table 6-1). Magnesium decreased in all but two individuals.

Blood urea nitrogen values on day L+0 had increased considerably over preflight control levels in all but one crewman, in whom it remained the same; whereas uric acid decreased in all but two crewmembers (Table 6-1).

Table 6-1
Serum or Plasma Biochemistry and Endocrinology

Parameter	Apollo Immediately Postflight Mean % Change from Preflight	Skylab Inflight Day 3,4 Mean % Change from Preflight	ASTP Immediately Postflight Mean % Change from Preflight	STS-1-4 Immediately Postflight Mean % Change from Preflight	STS-1-4 Several Days (3-5) Postflight Mean % Change from Preflight
Number of Crewmembers	33	9	3	8	8
Osmolality	-0.7	-0.6	-0.7	0.5	0.6
Na	-0.4	-1.5	-0.7	-1.0*	0.2
K	-7.3	3.6	-1.8	-8.9*	-2.6
Cl	-0.6	-0.9	-1.6	1.3	0.9
Ca	1.0	6.5	0.8	5.4*	1.8
Mg	-5.0		-3.2	-2.1	9.3
IPO_4	0	11.7	5.7	5.3	0.5
Uric Acid	-14.8		-9.0	-6.3	-12
BUN	11.9		30	19.1	-7.0
Creatinine	8.3	4.3	22	8.3	-0.6
Glucose	9.8	4.2	-0.4	24.3*	-1.9
Triglycerides	-24.3		3.6	-18.4	-28.1
Cholesterol	-6.0		-5.7	1.6	-10.8
HDL Cholesterol				1.6	
LDL Cholesterol				4.6	
VLDL Cholesterol				-17.9	
Chol/HDL Risk				-0.1	
LDL/HDL Risk				1.4	
Total Bilirubin	12.5		-49	12	-23
ALT			169	-2.1	-0.9
AST	-4.2		33	-13	-0.8
Alkaline Phosphatase	2.8		24	11	5.0
CPK	-11.3		-16	37.6	-10.1
GGTP				18	1.5
LDH	-10.1		48.5	21.9	7.8
T_3	-1			2.8	-3.5
T_4	12			22*	10
TSH				21	-9.1
Insulin	32	-9.1	160	183*	34
HGH	304	52.1	8.0	63	-1.0
Angiotensin I	488	135.3	221	142.0	53.6
Aldosterone		-4.7	12.9	48.6*	25.6
Cortisol	-27	-7.5	19.9	1.5	16.6
ACTH	-24	-58.3		72.3	-1.6

*Statistically significant differences - Preflight vs Immediately Postflight (t-test)

Blood glucose and triglycerides decreased in all but one person. Total and LDL cholesterol increased in all crewmembers on the shorter flights but decreased in all crewmembers on the longer flights. VLDL cholesterol decreased in all but one crewman, and HDL cholesterol varied considerably to result in a mean increase of 1.6%.

There was a mean increase in total bilirubin (Table 6-1) but this was due to a substantial increase in only two crewmen, the same two in which uric acid increased. Bilirubin decreased substantially in five crewmen and remained the same in one.

Alkaline phosphatase and total LDH increased in most crewmen (Table 6-1). The proportion of LDH isoenzyme 1 relative to total LDH decreased in all crewmembers on the shorter flights and increased in all crewmembers on the longer flights. The proportion of isoenzymes 2 and 3 decreased in all but two or one crewmember(s), respectively, whereas the proportions of isoenzymes 4 and 5 increased in all but two crewmembers (the same two for both isoenzymes).

Serum aspartate aminotransferase decreased in most crewmembers but increased in two and remained the same in one crewmember (Table 6-1). CPK increased in six crewmembers and decreased in the other two, and GGTP increased in six individuals and remained the same in two. CPK isoenzyme 1 (MM) was the only CPK isoenzyme in all but one crewmember.

Serum Biochemistry - Several Days Postflight

Differences between the preflight values and those from several days postflight were generally small (less than 10%), being greatest for magnesium (mean increase of 9.3%). Potassium was the same as or below preflight values, but it had generally increased from L+0 values; this was the most consistent blood chemistry finding at this time point (Table 6-1).

By several days postflight cholesterol, which had been higher in short-flight crewmembers and lower in long-flight crewmembers than it was preflight, had decreased below the preflight value in all crewmembers. Glucose and triglycerides were below preflight levels in all but one crewmember. Bilirubin was at or below preflight levels in all crewmembers. Other parameters were more variable, but the mean change in BUN, uric acid, creatinine, AST, ALT, CPK and LDK isoenzymes 3-5 was negative while the mean change in Alk Phos, GGTP, total LDH and LDH isoenzymes 1 and 2 was positive.

Plasma Endocrinology - L+0

Plasma angiotensin and aldosterone each increased in seven crewmembers and decreased in one (Table 6-1). Increases of over 200% were observed in angiotensin in four crewmen. Cortisol, on the other hand, decreased in all but two crewmen (in whom it increased, by more than 200% in one person). ACTH increased (a maximum of 207%) in five crewmen and decreased in three. Aldosterone was the only one of these hormones for which the change was significantly different from preflight levels.

Changes in HGH were highly variable, with four increases (one over 400%) and four decreases among the crewmen (Table 6-1). Insulin and thyroxine were consistently and significantly higher upon landing than they were preflight; changes in T3 and TSH were highly variable but resulted in mean increases.

Plasma Endocrinology - Several Days Postflight

Several days after landing, angiotensin was consistently elevated over

preflight values, although in all but two crewmembers it was lower than it had been immediately after landing. Thyroxine also remained increased over preflight levels in all but one individual, but in all crewmembers it was lower than it had been upon landing. Aldosterone, cortisol and insulin were more variable but the mean change for all crewmembers showed an increase over preflight values; ACTH, HGH, T3, and TSH each showed a mean decrease (by less than 10%) from preflight values.

Urine Biochemistry

The most consistent changes (found in all crewmembers) in chemical parameters of urine were decreases in sodium, potassium, and chloride in specimens obtained during the 24 hours immediately after landing (Table 6-2). Magnesium and uric acid had each decreased at this time in five out of six crewmembers and had increased in one. The changes in sodium, chloride and uric acid were significantly different from preflight levels. Other parameters were more variable, but when means of the percent changes were obtained, specific gravity did not change, whereas osmolality increased and urine volume, calcium, inorganic phosphate and creatinine decreased.

For STS-4, specimens were obtained on the fourth day after landing. The pool represented 24 hours for only one crewman. Excretion of sodium, potassium, chloride, calcium and magnesium had increased by at least 24% in this crewman over values from the preflight specimen (Table 6-2). Urine volume, phosphate, uric acid and creatinine had decreased slightly (by 2-8%).

Urine Endocrinology

On the day of landing, the mean percent change (for six crewmembers) in excretion of all hormones measured showed an increase over preflight levels. The only change that was statistically significant, however, was the increase in aldosterone. Excretion of cortisol and epinephrine had increased in crewmembers of STS-2 and -3 but had decreased in the crew of STS-1, as compared to preflight specimens.

On the fourth day after landing, excretion of aldosterone, ADH and norepinephrine was elevated and excretion of cortisol and epinephrine was depressed in the crewmember for which a 24-hour pool was obtained.

DISCUSSION

Comparison to Results from Other Flight Series

Biochemical and endocrinological results for the first four STS missions are compared to findings on landing of previous space flight crews (34, 35,36). The duration of the STS-1 and STS-2 missions was about 54 hours, that of the STS-3 mission was 192 hours (eight days) and that of the STS-4 mission was 169 hours (seven days). The Apollo crewmen spent an average of twelve days in space, Apollo-Soyuz Test Project (ASTP) crewmembers spent nine days and Skylab data presented were obtained on inflight day three or four.

The most consistent blood chemistry and biochemistry changes in the four series of flights were decreases in sodium, magnesium and uric acid, and increases in calcium, phosphate, BUN, creatinine, alkaline phosphatase, HGH, and angiotensin. Urine specific gravity, osmolality, aldosterone, and cortisol increased while urine volume, sodium, potassium, chloride, phosphate, creatinine, and uric acid decreased in the three series of flights compared in Table 6-2. For most parameters, results from the STS missions were similar to those from other missions. However, STS was the

Table 6-2

Urine Biochemistry and Endocrinology

Parameter	Skylab Inflight Day 1-28 Mean % Change from Preflight	Apollo Immediately Postflight Mean % Change from Preflight	ASTP Immediately Postflight Mean % Change from Preflight	STS-1-3 Immediately Postflight Mean % Change from Preflight	Apollo 72 Hours Postflight Mean % Change from Preflight	STS-4 Five Days Postflight % Change from Preflight
Number of crewmembers	9	33	3	6	33	1
Specific gravity		0.5	0.3	0	-0.3	0.4
Osmolality	21.4	28.9	5.5	15.6	48.3	43.5
Urine volume		-49.2	-12.2	-6.3	-31.1	-8.1
Na	8.8	-48.0	-49.9	-48.2*	-9.8	43.6
K	11	-41.1	-41.3	-23	-31.5	24
Cl	9.5	-61.5	-47.9	-58*	-12.2	49
Ca	80	-16.1	32.5	-19.0	6.5	30
Mg	21.3	-33.7	48.9	-17.7	-19.8	36
IPO_4	21.5	-0.9	-20.1	-5.9	-13.8	-4.4
Creatinine	6.3	-0.5	-20.3	-11.3	-3.9	-6.1
Uric acid	-7.2	-22.7	-27.7	-35.8*	-18.2	-2.2
ADH	-16.7	+152	-24.7	6.2		20.5
Aldosterone	190	+57	231	171		29
Cortisol	73.8	+24	44.4	56.0		-13.5
Epinephrine	-10.7	-8	-41.5	56.9		-40.8
Norepinephrine	-13.7	+0.5	-29.4	36.9		105

*Statistically significant differences - Preflight vs Immediately Postflight (t-test)

only flight series of the group in which serum osmolality and chloride did not decrease. Serum LDH and CPK decreased in Apollo crewmembers but increased in STS crewmembers. Plasma cortisol increased in crewmembers of the STS and ASTP flights but decreased in Apollo and Skylab crewmembers.

Ground simulations have indicated that changes in fluid and electrolyte metabolism probably occur within a few hours of reaching orbit. There were few striking differences between data from the two- and seven-day STS flights. It is possible that after 54 hours of weightlessness a new condition of homeostasis has been established for most parameters. Data from the Skylab missions also indicate that this occurs and that many changes take place during the first day or two of flight (35).

Serum cholesterol increased in all four crewmen on the two day flights but had decreased below preflight levels in these crewmen by several days after landing; in crewmen of the longer STS flights as well as the Apollo flights, it was already decreased at the time of landing. Similar results were seen in both LDL and HDL cholesterol in the STS immediate postflight data.

There is some evidence of a shift in the LDH isoenzymes away from isoenzyme 1 in short flights and toward it in longer flights. The differences in immediate muscle stress and duration of metabolic changes may account for these findings.

Postflight changes in several parameters were more pronounced in urine than in blood. Analyses of urine showed distinct increases in osmolality, aldosterone and cortisol and decreases in sodium, potassium, magnesium and uric acid. Serum chloride changed little from preflight values, but chloride excretion decreased by 58% on landing. Calcium, phosphate, and creatinine increased in serum but decreased in urine, indicating conservation of these substances by the body even though they were apparently released from tissue.

Recovery from Space Flight

Most parameters in which changes were demonstrated at L+0 had returned to or were at least closer to preflight values by three to five days after landing. Since urine data for five days postflight are from only one crewman, they may not be representative. Several blood and urine parameters had continued to change in the same or in the opposite direction. Serum magnesium and urinary sodium, potassium, chloride, calcium and magnesium had increased above preflight values, whereas they had decreased in L+0 specimens. Blood BUN, glucose, cholesterol, bilirubin, CPK, T3 and TSH and urinary cortisol as well as epinephrine had decreased below preflight values after having increased in L+0 specimens. Plasma cortisol and urinary osmolality, ADH and norepinephrine had increased more while serum triglycerides and uric acid had decreased more than at L+0. Plasma insulin, T4 and aldosterone remained elevated and urine volume remained low, although values for these parameters had begun to return to normal.

Blood specimens were collected from the crewmembers of STS-3 on day L+10. A return to normal was indicated for most but not all parameters. The number of samples was so small that no general conclusions can be drawn for the STS missions, but studies of other space flight series (34,35,36) indicate that some parameters do not return to normal for more than a week.

Fluid and Electrolyte Balance

Results indicate that body fluids were decreased on return to normal gravity. Plasma osmolality increased and serum protein and hematocrit were significantly increased over preflight values (see "Hematological and Immunological Analysis"). The consistently increased BUN postflight is further evidence of a body fluid loss. Sodium and potassium had decreased but chloride had increased, suggesting this change may not be aldosterone-mediated. A few days after landing, electrolytes had returned to normal except that potassium remained slightly lower than preflight values. Immediate postflight increases in plasma and urinary aldosterone, which stimulates sodium retention, indicate that a process of fluid and electrolyte conservation had been initiated, probably at about the time of landing since in Skylab crewmembers during flight aldosterone concentration was lower than preflight levels. Serum potassium decreases reflect potassium loss from the body during flight, probably via aldosterone mechanisms. Increased plasma angiotensin also correlates with increased aldosterone. Excretion of sodium, potassium and chloride was decreased on landing, again indicating conservation of electrolytes. This occurred in spite of ingestion by some crewmembers of Gatorade (sugar solution containing a low concentration of electrolytes) or other liquids and salt before or immediately after landing. Several days after landing, the hormones which respond to fluid and electrolyte changes (aldosterone, cortisol and angiotensin) continued to indicate a response to space flight.

Weight Loss

All but one of the STS crewmembers experienced the expected weight loss (1-4%) during flight. After landing all crewmembers began to regain the lost weight. Some of them may have actually lost more weight than the data indicate and the one who apparently gained weight may not have actually gained, because of their ingestion of fluids before the first postflight weighing. Astronauts who participated in the Apollo flights lost an average of 5% of preflight body weight. Part of the STS crewmembers' weight loss is due to loss of fluids but, as in other flight series, there is evidence for loss of lean body mass. Increased BUN serum and creatinine can be associated with increased protein catabolism. Anabolism may begin to increase immediately upon return from space; decreased excretion of uric acid may reflect this occurrence.

Bone Mineral Loss

As in other flight series, serum calcium and phosphate were increased on landing day, indicating loss of these minerals from tissues during flight. However, excretion of calcium and phosphate decreased on landing day, perhaps another indication of conservation of minerals when the flight is over or of a lower intake.

Stress

The plasma indicators of stress consistently indicated a hormonal response to mission conditions. The tissue enzymes CPK, LDH, and GGTP were increased in serum, whereas CPK and LDH had decreased in the Apollo crewmen after two weeks of flight. Differences in the isoenzyme pattern for LDH have been described above, but in general, except in relation to dramatic clinical conditions, isoenzyme patterns are of little value in identifying the tissue responsible for increased serum LDH (37). Immediately after landing, plasma cortisol, ACTH and aldosterone were at levels higher than preflight, and excretion of aldosterone, cortisol, epinephrine, and norepinephrine were increased.

These data suggest that the Shuttle landings were more mentally and physically stressful than landings from Apollo flights because of the increase in both serum enzymes and urine epinephrine concentration. During the postflight testing period, parameters which could relate to diet and stress generally returned to preflight values.

Other Metabolic Changes

HGH has been increased in plasma of crewmembers of all space flight series compared here. Its secretion is usually stimulated by hypoglycemia and it causes blood glucose to increase. Increase of the hormone on day L+0 was associated with increased blood glucose. Bedrest also results in glucosemia (38), possibly because inactive muscle cells take up glucose at a low rate (39). Insulin was also increased postflight. The reasons for increased plasma HGH and insulin at the same time are unclear.

Decreases in plasma uric acid are unusual and could be related to a change in the renal mechanism responsible for return of this metabolite to the systemic circulation or to the uricosuric effects of cortisol or the relationship of LDH to uric acid (40). Increased BUN and creatinine may also indicate changes in renal function. Soviet investigators have also presented evidence (41) that minor alterations in renal function occur during space flight.

Possible Sources of Error

In reviewing the postflight data, differences among treatment of each crew during the immediate postflight activity (for example, ingestion of large amounts of fluids sometimes containing glucose and electrolytes) before acquisition of blood and urine specimens must be remembered. The fact that immediate postflight specimens were obtained at a time of day (usually about noon) different from that for collection of other specimens may also have affected results. The increase in plasma cortisol, for example, may actually have been greater than the data indicate because the peak in circadian rhythm of this hormone occurs early in the morning, close to the time when preflight specimens were obtained (42).

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HEMATOLOGICAL AND IMMUNOLOGICAL ANALYSIS

CHAPTER 7

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ABSTRACT

Peripheral circulating blood from the STS-1 through STS-4 crewmembers was analyzed, generally three times before and twice after each mission. The characteristics of the cellular and humoral blood components and the in vitro reactivity of circulating lymphocytes to mitogenic challenge were evaluated. Lymphocyte stimulability was always decreased postflight with the magnitude of the decrease relating directly to the subjectively-derived degree of stress engendered during the flight. This immunoincompetence was invariably accompanied by a postflight neutrophilic leukocytosis, lymphocytopenia and granulocytopenia which constitutes a classic stress response. The erythrocytic response of the first two crews was typified by a postflight increase in erythrocyte concentration simultaneous with a decreased mean corpuscular volume and an increased hematocrit, all of which signify a loss of fluids (dehydration). For STS-3 and 4, where hemoconcentration was not a problem, there was a decrease in circulating erythrocyte concentration which is consistent with previous findings. Meaningful postflight changes in humoral blood components were not observed. Vigorous, continued investigations of the noted leukocyte and erythrocyte responses are stongly indicated.

INTRODUCTION

Hematological and immunological analyses were conducted on the crewmembers of STS-1 through STS-4 so that body function values necessary for the objective assessment of the health status of the crew before launch and after flight could be evaluated by the medical staff.

MATERIALS AND METHODS

Blood samples were collected by venipuncture from the crewmembers as outlined in Table 7-1. For STS-1 through STS-3 both the prime crew (N=2) and the backup crew (N=2) were sampled. For STS-4 there was no backup crew. Further specifications are given in "Clinical Laboratory Support Plan for Orbital Flight Test (OFT) Missions" (JSC-14374). To obtain useful data, the following constraints were observed: a) a 14-hour fasting preceded all blood withdrawals with the exception of the immediate postflight (L+0) sample which was collected before any postflight intake of food; b) alcoholic beverages were not consumed for a minimum of 14 hours preceding blood sampling; c) blood sampling occurred as one of the first scheduled activities during the examination period and was performed as early in the morning as possible. The L+0 sample was not collected upon arising and therefore is not strictly analogous with the other samples. Three sets of parameters were studied as outlined below.

Cellular Blood Components

The cellular blood components outlined in Table 7-2 were evaluated at each blood draw, except the routine serologies which were performed only on the first sample collection (typically F-30). The methods are detailed in JSC 14374.

TABLE 7-1 - TEST FLIGHT BLOOD SAMPLE COLLECTION SCHEDULE

SAMPLE COLLECTION SCHEDULE

Mission	Duration	Preflight		Postflight	
		Descriptor	Date	Descriptor	Date
STS-1	54 hrs., 21 min.	F-30	3/3/81	L+0	4/14/81
		F-10	3/31/81	L+3	4/17/81
		F-2	4/8/81		
STS-2	54 hrs., 13 min.	F-62	9/11/81	L+0	11/14/81
		F-22	10/21/81	L+4	11/18/81
		F-10	11/2/81		
		F-2	11/10/81		
STS-3	192 hrs., 5 min.	F-30	2/22/82	L+0	3/30/82
		F-12	3/10/82	L+3	4/2/82
		F-2	3/2/82	L+10	4/9/82
STS-4	169 hrs., 11 min.	F-30	5/24/82	L+0	7/4/82
		F-10	6/17/82	L+5	7/9/82
		F-2	6/25/82		

TABLE 7-2 - CELLULAR COMPONENTS EVALUATED FROM SHUTTLE 1-4 CREWMEMBERS

Parameter	Anticipated Range	
Erythrocyte Count	4.1-5.5	($X10^{12}/1$)
Reticulocyte Count	0.3-1.4	(%)
Reticulocyte Number	18-158	($X10^{9}/1$)
Reticulocyte Production Index	1	
Hemoglobin	12.9-16.5	(g/dl)
Hematocrit	0.39-0.48	(1/1)
Indices		
Mean Corpuscular Volume	82-100	(fl)
Mean Corpuscular Hemoglobin	28-33	(pg/cell)
Mean Corpuscular Hemoglobin Concentration	31.5-36	(g/dl)
Zeta Sedimentation Rate	0.43-0.56	(m/m)
Platelet Count	132-348	($X10^{9}/1$)
White Cell Count	2.9-8.2	($X10^{9}/1$)
Differential		
Neutrophil %	36.8-72.4	(%)
Neutrophil Number	1.1-6.05	($X10^{9}/1$)
Lymphocyte %	21.5-57.9	(%)
Lymphocyte Number	0.8-3.5	($X10^{9}/1$)
Monocyte %	0-6	(%)
Monocyte Number	0.2-0.4	($X10^{9}/1$)
Eosinophil %	0-8	(%)
Eosinophil Number	0-0.5	($X10^{9}/1$)
Basophil %	0-1.5	(%)
Basophil Number	0-0.9	($X10^{9}/1$)
Bands %	0-2.7	(%)
Bands Number	0-0.2	($X10^{9}/1$)
Routine Serology		
Hb_S AG	Non-Reactive	
HAVAB	Non-Reactive	
RPR	Non-Reactive	
CRP	Negative	

Humoral Blood Components

The humoral blood components outlined in Table 7-3 were evaluated for each crewmember at each blood draw. The methods are detailed in JSC 14374.

Cellular Immunology Analyses

The ability of peripheral lymphocytes to respond in vitro to mitogenic challenge was evaluated by the measurement of 3_H thymidine incorporation into newly-formed DNA. A unique and highly sensitive modification of the Apollo and Skylab methodology was used for the first time with the STS samples. With this technique, aliquots of lymphocytes were incubated with the mitogen phytohemagglutinin for 60, 72, 84, or 96 hours at a concentration of 1, 2, 5, 10, 25, 50, or 100 mg of mitogen per millimeter of culture. In this way, response curves relating 3_H thymidine uptake both to incubation time and to mitogen concentration could be constructed. The lymphocyte response was then taken to be represented by the maximum count per 10 minutes at the optimum incubation time and optimum mitogen concentration, minus the background count for the control which was incubated for the same length of time (without mitogen).

Cellular immunology analyses were conducted on blood collected with sodium heparin whereas ethylenediaminetetraacetic acid (EDTA) was the anticoagulant of choice for the cellular hematology measurements. Humoral evaluations were conducted on serum from standard clot tubes. In all cases, Vacutainer (TM) tubes were used for blood collection. The blood collection and distribution schedule is presented in Table 7-1.

RESULTS

Cellular Immunology Analyses

The results of the in vitro lymphocyte blast transformation analyses are given in Table 7-4. To preserve the anonymity of each subject, the crewmembers are identified in the order of the magnitude of the postflight decrease in lymphocyte response to phytohemagglutinin. The same identification schema is used throughout this report. In all cases the postflight blast transformation was less than the preflight mean. Although no subjective measurements were made of the stress responses experienced by the astronauts, the numerical ordering of the crewmembers generally follows decreasing incidence of inflight difficulties.

Cellular Blood Components

The postflight alterations in the number of the major leukocyte components are presented in Table 7-5. The total number of neutrophils in the peripheral blood of all astronauts were increased postflight. In contrast, the numbers of lymphocytes and eosinophils were decreased postflight. This noted decrease in the lymphocyte number did not numerically affect the above mentioned loss of lymphocyte function as all blast transformation analyses were conducted on lymphocyte populations of the same density.

The postflight alterations in the numbers of major erythrocyte indicators are presented in Table 7-6. Erythrocyte concentrations increased in the postflight peripheral blood of crewmembers 1 through 4. Additionally, postflight hematocrits were increased and the mean corpuscular volume was decreased for these crewmembers, all of which belonged to the first two Shuttle missions. By contrast, the erythrocyte concentrations and mean corpuscular volumes increas-

TABLE 7-3 - HUMORAL BLOOD COMPONENTS EVALUATED FROM SHUTTLE 1-4 CREWMEMBERS

Parameter	Anticipated Range	
Total Serum Proteins	6.4-7.8	(g/dl)
Protein Electrophoresis		
Albumin	3.7-5.2	(g/dl)
Alpha-1-Globulin	0.1-0.4	(g/dl)
Alpha-2-Globulin	0.3-0.8	(g/dl)
Beta Globulin	0.6-1.0	(g/dl)
Gamma Globulin	0.6-1.5	(g/dl)
Immunoglobulins		
IgG	500-1586	(mg/dl)
IgA	26-347	(mg/dl)
IgM	1.5-300	(mg/dl)
IgD	0-14	(mg/dl)
Transferrin	100-352	(mg/dl)
Haptoglobin	0-278	(mg/dl)
Ceruloplasmin	16-46	(mg/dl)
Alpha-2-Macroglobulin	60-639	(mg/dl)
Alpha-1-Anti-Trypsin	112-336	(mg/dl)
Beta-1-A-Globulin	35-141	(mg/dl)
Complement Factor 3	75-232	(mg/dl)
Complement Factor 4	12-49	(mg/dl)
Hemopexin	51-107	(mg/dl)
Alpha-1-A-Glycoprotein	29-103	(mg/dl)
Lipoprotein		
Alpha	19-39	(%)
Pre-Beta	7-25	(%)
Beta	45-64	(%)
LDH Isoenzymes		
Isoenzymes 1	19-40	(%)
Isoenzymes 2	21-42	(%)
Isoenzymes 3	10-23.5	(%)
Isoenzymes 4	2-14	(%)
Isoenzymes 5	4-23.5	(%)
CPK Isoenzymes		
MM	4-187	(IU/l)
MB	0-9	(IU/l)
BB	0	(IU/l)

TABLE 7-4 - IN VITRO LYMPHOCYTE BLAST TRANSFORMATION AMONG CREWMEMBERS OF STS-1 AND STS-4

LYMPHOCTYE BLAST TRANSFORMATION

COUNT*

Crewmember	Preflight Mean	Postflight Value	% Change
1	126,352	48,784	- 61
2	119,618	53,121	- 56
3	101,368	51,016	- 50
4	103,421	53,345	- 48
5	113,151	67,848	- 40
6	97,746	70,644	- 28
7	77,798	58,444	- 25
8	110,339	90,146	- 18

Lymphocytes are stimulated with phytohemagglutinin and evaluated by measurement of ^{3}H thymidine uptake - *Counts are given as maximum ^{3}H degradation in 10 minutes minus the background.

TABLE 7-5 - POSTFLIGHT ALTERATIONS IN MAJOR LEUKOCYTE INDICATORS
(SHUTTLE MISSIONS 1-4)

Measured Factor	Crewmember	Preflight Mean	Preflight SD	Postflight Value	% Change
Neutrophil Number ($\times 10^9$/L)	1	3.43	0.54	9.01	+ 163
	2	2.62	0.13	7.14	+ 195
	3	2.12	0.48	4.90	+ 131
	4	2.96	0.24	5.96	+ 101
	5	2.86	0.45	7.45	+ 160
	6	1.77	0.38	6.46	+ 265
	7	3.06	0.21	8.22	+ 169
	8	2.82	0.06	12.64	+ 348
Lymphocyte Number ($\times 10^9$/L)	1	2.21	0.67	2.17	- 2.1
	2	2.18	0.32	1.27	- 41.7
	3	1.94	0.05	1.89	- 2.6
	4	1.50	0.32	1.07	- 28.7
	5	1.73	0.31	1.57	- 9.2
	6	2.26	0.27	2.09	- 7.5
	7	2.24	0.71	1.49	- 33.5
	8	2.67	0.14	4.98	+ 86.5
Eosinophil Percent (%)	1	6	2.65	0	- 100
	2	2	0	0	- 100
	3	1	0.58	1	0
	4	5	1.50	0	- 100
	5	0.3	0.47	2	+ 567
	6	4	3	0	- 100
	7	7	1.73	0	- 100
	8	4	1.53	0	- 100

TABLE 7-6 - POSTFLIGHT ALTERATIONS IN MAJOR ERYTHROCYTE INDICATORS
(SHUTTLE MISSIONS 1-4)

Measured Factor	Crewmember	Preflight Mean	Preflight SD	Postflight Value	% Change
Erythrocyte Number ($\times 10^{12}$/l)	1	5.24	0.34	5.91	+ 12.9
	2	4.70	0.09	5.21	+ 10.9
	3	4.51	0.08	5.15	+ 14.2
	4	4.18	0.11	4.71	+ 12.7
	5	5.28	0.08	4.83	- 8.5
	6	4.93	0.03	4.50	- 8.7
	7	4.72	0.18	4.45	- 5.7
	8	4.79	0.13	4.38	- 8.6
Reticulocyte Number ($\times 10^{9}$/l)	1	29.4	7.0	29.5	+ 0.3
	2	31.0	12.0	57.0	+ 83.8
	3	27.2	4.5	20.6	- 24.3
	4	39.0	16.9	28.0	- 28.2
	5	77.1	19.1	67.6	- 12.3
	6	50.9	16.0	22.5	- 55.8
	7	43.9	9.7	35.6	- 18.9
	8	47.8	16.0	21.9	- 54.2
Hematocrit (l/l)	1	0.42	0.03	0.48	+ 14.3
	2	0.44	0.01	0.47	+ 6.8
	3	0.42	0	0.46	+ 9.5
	4	0.39	0.01	0.41	+ 5.1
	5	0.46	0.01	0.45	- 2.2
	6	0.45	0	0.43	- 4.4
	7	0.42	0.02	0.44	+ 4.8
	8	0.46	0.01	0.50	+ 8.7
Mean Corpuscular Volume (Fl)	1	85	2.08	81	- 4.7
	2	94	0.58	90	- 4.3
	3	93	1.73	89	- 4.3
	4	93	0.50	87	- 6.5
	5	87	0.82	93	+ 6.9
	6	91	0	95	+ 4.4
	7	89	2.08	103	+ 15.7
	8	97	1.15	114	+ 17.5

ed following the STS-3 and 4 flights, with the postflight hematocrit likewise elevated for crewmembers 7 and 8 (STS-4).

Humoral Blood Components

Meaningful postflight changes in humoral blood components were not observed for the first four Shuttle missions.

DISCUSSION

The major postflight alterations may be loosely considered to be the results of two separate phenomena. One phenomenon is manifested by a decrease in *in vitro* lymphocyte function and *in vivo* alterations in the numbers of major leukocyte components in the peripheral blood. For simplicity this will be referred to as the leukocyte response. The second phenomenon, referred to as the erythrocyte response, involved postflight changes in the number and size of erythrocytes, numbers of circulating reticulocytes, and plasma-cell volume balance. Although all of these factors are interconnected (and are influenced by many physiological processes not herein discussed) they will be evaluated in terms of the resultant on either the leukocytic or erythrocytic component of peripheral blood. A summary of our space flight experience with these systems is outlined in Table 7-7.

The Leukocyte Response

The postflight leukocyte response of American astronauts and of Soviet cosmonauts has been studied by various methods for more than a decade. Analyses conducted throughout the eleven flights of the American Apollo program failed to demonstrate any postflight alteration in RNA or DNA incorporation in response to phytohemagglutinin (PHA) exposure, although a postflight lymphocytosis was reported for a majority of the 33 crewmembers (1,2). The technique used for lymphocyte isolation during the Apollo series has been shown to selectively remove B lymphocytes and a subset of T lymphocytes prior to culture (3,4) and may have contributed to the inability to demonstrate alterations. Similarly, the postflight functional capacity of crew lymphocytes, measured in terms of DNA production in response to PHA, was reported unchanged following the three American Skylab visits (5). However, postflight RNA production was reported to have been depressed concomitant with an increase in leukocyte absolute count (5,6). Variable lymphocyte responses to a variety of mitogens, as well as absolute leukocytes were reported among the participating astronauts following the US-USSR joint Apollo-Soyuz Test Project (ASTP) Flight (7). It is not possible to attach any space flight-related importance to the resulting data because the astronauts were exposed to toxic levels of nitrogen tetroxide upon landing.

Alterations in the *in vitro* response of cosmonaut lymphocytes were reported following the flights of Soyuz 6, 7, 8 and 9 (8,9). Although 3_H uridine uptake was estimated by photographic film exposure, and the results were variable, these analyses gave an early indication that lymphocyte activity may be depressed following space flight. Comparative pre- and postflight measurements of peripheral lymphocyte and total leukocyte numbers were taken for these missions as well as for the Soyuz 11 visit to the Salyut 1 space station and the Soyuz visits to the Salyut 4 space station. Although results were quite variable an impression is given of a postflight leukocytosis concurrent with a postflight lymphocytopenia (10-12). In addition, a "... diminished (postflight) reactivity of T lymphocytes..." was reported after both the 30-day and the 63 day visit to the Salyut 4 space station (10).

TABLE 7-7 - MAJOR REPORTED POSTFLIGHT TRENDS FOR THREE AMERICAN SPACE FLIGHT SERIES

Mission Series	Postflight Decreases	Postflight Increases	No Change
Gemini	Erythrocyte Mass Erythrocyte Cell Membrane Components	Mean Corpuscular Volume Osmotic Fragility Leukocytes (Neutrophils)	
Apollo	Erythrocyte Mass	Hemoglobin Concentration (MCH, MCHC) Leukocytes (Neutrophils) α_2 - globulin Ig A Haptoglobin and Ceruloplasmin	Erythrocyte Count Hematocrit Most Serum Proteins Cell Imunology
Skylab	Erythrocyte Mass Erythrocyte Number Reticulocyte Number Plasma Volume Hemoglobin Concen. Hematocrit Blast RNA production	Leukocytes (Neutrophils) Mean Corpuscular Volume Mean Corpuscular Hemoglobin (MCH)	Lymphocyte Absolute Count

Following the flights of Soyuz 24/Salyut 5, Soyuz 26 and 27, and Soyuz 28/Salyut 6 there was an increase of both the spontaneous lymphocyte activity and the maximum PHA-induced response. Since the data were converted to a Stimulated Index a decrease in lymphocyte reactivity was reported (13).

Analysis of the results presented in Table 7-4 indicates that the in vitro lymphocyte response to the mitogen phytohemagglutinin was always reduced following the first four Shuttle flights. Although the crewmembers are ranked, for the sake of anonymity, in order of the magnitude of the response, this order closely coincides with the mission sequence. Crewmembers one through four represent the crews from the first two Shuttle space flights. Although both of these missions lasted for only 35 orbits (STS 1 = 54 hrs, 21 min.; STS 2 = 54 hrs., 13 min.) they contained the most stressing situations. Crewmembers 5 and 6 flew on the 129 orbit (192 hrs., 5 min.) STS 3 flight. Crewmembers 7 and 8 comprised the 112 orbit (169 hrs., 11 min.) STS 4 crew (Table 7-1) and are generally considered to have been subjected to the least amount of inflight stress. Therefore, if one remembers that evaluations of the degree of stress experienced in the mission is based on subjective evidence, this factor may be shown to relate directly to the degree of loss in blast transformability.

Reduction in the ability of lymphocytes to respond to the mitogen PHA has been reported to result from ingestion of certain drugs (14), thermal trauma (15), viral infections (16), prolonged exercise (17), bereavement (18), sleep deprivation (19), radiation exposure (20), anxiety, depression, and life change stress (21). At this time we have no reason to believe that reduced gravity directly affects blastogenesis. However, there may be some indirect effects as in the case of the stress produced by trying to maintain positional equilibrium in the absence of a significant gravitational vector. Therefore, it is most logical to assume that the noted postflight decrease in "T" lymphocyte activity is caused by conventional stressors, as described by Selye (22) and has no direct connection to the hypogravity state. This analysis should in no way be used to suggest that the noted response is unimportant to space flight. Regardless of the affectors involved, the decrease in blastogenic response represents an indication of a major change (or changes) in the immune mechanism(s) during space flight. The phenomenon deserves thorough investigation during future Shuttle missions.

Analysis of the postflight numerical changes experienced within the population of circulating eosinophils and lymphocytes (as demonstrated in Table 7-5) support the hypothesis that stress is important as an affector. Granulocytes are sequestered in, and dynamically balanced between a circulating granulocyte pool (CGP) and a marginal granulocyte pool (MGP). Normally the pools are of about equal size (23), although an imbalance has been shown to result from a variety of stress-inducing situations. For example, it has long been known that exercise and/or excitement give rise to an increased leukocyte count (23,24) as does acute anoxic anoxia (25), pain, nausea, vomiting, anxiety (26) and increased steroid levels (27). The resulting neutrophilia reflects demargination of cells (that is, release from walls of postcapillary venules) and is generally quite transitory (23). Although there is generally a diurnal variation in the balance between the two granulocyte pools (23) the magnitude of such a change would not account for the noted postflight increases (Table 7-5).

As opposed to the neutrophil response, stress generally results in a sequestering of eosinophils in the reticuloendothelial system and is therefore associated with a decrease in the circulating pool (28). This phenomenon is consistent with the postflight loss of circulating eosinophils as illustrated in Table 7-5. Such a response has long been associated with increases in various affectors such as adrenal steroids and ACTH (29,30) which were associated, several decades ago, with a simultaneous reduction in eosinophils and lymphocytes and a rise in neutrophils (31).

The Erythrocyte Response

The data presented in Table 7-6 illustrate that the STS-1 and 2 crewmembers experienced a postflight increase in the number of peripheral circulating erythrocytes with a simultaneous decrease in mean corpuscular volume. This response, which is generally opposite to that which was reported to occur following Apollo (2) and Skylab (5) missions, was likely the result of fluid loss as indicated by the increase in hematocrit. Conversely, the STS 3 and 4 crewmembers demonstrated a postflight decrease in the number of circulating erythrocytes and an increase in the mean corpuscular volume. For crewmembers 7 and 8 (STS 4) the MCV was high enough to affect an increase in the hematocrit.

The decreases in red cell mass which have previously been reported were at one time thought to be the results of an intravascular hemolysis, triggered by a failure to maintain osmotic balance in an hyperoxic breathing atmosphere (32,33). Nevertheless, subsequent studies with Apollo and Skylab (2,5,34) crewmembers led investigators to speculate that the loss may not be due to erythrocyte destruction but to a reduction in the production of cells without compensatory erythropoiesis (2). Whatever the mechanism, it is evident from the data summarized in Table 7-6 that the phenomenon is still with us. Active experimentation leading to the elucidation of this mechanism seems to be in order.

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MEDICAL MICROBIOLOGY OF CREWMEMBERS AND SPACECRAFT DURING OFT

CHAPTER 8

Duane L. Pierson, Ph.D.

INTRODUCTION

The first flight of the Columbia began the era of reusable spacecraft. This concept introduced additional concerns for the health and safety of the crewmembers. The potential buildup of microorganisms on the interior components of the Orbiter necessitated the implementation of an effective microbial contamination control plan.

During the Orbital Flight Test (OFT) phase of the Space Transportation System (STS) program, the major objective of the Microbiology Laboratory was the maintenance of the health and safety of the crewmembers. A pre- and postflight microbial analysis of the crewmembers and the Orbiter was conducted for each OFT flight. An assessment of the patterns and extent of microbial contamination of the Orbiter was completed at the conclusion of each mission.

MATERIALS AND METHODS

Crew Sample Collection

Samples were collected from each crewman for microbial evaluation at approximately F-30, F-10, F-2, L+0, and L+5. Samples were taken from the following areas: ears, nose and throat; a fecal specimen (or rectal swab) and a mid-stream first-void urine specimen. The samples were obtained by Microbiology Laboratory personnel as well as the flight surgeon (rectal swab) and delivered to the laboratory for analyses.

Spacecraft Sample Collection

Microbiology monitoring of the spacecraft was comprised of collecting and analyzing samples from the Orbiter's interior surfaces, waste management system, flight hardware, cabin air and potable water supply. Calcium alginate swabs were utilized to sample 21 surface sites throughout the mid- and flight decks. Samples were collected at F-30, F-2 and L+0. Sampling techniques and analytical procedures are described in the "Microbial Sample Collection Handbook-OFT." The designated areas (25 cm^2) were sampled using two phosphate buffer-moistened swabs. One swab was placed in trypticase soy broth for bacterial culturing, and the other swab was placed in yeast malt broth with antibiotic for isolation of fungi. Samples were placed on appropriate media for quantitation and identification.

The microbial content of the air in the Orbiter was determined by using a small, portable centrifugal air sampler. Cabin air was drawn into the drum by an impeller blade assembly and the microorganisms present in the air impinged upon the surface of a flexible agar strip lining the inside of the drum. The nutrient-containing agar strip was incubated for 48 hours at 25°C for bacterial quantitation. Incubation was continued for seven days for fungal quantitation.

Samples were collected from the Orbiter's potable water supply following servicing for flight and again at F-3. Tests for total bacteria quantitation and for the presence of coliforms, fungi and anaerobic bac-

teria were performed on these samples. All microorganisms isolated from the potable water supply were analyzed in the laboratory for specific identification.

Random samples of all foodstuffs stored onboard the Orbiter were analyzed to assure that acceptable microbial levels were not exceeded. The analytical procedures and microbiological standards have been established for both non-stabilized and thermostabilized foods.

RESULTS AND DISCUSSION

Crew Microbiology

All crewmembers exhibited normal microbial flora in ears, nose, throat and fecal cultures. Table 8-1 lists the medically important microorganisms isolated from the crew samples during the OFT missions. A variety of potential bacterial and fungal pathogens were isolated from the crewmembers during the sampling period, but no overt clinical manifestations resulting from these microorganisms occurred. All fecal specimens were microscopically examined for ova and parasites; no evidence of parasitic infection was found in any sample obtained during the OFT phase.

Cross-contamination of crewmembers occurred during some Apollo missions and the possible consequences made careful monitoring of the crewmembers an important aspect of the Microbial Contamination Control Plan. No evidence for cross-contamination of crewmembers during OFT was recorded. However, it was demonstrated during STS-3 that the microbes present in the cabin air at landing were isolated from the upper respiratory tract of crewmembers. The microbes were not recovered from the crewmembers prior to the flight. This indicated the need for careful monitoring of the air to assure safe levels of airborne microbes were not exceeded. The increase in the number of crewmembers from two to six during the operational phase of STS will greatly augment the potential for microbial cross-contamination among crewmembers; thus, careful monitoring will continue.

Crew Virology

The crewmembers' immunities to specific viral agents were determined by serological analyses. Serum samples were screened for the hepatitis B surface antigen and antibody to the hepatitis A virus. No evidence of infection (prior or current) was found in any of the crewmembers. In addition, all crewmembers demonstrated sufficient immunity to rubella, rubeola and mumps viruses.

Spacecraft Microbiology

The spacecraft environment was further evaluated by collecting and analyzing air samples from both the mid- and flight decks. Quantitative results of both preflight and postflight measurements are shown in Table 8-1. Only the bacterial results are included, but the fungal analysis was similar. A rather significant increase in the numbers of airborne microorganisms occurred during the STS-1 preflight sampling periods. This increase was believed to have resulted from the temporary installation of a blower in the cabin prior to launch. This blower was not utilized on subsequent flights. A significant increase in airborne microbes occurred during STS-2, however, this inflight buildup was not observed during the STS-3 and 4 flights.

Twenty-one surface sites on the mid- and flight decks were sampled at F-30, F-2 and L+0. The F-30 sample allowed an assessment of the cleanup procedures used by ground personnel between flights and the determination of the Orbiter's flight readiness.

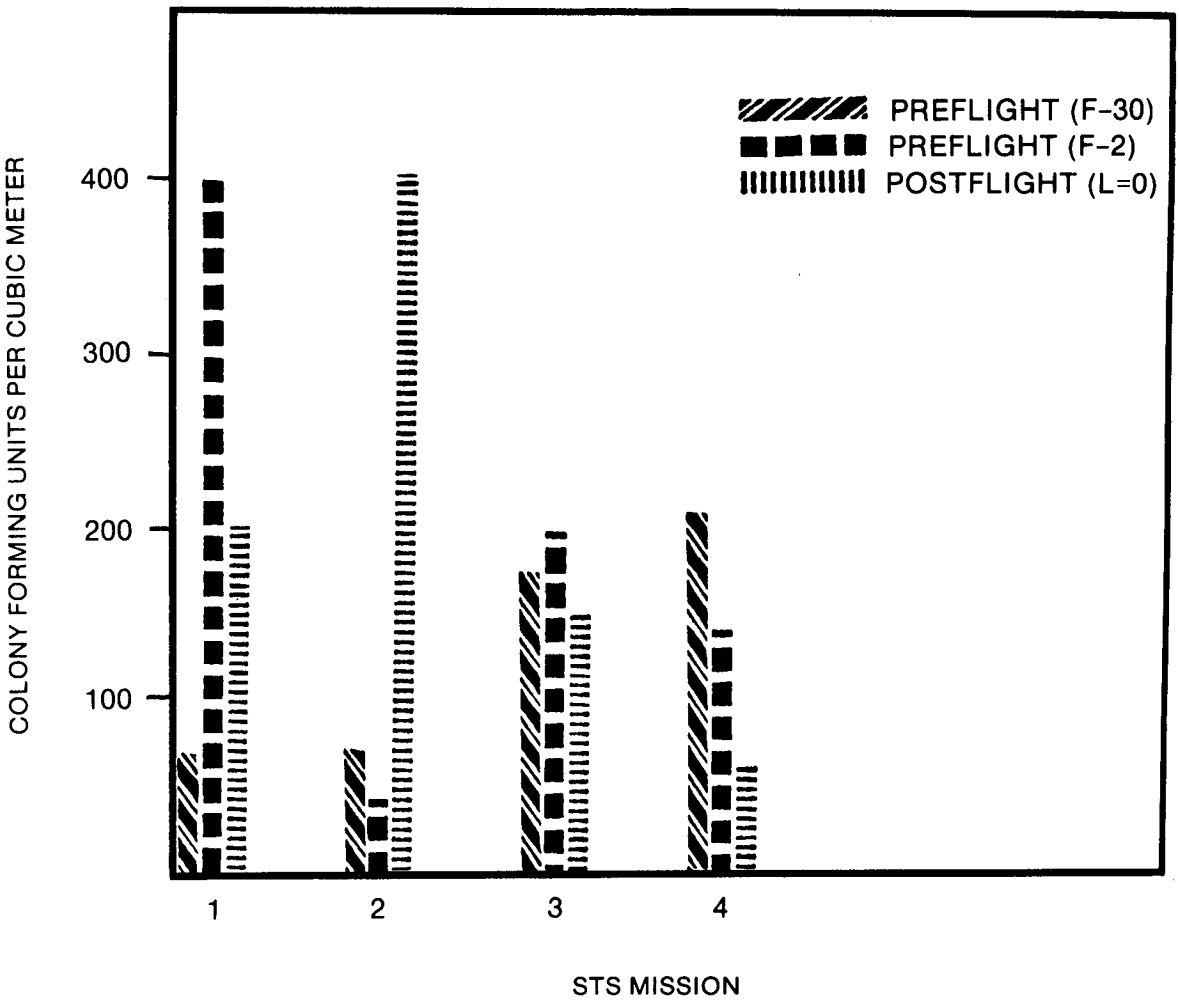

Figure 8-1.- Quantitation of airborne bacteria during OFT.

Samples were taken at F-2 and L+0 to obtain baseline preflight levels and end of mission levels, respectively. The extent of microbial buildup at specific sites during the flight could then be determined. Most sites exhibited a pronounced buildup during the flight. Nevertheless, the bacteria levels dissipated sharply by the time of the F-30 certification sampling for the subsequent flight. This reduction in numbers of microorganisms is the result of either the cleanup procedures between flights or the natural decline of microbes in an unfavorable environment. During the first four flights none of the selected sample sites maintained a high residual level of microorganisms from flight to flight.

In addition to the inflight buildup of microorganisms at various interior sites, a variety of medically important microbes were isolated from the Orbiter's interior (Table 8-2). Most of the potential pathogens were fungi with Aspergillus being the predominant genus isolated.

Potable Water Microbiology

The Orbiter's potable water was sampled after servicing, at F-3 and again at L+0. Microorganisms in the water were quantitated and identified. Various species isolated from the water during the OFT missions are given in Table 8-3. The numbers ranged from 5 to 9100 colony forming units per 100 milliliters of water.

TABLE 8-1
POTENTIAL PATHOGENS ISOLATED FROM CREWMEMBERS DURING OFT

Potential Pathogens	Isolation Site
Staphylococcus aureus	Nose, throat, ear
Pseudomonas aeruginosa	Nose, throat
Enterobacter aerogenes	Nose, throat
Enterobacter hafnia	Throat
α-hemolytic streptococcus	Throat
Candida albicans	Throat, feces
Candida parapsilosis	Nose, ear
Aspergillus (six species)	Nose, throat, ear, feces
Klebsiella pneumonia	Throat
Proteus morganii	Nose
Penicillium citrinum	Urine, feces
Rhodotorula rubra	Ear

TABLE 8-2
POTENTIAL PATHOGENS ISOLATED FROM ORBITER DURING OFT

Potential Pathogens
Staphylococcus aureus
Drechslera hawaiiensis
Rhodotorula rubra
Paecilomyces variotti
Trichosporon cutaneum
Geotrichum candidum
Enterobacter agglomerans
Aspergillus (six species)
Acinetobacter calcoaceticus

TABLE 8-3
POTENTIAL PATHOGENS ISOLATED FROM POTABLE WATER SYSTEM

Potential Pathogen
Pseudomonas denitrificans
Pseudomonas fluorescens
Pseudomonas sp.
Flavobacterium sp.
Enterobacter sp.
Rhodotorula minuto

FOOD AND NUTRITION CHAPTER 9

Richard Sauer and Rita Rapp

The objective of the Shuttle Orbital Flight Test (OFT) food system was to provide a safe, nutritious food supply within the various biomedical, operational and engineering constraints. It was designed to be in a convenient, acceptable form which would allow easy manipulation in the microgravity environment and require a minimum amount of time and effort for preparation and cleanup.

DISCUSSION

Although individual menus were designed and flown for each astronaut on all previous U.S. space programs, for Shuttle OFT a standard four day menu which included three meals and supplied a total of 3000 kilocalories per person per day was used. The standard menu is shown in Table 9-1. Meals stowed aboard Columbia for OFT began with meal B on day one and continued through meal B on Landing Day. The menus were designed to maintain good nutrition by providing at least the recommended levels of twenty nutrients listed in Table 9-2.

A pantry was used on each flight to accommodate individual food preferences and to function as a contingency food supply in case the mission was extended. On nominal missions, the pantry provided extra beverages and snacks. Pantry items could be exchanged for menu items. The pantry was selected and approved by each crew and supplied enough food to provide approximately 2100 kilocalories per person for three days. The pantry contents used on each of the four OFT flights are summarized in Table 9-3. In addition, sufficient food was flown on STS-3 to increase the energy level of menus by approximately 1000 kilocalories per day since one of the crewman had consumed an average of 3900 kilocalories per day during a Skylab mission.

The OFT missions did not have a galley for meal preparation. A water heater and food warming oven were components of the food galley, but since these were not available for OFT, a portable suitcase-type food and beverage warmer was developed for use on missions which do not carry a galley. The food warmer, which was attached to the outside of a stowage locker during the orbital phase of flight, contained a heater in a central plate. Food placed adjacent to the heating plate was heated by conduction (Figure 9-1). The two member OFT crews found that food was heated to a good serving temperature in 15-20 minutes and was too hot to handle or eat in 30 minutes. A metered water dispenser was available, but there was no capability of measuring water added to food.

The food system for OFT utilized types of food and packaging previously used during Apollo, Skylab and ASTP. Types of foods used on OFT included thermostabilized, rehydratable, irradiated, natural form and intermediate moisture. Packages used for individual servings are shown in Figure 9-1 and include the Apollo spoonbowl, Skylab beverage, bite size, flexible foil retort pouches, aluminum and bi-metallic cans. Commercial serving-size portion packets of mustard, catsup, mayonnaise, hot sauce and polyethylene dropper bottles for liquid pepper and liquid salt were supplied. Individual meals were packaged in single meal overwraps, assembled in locker trays and stowed in lockers at the Johnson Space Center (JSC) Food Facility. A new Shuttle package was developed for rehydratable food and beverages to

TABLE 9-1

SHUTTLE-STANDARD OFT MENU

MEAL	DAY 1[1], 5		DAY 2, 6		DAY 3, 7		DAY 4, 8	
A	Peaches	(T)	Applesauce	(T)	Dried Peaches	(IM)	Dried Apricots	(IM)
	Beef Pattie	(R)	Dried Beef	(NF)	Sausage	(R)	Breakfast Roll	(I)(NF)
	Scrambled Eggs	(R)	Granola	(R)	Scrambled Eggs	(R)	Granola w/Blueberries	(R)
	Bran Flakes	(R)	Breakfast Roll	(I)(NF)	Cornflakes	(R)	Vanilla Inst. Brkfst	(B)
	Cocoa	(B)	Choc. Inst. Brkfst	(B)	Cocoa	(B)	Grapefruit Drink	(B)
	Orange Drink	(B)	Orange-Grapefruit Drk	(B)	Orange-Pineapple Drink	(B)		
B	Frankfurters	(T)	Corned Beef	(T)(I)	Ham	(T)	Ground Beef w/	(T)
	Turkey Tetrazzini	(R)	Asparagus	(R)	Cheese Spread	(T)	Pickle Sauce	
	Bread (2X)	(I)(NF)	Bread (2X)	(I)(NF)	Bread (2X)	(I)(NF)	Noodles & Chicken	(R)
	Bananas	(FD)	Pears	(T)	Gr. Beans & Broccoli	(R)	Stewed Tomatoes	(T)
	Almond Crunch Bar	(NF)	Peanuts	(NF)	Crushed Pineapple	(T)	Pears	(FD)
	Apple Drink (2X)	(B)	Lemonade (2X)	(B)	Shortbread Cookies	(NF)	Almonds	(NF)
					Cashews	(NF)	Strawberry Drink	(B)
					Tea w/Lemon & Sugar (2X)	(B)		
C	Shrimp Cocktail	(R)	Beef w/BBQ Sauce	(T)	Cr. Mushroom Soup	(R)	Tuna	(T)
	Beef Steak	(I)	Cauliflower w/Cheese	(R)	Smoked Turkey	(T)(I)	Macaroni & Cheese	(R)
	Rice Pilaf	(R)	Gr. Beans w/Mushrooms	(R)	Mixed Italian Vegetables	(R)	Peas w/Butter Sauce	(R)
	Broccoli au Gratin	(R)	Lemon Pudding	(T)	Vanilla Pudding	(T)	Peach Ambrosia	(R)
	Fruit Cocktail	(T)	Pecan Cookies	(NF)	Strawberries	(R)	Chocolate Pudding	(T)
	Butterscotch pudding	(T)	Cocoa	(B)	Tropical Punch	(B)	Lemonade	(B)
	Grape Drink	(B)						

NOTE: [1] Day 1 (launch day) consists of Meal B and C only

Abbreviations

T --- Thermostabilized
IM --- Intermediate Moisture
R --- Rehydratable
I --- Irradiated
FD --- Freeze-Dried
NF --- Natural Form
B --- Beverage (Rehydratable)

Table 9-2: Minimum Daily Nutritional Levels
Supplied by Shuttle OFT Menus

Nutrient	Amount
Kilocalories	3,000
Protein	56 gm
Vitamin A	5,000 IU
Vitamin D	400 IU
Vitamin E	15 IU
Ascorbic Acid	45 mg
Folacin	400 µg
Niacin	18 mg
Riboflavin	1.6 mg
Thiamin	1.4 mg
Vitamin B_6	2.0 mg
Vitamin B_{12}	3.0 µg
Calcium	800 mg
Phosphorus	800 mg
Iodine	130 µg
Iron	18 mg
Magnesium	350 mg
Zinc	15 mg
Potassium	70 mEq
Sodium	150 mEq

Table 9-3: Pantry for Orbital Flight Test Missions

Food Item	STS-1	STS-2	STS-3	STS-4
Rehydratable Beverages				
Apple Drink	8	8	10	0
Coffee, Black	12	10	0	30
Coffee, Cream and Sugar	8	10	0	0
Coffee, Sugar	0	0	0	20
Grape Drink	0	0	0	3
Grapefruit Drink	6	6	10	10
Instant Breakfast, Chocolate	0	0	0	2
Instant Breakfast, Vanilla	0	0	0	2
Lemonade	8	8	10	3
Orange Drink	8	8	10	2
Strawberry Drink	0	0	10	3
Tea	10	10	0	0
Tea with Sugar	0	0	0	3
Tea with Lemon and Sugar	0	0	10	2
Total	60	60	60	80
Snacks				
Almonds	2	4	2	3
Apricots, Dried	4	4	2	2
Bananas, Freeze Dried	2	0	0	0
Dried Beef	4	4	4	2
Butter Cookies	0	0	3	3
Candy Coated Chocolates	0	0	4	3
Cashews	2	4	2	3
Chocolate Chip Food Bar	0	0	5	2
Graham Crackers	0	0	0	3
Granola/Raisin Food Bar	4	4	5	0
Jelly	0	0	0	2
Peaches, Dried	2	2	2	2
Peanut Butter	4	4	2	2
Peanuts	4	4	2	7
Pears, Freeze Dried	2	0	0	0
Pecan Cookies	0	0	3	2
Rye Bread	4	4	0	0
Shortbread Cookies	4	4	0	0
Soda Crackers	4	4	4	3
Total	50	42	40	40

Table 9-3: Pantry for Orbital Flight Test Missions (Continued)

Food Item	STS-1	STS-2	STS-3	STS-4
Thermostabilized Food				
Beef Steak (I)	4	8	4	4
Corned Beef (I)	4	4	0	0
Frankfurters	0	0	2	2
Ham	4	4	4	4
Meatballs w/BBQ	0	0	2	2
Pudding, Butterscotch	2	0	0	0
Pudding, Lemon	2	0	0	2
Salmon	2	2	0	0
Turkey, Smoked (I)	4	2	2	2
Total	22	20	14	16
Rehydratable Food				
Asparagus	3	2	0	0
Beef Patty	2	2	2	2
Chicken and Rice Soup	0	0	4	2
Green Beans w/Broccoli	3	2	0	0
Green Beans w/Mushrooms	2	2	0	0
Italian Vegetables	2	2	0	2
Peach Ambrosia	3	2	0	4
Peas w/Butter Sauce	0	0	2	2
Potato Patty	0	2	2	2
Rice Pilaf	0	0	2	0
Sausage Patty	2	2	0	0
Scrambled Eggs	0	0	2	2
Strawberries	3	2	0	4
Turkey Tetrazzini	0	0	2	2
Total	20	18	16	22

replace both the Apollo spoonbowl and the Skylab beverage packages (Figure 9-2). The square package has a rigid, opaque base with a clear, flexible lid. Water is introduced into the package through a septum by a needle. Rehydratable foods and beverages were packaged in the new container for meal C, day three, on STS-3 and meal C for days three, four and five on STS-4. The new packages were packed two meals per overwrap (Figure 9-2). For these two missions, a needle adapter was attached to the water dispenser. This dispenser was normally used to rehydrate food and beverages in packages containing a one-way water valve.

Foods are opened by removing the flexible lids with a sharp knife or

SHUTTLE
OFT FOOD SYSTEM

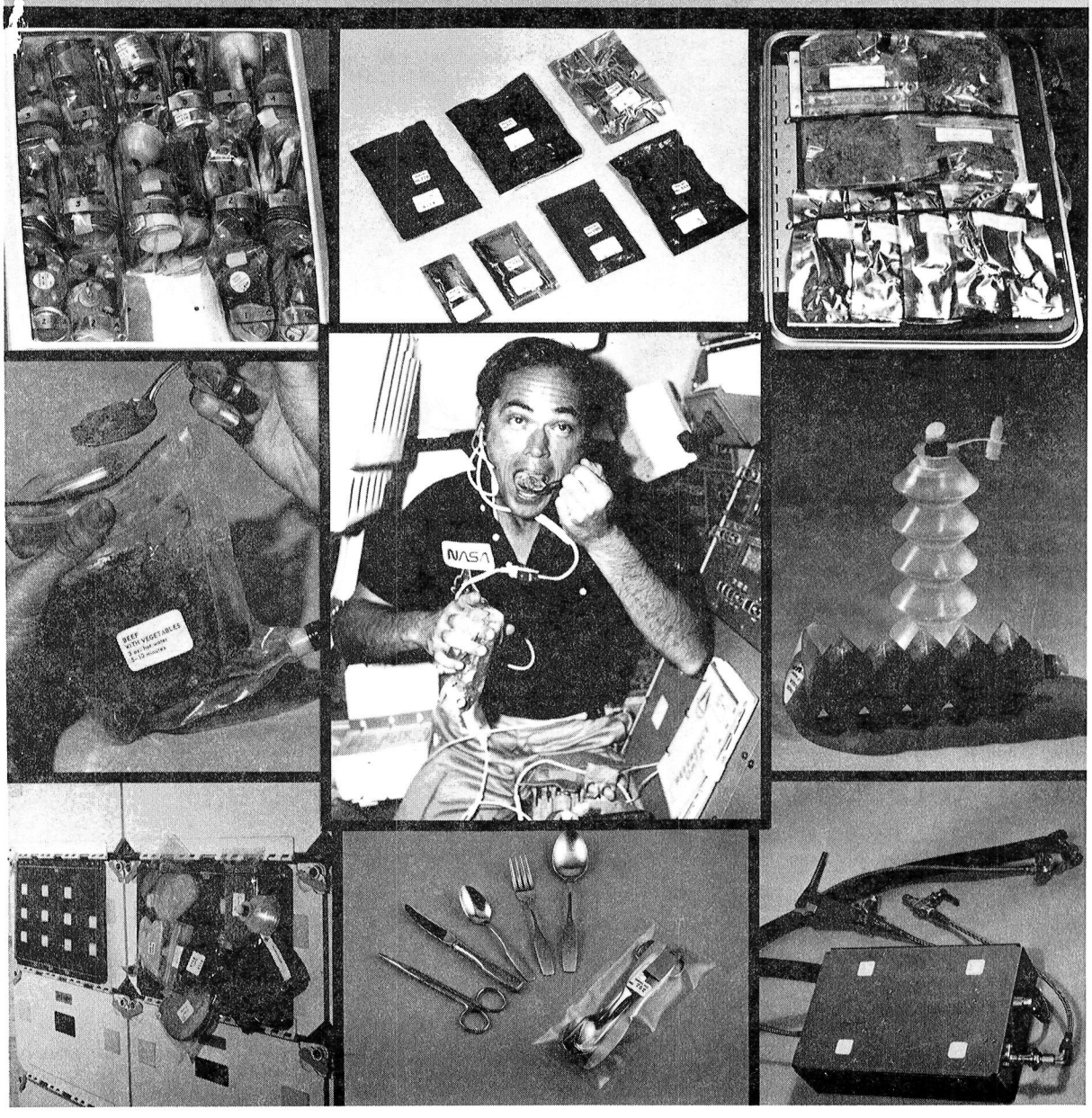

Figure 9-2.- The new square Shuttle package for rehydratable foods and beverages. Velcro was attached to the bottom of the square so it would adhere to the OFT meal tray for evaluation on STS-3 and STS-4.

scissors and eaten using normal utensils. Beverages are consumed from the square-rehydratable package through a polyethylene straw inserted into the septum after the beverage is rehydrated. The STS-4 crew found that the clamp on the straw, which is designed to prevent the fluid from flowing out of the package, is necessary for some beverages. In general, the square rehydratable package functioned very well with no problem encountered with the needle-septum rehydration concept. The package facilitates eating by allowing consumption from an open container with normal utensils. The only disadvantage was that it generated a larger volume of trash. All rehydratable foods and beverages will be packaged in the square rehydratable package on STS-5 and subsequent missions.

Frozen sandwiches were prepared in the JSC Food Facility and shipped to the Kennedy Space Center (KSC) for STS-1, 2 and 3. Water was placed in two flight beverage packages the night before launch and refrigerated. The water and frozen sandwiches were placed in each astronaut's suit pocket on launch morning for their first inflight snack. The sandwiches were to be consumed within six hours of launch or discarded. For STS-4, ham sandwiches were prepared at KSC on the morning of launch, placed in polyethylene zip-lock bags and kept refrigerated until they were placed in the astronaut's suit pockets. An apple was also stowed in the suit pocket on STS-4.

An in-suit food bar was provided for each astronaut on all flights for use in case of an extra vehicular activity (EVA), but these were not used during the OFT missions.

A small experimental freezer was placed onboard for the STS-4 mission. It contained three servings of hand-packed vanilla ice cream in the new square Shuttle package and one filet mignon which had been broiled, packaged in a laminated-foil pouch, and quick frozen at the JSC Food Facility. On the second day of flight, the freezer was turned off for six hours and then switched to a refrigerator temperature, so the frozen food scheduled to be consumed on days one and two of the flight could thaw. The crew used the refrigerator to chill beverages, fruits, and pudding enhancing the flavor and acceptability of these items.

Preflight food service was provided for the prime, back-up and support crews during Countdown Demonstration Test (CDDT) and Health Stabilization Period for all OFT missions. Meals were prepared and served at both the JSC preflight food facility and the KSC crew quarters. There were no requirements to determine nutritional intake data during preflight or inflight phases of the OFT missions except for STS-4. On STS-4, two student experiments required nutritional intake data both preflight and inflight. Nutrient intake was estimated for each crewman during the seven days immediately preceding and the seven and one half days of the flight. During the STS-4 preflight period, all food was weighed for each crewman and nutrient intake was determined using a computerized USDA data base. During the STS-4 flight, the crew kept a log of their food intake. All flight foods were analyzed in the Medical Sciences Laboratory at JSC.

In support of fluid loading as a countermeasure to deconditioning, four additional eight ounce beverages per crewman were provided for the morning of reentry on STS-3 and STS-4. On STS-3, the crew consumed the beverages on the day of scheduled reentry, which was 24 hours prior to actual landing. On STS-4, one gram sodium chloride tablets (eight per crewman) were added. They consumed two salt tablets with each eight ounce beverage.

Sandwiches and snacks were provided postflight for all crews on their return trip from the landing site to Ellington, AFB, TX. Postflight food service was also provided for the prime crew immediately after touchdown at White Sands, N.M., for STS-3 and at Edwards AFB, CA. for STS-4.

Although there was no requirement to measure inflight nutrient intake on the first three missions, food consumption was estimated from an inventory of food packages returned either unused in locker trays or empty in the trash. The food package inventory from STS-4 was compared with the crew's onboard food log to more accurately determine the inflight nutrient intake. Table 9-4 lists the mean daily inflight nutrient consumption per person per OFT mission.

Problems encountered during the flights which impacted the food system were as follows:

STS-1	The pantry was packed too tightly and it was difficult to restow the food packages once they were removed.
STS-2	The water flow was slow and there was excessive gas in the water system.
STS-3	Five beverage packages failed due to an inadequate heat seal. Problems were encountered restowing unused food packages because they kept floating out of the locker tray.
STS 1,2,3,4	Interruption of meal periods by Mission Control contributed to a decreased food consumption because the crews did not have time to eat at the scheduled meal periods.

CONCLUDING REMARKS

The OFT food system used a combination of Apollo and Skylab type food packages which served their purpose well while an operational food system was being developed. The new square Shuttle packages for rehydratable foods were evaluated on two of the missions as a test demonstration. Since the new food package was designed to function with the galley, the delay in the use of the galley prompted the development of the portable food warmer which was used successfully on all of the OFT missions. The food warmer proved to be a valuable asset to the food system.

The OFT missions also provided an opportunity to evaluate a new concept in menu design for U.S. space missions. Previous space food systems used personal preference menus for each astronaut. Due to the logistics involved in providing personal preference menus, a standard four-day menu cycle was used on all Shuttle OFT missions with a pantry that accommodated personal preferences and also served as a contingency food supply. The standard menu/pantry concept proved to be a workable solution to the logistics problem and was accepted by all crewmembers.

In general, all crews were satisfied with the quality of the food and the performance of the preparation equipment.

Table 9-4 Mean Daily Inflight Nutrient Consumption Per Person Per OFT Mission

STS Flight	Days	RH_2O* gm	NH_2O** gm	Kilo-calories	Pro-tein gm	Fat gm	CHO gm	Ca mg	Phos mg	Na mg	K mg	Iron mg	Mg mg	Mn mg	Cu mg	Zn mg	Cl
1	2			2656	106.8	83.1	358.6	1210	1706	4506	3238	27.1	387			17.6	
2	2	1134	88.4	1100	58.5	28.0	152.0	687	916	1782	1362	12.4	154			9.4	
3	8	1393	353.0	1910	66.1	49.6	280.2	885	1210	3010	2244	16.6	229	1.6	1.9	10.1	4407
4	7	1710.8	325.5	2446	85.6	73.5	319.2	954	1474	3506	2558	20.2	286	2.2	2.2	11.6	4784

*RH_2O = Rehydration water.

**NH_2O = Moisture in food.

CABIN ACOUSTICAL NOISE

CHAPTER 10

Jerry L. Homick, Ph.D.

INTRODUCTION

Throughout a major portion of the manned space flight program, personnel at the Johnson Space Center (JSC) have been involved in the specification of acceptable spacecraft noise levels, the measurement of spacecraft noise (both real and simulated) and the assessment of spacecraft noise on crew well-being and performance. On the basis of limited data it is known that with a few minor exceptions the Apollo, and especially Skylab, spacecraft internal noise environments were within acceptable limits. The ambient acoustical noise in these vehicles at no time presented a hazard to the crewmen's hearing and seldom interfered with their ability to effectively communicate, perform and obtain adequate sleep. In order to preclude crew related acoustical noise problems on future spacecraft the JSC convened a committee in 1972 which developed a standard set of acoustical noise criteria for spacecraft design. This standard, JSC Design and Procedures; Standard 145 "Acoustical Criteria", specifies maximum allowable crew exposures to short duration noises (e.g., launch noise) and sustained on-orbit ambient noise. The on-orbit maximum allowable noise defined by Standard 145 is 55 dB-A (A-weighted decibals). Fifty-five dB-A is approximately equivalent to an NC-50 (Noise Criteria) noise contour. Standard 145 was applied as a design goal for the Space Shuttle Orbiter.

Analytical studies performed by Rockwell in the mid to late 1970's indicated that the actual on-orbit internal acoustical noise environment would exceed Standard 145. Although the JSC specification was not formally imposed on them, reasonable cost effective measures were taken to lower the levels. Prototype GFE Inertial Measurement Unit (IMU) mufflers were developed and used in vehicle ground tests to measure their effectiveness in reducing overall noise levels. These mufflers were updated to a flight configuration for OV-102, built-in acoustic blankets were added to avionics bay closeouts, and crew installed acoustic blankets were provided. For operational vehicles, IMU mufflers and built-in acoustic blankets were approved for implementation. Ear plugs were provided for the flight crew to wear, if supplementary noise attenuation was required. Ground based noise tests performed on OV-102 at Palmdale, California, (January 1979) and at Kennedy Space Center (KSC) (May 1980) confirmed that the internal Orbiter acoustic noise did exceed Standard 145 even with the various "fixes" installed. To determine the extent of the Shuttle Orbiter acoustic noise problem during actual flight, a Detailed Test Objective (DTO) entitled "Cabin Acoustical Noise" was developed for implementation on STS-1. Similar DTO's were developed for implementation on STS-2 and STS-4.

The objectives of these DTO's were to quantitatively measure the extent to which on-orbit cabin acoustical noise met or exceeded the levels defined by JSC Design and Procedural Standard 145, and to ensure that noise levels were operationally acceptable.

MATERIALS AND METHODS

Using a hand-held sound pressure level meter the STS-1 crew made one-

band and A-weighted sound level measurements at four locations on Mission Day 1. The data were voice recorded and transmitted to the ground prior to the first inflight sleep period.

Using the same sound level meter used on STS-1, the STS-2 crew made A-weighted sound level measurements at 12 predetermined locations on Mission Day 1. One octave band measurements were made at four of these locations. The data were logged onboard in the Orbit Operations Checklist and retrieved postflight.

The noise environment on STS-1 and STS-2 elicited mild complaints from the crewmen. For this reason and in order to reduce stowage weight, the Acoustical DTO was deleted from the STS-3 mission.

Following the STS-3 mission, data obtained from onboard Development Flight Instrumentation (DFI) microphones indicated the presence of a relatively high intensity, low frequency noise. This was judged to be potentially hazardous to the crew's hearing, especially if it were not corrected for STS-4 and became worse inflight. An investigation of OV-102 indicated that the noise was being produced by a failing bearing in an IMU fan. The fan was replaced prior to STS-4 and subsequent ground noise measurements indicated that the problem was apparently corrected. In order to verify that the noise would not reoccur in orbit and present a potential hazard to the crew, the Cabin Acoustic Noise DTO was reassigned to STS-4.

Using a hand-held sound pressure level meter the STS-4 crew made one-octave band and A-weighted sound level measurements at two sleep locations on Mission Day 1. They were instructed to report the data prior to the first sleep period only if the levels exceeded 65 dB-A. Otherwise, the data were to be logged and returned postflight. The crew was also asked to make measurements at other designated locations if time permitted later in the mission.

RESULTS AND DISCUSSION

The data obtained from STS-1 are summarized in Table 10-1. For comparison, JSC Standard 145 is shown.

TABLE 10-1 - STS-1 NOISE LEVELS AT SELECTED ORBITER LOCATIONS

	Octave Band SPL								
Hz:	63	125	250	500	1K	2K	4K	8K	dB-A
JSC Standard 145 (NC50)	73	66	60	55	52.5	50	48	47.5	55
Flt. Deck (between seats)	64	58	55	55	58	53	48	42	60
Flt. Deck (aft overhead windows)	63	61	55	59	63	57	51	46	66*
Mid-deck (center)	61	61	63	58	61	61	58	53	67*
Mid-deck (sleep station)	60	63	67	59	62	61	58	52	67

Acoustic noise measured between the ejection seats exceeded the Noise Criteria NC-50 spectrum only in the 1K Hz (1,000 hertz) and 2K Hz octave bands. Noise at the aft flight deck measurement location exceeded from 3 to 9.5 decibels (dB) the NC-50 spectrum in the octave band range from 500 Hz to 4K Hz. At this location the A-weighted sound pressure level was 11 dB greater than the level (55 dB-A) specified by the NC-50 spectrum.

Noise measured at both locations on the mid-deck was generally higher than the noise levels on the flight deck. At both mid-deck locations the noise exceeded the NC-50 spectrum at all octave bands above 125 Hz. The A-weighted level was 12 dB above the specified A-weighted level.

The data obtained on STS-2 are summarized in Table 10-2.

All of the noise levels measured on STS-2 were considerably in excess of the level (55 dB-A) specified by JSC Standard 145. Noise levels at several locations (e.g., forward avionics bay, WCS operation, ARS servicing housing and aft air outlet) exceeded the level (76 dB-A) beyond which limited physiological damage to the auditory system may be expected. It should be noted, however, that these high readings were obtained with the sound level meter microphone in very close proximity to the noise source or in an air flow.

TABLE 10-2 - STS-2 NOISE LEVELS AT SELECTED ORBITER LOCATIONS

	Octave Band SPL								
Hz:	63	125	250	500	1K	2K	4K	8K	dB-A
JSC Standard	73	66	60	55	52.5	50	48	47.5	55
Flight Deck (aft overhead window)	65	64	58	59	66	62	62	48	67*
RS Air Outlet (Flt. Deck)	-	-	-	-	-	-	-	-	76
Aft Air Outlet (Flt. Deck)	-	-	-	-	-	-	-	-	77
Sleep Location (Flt. Deck, Seats)	-	-	-	-	-	-	-	-	61
Sleep Location (Flt. Deck, Floor Behind Seats)	59	60	63	57	61	56	51	44	64
Mid-deck Center (Mid-deck)	-	-	-	-	-	-	-	-	68*
IMU Inlet (Mid-deck)	64	63	66	57	62	62	61	55	68
Ceiling Air Outlet (Mid-deck)	-	-	-	-	-	-	-	-	71
FWD Avionics Bay (Mid-deck)	-	-	-	-	-	-	-	-	80
WCS Air Inlet (Mid-deck)	-	-	-	-	-	-	-	-	75
WCS Operation (Mid-deck)	-	-	-	-	-	-	-	-	87
ARS Servicing Housing (Mid-deck)	-	-	-	-	-	-	-	-	77

No data were voiced to the ground during the STS-4 flight. The results of the only logged data retrieved postflight are summarized in Table 10-3.

TABLE 10-3 - STS-4 NOISE LEVELS AT SELECTED ORBITER LOCATIONS

	Octave Band SPL								
Hz:	63	125	250	500	1K	2K	4K	8K	dB-A
W7/W8 Windows (Flt. Deck)	65	67	58	58	62	56	51	46	65*
Sleep Location (Mid-deck)	-	-	-	-	-	-	-	-	69*

Two measurement locations (those marked with an * in Tables 10-1, 10-2 and 10-3) were common to STS-1, STS-2 and STS-4. The noise levels measured at these locations were very similar on all three flights. These limited comparisons suggest that the overall flight deck and mid-deck noise environments on these three flights were essentially the same.

From a physiological viewpoint the noise levels measured on STS flights 1, 2, and 4 were not hazardous. Continuous exposure to the measured mid-deck noise spectrum for periods up to seven days in duration would not cause permanent hearing damage. However, some temporary hearing threshold shifts could be experienced. These temporary shifts could have subtle effects on speech communications and auditory signal detection. It was for this reason that JSC earlier developed a guideline which recommended that in spacecraft noise environments between 65 dB-A and 75 dB-A hearing protection devices be worn during sleep to permit recovery from noise induced temporary threshold shifts. During postflight crew debriefings the STS-1, STS-2 and STS-3 crews stated that noise did not appear to interfere with sleep, nor did noise interfere with communications. Nevertheless, the STS-4 crew indicated that they had experienced speech communications difficulties that were apparently related to the spacecraft noise levels. This finding warrants further study on future Shuttle missions.

The noise measurements made on STS-1, STS-2 and STS-4 appear to adequately characterize the acoustical noise environment in the OV-102 OFT configuration. Steps should be taken to ensure that the first operational configuration Orbiter and subsequent Orbiters have acceptable levels of acoustic noise. It is planned to make measurements on the first operational Orbiter. It will be determined whether this data can be obtained in ground based tests or whether additional on-orbit measurements must be taken. Emphasis will be placed not only on repeating some of the standard flight deck and mid-deck measurements, but also on repeating some of the locations where unusually high levels were recorded.

RADIATION PROTECTION PROGRAM CHAPTER 11

D. Stuart Nachtwey, Ph.D.
and Robert Richmond

The Shuttle Orbiter operates in regions of enhanced natural radiation attributable to the Van Allen trapped radiation belts. Other extravehicular radiation could potentially come from a solar particle event (solar flare) or from an exoatmospheric nuclear device detonation (artificial event). Onboard radioactive sources could also contribute to radiation exposure. NASA's Radiation Protection Program for the Space Transportation System (STS) flights involves (1) projection of expected doses for each flight, (2) monitoring of solar activity and intelligence sources for unpredictable radiation events, (3) measurement of radiation exposures from all of these sources (in real time if necessary), (4) maintenance of exposure records for all astronauts (includes medical), (5) budgeting of radiation exposures over each crewman's career to keep exposures as low as reasonably achievable (the ALARA principle), and (6) preventing any astronaut from exceeding allowable exposure limits. The application of these radiation protection procedures to the Orbital Flight Test (OFT) flights STS-1 through STS-4 are presented.

Projection of Expected Doses

The Flight Planning Branch calculated the expected dose for each mission. The projected dose was based upon the Vette AE17 and AP8 MAC trapped radiation belt models, trajectory (orbital inclination and altitude), geomagnetic field conditions, Orbiter shielding, and self shielding. Projected doses/day for the OFT flights were 10 millirads/24 hours for STS-1 and 6 millirads/24 hours for STS-2 through STS-4. The dose point selected was the skin of the Commander's chest when sitting on the flight deck.

Monitoring Unpredictable Radiation Events

A constant watch was maintained to project the incidence of potentially hazardous radiation conditions which might occur during a mission. In cooperation with the National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense (DOD), constant evaluation of the space environment was conducted. Solar activity was carefully monitored by ground stations. Solar Particle Events (SPE) or solar flares can cause a buildup of electrons and protons in the Earth's magnetosphere. Earth satellites which measure radiation levels in the Earth-solar interspace also yield information which assists in determining progress and resultant hazards from solar eruptions. Data from the above sources provide a projected dose to crewmen far enough in advance to allow modification of the flight plan if necessary. During OFT flights, no significant solar particle event occurred.

During each STS flight, national security sources provided information about artificial events so that the dose at the Orbiter could be calculated. No artificial event occurred, OFT.

Measurement of Doses Received

Onboard passive and active radiation dosimeters measure the radiation encountered inside the spacecraft. The relatively large, area passive dosimeter (APD), measuring 10x10x5 centimeters, contains five stacks of plastic particle detectors and four corner modules. These plastic stacks are oriented in three mutually perpendicular directions and are used to

record HZE (high atomic number and energy) cosmic ray particles. The four-corner modules are designed to monitor the total and neutron components of the radiation exposure through the use of thermoluminescent dosimeter (TLD) chips and plastic recoil detectors in combination with various types of radiation foils.

A smaller dosimeter, the crew passive dosimeter (CPD), measures approximately 11x6x0.7 centimeters and contains a thin stack of plastic detectors and a TLD module. It is worn as a personnel dosimeter and is deployed also to monitor the dose at six different locations within the spacecraft.

Active dosimeters may be read out by the crewmember at any time and are used to determine if it is necessary to modify the mission. These active integrating dosimeters are reliable, pen-sized ion chambers which measure in three ranges. The low range (PDL) measures accurately in the range of 0-200 millirad. The high range (PDH) measures accurately in the range of 0-100 rad. In addition, a contingency high rate dosimeter (HRD) is provided for measurement of doses of 0 to 600 rad such as might result from an artificial event.

Through this system, the unique radiation of space was measured adequately for the OFT missions. This included electron, proton and heavy cosmic rays encountered during a typical mission profile. The measurement results from the STS-1 through STS-4 missions are summarized in Table 11-1.

The most relevant medical doses are those listed in Table 11-1 after "CPD TLD-700" (from the Crew Passive Dosimeter TLD-700 thermoluminescent dosimeter chips consisting of lithium-7 fluoride). STS-1 TLD dosimetry results were unusable because the dosimeter packages were irradiated during postflight commercial transportation, presumably by radioactive material also being transported. The PDL dosimeters were transported separately, so the readings are valid. On STS-1 and STS-2 some of the ion chamber dosimeters malfunctioned.

The APD's stowed in middeck lockers provided data for a better characterization of the radiation environment inside the spacecraft but not necessarily where the crew spent the most time. The anlysis of the APD measurements are shown under Dosimetry Analysis. The neutron dosimetry readings for STS-1 and STS-2 were in the "noise" range of the detectors so the values in Table 11-1 represent the limits, of detectability. Neutron dosimetry was improved for STS-3 and STS-4 as a result of STS-1 and STS-2 dosimetry. Even so, these results are somewhat uncertain.

The plastic stacks, which measure high energy particles with Z>6, registered between 5-10 particles/cm^2/flight for STS-1, STS-2, and STS-4. These values are barely above background and the uncertainties are large. Therefore, in these three OFT flights, high LET galactic cosmic rays contributed little to rad dose. For the STS-3 flight (194 hours, 38^0 inclination) the average net mission fluence was 22 ± 3 particles/cm^2 with LET > 32 keV/μm of water over 2π steradian. Benton (STS-4 Final Dosimetry Report), in a detailed analysis, has determined the total dose equivalents (rem dose) for the OFT flights to the extent that the data allow. His results are presented in Table 11-1 under "Dosimetry Analysis." The ICRU quality factors have been applied to the high LET and neutron doses to obtain dose equivalents. It may be seen that for STS-2 to STS-4, the major portion of the dose equivalent results from low LET radiation with a quality factor of about 1. The total mission dose

TABLE 11-1 - OFT RADIATION DOSIMETRY SUMMARY

Orbital Parameters	STS-1	STS-2	STS-3	STS-4
Duration (hr)	54.3	54.2	192.1	169.2
Inclination (deg)	40.3	38	38	28.5
Altitude (km)	240	254	280	297
Preflight Total Dose				
CDR (gram-rem/WBE[a])	318,405/4.55	162,174/2.32	681,426/9.73	198,544/2.84
PLT (gram-rem/WBE)	107,190/1.53	44,122/0.63	116,721/1.67	80,413/1.15
Flight Dosimetry[b] (Dosimeter/Units/N)				
PDL (mrad) (6)	20	12.5	54.5	48.7
PDH (rad) (2)	0,30[c]	0, off-scale[c]	0	0
HRD (rad) (2)		0, -25[c]	0	0
CPD TLD-700 (mrad)				
CDR	-----[d]	5.6	47.1	40.4
PLT	-----[d]	9.7	45.9	40.8
Dosimetry Analysis[e] (mrem)				
Low LET[f]		11.8 ± 1.8	46.5 ± 1.8	39.0 ± 1.1
Neutrons				
Thermal	<0.05	<0.03	0.03	0.04
Resonance	<0.75	<0.3	2.0	1.6
High Energy			7.7	14.0
Total	<15	<6	9.7	15.6
High LET[g]		1.0 ± 0.4	6.3 ± 1.0	7.7 ± 2.9
Total Mission Dose Equivalent (mrem)		<19	62.5	62.3

[a] WBE = Whole Body Equivalent in rem = gram-rem/70,000 gram).
[b] "Flight doses" are the doses after correcting for background radiation and that received during transportation. Averages of N dosimeters deployed in 6 locations or stowed in a locker.
[c] Malfunction.
[d] TLD's irradiated during postflight commercial transport to University of San Francisco.
[e] E.V. Benton (STS-4 Final Dosimetry Report, 12 October 1982).
[f] Photons and electrons of any energies. High-LET at lower efficiency.
[g] HZE particles with LET >20kev/μm of water.

equivalents are comparable to that received from a photofluoroscopic-type chest x-ray.

Exposure Records

Table 11-1 also includes the whole-body equivalent (WBE) radiation dose-equivalents from all known sources (medical and previous flights). The whole-body equivalent rem dose is calculated from the sum of partially exposed body volumes (in grams) times the radiation exposure to that volume divided by the total weight of a "Standard Man" (70 kilograms). It may be seen that the doses received during the OFT flights have added a small fraction to that already received.

Adherence to ALARA Principle and Astronaut Exposure Limits

Permissible radiation exposure limits for space flight (see Table 11-2) have been set by the JSC Radiation Constraints Panel and approved by the NASA Administration. These limits are based on a risk versus gain assessment and recommendations by the National Academy of Sciences.

The periodic rate constraints, which are derived from the career limit, cover a variety of potential missions. For OFT flights and for future STS missions, the 30-day dose limits are taken as the mission allowable dose. As seen in Table 11-1, OFT mission doses did not come close to the allowable. If any had (for example, from a solar flare or artificial event) this result could be factored into the crew's selection for subsequent flights.

TABLE 11-2 - EXPOSURE LIMITS AND EXPOSURE ACCUMULATION RATE CONSTRAINTS FOR UNIT REFERENCE RISK CONDITIONS

	Primary	Ancillary Reference Risks			
	Constraint Reference Risk (rem at 5 cm)	Bone Marrow (rem at 5 cm)	Skin (rem at 0.1 mm)	Ocular Lens (rem at 3 mm)	Testes[b] (rem at 3 cm)
1-year average daily rate		0.2	0.6	0.3	0.1
30-day maximum		25	75	37	13
Quarterly maximum[a]		35	105	52	18
Yearly maximum		75	225	112	38
Career limit	400	400	1200	600	200

[a] May be allowed for two consecutive quarters followed by six months of restriction from further exposure to maintain yearly limit.

[b] Applies only if the possibility of oligospermia and temporary infertility is to be avoided.

POTABLE WATER CHAPTER 12

Richard L. Sauer

INTRODUCTION

Potable water was provided for the Orbital Flight Test (OFT) crews by the Shuttle Orbital Potable Water System. The system is similar to Apollo in that it consists mainly of fuel cells (which produce water as a by-product of producing electricity), water storage tanks, a water dispenser, a water disinfection capability and interconnecting tubing. It differs from Apollo in that it is made of stainless steel rather than aluminum and does not require crew involvement to provide water disinfection. Rather than in Apollo, where a chlorine solution was added daily by the crew to the water storage tanks, microbiological control in Shuttle is provided by a Microbial Check Valve (MCV). The MCV continually iodinates all water to the potable water tank to a level of 2-5mg/l and does not require any crew action. To prevent back-contamination of the system, the OFT water dispenser contains three MCV's.

DISCUSSION

Periodic samples were obtained from the potable water system to assure the continuing chemical and microbiological acceptability of the water. These samples were obtained at the time of servicing, between servicing and launch, three days prior to launch and at landing. All samples were analyzed per SE-0073, "Space Shuttle Fluid Procurement and Use Control."

Throughout the OFT Program, the potable water system performed as expected with the exception of STS-2. During STS-2, a problem developed with one of the fuel cells and it was shut down. The potable water tank was isolated from the system and was not used for the remainder of the mission for fear it had become contaminated. Air in the potable water was another problem encountered during STS-2. The air was initially thought to be related to the fuel cell failure, but later was determined to be a result of improper water system servicing preflight. Subsequent missions had no problems with the water system.

CONCLUSION

Problems encountered on STS-2 (fuel cell failure) impacted, but were not caused by, the potable water system. Although some parameters occasionally were above specification limits, all were minor excursions and none were considered harmful to the crew.

SHUTTLE TOXICOLOGY CHAPTER 13

Wayland J. Rippstein, Jr.

The toxicological support provided for the Shuttle program has largely resulted from experience gained during NASA's previous space programs, mostly from the Apollo flights. It was during this period that a strong emphasis was placed on selection of nonmetallic materials. The materials selection program included not only spacecraft materials' evaluation from the flammability and applicability stand points, but also the quantities of contaminants that might be outgassed into the cabin environment. Outgassed contaminants from Apollo nonmetallic materials resulted in the detection and identification of over 300 different compounds. Strict control has to be maintained on the kinds and quantities of compounds allowed in the cabin area if the crew was to be safeguarded from potential hazards.

This same materials selection program was adopted during the early phases of the development and manufacturing of the Shuttle Orbiter vehicles. Outgassing analyses were conducted on such Orbiter materials as heat exchanger fluids, thermal insulation, paints, fire extinguisher fluids, lubricants, adhesives, electrical wire insulation, plastics, rubbers, and elastomers. Special attention was placed on the evaluation of selected nonmetallic materials on the basis of their combustion products. These were also evaluated from both the chemical composition and inhalation toxicity standpoints.

Two other areas of support program has been ingestion and contact toxicity assessments. However, the greatest number of toxicity problems concerning the Shuttle vehicles have been in the area of inhalation toxicology. Therefore, this report deals solely with inhalation toxicity.

RESULTS AND DISCUSSION

Four major areas of importance were identified:

- o Establishment of space flight toxicity standards.
- o Establishment of a method for control and evaluation of candidate spacecraft materials selection and/or use.
- o Development of methods and hardware for removal of spacecraft contaminants.
- o Development of methods for conducting measurements of spacecraft contaminant levels during missions.

New inhalation standards were required for space flight since all existing inhalation toxicity standards dealt with 40-hour work-week exposures, except for U.S. submarine operations. In the case of submarine operations where atmospheric maximum allowable concentrations are reached, the vessel could, in most cases, surface to vent contaminant gases. However, a spacecraft crew could not rid the crew compartment of contaminant gases as readily as would be required. For this reason the spacecraft maximum allowable concentration (SMAC) values for contaminant gases are in most cases from one-half to one-tenth of the value set for a standard 40-hour week maximum allowable concentration value. A second and possibly equally important reason for requiring the setting of SMAC values at significantly lower levels than is required for industry is that industrial values are mainly based upon physiological criteria while spacecraft values are based upon decrement of performance (behavioral changes) and physiological criteria.

A list of known spacecraft contaminant gases was submitted to an ad hoc committee of the National Academy of Sciences. The committee was composed of governmental, institutional, and industrial toxicologists to established long-term, continuous exposure limits for space flight. They recommended a list of SMAC values to NASA. These values were used in later activities involving spacecraft materials selection and the development of spacecraft breathing gas standards.

When new gases (those not evaluated by the National Academy of Sciences) were used in the Shuttle Program, inhouse or contracted toxicity studies were conducted to determine the SMAC value.

The second phase of the Shuttle Toxicology Program was carried out by establishing a materials selection program that included the evaluation of spacecraft candidate nonmetallic materials for outgassing characteristics. Outgassing analyses were conducted to determine both qualitative and quantitative information. A criteria for acceptance was established for all nonmetallic materials based upon outgassing characteristics, spacecraft volume, mission duration, SMAC values, and performance of the spacecraft atmospheric revitalization system (ARS).

A procedure was incorporated in the materials program for accepting certain critical hardware materials by use of waivers. This involved a review of hardware materials used in the spacecraft. In some cases, the review required more thorough chemical and toxicological testing of the candidate spacecraft materials or hardware.

The third part of the overall Toxicology Program involved the development of methods and hardware to control the levels of contaminant gases not eliminated in the materials selection program. This effort consisted mainly of the establishment of a close working relationship between the NASA toxicology scientists and ARS design engineers. The spacecraft ARS design incorporated provisions for the removal of contaminant gases by three different methods.

The primary method for removal of contaminant gases is by adsorption onto a bed of activated carbon that is contained in the ARS carbon dioxide (CO_2) removal bed (lithium hydroxide).

The second method for contaminant gas removal is in a specially designed canister known as the ambient temperature catalytic oxidizer (ATCO). The ATCO was approved for use in the Orbiter for the purpose of catalytically converting trace quantities of carbon monoxide (CO) into CO_2. The CO_2 would then be removed in the CO_2 scrubber portion of the ARS. Certain other lesser important contaminant gases would also be catalytically oxidized in the ATCO. These compounds would then be adsorbed in the activated carbon beds contained both in the ATCO and ARS.

The final means of contaminant gas removal is in the spacecraft ARS dehumidifier. The cabin atmosphere passes over this moisturized surface, where trace levels of water soluable contaminants are carried out of the dehumidifier with the effluent water stream. This part of the ARS was not designed with this function in mind, but its scrubbing effect is considered to be part of the overall contaminant gas removal capability.

The last phase of the Shuttle Toxicology Program concerns the methods used for assessing the trace atmospheric contaminants condition during an actual mission. From previous experiences with assessments of closed environments in manned chamber tests and previous analyses of spacecraft

cabin atmospheres, it was concluded that two methods would be employed to obtain a complete qualitative and quantitative analyses of the Orbiter atmospheres. These methods are known as whole- and adsorbed-gas-sampling procedures.

The whole-gas-sampling procedure used an evacuated stainless steel cylinder (Figure 13-1). When a gas sample is required, a valve on the evacuated cylinder is opened and an atmospheric sample is drawn into the cylinder. The cylinder valve is immediately closed to trap the sample for later analyses. The adsorbed-gas-sampling procedure involves the use of the Shuttle air sample assembly (Figure 13-2). This assembly consists of seven pairs of tubes containing a substrate known as Tenax. Tenax has been found to be an excellent substance for the adsorption of most airborne contaminant gases, especially in the presence of water vapor. The adsorption property of Tenax has been employed as a contaminant gas sampling media by drawing atmospheric samples through small stainless steel tubes containing a measured quantity of the white powder-like substance. As the atmospheric samples are drawn through the Tenax bed of powder, the organic contaminant gases are retained while oxygen, nitrogen, argon, CO, CO_2 and most water vapor pass directly through the bed with a minimum of adsorption. The tubes are sealed after the specific sampling period (usually 24 hours of continuous sampling) and analyzed at a later time.

The application of both the whole- and adsorbed-gas-sampling procedures provides a high degree of accuracy in both qualitative and quantitative assessment of spacecraft cabin atmospheres. The whole gas samples provide accurate quantitative determinations of the contaminant gas contained in the cabin atmosphere at the time of sampling (instantaneous). Whole gas samples also allow a determination of the CO contained in the atmospheric sample. CO is not adsorbed in the Tenax trap. The major problem in using the whole-gas-sampling procedure is that since only a gas is trapped in the sampling cylinder, some difficulty is experienced in attempting to identify very small quantities of contaminant gases in the sample. The function of the Tenax trapping procedure is important for the overall analysis of a spacecraft cabin atmosphere. Since the Tenax trap can be used to continuously trap gases for 24 hours, large amounts of contaminants can easily be contained in the final trapped sample. This makes the qualitative process much easier to accomplish. Because of the concentration effect, the 24-hour sampling procedure permits the trapping of contaminants possibly missed by the whole-gas-sampling method. Once the compounds are identified, the quantitative results are determined using the whole gas samples.

Atmospheric samples were obtained from the first four STS flights. Four whole-gas-sampling cylinders were carried on STS-1 through STS-3. Due to weight restrictions, only one whole-gas-sampling cylinder was carried on STS-4. The solid sorbent, Shuttle air-sampling assembly was used for sample acquisition on STS-1 and STS-2. Due to technical difficulties experienced with the unit, the device was not flown on STS-3 or STS-4.

The samples obtained from all four missions have made possible excellent analytical results. Only the analytical, qualitative and quantitative aspects of returned samples are discussed under the heading of concluding remarks.

The samples returned from the STS-1 mission resulted in the identification of 56 compounds. Compound concentration ranged from a high for

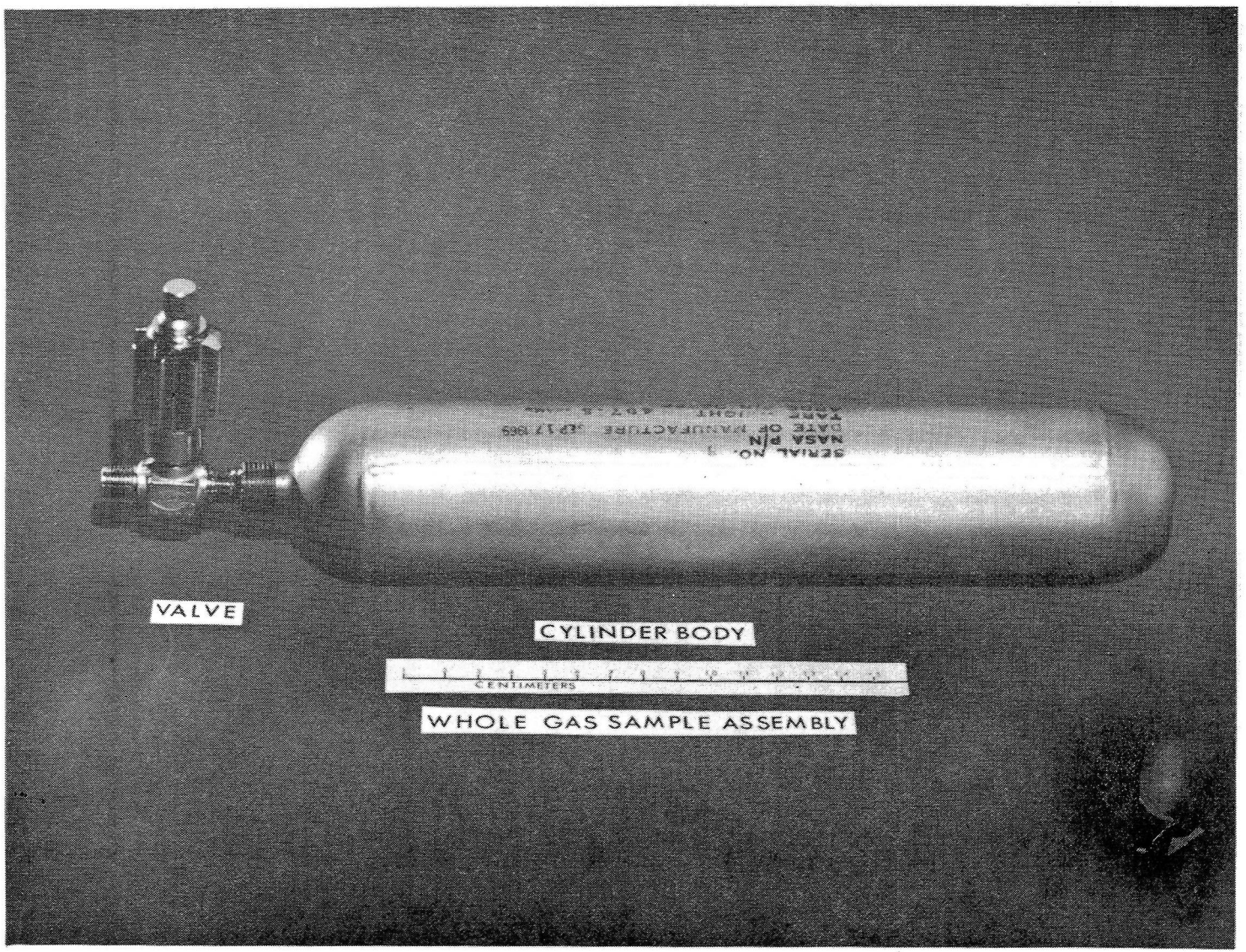
VALVE
CYLINDER BODY
CENTIMETERS
WHOLE GAS SAMPLE ASSEMBLY

FIGURE 13-1

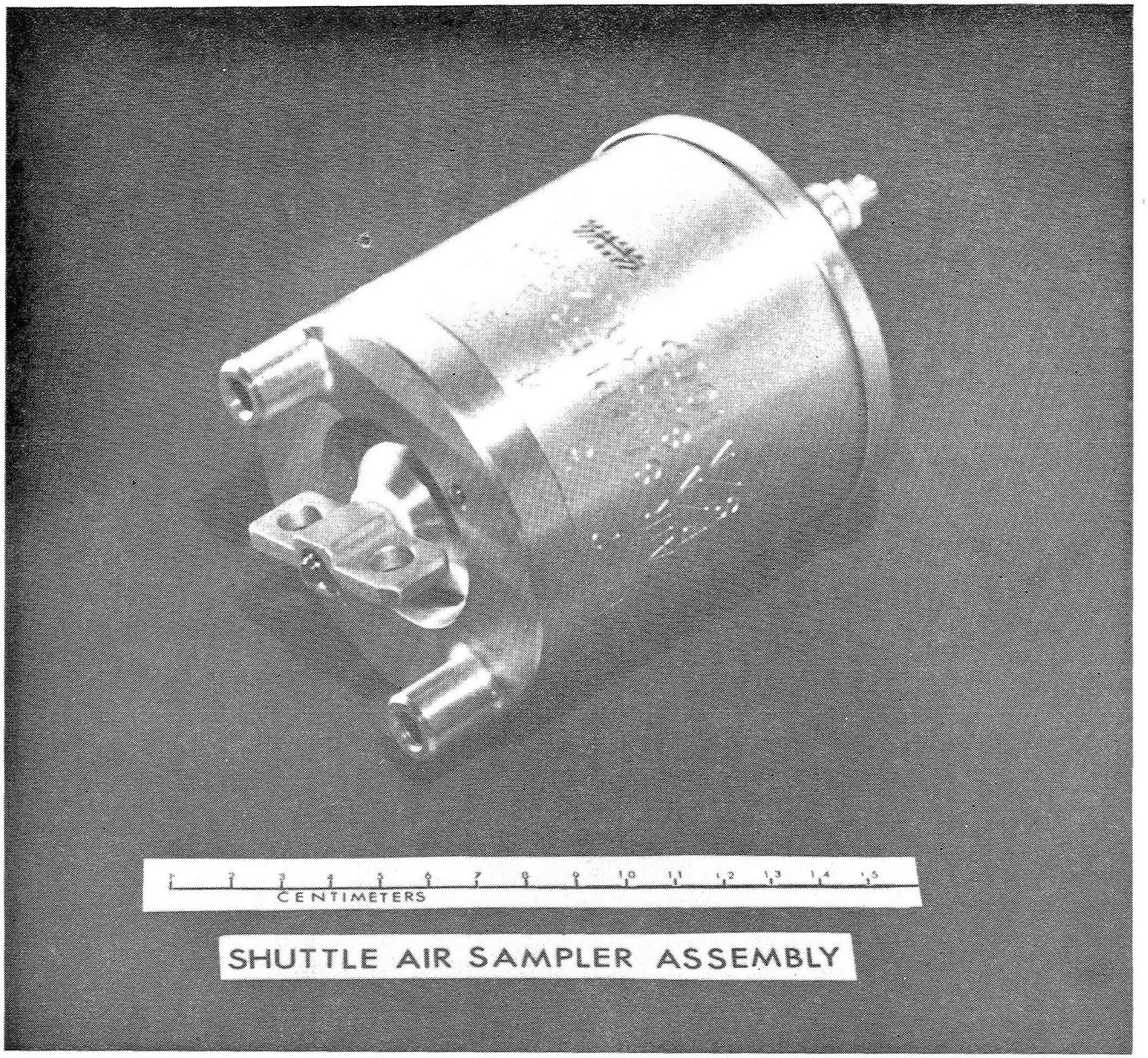

FIGURE 13-2

methane of 28 parts per million (ppm) to a low of 0.001 ppm for 1,4-dimethylbenzene. A total of 99 compounds were identified in the STS-2 samples. The compounds detected ranged from a high of 17 ppm for toluene to less than 0.001 ppm for carbon disulfide. The analyses of the STS-3 samples indicated the presence of 40 compounds in the spacecraft cabin environment. Methane was present at 7.5 ppm and Halon 1301 was present at 2.7 ppm. Benzene was present at less than 0.001 ppm. Only six compounds were detected in the STS-4 mission sample. Methane was present at 135 ppm and Freon 12 was detected at 0.033 ppm.

In most cases, the same compounds were detected in all four missions. A total of 58 well defined compounds were identified in the four STS missions. Another 88 different compounds were identified on a hydrocarbon grouping basis. These groupings include C_7-aliphatic hydrocarbons, C_8-alkane, C_8-olefinic hydrocarbons or C_3-substituted benzene. Table 13-1 contains a complete list of the compounds detected for the four STS flights.

It is important to recognize the significant decrease in the number of compounds detected in the STS-4 compared with those detected in STS-1 through STS-3. Two important factors may have contributed to this reduction. It was during the STS-4 mission that the ambient temperature catalytic oxidizer was first used. Secondly, only one whole-gas-sampling cylinder was carried on STS-4. If more samples had been obtained, a greater number of components may have been detected.

The reason for the presence of such a high concentration of methane in the STS-4 sample is not known. Samples returned from future flights will help resolve this question. The ambient temperature catalytic oxidizer is being investigated to determine if it had anything to do with the elevated methane concentration detected in the STS-4 cabin atmospheric sample.

CONCLUDING REMARKS

In most toxicity evaluations involving contaminant gases, only one or at most several gases are considered at one time. However, in the case of the spacecraft flown for STS-1 through STS-4, it was necessary to assess an atmosphere containing as many as one hundred different contaminant gases. In the early phase of the Orbiter development program a list of contaminant gases was made for compounds suspected as most likely to be present as outgassed products of Orbiter nonmetallic materials. Quantitative values were determined for spacecraft maximum allowable concentrations for crew exposures. These values were based upon the following set of criteria:

- Continuous exposure for 24 hours per day for up to seven days.
- Exposure to a single contaminant gas.
- No other physiological threat from other stress factors, e.g., heat, cold, and work.
- Where toxicity data were not available for a given compound, a SMAC value was assigned for that compound, at a level equal to the toxicity value for the most toxic compound in the compound family. A complete list of these compounds is contained in NASA Document NHB 8060.1b and titled "Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion."

In order to conduct toxicity assessments of the data obtained from outgassing sampling of the Columbia (OV-102), the contaminant gases were

categorized into groups according to their relevant effects on h' ians. These groupings are as follows:

- o Irritants: e.g., aldehydes and ammonia
- o Asphyxiants: e.g., carbon dioxide, carbon monoxide, and methane
- o Central Nervous System Depressants (Anesthetics and narcotics): e.g., ethers, ketones, alcohols, halogenated hydrocarbons, and paraffinic hydrocarbons.
- o System Poisons: e.g., benzenes, phenols, and napthalenes.
- o Particulates: e.g., silicon and asbestos.

Depending upon the concentration, the examples given in each of the above five categories can in some cases be changed from one grouping to another. In order to arrive at an overall assessment where a very large number of contaminant gases exist simultaneously in the cabin atmosphere, only the additive effects in a given physiological response grouping have been considered. The possibility does exist, however, for synergistic effects between compounds in different groups or even with the same group. Scientific information does not exist for dealing with synergistic effects of the contaminants gases detected in the Orbiter cabin.

Since particulate materials are not monitored in the Orbiter cabin, and since the ARS contains a micro sized filter, this subject is not addressed in this report.

Each of the four physiological effect categories was evaluated on a group limit concept. This was accomplished by determining the summation of the ratios of the crew cabin contaminant gas concentrations to the SMAC concentrations. This summation must not exceed unity if a safe environment is to be maintained. The following mathematical expression is employed to describe the above condition:

$$0 < \frac{C_1}{SMAC_1} + \frac{C_2}{SMAC_2} + \frac{C_n}{SMAC_n} > 1$$

where C = contaminant gas concentration
SMAC = spacecraft maximum allowable concentration

Upon applying the above mathematical treatment to the analytical data resulting from the four STS flights, only one over-limit condition was experienced. This occurred during the STS-2 mission when toluene reached a level of 17 ppm. The contribution of the other compounds in the category of systemic poisons in conjunction with the 17 ppm for toluene (SMAC value is 20 ppm) resulted in summation value greater than unity.

Corrective measures were taken immediately after the over limit situation was identified and reported. These corrective measures were taken between the STS-2 and STS-3 missions. NASA materials and safety engineers determined that the toluene detected on STS-2 had the highest probability of being introduced into the cabin atmosphere as the result of having used this solvent to clean spacecraft interior surfaces for the application of a fastening material known as Velcro. Restrictions were placed on the amounts of toluene allowed in the vehicle at any given time and the time of its use prior to launch.

In conclusion, significant information has been gained from the OFT flights that allows greater confidence in the appropriateness of the Shuttle Toxicology Program. This is especially true in light of the greatly reduced number of contaminants contained in the STS-4 cabin atmosphere. It is felt that the knowledge and experience gained from these flights will result in better toxicological support for the ongoing Shuttle program.

Table 13-1
CONTAMINANTS FOUND IN ORBITER
ATMOSPHERIC SAMPLES

Compound Identity	STS Mission Number 1	2	3	4
Acetic Acid, n-Butyl Ester	X			
Acetic Acid, 2-Ethoxyethlyester	X			
Benzaldehyde		X		
Benzene	X	X	X	
Bromotrifluoromethane			X	X
1-Butanal	X	X	X	
1-Butanol	X	X		
2-Butanone	X	X	X	
n-Butylbenzene	X			
Carbon Disulfide		X		
Carbon Monoxide	X	X	X	
Cyclohexane		X		
Decane		X		
Dichlorodifluoromethane				X
1,1-Dichloroethene		X		
Dichloromethane	X	X	X	
1,2-Dimethylbenzene	X	X	X	
1,3-Dimethylbenzene	X	X	X	
1,4-Dimethylbenzene	X			
1,1-Dimethylethanol	X			
Ethanal	X	X	X	
Ethanol	X	X	X	X
Ethylbenzene	X	X	X	
2-Ethylhexanal		X		
1-Heptanal	X			
Heptane		X	X	
2-Heptanone	X			
3-Heptanone	X			
Hexamethylcyclopentane		X		
Hexamethylcyclotrisiloxane	X			
1-Hexanal	X			
Hexane	X	X		
Indan		X		
Methane	X	X	X	X
Methanol	X	X		
2-Methyl-1,3-Butadiene	X			
Methylcylopentane	X	X		
Methylethylcyclopentane			X	
6-Methyl-2-Heptanone		X		
2-Methylpentane		X		
2-Methyl-1-Propanol		X		
2-Methyl-2-Propanol		X	X	
4-Methyl-2-Propantanone	X		X	
Naphthalene		X		
Nonane		X		
Octane		X		

TABLE 13-1 - Concluded.

Compound Identity	STS Mission Number 1	2	3	4
1-Pentanal	X	X	X	
Pentane		X	X	
1-Propanal	X	X	X	
2-Propanol	X		X	
2-Propanone	X	X	X	X
Propylbenzene	X	X		
Toluene	X	X	X	
1,1,1-Trichloroethane	X	X	X	
Trichloroethane		X	X	
Triochlorofluoromethane	X	X	X	
1,1,2-Trichloro-1,2,2-Trifluoroethane	X	X	X	X
Trimethyl Silanol		X		
C_7-Aliphatic Hydrocarbons (1)*		X		
C_8-Aliphatic Hydrocarbons (7)		X		
C_9-Aliphatic Hydrocarbons (9)		X		
C_{10}-Aliphatic Hydrocarbons (8)		X		
C_{11}-Aliphatic Hydrocarbons (8)		X		
C_{12}-Aliphatic Hydrocarbons (8)		X		
C_{13}-Aliphatic Hydrocarbons (1)		X		
C_{14}-Aliphatic Hydrocarbons (13)		X		
C_8-Alkane (1)				X
C_9-Alkane (4)				X
C_{10}-Alkane (6)	X		X	
C_{11}-Alkane (5)	X		X	
C_{12}-Alkane (4)	X		X	
C_8-Olefinic Hydrocarbon (1)		X		
C_9-Olefinic Hydrocarbon (2)		X		
C_3-Substituted Benzene (11)	X	X		
C_4-Substituted Benzene (6)	X			

*Denotes number of different compounds identified for each given category.

MEDICAL OPERATIONS PANEL AND SUPPORTING STRUCTURE

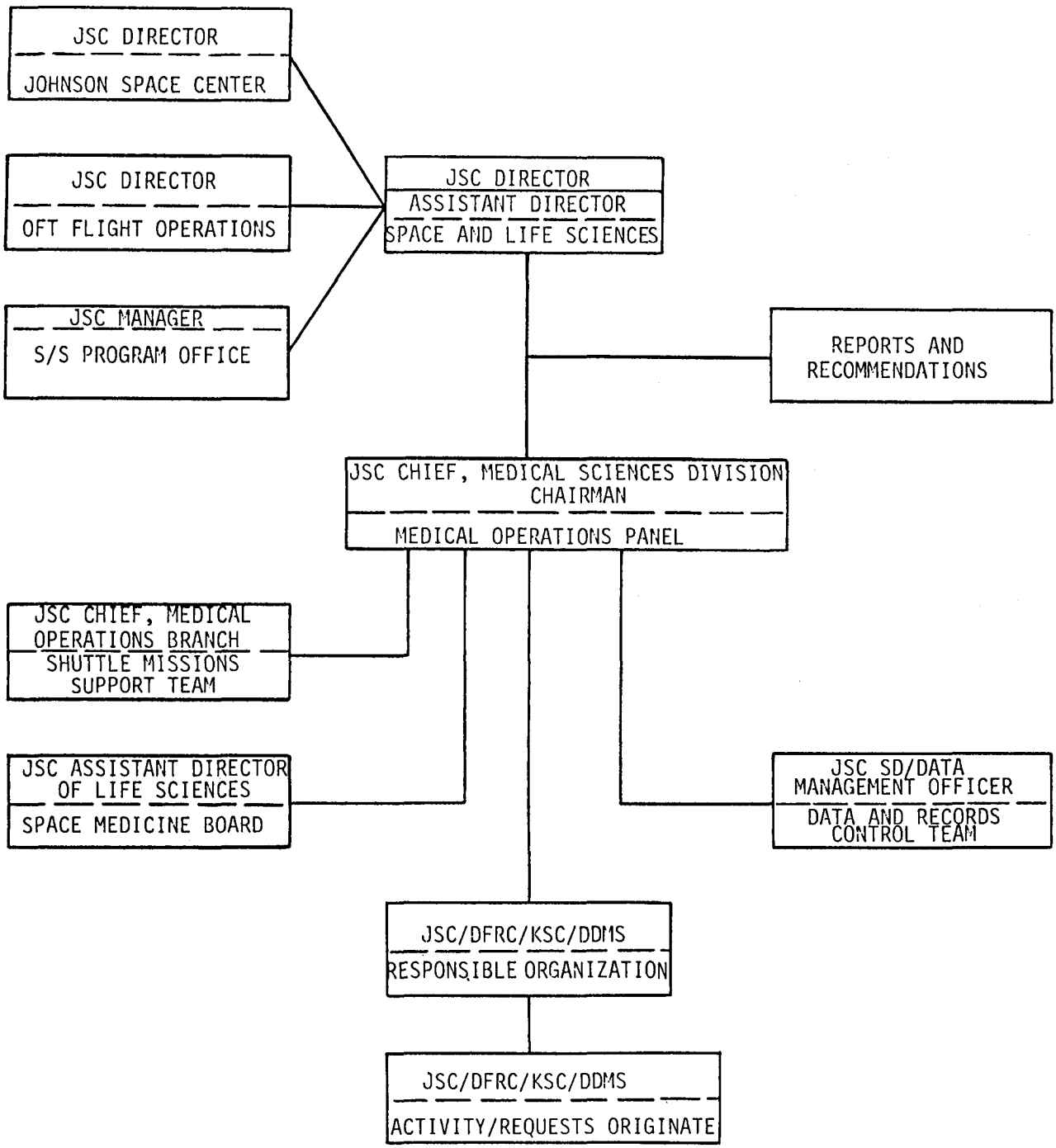

FIGURE 14-1

MANAGEMENT, PLANNING, AND IMPLEMENTATION OF MEDICAL OPERATIONS

CHAPTER 14

Norman Belasco

MANAGEMENT OF MEDICAL OPERATIONS

The Medical Operations Management objectives for the Orbital Flight Tests (OFT) were to organize, implement, and direct a medical operations team that would effectively and efficiently assure the health of flight personnel during of the Shuttle missions. This included medical management, analysis, treatment and expertise from preflight through postflight including Emergency Medical Services.

The Shuttle Program Directives assigning Medical Operations roles are NMI 8900.1A, "Operational Medical Responsibilities for the Space Transportation System" (STS), and Space Shuttle Program Directive 77A, "Space Shuttle Medical Operations Management and Implementation Responsibilities for Orbital Flight Test" (OFT). These directives assign the lead center role to the Johnson Space Center (JSC), and support roles to Kennedy Space Center (KSC), Dryden Flight Research Facility (DFRF), and Department of Defense Manager for Space Shuttle Support (DDMS). Within JSC, the Operations Integration Office is responsible for the overall management and has assigned these management functions to the Space and Life Sciences Directorate who administers the activity through the Medical Sciences Division's Medical Operations Branch.

The Medical Operations Branch has responsibilities in ten areas: (1) structuring and leading the Medical Operations team, (2) establishing requirements, (3) planning and coordination, (4) assuring implementation, (5) interfacing with all involved organizations, (6) guidance and assistance to participating organizations, (7) monitoring and statusing system activities, (8) configuration management, (9) conduct in reviews, evaluations, and status activities, as well as (10) reporting. Supporting expertise was acquired from all organizations involved (within and external to JSC).

The roles of the primary team member organizations are summarized below.

Headquarters Role

- Define and coordinate Field Center Medical Operations
- Establish Medical Operational policies and guidelines
- Review and approve requirements, standards, and guidelines
- Participate in program planning, budgets, and reviews
- Exercise surveillance and conduct reviews of Medical Operations management and support

JSC Role

- Overall requirements planning, management, and implementation of all Medical Operations activities
- Conduct Medical Operations reviews
- Training coordination
- Documentation
- Health Stabilization Program
- Planning, coordinating and assuring implementation of Medical Operations at Northrup Strip (NS), DFRF, and KSC

KSC Role at KSC

- o Medical Operations support, planning, coordination, and implementation
- o Medical Operations training
- o Emergency Medical Service System (EMSS)
- o Occupational medicine for all ground operations personnel

DFRF Roles at DFRF

- o Medical Operations support, planning, coordination, and implementation
- o EMSS planning, coordination, and implementation
- o Occupational Medicine for NASA/Contractor Shuttle personnel deployed to DFRF

DDMS Role

- o Emergency Medical Support System (EMSS) support at launch and landing sites
- o Participate in planning, coordination, and implementation of Medical Operations support
- o Medical Operations training support at launch and landing sites

Medical Operations Panel (MOP) and Supporting Structure for Management Implementation

As depicted in Figure 14-1, the JSC Space and Life Sciences Directorate established an organizational management structure to effectively conduct Medical Operations. This structure employed members and participants from both staff function and line organizations. These become active, as needed, during premission preparations.

The participants included those at JSC, Headquarters, DFRF, KSC, White Sands Test Facility (WSTF), and DDMS organizations who provided the required background and authority for the Medical Operations activities.

The Medical Operations Panel's technical support group, the Medical Operations Flight Control Team (MOFCT), and a Data and Records Control Team (DRCT) provided support to the panel as did the Space Medicine Board (SMB).

RESULTS

The management roles were organized, planned, integrated, and coordinated in a manner that produced the desired results.

Through reviews, the MOP assured the implementation of requirements identified in the Medical Operations Requirements Document (MORD). The Panel verified conformance to policy and reviewed documentation. To assure timely preparation the MOP held status and readiness reviews.

Communications among the responsible participants at all sites and working levels went very well. Reports to the Program Office and Headquarters Shuttle Readiness Review Boards indicated no significant incomplete actions remained beyond one week prior to any launch.

No significant problem has identified with respect to Medical Operations Management.

MEDICAL OPERATIONS PLANNING

The Medical Operations planning objectives were to provide coordinated, accurate, comprehensive plans that

would be the road map for Medical Operations conduct with other Shuttle operations facets.

Medical Operations personnel coordinated closely with the JSC Program Office in person and by telecon on an almost daily basis, resolving open issues, scheduling changes, and receiving program guidance.

Planning documentation for Medical Operations was structured to support the Universal Documentation System (UDS) used for the Shuttle program. In addition, it presented the Medical Operations requirements for the entire Medical Operations system and provided implementation details that assured acceptable responsiveness to the operational requirements.

MEDICAL OPERATIONS IMPLEMENTATION

The Medical Operations implementation objective was to conduct the increments of planned Medical Operations activities in order to achieve end item STS mission goals for all levels of Medical Operations.

The implementation of the systems management approach proceeded in the following manner:

- JSC's lead center role as Medical Operations System Manager was implemented through coordinating and establishing requirements, interfacing planning and producing planning documentation, disseminating pertinent information, organizing and conducting training, providing guidance and direction through the Medical Operations Panel and its supporting groups, participatinng in simulations, training exercises, and verification testing and conducting as well as participating in readiness reviews.

- The participating sites, JSC (including WSTF for Northrup Strip), KSC, DFRF, and Contingency Landing Sites (CLS), each had a Site Medical Officer who was responsible for all Medical Operations support and coordination with respect to their site. Medical officers at JSC, DFRF, and NS were JSC flight surgeons. At KSC the medical officer was the medical director, and at the CLS's this assignment was given to the respective DOD medical officers in command. At all sites the medical officer doubled as the EMSS coordinator, functioning from a local site control center position that enabled him to have an EMSS communications network at his disposal. Table 14-1 lists the JSC mission Medical Operations participants for JSC, KSC, DFRF, and NS.

- At JSC the Flight Control Team supported Launch, Orbit, and Entry phases in the Mission Control Center (MCC), Mission Operations Control Room (MOCR), and Staff Support Room (SSR). Staffing during the mission included MOCR surgeons, SSR biomedical engineers (BME), clerical support, MCC clinic nurses, and the data management officer.

During mission activity periods, the Deputy Chief of the Medical Operations Branch provided the coordination of overall mission support elements throughout the system as needed.

Field Site Implementation

At KSC, the Health Stabilization Program (HSP) office at JSC supervised the HSP procedural implementation. In addition, food services were provided in the KSC crew quarters by the JSC dietician and food technicians.

Microbiological and clinical lab sampling were completed, processed, and prepared for transport by the JSC microbiologist and his technical assistants. Crew physicals were conducted by the crew physician and

TABLE 14-1.- FLIGHT SURGEON STAFFING AND DEPLOYMENT

LOCATION	FUNCTION	MISSION PHASE	STS-1	STS-2	STS-3	STS-4
JSC MCC	MOCR Surgeon	Entry	Susan Tilton	M.A. Berry	M.W. Bungo	J.S. Logan
MCC	MOCR Surgeon	Ascent	M.A. Berry	P.C. Johnson	E.L Shulman	M.W. Bungo
MCC	MOCR Surgeon	On Orbit	M.W. Bungo	J. Vanderploeg	J.S. Logan	E.L. Shulman
SSR	Senior Medical Staff	Ascent, On Orbit, Entry	L.F. Dietlein	L.F. Ditelein	L.F. Dietlein	L.F. Dietlein
SSR	Senior Medical Staff	Ascent, On Orbit, Entry	S.L. Pool	S.L. Pool	S.L.Pool	S.L. Pool
KSC						
LCC then Crew Vehicle	Crew Physician	Through launch; after launch, goes to SLF if there is an RTLS, or to PLS if no RTLS.	C.L. Fischer	C.K. LaPinta	C.L. Fischer	J. Vanderploeg
LCC	EMSS Coordinator	Launch through landing	P. Buchanan	P. Buchanan	P. Buchanan	P. Buchanan
Helo	Deputy Crew Physician	To PLS after RTLS	J. Degioanni	C.L. Fischer	J. Vanderploeg	S.L. Pool
Helo	Flight Surgeon	Launch through RTLS	M.R. Seddon	N.E. Thagard	J.P. Bagian	A.L. Fisher
EAFB/DFRF						
Crew Vehicle	Crew Physician	EOM	C.L. Fischer	C.K. LaPinta		J. Vanderploeg
Control Room	EMSS Coordinator	EOM	J. Degioanni	A.T. Hadley	A.T. Hadley	W. McBride
Helo	Flight Surgeon	AOA or landing before EMSS Coordinator arrival	W.E. Fisher	J.P. Bagian	M.R. Seddon	J.P. Bagian
Helo	Flight Surgeon	EOM	N.E. Thagard	A.L. Fisher	N.E. Thagard	W. Thornton
N/S						
Crew Vehicle	Crew Physician	EOM			*C.L. Fischer	
Strip Disp	Deputy Crew Physician	EOM			*J. Vanderploeg	
NSOCC	Alt. Crew Physician	EOM			C.K. LaPinta	
WSMR	EMSS Coordinator	AOA, Underburn, CL, EOM	C.K. LaPinta	S.A. Bergman	S.A. Bergman	
Helo	Flight Surgeon	AOA, Underbrun, CL, EOM	A.L. Fisher	M.E. Seddon	A.L. Fisher	
Helo	Flight Surgeon	AOA, Underburn, CL, EOM	J.P. Bagian	W.E. Fisher	W.E. Fisher	
Senegal						
Dakar-Yoff Airport	Medical Officer	TAL				C.K. LaPinta

* Redeployed to NS when landing site was changed.

deputy crew physician. For launch the crew physician (JSC) joined the EMSS coordinator (KSC) and the BME (KSC) in the Launch Control Center (LCC) for the purpose of providing the "go", or "no go" crew health status to the Flight Director through the MOCR surgeon. The deputy crew physician deployed to the rescue helicopter assembly area for duty as a "helo" flight surgeon should there be a contingency EMSS situation at launch, or in preparation of a contingency landing should there be a Return to Launch Site (RTLS) decision. Once the RTLS decision point was past (257 seconds approximately) both the crew physicians utilized NASA provided transport aircraft to travel to the Primary Landing Site at DFRF (and NS for STS-3).

At NS, in addition to the medical officer duties, the JSC flight surgeon was the EMSS coordinator, stationed in the NS Operations Control Center (NSOCC) for STS-1 and STS-4, and at White Sands Missile Range (WSMR) for STS-2 and STS-3. In addition to the EMSS coordinator, there were two JSC flight surgeons, (one assigned to each of two rescue helicopters containing medical equipment) and a DOD physician, as backup. The NS was designated as the landing site for an Abort-Once-Around (AOA), Underburn, or Contingency Landing, in addition to being the backup End of Mission (EOM) site for STS-1, 2 and 3. For STS-4 NS was only a Contingency Landing Site (CLS).

For any landing, other than a (prescheduled) EOM at NS, there would be no microbial samples or clinical lab samples taken. For an EOM, the crew physician, deputy crew physician, microbiology, and clinical lab teams would deploy to NS. This was the case for STS-3 which landed at NS.

The crew physician arrived from KSC and deployed to the convoy assembly area where he became part of the crew van complement. Additionally, two JSC flight surgeons were each assigned to rescue helos. The convoy also contained an ambulance staffed with two EMT's and a DOD physician. After vehicle rollout, and when the area around the spacecraft was safe for crew egress, the crew van approached the Columbia. The egress procedures called for the crew physician to enter the vehicle with the first changeout crewman, briefly assess the condition of the crewmembers, egress with crewmembers, board the crew van and depart for the DFRF clinic where a complete crew examination could be conducted. Once in the van the crew doffed their suits in transit to the clinic where two JSC physiological technicians assisted the crew physician and the deputy crew physician with the postflight examinations.

During and after crew egress, the microbial sampling went according to plan. Clinical lab samples were acquired from the crew during their exams.

There were no significant problem during implementation for STS-1 through STS-4.

CONCLUDING REMARKS

The success of the readiness reviews, mission verification tests and STS mission support attest to the high quality of management, planning, coordination and implementation achieved in support of the OFT flights. It is estimated that changes and improvements to the existing Medical Operations system for STS operations will be small. Each participant deserves a special word of praise for his/her cooperation and dedication to the total Medical Operations support of the OFT missions.

HEALTH STABILIZATION PROGRAM

CHAPTER 15

James K. Ferguson, Ph.D.

A well-defined Health Stabilization Program was first introduced into the space program on the Apollo 14 mission. The Program was put into effect following a number of prime crew illnesses and exposures to persons with communicable diseases. These illnesses and exposures occurred at critical mission times, immediately before or during the earlier Apollo missions. As a result of these occurrences, it was recognized that crew illnesses could cause a loss of valuable crew training time, postponement of missions, or even compromise crew safety and mission success. The health program was therefore established to provide an environment surrounding the prime and backup crewman which would reduce and hopefully eliminate their exposure to infectious disease.

The Apollo 14 Health Stabilization Program was successfully completed without an illness occurrence in the crewmen. Following the Apollo 14 mission, the Program was effectively used for the remainder of the Apollo missions and for the Skylab and ASTP missions. There have been no known illnesses in the crewmembers at critical mission times since the Program was initiated. A comparison between the results observed with and without the program showed a significant ($p<.001$) decrease in the number of illness events when the program was used.

MATERIALS AND METHODS

For the STS-1 mission all personnel who were required to work in crew areas were identified and given medical examinations. All of those who passed the examination were designated as primary contacts. Security was placed at the door of the training building and crew quarters, and only primary contacts were allowed to enter. The participants were instructed to wear surgical masks when within six feet of a crewmember. Each primary contact was asked to voluntarily report any illness to his or her site clinic and receive a medical examination. If an infectious disease was found they were not allowed to return to the crew work area.

Crew housing was required for the prime and backup crewmen at the Johnson Space Center (JSC), Kennedy Space Center (KSC), and Dryden Flight Research Facility (DFRF) locations and only primary contacts were allowed to enter. Food control and specific security measures were carried out.

On all subsequent missions, STS-2 through STS-4, the Health Stabilization Program was altered to meet the needs of the advancing Shuttle program. Security coverage was eliminated to remove the restrictions placed on the work areas. The objective of the new approach known as the Level 1 program was to create a health awareness among the personnel entering the crew work areas. Posters, signs and information sheets were placed on the walls asking for voluntary compliance to the specific health rules. Information sheets were also distributed. Briefings were given to the flight crewmembers with recommendations for illness prevention measures. Since work areas were not restricted to primary contacts, special crew travel routes were established to prevent accidental exposures. All persons who were known to have to be within six feet of a crewmember during the seven days immediately prior to launch were identified as primary contacts and

were badged. Medical consultation was made available to all personnel who worked in crew areas. Security was not used in the work areas or for crew movement from place to place. Health protection for the crew was based on personal compliance to the program recommendations. Crew housing and food service was made available for crew use on a voluntary basis at the training and launch sites.

RESULTS AND DISCUSSION

The STS-1 Health Stabilization Program was continued for 11 days until the Orbiter landed on April 14, 1981. The illness prevention measures for crew protection were carried out as outlined in the document JSC-11852, "Health Stabilization Program (OFT)."

The number, type, and location of STS-1 personnel who were given medical examinations and approved as primary contacts are found in Table 15-1.

STS-1 illness or contact with illness was reported by the primary contacts at three NASA Centers and their reports were distributed as shown in Table 15-2.

The illness rate in the primary contact population during the STS-1 program was 28 illnesses per 1000 persons per week. A summary of the types of illness which occurred is shown in Table 15-3.

Eight contacts with illness were reported during the 11-day program and were distributed as shown in Table 15-4.

Coverage was provided for the largest number of primary contacts since the Program was initiated with Apollo 14. The increased number of primary contacts was due to the addition of two shifts of personnel in support of the Shuttle simulators.

A total of 38 known ill persons were kept out of crew work areas and thereby possibly prevented crew illness. It is suspected that many ill individuals did not enter crew areas and did not report their illnesses. Personnel awareness of possible flight crew illness was probably one of the most effective elements of the STS-1 Health Stabilization Program.

The Program limited the access of large numbers of newspersons to the crew. All non-NASA persons who visited the crew were given medical examinations. Also, large numbers of personnel were restricted from entering building 5, including NASA personnel, contractor personnel, and public visitors to the exhibits, thereby eliminating overcrowding and reducing possible exposures.

As expected, the change in the Health Stabilization Program produced a significant reduction in the number of primary contacts as shown in Table 15-5.

A significant reduction in the number of illness reports was also observed during these missions. Only three illness reports were received for STS-2 and STS-3, and none were reported for STS-4. The posters and instructional signs placed in the work areas seemed to increase personnel awareness. A number of persons working in the crew areas who were not primary contacts did report to the JSC and KSC clinics with illness. These indiiduals were given medical examinations and advised to work in another area, to take sick leave or administrative leave according to their supervisors instructions.

The Health Stabilization Program was successfully completed for each of the OFT missions. The clinical work has been reduced and will be able to function with the increased frequency of missions that are planned for the operational STS program.

TABLE 15-1.- NUMBER, TYPE, AND LOCATION

Type	JSC	KSC	DFRF	ARC	HQs	Subtotal
NASA	216	35	7	1	5	264
Contractor	643	42	12	0	0	697
Others	10	1	0	0	0	11
Subtotal	869	78	19	1	5	972
						GRAND TOTAL

TABLE 15-2
NUMBER AND LOCATION OF PRIMARY CONTACT REPORTS

Report	JSC	KSC	DFRF	Other	Total
Illness	31	4	3	0	38
Contacts with Illness	6	2	0	0	8

TABLE 15-3
SYMPTOMS AND ILLNESSES REPORTED BY PRIMARY CONTACTS ON STS-1

Illness*	JSC	KSC	DFRF	Percent Total
Upper Respiratory Infection	24	3	3	70
Bronchitis	1	0	0	2
Pneumonia	0	0	0	0
Upper Enteric Illness	3	0	0	7
Lower Enteric Illness	2	0	0	5
Fever Present	4	0	0	9
Headache Present	1	0	0	2
Skin Infection Present	0	0	0	0
Other Infectious Illness	1	1	0	5

*One illness may contain more than one system complex.

TABLE 15-4
TYPES OF ILLNESS CONTACTS REPORTED BY PRIMARY CONTACTS ON STS-1

Illness	KSC	JSC	Other	Percent Total
Upper Enteric	1	0	0	13
Lower Enteric	0	1	0	13
Upper Respiratory	1	4	0	62
Scarlet Fever	0	1	0	13

TABLE 15-5
PRIMARY CONTACTS

Mission	JSC	KSC	DFRF	ARC	HQS	Total
STS-1	869	78	19	1	5	972
STS-2	139	19	6	0	0	164
STS-3	182	48	6	0	0	236
STS-4	243	53	9	0	0	305

ENVIRONMENTAL EFFECTS OF SHUTTLE LAUNCH AND LANDING

CHAPTER 16

Andrew E. Potter, Ph.D.

INTRODUCTION

Because the Space Shuttle was a new launch vehicle, employing larger solid rocket boosters than any previous vehicle, its environmental effects were not known prior to the first launch. Thus, the Environmental Impact Statement (EIS) for the Space Shuttle Program, published in 1978, relied on estimates and extrapolations derived from Titan III launch cloud measurements and on supersonic wind tunnel tests for prediction of sonic booms. The objective of the Shuttle Environmental Effects Program is to verify the estimates and extrapolations published in the 1978 EIS by means of measurements of launch cloud effects and sonic booms.

The principal exhaust products from the Shuttle engines are aluminum oxide dust, hydrogen chloride gas, carbon dioxide gas and steam along with traces of nitrogen oxides. Since the vehicle rises slowly during the first few seconds after ignition, the exhaust products accumulate in a large cloud near ground level. Steam and spray from deluge water at the launch pad are entrained into the rocket exhaust, and also contribute to the exhaust cloud. Initially the exhaust cloud is hot and buoyant, rising to an altitude of about 3000 feet where it stabilizes and drifts with the prevailing winds. The estimated amount of exhaust constituents in the cloud are large: aluminum oxide dust, 56 metric tons; hydrogen chloride, 35 metric tons; and approximately 100 metric tons of steam and spray. The possibility of significant environmental effects from toxic hydrogen chloride is the major concern relative to the launch cloud. Of lesser concern are potential weather modification effects by the aluminum oxide dust suspended in the launch cloud and acoustic noise effects on wildlife.

Sonic booms are produced by the Shuttle both during launch and during reentry, launch booms impact the sea off the launch site, and are of less concern than reentry booms, which impact populated land areas. As a consequence, sonic booms were measured in the reentry corridor west of Edwards Air Foce Base, California.

MATERIALS AND METHODS

Exhaust Cloud Predictions

The NASA/Marshall Space Flight Center (MSFC) Multilayer Diffusion Model was used to predict exhaust cloud deposition footprints for hydrogen chloride and aluminum oxide dust prior to each launch, using meteorological data from preflight soundings. A prediction was provided to the Kennedy Space Center (KSC) Medical Operations at about F-2 hours to provide advance warning in the event that there might be a potential hazard to the viewing public from cloud fallout. After the STS-1 launch, for which an unexpectedly large fallout of hydrogen chloride-wet particles of aluminum oxide was noted, the dust deposition parameters in the model were empirically altered to provide a better fit between the observed and calculated fallout patterns of wet dust fallout.

Surface Measurements of the Exhaust Cloud

Surface measurements were made by deploying a network of monitor sta-

tions, each of which included several measurement devices. A complete monitor station initially included a nucleopore filter (for dust), pH paper, dry buckets, hydrogen chloride dosimeter, indicator plants and mineral oil dishes. After STS-1, polished copper plates were added. After STS-3, the mineral oil dishes and indicator plants were deleted. At some stations, a Geomet hydrogen chloride gas analyzer was included. Partial instrumented stations were also deployed. These generally included pH paper and a polished copper plate.

The deployment statistics for these stations for STS-1 through STS-4 were as follows:

	Complete Stations	Partial Stations
STS-1	44	9
STS-2	52	8
STS-3	17	34
STS-4	17	34

After STS-2, the number of complete stations was reduced, reflecting the fact that hydrogen chloride concentrations measured in STS-1 and STS-2 were extremely small. Most of the stations were deployed along the predicted exhaust cloud footprint, with the remainder at random locations around the KSC area.

In addition to the mobile monitor systems, four permanent air monitor stations (PAMS) were operated during each launch. These stations measure ozone, sulfur dioxide, hydrogen chloride and nitrogen oxides. They were located near the launch pad, near the south gate, at Dunn Airport in Titusville and the National Wildlife Refuge northwest of the launch pad.

Airborne Measurements of the Exhaust Cloud

For STS-1, an instrumented aircraft operated by Langley Research Center (LaRC) was used to sample the exhaust cloud, measuring the total and gaseous hydrogen chloride concentrations as well as the size distribution of aluminum oxide dust, using a 10-stage QCM analyzer. The substantial fallout of hydrogen chloride-wet particles noted for the STS-1 cloud led to a change in measurement strategy for STS-2. For this case, the 10-stage quartz crystal microbalance (QCM) analyzer on the LaRC aircraft was replaced by a Knollenberg probe designed to measure large particles, both inside the cloud, and falling below it. In addition, a National Oceanic and Atmospheric Administration (NOAA) aircraft fitted with cloud physics instrumentation collected data from the STS-2 exhaust cloud.

Ecological Measurements

Native vegetation at various sites was examined and tagged prior to the launch. Postflight examinations of the plants were made to assess any effects. Aerial photography using false-color infrared film was made of the areas believed to be affected by fallout from the cloud in order to detect any changes in vegetation appearance. Observations of wildlife were limited to birds. Five sites were monitored during STS-1. Little or no disturbance was noted for STS-1, so that no further observations were made.

Benthic organisms (bottom-dwelling microscopic invertebrates) were sampled from the lagoon muds before and after each launch. The number and diversity of the benthic population is a sensitive measure of environmental stress.

Acoustic Measurements

Acoustic noise at various points around the launch pad was measured using recording sound level meters. Fifteen meters were deployed for

STS-1, six for STS-2, and two for STS-3 and STS-4.

Sonic Booms

Sonic booms were recorded by ground stations located under the flight path of the Orbiter just prior to its landing at Edwards Air Force Base (EAFB). These stations each consisted of a wide-response microphone (0.1 to 10,000 hertz), a time-code generator and a 14-track AM/FM tape recorder. Eleven stations were deployed for STS-1, four for STS-2 and STS-4. Four stations were also deployed for STS-3, but no data were obtained because the Orbiter landed at the Northrup Strip, White Sands, New Mexico.

RESULTS

The NASA/MSFC Multilayer Diffusion Model was successful in predicting the general direction of the exhaust cloud movement to within about 30° azimuth. Far-field surface concentrations of hydrogen chloride predicted by the model were much larger than observed. In fact, virtually no gaseous hydrogen chloride was measured at the surface, other than at the pad surface itself.

Comparison of airborne measurements of hydrogen chloride with model predictions for STS-1 led to a similar result, in that the predicted values inside the airborne cloud were a factor of two or more larger than the measured values. As the cloud aged, this discrepancy decreased, indicating that the diffusion rates used in the model were too large. In summary, it appears that the model was conservative by at least a factor of two, and perhaps much more. The fact that gaseous hydrogen chloride was not observed at the surface was probably due to scavenging of gaseous hydrogen chloride by a water aerosol. The discrepancy between calculated and observed airborne total hydrogen chloride was most likely due to scavenging of hydrogen chloride from the exhaust gases by deluge water.

Surface Measurements of the Exhaust Cloud

Surface measurements revealed an unexpected environmental effect of the exhaust cloud. A widespread deposition of acidic droplets occurred. The fallout was heavy in the region just north of the launch pad, where substantial damage to one to two hectares of vegetation and minor fish kills took place. The fallout region near the pad was clearly outlined by dead vegetation. Hot acidic spray resulting from interaction of the deluge water with the solid rocket booster exhaust flame was believed to be the cause. Leaf and soil surfaces in this region showed traces of tan aluminum oxide deposits. A choking odor was evident for several hours following the launch. At least part of the odor was found to be due to gaseous hydrogen chloride which appeared to originate from evaporation of a gaseous hydrogen chloride present on the soil and vegetation following the launch. There was another component, as yet not identified, to the odor.

Outside the pad region, fallout effects were much less marked, but nonetheless could be detected for considerable distances. For STS-1, acidic droplets were detected 8 km from the pad, and for STS-2, acidic droplets were detected 15 km from the pad. STS-3 and STS-4 produced clouds which went directly out to sea, so no data are available from them. The pH of these droplets was <1, so that they produced damage spots on the leaves of sensitive vegetation, like native pennywort. Plants with resistant leaves, such as mangrove, were unaffected.

Each of the acidic droplets appeared to contain a nucleus of aluminum

oxide dust, so that the fallout particles could be called wet aluminum oxide dust, as well as acidic droplets or mist.

Curiously enough, the Geomet analyzers and hydrogen chloride dosimeters detected very little gaseous hydrogen chloride from the exhaust cloud. The few positive indications found were either from very near the pad, or appeared to be anomalous. This differs from Titan exhaust clouds, for which surface hydrogen chloride was detected, even though the amount of hydrogen chloride in the Titan exhaust cloud was about a third of that expected in the Shuttle exhaust cloud.

It appears that the exhaust cloud for the Shuttle was altered by the deluge water, which was applied in unprecedented amounts. Steam and spray from the deluge water evidently mixed with the exhaust cloud and scavenge hydrogen chloride. Most of the effect was noted close to the pad, where the hot acid spray damaged vegetation for half a mile north of these areas. Substantial amounts of hydrogen chloride must be removed from the cloud at this point. Some of the steam and spray were carried aloft by the updrafts associated with the hot buoyant cloud. Eventually, this material fell out as droplets or wet aluminum oxide dust as the cloud moved with the prevailing wind.

Several instances were reported (STS-1 and STS-2) of acidic droplets (or wet acidic dust) falling on exposed skin of observers. In some cases, a slight burning sensation was reported, which disappeared after washing the skin with water. No long-lasting or recurrent effects have been reported.

During STS-2, many automobiles received acidic droplet fallout, in some cases at densities in excess of $100/cm^2$. The drops evaporated quickly, leaving behind only a trace of aluminum oxide dust. No damage to the automobile finish was observed on the eight to ten automobiles inspected.

Airborne Measurements of the Exhaust Cloud

As noted previously, aircraft measurements of hydrogen chloride (total and gaseous) during STS-1 and STS-2 showed the hydrogen chloride concentration to be less than predicted by the model, presumably due to scavenging.

Measurements of the dry particle size distribution in the range 5-35 microns performed for STS-1 gave results similar to those found for Titan exhaust clouds.

For STS-2, wet (or aerosol) particle size measurements were made over a wide range, using Knollenberg probes, both on the LaRC and NOAA aircraft. A few minutes after launch, the exhaust cloud aerosol size distribution peaked near 200 microns. Particles this size were suspended by updrafts in the cloud during the period of cloud rise. At later times, when the cloud stabilized and the updrafts ceased, these particles fell out of the cloud. Measurements of ice nuclei in the cloud showed very little activity above ambient levels. The NOAA aircraft collected a very complete set of cloud physics data, which is still being analyzed. Preliminary indications from the data are that the large cloud droplets originate primarily from the deluge water.

Ecological Measurements

No significant ecological effects were noted. Wildlife was slightly and temporarily disturbed by the launch. Vegetation spotted or damaged by fallout from the cloud recovered quickly, except in the damage

area adjacent to the launch pad. Benthic organisms in the lagoon were unaffected by launch operations, although the population did display symptoms of a mild chronic stress.

Acoustic Measurements

Sound levels at all monitor sites were less than the 90 decibels A-weighted (dB-A) permissible for 8hours of occupation. The closest site was 4.8 km from the launch pad. The highest sound level recorded was 111 dB-A at 4.8 kilometers from the launch pad. By extrapolation, it was predicted that the peak sound level at the pad was about 127dB-A. Based on these data, it was recommended that personnel at sites closer or equal to 3 km from the launch pad should be provided hearing protection, but those at larger distances did not require protection.

Sonic Boom

Reentry sonic booms were measured for STS-1, 2, and 4. The most extensive measurements were made for STS-1, when eleven stations were deployed, nine directly beneath the ground track. For later flights, only four stations were deployed. No data were collected for STS-3, due to the landing at Northrup Strip.

Only the data for STS-1 have been completely analyzed. For this analysis, sonic boom overpressure levels were calculated from supersonic wind tunnel, meteorological data and the actual flight path, and were compared with the measured overpressures. In all but one case, agreement between calculated and observed values was within ±10%. The single anomaly noted may have been due to a local variation in meteorology.

The follow-on measurements for STS-2, and for STS-4 were aimed at determining the peak overpressure and the lateral extent of the sonic boom, respectively. Peak overpressures were sought in STS-2, but a change in wind conditions evidently moved the peak overpressure region away from the measurement sites, since overpressures less than expected were measured. Lateral cutoff was sought in STS-4, and this was observed, as two of the outermost stations recorded no sonic boom. Analysis of these data is still underway.

EMERGENCY MEDICAL SERVICES SYSTEM (EMSS)

CHAPTER 17

Sam L. Pool, M.D. and Norman Belasco

The responsibility for planning and implementation of the Emergency Medical Services System (EMSS) during the first four Space Transportation System (STS) Shuttle flights resided with the Space and Life Sciences Directorate at the Johnson Space Center (JSC). Emergency medical support for launch and landing operations of the Shuttle was mobilized by JSC with aid from the Department of Defense Management of Shuttle (DDMS). The objective of the EMSS was to provide the ill or injured crewmen with rapid access to the appropriate level of medical care. To meet this objective, the following factors were carefully considered in developing the EMSS for STS: accessibility to health care centers, personnel, training, experience, transportation, response times, equipment, communications, medical records, costs, special environmental hazards and rescue procedures.

DISCUSSION

To properly structure the EMSS, the launch and landing environs were examined to determine the capability of the local health care centers, and accessibility to more distant medical facilities that could provide definitive care. Also, means of transportation, possible routes and Medevac techniques were studied. After careful planning, the EMSS was structured to effectively utilize existing capabilities and proven techniques by largely standardizing elements and functions among the participating sites.

Local hospitals were available at or near each site. The following local hospitals were designated as intermediate care facilities: Edwards AFB Hospital for Dryden Flight Research Facility (DFRF), Jess Parish Hospital for Kennedy Space Center (KSC), and Holloman AFB Hospital for the Northrup Strip (NS). For definitive medical care, NASA negotiated agreements with Shands Teaching Hospital, Gainesville, Florida (for KSC); Loma Linda University Medical Center, Loma Linda, California (for EAFB); and a DOD facility, William Beaumont Army Medical Center, El Paso, Texas (for NS). Staffs at all facilities had been trained in the Shuttle unique medical requirements. They participated in Medevac training exercises and in mission alerts.

Helicopters would be used for transportation of ill or injured crewmembers. Prior to transportation, patients are stabilized at the scene. The equipment for most of the stabilization process is flown on the helicopters. Special training is given to the physicians (NASA/DOD) and parajumpers who fly on the helicopters. All physicians are given additional instruction in care of trauma victims. Once the ill or injured crewman's health problems have been assessed and initial stabilization given, the helicopter physician may elect to transport the crewmen to either the intermediate or definitive care facility.

An emergency medical record would be required for any patient emergency care. It would contain the following information: a history of physical findings relevant to the injury or illness treated, a medical diagnosis or impressions, complete list of any treatments given, patient's condition upon delivery to the hospital, and signature of the responsible physician.

The main elements of the EMSS at JSC are the Mission Control Center (MCC) positions of Mission Operations Control Room (MOCR) surgeon and biomedical engineer (BME). At the launch and landing sites (KSC, DFRF and NS) the focal position is EMSS Coordinator. Other elements at these sites are two medical helicopters, each with a JSC flight surgeon and two parajumpers onboard; an ambulance staffed with emergency medical technicians (EMT); and access to intermediate and definitive medical facilities (Figure 17-1). Deployment of personnel at each of the sites is described in Section III of "Management, Planning and Implementation of Medical Operations."

At all sites, a physician EMSS Coordinator communicates through the local site control center to assure that the field centers are appropriately staffed and ready for any emergency operation. He also communicates with EMSS coordinators at other field sites and the MOCR surgeon at JSC.

The EMS as standardized among the sites, Edwards AFB (EAFB) in California at KSC and NS, permits the JSC MOCR surgeon (EMSS physician in Mission Control) to relay any inflight problems that might affect the recovery operations to the EMSS Coordinator at his respective site.

A communication system was established at KSC, the launch site, and CONUS landing sites EAFB and NS to permit the Emergency Medical System Coordinators to coordinate the activities of the emergency medical helicopters in the event of a problem. Once the helicopters are airborne and within range they can communicate with the local hospitals as well as the definitive care facility.

KSC was identified as the launch site for STS-1 through STS-4. EAFB was used as the primary landing site for STS-1, STS-2 and STS-4. NS was used as STS-3 End of Mission (EOM) landing site because of weather problems at EAFB. For STS-1 through STS-4, the NS was initially considered the back-up landing site. The NS was also designated as a landing site if an underburn occurred or an Abort-Once-Around was required. Other DOD (non-CONUS) contingency landing sites (CLS's) were identified at Hickam AFB, Hawaii; Kadena AFB, Japan; and Rota, Spain. Dakar, Senegal, was selected as the landing site for a transatlantic landing (TAL), for STS-4. At Dakar, where there was no USA military, JSC provided for EMS by stationing a JSC flight surgeon at the airstrip, supported by a DOD C-9 "Nightingale" (an airborne medical facility) staffed with a trauma trained physician, two nurses and two medics. If necessary, this team could transport the ill or injured crewmember to Wiesbaden, West Germany, for definitive medical care.

CONCLUDING REMARKS

In conclusion, the Emergency Medical Services System established for STS-1 through STS-4, was on station for each mission with trained personnel appropriately equipped, and ready to deal with any launch or landing contingency that resulted in a medical emergency.

MISSION SUPPORT
REPRESENTATIVE MEDICAL OPERATIONS SYSTEM - EMS

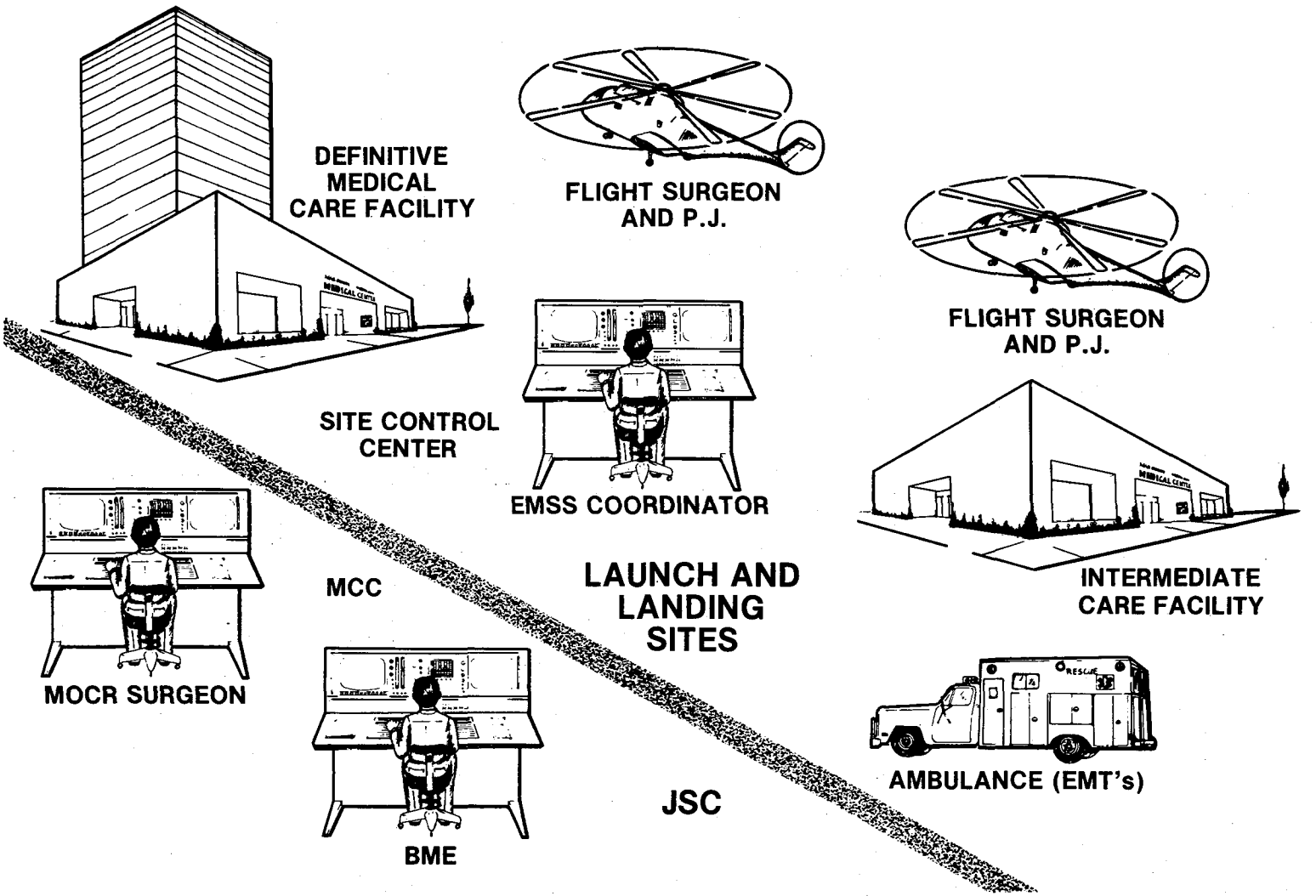

FIGURE 17-1

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16. Abstract

The medical operations report for the Orbital Test Flights (STS-1, 2, 3, and 4) includes a review of the health of the crews before, during, and immediately after the four Shuttle orbital flights. Areas reviewed include health evaluation, health stabilization program, medical training, medical "kit" carried in flight, tests and countermeasures for space motion sickness, cardiovascular profile, biochemistry and endocrinology results, hematology and immunology analyses, medical microbiology, food and nutrition, potable water, Shuttle toxicology, radiological health, and cabin acoustical noise. Also included is information on environmental effects of Shuttle launch and landing, medical information management, and management, planning, and implementation of the medical program.

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