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APOLLO 7 TO 11: MEDICAL CONCERNS AND RESULTS

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ABSTRACT

The goal of the Apollo Program is to land men on the moon and safely return them to earth. The medical task thus outlined required confirmation of the Gemini findings and definition and solution of any problems encountered in the four Apollo flights prior to the Apollo 11 lunar landing. The medical concerns included the following.

1. The effect of decreased red blood cell mass and decreased exercise capacity and of cardiovascular deconditioning on the ability of the crew to do lunar-surface activity

2. The capability to work effectively in one-sixth g and the energy cost of such work

3. The ability to get adequate rest and sleep in flight and on the lunar surface

4. The prevention of preflight, inflight, and postflight illness by proper preventive medicine

5. The possible development of motion sickness of vestibular origin

6. The conduct of a postflight quarantine of crew and lunar samples

The results of the Apollo 7 to 11 missions, demonstrating the ability of man to handle this difficult task and the environment successfully, are discussed in detail and are related to the future of manned flight.

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APOLLO 7 TO 11: MEDICAL CONCERNS AND RESULTS

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INTRODUCTION

The goal of the Apollo Program is to land men on the moon and safely return them to earth. This goal was achieved with the successful lunar landing of Apollo 11 on July 20, 1969. Future lunar-landing missions will be accomplished under the more advanced lunar exploration phase of the Apollo Program. This paper summarizes the medical knowledge and experience gained during the Apollo 7 to 11 missions. The Apollo Program was designed as a series of steps beginning with an earth-orbital checkout of the command and service module (CSM), progressing to lunar-orbital checkouts of the CSM and the lunar module (LM), and finally achieving a lunar landing. The five manned Apollo missions are listed in table I. Thus far, space-flight experience during the three U.S. space-flight programs is comprised of 54 man-hours during Project Mercury, 1939 man-hours during the Gemini Program, and 3105 man-hours during the Apollo Program, which includes 2 hours 14 minutes of lunar-surface exploration for the Apollo 11 commander (CDR) and 1 hour 42 minutes of lunar-surface exploration for the Apollo 11 lunar module pilot (LMP). The duration of the longest Mercury mission was 30 hours, and the durations of the longest Gemini and Apollo missions were 14 and 11 days, respectively. Space-flight experience to September 1969 totaled 5098 man-hours.

The successful completion of the Apollo 11 lunar-landing mission required planning that was based on the results of all previous manned space flights. The medical information obtained from the Gemini Program was the basis on which the medical support and investigation for the Apollo flight series were planned. The significant positive medical results from the Gemini Program have been previously reported (refs. 1 to 8) and are summarized as follows:

1. Moderate loss of red blood cell mass
2. Moderate cardiovascular deconditioning
3. Moderate loss of exercise capacity
4. Minimal loss of bone density
5. Minimal loss of calcium and muscle nitrogen
6. High metabolic cost of extravehicular activity (EVA)

The possible effects of the EVA difficulties, the cardiovascular deconditioning, the loss of red blood cell mass, and the loss of exercise capacity on crewman performance during the proposed lunar-surface activity were of particular concern. The Apollo spacecraft was a new vehicle which provided, for the first time, sufficient cabin volume to allow freedom of movement and exercise, thus reducing the marked confinement of the earlier Mercury and Gemini flights. Accordingly, the following medical objectives for the Apollo Program were established:

1. The assurance of crew safety

2. The assurance of mission completion and completion of those activities contributing to mission success

3. The prevention of back contamination of the biosphere

4. The continuance of the understanding of the biomedical changes incident to manned space flight

To meet these objectives, it was necessary to develop a medical requirements document which detailed a preflight and postflight medical evaluation program. This program would provide information that would assure a proper medical-support capability for the lunar landing. Development of the medical program was particularly important because all inflight medical experiments had been removed from the Apollo Program after the Apollo spacecraft fire in 1967 in order to concentrate on the operational complexity of the missions. The concern about the lunar mission was summarized in a recent article on lunar medicine (ref. 9).

The confirmation of the Gemini Program data in the larger Apollo spacecraft was vital to the prediction of the physiologic state of the crewmen at the time of the lunar-surface activity. The acquisition of microbial base-line data for the lunar-quarantine operations and the further documentation of space-flight effects upon man were also critical objectives. The medical procedures that were conducted were developed by a multidisciplinary team in the Medical Research and Operations Directorate of the NASA Manned Spacecraft Center at Houston, Texas. Evaluations included physical examinations, hematology, immunology, biochemistry, bone densitometry, cardiovascular response, exercise capacity, and microbiology. These evaluations were supplemented by the observations made in flight from continual voice monitoring, the monitoring of electrocardiogram and respiration during command module (CM) operations, and the monitoring of voice and electrocardiogram during LM operations. During the Apollo 7 and 8 CM operations, it was possible to monitor the electrocardiogram and respiration of only a single individual at any given time. During the Apollo 9, 10, and 11 missions, simultaneous monitoring of all three CM crewmen was possible, and monitoring of one crewman at a time was possible in the LM. During the Apollo 11 lunar-surface exploration, both crewmen were monitored simultaneously.

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NATURAL AND SPACECRAFT ENVIRONMENT

Cabin Atmosphere

Following the Apollo spacecraft fire in 1967, it was decided that the cabin atmosphere at launch would contain less than 100 percent oxygen. Calculations and studies showed that if a 60-percent-oxygen/40-percent-nitrogen atmosphere were used at launch and if the crewmen were denitrogenated for 3 hours prelaunch, problems of hypoxia and dysbarism could be avoided when the spacecraft attained the nominal cabin pressure of 5 psia. The Apollo spacecraft have actually been launched with a 64-percent-oxygen/36-percent-nitrogen atmosphere. The cabin urine-dump valve was left open at launch and for a number of hours after launch to establish a given leak rate and to aid in the oxygen enrichment of the cabin. On the Apollo 7 flight, an oxygen analyzer was carried on board, and readings of the oxygen percentage were taken during the mission. The oxygen enrichment profile is shown in figure 1. The oxygen partial pressure was never less than that normally present at sea level. The crewmen always removed helmets and gloves within the first hour after launch and usually within the first half hour. The suits were removed at convenient times early in the mission, and flight coveralls were worn for the major portions of the flight. During the Apollo 7 mission, the crew donned the suits at one time to check their capability to do so and to check their reentry configuration. The crew also donned the suits without the helmets and gloves in order to use the foot restraints which were built into the suit loop for use during reentry. On the flights since Apollo 7, the suits have not been worn during reentry but have been redonned for critical mission phases such as the separation and docking of the LM and CM and the lunar-surface activity.

Cabin and Suit Temperatures

During the Apollo 7 to 11 missions, the CM cabin temperature was maintained at approximately 70° F, varying from 62° to 80° F. This temperature was generally maintained without the use of cabin fans. Occasionally, crewmen were cool during translunar coast, but adjustment of the environmental control system returned the cabin to comfort levels (fig. 2). The suit temperatures were measured at the suit inlet and were always maintained at a lower level than that of the cabin. The temperature in the LM during earth orbit or lunar orbit was maintained between 65° and 70° F except during and immediately following depressurization (fig. 3). During the sleep period following the lunar-surface activity on Apollo 11, the crewmen complained that chilling and shivering interfered with sleep. The chilling was principally an effect of the liquid-cooled garment temperature and was not reflected in the cabin gas temperatures (fig. 4). The Apollo 11 LM crewmen were suited with helmets on and with the liquid-cooled garment operating during the rest period.

Noise and Vibration

During the early checkout of the Apollo spacecraft, a noise problem was noted which involved the cabin fans and the glycol pump. The pump noise was attenuated by the use of padding, and the cabin fans have generally not been used. The noise level in the cabin at lift-off has been high, but the level during flight has been quite acceptable and has created no problems of annoyance or interference with sleep. During all three LM missions, the noise level in the LM was also reported to be high because of noise created principally by the cabin fans. When helmets were removed, the noise levels in the LM were annoying. Pogo vibrations of the launch vehicle were reported, but vibration transmission to the crew has been physiologically unimportant.

ACCELERATION AND IMPACT

All launch accelerations have approached 4g (fig. 5). Reentry from earth orbit has produced accelerations approaching 3.4g, and reentry from lunar missions has produced accelerations of almost 6.7g (fig. 6). Accelerations resulting from the ignition of the Saturn S-IVB stage for translunar injection and from all service propulsion system (SPS) burns of the CSM have been less than one g (table II). All of these acceleration levels were well tolerated and had been experienced by the crewmen during centrifuge training. The landing impacts have been estimated at 6g to 8g and were well tolerated by all crewmen.

Radiobiology

Two of the five manned Apollo missions, Apollo 7 and 9, have occurred within the protective magnetic field that surrounds the earth and provides a shield against galactic radiation and against the particles of major sun flares should such flares occur. Figure 7 schematically depicts the effect of this magnetic field on artificially produced electrons at high altitude and also depicts the general location of the galactic protons and electrons that surround the earth. Horizontal distances on figure 7 are measured in earth radii, and it is easy to see how, on earth-orbital missions of 100- to 200-mile altitudes, it is possible to stay below the radiation belts except for an area known as the Atlantic Anomaly. Fortunately, only one of approximately seven orbits goes through the center of the anomaly.

The launch trajectory in earth-orbital missions has been determined such that the polar regions have been avoided. It is obvious from figure 7 that there would be direct radiation from space on polar orbits because the polar region is not protected by the magnetosphere. To date, no manned missions have followed true polar trajectories.

As opposed to earth-orbital missions, the lunar missions must pass through the radiation belts en route to and on return from the moon. Actually, the radiation dose received during each passage through a radiation belt has been quite small, equivalent to approximately 10 millirads. This small dose is attributed primarily to the speed with which the spacecraft is traveling through the radiation belts.

With the Apollo lunar missions, man, for the first time, penetrates the protective "magnetic umbrella" and exposes himself to direct galactic radiation and to particles from solar flares should such flares occur. It now appears from actual measurements that, under normal circumstances, true space is devoid of significant radiation, consisting principally of galactic radiation at levels approximating 10 mrad/day. Solar flares seem to occur at random intervals and, with short-duration missions to the lunar surface, it is improbable that a solar flare producing a significant particle event would occur during the time of a lunar mission. Should a particle event occur, the radiation doses received by the crewmen are expected to be medically insignificant because of protection afforded by the thickness of the spacecraft wall. As a typical example, the worst solar flare measured during the last solar cycle, November 12, 1960, would have given the CM crewmen a skin dose (0.07-mm depth) of 237 rads and a depth dose (5 cm) of only 15 rads. The effect of these doses on an average man would be minimal. It is possible to have multiple flares, but the probability of such an occurrence during the time interval required for an Apollo mission is low.

During later Apollo flights, there is a short period of time during crew occupancy of the LM and also during lunar-surface EVA when a large solar flare, should such a flare occur, could be of some medical significance. Under the worst conditions conceivable, skin doses to an astronaut could be as high as 691 rads, but because of the radiation spectrum, the depth doses would not exceed 25 rads. Although no pathological effects are predicted as a result of such a depth dose, the skin dose possibly could affect crew performance moderately because of skin irritation, blepharitis, and so forth. In addition, a radiation dose of this magnitude approaches the threshold of a radiation dose that could result in more serious latent sequelae such as epilation, fibrosis, edema, and moist desquamation. Fortunately, certain operational constraints can be used to limit radiation exposure. In addition, the probability of a solar flare of the magnitude described is quite small, probably no more than one in 5000 missions. Radiation of the Apollo spacecraft is being measured by the instruments listed in table III, some of which were also used in the Gemini series of earth-orbital missions.

The results of the radiation measurements made by the dosimeters on the Apollo 7 to 11 missions are reported in table IV. The doses, reported in rads, are the mean values of all measurements made. A final precise estimate of the Apollo 11 radiation dose has not been determined because certain instrumentation has been quarantined.

The radiation doses accumulated by the astronauts are generally much less than radiation doses to specific organs of the body during routine diagnostic procedures. Certainly, the radiation risk from the Apollo 7 to 11 series of flights has been minimal.

Toxicology

Three approaches were taken to assure the safety of the Apollo CM and LM atmospheres.

1. Material selection based on off-gassing

2. Animal toxicological evaluation of off-gassed products from materials

3. Analysis and evaluation of the atmospheres of the Apollo 7 CM, the Apollo 8 CM, and the Apollo 9 LM during altitude chamber tests at the NASA Kennedy Space Center (KSC)

The objectives of these end-item tests were to examine the atmospheres for known contaminants, to identify and quantitate known contaminants, and to establish the fact that contaminants were below levels that would produce physiological effects. It was revealed through these verification tests that approximately 50 compounds existed in the spacecraft atmosphere, but concentrations were too low to be of toxicological significance, even when grouped according to primary modes of action. Off-gassing was shown to increase with time and, significantly, was not reduced by curing out at a hard vacuum for a 7-hour period.

From postflight analyses of charcoal from the Apollo 7 to 10 missions, the presence of over 50 compounds in the spacecraft atmosphere was established; however, not all of these compounds were evident during preflight analysis. Of most significance was the presence of relatively large amounts of halocarbons such as methanol, ethanol, propanol, isopropanol, methyl chloride, mesitylene, and N-octane.

The following three problem areas still exist.

1. Observed methemoglobinemia. A review of the contaminants of the spacecraft shows no contaminant of sufficient concentration to produce a methemoglobinemia.

2. Halocarbons. Halocarbons can react with the lithium hydroxide (LiOH) of the environmental control system (ECS) canister to produce highly toxic products. Action is being taken to reduce this potential hazard.

3. Odor. Odors have been detected in the Apollo 9 and 11 spacecraft and the causes and effects are unknown. Sample bottles are available for potential use in the determination of the presence and possible sources of odors on future flights.

General Weightlessness

Flightcrews have confirmed the Gemini observations of an initial feeling of fullness in the head when weightless flight is attained. This sensation has lasted for varying lengths of time during the first day of flight. An awareness of a lack of weight of objects and clothing has been noted by crewmembers, and the capability to impart minimal velocities to objects in the weightless environment has been used repeatedly for living and working within the spacecraft. Intravehicular activity has required minimal effort to move about, and crewmen have been able to move quite freely, frequently in an underwater swimming manner, and have done acrobatic movements such as rolling, tumbling, and spinning without difficulty. There has been no evidence of increased workload in intravehicular weightless movement; in fact, it appears that the workload is less than that required for movement in a one-g environment. Some instances of soreness in the costovertebral angle areas have been reported. The crews have related

this soreness to the frequently assumed fetal position in the weightless environment. However, the soreness has not created any real difficulty. In general, the crews have adapted extremely well to the weightless environment, have found the environment pleasant, and have used the environment to assist them in accomplishing inflight activities. Specific comments relating to particular problem areas are noted in later portions of this discussion.

Food

Freeze-dehydrated, rehydratable, and bite-sized foods similar to those used in the Gemini Program were used for the Apollo 7 and 8 missions. One exception was the introduction of "wet-pack" turkey bites and gravy on the Apollo 8 mission. Extensive changes in the types of food and packaging were implemented during the time period encompassing the Apollo 9, 10, and 11 missions. These changes and the approach to inflight nutrition were necessary because of the following factors:

1. Inflight food comsumption was inadequate to maintain metabolic balance (less caloric intake than calories expended and loss of tissue fluid and electrolytes).

2. Meal preparation and consumption required too much time and effort.

3. Water for reconstitution of dehydrated foods was off-flavor and contained large quantities of undissolved hydrogen and oxygen gas.

4. Functional failures occurred in rehydratable food packages.

5. Development of a system of foods and packaging that was more familiar in appearance, flavor, and method of consumption was required.

6. Anorexia occurred during flight.

7. The probable reduced energy requirements for performance in weightlessness were considered.

Ninety-six different foods were available before the first manned Apollo mission. Approximately 60 of these foods were developed during and carried over from the Gemini Program. Of the 42 different foods to be used on the Apollo 12 flight, only 24 are from the original Apollo food list. New foods and packaging consist primarily of high-moisture-content (60 to 70 percent) thermostabilized meat portions (called wet-packs), freeze-dehydrated meat and vegetable combinations that contain larger pieces of meat than the wet packs and that are package-designed for utensil or spoon usage, some new flavors of powdered beverage, intermediate-moisture-content (10 to 30 percent) fruits and candylike items, and sandwich spreads with sliced "fresh" breads (fig. 8). The sandwich spreads are heat sterilized in hyperbaric chambers to reduce deterioration of food texture and are packaged in either cans or flexible aluminum tubes. Crew acceptance of all of the new foods and packaging has been quite high, which brings closer the goal of understanding which foods stand the best chance of being eaten in flight. However, it appears that the quantity of food consumed during a mission has not increased and that the crews have been subsisting primarily on the supply of new foods that were intended only to supplement the nominal food supply.

The Apollo 10 and 11 crews were highly complimentary of the food system, but their compliments are not valid criteria of success since postflight body weights still indicate a negative caloric and water balance. Changes in body weight and estimated inflight caloric intake are listed in table V. Despite the fact that there is no "average astronaut," it is significant to note that 15 men who had a combined weight of 2500 pounds (average weight of 166.6 pounds per man) have flown the Apollo missions. At recovery, the combined weight of the men was 2407 pounds (average weight of 160.4 pounds per man); 1 day after recovery, the combined weight was 2453 pounds (average weight of 163.5 pounds per man). Total inflight weight loss has been 93 pounds (average of 6.2 pounds per man) with approximately one-half of the weight loss (46 pounds, or 3.1 pounds per man) attributable to water loss.

Precise measurements of changes in body mass and accurate records of food intake would provide the data necessary to determine food requirements. Some of these measurements should be possible before the end of the lunar exploration phase of the Apollo Program and will provide necessary base-line information for the evaluation of the musculoskeletal status of crewmembers for Apollo Applications Program flights of 28- and 56-day durations.

In the Apollo 7 to 11 missions, procedures were simplified and time was reduced for meal preparation by the inclusion of foods that do not require rehydration prior to consumption. These foods also circumvented the problems of off-flavor water and dissolved gases in the spacecraft water supply. Packaging failures which occurred in flight have now been effectively prevented through design changes and additional quality-control inspection procedures. Inflight anorexia had caused crewmembers to comment that the food supply would be more desirable if food were stowed in bulk units similar to a pantry. This plan would allow each crewmember to make a real-time selection of desired foods based on appetite rather than on a meal sequence established a month before the flight. Apollo 11 food stowage was configured in nominal-meal units (45 meals, 15 man-days, or five mission days) in the lower equipment bay and in bulk units (nine mission days) in the left-hand equipment bay and beneath the center couch. Postflight debriefing indicated that this configuration was satisfactory but not absolutely necessary. The Apollo 11 crew estimated that 80 percent of the nominal-meal-unit food was consumed and that 40 percent of the bulk-stowage food was consumed. Food stowed in the LM was designed for four meal periods during the scheduled 21-hour occupancy period. The two Apollo 11 LM crewmembers estimated that 40 percent of the food supplies were eaten.

Postflight debriefing of the Apollo 7 to 11 crews has indicated that the intensity of hunger sensations was similar to that during the preflight phase. However, the crews have reported that the frequency of occurrence of hunger is reduced and that the food requirements are only two-thirds of the normal requirements. At least one crew has observed that gastric distention precluded the intake of normal quantities of food and beverage. Based on these observations and critical stowage volume, menus are presently designed to provide approximately 2300 kg-cal of energy per man per day.

Water Management

Analysis of data from the various Apollo LM and CM spacecraft indicates that spacecraft systems concerned with providing suitable drinking water and the

accompanying water-servicing procedures and water-bactericide addition (chlorine in the CM and iodine in the LM) have delivered potable water throughout the Apollo flights.

The addition of bactericides is necessary because of the cross connections between the potable- and waste-water systems and the potential for migration of organisms through the check valves (fig. 9). During the early Apollo CM flights, the crew expressed adverse reactions to the taste of chlorine in the water. The revision of chlorination procedures has eliminated this problem. Objectionable amounts of free gas in the Apollo 9 CM potable water were observed by the crew. On the Apollo 11 flight, the use of a hydrophobic-hydrophilic water/gas separator satisfactorily eliminated most of this free gas. In addition to the water/gas separator, the use of a silver-palladium hydrogen separator in the Apollo 12 CM will further decrease the amount of free gas in the potable water. Because of adverse iodine depletion rates in the LM-3 (Apollo 9) and LM-4 (Apollo 10) water systems, it was necessary to employ a microbial filter upstream of the water-use port. Alteration of the LM-5 (Apollo 11) water-system preservicing procedures resulted in the maintenance of a microbially effective iodine residual throughout the flight of LM-5 and eliminated the need for the microbial filter. Continuation of this revised preservicing procedure will eliminate the need to incorporate the microbial filter in subsequent spacecraft.

No other immediate changes in the Apollo CM and LM potable-water systems, procedures, and equipment are anticipated. With the extension of the LM lunar stay, however, revisions to the servicing procedure of the water system will be required to ensure that an effective iodine residual will be maintained in the LM water system.

Waste Management

Feces collection in both the LM and the CM is accomplished through the use of the Gemini fecal collection system. This system is a tape-on bag which is only marginally adequate because an inordinate amount of time is required for its use and because no provision is made to isolate odors that accompany defecation.

Urine collection in the CM is afforded by an updated Gemini urine transfer assembly. This device incorporates a roll-on cuff and an intermediate urine storage bag. The Apollo 12 CM will be equipped with an experimental urine collection assembly which will eliminate a direct interface between the user and the urine collection device.

Urine collection on board the LM is accomplished by an in-suit urine bag fitted with a roll-on cuff. This device has performed satisfactorily, and no changes are planned (fig. 10).

Work/Sleep Cycles

Before manned space flight became a reality, some members of the medical community predicted that such flights would produce serious disturbances and alterations in man's sleep, ranging from narcolepsy to insomnia. During Project Mercury, these extreme forecasts were shown to be incorrect, but during the Gemini Program, longer earth-orbital space flights were found to generate conditions that interfered

with adequate sleep. The primary factors that contributed to the fact that inflight sleep was less than that obtained on earth were (1) cyclic noise disturbances resulting from such events as thruster firings, communications, or movement within the spacecraft; (2) staggered sleep periods; (3) significant displacements of the astronaut's normal diurnal cycle; (4) the so-called command-pilot syndrome; (5) the unfamiliar sleep environment; and (6) excitement.

During the Apollo Program, no new sleep problems have been encountered. The old problems originally defined in Gemini missions continue to be investigated. The main difficulty has been in the application of medical knowledge and expertise to mission planning. Apollo missions are necessarily tailored around an operational trajectory which, by nature, is highly inflexible and constraining. The astronaut must be integrated into this fixed mission plan in the best possible way. That is, man is required to accommodate to the mission and not the converse. No ideal solution to this dilemma exists, if the program objectives are to be met in a timely fashion.

The Apollo 7 work/sleep cycles were characterized by irregular and drastic shifting of the staggered sleep periods around the nominal bedtime of 11 p.m. e.s.t. The crew never adapted to this bizarre work/sleep schedule, and in postflight debriefing, they reported that they experienced unsatisfactory sleep periods during the first 3 days of flight. One crewmember also reported that he once fell asleep on his watch because of fatigue and exhaustion and that he took 5 milligrams of Dexedrine on another occasion to stay awake during his work period. The Apollo 7 CDR recommended that future flightcrews carefully evaluate the work/sleep cycles.

Based on experience during the Apollo 7 mission and on the fact that staggered sleep periods were to remain in effect as a crew option on the Apollo 8 mission as spacecraft systems confidence was gained, Seconal, in 50- and 100-milligram doses, was added to the medical kit. The Apollo 8 work/sleep cycles are shown in figure 11. These cycles varied greatly from the KSC diurnal cycle and had the added complication of a 20-hour loitering period in lunar orbit. Real-time changes to the flight plan were required because of crew fatigue, particularly prior to transearth injection. Crew performance was slightly degraded, and minor procedural errors were committed. Only the LMP regularly took 50 milligrams of Seconal at bedtime for sleep.

Apollo 9 was the first Apollo mission during which all three astronauts slept simultaneously. A definite improvement over the previous two missions in both quantity and quality of sleep was noted, and a lack of postflight fatigue was evident during the recovery-day physical examination.

The Apollo 10 mission sleep periods were simultaneous and deviated little from the normal circadian periodicity of the crew, except during the lunar-orbital phase in which the CDR and the LMP checked out and exercised the LM. On the Apollo 11 lunar-landing mission, the work/sleep cycles were actually quite ideal before lunar orbit insertion (fig. 12). Table VI provides the quantitative sleep estimates obtained from study of the telemetered biomedical data compared with the subjective reports of the crew. The limitations in estimating sleep from heart rate and respiratory rate must be recognized, of course; nevertheless, the adequacy of sleep, as determined by either method, was sufficient to give medical approval to an earlier EVA than was planned originally. During the lunar stay, neither the CDR nor the LMP slept well. The LM environment was too cold and noisy for adequate sleep while on the lunar surface. In

addition, the LM sleep accommodations were poor. The CDR estimated he had little, if any, sleep in the LM, while the LMP estimated he had approximately 2 hours sleep. On the return flight, the crew slept well during the three transearth sleep periods. Coordinated efforts of the medical staff and the flight planners must be continued to maintain a 12-hour inflight workday, an 8-hour allowance for sleep, and a 4-hour period for leisure and relaxation. Future programs will afford better tools, such as the electroencephalogram, for an objective assessment of sleep quality.

Medical Kit

The Apollo medical kit is shown in figure 13. The LM medical kit contains eight Lomatil tablets, four Dexedrine tablets, 12 aspirin tablets, two Seconal capsules, one bottle of methylcellulose (1 percent) eye lotion, and two compression bandages. To date, no item from this medical kit has been used. The contents of the CM medical kit, the number of tablets or items stowed, and the number of items used on a particular mission are given in table VII. Some changes in the medical kit contents have been implemented as a result of flight experience. Included on a one-mission basis were items such as Benadryl and Tylenol, both of which were carried because of the aspirin sensitivity of one crewman. Two new medications added to the Apollo 11 kit were Scopolamine and Dexedrine in a combination capsule for the treatment of motion sickness and Mylicon tablets to reduce the size of the gastrointestinal gas bubbles. All crewmembers are tested for both sensitivity and response to each of the medications carried in the medical kit. Particular interest has been centered on the ability of crewmen to perform effectively at periods of 1, 2, 3, and 4 hours following the ingestion of Seconal. Crewmen have been given flight-related performance tests at each of these four time intervals, and all have exhibited most satisfactory performance.

Bioinstrumentation

The difficulties encountered with bioinstrumentation on the Apollo 7 flight have been detailed in a previous report (ref. 10), as has the fact that no difficulties were encountered following a redesign of the harness for Apollo 8. No bioinstrumentation failures have occurred on the Apollo 9, 10, or 11 missions. The crews receive detailed preflight briefing concerning the application of sensors, the temperatures to be expected on the dc-to-dc converter, and signal conditions. On occasion, degraded electrocardiographic data have been evident because of some drying of the electrode paste; replacement of the sensor has invariably restored the signal quality and provided excellent data for the remainder of the mission.

Preventive Medicine and Inflight Disease

Following the Apollo 7 preflight, inflight, and postflight experience, a preventive medicine regimen was detailed in the medical requirements document. Since the Apollo 7 mission, a 21-day preflight period of modified crew isolation has been maintained. It is impossible and unrealistic in the operational environment to require total isolation of the crew from all individuals and yet to have the crew accomplish its mission. Every attempt has been made to control the environment of the crew, whereever possible, concerning food, water, and air and to limit crew contacts to the minimum

necessary to accomplish the mission. Great cooperation and dedication is required on the part of the crews and all Apollo team members who must have direct contact with the crew. As flight durations in excess of a week are being considered, it is quite possible for inflight disease to develop from preflight exposure without any evidence of the disease prior to launch. There is a tremendous impetus to launch lunar missions at the scheduled time in order to utilize a particular lunar launch window. There is also an obvious desire to accomplish the mission in the best manner possible without jeopardy to LM or lunar-surface activity by crew illness. In addition, because of the Apollo 11 mission 21-day postflight quarantine period, the preflight preventive medicine program assumed greater importance. Details of the preflight and inflight upper respiratory diseases of the Apollo 7 crew and the gastrointestinal disturbance of an Apollo 8 crewman have been reported in reference 10. The preflight clinical problems associated with the Apollo 7 to 11 missions are summarized in table VIII. Apollo crews have experienced occasional mild dermatologic problems such as seborrhea, ringworm, and tinea. In addition, crewmembers have had a number of upper respiratory tract infections including rhinitis, pharyngitis, and influenza, as well as a few episodes of gastroenteritis. The Apollo 9 mission was delayed because of the preflight development of the rhinitis and pharyngitis in one crewmember. None of these illnesses have been severe, but the potential impact any illness may have on a mission emphasizes the concern with which even common and mild viral infections such as gastroenteritis and upper respiratory infections must be viewed in the prelaunch phase. The inflight clinical problems are detailed in table IX. The three cases of coryza occurred during the Apollo 7 mission. The single episode of nausea and vomiting of unknown origin was probably secondary to a viral gastroenteritis and occurred during the Apollo 8 mission. All the fiber-glass irritation occurred during the Apollo 10 mission.

Five of the six crewmen aboard the Apollo 8 and 9 spacecraft developed some symptoms of motion sickness. The symptoms ranged from mild stomach awareness following head and body motion in the weightless environment to frank nausea and vomiting in one individual. The symptoms lasted from 2 hours to 5 days. Following these time periods, the affected crewmen were able to make any movement within the spacecraft without symptoms and, thus, had successfully adapted to the environment.

On the Apollo 10 mission, one crewman had stomach awareness for a 2-day period before he too adapted to the environment. Prior to the Apollo 10 mission, the crew had been instructed in the use of programed head movements designed to speed the adaptive process. These movements were tried by the affected Apollo 10 crewman on the first and second days of flight, and he noted an increase in stomach awareness symptoms after 1 minute of head movement. The movements were tried again on the seventh day of the flight after the crewman had "adapted" and after the LM activity. Again, the crewman noted the development of increasing symptoms of stomach awareness after 5 minutes of head movement.

Before the Apollo 11 mission, the crew was briefed concerning the availability of head movements and medication and concerning the use of cautious movement in the spacecraft to facilitate adaptation. No motion sickness symptoms were reported by the crew nor were special preventive measures used. Medication has been used in three of the six inflight motion sickness episodes. It appears that the larger volume of the Apollo spacecraft which provides the opportunity to move about freely in the weightless state is a factor in the etiology of the motion sickness noted.

The proprioceptive inputs to the central nervous system of a weightless astronaut are thought to be deterred and reduced. The semicircular canal inputs generated by head movements are enhanced in the weightless state because of diminished filtration action normally accomplished by the otolith organ. Under weightless conditions, the otolith becomes essentially inactive, and therefore its impulse filtration activity is reduced or ceases entirely. This is a real and potentially critical problem that must be closely watched during the continuing flight program because this problem can seriously interfere with the flight activity.

The postflight crew illnesses (table X) included several cases of viral gastroenteritis, miscellaneous respiratory and influenza syndromes, one case of congestive prostatitis, and one case of serous otitis media. Influenza B was implicated in two of the postflight illnesses, and influenza A_2 in one.

The lack of crew illness on the Apollo 10 and 11 missions has been gratifying. It appears that a number of factors were involved in the improvement noted over the Apollo 7, 8, and 9 missions: (1) the Apollo 10 and 11 launches took place during the time of year in which infectious illnesses are less prevalent in the general population, (2) the crews made increased attempts to secure adequate preflight rest and to maintain immunity, and (3) the number of personal contacts was reduced as prescribed by the preventive medicine program.

PHYSICAL EXAMINATIONS

Thirty days before the mission launch date, the programed medical evaluations begin with a detailed crew briefing concerning all of the potential examinations and the clinical problems encountered on previous missions. Concerns relating to the particular flight are also discussed, and the first physical examination and collection of laboratory data are completed. Detailed physical examinations are conducted again at 14 and 5 days preflight, and an abbreviated physical examination is conducted on the day before lift-off. For the Apollo 11 mission, the crewmen were examined on a daily basis for the 5 days preceding the flight. The postflight examinations are performed immediately after recovery and 24 hours after recovery. Daily physical examinations were conducted on the Apollo 11 crew during the 21-day quarantine period. No body system decrement or abnormality has been evident other than those to be discussed subsequently under specific headings such as cardiovascular response and exercise capacity. The physical findings of importance have been detailed in the previous section entitled "Preventive Medicine and Inflight Disease."

Cardiovascular Response

That diminished orthostatic tolerance may result from relative inactivity or confinement has been documented sufficiently from earth-based simulations of weightlessness, such as recumbency or water immersion, and from the space-flight environment itself. Potential problems of cardiovascular deconditioning were anticipated and seriously studied through various simulation techniques even before man first ventured into space. Cardiovascular deconditioning or diminished orthostatic tolerance was consistently observed in crewmen during the early postflight period of the Mercury and

Gemini missions. It was demonstrated through these programs that such deconditioning posed no serious problems for earth-orbital flights of a 14-day duration or less, nor did deconditioning pose a problem during ascent from the lunar surface in the erect position at the proposed launch accelerations under lunar gravity (one-sixth g). Indeed, the gravity vector and astronaut physical activity on the lunar surface were considered salutary factors which could reduce the severity of postflight orthostatic intolerance. Therefore, preflight and postflight cardiovascular evaluations were performed on all Apollo 7 to 11 crewmembers and on control subjects to assess the effects of these new variables on the orthostatic intolerance phenomenon.

The test methods used in assessing the degree of cardiovascular deconditioning or orthostatic tolerance are presented in table XI. These methods included lower body negative pressure (LBNP) and the 90° passive stand test when the use of LBNP was precluded by quarantine constraints. The physiological measurements obtained during each test were heart rate, blood pressure, and calf circumference. Other data considered in evaluating the test results included body weight, blood volume, exercise response, and vasoactive hormones. Representative data plots for LBNP and for the 90° stand test are detailed in figures 14 and 15, respectively.

Whatever may be the etiological factors involved in cardiovascular deconditioning, heart rate remains the most sensitive current index of orthostatic intolerance. A summary of the heart-rate responses obtained during provocative testing of the crewmembers of the Apollo 7 to 11 missions is given in table XII. It should be stated that only 60 percent of the 15 Apollo astronauts exhibited significant postflight elevations of the supine heart rate, whereas 77 percent of the astronauts stressed by LBNP and 100 percent of the astronauts stressed by simply standing had significantly elevated pulse rates. It is clear, therefore, that provocative or stress testing reveals altered cardiovascular responses which otherwise would not be detected. Thus far, nearly all Apollo crewmen have returned to preflight response levels within 30 to 50 hours after recovery; the time required for return to preflight response levels agrees well with that noted after the Gemini missions.

The nine crewmen of Apollo 7 to 9 missions underwent LBNP testing. Only two crewmen exhibited significantly increased calf circumference during LBNP testing, whereas three subjects exhibited decreased calf size significant at the $p < 0.05$ confidence level (table XIII). This finding suggests that the postflight heart-rate response is disproportionately greater than the degree of blood pooling in the lower extremities during LBNP testing.

Theoretically, blood pressure should bear a close relationship to real or simulated gravitational stresses on the cardiovascular system. No quantitative consistency in either systolic or diastolic blood pressure patterns has been exhibited when either the LBNP or 90° stand test modes were used in Apollo Program testing (figs. 16 and 17). Pulse pressure readings also have not correlated well with other measurements, but, generally, the resting supine pulse pressure (table XIV) was decreased postflight (in 13 of 15 astronauts). Only four of the 13 decreases were statistically significant at the $p = 0.05$ level, however. In all cases, pulse pressure was decreased over preflight values during LBNP testing (five significantly), and three episodes of postflight presyncope were noted. Seven of nine test subjects had diminished pulse pressure values during the 90° stand test. (Three of the nine were reduced significantly.)

Contributing to this marked pulse pressure variability was the pronounced lability of blood pressure observed during the recovery period (up to 3 days postrecovery).

Weight loss was observed in all 15 Apollo 7 to 11 astronauts. The mean loss was 5.6 pounds with a 1.25- to 10-pound range over the 8- to 11-day missions. The bulk of this weight change represented fluid and electrolyte loss. Fluid compartmental changes doubtless were involved in the observed cardiovascular responses. Preliminary reports indicative of highly significant postflight changes in vasoactive and adrenocortical hormone titers add additional credence to this view.

Hematology-Biochemistry

Certain essential hematological and biochemical analyses of preflight and postflight specimens have been performed for the Apollo 7 to 11 missions whenever possible. However, certain determinations were not performed during the Apollo 10 and 11 missions because of quarantine or other operational constraints. The immediate postflight absolute neutrophilia and lymphopenia have continued to be noted and are shown in table XV. This finding was consistently observed following the Gemini missions. In all cases, this change in white blood cell count and differential is transient and reverts to normal 24 hours postflight.

The red blood cell mass data have been of particular interest in view of the Gemini experience during which a fairly consistent loss of red blood cell mass to a maximum of 20 percent was observed. As mentioned previously, the Apollo spacecraft, unlike that of Gemini, has been launched with an atmosphere of 60 percent oxygen/40 percent nitrogen. The inflight spacecraft pressure of 5 psia is maintained by oxygen replenishment so that the orbital-spacecraft gaseous environment is progressively altered in flight toward a concentration of 100 percent oxygen, but has generally leveled off at the 93- to 95-percent figure. There was essentially no change in red blood cell mass following the Apollo 7 and 8 missions (2.4 percent). Red blood cell mass measurements were performed on a training crew following an Apollo spacecraft 11-day altitude chamber test, using a gaseous atmosphere profile identical to that of the Apollo 7 and 8 missions. The mean red blood cell mass decrease observed in this study was 4.4 percent. In contrast to the Apollo 7 and 8 red blood cell mass data, a modest but significant loss of red blood cell mass was observed following the Apollo 9 mission. This mission, however, was uniquely different from the previous Apollo missions in that, early in the mission, the LM activation and EVA activity required decompression of the CM (exposure to the space vacuum), following which the spacecraft was repressurized with 100 percent oxygen. Thus, there was no residual nitrogen in the spacecraft for the remaining 7 days of the 10-day mission. This finding of reduced red blood cell mass thus lends further support to the hypothesis that the toxicity of 100-percent-oxygen atmospheres is a major factor in the red blood cell mass loss observed during the Gemini missions and, to a lesser extent, during the Apollo 9 mission. Mean plasma volumes, however, were unchanged (decreased 4 percent) in the Apollo 7 crew, decreased in the Apollo 8 crew (13 percent), and somewhat decreased in the Apollo 9 crew (8 percent). These and other radioisotope hematologic data are summarized in table XVI.

A battery of additional hematologic determinations was performed on both plasma and red blood cells. The results of these tests are qualitatively summarized in table XVII.

The hematologic studies conducted thus far in the Apollo Program revealed a significant loss of red blood cell mass following only the Apollo 9 mission. The data thus far suggest that hyperoxia as opposed to weightlessness is an important factor in the red-blood-cell mass loss phenomenon and that perhaps even small quantities of diluent gas (nitrogen) may exert a protective or moderating effect on oxygen toxicity as expressed in the context of red blood cell-mass loss.

A plethora of clinical biochemical determinations has revealed a transient postflight hyperglycemia and decreased serum cholestrol and uric acid levels (table XVIII). Postflight urinary excretion of hydroxyproline was increased over preflight base-line levels, and there was a consistently diminished excretion of sodium, potassium, and chloride in the immediate postflight period (table XIX).

Immunology

Immunologic studies during the Apollo Program have included a profile of appropriate serum protein fractions, lymphocyte response, and RNA and DNA syntheses. Postflight increases in C-reactive protein levels were noted in two of the Apollo 7 crewmen, consistent with their inflight illness, as previously reported. Later Apollo flights revealed significant postflight increases of immune globulin G, M, and Am as well as in haptoglobin, ceruloplasmin, and Alpha-2 macroglobulin. Increases in the immunoglobulius are related to the episode of clinical illnesses previously alluded to, and increases in haptoglobin and ceruloplasmin are probably related to a moderate generalized stress reaction. No significant changes were observed in the other determinations listed in table XX.

Microbiology

The Apollo microbiology program includes the disciplines of bacteriology, mycology, virology, parasitology, and protozoölogy. The prime objective of the program is the qualitative and quantitative definition of the "normal" (preflight) and "space-flight adjusted" (postflight) microbiota of each crewmember. Swab samples from eight body areas and specimens of urine, feces, and a throat-mouth gargle are collected from each astronaut at intervals of launch date minus 30 days (F-30), F-14, F-0 (8 hours prior to lift-off), and immediately upon return. Results of comprehensive microbiological analyses of such specimens are used to (1) permit early recognition and treatment of infectious diseases or potential problems during the preflight phase, (2) predict the possible qualitative contamination of returned lunar samples and lessen the impact of such contaminants on procedures for bioassay and release of lunar samples from quarantine, (3) determine the aggregate effects of spacecraft environmental parameters on the microbiota of each crewmember, and (4) ascribe specific etiologies to illness events. Approximately 12 data bits on some 4000 micro-organisms have been collected during the Apollo 7 to 11 missions and have been stored in a computer. Although demanding Apollo mission schedules (60-day launch centers) have not permitted a thorough analysis of the data, certain consistent findings may be indicative

of biological trends. Man-to-man transfers of potential pathogenic bacteria and fungi were found to be a regular occurrence within the closed ecological environment. This phenomenon was accompanied by a significant increase in the number of crewmembers infected and in the number of sites per man from which organisms could be isolated. The appearance of certain organisms only during the postflight sampling interval suggests that microbial shifts may favor the growth of opportunist organisms. Furthermore, certain other components of the normal flora have been isolated from aberrant sites. Taken together, these observations suggest that microfloral changes occurring in the spacecraft environment may not be compatible with man's health and welfare during extended-duration missions. No observations have been made which suggest that the spacecraft environment may predispose to viral-induced illness. Rather, the illnesses occurring in Apollo 7 to 11 crewmembers have been correlated with the normal seasonal occurrence of upper respiratory infection in the population at large.

During the postflight Apollo 11 analyses, no micro-organisms with unfamiliar morphological structures or unusual physiochemical responses were detected. Neither the preflight nor the postflight phases of Apollo 11 were marred by the occurrence of viral-induced illnesses in the crewmembers. The postflight quarantine seemed to have a protective effect on the astronauts. Despite the fact that viruses associated with upper respiratory infection and gastrointestinal upsets were isolated from personnel working in the Lunar Receiving Laboratory, the astronauts and other personnel isolated in the crew reception area (CRA) remained free from overt manifestations of similar illnesses.

Exercise Capacity

The Apollo preflight and postflight exercise capacity test used a bicycle ergometer programed to respond to the heart rate of the test subject. The workload required to maintain a heart rate of 120 beats per minute (bpm) for 3 minutes was followed uninterrupted by the work expenditure required to sustain a heart rate of 140, 160, and (in three subjects) 180 bpm — for periods of 3 minutes at each level. Gas samples were obtained at appropriate times during each test. The exercise capacity test was scheduled for each crewmember at 30, 14, and 4 days preflight, and as early as possible after recovery, with a repeat test 24 to 36 hours later.

Following the five Apollo 7 to 11 missions, 12 of the 15 crewmen demonstrated a significant decrement in work performed and in oxygen consumed at submaximal levels of heart rate, as compared with their preflight test levels (table XXI, fig. 18). Of the three crewmembers tested at maximal heart-rate levels (180 bpm), all have exhibited a similar decrement. All subjects, except one, returned to preflight exercise performance levels within 24 to 36 hours after recovery. The particular individual that was the exception to this pattern had identical responses before and after the Apollo 8 mission. Supplementary supporting data indicated that the decrements observed in work performance were not caused by altered ventilatory function nor were they caused by an inability of the subjects to extract oxygen from the atmosphere. All pulmonary function tests were well within expected physiological limits. Pinpointing the physiological mechanism(s) responsible for the observed decrement in postflight exercise response remains unclear at this time and must await further investigation.

Lunar-Surface Activity

In planning and training for lunar-surface activity, NASA medical personnel were aware that previous Apollo flights had shown there would be some effect on the crew because of 3 days of weightlessness. This effect would probably manifest itself in a heart-rate change resulting from some cardiovascular deconditioning and decrease in exercise capacity. Fortunately the red blood cell mass loss had been removed from consideration. The crewmen were sensored and monitored during three preflight simulations, once in the water immersion facility, once in the altitude chamber, and once duplicating the lunar-surface time line on a simulated lunar surface. None of these produced exactly the real-time lunar-surface conditions relative to one-sixth g, motion, and so forth, but the monitored results were used to predict the energy cost of the lunar activity. Table XXII indicates these predictions from each simulation for the CDR and LMP and the comparison with the actual mission estimate. The predictions and actual mission estimates were quite close for the LMP and quite at variance for the CDR. The three methods used for real-time metabolic monitoring were (1) heart rate compared to a Btu calibration curve obtained by bicycle ergometry, (2) oxygen usage from the portable life-support system (PLSS), and (3) water inlet and outlet temperature of the liquid-cooled undergarment (LCG).

The data revealed that the oxygen usage and LCG methods resulted in energy cost levels 61 percent below those estimated by heart rate in the CDR and 81 percent above those estimated by heart rate in the LMP. The LCG and oxygen methods agree and match the evaluation by television monitoring of the activity. The sources of heart-rate error are many and include laboratory calibration, uncertain area of the regression curve at low heat rate, psychogenic effect, deconditioning, and heat storage. The metabolic estimates of the surface activity for each crewman by each method are shown in figures 19 and 20 with an integrated best estimate of the actual energy cost. Figures 21 and 22 illustrate the premission predictions for each task in the time line compared with the best estimate based on real-time data. The latter compared favorably with the premission estimate in both cases and appeared to be well within the calculated margins for the expendables (water and oxygen) in the PLSS.

The integrated Btu production for the LMP for each task in the time line is detailed in table XXIII. The energy cost of the entire 146 minutes of surface activity was 2982 Btu.

The heart rates for each crewman during the lunar-surface activity are shown in figure 23. The highest rates noted were 140 to 160 bpm for the CDR during documented sample collection and transfer of the sample box to the LM.

It can be concluded from these data that the energy expenditure for a given task varies with individual crewmen, but the average hourly total Btu production was 900 to 1200. The LCG method appears best suited for estimating crewman Btu production for use in calculating consumables. The heart-rate method is a valuable relative indicator of Btu production, but a poor absolute indicator. The Apollo 11 data indicate that an extension of EVA to 4 to 5 hours is within the physiological limitation of man and the present life-support equipment. These data will be used in planning the Apollo 12 mission.

Quarantine

Approximately 3 years prior to the Apollo 11 flight, a decision was made to conduct a quarantine operation to preclude the possibility, even though remote, of contaminating our biosphere with lunar organisms. This decision was based on a National Academy of Sciences report stating that there was a remote possibility of such contamination. The quarantine was to start at hatch closure of the LM on the lunar surface and was to continue for a 21-day period. This was an arbitrary time period which did not encompass all known disease incubation periods, but which was believed to be reasonable and sufficiently broad to cover the bulk of the virulent contagious diseases. A series of procedures was developed for crew action through recovery and placement in the mobile quarantine facility (MQF) for transport to the Lunar Receiving Laboratory quarantine facility at Houston.

The crew kicked dust off their boots on the LM ladder and used a brush attachment on the suit hoses to vacuum clean the lunar rock box and film containers. There was a considerable accumulation of dust on the legs and arms of the suit and in the LM. The dust was described as a fine, slippery, dark-grey, talcum-powder-like material which smeared and adhered to foreign objects and smelled like wet fireworks.

The astronauts eventually were contaminated by the adherence of this material to their skin and under their fingernails, and they apparently inadvertently inhaled and ingested it. The rock boxes, film packs, and other items were repackaged after vacuuming, and little dust was transferred from the LM to the CM. The suits were doffed and packaged in the CM and the cabin air constantly filtered during transearth transit by the LiOH canisters. Thus, no dust should have been present upon landing. The actual recovery operation involved protecting the swimmers with SCUBA gear and protecting one swimmer with a biological isolation garment. The swimmer scrubbed the hatch area and postlanding vent with an iodine preparation and opened the hatch and gave biological isolation garments to the crew who donned the garments and egressed into the liferaft. The hatch was then closed and again decontaminated, as were the crewmen and the swimmer, with the same iodine solution. The crew was then transferred by a helicopter to the aircraft carrier and into the MQF. Microbial sampling and initial physical examinations were completed in the MQF, and the samples of blood, microbiological samples, and so forth were transferred outside through a sodium hypochlorite dunk tank.

The crew, a physician, and a recovery technician remained in the MQF during the 3-day transit time by ship and aircraft to Houston. There, the MQF was moved to the Lunar Receiving Laboratory, and the five individuals in the MQF were transferred to the CRA. Daily examinations were conducted on all CRA personnel, and blood and microbiological samples were taken at scheduled intervals. The crew quarantine period was remarkable for the lack of positive findings, and no evidence of infectious disease was found in the examination of the crew nor in similarly quarantined personnel. Careful evaluation of the microbiological samples and immunological tests revealed no evidence of bacterial, viral, or fungal growth not noted preflight. Cultures taken of the lunar dust from the space suit showed no growth. One-half of each core tube was used as a prime biological sample and was placed in five viral-tissue culture lines, on a number of bacterial and fungal media, and injected intraperitoneally into mice. No evidence of growth or adverse effect was noted. Consultation with the Interagency Committee on Back Contamination gave approval for crew release on the

21st day of quarantine. Continued surveillance will be maintained for 1 year, and to date, there have been no infectious diseases or illnesses of any sort noted. In the ensuing months, the crew will doubtless develop some of the common infections which plague man, and an attempt will be made to identify these (by laboratory methods) as being of terrestial origin.

The quarantine of the lunar samples continued until 50 days postrecovery. Representative chips of the rocks and fines were pulverized and placed in solution. Detailed bacteriological, viral, and fungal studies were performed, and the material was used to expose groups of plants, insects (cockroaches, moths, and flies), fish, shrimp, oysters, quail, and mice. In each instance, one group (a control) was kept in an identical environment but not exposed to lunar material, one group was exposed to sterilized lunar material, and the third group was exposed to untreated or virgin lunar material. Although there were some animal deaths during the quarantine period, they were principally in the control groups, thus facilitating the decision for release of the crew from quarantine. The conduct of such a quarantine is a demanding task requiring constant 24-hour surveillance punctuated by frequent critical decision points.

CONCLUSION

The 3105 man-hours of Apollo exposure to space flight has added greatly to our knowledge of man's response to the space environment. The spacecraft environment has been maintained in a suitable range for man, and the radiation environment has been benign in the absence of solar flares. Crews have generally adapted to weightlessness and used its advantages. Improvements in inflight food have evolved with the addition of moisturized packs and such items as sandwiches and dried fruit. Crew weight loss that is not entirely caused by fluid loss is still noted. The supplying of potable water has been effective, and strides have been made in removing dissolved gases from the water supply. Waste management remains an area that requires further design efforts. Work/sleep cycles have improved with the adoption of simultaneous sleep periods and with constant effort in mission planning to keep the sleep periods related to crew cycles in training.

The medical kit has been adequate on all missions since Apollo 7, and medication has been added as the need arose. Bioinstrumentation has functioned well. A preflight preventive medicine program has been difficult to implement, but has been effective in the later flights in reducing preflight, inflight, or postflight diseases. Infectious illnesses, usually viral-type upper-respiratory or gastrointestinal illnesses, have been noted in all these periods on early missions. Motion sickness has been noted in varying degree, but all crews have adapted. This problem will require constant surveillance by the crew and by the medical team. Cardiovascular deconditioning has been noted during LBNP or erect standing stresses and has been similar in degree and duration to that noted after the Gemini flights. A significant decrement in work capacity has been noted immediately postflight and has lasted 24 to 36 hours.

Immediate postflight neutrophilia has been noted as in the Gemini Program. The red blood cell-mass reduction noted on Gemini missions was noted only on Apollo 9; this confirms that hyperoxia is an important etiologic factor and indicates that nitrogen is protective to the red blood cell. The microbiological studies indicate that organisms are transferred among crewmembers and that growth of opportunist organisms appears

to be favored by microbial shifts. The Apollo 11 lunar-surface activity was conducted within expected energy costs at an average of 1200 Btu/hr. The LCG temperature method of energy-use estimation is best, and it appears that the lunar-surface activity time can be safely extended. The Apollo 11 quarantine was a demanding operation and was conducted very successfully. Further lunar exploration is anticipated with much more confidence as a result of the knowledge gained from Apollo missions 7 to 11.

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TABLE I. - APOLLO MANNED MISSIONS

Mission	Crew	Launch date	Description	Duration, hr: min: sec
Apollo 7	Schirra Eisele Cunningham	Oct. 11, 1968	Earth-orbital checkout of the CSM	260: 09: 45
Apollo 8	Borman Lovell Anders	Dec. 21, 1968	First lunar-orbit flight for checkout of the CSM at lunar distance	147: 00: 11
Apollo 9	McDivitt Scott Schweikart	Mar. 3, 1969	First manned earth-orbital checkout of the LM, CSM/LM rendezvous, and EVA	241: 00: 54
Apollo 10	Stafford Young Cernan	May 18, 1969	First lunar-orbit rendezvous and low pass over lunar surface	192: 03: 23
Apollo 11	Armstrong Collins Aldrin	July 16, 1969	First lunar landing and EVA on the lunar surface	195: 18: 35

TABLE II. - MAXIMUM ACCELERATION

Mission	Acceleration in g at —			
	Launch	S-IVB reignition	SPS burns	Reentry
Apollo 7	4.2	<1	--	3.4
Apollo 8	3.97	--	[a]0.68	6.84
Apollo 9	3.9	--	[b]<1	3.35
Apollo 10	3.97	--	--	6.78
Apollo 11	4.0	--	--	6.5

[a]At TEI.

[b]First deorbit.

TABLE III. - ONBOARD RADIATION INSTRUMENTATION

Instrument	Measurement	Location
Nuclear particle detection system (NPDS)	Alpha-proton spectrometer (4 channels proton, 15 to 150 MeV; 3 channels alpha, 40 to 300 MeV); telemetered	Service module
Van Allen belt dosimeter	Skin and depth dose rates; telemetered	CM
Radiation survey meter	Portable, hand-held ratemeter; 4 linear ranges, 0 to 0.1 to 0 to 100 rad/hr; visual readout	CM (portable)
Personal radiation dosimeter	1/crewman; accumulated radiation dose; 0.01 to 1000 rad; visual readout	Suit
Passive radiation dosimeter	4/crewman; emulsion/thermoluminescent dosimeters; postflight analysis	Constant-wear garment

TABLE IV. - APOLLO MISSIONS: RADIATION DOSE

[Thermoluminescent dosimeters]

Mission	Average dose, rad
Apollo 7	0.16
Apollo 8	.16
Apollo 9	.20
Apollo 10	.47
Apollo 11	.18

TABLE V. - BODY WEIGHT CHANGES AND CALORIE INTAKE

FOR APOLLO 7 TO 11 MISSIONS

Crewman	Body weight, lb				Average daily inflight calorie intake, kcal
	Average preflight (F - 28, F - 24, F - 5)	Launch day (F - 0)	Recovery (R + 0)	Recovery +1 day (R + 1)	
Apollo 7					
CDR	195	194	188	191	1 966
CMP	153	157	147	151	2 144
LMP	157	156	148	154	1 804
Apollo 8					
CDR	169	169	161	163	1 477
CMP	169	172	164	165	1 688
LMP	146	142	138	139	1 339
Apollo 9					
CDR	161	159	154	156	1 924
CMP	181	178	173	181	1 715
LMP	164	159	153	157	1 639
Apollo 10					
CDR	175	171	169	171	1 407
CMP	169	165	160	161	1 487
LMP	175	173	163	165	1 311
Apollo 11					
CDR	173	172	164	170	2 040
CMP	167	166	159	159	1 645
LMP	172	167	166	170	2 278
Total					
	2 526	2 500	2 407	2 453	25 201
Average					
	168.4	166.67	160.47	163.53	1 680

TABLE VI. - APOLLO 11: ESTIMATED SLEEP BEFORE LUNAR LANDING

Date	Estimated sleep, hr: min					
	Telemetry			Crew report		
	CDR	CMP	LMP	CDR	CMP	LMP
July 16, 1969	10:25	10:10	8:30	7:00	7:00	5:30
July 17, 1969	9:40	10:10	9:15	8:00	9:00	8:00
July 18, 1969	9:35	NA[a]	9:20	7:30	7:30	6:30
July 19, 1969	6:30	6:30	5:30	6:30	6:30	5:30
TOTAL	36:10	--	32:35	29:00	30:00	25:30

[a]Not available.

TABLE VII. - APOLLO CM MEDICAL KIT CONTENTS

Item	Quantity per flight									
	Apollo 7		Apollo 8		Apollo 9		Apollo 10		Apollo 11	
	Stowed	Used	Stowed	Used	Stowed	Used	Stowed	Used	Stowed	Used
Eye drops, 1/4 percent methylcellulose	2	1	2	2	2	0				0
Compress; bandage	2	0	2	0	2	0	2	0	2	0
Band-aids	12	2	12	0	12	0	12	0	12	0
Antibiotic ointment	1	1	1	0	1	0	1	0	1	0
Skin cream	1	0	1	1	1	1	1	0	1	0
Demerol injectors	3	0	3	0	3	0	3	0	3	0
Marezine injectors	3	0	3	0	3	0	3	0	3	0
Marezine tablets	24	3	24	1	24	4	12	0	0	0
Dexedrine tablets	12	1	12	0	12	0	12	0	12	0
Darvon compound capsules	12	2	[a]18	0	18	0	18	0	18	0
Actifed tablets	24	24	60	0	60	12	60	2	60	0
Lomotil tablets	24	8	24	3	24	1	24	13	24	2
Nasal emollient	1	1	2	1	3	3	1	0	3	0
Aspirin tablets	72	48	72	8	72	2	72	16	72	(b)

[a]Plain.

[b]Quantity unknown.

TABLE VII. - APOLLO CM MEDICAL KIT CONTENTS - Concluded

Item	Quantity per flight									
	Apollo 7		Apollo 8		Apollo 9		Apollo 10		Apollo 11	
	Stowed	Used	Stowed	Used	Stowed	Used	Stowed	Used	Stowed	Used
Achromycin tablets	24	0	24	0	24	0	15	0	15	0
Ampicillin			60	0	60	0	45	0	45	0
Seconal, 100-mg capsules			21	1	21	10	21	0	21	0
Seconal, 50-mg capsules			12	7						0
Nasal spray (Afrin)			3	0	3	1	3	0	3	0
Benadryl, 50 mg			8	0						0
Tylenol, 325 mg			14	7						0
Eye drops, 1 percent methylcellulose					1	0	2	0	2	0
Opthalmic ointment (Bacitracin)					1	0				0
Scopolamine-Dexedrine									12	6
Mylicon tablets									20	0

TABLE VIII. - APOLLO 7 TO 11 CLINICAL PROBLEMS, PREFLIGHT

Symptoms/findings	Etiology	No. of occurrences
Mild uri	Undetermined	3
Rhinitis and pharyngitis	Herpes simplex	2
Gastroenteritis	? salmonellosis (walnut meats)	2
Gastroenteritis	Undetermined	3
Facial rash	Seborrhea	2
Folliculitis (abdomen)	Undetermined	1
Ringworm (arm)	Microsporum canis	1
Tinea crura	Undetermined	1
Tinea pedis	Undetermined	1
Pulpitis, tooth no. 31	Previous restoration and caries	1
Influenza syndrome	Undetermined	2

TABLE IX. - APOLLO 7 TO 11 CLINICAL PROBLEMS, INFLIGHT

Symptoms/findings	Etiology	No. of occurrences
Coryza	Undetermined	3
Stomatitis	Apthous ulcers	1
Nausea and vomiting	Undetermined	1
Nausea and vomiting	Labyrinthine	1
Stomach awareness	Labyrinthine	5
Recurrence of facial rash	? contact dermatitis	1
Respiratory irritation	Fiber glass	1
Eye irritation	Fiber glass	1
Skin irritation	Fiber glass	2

TABLE X. - APOLLO 7 TO 11 CLINICAL PROBLEMS, POSTFLIGHT

Symptoms/findings	Etiology	No. of occurrences
Gastroenteritis	Possible food poisoning	1
Mild uri	Undetermined	1
Rhinitis, pharyngitis	Influenza B	1
Influenza syndrome	Influenza B	1
Influenza syndrome	Undetermined	1
Influenza syndrome	Influenza A_2	1
Pulpitis, tooth no. 7	Caries and previous restoration	1
Congestive prostatitis	Undetermined	1
Unilateral nasal discharge	Undetermined	1
Serous otitis media (very mild)	Undetermined	1

TABLE XI. - METHODS FOR EVALUATING ORTHOSTATIC TOLERANCE

Test	Method	Mission
Provocative tests of the antigravity responses of the cardiovascular system (Preceded by 5-minute supine control data. The LBNP also has 5-minute recovery data.)	LBNP by incremental differential pressure	Apollo 7, Apollo 8, and Apollo 9
	90° passive stand test	Apollo 9, Apollo 10, and Apollo 11
Preflight and postflight collection of timed physiologic measurements	Heart rate (HR)	--
	Blood pressure (systolic blood pressure, diastolic blood pressure, pulse pressure, mean blood pressure)	--
	Change in leg volume (ΔLV)	--
	Other related data (weight, blood volume, vasoactive hormones, exercise capacity)	--

TABLE XII. - SUMMARY OF HEART RATE RESPONSES FOR APOLLO 7 TO 11 MISSIONS

[Indicated postflight values versus mean of three preflight values]

Subjects	Test day[a]	Test mode	Total no. of subjects	No. of subjects by category of significance			Range, Δbpm
				>2	No significance	<2	
Apollo crew-members	R + 0	Rest supine	15	9	4	2	-7 to +22
		LBNP	9	7	2	--	+13 to +66
		90° stand	9	9	--	--	+13 to +47
	R + 1	Rest supine	15	5	9	1	-7 to +9
		LBNP	9	5	4	--	-3 to +38
		90° stand	9	6	3	--	+1 to +35
	R + 2	Rest supine	6	2	3	1	-7 to +10
		LBNP	6	1	5	--	-11 to +19
		90° stand	3	1	2	--	-4 to +18
Controls	R - 1	Rest supine	13	2	11	--	-8 to +11
		LBNP	7	1	5	1	-15 to +9
		90° stand	7	1	6	--	-2 to +11

[a]Data returned to preflight values generally by R + 30 to R + 50 hours.

TABLE XIII. - SUMMARY OF CALF CIRCUMFERENCE DATA

FOR APOLLO 7 TO 11 MISSIONS

[Postflight value versus mean of three preflight measurements]

Test mode	No. of subjects	Status	Significance
Rest supine	15 of 15	Decreased	
	10 of 15	Decreased	$p < 0.05$
LBNP stressed[a]	2 of 9	Increased	$p < 0.05$
	3 of 9	Decreased	$p < 0.05$
	4 of 9	Variable	NS[b]

[a]Apollo 7, 8, and 9 only.

[b]Not significant.

TABLE XIV. - PULSE PRESSURE RESULTS FROM APOLLO 7 TO 11 MISSIONS

[Postflight values versus mean of three preflight values]

Test mode	No. of subjects	Status	Significance
Rest supine	13 of 15	Decreased	
	4 of 15	Decreased	$p < 0.05$
LBNP[a, b]	9 of 9	Decreased	
	5 of 9	Decreased	$p < 0.05$
90° stand	7 of 9	Decreased	
	3 of 9	Decreased	$p < 0.05$

[a]Apollo 7, 8, and 9 only.

[b]Three subjects experienced presyncopal episodes during immediate postflight LBNP.

[c]Apollo 9, 10, and 11 only.

TABLE XV. - ROUTINE HEMATOLOGY

Parameter	Mission					
	Apollo 7	Apollo 8	Apollo 9	Apollo 10	Apollo 11	AOA[a]
Red blood cells	0	↑↑	↓↓	↑↑	0	0
Hematocrit	0	↑↑	0	↑↑	0	0
Hemoglobin	0	↑↑	↑↑	0	0	
Reticulocytes	0	0		0	0	
White blood cells	↑↑↑	↑↑↑	0	↑↑	↑↑↑	↑↑↑
Neutrophils	↑↑	↑↑	0	↑↑↑	↑↑↑	↑↑
Lymphocytes	↓↓	↓↓	0	↓↓	↓↓	↓↓
Monocytes	0	↓↓	0	0	↓↓	↓↓
Eosinophils				↓↓	↓↓	↓
Basophils				↓↓		0
Platelets	0	0	0	0	0	0

[a]Apollo over all.

Legend:

0 No occurrence
↑ Significant trend (positive)
↑↑ +2σ (σ represents standard deviation)
↑↑↑ +3σ
↓ Significant trend (negative)
↓↓ -2σ
↓↓↓ -3σ
ND Not done
\+ Occurrence
TF Data to follow

TABLE XVI. - RADIOISOTOPE HEMATOLOGY

Parameter	Mission			
	Apollo 7	Apollo 8	Apollo 9	Apollo 10
Plasma volume	0	↓↓	↓	ND
Red blood cell mass	0	0	↓	ND
Ferrokinetics	↓	↓	ND	ND
^{14}C-glycine survival	0	0	0	ND
^{51}Cr survival	0	0	↓	ND
Active red blood cell Na-K flux	ND	ND	↓	0
Passive red blood cell Na-K flux	ND	ND	0[a]	0[a]

[a]Technically unsatisfactory.

Legend:

(See table XV.)

TABLE XVII. - HEMATOLOGY DATA SUMMARY

Parameter	Mission				
	Apollo 7	Apollo 8	Apollo 9	Apollo 10	Apollo 11
Decrease in reticulocyte count	0	0	+	0	0
Depressed ferrokinetics	+	+	ND	ND	ND
Loss of red blood cell mass	0	0	+	ND	ND
Decrease in plasma vitamin E	0	+	+	TF	ND
Decrease in red blood cell vitamin E	0	0	0	TF	ND
Decrease in plasma vitamin A	ND	ND	+	TF	ND
Decrease in red blood cell membrane lipids	0	0	+	TF	ND
Decrease in phosphofructokinase	0	+	0	ND	ND
Increase in hexoskinase	+	0	0	ND	ND
Decrease in phosphoclyceric kinase	0	0	+	ND	ND
Increase in phosphoglyceric kinase	+	0	0	ND	ND
Increase in glucose-3-phosphate dehydrogenase	0	0	+	ND	ND
Decrease in glucose-3-phosphate dehydrogenase	0	+	0	ND	ND
Increase in glutathion (reduced form)	0	0	+	ND	ND
Decrease in glutathion (reduced form)	+	0	0	ND	ND
Increase in Na-K flux	ND	ND	0[a]	0[a]	ND
Decrease in active Na-K flux	ND	ND	+	0	ND
Increase in red blood cell adenosine triphosphate contact	0	+	0	ND	ND
Increased H_2O_2 sensitivity	+	0	+	ND	ND
Methemoglobin formation	0	+	0	ND	TF
Red blood cell morphologic changes (wet preparation)	0	0	+	ND	ND
Postflight leukocytosis	+	+	0	+	+
Absolute neutrophilia	+	+	0	+	+
Absolute lymphopenia	+	+	0	+	+

[a]Technically unsatisfactory.

Legend:

(See table XV.)

TABLE XVIII. - BIOCHEMISTRY DATA SUMMARY

Parameter	Mission					
	Apollo 7	Apollo 8	Apollo 9	Apollo 10	Apollo 11	AOA[a]
Glucose	↑↑↑	↑↑	↑	↑↑↑		↑↑
Cholesterol	↓	↓↓	↑	↓		↓
Serum glutamic-oxalacetic transaminase						
Blood urea nitrogen				↑↑		
Uric acid	↓	↓↓	↓	↓↓	↓↓	↓
Alkaline phosphatase			↑↑↑			
Ca						
Mg				↓↓	↓↓	
Inorganic phosphate		↑↑	↑↑↑	↑↑	↓↓	
Total bilirubin		↑		↑↑	↑↑	
Creatinine	↑↑					↑↑
Creatinine phosphokinase		↑↑	↓↓			
Lactic dehydrogenase (LDH)	↑↑		↓↓	↓↓	↓↓	
English nomenclature: LDH1, LDH2 (heart fraction)		↑↑	↑↑↑	↓↓	↓↓	
English nomenclature: LDH3			↓↓		↓↓	↓↓
English nomenclature: LDH4		↓↓	↓↓		↑↑↑	↑↑
English nomenclature: LDH5 - liver fraction				↑↑		
Na	↑↑	↓	↓↓	↓↓	↑↑	
K	↓↓	↓				
Cl	↑	↓		↓↓		
Osmolality	↓↓	↓↓	↑↑	↓↓	↓↓	
Total protein			↑↑	↑	↑↑	
Albumin			↑↑	↑		
Alpha 1			↑↑	↑↑		
Alpha 2	↑		↑↑	↑↑	↑↑	
Beta				↑↑		
Gamma				↑↑		

[a]Apollo over all.

Legend:

(See table XV.)

TABLE XIX. - URINE (24 HR) CHEMISTRY SUMMARY

Parameter	Mission					
	Apollo 7	Apollo 8	Apollo 9	Apollo 10	Apollo 11	AOA[a]
Urine volume					↓↓	
Specific gravity		↑↑				
Hydroxyproline		↑↑↑				↑↑↑
Uric acid		↑↑↑			↓↓	
Creatinine		↑↑↑		↓↓		
Inorganic phosphate		↑↑↑			↓↓	
Na			↓	↓↓	↓↓	↓
K			↓	↓↓	↓	↓
Ca		↓↓	↑↑	↓↓	↓↓	
Mg		↓↓			↓↓	
Cl		↓	↓↓	↓↓	↓↓	↓↓

[a]Apollo over all.

Legend:

(See table XV.)

TABLE XX. - HUMORAL IMMUNOLOGY DATA SUMMARY

Parameter	Mission					
	Apollo 7	Apollo 8	Apollo 9	Apollo 10	Apollo 11	AOA[a]
Immune globulin G				↑↑	↑	↑↑
Immune globulin M						
Immune globulin A			↑↑	↑↑↑	↑	↑
Haptoglobin			↑↑	↑↑	↑	↑↑
Ceruloplasmin			↑↑	↑↑↑		
Transferrin				↓↓		
Alpha-1 antitrypsin				↑↑		
Alpha-1 acid glycoprotein						
Alpha-2 macroglobulin				↑↑	↑↑↑	↑↑
C-reactive protein						
Beta-1 alpha globulin (third fraction of complement)				↑↑	↑↑	↑

[a]Apollo over all.

Legend:

(See table XV.)

TABLE XXI. - APOLLO EXERCISE RESPONSE TEST

[Oxygen consumption immediately postflight]

Heart rate, bpm	$\overline{X}$, percent[a]	σ	No. of subjects
120	68.6	15.2	15
140	74.5	11.6	15
160	77.8	10.8	15
180	77.0	8.1	3
Over all	73.8	12.7	48

[a]100 percent = mean of three preflight measurements.

TABLE XXII. - APOLLO EMU METABOLIC ASSESSMENT:

APOLLO 11, COMPARISON OF ESTIMATED METABOLIC PRODUCTION

Location and comments	CDR		LMP	
	A. H. T. Btu[a]	Percent[b]	A. H. T. Btu[a]	Percent[b]
Water immersion facility	775	--	800	--
Altitude chamber; suited, one g	1050	17	1300	8
Building 9; walkthrough	1850	106	1375	15
Premission predictions	1350	50	1275	6
Estimation of actual mission	900	--	1200	--

[a]Average hourly total Btu.

[b]Percentage variation from estimation of actual mission.

TABLE XXIII. - APOLLO EMU METABOLIC ASSESSMENT: APOLLO 11 LMP, INTEGRATED Btu PRODUCTION

EVA events	Time		Integrated Btu production		
	GET hr:min	Interval, min	Rate, Btu/hr	Total Btu for interval	Btu accumulation
Assist and monitor CDR	109:13	26	1200	520	520
Perform initial EVA	109:39	5	1950	163	683
Environment familiarization (deploy TV cable)	109:44	14	1200	280	963
Deploy Solar Wind Composition experiment	109:58	6	1275	128	1091
Supply flag and listen to Presidential message	110:04	14	1350	315	1406
Evaluate EVA capability (environment)	110:18	16	850	227	1633
Inspect LM	110:34	19	875	277	1910
Deploy EASEP	110:53	18	1200	360	2270
Collect documented sample and recover Solar Wind Composition Experiment	111:11	12	1450	290	2560
Terminate EVA (ingress with sample return container)	111:23	14	1650	385	2945
Assist and monitor CDR	111:37	2	1100	37	2982
Close feedwater	111:39	Total, 146	--	--	Total, 2982

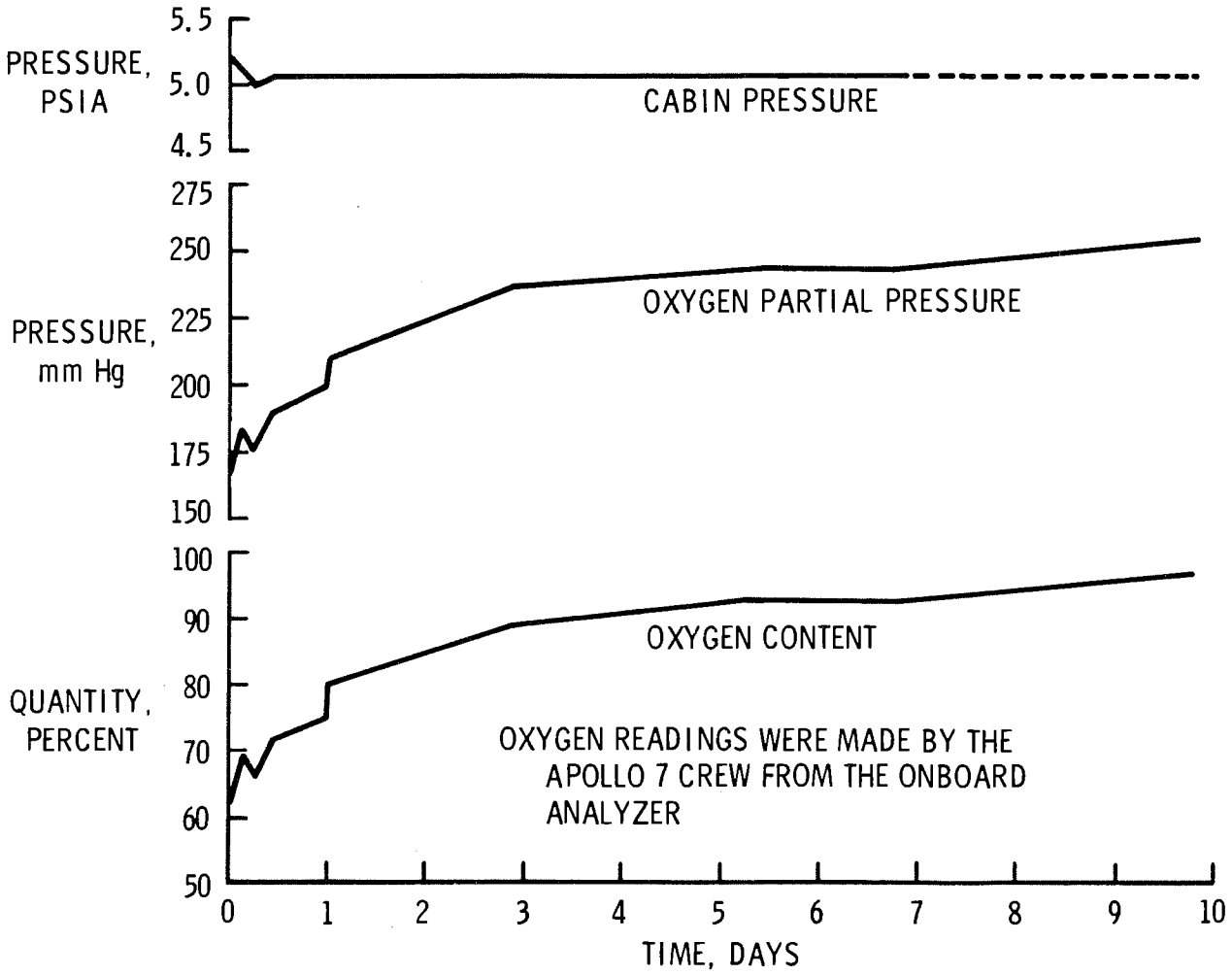


Figure 1.- Cabin oxygen enrichment sequence during Apollo 7 10-day flight.

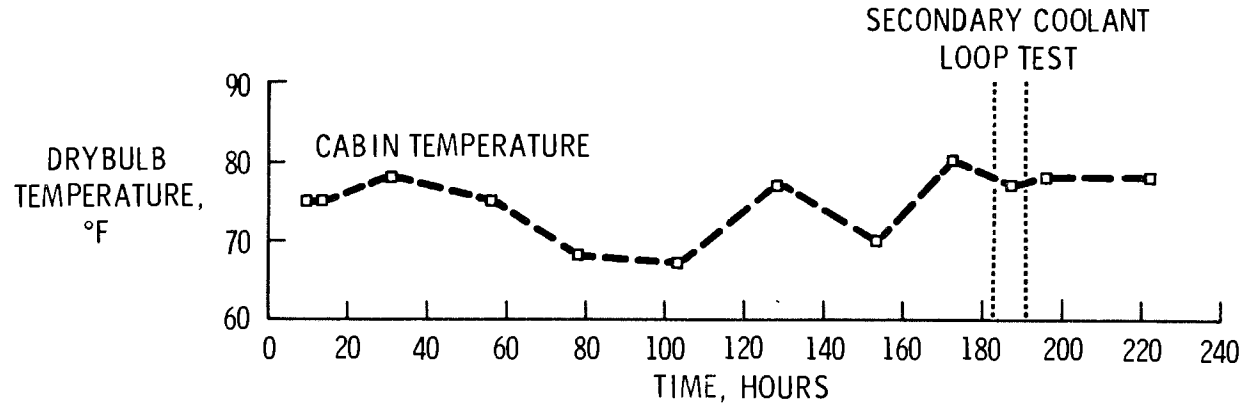


Figure 2.- Representative Apollo CM cabin temperatures (Apollo 7 data).

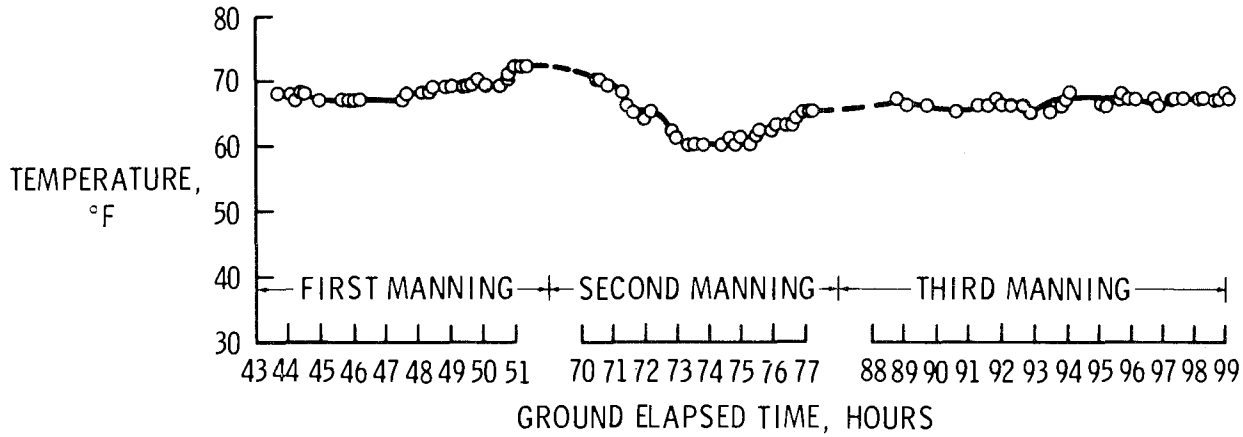


Figure 3.- Representative LM cabin temperatures (Apollo 9 earth-orbital data).

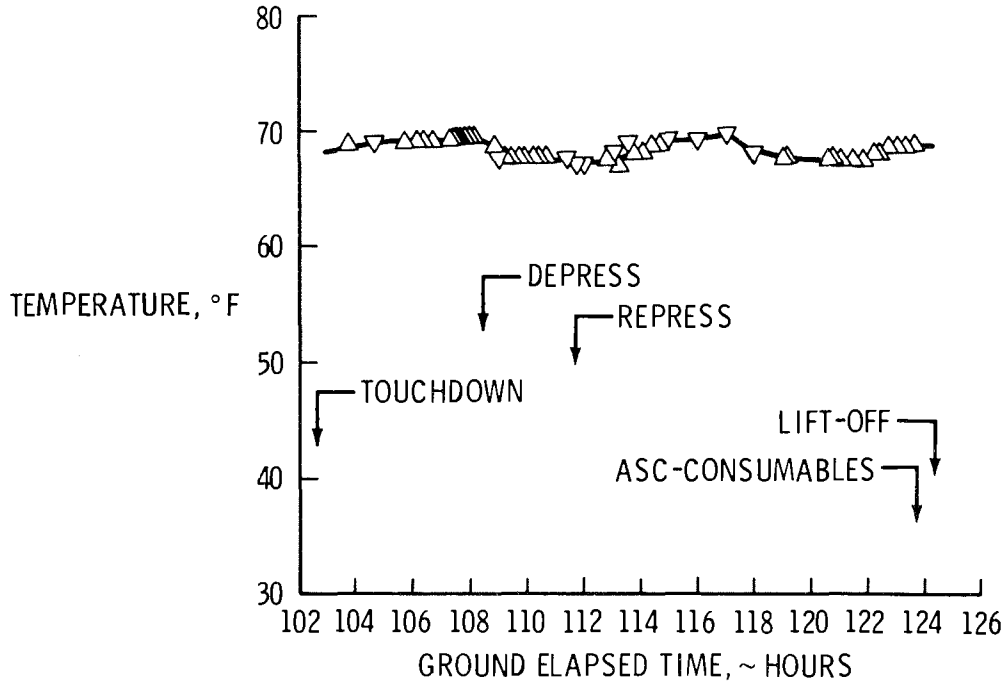


Figure 4.- Representative LM cabin temperatures (Apollo 11 lunar stay).

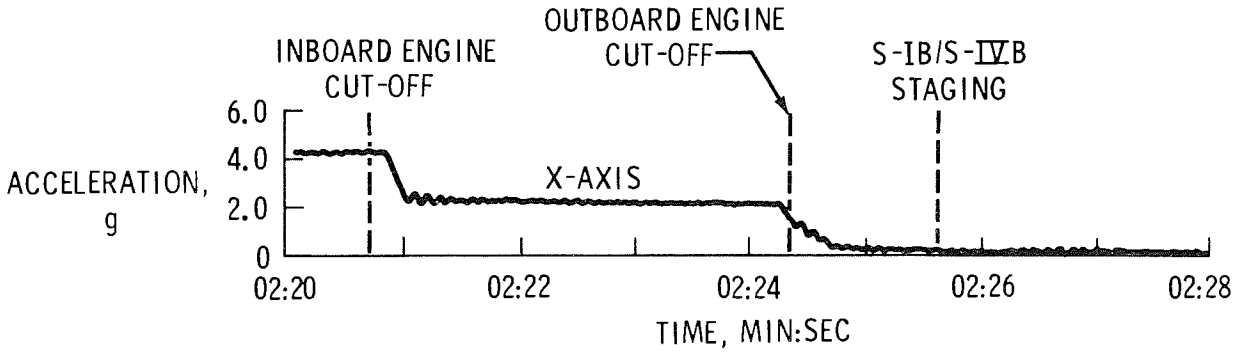


Figure 5.- Launch accelerations (Apollo 7 data).

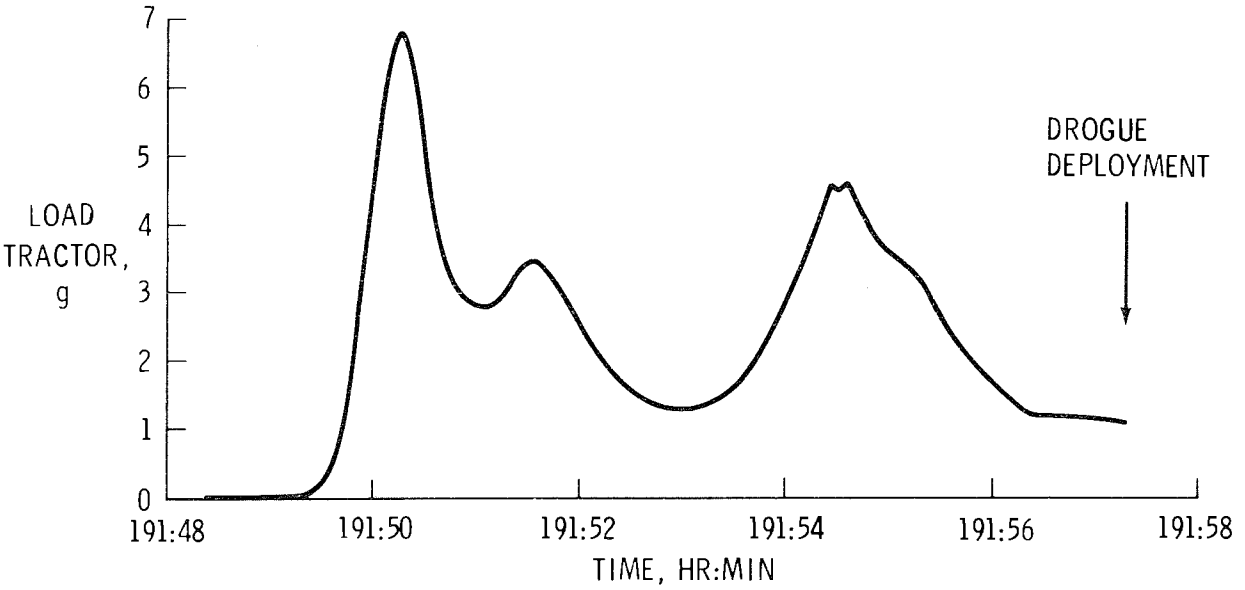


Figure 6.- Apollo 10 entry acceleration.

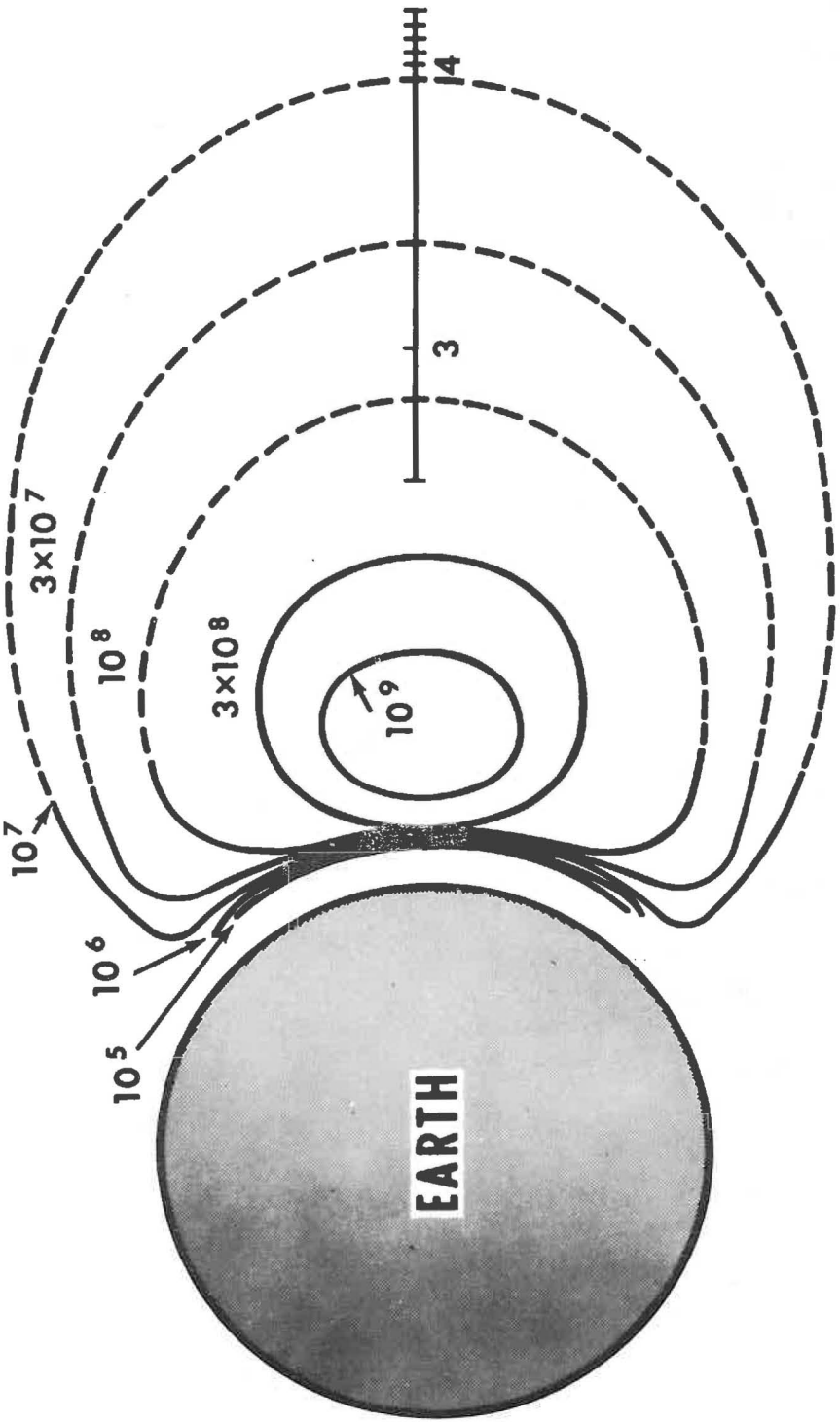


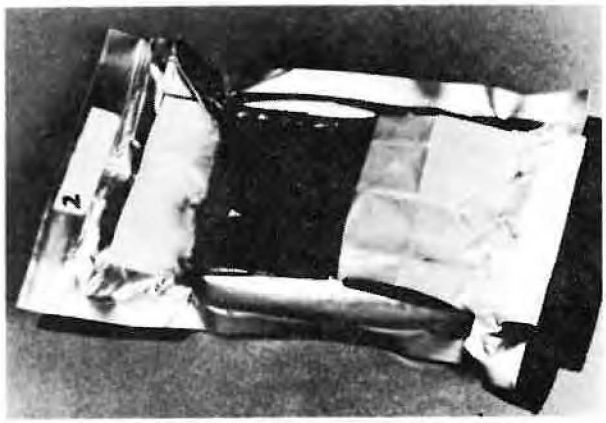
Figure 7. - Artificial electron belt.

DRIED FRUIT

APOLLO FOOD

BEEF WITH VEGETABLES

CHICKEN SALAD



FRANKS

TURKEY WITH GRAVY

Figure 8.- New foods and packaging for the Apollo Program.

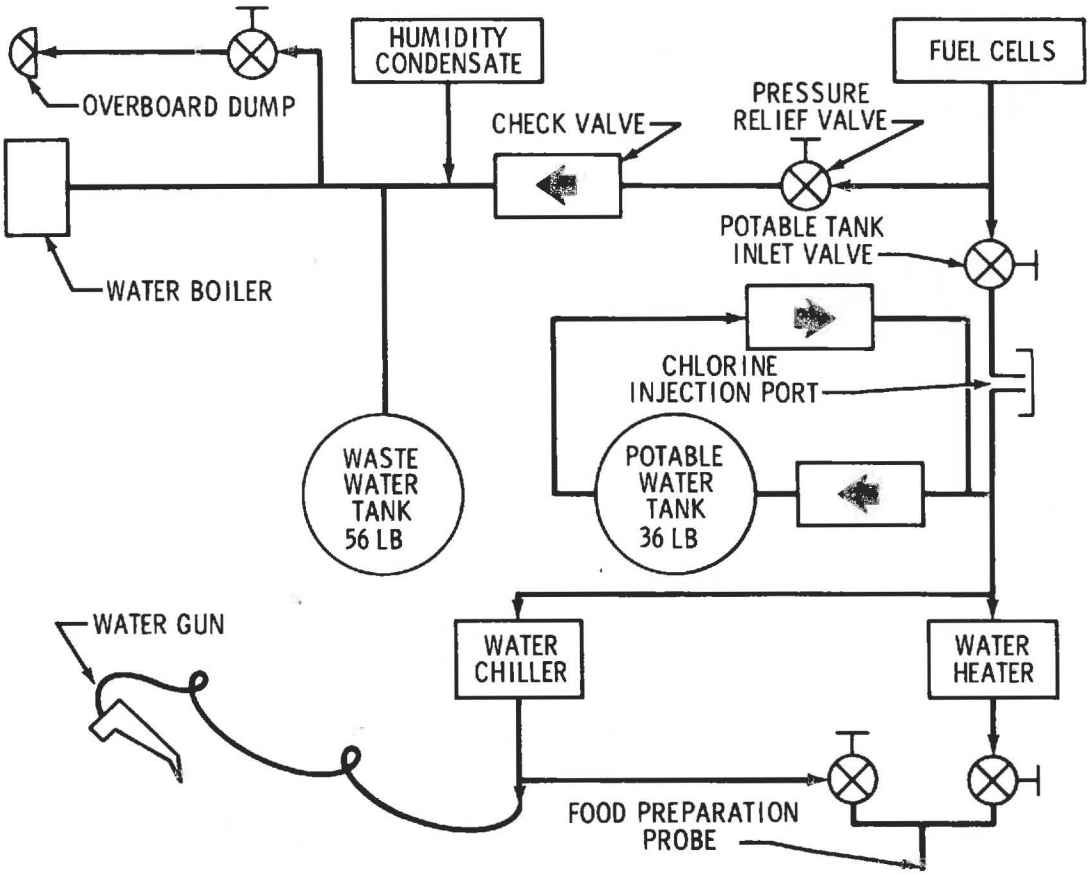
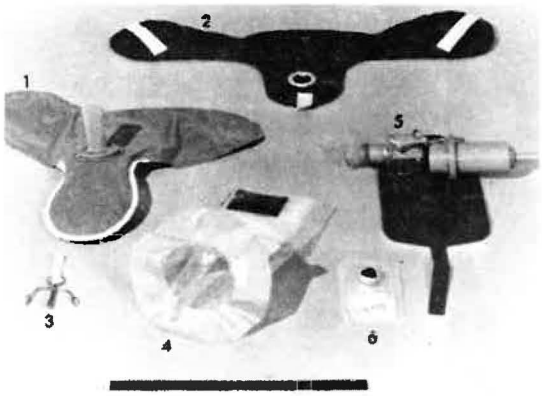


Figure 9. - Apollo CM potable water system.



ITEMS

1 URINE COLLECTION DEVICE (GEMINI TYPE)

2 URINE COLLECTION TRANSFER ASSY

3 UCD CLAMP

4 DEFECATION COLLECTION DEVICE (GEMINI TYPE)

5 M5A/M7 EQUIPMENT (MODIFIED GEMINI TYPE)

6 URINE SAMPLE BAG (GEMINI TYPE)

Figure 10. - Apollo waste management equipment.

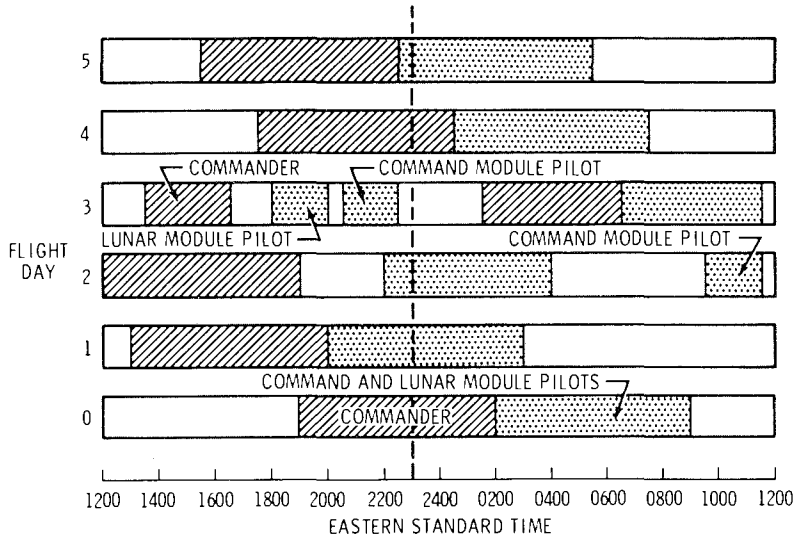


Figure 11.- Crew rest cycles (Apollo 8 data).

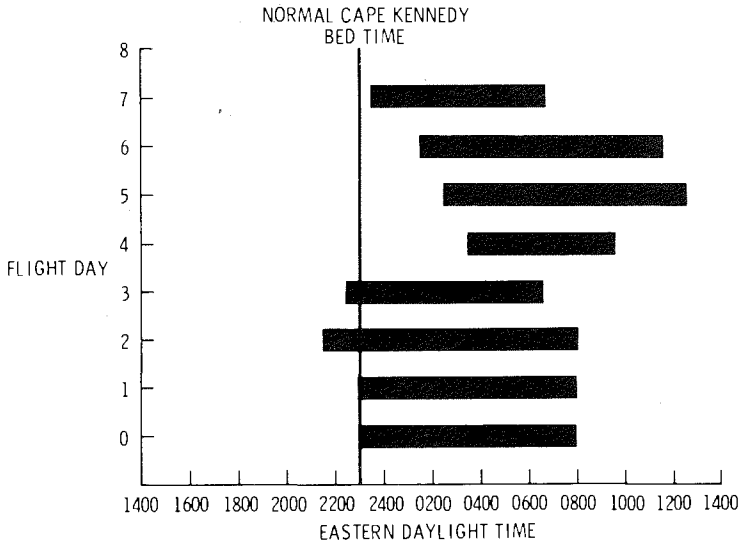


Figure 12.- Apollo 11 crew sleep periods.

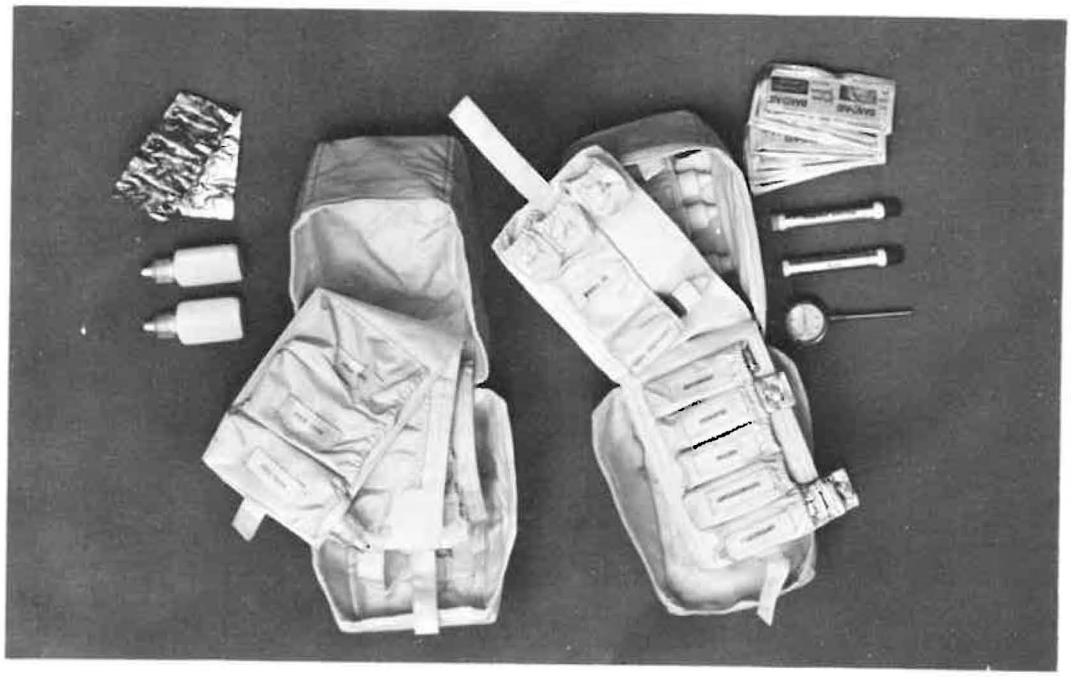


Figure 13. - Apollo medical kit.

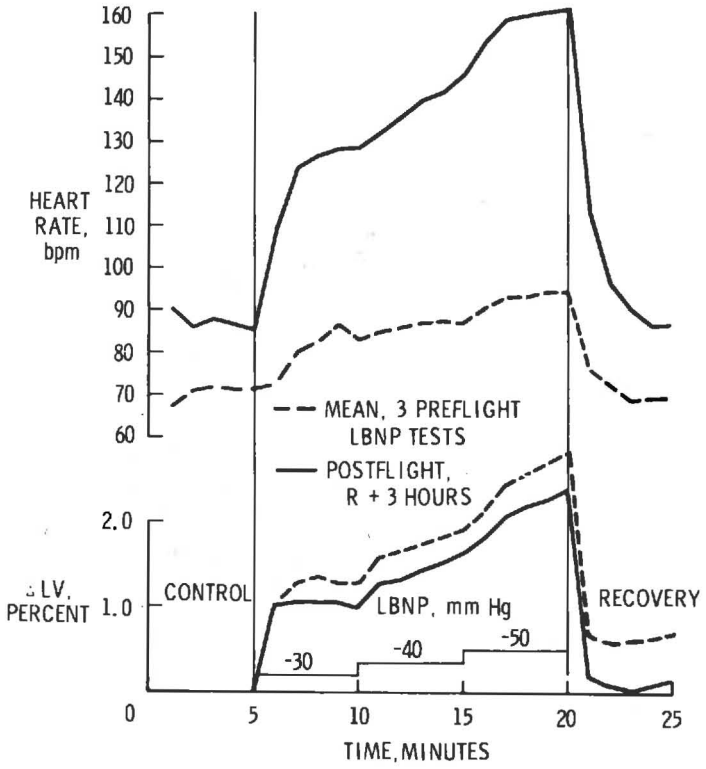


Figure 14. - Apollo crewman heart rate and leg volume response to LBNP.

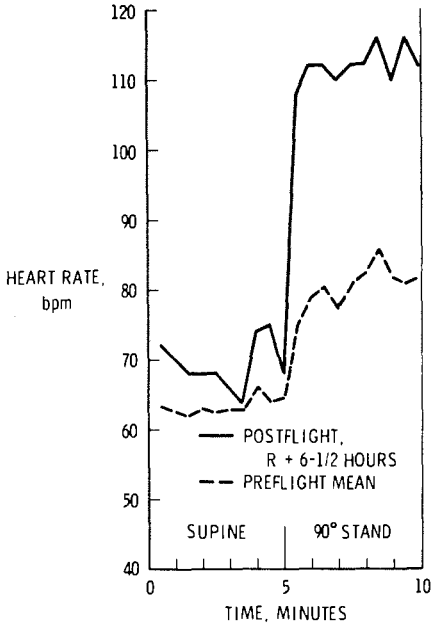


Figure 15. - Apollo crewman heart rate response to 5-minute 90° stand tests.

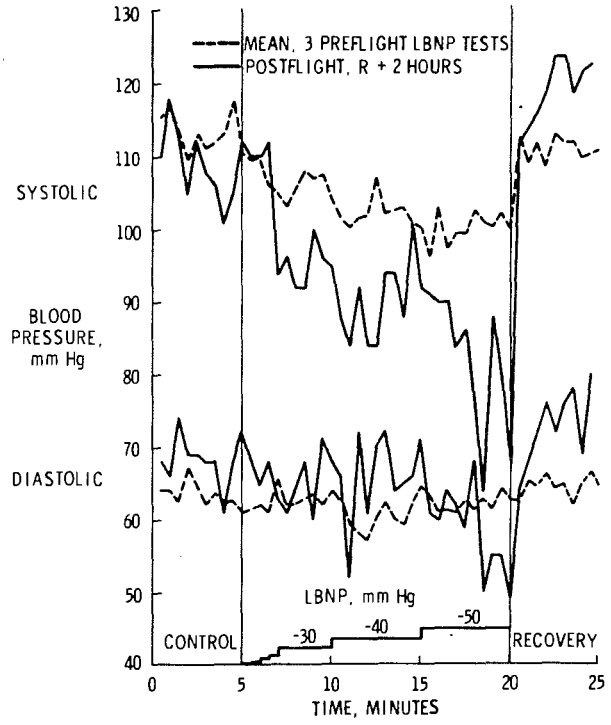


Figure 16. - Apollo crewman blood pressure response to LBNP.

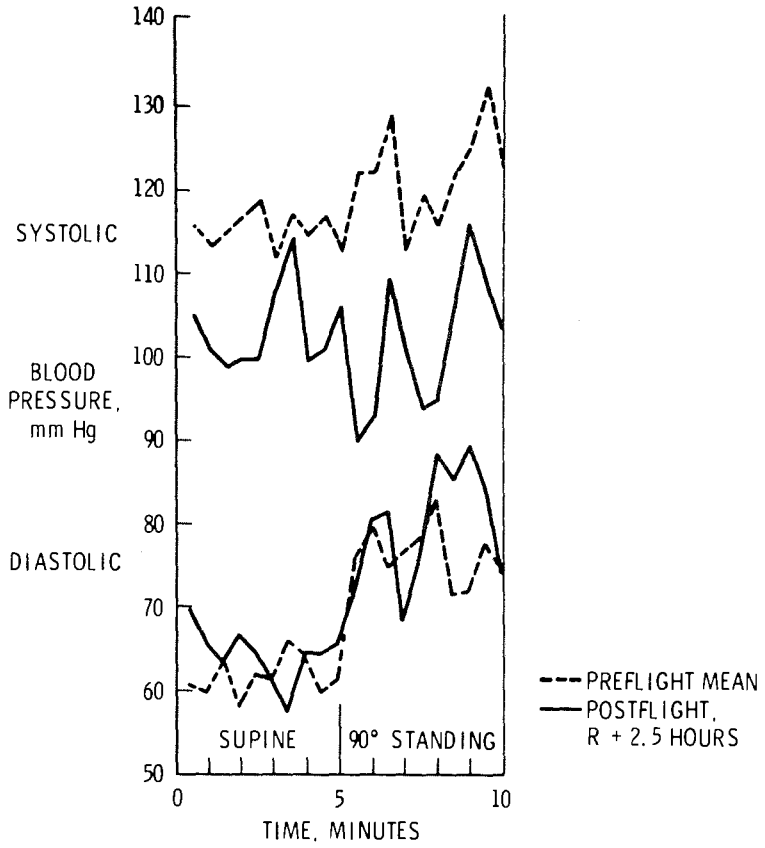


Figure 17. - Apollo crewman blood pressure response to 5-minute 90° stand test.

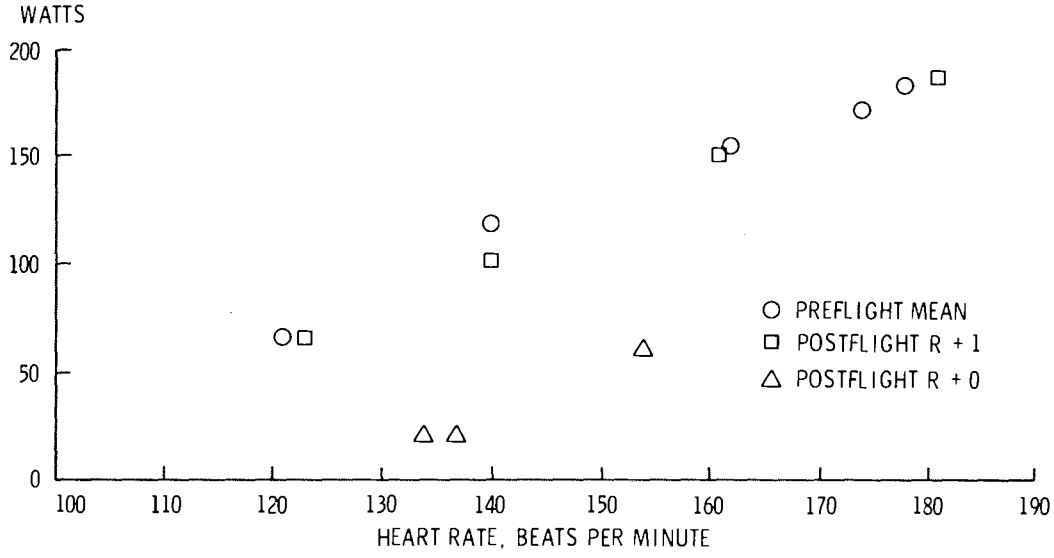


Figure 18. - Workload /heart rate.

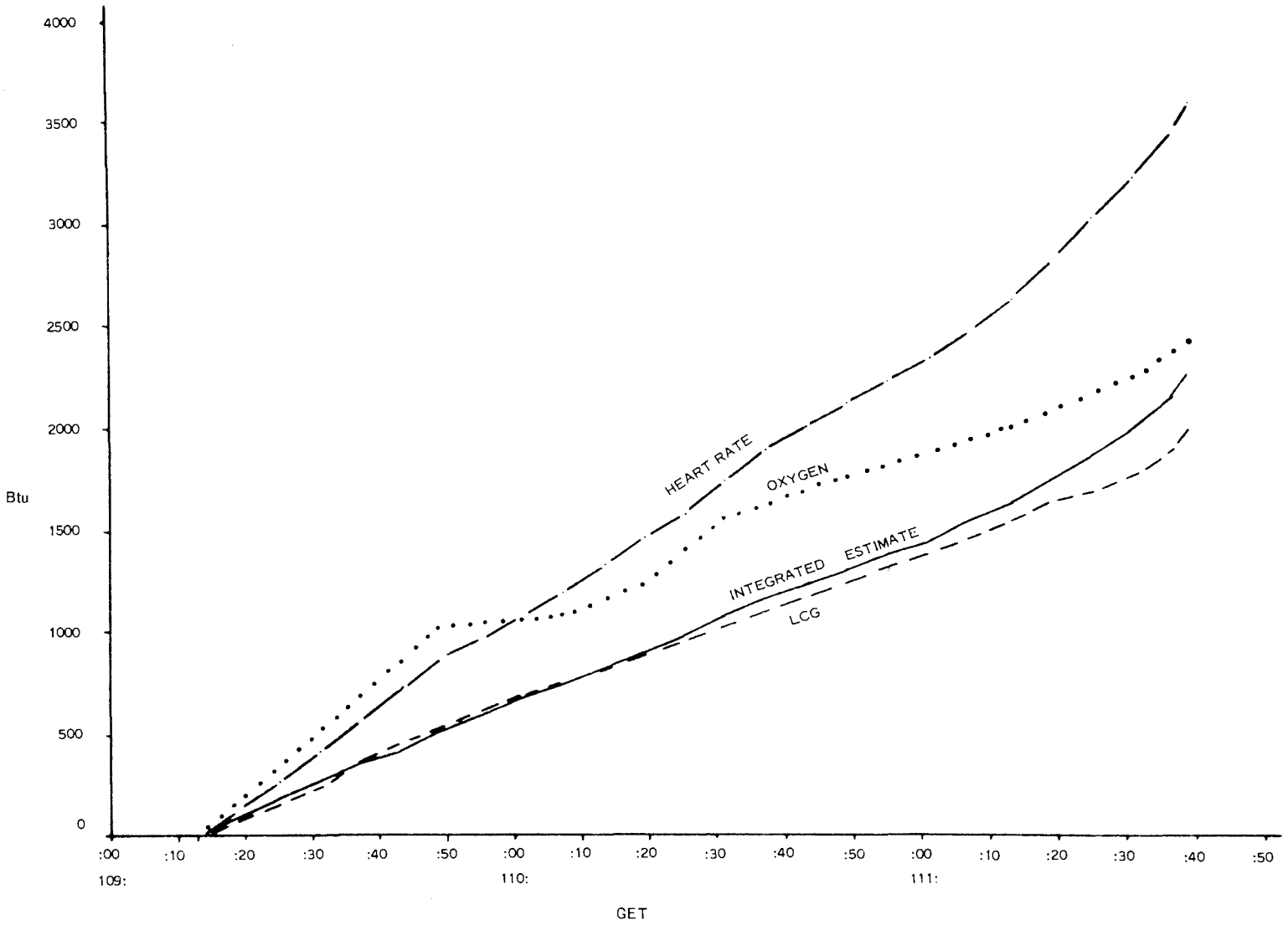


Figure 19.- Apollo EMU metabolic assessment (Apollo 11 CDR, real-time data, accumulated Btu).

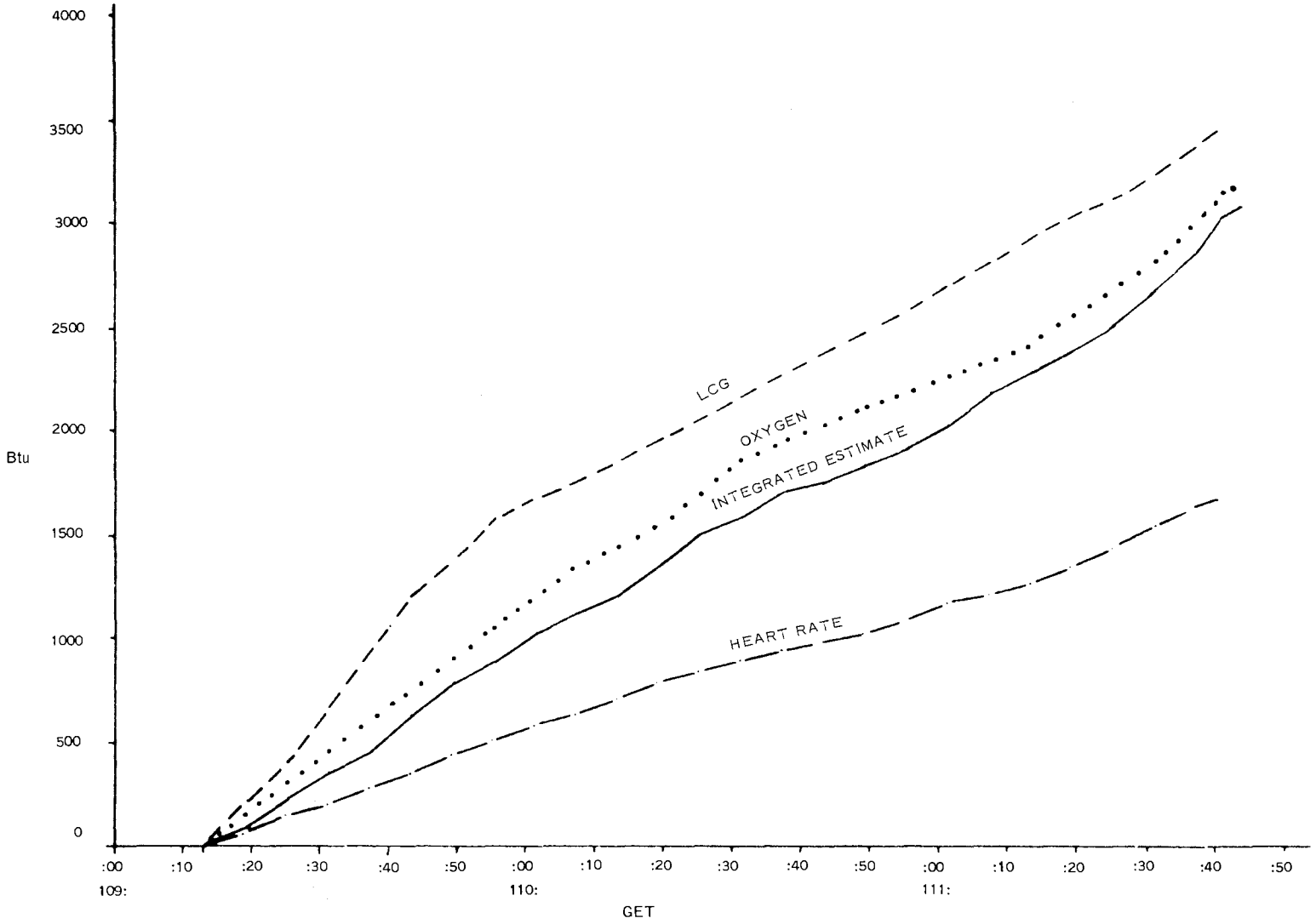


Figure 20. - Apollo EMU metabolic assessment (Apollo 11 LMP, real-time data, accumulated Btu).

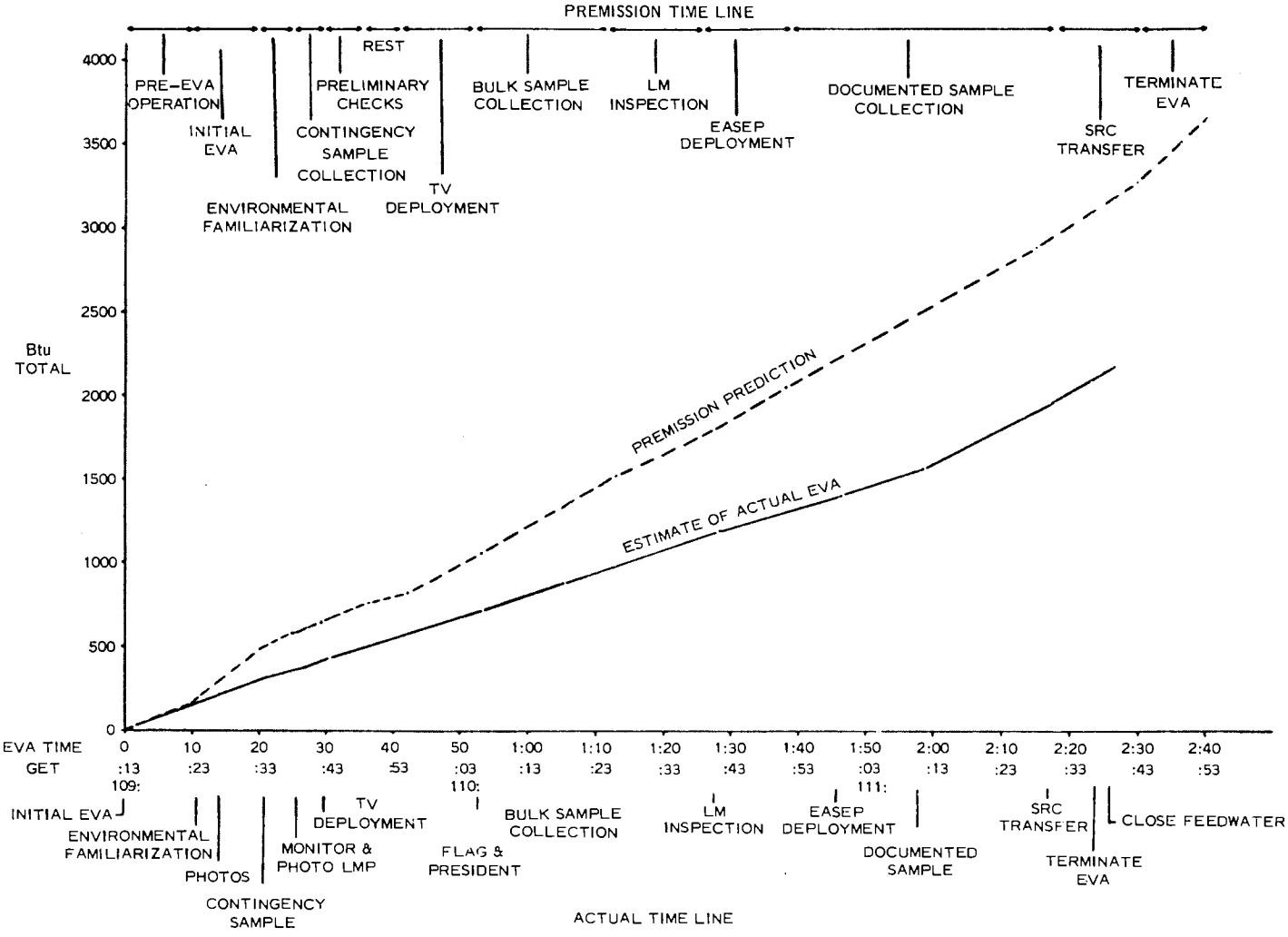


Figure 21. - Apollo EMU metabolic assessment (Apollo 11 CDR).

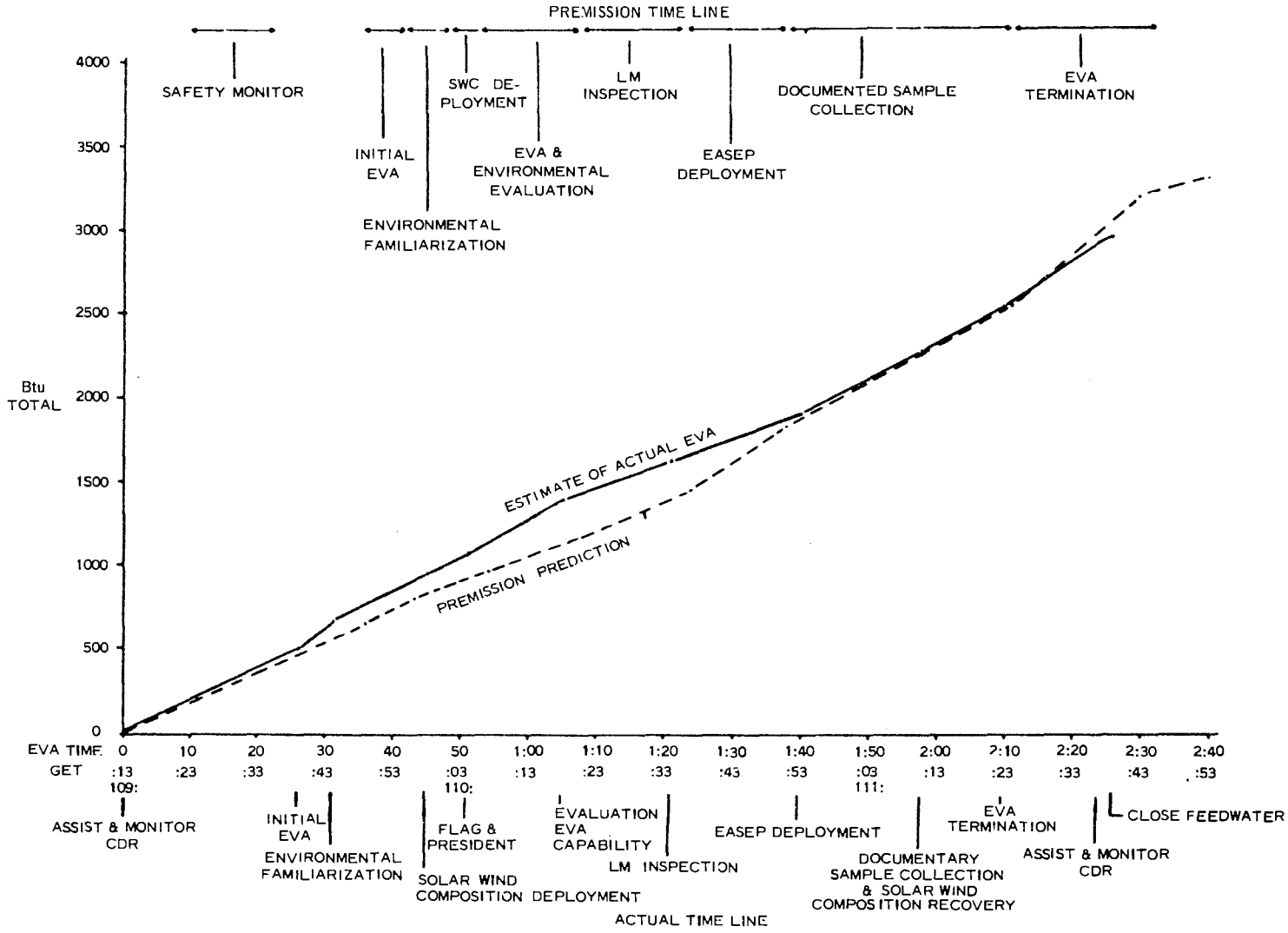


Figure 22. - Apollo EMU metabolic assessment (Apollo 11 LMP).

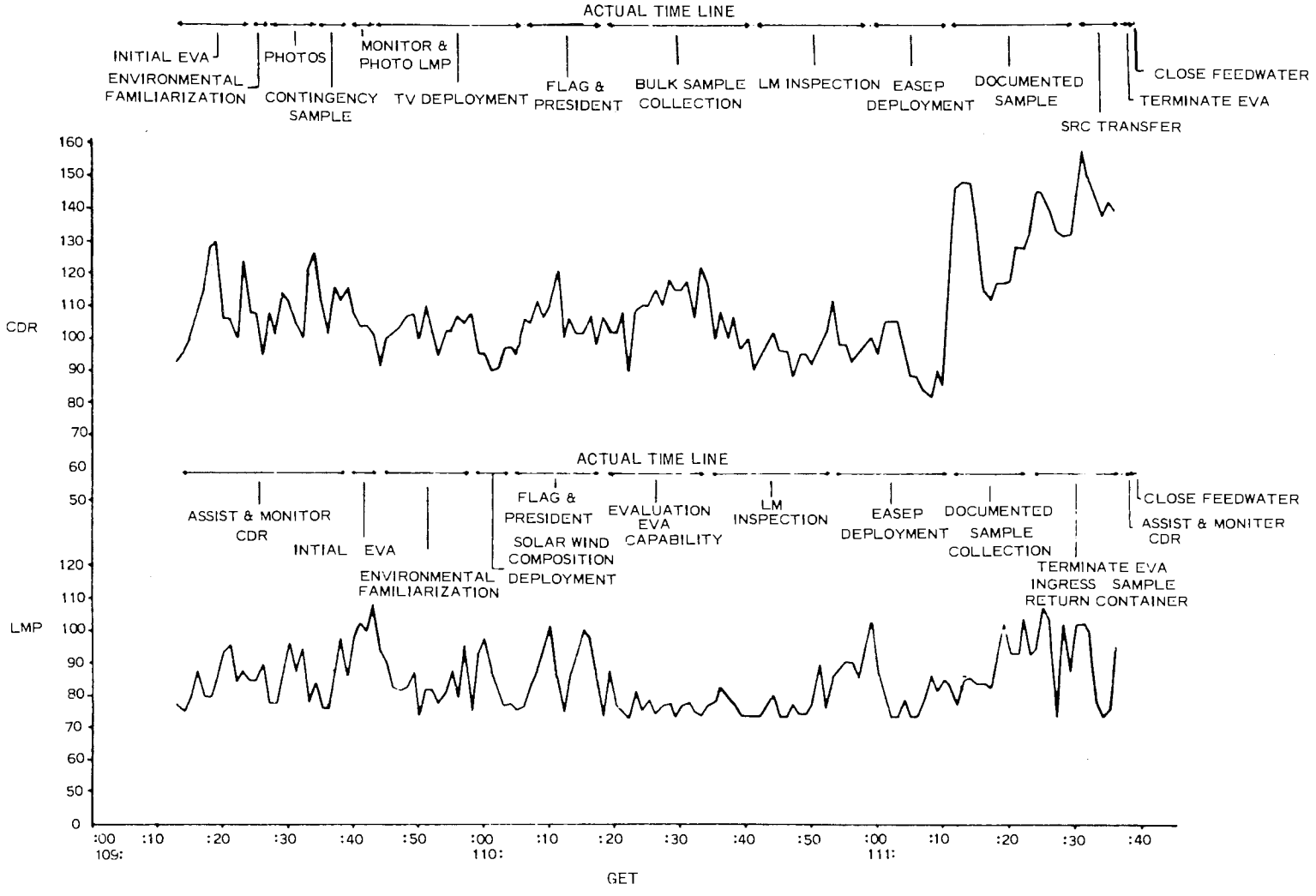


Figure 23. - Apollo EMU metabolic assessment (Apollo 11 heart rates).