# Summary of Medical Experience in the Apollo 7 Through 11 Manned Spaceflights

CHARLES A. BERRY

*National Aeronautics and Space Administration Manned Spacecraft Center, Houston, Texas 77058*

BERRY, C. A. *Summary of medical experience in the Apollo 7 through 11 manned spaceflights.* Aerospace Med. 41(5):500-519. 1970.

**The 3105 hours of exposing man to space flight during the Apollo program have added greatly to knowledge of man's response to space travel. The spacecraft cabin environment has been suitably maintained for the crew. The radiation environment has been benign, no solar flares occuring during the Apollo program missions. Crews have generally adapted well to weightlessness, and have learned to utilize it to their advantage. Improvements have been made in in-flight food, with the addition of moisturized packs and such items as sandwiches and dried fruit. The body weight losses, which have continued to occur during space missions, are not entirely due to body fluids loss. Work-sleep cycles have been improved somewhat by having all crew members sleep at the same time, and by having cycles more closely related to those during training period. Cardiovascular deconditioning has been identified postflight with both lower body negative pressure and 90° passive standing techniques. Microbiological studies have shown that organisms transfer between crewmembers. Moreover, the growth of opportunist organisms appears to be favored by these shifts. Extravehicular activities on the lunar surface during the Apollo 11 mission were conducted within expected energy costs, at an average of 1,200 BTU per hour. The liquid-cooled-garment-temperature method of energy cost estimation is the most suitable. It appears that lunar surface time can be expanded safely. The Apollo 11 quarantine was a demanding operation, conducted very successfully.**

THE GOAL OF THE APOLLO PROGRAM was to land men on the Moon and return them safely to Earth. This goal was achieved in the Apollo 11 mission, with two astronauts stepping onto the lunar soil on July 20, 1969. A number of similar missions for further exploration of the Moon are planned.

The Apollo Program was a series of unmanned and manned spaceflights in both earth and lunar orbits, first to check out the operational safety of spacecraft components, and then to land on the Moon. Apollo manned spaceflights, summarized in Table I, gave a spaceflight experience of 3,105 man hours, including extravehicular lunar surface times of 2 hr. 14 min. for astronaut Armstrong and 1 hr. 42 min. for astronaut Aldrin. The total American spaceflight experience, including 54 man-hours in the Mercury Program and 1,939 man-hours in the Gemini Program, is now 5,098 man-hours.

Medical information gained especially in the Gemini Program[1,4,6,7,8,10] was utilized extensively in planning the medical support and investigations conducted during the Apollo manned spaceflights. Such significant biomedical observations in the Gemini Program as high energy cost of extravehicular activity, cardiovascular deconditioning, diminished exercise capacity and loss of red cell mass had to receive thorough consideration, particularly with respect to their possible effect on astronaut performance during proposed lunar surface activity.[3] Although the contribution of confinement per se to the deteriorative physiologic changes observed after flights of long duration in the small Mercury and Gemini spacecraft cabins could not be determined, it was thought that the freedom of movement and exercising allowed in the Apollo spacecraft would maintain the astronauts in optimum physical condition for the duration of the Apollo 11 mission.[1-12]

## MEDICAL OBJECTIVES FOR APOLLO PROGRAM

The following medical objectives were established for the Apollo Program:

1. Assurance of crew safety
2. Assurance of mission completion and those activities contributing to mission management

TABLE I. APOLLO MANNED SPACEFLIGHTS

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

Reprinted from *Aerospace Medicine*, Vol. 41, No. 5, May 1970

3. Prevention of back contamination of the earth's biosphere
4. Continuance of the understanding of the biomedical changes incident to manned spaceflight

To meet these objectives it was necessary to prepare a medical requirements document detailing a pre- and postflight medical evaluation program which would provide information to assure capability for the proper support of lunar landing. This program[2] was particularly important for the reason that all inflight medical and other experiments in the Apollo program were deleted after the fatal spacecraft fire in order to concentrate on the operational complexity of the Apollo missions. Areas of concern in planning the lunar mission have been summarized.[6]

Comparison of biomedical data obtained in the Gemini Program with that from Apollo missions prior to the lunar mission was vital to predicting the physiologic state of the astronauts at the time of lunar surface activity.[5,6] The provision of a microbial baseline for lunar quarantine operations and the further documentation of spaceflight effects on man were also valuable objectives.

The medical procedures conducted were developed by a multidisciplinary team in the Medical Research and Operations Directorate of the National Aeronautics and Space Administration Manned Spacecraft Center at Houston, Texas.[4] In addition to detailed physical examinations, exhaustive studies were performed in the areas of hematology, immunology, biochemistry, bone densitometry, cardiovascular functions, exercise capacity and microbiology. These evaluations were supplemented by observations made during flight from continual monitoring of voice, electrocardiogram and respiration during Command Module (CM) operations, and monitoring of voice and electrocardiogram during Lunar Module (LM) operations. While only one crewman could be monitored at a time during Apollo 7 and 8 CM operations, all three CM crewmen could be monitored continuously for later missions. Only one could be monitored at a time while in the LM except during lunar surface activity, when both could be monitored continuously.

## SPACECRAFT ENVIRONMENT CHARACTERISTICS

*A. Cabin Atmosphere*—After the fire in the Apollo CM two years ago, it was decided that the CM cabin atmosphere should not be 100% oxygen. Calculations and studies demonstrated that if this atmosphere contained 60% oxygen and 40% nitrogen at launch, and the crew denitrogenated for 3 hours prior to launch, hypoxia and dysbarism could be avoided when the nominal cabin pressure of 5.0 psia was attained. The Apollo spacecraft have actually been launched with cabin atmospheres containing 64% oxygen and 36% nitrogen. The valve for dumping urine into space was left open at launch and for several hours thereafter to allow purging of the nitrogen from the atmosphere at a specified rate. An oxygen analysis on the Apollo 7 mission recorded the oxygen enrichment profile shown in Figure 1. The partal pressure of oxygen was never less than that at sea level.

Apollo astronauts removed space suit helmets and gloves usually within the first half-hour, always within the first hour after launch. Space suit doffing was completed when convenient, and flight coveralls donned for the major portions of the missions. In the Apollo 7 mission the crew donned their space suits inlet to check their capability to do so and their reentry configuration. They also donned their suits, without helmets and gloves, to use the foot restraints built for the suits during reentry. Since this mission space suits have not been worn for reentry, but have been donned for critical mission phases such as separation and docking and, of course, lunar surface activity.

*B. CM and LM Cabin Atmospheric Temperatures*—The CM cabin temperature has been maintained about 70° F (range 62° F to 80° F), usually without the use of the cabin fans. Crews occasionally felt cool during translunar coast, but adjustment of the environmental control system returned the temperature rapidly to the comfort level. The LM cabin temperature was kept between 65° F and 70° F, except during and immediately following depressurizations. The Apollo 11 astronauts did complain of sleep interference from chilling and shivering during their rest period on the lunar surface. Since their space suits, including helmets, were donned during this period, their discomfort was attributed primarily to operation of the liquid-cooled garment, the temperature of which is not reflected by the cabin gas temperatures.

*C. Noise and Vibration*—The cabin fans and glycol pump created a noise problem during preflight checkouts of the Apollo spacecraft. Gylcol pump noise was attenuated with padding, and the cabin fans have generally not been used during flight. The cabin noise level during lift-off has been high, but an acceptable level has been reported during all missions, neither being distractive nor interfering with sleep.

The noise levels in the LM cabin were also reported to be high during the three LM flights, due to the cabin

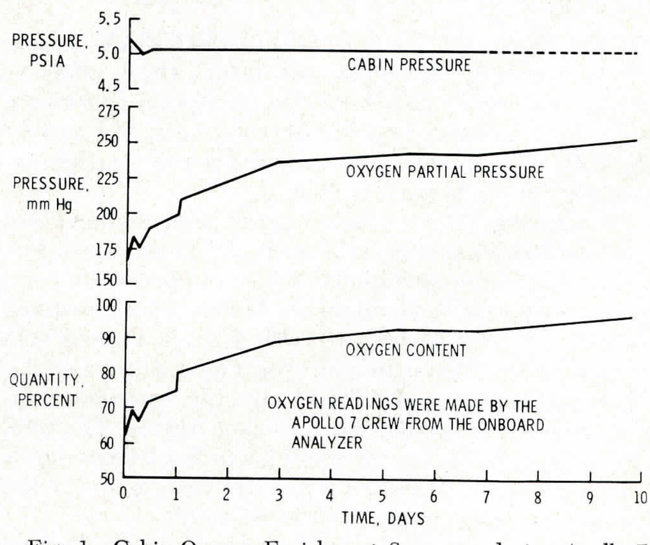


Fig. 1. Cabin Oxygen Enrichment Sequence during Apollo 7, 10-Day Flight.

fans primarily. This noise was annoying to the astronauts when their space suit helmets were removed.

"Pogo" vibrations were reported during all spacecraft launches. However, any transmission of these vibrations to the crews was considered physiologically insignificant.

## ACCELERATIONS AND IMPACT

As anticipated and shown in Figure 2, accelerations ($+G_x$) during launch have not been much greater than 4 g. Reentry from earth orbit has produced levels near 3.4 g and, as illustrated in Figure 3, reentry from lunar missions has produced levels near 6.7 g. Accelerations from S-IVB booster reignition for translunar injection, and all ignitions of the Service Module engine have been below 1 g. All these acceleration levels, which had been previously experienced by the crews during centrifuge training, were well tolerated. Landing impacts, estimated from 6 to 8 g, were also well tolerated by the astronauts.

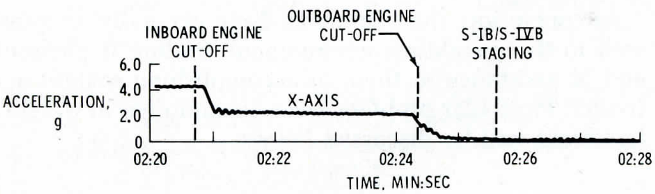


Fig. 2. Launch Accelerations (Apollo 7 Mission).

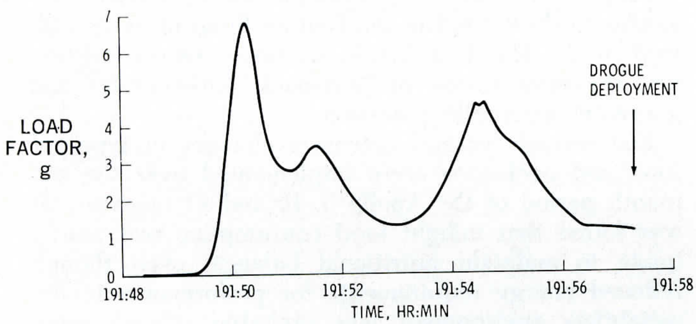


Fig. 3. Re-entry Decelerations from Lunar Mission (Apollo 10).

TABLE II. RADIATION INSTRUMENTATION ON APOLLO MISSIONS

| 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 III. AVERAGE RADIATION DOSES TO SKIN DURING APOLLO MISSIONS, MEASURED BY THERMOLUMINESCENT DOSIMETER

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

## RADIOBIOLOGY

Only two of the five manned Apollo missions (Apollo 7 and 8) have occurred under the Van Allen, or natural radiation belt, which consists principally of protons and electrons trapped in the geomagnetic field. This belt, the boundaries of which are about 38° geomagnetic latitude, shields all the Earth but the polar regions from externally-generated radiations, such as solar flare protons. Orbital missions of 100 to 200 miles altitude stay well below the belt, except where the belt dips in the south Atlantic Ocean. Although orbiting Apollo and other flights have passed through this region once every seven orbits, it has not presented a radiobiological hazard. The polar regions, where spacecraft are exposed to untrapped space radiations, have been avoided in manned space missions.

Lunar missions passed through the Van Allen belt enroute to, and on return from the Moon. The skin radiation dosage received by the astronauts during belt passage has actually been of low magnitude, measured as approximately 10 millirad, due primarily the short transit times through the belt. It is important to point out that in the Apollo missions, beyond the earth's protective "magnetic umbrella", man is subjecting himself for the first time to direct galactic radiations and particles from solar flares, should this event occur. However, measurements have shown that under normal circumstances galactic radiations are an insignificant hazard, giving only about a 10 millirad skin dose daily.

Since solar flares are random, occur infrequently, and are of short duration, the risk of exposure to a solar flare during a lunar mission is considered quite low, probably less than once in 5,000 missions. Even if a solar flare should occur, radiation doses received by CM crewmen should be medically insignificant due to absorption of incident radiations by the thick CM wall and surrounding equipment. For example, it has been estimated that the solar flare of greatest magnitude in the last solar cycle would have given a CM crew a skin dose (0.7 mm depth) of 237 rad. Such doses would have a minimal effect on the average man. Although several flares can occur over several days duration, the probability of this during the time required for an Apollo mission is quite low.

On the other hand, occurrence of a solar flare of large magnitude while astronauts occupied the LM and explored the lunar surface could present a significant medical hazard. Under the worst unprotected length-of-exposure conditions conceivable, the skin doses could reach 691 rad (0.7 mm depth) and the depth dose (5.0 cm) 25 rad. Although this depth dose would not be expected to have a significant pathological effect this skin dose could conceivably produce sufficient skin irritation and blepharitis to moderately affect crew performance. Also a skin dose of this magnitude is approaching the threshold for producing more serious latent radiation sequelae, such as dry and most desquamation, ulceration, subcutaneous edema and fibrosis. Fortunately, there are certain operational constraints which can be used.

Radiations encountered during Apollo missions were measured by a variety of sophisticated devices, listed in Table II. Table III shows the average skin doses received by the astronauts during the five Apollo missions, as measured by the thermoluminescent dosimeter. It should be noted that these doses are much less than doses to various organs of the body during routine X-ray diagnostic procedures.

## TOXICOLOGY

Three approaches were used to assure that compounds would not enter the CM and LM atmospheres and reach levels toxic to the astronauts. Spacecraft cabin materials were selected on the basis of their offgassing characteristics. Animal toxicologic studies were made with off-gassed compounds from materials. The atmospheres of Apollo 7 and 8 CM's and the Apollo 9 LM were analysed for off-gassed compounds during altitude chamber tests at Cape Kennedy. Also charcoal from the environmental control systems on the Apollo spacecraft was analysed postflight.

Although approximately 50 compounds have been identified in the spacecraft cabin atmosphere, their concentrations have been too low to be of toxicologic significance, even when these compounds were grouped according to their primary modes of action. Of greatest significance was the presence of relatively large concentrations of halocarbons, such as methanol, ethanol, proponal, isopropanol, methyl chloride, mestiylene and N-octane. Since halocarbons can react with the carbon dioxide absorbing lithium hydroxide to produce highly toxic compounds, action is being taken to reduce halocarbon concentrations still further on future flights. A review of the contaminants in the spacecraft cabin atmosphere did not identify the cause of a very minor degree of methemoglobinemia observed in the astronauts postflight. Although offensive odors were detected in the Apollo 9 and 11 spacecraft, their cause, nature and potential effects remain undetermined. Atmospheric sampling has been proposed for future flights.

## WEIGHTLESSNESS

As in the Gemini missions, Apollo crews have reported an initial feeling of fullness in the head after attaining weightless flight. This sensation has lasted for a varying duration during the first day. There is also an awareness of the lack of weight of objects and clothing.

The capability to impart minimal velocities to objects in the weightless environment has been utilized repeatedly while living and working in the spacecraft. Minimal effort has been required in moving about the spacecraft, frequently in a swimming manner. A number of acrobatic maneuvers, such as rolling, tumbling and spinning, have been accomplished without difficulty. It appears that movement in the weightless environment requires much less work than in the unit gravity environment.

Some soreness in the costo-vertebral area has been reported. Crews have related this to body position and have frequently assumed the fetal position while resting in the weightless environment. It has been of no serious consequence.

In conclusion, the astronauts have generally adapted well to the weightless environment, finding it pleasant and of assistance to them in accomplishing inflight activities. Particular problem areas encountered in weightless flight will be discussed below.

## NUTRITION

Freeze-dehydrated, rehydratable and bite-sized foods similar to those used in the Gemini Program were utilized in the first two Apollo missions. One exception was the introduction of "wet-pack" turkey bites and gravy on the Apollo 8 mission.

For several reasons, extensive changes in types of food and packaging were implemented over the six-month period of the Apollo 9, 10 and 11 missions. It was found that inflight food consumption was inadequate to maintain nutritional balance, even though reduced energy requirements for performance in the weightless environment was probable. Crews were reporting anorexia. Meal preparation and consumption was requiring too much time and effort. Water for reconstitution of dehydrated foods was off-flavor and contained large quantities of undissolved hydrogen and oxygen. Functional failures were occuring with rehydratable packages. There appeared to be a definite requirement to develop food which was more familiar in appearance, flavor and method of consumption.

New food consisted primarily of thermostabilized meat dishes of high moisture content (60 to 70% water), called "wet-packs." Larger pieces of meat were used than previously. These foods, along with freeze-dehydrated meat and vegetables, were packaged so that they could be eaten with a spoon. Also added to the dietary provisions were some new beverage powder flavors, fruits and candy-like items of intermediate moisture (10 to 30% water) content, and sandwich spreads with "fresh," sliced bread. The sandwich spreads were heat sterilized in a hyperbaric chamber to reduce deterioration of food texture, and packaged either in cans or flexible aluminum tubes. Of the 96 different "space" foods available prior to the Apollo Program, about 60 were utilized in the Gemini Program. It is notable that of the 42 different foods to be provided on the forthcoming Apollo 12 mission, only 24 were on the original Apollo dietary list.

The inclusion of foods which did not require rehydration prior to consumption simplified procedures and reduced the time taken for meal preparation. This measure also circumvented problems of off-flavor and undissolved gas from the spacecraft water supply. The packaging failures which occurred in flight have now been effectively prevented through design changes and additional quality control procedures.

Inflight anorexia has led some crewmen to comment that the foods supplied would be more desirable if they were stowed in bulk units, similar to a pantry, than if stowed in nominal meal units. This would allow a crewmember to make a meal-time selection of desired foods based on appetite rather than accept a menu established a month prior to flight. Apollo 11 CM food stowage was configured in nominal meal units (45 meals, 15 man-days, or 5 mission days) located in the lower equipment bay, and in bulk units (9 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 crew estimated that 80% of the nominal meal unit food was consumed, whereas 40% of the bulk stowage food was consumed. LM food, stowed in the LM, was provided for 4 meal periods over the scheduled 21 hours of lunar surface time. The two LM crewmembers estimated that 40% of these supplies were eaten.

TABLE IV. BODY WEIGHTS AND ENERGY INTAKES OF ASTRONAUTS FOR APOLLO 7 THROUGH 11 MISSIONS

| Crewman | Body weight, lb: Average preflight (F-28, F-24, F-5) | Launch day (F-0) | Recovery (R+0) | Recovery +1 day (R+1) | Average daily inflight calorie intake, kcal |
|---|---|---|---|---|---|
| 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 |

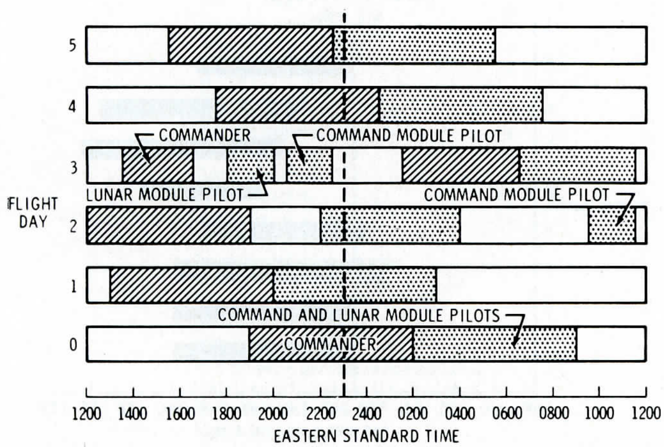


Fig. 4. Crew Rest Cycles during Apollo 8 Mission.

Crew acceptance of all new foods and packaging has generally been quite high. Also, a much better understanding of food preference has been attained. However, it appears that the quantity of food consumed during Apollo missions did not increase, for the crews have subsisted primarily on the supply of new foods, which were intended only to supplement the nominal food supply. Although the crews of Apollo 10 and 11 spacecraft were quite pleased with the foods provided, their postflight body weights still indicated that they attained a negative nutritional balance.

Body weights and energy intakes of the Apollo crews are given in Table IV. Although there is no "average astronaut," it is of interest to note that 15 men with an average weight of 166.6 lbs. were launched in the Apollo Program. At recovery, their weight averaged 160.4 lbs., and one day after recovery averaged 163.5 lbs. Hence, the average inflight weight loss was 6.2 lbs., half of which has been attributed to water loss.

Precise measurements of changes in body mass and accurate records of food intake should provide data necessary to determine future food requirements. Such data will, in particular, be vital to establishing a baseline for the evaluation of the effects of space flight on the musculoskeletal system in the Apollo Applications Program flights of 28 and 56 days duration.

Finally, it should be noted that in their postflight debriefing, all Apollo crews indicated that the intensity of hunger sensations is similar to that of preflight. However, they did observe that hunger occurs less frequently and that their food requirements are only two-thirds of "normal" in space. At least one crew has reported that gastric distension precluded intake of normal quantities of food and beverage. Based on these observations and critical stowage volume, menus were designed to provide approximately 2300 Kcal energy per man per day.

## WATER MANAGEMENT

Data indicates that water servicing procedures and the addition of disinfectant chemicals (chlorine in CM and iodine in LM) have been effective in rendering water delivered from Apollo CM and LM spacecraft systems potable. The crews did complain of the chlorine taste of water during early Apollo missions. However, revised chlorination procedures eliminated this problem. Objectionable amounts of free oxygen and hydrogen were present in the Apollo 9 CM potable water supply. On the Apollo 11 flight a water/gas separator satisfactorily removed this gas. In addition to the water/gas separator, Apollo 12 will utilize a silver-palladium hydrogen separator which will further decrease the amounts of these gases in potable water.

Rapid iodine depletion rates in the first two manned LM spacecraft made it necessary to install a microbial filter upstream of the water outlet. Alteration of the Apollo 11 LM water system servicing procedure resulted in a microbially effective iodine residual throughout flight, without having to use the microbial filter. Future LM flights should not have to use this filter, although with extension of lunar surface times, revisions of the water system servicing procedure will be required to assure that an effective iodine residual is maintained in the LM water system.

## WASTE MANAGEMENT

Feces collection in the CM and LM is accomplished with the fecal collection system used in the Gemini Program. This tape-on bag is considered only marginally adequate, since its use is quite time-consuming and no provision is made to eliminate odors which accompany defecation.

The Gemini urine transfer assembly was improved for use in the CM. This device incorporates a roll-on cuff and an intermediate urine storage bag. The Apollo 12 crew will test a urine transfer assembly which eliminates direct interface of the user with the collecting portion.

Urine collection in the LM has been accomplished satisfactorily with a roll-on cuff assembly connected to a urine bag in the space suit. Its use is planned for future Apollo missions.

## WORK/SLEEP CYCLES

Before manned spaceflight became a reality, many in the medical community predicted that space flight would produce serious disturbances and alterations in man's sleep, ranging from narcolepsy to insomnia. Although the Mercury Program disproved these extreme forecasts, the Gemini Program clearly demonstrated that earth-orbiting spaceflights of long duration could produce conditions which prevented adequate sleep. These conditions included cyclic noise disturbances from such events as thruster firings, communications, or movement within the spacecraft, staggered sleep periods, significant alteration of the preflight diurnal cycle of crewmembers, the so-called "command pilot syndrome," the unfamiliar sleep environment and excitement.

The Apollo astronauts have faced the same sleep difficulties as their predecessors. Unfortunately medical knowledge and expertise can provide little assistance in resolving this problem area, for Apollo mission plans must be highly inflexible and constraining. The astronaut must then be integrated into the fixed mission plan as best he can.

The Apollo 7 work/sleep cycles were quite irregular, and staggered sleep periods shifted considerably from the preflight (Cape Kennedy) bedtime. The crew never adapted to these cycles, reporting very poor sleep during the first 3 days of flight. One crewmember fell asleep on his watch, and on another occasion took 5 mg. d-amphetamine to stay awake during his work period. The Apollo 7 Commander recommended that future flight crews evaluate their work/sleep cycles carefully.

Sleep period scheduling became a crew option on the Apollo 8 mission as confidence in spacecraft systems was gained. Also, the sedative, secobarbital, in 50 and 100 mg. doses was added to the medical kit. The Apollo 8 work/sleep cycles are shown in Figure 4. They varied greatly from Eastern Standard Time (Cape Kennedy), and had the added complication of a 20 hour loitering period in lunar orbit. Crew fatigue, particularly prior to trans-earth injection, led to minor procedural errors, and forced "real-time" changes of the flight plan. Only the LM Pilot used secobarbital (50 mg) regularly for sleep.

On Apollo 9 all three astronauts slept simultaneously. The quantity and quality of crew sleep was definitely improved over the preceding mission experience, and the lack of postflight fatigue was evident during medical examination of the crew on the recovery day.

Sleep periods occurred simultaneously during the Apollo 10 mission and deviated little from the normal diurnal rhythm of the crew. One exception was when the Commander and LM Pilot flew the LM during the lunar orbit phase.

On the Apollo 11 lunar landing flight the work/sleep cycles of the crew, as shown in Figure 5, were actually quite ideal prior to lunar orbit insertion. Table V lists quantitative sleep estimates during the first four days of flight, from the study of telemetered heart and respiratory rates, and from the crew's reports. Limitations in estimating sleep durations from heart and respiratory rates must be recognized. Nonetheless, the amount of sleep was adequate enough by either method of estimation to approve medically earlier extravehicular activity on the lunar surface than was originally planned.

During their lunar stay neither the Commander nor the LM Pilot slept well. The LM environment was too noisy and the space suit too cold for adequate sleep. In

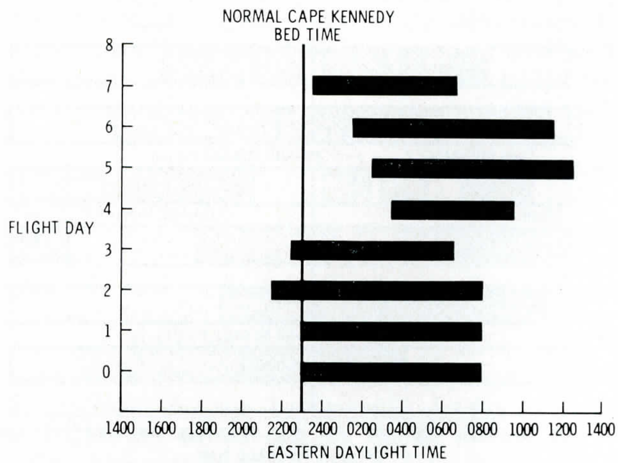


Fig. 5. Crew Sleep Periods during Apollo 11 Mission.

addition, accommodations for sleeping in the LM were quite poor. The Commander estimated that he had little, if any, sleep in the LM. The LM Pilot had about 2 hours sleep. On the return flight, the crew slept very well during the three trans-earth sleep periods.

In summary, efforts must be continued with flight planners to maintain the workday inflight at about 12 hrs., and allowing 8 hrs. for sleep, and 4 hrs. for leisure. Better tools, such as the electroencephalogram are required for more detailed assessment of sleep in future space programs.

## MEDICAL KIT

Contents of the Apollo CM and LM medical kits are listed in Tables V and VII. Table VI also indicates the number of items used during the missions. Flight experience has dictated some changes in the types and numbers of drug items carried. On one flight Benadryl and Tylenol were replacements due to drug sensitivity in one of the crewmen. Added to the Apollo 11 CM medical kit were a Scopolamine-Dexedrine combination for the treatment of motion sickness and Mylicon to reduce gastrointestinal gas bubble size.

All astronauts are tested for sensitivity and response to each of the medications carried in their medical kit. Particular interest has been focused on performance from one to 4 hours after the ingestion of Seconal. Flight related performance tests have been satisfactory after use of this drug.

TABLE V. ESTIMATED SLEEP PERIODS OF APOLLO 11 CREWMEMBERS BEFORE LUNAR LANDING

| Date | Estimated sleep, hr:min — Telemetry CDR | Telemetry CMP | Telemetry LMP | Crew report CDR | Crew report CMP | Crew report 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.

## BIOINSTRUMENTATION

Difficulties encountered with bioinstrumentation on the Apollo 7 flight have been detailed in a previous report.[5] No difficulties were encountered in recording biomedical data following redesign of the bioinstrumentation harness for the Apollo 8 mission. Subsequent Apollo mission bioinstrumentation has also performed satisfactorily. Crews have been briefed preflight concerning sensor application and temperature to be expected in the DC to DC converter and signal conditioners. Drying of electrode paste has caused some degradation of electrocardiographic data at times, necessitating replacement of the sensor, which then operated satisfactorily. Biomedical data recorded during the Apollo missions are reported elsewhere in this paper.

## PREVENTIVE MEDICINE AND INFLIGHT DISEASE

The preventive medicine program was detailed in the Medical Requirements Document. Following the experence with preflight, inflight and postflight illnesses

TABLE VI. APOLLO CM MEDICAL KIT CONTENTS (QUANTITY PER MISSION) MISSION NUMBER

| Item | Quantity per flight — Apollo 7 Stowed | Apollo 7 Used | Apollo 8 Stowed | Apollo 8 Used | Apollo 9 Stowed | Apollo 9 Used | Apollo 10 Stowed | Apollo 10 Used | Apollo 11 Stowed | Apollo 11 Used |
|---|---|---|---|---|---|---|---|---|---|---|
| Eye drops, ¼ 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 |
| 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 |
| Ophthalmic ointment (Bacitracin) | | | | | 1 | 0 | | | | 0 |
| Scopolamine-Dexedrine | | | | | | | | | 12 | 6 |
| Mylicon tablets | | | | | | | | | 20 | 0 |

[a]Plain.

[b]Quantity unknown.

on the Apollo 7 mission, space crews have maintained modified-isolation during the 21-day preflight period. Their food, water and air has been controlled as best as possible, and their contacts with other individuals have been kept to a minimum compatible with mission success. This has required great cooperation on the part of both the astronauts and supporting personnel.

Several factors dictate the need for an isolation period lasting at least 21 days. In flights of greater than a week in duration it is quite possible for disease to occur in flight without being evident in preflight medical examinations. One must be maximally sure that illness in the crew will not cause a launch delay, especially when the spacecraft must enter a particular launch "window" in lunar missions. Possible consequences of crew illness during lunar surface time are readily apparent. Moreover, on the Apollo 11 mission the 21-day postflight quarantine period made the preflight preventive medicine period assume great importance.

Details of the preflight and inflight upper respiratory illnesses which occurred on the Apollo 7 mission, and the gastrointestinal disturbance which occurred on the Apollo 8 mission have been reported elsewhere.[5] Table VIII summarizes medical problems identified in the preflight phase of the Apollo 7 to 11 missions. Rhinitis and pharyngitis caused a delay of the Apollo 9 mission. Although none of these conditions were severe, such common, mild viral infections as upper respiratory infections and gastroenteritis in the preflight phase must be viewed with great concern with respect to their possible effects on astronaut performance, and hence mission success.

Inflight medical problems in the Apollo 7 to 11 missions are listed in Table IX. The three cases of coryza occurred on the Apollo 7 mission. One episode of nausea and vomiting, probably due to viral gastroenteritis, and the apthous ulcers were reported on the flight of Apollo 8. The fiberglass irritation occurred on the Apollo 10 mission.

Five of the 6 crewmen on the Apollo 8 and 9 missions reported symptoms of motion sickness ranging from mild stomach awareness with head and body motion in the weightless environment, to nausea and vomiting in one crewman and lasting from 2 hrs. to 5 days, after which adaptation allowed movement without symptoms occurring. One Apollo 10 crewman also had stomach awareness lasting 2 days, again indicating that adaptation to the weightless environment takes place. Antimotion sickness medication was used in 3 of the 6 episodes reported.

It should be noted that prior to the Apollo 10 mission the crew had been instructed to carry out programmed head movements during the first two flight days to hasten the adaptive process. The crewman reporting stomach awareness noted an increase in the severity of this symptom after one minute of head movement. When attempted on the seventh flight day, these head movements produced stomach awareness after 5 minutes.

The Apollo 11 astronauts were briefed about the head movement program, the availability of medication for the prevention and control of motion sickness symptoms, and the use of cautious movement in the spacecraft during the adaptive period. No symptoms were noted nor were the special preventive measures used.

It appears that the opportunity to move about more freely in the Apollo cabin than in previous spacecraft is a factor producing the motion sickness problem. Sensory inputs from the semicircular canals to the central nervous system during head movements in space are thought to be enhanced due to altered activity of the otolith organs in the weightless state. This is a significant problem which must receive continued atten-

TABLE VII. APOLLO LM MEDICAL KIT CONTENTS (QUANTITY PER MISSION)

| | |
|---|---|
| Lomotil Tablets | 8 |
| Dexedrine Tablets | 4 |
| Aspirin Tablets | 12 |
| Seconal Capsules | 2 |
| Methylcellulose, 1% Solution | 1 |
| Compress Bandages | 2 |

TABLE VIII. PREFLIGHT MEDICAL PROBLEMS IN APOLLO 7 TO 11 CREWS

| 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. INFLIGHT MEDICAL PROBLEMS IN APOLLO 7 TO 11 CREWS

| 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. POSTFLIGHT MEDICAL PROBLEMS IN APOLLO 7 TO 11 MISSIONS

| 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 |

tion in the space program, for it can markedly affect astronaut performance.

A number of medical problems, listed in Table X, have occurred in the postflight period. Again, viral illnesses predominated.

The lack of illnesses in the Apollo 10 and 11 missions has been gratifying. A number of factors might have contributed to this, including the facts that the disease incidence in the general population was less at mission times, that attempts were made to assure adequate rest in the preflight periods and that contact of crews with other individuals was restricted as dictated by the preventive medicine program discussed above.

TABLE XI. METHODS FOR EVALUATION OF ORTHOSTATIC TOLERANCE IN APOLLO PROGRAM

| 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 presure, pulse pressure, mean blood pressure) | — |
| | Change in leg volume (ΔLV) | — |
| | Other related data (weight, blood volume, vasoactive hormones, exercise capacity) | — |

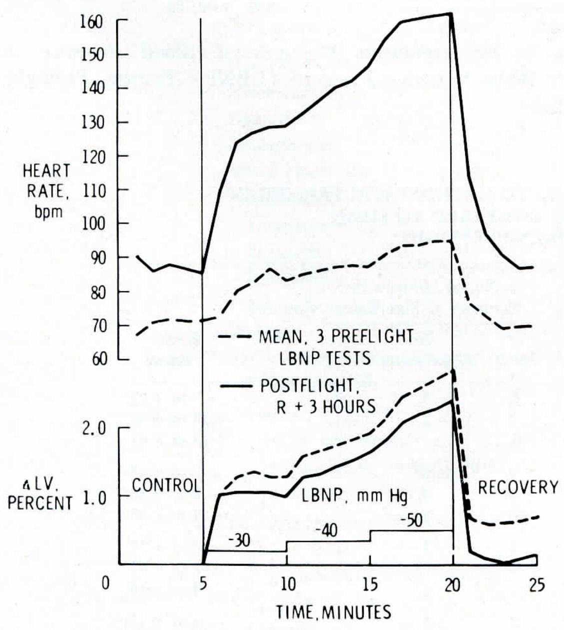


Fig. 6. Representative Changes of Heart Rate and Calf Circumference during Lower Body Negative Pressure (LBNP) Testing, Preflight and Postflight.

## MEDICAL EVALUATION

The medical monitoring program for each Apollo mission began 30 days prior to launch with a crew briefing on medical examinations to be performed and biomedical findings on previous missions. Concerns relating to the particular flight were also discussed, and the first physical examination and collection of specimens for laboratory analysis completed. Detailed medical examinations were conducted at 14 and 5 days in the preflight period. A brief physical examination was performed on the launch day, except for the Apollo 11 mission, before which the crewmen were examined daily for 5 days. Postflight medical examinations were conducted as soon as possible and at 24 hours after recovery. The Apollo 11 crew was examined daily during their 21-day quarantine period.

Other than those observations to be discussed below, there has been no evidence of deterioration of body system function. Medical problems occurring in the Apollo missions were discussed above.

A. *Cardiovascular Evaluation*—It has been well documented in the literature that orthostatic tolerance can be diminished by inactivity, such as earth-based simulations of weightlessness as water immersion or recumbency and, indeed, by the flight environment itself. Potential problems from cardiovascular deconditioning had been predicted long before man first ventured into space. Cardiovascular deconditioning, as evidenced by diminished orthostatic tolerance, was consistently demonstrated in early postflight periods in the Mercury and Gemini Programs. However, this phenomenon appeared to pose no serious problems following flights of 14 days in duration in Earth orbit, nor was it thought that it would have a detrimental effect on the astronauts during ascent from the lunar surface, even though they would be standing in the erect position during launch.

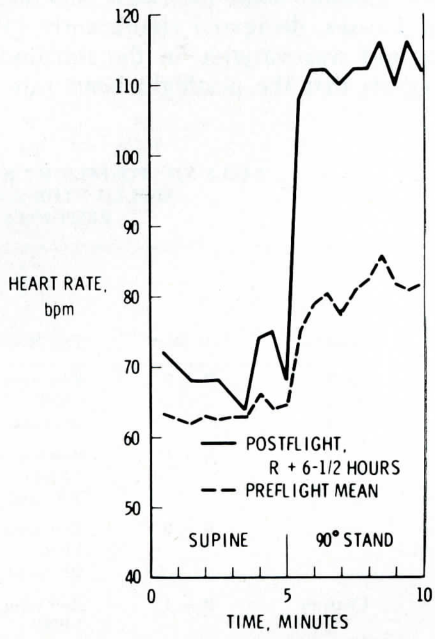


Fig. 7. Representative Changes of Heart Rate during 90° Passive Standing, Preflight and Postflight.

In fact, one might expect that exposure to ⅙ G while on the lunar surface might reverse somewhat the cardiovascular deconditioning which occurred during the early phase of the Apollo 11 mission.

Pre- and postflight cardiovascular evaluations were performed on all Apollo crewmembers, and on suitable control subjects, to assess the effects of the mission profiles on orthostatic tolerance. Table XI lists the test methods used. The use of lower body negative pressure (LBNP) was precluded by quarantine constraints on Apollo 11. Physiologic measurements obtained during each orthostatic test were heart rate, blood pressure and calf circumference. Other data utilized in evaluating test results included body weight, blood volume, exercise capacity and vaso-reactive hormone level. Representative data plots for LBNP and 90° passive stand tests are detailed in Figures 6 and 7 respectively.

Whatever may be the factors causing cardiovascular deconditioning, heart rate remains the most sensitive index of orthostatic tolerance at this time. Table XII summarizes the heart rate responses to orthostatic testing of Apollo 7 through 11 crewmembers. Notably, only 9 (60%) of the 15 astronauts exhibited significant postflight elevations in their supine heart rates, whereas 7 (77%) of the 9 stressed by LBNP, and all of the 9 stressed by 90° passive standing revealed significantly elevated pulse rates. Therefore, it appears that provocative cardiovascular testing reveals a cardiovascular response which might otherwise not be detected merely by observation of a resting individual. Finally, it should be noted that nearly all crewmembers have returned to their preflight response levels, as measured by pulse rate, changes during repeated provocative cardiovascular testing, within 30 to 50 hours after recovery. This recovery period of time was also observed after missions of longer duration in the Gemini Program. Calf circumference changes were measured during LBNP testing in the 9 crewmembers from the Apollo 7 through 9 missions. This measurement increased significantly ($P < 0.05$) in 2 cases, decreased significantly ($P < 0.05$) in 3 cases, and was variable in the remainder. This finding suggests that the postflight heart rate response is a much better index of cardiovascular deconditioning than changes in calf circumference, or degree of lower extremity blood pooling, during LBNP.

One would think that changes in blood pressure would reflect consistently the effects of actual and simulated gravity on the cardiovascular system. However, as shown in Figures 8 and 9, blood pressure responses to LBNP and 90° passive standing pre- and postflight were quite variable. This was generally also true for pulse pressure changes. Although pulse pressures taken in the supine position were decreased in the postflight period in 13 of the 15 crewmembers, this change was significant ($P < 0.05$) in only 4 cases. The pulse pressure decrease during LBNP was greater postflight than preflight in 9 astronauts tested, but only to a significant degree ($P < 0.05$) in 5 cases. Interestingly,

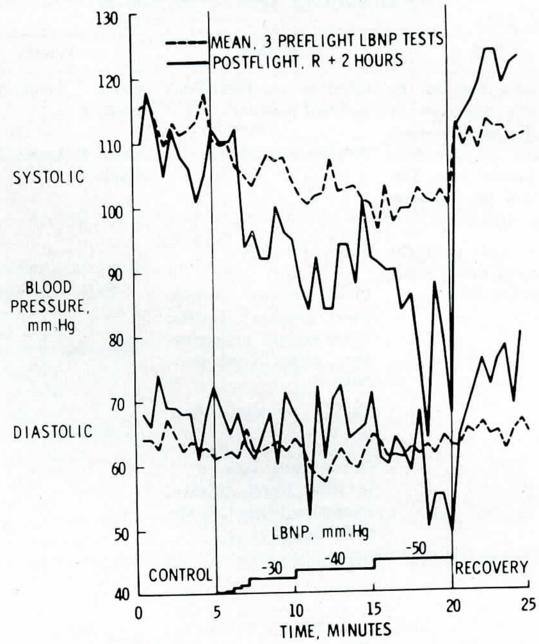


Fig. 8. Representative Changes of Blood Pressure during Lower Body Negative Pressure (LBNP) Testing, Preflight and Postflight.

TABLE XII. POSTFLIGHT HEART RATE RESPONSES TO ORTHOSTATIC TESTING OF APOLLO 7 THROUGH 11 CREWMEMBERS COMPARED TO MEAN RESPONSES OF THREE TESTS TAKEN PREFLIGHT

| Subjects | Test Day[a] | Test Mode | Total No. of Subjects | No. of Subjects by Category of Significance > 2 | No Significance | < 2 | Range, Δbpm |
|---|---|---|---|---|---|---|---|
| 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.

3 crewmembers experienced presyncope during postflight LBNP testing. The pulse pressure decrease during 90° passive standing was greater postflight than preflight in 7 of the 9 astronauts tested, but only to a significant degree ($P < 0.05$) in 3 cases. Finally, it should be noted that blood pressures of the crewmen have been found quite labile up to 3 days after recovery.

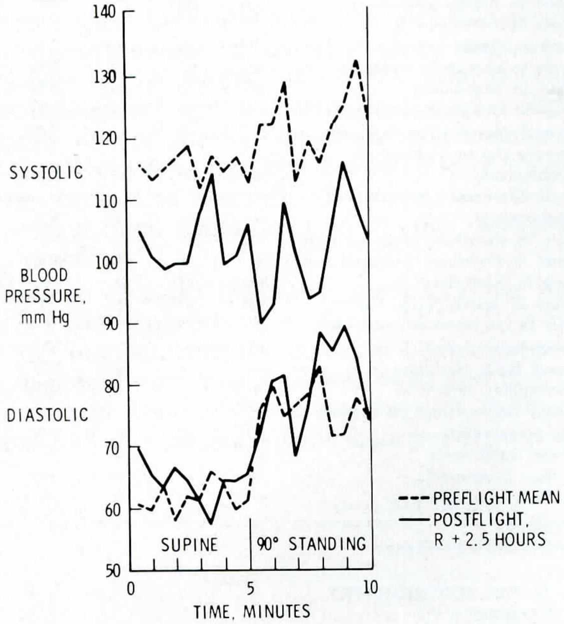


Fig. 9. Representative Changes of Blood Pressure during 90° Passive Standing, Preflight and Postflight.

All 15 Apollo Program astronauts lost weight during their respective missions. Their weight data is recorded in Table IV. Their mean weight loss was 5.6 lbs. (range 1.25 to 10 lbs.) over periods of 8 to 11 days in space. Fluid, and associated electrolyte losses have been implicated as responsible for most of the weight change. Alterations in body fluid compartments would therefore account to a degree for the altered cardiovascular responses to orthostatic tests, discussed above, during the postflight periods. Finally, preliminary data indicates that altered vasoactive and adrenocortical hormone production postflight may be responsible for these cardiovascular responses.

*B. Hematological and Biochemical Evaluations*—Essential hematological and biochemical studies have been performed pre- and postflight in the Apollo Program. Although initially broad in spectrum, these studies were curtailed somewhat in the Apollo 10 and 11 missions by quarantine and other operational constraints.

Changes in the routine hematological profiles during the Apollo missions (pre- versus immediate postflight periods) are summarized in Table XIV. As in the Gemini Program, a leucocytosis, associated with an absolute neutrophilia and an absolute lymphopenia, has been observed in the immediate postflight periods. These changes were transient, the total and differential white blood cell counts always reverting to preflight levels within 24 hr. postflight. They are probably a consequence of increased blood epinephrine and steroid levels associated with mission stresses.

Data on the red cell fraction of the blood have been of particular interest in the Apollo Program in the light of the consistent loss of red cell mass, to a maximum of

TABLE XIII. CHANGES IN ROUTINE HEMATOLOGICAL PROFILE DURING APOLLO MISSIONS (PRE- VERSUS IMMEDIATE POSTFLIGHT PERIODS)

| | Mission | | | | | |
|---|---|---|---|---|---|---|
| Parameter | 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)
- ↑↑ $+2\sigma$ ($\sigma$ represents standard deviation)
- ↑↑↑ $+3\sigma$
- ↓ Significant trend (negative)
- ↓↓ $-2\sigma$
- ↓↓↓ $-3\sigma$
- ND Not done
- + Occurrence
- TF Data to follow

20%, observed in the Gemini Program. A favored hypothesis for this phenomenon is a lysing effect of the pure oxygen, 5 psia atmosphere, used in the Gemini spacecraft, on red blood cells. As shown in Table XV there was essentially no change in red cell mass in Apollo 7 and 8 crewmembers. This might be due to the fact that 5 to 7% nitrogen remained in the space cabins from the original prelaunch atmosphere (Figure 1) and had an inhibitory effect on red cell lysis. Yet, using an identical simulation of atmospheric exposure in an 11-day test, 3 crewmembers showed a mean decrease of 4.4% in red cell mass.

A significant loss of red cell mass occurred in the Apollo 9 mission. The space cabin atmosphere in this mission was different from that in the Apollo 7 and 8 spacecraft, since early in the flight, LM activation and extravehicular activity required depressurization of the CM cabin to a vacuum, followed by repressurization with pure oxygen. Thus, there was no residual nitrogen in the spacecraft cabin for 7 days of the 10-day Apollo 9 mission. This finding therefore lends further support to the hypothesis that pure oxygen space cabin atmospheres have been a major factor in producing the red cell mass losses observed in space flights; and that perhaps even small quantities of diluent gas (nitrogen) may exert a protective or modifying effect on oxygen toxicity as evidenced by loss of red cell mass.

As shown in Table XV, mean plasma volumes were

TABLE XIV. SUMMARY OF CHANGES IN HEMATOLOGY DATA DURING APOLLO MISSIONS (PRE- VERSUS IMMEDIATE POSTFLIGHT PERIODS)

| 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 phosphoglyceric 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.

TABLE XV. SUMMARY OF CHANGES IN BLOOD BIOCHEMISTRY DATA DURING APOLLO MISSIONS (PRE- VERSUS IMMEDIATE POSTFLIGHT PERIODS)

| 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 } heart fraction | | | | | | |
| LDH2 } heart fraction | | ↑↑ | ↑↑↑ | ↓↓ | ↓↓ | |
| LDH3 | | | ↓↓ | | ↓↓ | ↓↓ |
| LDH4 | | ↓↓ | ↓↓ | | ↑↑↑ | ↑↑ |
| LDH5—liver fraction | | | | ↑↑ | | |
| Na | ↑↑ | ↓ | ↓↓ | ↓↓ | ↑↑ | |
| K | ↓↓ | ↓ | | | | |
| Cl | ↑ | ↓ | | ↓↓ | | |
| Osmolality | ↓↓ | ↓↓ | ↑↑ | ↓↓ | ↓↓ | |
| Total protein | | | ↑↑ | ↑ | ↑↑ | |
| Albumin | | | ↑↑ | ↑ | | |
| Alpha 1 | | | ↑↑ | ↑↑ | | |
| Alpha 2 | ↑ | | ↑↑ | ↑↑ | ↑↑ | |
| Beta | | | | ↑↑ | | |
| Gamma | | | | ↑↑ | | |

[a] Apollo over all.

essentially unchanged (decreased 4%) in the Apollo 7 mission and decreased (13%) in the Apollo 8 mission. The plasma volume also decreased (8%) somewhat during the Apollo 9 mission. A battery of additional hematological tests performed on both the plasma and red blood cells is also summarized qualitatively in Table XV.

Results of a great number of biochemical studies performed on the blood of Apollo Program crews are summarized in Table XVI. The consistently occurring transient postflight hyperglycemia is a probable result of an increased output of catecholamines and steroids secondary to the "stress" of reentry. The decline of serum cholesterol and uric acid levels during flight is probably due to altered diet of the crewmembers. A transient decrease in fractions 3, 4 and 5 lactic dehydrogenase were often observed. However, no other biochemical changes supporting liver or other disease have been noted.

Findings of urine chemistry studies during Apollo missions are summarized in Table XVII. It is noted that the postflight urinary excretion of hydroxyproline was increased over preflight basal levels and that there were consistently diminished excretions of sodium, potassium and chloride in the immediate postflight periods.

*C. Immunological Evaluation*—A great number of immunologic studies, summarized in Table XVIII, have been conducted in the Apollo Program. The postflight increases in C-reactive protein levels observed in two Apollo 7 crewmembers were consistent with their inflight illnesses, as reported above. Later Apollo flights revealed significant postflight increases of immune globulins G and A, and haptoglobulin, ceruloplasmin and alpha-2 globulin concentrations. Increases in the immunoglobulins are probably related to the episodes of clinical illnesses reported above, and increases in the haptoglobulin and ceruloplasmin portions are probably due to the moderate generalized stress reaction of the crewmen.

*D. Microbiological Evaluation*—Microbiological studies in the Apollo Program have fallen into the realms of bacteriology, mycology, virology, parasitology, and protozoology. The prime objective of these studies is to define "normal" (preflight) and "spaceflight-adjusted" (postflight) microbiota of each crewmember, both qualitatively and quantitatively. Swab specimens from eight body areas and specimens of urine, feces and a throat-mouth gargle were collected 30 and 14 days preflight, 8 hours prior to lift-off, and immediately after recovery. The results of comprehensive microbiological analyses

TABLE XVI. SUMMARY OF CHANGES IN URINE CHEMISTRY DATA DURING APOLLO MISSIONS (PRE- VERSUS IMMEDIATE POSTFLIGHT PERIODS)

| | Mission | | | | | |
|---|---|---|---|---|---|---|
| Parameter | 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.

TABLE XVII. SUMMARY OF CHANGES IN HUMORAL IMMUNOLOGY DATA DURING APOLLO MISSIONS (PRE- VERSUS IMMEDIATE POSTFLIGHT PERIODS)

| | Mission | | | | | |
|---|---|---|---|---|---|---|
| Parameter | 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.

of such specimens would allow the early recognition and treatment of infectious diseases or other potential problems during the preflight phase and the prediction of possible qualitative contamination of returned lunar samples, so lessening the impact of such contaminants on procedures for bioassay and the release of lunar samples from quarantine. Such results also indicate the aggregate effects of spacecraft environmental parameters on the microbiota of each crewmember and the causative factors producing illness.

Approximately 12 data bits on some 4000 microorganisms have been collected and stored in a computer during the Apollo 7 to 11 missions. Although demanding mission schedules have not permitted a thorough analysis of these data to date, certain consistent findings may be indicative of biological trends. Man-to-man transfers of pathogenic bacteria and fungi are regular occurrences in the closed ecological environment of the Apollo spacecraft. This phenomenon is accompanied not only by a significant increase in the number of crewmembers infected but also by an increase in the number of sites from which organisms can be isolated, per man. The appearance of certain organisms only during the postflight sampling interval suggests that microbial shifts may favor the growth of opportunist organisms. Further, certain other components of the normal flora have been isolated from aberrant sites. Taken together, these observations suggest that microflora changes occurring in the spacecraft environment may not be compatible with man's health and welfare during missions of extended duration.

No observations have been made which suggest that the spacecraft environment may predispose to viral-induced illness. Rather, the illnesses occurring in Apollo crewmembers have been correlated with the normal seasonal occurrence of upper respiratory infection in the population at large and preflight exposure of the crew.

No microorganisms with unfamiliar morphological structures or unusual physiological responses were detected in microbiological analyses following the Apollo 11 mission. Neither the preflight nor postflight phases of this mission were marred by the occurrence of viral 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 Sample Laboratory, the astronauts and other personnel in the Crew Reception Area remained free from overt manifestations of similar illnesses.

*E. Evaluation of Exercise Capacity*—The Apollo pre- and post-flight exercise capacity test utilized a bicycle ergometer programmed to maintain the heart rate at a given level. The primary purpose of this test was to determine if there were any changes in the physiological response to work which could affect the completion or monitoring of lunar surface extravehicular activity. For this test, heart rates of 120, 140, 160 and, in three subjects, 180 beats per minute, were progressively maintained at each level for 3 minutes. Samples of expired gas were obtained at appropriate times during each test, which was conducted 30, 14 and 4 days preflight, as soon as possible after recovery, and within 24 to 36 hrs. after recovery.

In immediate postflight periods, twelve of the fifteen Apollo crewmen have demonstrated a significant decrease in work performed and in oxygen consumed at submaximal heart rate levels, as compared to data taken preflight. The 3 crewmen tested at the maximal heart rate level of 180 beats per minute exhibited similar decrements as shown in Table XVIII. Except for one individual who showed identical responses to exercise before and after the Apollo 8 mission, all crewmen returned to preflight response levels within 24 to 36 hrs. after recovery. Supplementary supporting data indicated that decrements in work performance were not due to altered pulmonary function or to diminished ability of the crewmen to extract oxygen from the atmosphere. The physiologic mechanisms responsible for changes observed in the exercise response test following space missions remain to be identified through further investigation.

## LUNAR SURFACE ACTIVITY

Planning and training for extravehicular activity on the lunar surface had to take into consideration that, as previous Apollo missions had shown, there would be some effect on the crew of exposure for 3 days to weightlessness, probably manifesting as a heart rate increase due to cardiovascular deconditioning, and decrease in exercise capacity. Fortunately, decrease in red cell mass, and possible consequences thereof, appeared unlikely.

The Apollo 11 crew was appropriately monitored during 3 preflight simulations—under water immersion conditions, in the altitude chamber and while duplicating the lunar surface timeline on a simulated lunar surface.

TABLE XVIII. APOLLO EXERCISE RESPONSE TEST—OXYGEN CONSUMPTION IMMEDIATELY POSTFLIGHT

| Heart rate, bpm | $\bar{X}$, percent[a] | $\sigma$ | 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 XIX. PREDICTIONS OF ENERGY COST OF EXTRAVEHICULAR ACTIVITY ON LUNAR SURFACE AND THEIR COMPARISON WITH ACTUAL APOLLO 11 MISSION ESTIMATES

| | CDR | | LMP | |
|---|---|---|---|---|
| Location and comments | 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 XX. INTEGRATED ENERGY COSTS OF EXTRAVEHICULAR ACTIVITY OF THE APOLLO 11 LUNAR COMMAND PILOT ON THE LUNAR SURFACE

| Events | Time | | Integrated BTU Production | | |
|---|---|---|---|---|---|
| EVA—Lunar Surface | G.E.T.* (Hours:Minutes) | Interval (Minutes) | Rate (BTU/Hr) | Total BTU For Interval | BTU Accumulated |
| Assist and Monitor CDR | 109:13 | 26 | 1200 | 500 | |
| Initial EVA | 109:39 | 5 | 1950 | 163 | 683 |
| Environmental Familiarization (Television Cable Deployment) | 109:44 | 14 | 1200 | 280 | 963 |
| Solar Wind Composition Deployment | 109:58 | 6 | 1275 | 128 | 1091 |
| Flag and Presidential Message | 110:04 | 14 | 1350 | 315 | 2270 |
| Evaluation EVA Capability (Environment) | 110:18 | 16 | 850 | 227 | 1633 |
| Lunar Module Inspection | 110:34 | 19 | 875 | 277 | 1910 |
| EASEP Deployment | 110:53 | 18 | 1200 | 360 | 2270 |
| "Documentary" Sample Collection (Solar Wind Composition Recovery) | 111:11 | 12 | 1450 | 290 | 2560 |
| EVA Termination (Ingress) (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 | | | 2982 |

*Ground elapsed time.

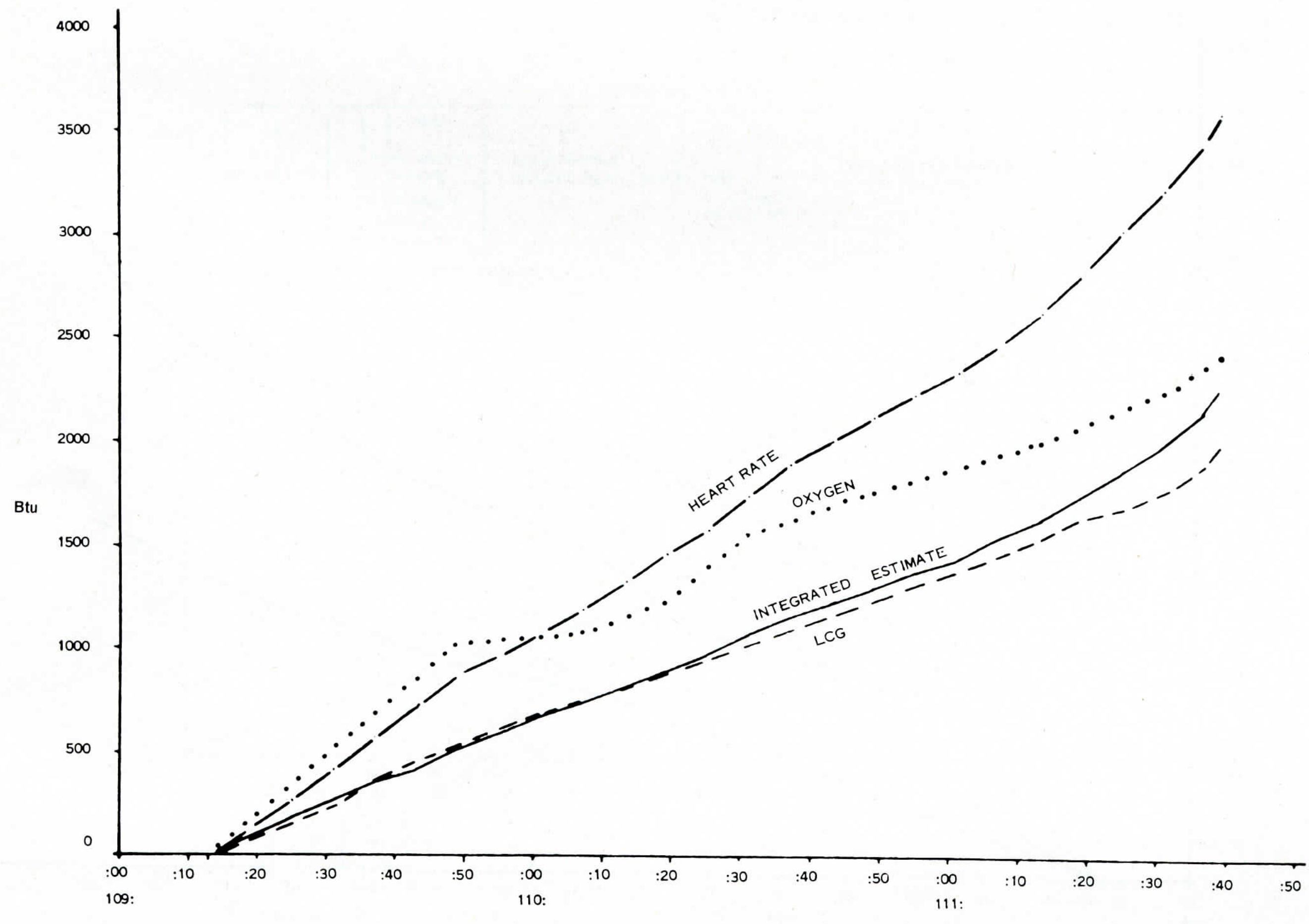


Fig. 10. Accumulated Data on Energy Cost of the Apollo 11 Commander during Extravehicular Lunar Surface Activity, Using Three Methods of Metabolic Assessment, and an Integrated Estimate of the Energy Cost of This Activity.

Although none of these simulations exactly reproduced the lunar conditions to be encountered, such as ⅙ g, motion and surface friction, physiological information obtained during these simulations was still used for the predictions of the energy cost of lunar surface activity. These predictions and their comparison with the actual mission estimates are listed for both the Commander (CDR) and the lunar module pilot (LMP) in Table XIX. Predictions were quite close for the LMP, yet quite at variance for the CDR.

Three methods were used for real-time metabolic monitoring while the astronauts were extravehicular on the lunar surface. The heart rate was compared to that on an energy cost (BTU) calibration curve obtained preflight by bicycle ergometry. Oxygen usage from the portable life support system (PLSS) was measured. Differences in the inlet and outlet temperatures in the water-cooled undergarment (LCG) were recorded. Accumulated data obtained by these methods and an integrated estimate of energy cost for the Apollo 11 CDR and LMP during extravehicular activity are summarized in Figures 10 and 11. These data showed that the oxygen usage and LCG methods gave energy cost levels 61% below those estimated by the heart rate method in the CDR and 81% above those estimated by the heart rate method in the LMP. The oxygen usage and LCG methods not only yielded similar data, but also reflected well the physical activity observed by television monitoring. The loss in accuracy of the heart rate method might be attributed to many causes, including psychological, heat storage, and cardiovascular deconditioning effects on the heart rate, and poor correlation of slow heart rates with energy cost.

Figures 12 and 13 show the accumulated premission and actual mission estimates of the energy costs of extravehicular activity on the lunar surface for the Apollo 10 CDR and LMP. These estimates compare favorably and appear to be well within the calculated margins for expendable (water and oxygen) usage. The integrated energy costs during extravehicular activity of the Apollo 11 LMP on the lunar surface is further detailed in terms of BTU production while performing specific tasks in Table XX.

The heart rates for each Apollo 11 crewman during his extravehicular activity on the lunar surface is shown in Figure 14. The highest heart rates recorded were from 140 to 160 beats per minute in the CDR during lunar sample collection and transfer of the sample box to the LM.

In summary, it has been found that even though the energy cost of performing a given task differs among crewmen, the average hourly total energy cost for the crewmen was still 900 to 1200 BTU. The LCG method appears best for estimating energy cost of work for use

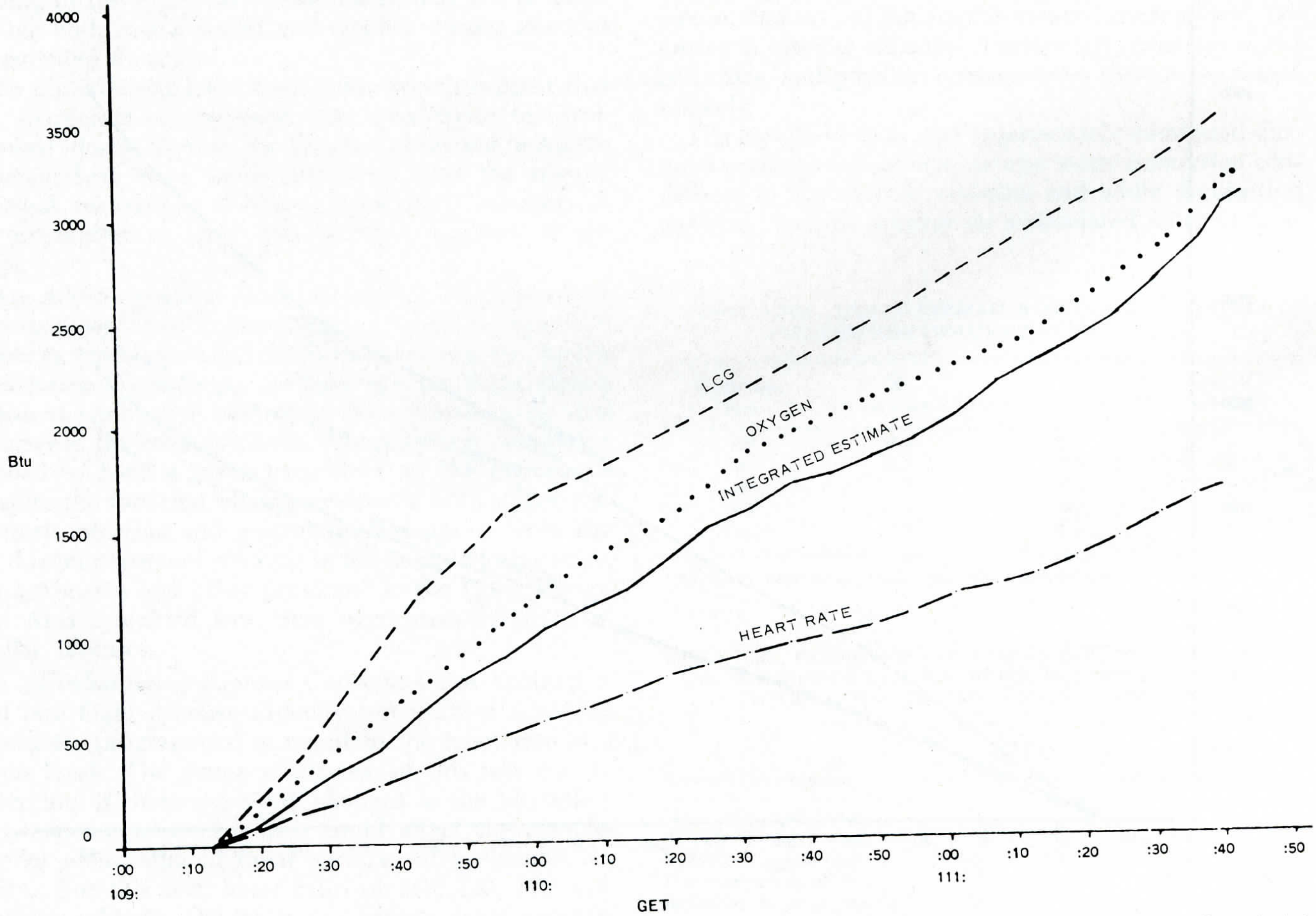


Fig. 11. Accumulated Data on Energy Cost of the Apollo 11 Lunar Module Pilot during Extra-vehicular Lunar Surface Activity, Using Three Methods of Metabolic Assessment, and an Integrated Estimate of the Energy Cost of This Activity.

in consummable calculations. On the other hand, the heart rate method is a valuable relative indicator, but a poor absolute indication of the energy cost of work. Apollo 11 data indicate that extravehicular activity for 4 to 5 hours on the lunar surface is not outside man's physiological limits and the limits of the present support equipment. These data were utilized in planning the Apollo 12 extravehicular activity.

## QUARANTINE

Approximately three years before the Apollo 11 mission a decision was made to conduct a quarantine operation to preclude the possibility, even though remote, of contaminating the earth's biosphere with lunar organisms. This decision was based on a National Academy of Sciences Report which stated that there was a remote possibility of such contamination and recommended a quarantine. The quarantine was to start at closure of the LM hatch on the lunar surface and continue for a 21-day period. Although this was an arbitrary time period, not covering all disease incubation periods, it covered most of the virulent contagious diseases. A series of procedures were 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, Texas.

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

The astronauts got this material on their skin, under their fingernails, and apparently inadvertently inhaled and ingested it. The rock boxes and film packs were repackaged after vacuuming, so that little dust was transferred from CM to LM. The space suits were doffed and packaged in the CM and the cabin air constantly filtered during return to Earth by the lithium hydroxide cannisters. Thus, no dust should have been present on landing.

The actual recovery involved protecting the swimmers with SCUBA gear and one swimmer with a biological isolation garment. This swimmer scrubbed the hatch area and postlanding vent with an iodine preparation. He opened the hatch and gave biological isolation garments to the crew who donned them and egressed into the raft. The hatch was closed and again decontaminated, as were the crewmen and swimmer with the same iodine solution. The astronauts then transferred to the helicopter to the recovery ship, and thence into the Mobile Quarantine Facility (MQF). The microbial sampling and initial examination were

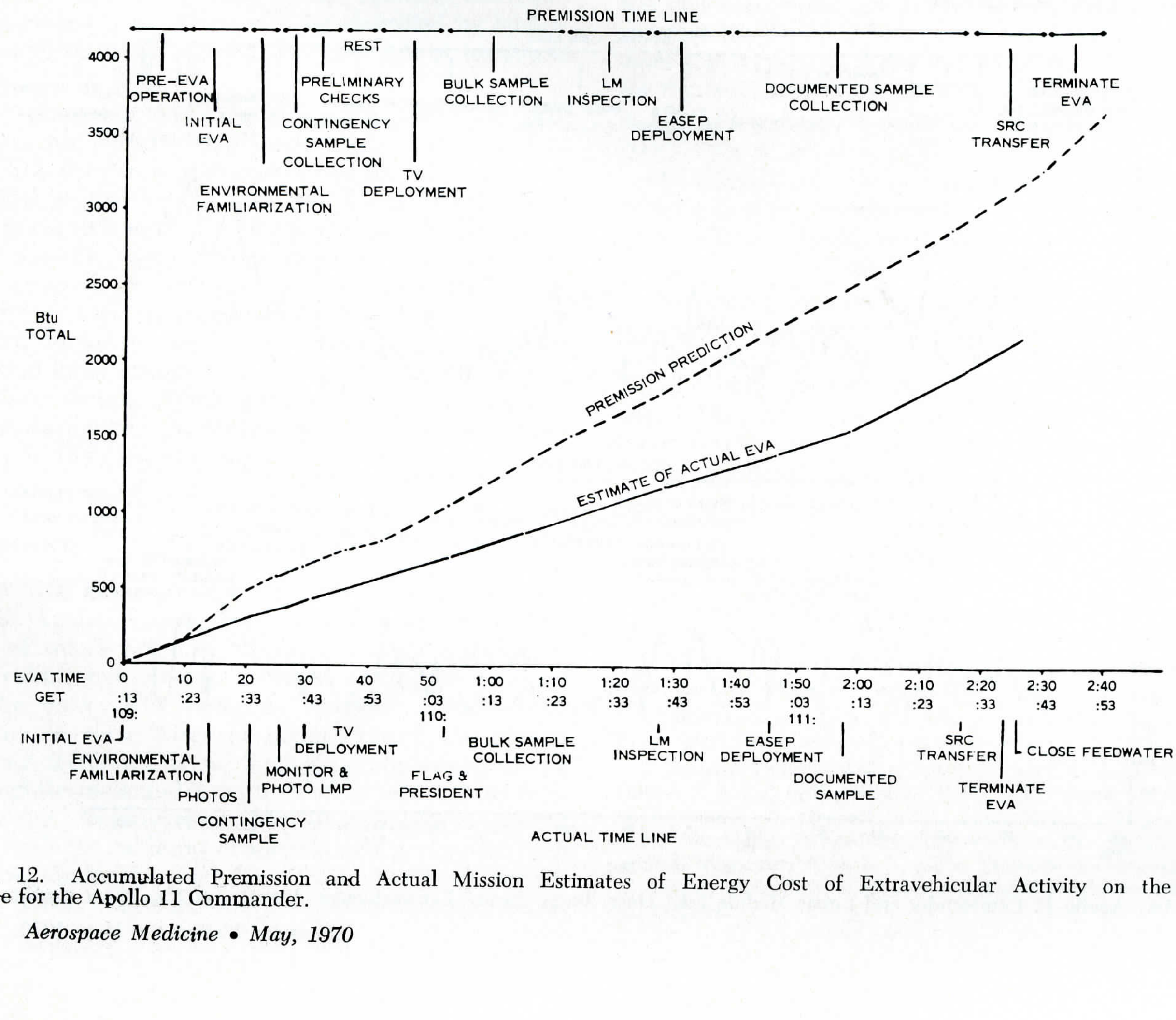


Fig. 12. Accumulated Premission and Actual Mission Estimates of Energy Cost of Extravehicular Activity on the Lunar Surface for the Apollo 11 Commander.

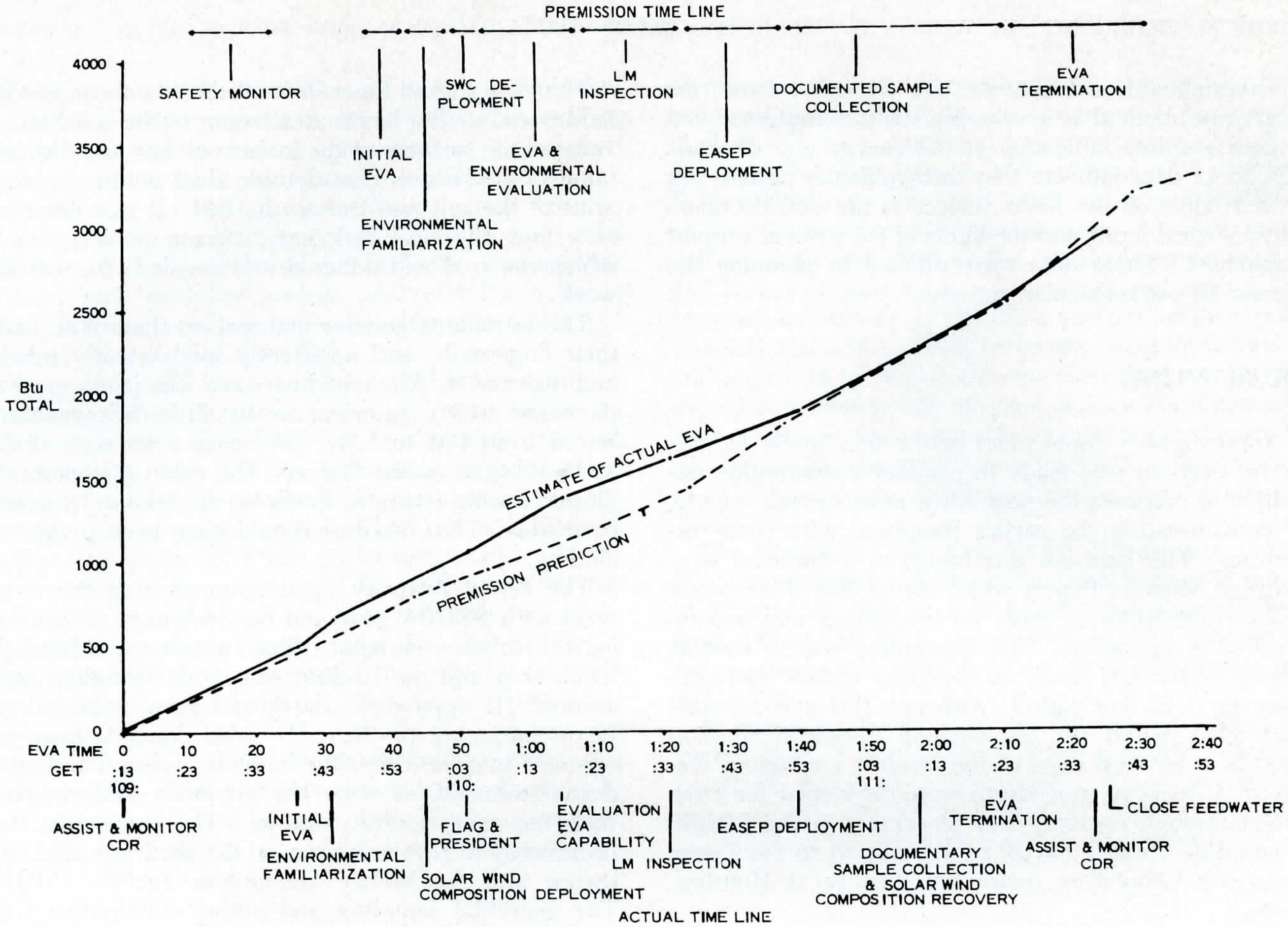


Fig. 13. Accumulated Premission and Actual Mission Estimates of Energy Cost of Extravehicular Activity on the Lunar Surface for the Apollo 11 Lunar Module Pilot.

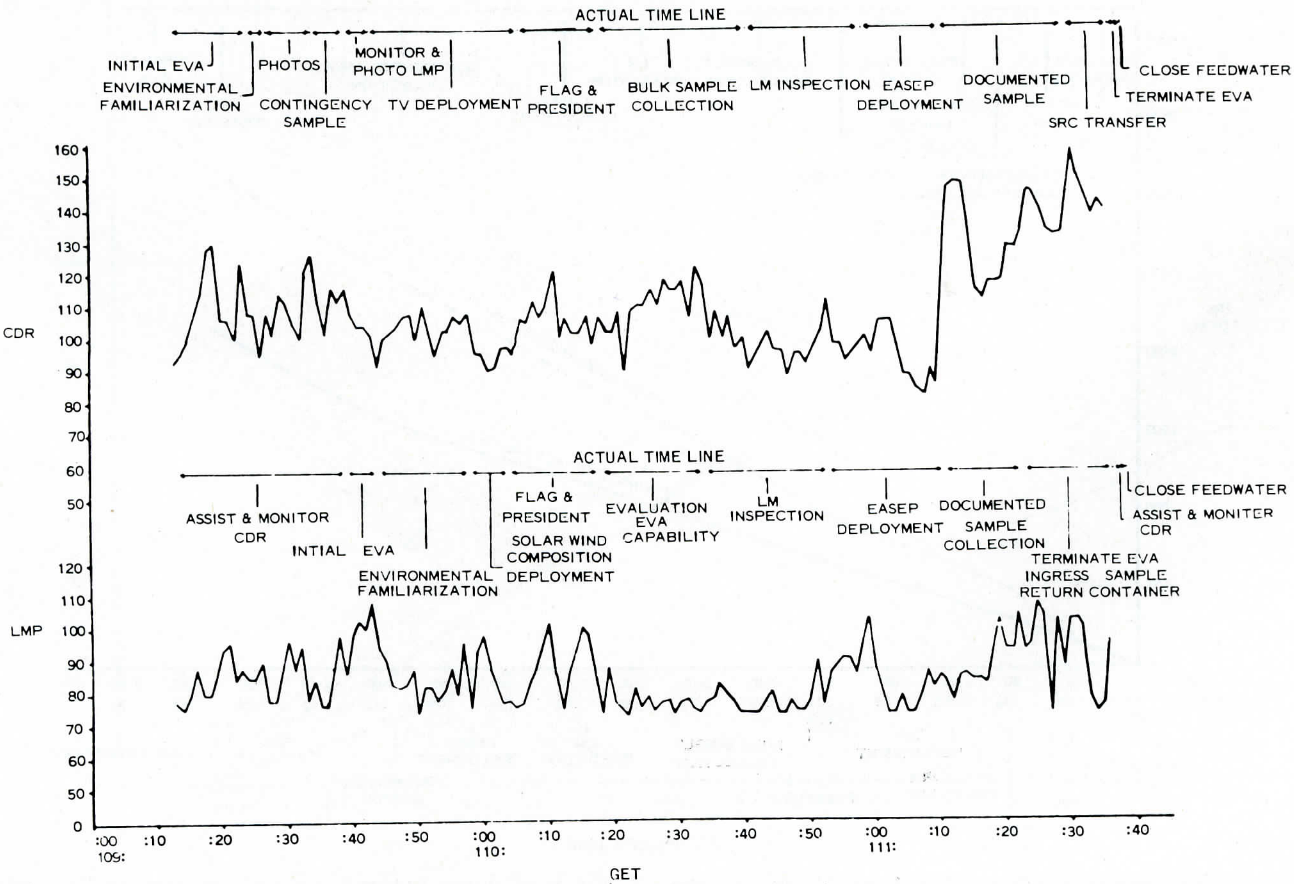


Fig. 14. Apollo 11 Commander and Lunar Module Pilot Heart Rates during Extravehicular Activity on the Lunar Surface.

completed in the MQF and the biological samples transferred to the outside through a tank containing a sodium hypochlorite solution.

The crew, a physician and a recovery technician remained in the MQF during the three days of transit time by ship and aircraft to Houston where the MQF was moved to the Lunar Receiving Laboratory. There the five individuals transferred to the Crew Reception Area (CRA). Daily examinations were conducted on all CRA personnel, and blood and microbiological samples for analysis were obtained at intervals. The crew quarantine period was remarkable for the lack of positive medical findings. No evidence of infectious disease was found in the examination of crew or similarly quarantined personnel. Careful evaluation of the microbiological samples and immunological studies 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 placed in five viral tissue cultures, 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 twenty-first day. Continued surveillance will be maintained for one year. To date, there has been no infection, disease or illness of any type in the crew. Surely the crew will develop some of the common infections which plague man. These will be identified by laboratory methods to be assured that they are of terrestrial origin.

The quarantine of the lunar samples continued until 50 days after recovery. Representative chips of the rocks and fines were pulverized and placed in solution. Detailed bacteriological, viral and fungal studies were performed. Groups of plants, insects (cockroaches, moth and fly), fish, shrimp, oysters, quail and mice were exposed to the material. In each instance one group was kept in an identical environment but not exposed to lunar sample, one group was exposed to sterilized lunar sample, and the third group to the regular lunar sample. While some animal deaths have occurred during the quarantine period, they were principally in the control groups.

## SUMMARY

The 3105 hours of exposing man to spaceflight during the Apollo Program have added greatly to knowledge of man's response to space travel. The spacecraft cabin environment has been suitably maintained for the crew. The radiation environment has been benign, no solar flares occurring during the Apollo Program missions. Crews have generally adapted well to weightlessness and have learned to utilize it to their advantage. Improvements have been made in inflight food, with the addition of moisturized packs and such items as sandwiches and dried fruit. The body weight losses which continue to occur during space missions are not entirely due to body fluid loss. The supplying of potable water to the crews has been effective, and great strides have been made in removing gas bubbles in the water. Work/sleep cycles have been improved somewhat by having all crewmembers sleep at the same time and by having cycles closer related to those during training.

The medical kit has been adequate on all missions since the Apollo 7 mission, medications being added as the needs arose. Bioinstrumentation has continued to function well. Although a preflight preventive medicine program has been difficult to conduct, it has been effective in the later Apollo missions in reducing pre-, in- and postflight illnesses, which had occurred in all flight phases and were usually viral upper respiratory and gastrointestinal infections. Although crews have reported motion sickness to a varying degree of severity, all crews adapted to their motion environment. This area will require continuing attention.

Cardiovascular deconditioning has been identified postflight with both lower body negative pressure and 90° passive standing techniques. This phenomenon has been of a similar degree and has lasted for the same period as that following the Gemini missions.

A significant decrement in work capacity has been noted in the immediate period postflight. This condition usually lasts from 24 to 36 hrs. postflight.

As in the Gemini Program a postflight neutrophilia has been observed after crew recovery. The loss of red cell mass observed in the Gemini program occurred only during the Apollo 9 mission. This finding indicates that hyperoxia is the important factor responsible for this loss, and that even a small amount of nitrogen in the atmosphere may protect the red cell from the lytic action of oxygen.

Microbiological studies have shown that organisms transfer between crewmembers. Moreover, the growth of opportunist organisms appears to be favored by these shifts.

Extravehicular activity on the lunar surface during the Apollo 11 mission was conducted within expected energy costs, at an average of 1200 BTU per hour. The liquid-cooled garment temperature method of energy cost estimation is the most suitable. It appears that lunar surface time can be extended safely.

The Apollo 11 quarantine was a demanding operation, conducted very successfully.

ACKNOWLEDGMENTS

The author would like to acknowledge, by area of responsibility, the following members of the principal medical team.

1. Mission Control and Management: A. Duane Catterson, M.D.; and W. Royce Hawkins, M.D.

2. Mission Control: John F. Zieglschmid, M.D.; Kenneth N. Beers, M.D.; and George F. Humbert, M.D.

3. Mission Control Staff Support: Charles K. LaPinta, M.D.; Gilbert J. Sales, M.D.; Sam L. Pool, M.D.; Frank L. LeCocq, M.D.; Fredric F. Doppelt, M.D.; Emmett B. Ferguson, M.D.; Robert N. Hahn, Biomedical Engineer; Don W. Mangold, Biomedical Engineer; Russell J. Kelly, Biomedical Engineer; Dan H. Taylor, Biomedical Engineer; and David Bradshaw, Biomedical Engineer.

4. Flight Medicine: Clarence A. Jernigan, M.D.; M. Keith Baird, M.D.; William R. Carpentier, M.D.; Gilbert J. Sales, M.D.; Allan C. Harter, M.D.; John Teegen, M.D.; Jerry M. Joiner, M.D.; Clint L. Holt, M.D.; Dolores O'Hara, R.N.; and William J. Frome, D.D.S.

5. Exercise Capacity: John A. Rummel, Ph.D.

6. Lower Body Negative Pressure: Robert L. Johnson, M.D.; George W. Hoffler, M.D.; and Roger Wolthuis, Ph.D.

7. Immuno-Hematology: Craig L. Fischer, M.D.; Philip Johnson, Jr., M.D.; and Stephen E. Ritzmann, M.D.

8. Bone Densitometry: Pauline Mack, Ph.D.

9. Food: Malcolm C. Smith, D.V.M.; Paul C. Rambaut, Ph.D.; and Rita M. Rapp.

10. Water and Waste: Richard L. Sauer.

11. Virology: James L. McQueen, D.P.H.; and Bernard J. Mieszkuc, M.S.

12. Bacteriology: James K. Ferguson, Ph.D.; and Gerald R. Taylor, Ph.D.

13. Endocrine: Carolyn Leach, Ph.D.

14. Toxicology: Elliott S. Harris, Ph.D.

15. Radiation: Charles M. Barnes, D.V.M.; Richard E. Benson, D.V.M.; J. Vernon Bailey; Robert English; and Edward D. Liles.

16. Preventive Medicine: W. W. Kemmerer, Jr., M.D.; W. Carter Alexander, Ph.D.; and B. Wooley, Ph.D.

17. Bioinstrumentation: George G. Armstrong, M.D.

18. Quarantine Control Officers: Harold Eitzen, Ph.D.; Howard J. Schneider, Ph.D.; R. Graves, and G. McCollum.

19. Physiological Data Engineers: Edward L. Moseley, Ph.D.; and Frank A. Michelli.

20. EVA Metabolic Management Team: George F. Humbert, M.D.; Edward L. Moseley, Ph.D.; Frank A. Michelli; Lawrence J. Nelson; Russell J. Kelly; Lawrence Kuznetz; and J. M. Waligora.

## REFERENCES


1. Anon.: A Review of Medical Results of Gemini VII and Related Flights. NASA TM-X-60589, 1966.
2. Berry, C. A.: Space medicine in perspective: A critical review of the manned space program. *JAMA* 201:232-241, 1967.
3. Berry, C. A.: The medical legacy of Gemini. Life Sciences and Space Research, Vol. VI; A. H. Brown and F. G. Favorite, Ed., North Holland Publishing Co., (Amsterdam) 1968, pp. 1-19.
4. Berry, C. A.: Status report on space medicine in the United States. *Aerospace Med.* 40:762-769, 1969.
5. Berry, C. A.: Preliminary clinical report of the medical aspects of Apollos VII and VIII. *Aerospace Med.* 40:245-254, 1969.
6. Berry, C. A.: Lunar Medicine. *Sci. Journ.* 5:103-107, 1969.
7. Berry, C. A., and A. D. Catterson: Pre-Gemini medical predictions versus Gemini flight results. Gemini Summary Conference. NASA SP-138, 1967, pp. 197-218.
8. Berry, C. A., D. O. Coons, A. D. Catterson and G. F. Kelly: Man's response to long-duration flight in the Gemini spacecraft. Gemini Midprogram Conference, NASA SP-121, pp. 197-218, 1967.
9. Fischer, C. L., P. C. Johnson and C. A. Berry: Red blood cell mass and plasma volume changes in manned space flight. *JAMA* 200:579-583, 1967.
10. Gooch, P. C., and C. A. Berry: Chromosome analyses of Gemini astronauts. *Aerospace Med.* 40:610-614, 1969.
11. Graybiel, A., E. F. Miller, E. J. Billingham, R. Waite, L. Dietlein and C. A. Berry: Vestibular experiments in Gemini flights V and VII. *Aerospace Med.* 38:360-370, 1967.
12. Kelly, G. F., and D. O. Coons: Medical aspects of Gemini extravehicular activity. Gemini Summary Conference, NASA SP-138, pp. 107-125, 1967.