Research Resources Laboratory

UNIVERSITY OF ILLINOIS AT THE MEDICAL CENTER, CHICAGO

835 South Wolcott Street · Chicago, Illinois 60612

June 28, 1973

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Acting Director of Bioresearch (MMR)
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Washington, D. C. 20546

Dear Sherm:

I am writing to you with regard to your chapter, "Biological Indicators for Space Flight". As you know we have just returned from a meeting of the joint Editorial Board in Moscow. I am also certain that you have learned by this time from Stan White that we had a very successful meeting. During the course of the discussion of the board the ultimate disposition of your section of Volume 2, Part 5, Chapter 3, was again discussed. As you know, both the Soviet Editorial Board and our Board feel that you and Dr. Parfinov prepared excellent discussions on this topic. Your chapter has been forwarded to Russian personnel and the comments of the referees who examined the document were returned to us and I gave these to you in Las Vegas. At that time you will recall that they were in order and that you were willing to alter the text accordingly. Dr. Parfinov's section of the chapter has been in the United States since the middle of May and in the hands of a referee and I anticipate his response any day. These comments will be returned to Russia so Dr. Parfinov can examine them and incorporate those which in his judgment are pertinent.

During our deliberations at the joint Editorial Board meetings last week, the topic of ultimate location of your section and Parfinov's section came under discussion and it appeared to be the consensus of the editors of Volume 3 that your chapter might more appropriately be included in Volume 3 rather than in Volume 2, and that Parfinov's sections of this chapter would more appropriately be included in Volume 2. Professor Vasil'yev (the Russian Editor of Volume 2) and I more or less concurred in this observation but did not express strong feelings one way or the other. We left the ultimate decision of the location of your section of this chapter up to the joint Editorial Board. The matter was discussed here and the consensus was that your chapter could serve as a fine first chapter to Volume 3 or indeed could serve as an excellent final chapterto Volume 3. The volume editors of 3, however, although it appears that the chapter will be moved, wanted to defer final decision for about six weeks while other matters concerning their volume were pending.

Professor Vasil'yev and I agreed to this but I stated that in view of the fact that under any circumstances, whether your section of the chapter is included in Volume 2 or 3, discussion at this time is essentially irrelevant with regard to the next steps required in order to prepare final copy. I told the board and they concurred in this observation that upon my return to the United States I would write to you and instruct you with regard to final preparation of copy for this section. Then, whether it is included in Volume 2 or 3 will only require a change in the title sheet. I would hope that you would concur in this observation.

In preparing your chapter for final copy for the editors of Volume 3, these final additional instructions are submitted.

1. Please reread the "Instructions to Authors" and in preparing final copy please adhere to these suggestions.

2. The original instructions suggested that a glossary be prepared for each chapter. This matter was debated at some length during the Editorial Board meeting and it was decided that instead of preparation of a glossary for each chapter, the author of each chapter should be instructed to identify those terms which when translated could become ambiguous and have dual meanings. Each author should identify these terms and by footnote indicate the fact that they could have different meanings and define the usage of the author as he employed the term in his chapter. You may find two or three such terms in your chapter.

3. In preparing the final copy, please submit to this office the original type-written copy (unbound) with a complete set of glossy prints attached. Also please submit two xeroxed copies of your text with a complete set of glossy prints attached to each xeroxed copy. On one of the xeroxed copies with a colored pencil indicate in the margin where you have changed the text from the original version in order to comply with the comments of the Soviet referees. The Russians will follow similar instructions. The procedure will hopefully accelerate the translation process in that those pages which have no markings will be the same as the original text which they have already examined, and will then not have to be retranslated. A total of three copies, two xeroxed and one original, should be submitted to this office as soon as conveniently possible.

4. In discussing a possible due date to receive the completed copies, I have suggested that it would be possible for you to have these copies in my office by August 1, 1973. I hope that I have not been too presumptious in suggesting this date.

It was a pleasure to visit with you in Las Vegas and I hope that you are enjoying a pleasant summer in Washington, D. C.

Sincerely yours,

John P. Marbarger
American Editor, Volume 2
Fundamentals of Space
Biology and Medicine

JPM/jw
xc: Professor Vasil'yev
Stanley C. White

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ROUTING SLIP

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		Action
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p. 7

p. 10

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p. 8 P8

3-27-74 ALL PAGES NOW CORRECT EXCEPT P. 4 — THE WORD "OF" ADDED AT BOTTOM OF PAGE.

3-29-74 All corrected (p. 4 replaced)

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THE FOUNDATIONS OF

SPACE BIOLOGY AND MEDICINE

Volume 3, Part 5

Chapter 1

Research Toward the Future: An Appraisal of Future Life Sciences Research

Sherman P. Vinograd, M.D.
Office of Life Sciences
National Aeronautics and Space Administration

CONTENTS

INTRODUCTION

At the time of this writing, the combined experience of the two countries of the world which have launched man into space have demonstrated that man, supplied with his fundamental organic needs, is capable of existing, functioning, and carrying out his assigned activities normally in an extraterrestrial environment for at least a few months. The United States space flight programs from Mercury through Gemini and the manned lunar landings of Apollo verified man's capabilities for flight durations of up to 14 days, while the Soviet programs from Vostok through Soyuz and and Soyuz-Salut accomplished manned space flights of up to 24 days. With the recent completion of the U.S. Skylab Program, man has now flown successfully in space for almost 3 months.

We are now merging into a new era, one in which manned space flights can be extended to many months and even years; one in which man can expand his investigations of the moon and explore beyond into the solar system; one in which he can advance significantly by gaining new knowledge of his environment, his origins, and himself; and one which holds the opportunity for man to mature in the process, as well, by learning to join forces with his fellows across the earth in positive action to launch and sustain this promising future in space.

From the standpoint of science and technology, new growth will be required not only in the realm of space vehicle systems but also in the development of long-lived systems for the support of man and, most importantly, for the understanding of man, himself, in the environment of space. To a great extent, these requirements will vary according to the type and duration of mission to be undertaken. This chapter will, therefore, begin with a description of three general classes of manned space flight missions of the future: earth orbital, lunar, and planetary; and follow with a broad analysis of biomedical science and technology emphasizing areas of research needed to support future manned space flights and the information to be obtained from them.

FUTURE MANNED SPACE FLIGHT MISSIONS

Three distinct categories of future manned flight missions can be identified: missions in earth orbit, missions to the moon, and missions to the planets, including the minor planets [1, 28].

In earth orbital missions, the astronauts remain in close proximity of the earth, are in instantaneous communication with earth, and can be returned to the surface within hours should medical emergency demand it. Resupply and replacement of spacecraft components are within easy reach of the operations center on earth.

In lunar missions, the target is within a week's travel time from the earth, thus increasing the complexity of resupply and replacement. The systems required for lunar missions are more numerous and complicated since operations now include escape from the earth's gravity field, capture by the lunar gravity field, and landing and take-off from an extraterrestrial body.

Grateful acknowledgement is made to William L. Haberman, Ph.D., formerly of the Advanced Manned Missions Program Office of the NASA Office of Manned Spaceflight, for his compilation of the original section on Future Manned Space Flight Missions.

Finally, for the planetary missions with round trip durations of one year or more, the character and complexity of the mission changes completely. The spacecraft now travels to distances of several hundred million kilometers from the planet earth and, in most instances, the mission cannot be cancelled or aborted once the spaceship has departed from earth orbit. Mission operation and control will, of necessity, be almost autonomous from the earth. Medical emergencies must be handled aboard the spacecraft since fast return to earth generally is not possible (Figures 3 and 5).

The development of spacecraft systems, capable of maintaining the relatively narrow environmental range to which man is accustomed, will depend upon knowledge of the external environment as well as the characteristics of the vehicle and mission. The major features of the natural environment of the moon and several planets are presented in Table 1. Those of the earth are included for purposes of comparison. It is worthwhile to note that the presence of a planetary atmosphere not only has implications with respect to exobiology, life support, and toxicology, but also serves as protection against inherent radiation and micrometeoroid penetration, while an appreciable magnetic field about a planet will tend to trap and retain a radiation belt (Table 1).

Earth Orbital Missions

Manned orbital space flight began with Yuri Gagarin's historic flight in April, 1961. Beginning with John Glenn's flight (MA 6), the first U.S. orbital missions were carried out in 1962 and 1963, when four manned orbital missions were completed during the Mercury program. The maximum flight duration achieved during Mercury was about 34 hours on Gordon Cooper's MA 9. The next orbital manned space flight program in the U.S. spanned the years

TABLE 1. THE LUNAR AND PLANETARY ENVIRONMENT

	Surface Pressure (atmospheres)	Solar Thermal Irradiance (Cal/cm^2 - min)	Surface Temperature (^oC)		Solar Illuminance (thousands lux)	Albedo	Day/Night Cycle (Earth days)	Gravity	Magnetic Field Intensity (gammas)	Radiation Belt	Distance from Earth (millions km)
			Max.	Min.							
Earth	1	1.98	50	-30	140	0.34	1	1.00g	62,000 (poles) 31,000 (equator)	Yes	-
Moon	0	1.94	120	-170	140	0.07	27.3	0.17g	36	No	0.4
Mercury	0.001	10.9	340		935	0.058	88	0.35g	Not Available		80 to 220
Venus	90	3.88	475		267	0.76	250	0.90g	70	No	40 to 260
Mars	0.005	0.72 to 1.05	20	-70	60	0.148	1.02	0.38g	50	No	56 to 400
Jupiter	200,000	0.68	-140		5.2	0.51	0.41	2.40g	500,000	Yes	588 to 963

1965 and 1966, when the ten manned missions of the Gemini program accomplished stay times of up to two weeks in earth orbit. In addition to medical monitoring of the astronauts and medical experiments, the Gemini scientific experiments included synoptic earth terrain photography, astronomical photography, micrometeorite collection, and earth vision tests. These flights demonstrated man's capability to live and function under weightless conditions (for at least limited durations) and to perform activities outside a spacecraft with the protection of a spacesuit.

Aside from the relatively short duration Apollo-Soyuz docking mission scheduled for July, 1975, the only currently approved future U.S. manned space flight project is the Shuttle Program which will make a large experiment capacity available for a series of frequently repeated 7 day earth orbital flights during the 1980's. Future orbital missions beyond Shuttle may be carried out in semipermanent to permanent space stations in orbit where men can live and work for extended periods. A brief description of these concepts follows, emphasizing factors relating to the support of man and the environments critical to man.

Skylab, like Salyut, was a dedicated orbiting laboratory which in many aspects can be regarded as a space station prototype. Although its flight missions have now been completed, its data yield will continue to be analyzed for information for some time to come, and its Orbital Workshop will remain in orbit for another 9 or 10 years. It, too, is therefore briefly described.

The Skylab Program was by far the largest and most ambitious earth orbital manned space flight program completed to date. Its three missions of

28, 59, and 84 days, respectively were carried out from May, 1973 to February, 1974. It carried a large complement of medical, astronomy, earth resources and other experiments, all of which were successfully completed by its three three-man crews. One of its major objectives was to evaluate man's ability to live and work in space for durations extending to two to three months [27]. A number of significant physiological changes were measured, but except for a tendency toward severe motion sickness (space motion sickness) during the initial three days of weightlessness, crew well being and task performance during flight were essentially unimpaired. As a result, the data yield from Skylab was very large and a great deal more was learned about crew support and effective operations during long duration space flight.

The Skylab orbital facilities consisted of a workshop, a modified Apollo command and service capsule, a telescope and two interconnecting modules, the multiple docking adapter, and the airlock. The Orbital Workshop is a modified S-IVB stage which was made suitable for long-duration manned habitation in orbit. It contained the necessary crew provisions, living quarters, and food-preparation and waste management facilities to support a crew of three men for the three periods of 28, 59, and 84 days. The Skylab experiments and the necessary support facilities for their operation were also installed (Figure 1).

The Skylab series began with the unmanned launch of the workshop by a Saturn V launch vehicle into a circular orbit of 430 km altitude with an orbital inclination of about 50 degrees. The first crew, which was to be launched the following day aboard an Apollo Saturn IB (SL 2) to dock with the workshop, was delayed for 10 days while studies were carried out to determine the corrective procedures and equipment which the crew would employ to repair the damage to the solar panels and heat shield, which had occurred on launch. The crew demonstrated the importance of the human capability very clearly when they salvaged the entire Skylab Program by affecting the necessary repairs during the first two weeks after docking with the workshop. They returned via their Apollo spacecraft after their successful 28 day mission, to be followed successively by the SL 3 and, later, the SL 4 mission crews. These missions were launched at 3 month intervals although stay times ranged from 28 to 84 days, as indicated above.

The launch atmosphere was that used for the Apollo Program. At and prior to launch it consisted of a 60:40 oxygen:nitrogen ratio at sea level. During ascent the total pressure was reduced to 5 psia (260 mm Hg), and further losses through leakage or after cabin decompression for EVA were replaced with 100% oxygen. On return to earth, the Apollo atmosphere was 100% oxygen at 5 psia (260 mm Hg). In the workshop the atmosphere provided consisted of a nominal 70:30 oxygen:nitrogen mixture at 5 psia (260 mm Hg), although oxygen partial pressures actually ranged slightly higher. CO_2 levels ranged no higher than 5 mm Hg. Once the initial thermal problem was resolved by deployment of the sun shade, temperatures were maintained generally in the range of 70° to 80° F. Relative humidity was kept at 45 to 55%.

The acceleration levels experienced by the crew during launch and return to earth were those of the Saturn IB vehicle, which imposes a maximum acceleration (in the x-axis) of 4 g's during launch, and a maximum of about 3.5 g's during return. The data and samples were returned with the crew after the completion of each of the three missions. Emergency return to earth was feasible after several hours via the command module, and an emergency rescue capability from the ground was made available.

A new space transportation system, the Space Shuttle, is the only U.S. manned space flight program currently approved for the era beyond the 1975 Apollo-Soyuz mission. It was originally conceived as a vehicle to transport personnel, equipment, supplies, etc. to and from a space station [6, 7]. By virtue of its reusability, it is now being pursued as a relatively inexpensive means of greatly facilitating the accomplishment of all varieties of scientific and technological investigations in space. The Shuttle will consist of a booster and an orbiter. The orbiter will carry a two or three man crew, scientist passengers, and supplies and equipment to sustain orbital flights of 7 days. Later, this duration may be expanded to 30 days. It will also carry a large, independently pressurized habitable enclosure for experiments, called Spacelab, as well as non-pressurized pallets for experiments not requiring an atmosphere. These units, to be carried in the orbiter's after section, will be entirely exchangeable on the ground. The booster will supply launch power as a first stage, which will then be jettisoned. After achieving and maintaining earth orbit the orbiter will return, landing on a runway like an airplane. Several flights per year are planned.

There are still many undefined aspects to Shuttle, but some of those that are known have important implications to the life sciences. The sea level atmosphere which is to be provided will require further advancements in suit technology and dysbarism research. Although launch and reentry g levels are not yet known, reentry may for the first time impose g stresses in the long axis (z axis) of the body. It is likely that these g levels will be nominally low, of the order of 1.2 to 2 g's, but their durations may be up to 20 minutes or more. Importantly, they will follow a 7 day period of weightlessness with attendant decreases in human resistance to g stress. Another important "first" will be the flight of scientist passengers for whom medical selection standards, training procedures and supportive requirements must be established. Finally, the frequency of 7 day flight opportunities for biomedical experiments will necessitate preflight emphasis on thorough organization and planning of informational requirements and desires, and on the large amount of ground-based research needed to provide relevant experimental control data. These 7 day flights will afford excellent opportunities to obtain important medical data on mechanisms, and to look for changes in body functional areas which have not yet been examined.

As a long-lasting, general-purpose facility in earth orbit, a permanent space station can provide means of surveying earth resources as well as a base for research in astronomy, astrophysics, biology, space physics, and the technologies of material processing [17, 24]. The space station can also play a major role in the development of future space systems and operations. Its design, therefore, will be dominated by the need to accommodate a broad spectrum of activities which may change markedly over the years. The design keynotes are versatility and maximum exploitation of man's adaptability and talent for decision making.

The space station is thus envisioned as a flexible, multidisciplinary research center for operations in earth orbit. Features such as weightlessness, unlimited vacuum, rapid earth viewing, and unobstructed celestial observation, make a center of this type a unique scientific laboratory capable of many beneficial applications.

Although the space station concept has been studied extensively, it does not now exist as an approved flight program. In concept, it would be launched unmanned into an orbit with an average altitude of 430 km at the equator and an inclination of 55 degrees. This orbital inclination would provide maximum coverage for earth-related experiments. The first logistics flight would bring the crew (about eight men) and be followed by resupply and crew rotation flights several times a year via a space shuttle.

The space station would be designed to have a high degree of on-orbit autonomy, with the crew conducting a variety of experiments and controlling operations with little real-time support from the ground. Operations in orbit would be performed by astronaut-engineers who would control the space station during flight, and by astronaut-scientists who would conduct the many experiments aboard. The tour of duty of each crew member would range from 3 to 6 months.

The interior of the space station would be pressurized to 1 atmosphere with an earthlike oxygen-nitrogen mixture. Cabin temperature levels would be maintained at 18° to 24° C (65° to 75° F), with a relative humidity range of 40 to 60%. Living quarters volume would be about 400 to 1000 cubic feet (10 to 30 cubic meters) per crewmember. Accommodations would include private staterooms for on board personnel, well-appointed wardroom, exercise facilities, large galley, a dispensary for medical and dental care, and well-equipped laboratories. An artificial gravity environment of up to 0.5 g could be provided.

Lunar Missions

The historic first landing of man on an extraterrestrial body was in the summer of 1969, when two American astronauts landed on the moon, fulfilling the primary objective of the Apollo program [15, 18, 19]. During their 24-hour stay they left their spacecraft, clad in pressure suits to carry out experiments on the lunar surface, and to collect samples of lunar soil and rocks to be returned to earth for analysis. Subsequent Apollo missions have expanded these accomplishments. Further exploration and eventual exploitation of the lunar body will require much longer stay times, varying from several weeks to several months. Such missions will involve the establishment of semipermanent or even permanent stations on the moon and means of surface transportation over distances of several hundred kilometers. The lunar shelters would contain living quarters and research laboratories, maintain an earth sea level human environment, and serve as bases for carrying out the objectives of lunar exploration and exploitation, which would be:

1. To improve our understanding of the solar system and its origin through the determination of the physical and chemical nature of the moon and its environment.

2. To obtain a better understanding of the dynamic processes that shaped the earth and led to our present environment, including the development of life.

3. To evaluate the natural resources of the moon and utilize its unique environment for scientific and technological processes.

4. To extend man's ability in space and obtain experience to explore other planetary bodies.

The acceleration characteristics of the manned missions to the moon will depend on the type of launch and earth return vehicles used. A plot of the maximum accelerations (x-axis) during an Apollo-type lunar mission (Figure 2) shows that the greatest accelerations occur during earth launch, earth orbit escape, and maximally during the aerodynamic deceleration of reentry.

In later missions to the moon, advanced transportation systems could be utilized. Such a system might employ the Space Shuttle to transport the astronauts to a permanent space station in earth orbit. From earth orbit, another transportation system would deliver the crew to a lunar orbit station and then to the base on the lunar surface. The acceleration characteristics of such a system need not exceed 2.5 to 3.0 g's (x-axis). The crew size at the lunar base could be as many as 12 men. Emergency return from the surface of the moon could be accomplished within 3 1/2 days. Resupply and data and sample return missions would be flown as needed, averaging perhaps four per year.

Lunar observations and sorties would be conducted from the lunar orbit station, which would be a modified space station, described in the preceding section. Its orbit about the moon would probably be circular to an altitude of about 110 km with a 90-degree inclination (polar orbit). The six-man crews would be rotated at intervals of about 3 months. As in the space station, an artificial gravity environment of up to 0.5 g could be provided, if needed.

Planetary Missions

As our capability and experience with long-life manned space systems aboard a space station grows, as our knowledge of man's ability to survive and function in space is increased, and as the investigation of the surface of the moon progresses, it is likely that manned space exploration missions will turn to the planets in our solar system.

By means of fly-by's and probes, unmanned spacecraft of the Mariner series and similar U.S.S.R. flights have explored the topography and sparse atmosphere of Mars and examined the hot atmosphere of Venus. Recently, Pioneer 10 reached within 81,000 miles of the planet Jupiter transmitting voluminous data and thousands of pictures of its surface before continuing its journey out of the solar system. Viking, which is scheduled for launch in 1975, is planned to land on the Martian surface to perform *in situ* analyses of its soil and surface atmosphere and search for the presence of life. Future unmanned missions may eventually return samples of the Martian soil for detailed analysis on earth. It seems certain that unmanned exploration of the outer planets, Saturn through Pluto, will also be carried out in the future.

The unmanned missions are a necessary prerequisite for man's greatest venture into the unknown: his excursion to another planet many millions of kilometers away. Manned as well as further unmanned exploration of the planets would have as goals:

1. The improvement of our understanding of the solar system, its origin and evolution through the determination of the physical and chemical nature of other planetary bodies and the interplanetary medium.

2. The search for extraterrestrial life on other planets. It is currently thought that the

best planet for this purpose is Mars, where there are some expectations of life existing or having existed.

3. The development of a broader understanding of the earth and life on earth through comparative studies with other planets.

The planets within possible technological reach of manned missions during the next several decades are Mars, Venus, Mercury, and possibly Jupiter [23]. In addition, mission opportunities exist to a number of asteroids, such as Eros, Geographos, Toro, and Icarus. For the surface characteristics of these planets, reference is again made to Table 1. The asteroids have a surface gravity of 0 and no atmosphere. Since manned missions to the asteroids are technically easier to accomplish, they may precede Mars missions. Table 2 lists typical manned mission round trip durations and stopover times at the planets. In general, such manned trips are anticipated to be of 1-year duration and longer.

Because Mars is the most likely first target of a manned planetary mission, details of the probable mission profiles are given. As indicated in Table 2, there exist two classses of Mars missions: opposition and conjunction. Opposition-class missions are, in general, characterized by relatively short durations, short stay time at Mars, and high propulsive performance requirements. Within the opposition-class missions are the Venus swingby missions, which permit observations of both Mars and Venus during a single mission. The conjunction-class missions are, in general, characterized by lower propulsive performance requirements, longer durations, and longer Mars stay times.

A typical Mars opposition-class mission with a Venus inbound swingby (i.e., on the return trip) is shown in Figure 3. Upon departure from

TABLE 2 - TRIP DURATIONS OF MANNED PLANETARY MISSIONS

	Typical Total Mission Duration	Typical Portion Devoted to Stopover at Planet
MARS		
Conjunction	1000 days	460 days
Opposition, Venus Swingby	600 days	Up to 100 days
Opposition	450 days	Up to 30 days
VENUS		
Long Stay	800 days	450 days
Short Stay	400-500 days	40 days
MERCURY		
Direct	350 days	Up to 60 days
Venus Swingby	400 days	Up to 60 days
JUPITER	1500 days	Up to 60 days
ASTEROIDS	360-450 days	30 days

earth orbit, the space vehicle arrives at Mars after a 270-day transit. After an 80-day stay at Mars, the vehicle departs. The return trip to earth includes a swingby past Venus, 123 days after Mars departure. The remaining Venus-to-earth transfer requires 167 days. The total mission duration is 640 days.

The vehicle-sun distance history during the mission is illustrated in Figure 4, which shows that that maximum distance from the sun is 2.2×10^8 km and occurs upon arrival at Mars. The closest distance from the sun (perihelion) is 8×10^7 km and occurs during the vehicle passage between Venus and earth. The maximum distance between the space vehicle and earth is 2.8×10^8 km and occurs during the Mars-Venus leg of the journey.

A typical Mars conjunction-class mission is shown in Figure 5. The transit between earth and Mars requires 210 days. After a 580 day stay at Mars, the vehicle departs from earth. The return transit requires 250 days, making the total mission duration 1040 days. The maximum vehicle-sun distance occurs midway during the Mars stay and is 2.5×10^8 km. The maximum earth-to-vehicle distance of 4×10^8 km occurs at the same time.

A likely example of the acceleration profile of a manned mission to the planet Mars is given in Figure 6. Acceleration during launch into earth orbit will be about that of the space shuttle for which a maximum acceleration of 2.5 to 3 g's is foreseen. While in earth orbit, an artificial gravity of up to 0.5 g could be provided if needed. In the example shown, earth departure is accomplished by means of three propulsive impulses spaced about 18 hours apart. The maximum acceleration during the departure phase amounts to about 0.13 g. During the transit phase to Mars, the acceleration level is practically zero unless artificial gravity is provided. The acceleration loading during entry into the Martian atmosphere is shown at a maximum of 3.5 g's. A different atmospheric entry maneuver could reduce this level to as low as 0.7 g. During ascent from the surface of Mars to orbit, the acceleration will reach a level of about 1 g, while about 0.3 g will be reached during Mars orbit departure. The deceleration for capture into an earth orbit is about 0.2 g. Transfer of the crew from earth orbit is accomplished via space shuttle; there is a maximum deceleration of roughly 2 g's on reentry to earth. The crew size for such a planetary mission would be about 6 to 12, with the volume of crew living quarters about 1000 cubic feet (30 cubic meters) per man.

The capability for emergency return or rescue is very limited. Specifically, within 2 days after departure from earth orbit, a quick emergency return to earth orbit is still possible and would take only 1 or 2 days. During the transit period to the planet Mars, a quick return is no longer feasible, although it would be possible to reduce the nominal return time. For example, 50 days after departure from earth orbit, the return trip would take about 200 days. On the other hand, 120 days after departure the return would require about 350 days. Once the spacecraft has been placed in orbit about Mars, no reduction in return trip time is achievable.

MEDICAL AND BIOLOGICAL FACTORS IN MANNED MISSIONS

The biomedical research which will be needed to support these future missions is a subject of sufficient breadth and variety that it may be of practical benefit to begin by first establishing a serviceable organization of its content.

The outline offered (Table 3) divides the area into two major segments: factors which must be supplied to space flight personnel, and biomedical information to be gained from space missions. While these two basic elements are as distinctive as "intake and output", they are not entirely independent of each other. Information derived from crew responses to the flight environment supplied for a mission may lead to flight experiments. On the other hand, data obtained from flight experiments is often of importance toward improving flight crew support techniques and enhancing man's function in space. Indeed, this is a major purpose of the life sciences space flight experiments.

Both of these elements have in common the requirement for a strong foundation of ground-based research. In terms of the information needed, this total ground-based effort is, of itself, a scientific quest of significant magnitude. Its scope is extremely broad, it requires the inspired activities of many talented individuals of many scientific disciplines, and it is expensive to implement properly. As a fundamental part of the movement of our world to explore other worlds it seems clear that this large body of research would best be accomplished worldwide, both practically and ideally.

In the following paragraphs each of the factors outlined is reviewed, especially in light of research still to be accomplished to prepare for the three classes of missions discussed. Since a thorough review of each subject is the work of these entire volumes, comprehensive detail cannot be attempted. Instead, it is intended that the information needs

TABLE 3. BIOMEDICINE AND BEHAVIOR IN MANNED SPACE FLIGHT

I. Crew/Passenger Support
   1. Atmospheres
   2. Pressure suits and EVA (Extravehicular Activity) equipment
   3. Nutrition and food-water-waste management
   4. Hazard protection
      a. Toxic substances
      b. Particulate contamination
      c. Microbial hazards
      d. Electromagnetic forces
      e. Mechanical forces
      f. Micrometeoroids
      g. Fire hazard
   5. Clinical medicine; Preventive and Therapeutic
   6. Medical selection
   7. Training
   8. Group integrity
   9. Living conditions and standards
      a. Hygiene
      b. Work-rest-sleep cycles
      c. Volume requirements
      d. Clothing and laundry
      e. Furnishing and decor
      f. Exercise
      g. Diversions
   10. Performance factors
   11. Artificial gravity

II. Life Sciences Experiments
   1. Experiment content
      a. Medical
         (1) Neurophysiology
         (2) Pulmonary function
         (3) Cardiovascular function
         (4) Metabolism and nutrition
         (5) Endocrinology
         (6) Hematology
         (7) Microbiology and immunology
         (8) Behavioral response
         (9) Clinical medicine
      b. Biology
      c. Equipment Tests
   2. Experiment Support Equipment
      a. Bioinstrumentation
      b. Life Sciences Laboratory

identified will provoke thoughtful supplementation, planning, approaches to solutions, and constructive research in the direction of an internationally coordinated scientific effort.

I. CREW/PASSENGER SUPPORT

Atmospheres

The provision of a spacecraft atmosphere entails the establishment of desired levels, ranges, and limits of: total pressure, gaseous composition, humidity, temperature, and accumulations of toxic gases. In parallel with this medically oriented research is the hardware design and development to provide new, improved techniques and equipment to meet these specifications.

Although the first three United States manned space flight programs, Mercury, Gemini, and Apollo, provided spacecraft atmospheres of 100% oxygen at one-third sea level total pressure, future trends favor a progressively closer approximation to the sea level earth atmosphere for long-duration flights. There are two primary reasons. First, it is reasonable to assume that the gaseous environment in which man evolved, develops, grows, and lives is the one to which he is optimally adapted by nature. Although approximately 80% of this gaseous envelope is chemically inert, it cannot necessarily be assumed to be physiologically inert. The validation of alternative long-term artificial atmospheres for human physiological and functional normalcy would require a very large research effort, since possible gaseous combinations are virtually infinite and the burden of proof would rest with their proponents. Second, the interpretation of data derived from space flight medical experiments will be greatly facilitated by the removal of an unnatural gaseous environment as an experimental variable. Not only will requirements for expensive and complex long-term ground-based chamber studies be greatly reduced, but also flight findings will be more accurately interpretable.

The 5 psia (260 mm Hg) 100% oxygen atmosphere had the advantage of simplicity, low intrinsic weight, and reduced vehicular structural weight. Very importantly, it eliminated the threat of dysbarism during extravehicular activities in the 3 psia (155 mm Hg) suit. Its major disadvantages were the fire hazard which it imposed and its apparent action to reduce the mass of circulating red blood cells by mechanisms which are still not completely established. These problems, together with the reasons cited above, have resulted in abandonment of the pure oxygen cabin atmosphere for future manned space flights. Currently, increased launch power and vehicular load-carrying capacity have, in fact, devalued all of its advantages except one, elimination of the bends problem.

An appreciable amount of research has been done in several countries in an attempt to identify a gaseous mixture which would retain this advantage without disturbing the integrity of human function or creating new hazards. Helium-oxygen and other air substitutes have been studied but results, although promising in some respects, must be considered incomplete from the standpoint of validating long-term use. In the future, it might be more practical to place greater emphasis on dysbarism research which assumes nitrogen-oxygen cabin atmospheres with normal O_2 partial pressures and total pressures ranging from sea level downward, depending upon the mission characteristics anticipated. Such research would amplify nominal and emergency denitrogenization standards and techniques;

advance suit technology to permit greater freedom of movement at higher pressures; and develop in-flight therapeutic procedures and equipment. This work must be centered about not only the highly physically fit flight crew, but also the less stringently selected space flight passenger. Elucidation of the mechanisms of dysbarism and the effects of long-term exposures to non-sea level atmospheres will also continue to merit attention.

Temperature levels of 21° to 24° C (65° to 75° F), and a relative humidity of approximately 50% appear to be satisfactory. Technology to provide these levels in the spacecraft is currently available, but as new types of environmental control systems are developed, modifications and new component concepts may be required.

The setting of maximum CO_2 limits at 8 mm Hg, and approximately three times that figure for short-term emergencies, appears to be sound for purposes of safety. The extent to which prolonged exposure to such ranges as 4 to 8 mm Hg CO_2 might interfere with in-flight physiological investigations has not been precisely determined, but the probability of significant influence appears small.

Carbon monoxide accumulations should not be permitted to exceed 0.01 mm Hg. Visual effects have been observed at levels as low as 0.013 mm Hg [32]. Little carbon monoxide is produced endogenously but significant amounts may accumulate within the spacecraft over periods of a month or more unless ventilation and scrubbing methods are adequate. Other possible sources such as leakage from Bosch or similar CO_2 removal systems must be rigidly prevented.

Spacecraft ventilation requirements are determined largely by comfort factors and adequacy of flow rates through environmental control systems to permit their operation within established specifications. Ventilation must be pervasive enough to prevent pocketed accumulations of untreated cabin air.

For very long-term missions such as future lunar and planetary flights, increasing emphasis must be placed on regenerative systems. There is great need for continuing progress and innovation in perfecting present concepts and creating new ones. From time to time longer term testing of newly developed components in inhabited integrated systems will continue to be required. By means of careful preplanning such tests can be utilized as excellent sources of ground-based human data in many other areas of biomedical importance, as has been done in the past [5, 26]. The systems selected for any of the three classes of missions will depend on the duration of flight, crew size, power-weight-volume capacity of the vehicle, feasibility of resupply, and the state-of-the-art of regenerative systems. In general, environmental control systems requirements for stations on lunar or planetary surfaces will follow the same principles as those for manned spacecraft.

Pressure Suits and Extravehicular Activity Equipment

The full pressure suit is basically a portable environment essential for the performance of tasks away from the spacecraft. It is also a "cocoon" of refuge in the event of any failure of the spacecraft environment. Although used for relatively short periods, it must have the same protective characteristics as the spacecraft, itself, with modifications that both provide and utilize its mobility. It must supply a gaseous environment to support life and vigorous activity, adequately remove metabolic heat, prevent accumulations of toxic products, and protect against extreme ambient temperatures, micrometeoroids, high-intensity electromagnetic energies, and mechanical wear and tear. It must permit normal bodily functions such as eating and the discharge of wastes, and still afford maximum mobility and manipulative freedom. For EVA activities, it must permit the integration of space maneuvering units and sufficient dexterity for handling tools.

The Apollo Portable Life Support System, thermal garment, micrometeroid protection, ultraviolet filtration, water cooling, and urine management techniques have proven very satisfactory for the time required on the lunar surface as well as in space. For radiation protection, reliance was placed on probabilities of freedom from solar storms and the ability to move quickly to the relative shelter of the lunar module, and from there to the orbiting command module and return to earth. The Skylab EVA system consisted of a slightly modified Apollo suit used with an umbilical. It proved to be fully satisfactory for the tasks assigned.

Present soft suits provide reasonable maneuverability and dexterity if operated at 3 psia (155 mm Hg). At 5 psia (260 mm Hg), these attributes are seriously impaired. At higher pressures, even the most highly trained athlete is helplessly transfixed in a fully supine, doll-like attitude. Research into the capabilities of suits made of harder materials has resulted in the retention of some maneuverability at higher pressures, but movements are somewhat awkward and the suits are excessively bulky and difficult to store.

Among the goals to be achieved in future pressure suit research, foremost is increased ease of coarse and fine movement during operation at significantly higher pressures. Ideally, a suit pressure approximating cabin pressure would eradicate the specter of dysbarism, and a cabin atmosphere approximating sea level would fully satisfy all physiological and experimental requirements of the spacecraft gaseous environment. An easily stored, quickly donned, relatively long-duration suit with all of these utopian attributes need not necessarily remain beyond the range of our rapidly growing technology.

Nutrition and Food, Water and Waste Management

Apollo information indicated that caloric requirements in weightless space will probably be less than those on earth, based on reasoning from the 1/6 g data obtained. By indirect measurement from three forms of data, heart rate, suit coolant-water temperature, and oxygen consumption, metabolic costs of lunar surface activity averaged approximately 1200 Btu/hour (300 kcal/hour), significantly less than with commensurate earth-based work [2, 14]. *Ad libitum* caloric intake showed a wide range of individual variation in the Apollo program, but the reasons varied, and cause-and-effect relationships or even trends cannot yet be established. Skylab data are not yet completely analyzed but in-flight controlled studies will continue to be required in the future, owing to the many factors involved and high degrees of individual variation. The resulting data will have direct bearing on problems of food logistics and the support of man.

Food provisions allowing for an average daily intake of approximately 2800 k calories per day per man should be adequate for planning according to present indications. Skylab menus were planned successfully on the basis of 300 k calories per day less than individual averages on earth, and supplements were provided. The caloric intakes of some crewmen were phenomenally high normally, and were correspondingly high in space. Food composition similar to earth diets proved entirely satisfactory. It differed only where specific dietary controls were needed for experimental purposes. Protein intake of high quality was supplied at approximately 1.5 to 2 grams per kilogram body weight per day which, on the average, matched consumption. Standard vitamin requirements were assured by means of a standard minimum daily requirement tablet taken daily. There is some evidence to consider supplemental Vitamin E if exposure to high oxygen environments are anticipated [8], and mineral and trace mineral supplements if the diet is high in foods processed by chelation [32]. Vitamin D supplementation would seem indicated to compensate for lack of direct exposure to sunlight. There appears to be a valid case for increasing calcium and phosphorus intake to about double the normal daily required levels (i.e., to 2 grams and 3 grams, respectively) on very long missions to decrease the rate of bone demineralization [13]. Salt supplements should be carried in the event of exposures to excessive thermal stress. Skylab metabolic balance experiments required rigid control of the dietary intakes of calcium, phosphorus, sodium and magnesium. Potable water supplies providing for a daily intake for all metabolic purposes (food preparation included) of approximately 3 to 3.5 liters per man per day should be adequate. It would seem advisable to establish a daily minimum intake of about 1.5 liters per day for each crewmember to prevent dehydration and possible nephrolithiasis. Skylab potable water supplies were provided on the basis of 7.5 lbs. (3.5 liters) per man per day. Actual use on Skylab 2 averaged 75% of this amount; 90% on Skylab 3; and 90% on Skylab 4.

From the systems point of view, future research in food, water and waste management should be continued in the same three primary directions to perfect past accomplishments. These are to: provide crew nutritional support with improved ease, palatability, and aesthetic standards; furnish medical experiment requirements with maximum precision and simplicity; and develop improved regenerative systems. Although food storage and logistics problems will be a limiting factor, food systems research should be oriented toward providing nutritional and enjoyable earth-type meals with minimal artificial processing for storage. Ideally, menus should be punctuated with special meals of unprocessed natural food such as frozen poultry or steaks for morale purposes, as well as to provide needed roughage, dental exercise, and trace components. Requirements for containers can be relaxed to some extent since it has been demonstrated on Apollo and Skylab that foods with relatively small cohesive properties are easily handled with a spoon during weightless flight. Development of rather simple mechanical contrivances, such as a glove-box type of food preparation unit, might materially enhance appetite and morale by making it possible for the crew to prepare cooked foods, sandwiches, salads, and snacks.

Convenient techniques for precisely recording intakes of food, food components, and fluid should be available for scientific data. Real time readouts by individual crew members would make possible constant intakes of specific components, such as calcium, where necessary for experimental purposes. In support of medical experiments, urine and fecal outputs should also be recorded by automated means to minimize the need for crew intervention. Similarly, automated methods should be developed for the taking, packaging, and labeling of accurately measured urinary and fecal samples.

The disposal of fecal wastes is perhaps best accomplished by vacuum dehydration or freeze drying. Incineration or possibly some form of reutilization would resolve the problem of storing dried fecal material on long-duration flights. Water reclamation from urine is already within the state-of-the-art, but these techniques must be further perfected. Improved methods of preserving water for long periods and testing it at frequent intervals for chemical and microbial content must continue to be sought.

Hazard Protection

A good deal of forethought and preventive planning will continue to be required to protect crews against the potential environmental hazards which are either uniquely important or inherently unique to space flight. These may be classified as: toxic substances; particulate contamination; microbial hazards; radiation; mechanical forces; micrometeroids; and fire.

In dealing with toxic contamination, attention must be given to potential sources, means of transmission, purifying techniques, maximum acceptable concentrations, and therapeutic procedures. The variety of materials used within the spacecraft makes the range of potentially toxic substances quite broad. Significant levels can develop by simple accumulation, outgassing at sub-sea level pressures, increased rates of oxidation at high oxygen partial pressures, interactions with other spacecraft materials or energies, microbial action, failure of scrubbing devices or techniques, and leakage of contained substances such as coolants or fire extinguishing chemicals. All materials carried aboard the spacecraft must be considered as potential sources of toxicity. This is to include not only the substances of spacecraft systems, supplies and accommodations, but also human endogenous sources, experimental animals and plants, and the reagents, supplies, and various forms of apparatus used for all in-flight experiments. The means of transmission of toxic agents to onboard personnel parallel the three classic portals of entry into the body; the lungs, the gastrointestinal tract, and the skin, either by contact or accidental penetration. The vectors of concern, therefore, are gaseous and particulate contamination of the atmosphere; food, water, and accidental ingestibles; and wash water, soaps, clothes, laundry materials, bedding, and all equipment, materials and substances with which the human occupant will be in living and working contact.

Because the use of potentially toxic materials cannot be completely avoided, technical advancement must continue in developing sensors and purifying techniques for all modes of transmission. Filters, catalytic burners, exchange resins, semipermeable membranes, adsorbants and various combinations of these and other techniques need further investigation.

Maximum acceptable concentrations have been established for an extremely wide range of contaminants on earth, but almost all are based on 8-hour workday exposures. Relatively few limits have been established for 24-hour-a-day living environments. While this task applies less to ingested toxins than to the respiratory and contact vectors, it remains a formidable future research assignment.

The development of therapeutic procedures will continue to be accomplished primarily by nonspace-oriented clinical research. It is anticipated, however, that a few specific therapeutic problems may arise because of substances which may be uniquely produced by interactions within the spacecraft or space suit environment.

The more or less even distribution of particulate matter in the weightless atmosphere is a unique problem of space flight. These particles can be considered to consist of both soluble and insoluble substances, which by virtue of their protean distribution, are potential toxic hazards through all three portals of entry into the body. Insoluble materials such as fiber glass, asbestos, silicone, etc. must be minimized to prevent pneumoconiosis. Even more emphatically, beryllium and cadmium must be entirely eliminated from the spacecraft because of their extreme toxicity. The problems of particulate contamination should be largely preventable by avoiding the use of certain materials within the spacecraft and by providing on board control through effective airflow and filtration systems.

Possible changes in the microbial ecology on long-duration space flight were postulated as a potential problem area several years ago [4]. Ground-based and space flight evidence has been accumulated since, which appears to lend some support to that hypothesis [2, 14, 31]. The distribution of bacteria among crewmembers tends to become homogenous and there is some evidence that the relative dominance of pathogens may change in this closed microcosm. Tenable hypotheses have also been expressed concerning microbial genetic changes as a consequence of the space environment, as well as alterations of host resistance in human occupants who have been removed from the daily microbial assaults of ordinary living [30]. The microbial problem warrants a considerable amount of ground-based as well as in-flight amplification, especially in light of the fact that experimental findings can be expected to be influenced by so many variables, such as initial microbial populations, carrier states, individual resistance, interpersonal proximity, spacecraft or simulator volume, sources of contamination, and personal hygiene. While prevention of infectious disease aboard is a clear requirement, the possibility of microbial shock postflight militates against a sterile spacecraft environment. Consequently, the advancement of such methodologies as microbial filtration, food and water purification and preservation techniques, and perhaps selective destruction of specific kinds of bacteria, viruses, or fungi, in fact, all microbial ecological control and monitoring techniques would best be oriented to the preservation of an earth-simulated microbial environment.

Areas of particular interest within the radiation spectrum are ionizing radiation, and the ultraviolet, visible, and infrared ranges. The three kinds of ionizing radiation with which we must deal in space are now well established. They are the trapped radiation, the protons and electrons trapped by the earth's geomagnetic field to form the belts of radiation enveloping the earth; the solar flares which result in the eruption of protons, alpha-particles, and small fluxes of heavy nuclei into space; and cosmic or galactic radiation containing extremely high-energy particles of protons, alpha-particles, and heavy nuclei ranging through z-numbers of 26 and higher. Our orbital and lunar manned space flights to date have shown that our preflight calculations have tended to err slightly on the high side. Actual doses received by the astronaut flight crews have been extremely small [2, 14, 20, 21, 22]. The timing of lunar flights to avoid solar flares proved to be both well-planned and fortunate, since no flares were encountered.

An observation made by our Apollo lunar crews, however, may well be related to the relatively infrequent strikes of high-energy cosmic primaries (HZE). Similar occurrences have also been reported by Skylab crews. This is the "flashes of light" phenomenon. The relationship has not yet been established conclusively, however, nor the mechanisms which produce the phenomenon.

As flight durations lengthen, much more information will be needed concerning the acute, subacute, and chronic effects of ionizing radiation in terms of both somatic and genetic effects [16]. The relationship between specific dose levels and effects produced (symptoms, signs, pathology, recoverability, etc.) must be discerned for the types and energies of radiation which will be encountered in space. Very importantly, the modifying influence of dose rates, especially low dose rates, requires amplification. Questions concerning the effects of dose fractionation, nonuniform dose distribution, and linear energy transfer (LET) properties on injury and recovery times, and the influence of space flight physiological changes on susceptibility to radiation injury must be investigated. Finally, the technology of radiation dosimetry and the development of preventive or modifying medication are in need of more research. Continuing work in radiation shielding must also be emphasized, but as long as shielding effectiveness is a function of its density (disregarding for the moment its proclivity to produce secondaries), duration of flight as a function of acceptable radiation dosages will vary according to the weight load capacity of the spacecraft.

Protection of the space crews and passengers, particularly eyes and skin, from the potential hazards of ultraviolet, visible light, and infrared radiations of high intensities is of considerable importance. Knowledge of these dangers and protective techniques, however, is in general fairly well established. A special case within the visible light spectrum is the laser, since it is possible that laser technology may be utilized for instrumentation aboard spacecraft of the future. Safety and protective techniques will be required.

The potential hazards of mechanical forces are well-known, having been under study for many years in aviation as well as the relatively recent space program. The field includes the effects of noise and vibration as well as angular and linear acceleration forces of the long-duration, medium, and impact types. Although the general state-of-the-art with respect to tolerance limits and attenuation devices is quite well advanced, this research should continue because specific applications will be required and improvements desired. The acceleration profile of a given class of missions can be controlled as a function of the power of the launch vehicle and return mode, but contingency modes and violent emergencies must be anticipated as well as changes in g tolerance after extended periods of weightlessness. Extensive research into the effects of noise has resulted in the establishment of acceptable limits, but considerably less is known about long-term postexposure effects.

The probability of micrometeoroid penetration is relatively small, but introduces the possibility of decompression and, if the cabin oxygen partial pressure is high, the additional danger of flash fire. It is unlikely that decompression from this source would be explosive in character. Yet, in order to avoid dangerous reductions in pressure and to conserve cabin atmosphere, efforts should be directed toward development of an immediate warning system which would not only indicate a puncture, but also its precise location. Repair techniques, automatic puncture-sealing technology, and puncture prevention by means of lining materials, laminated coats, or other devices, must also be investigated, for space suits as well as cabins and shelters.

The danger of fire is an important threat to the safety of flight crews. Although future U.S. plans no longer call for a spacecraft atmosphere of 100% oxygen, the fire hazard is only reduced, not by any means eliminated. As partial pressures of nitrogen approach those of sea level atmosphere, the danger of fire approaches that at sea level. Although sources of ignition within the spacesuit are very minimal, operation at 100% oxygen, if only at 3 psia (155 mm Hg), still poses a greater potential threat than a mixed gas spacecraft atmosphere. Fire prevention requires the use of materials of very low flammability with relatively high ignition temperatures, low propagation rates, and minimal production of toxic materials on burning. The spacecraft must be scrutinized for ignition sources which must be contained. Volatile substances must be eliminated or scrupulously controlled. An immediate alarm system must be developed, and quick-response, automatic, nontoxic extinguishment techniques developed and employed. The capability of isolating at least one compartment of the spacecraft as a fire and smoke refuge should be seriously considered.

Clinical Medicine, Preventive and Therapeutic

Preventive medical procedures are directed toward maintaining optimal health of flight crews prior to flight, and minimizing possibilities of preflight contact with transmissible diseases which might become manifest during flight. Broadly, this entails attention to adequate nutrition, sleep, exercise, emotional well-being, and group compatibility; the implementation of an adequate schedule of preflight physical examinations; and isolation of the crew to the extent practicable from all other individuals for a reasonably selected incubation period prior to flight. Where feasible, inoculations should be instituted against diseases which may have been carried by suspected contacts. All preflight contacts, of course, must be carefully screened. Research to improve methods for the early detection of communicable disease is particularly important.

In-flight therapy on future extended missions will necessitate a considerably expanded capability, depending upon the characteristics of the mission. The level of sophistication of treatment facilities and personnel will vary as a function of such factors as duration of flight, "space ambulance" availability, and size and makeup of on-board personnel, i.e., age ranges, physical qualifications, inclusion of both sexes, and level of training of on-board medical and dental personnel. For missions of approximately 30 days or more with scientists or other passengers aboard it would seem wise to carry a physician crewmember. His equipment would be the equivalent of a large physician's bag plus that ordinarily found in an emergency room. He would be able to treat discomforts, acute illnesses, and a wide range of injuries, serving to protect the crew and its morale. He would provide the important diagnostic acumen to prevent the unnecessary abort of the mission.

A larger capability would be needed for a larger crew or longer duration mission; but, there is no real need for greater sophistication, as long as the flight is orbital, which can be aborted or reached by a shuttle or its equivalent on relatively short notice.

The most extensive in-flight therapeutic requirement would apply to a distant planetary mission with an intended duration of 1 to 3 years, and a large crew composed of both sexes of ages ranging to 55. Such a flight would require a medical and surgical team capable in all medical specialties as well as dentistry. Appropriate clinical facilities would be the equivalent of a small but fully equipped hospital.

Future research in this area will involve the development of equipment and techniques suited to a full array of medical and surgical procedures in weightless flight.

Although postlunar quarantine is no longer considered necessary, preparations to reinstitute these procedures following other planetary missions must be maintained, and improved techniques must continue to be pursued.

Medical Selection

The basic objectives of medical selection are to prevent, to the greatest extent possible, adverse effects during space flight or space flight training by applying carefully selected principles and techniques to screen out candidates with identifiable predisposing characteristics. It is the first and one of the most important steps in preventive medicine as applied to flight crews. The trend since the beginning of the U.S. manned space flight experience has been to eliminate the extremely rigorous selection tests used originally, such as the thermal and isolation tests. In addition, the training period has come to be increasingly regarded as a part of the selection process. Extensive jet flight experience in pilot astronauts, however, has proven so valuable a selection criterion that even nonaviator scientist-astronauts now routinely receive jet pilot training.

It seems reasonable to believe that the future course of medical selection criteria will parallel the history of aviation medical requirements. As space flight experience increases, as crew protective and supportive equipment is improved, as larger vehicles permit more room for the various niceties of life, and as space flight becomes more routinized in the future, it is envisioned that medical selection requirements will approach the categories and standards of criteria now established for aviation physical examinations. Whereas pilot standards will always remain high, medical standards for other specialized crewmembers will probably become less exacting and those for passengers might eventually become relatively minimal. At the same time, relaxation to the level of standards for present-day commercial passengers will probably not occur for a very long time.

The area warrants continuing reevaluation and considered thought along with the development of new, more relevant diagnostic techniques. The success, pertinence, and specificity of criteria used in the past must be continually reassessed against cumulative experience and modified accordingly.

Training

Training is another area calling for continuing study, for appraising and reappraising the relative values of techniques which have been employed by matching them against the events of each mission. The U.S. experience, overall, has tended to endorse our selection and training procedures. The astronauts have responded uniformly well to both nominal and emergency requirements. One of the greatest problems which has confronted us has been shortness of time. Training schedules are persistently crowded despite the fact that our flight crews have been uniformly avid, retentive, and rapid learners. Considering the complexities of the three classes of future flights under discussion, it may be decidedly advantageous to develop techniques to enhance learning speed without adversely affecting retention or well being.

The training of scientist-astronauts necessitates indoctrinating these highly qualified young scientists in the characteristics, sensations, techniques, procedures, and equipment of space flight, and at the same time providing time and opportunity for them to continue to advance in their respective scientific fields. As noted above, an important part of this training is jet pilot instruction for those not previously qualified, and continuation of jet flight experience afterward on a regular and frequent basis.

The multifaceted missions and relatively small crews of the near future will require considerable cross-disciplinary training. As crews become larger, even greater mission accomplishments will be obtainable through increased crew specialization. Still larger crews will permit redundancy within each specialty. Improved full and partial flight simulators, cross-training methods, and within-discipline training and reinforcement techniques merit continuing research.

Group Integrity

Group integrity may be defined as the efficient and harmonious functioning of a group or team of individuals. Both Soviet and American manned space mission have progressed beyond the initial single-man flight to two, and now three-man crews. Continuing expansion of space flight objectives and capabilities will result in very long missions and larger, more diversely specialized crews. The need for these people to live and work together and depend upon each other for extended periods has unique and important implications with respect to selection, training and on board reenforcement of group harmony. Group performance can be either more or less than the sum of the capabilities of its component personnel, for even highly qualified, strongly motivated, and emotionally stable individuals may form a disharmonious, noncohesive, and inefficient group [32]. Ideally, a well-selected and trained socially isolated team should function harmoniously and with synergistic efficiency under all nominal and emergency conditions, and should resist the deteriorative effects of time.

Although several studies have been carried out under a variety of conditions of group isolation, our current knowledge of the subject is far from adequate [29]. Furthermore, the complexity of variables influencing such studies and the relative infrequency of opportunities for them lead one to expect that significant conclusions will require many years of continuing research. Some of the more prominent component problem areas to be evaluated are: group efficiency as a function of individual contribution and as a function of individual personality characteristics; adaptation of the individual to group stresses and flexibility of adjustment; group function under various adverse conditions and as related to time; identification of group morale factors and preventive, corrective, and maintenance techniques; and the establishment of criteria and, where necessary, more sensitive and discriminating measurement procedures for selection of individuals as group members and leaders. These and related questions will be difficult and time-consuming to resolve. This highly significant research must therefore be strongly emphasized now, if usable conclusions are to be available for the more arduous space journeys of the future.

Living Conditions and Standards

The term, living conditions and standards, is intended to denote an area which gives consideration to the comforts and conveniences of normal human patterns of living with the objective of maintaining normal physical, emotional, motivational, and intellectual aptitudes and enhancing individual and team efficiency. Whereas living conditions aboard early manned space vehicles were considerably austere, these were, after all, initial flight tests of very short duration. As we have progressed, spacecraft comforts and conveniences were only moderately improved through Apollo and Soyuz, since flight durations increased to a maximum of only 2 weeks for U.S. flights and 18 days for the Soviet experience (Soyuz-9) [25]. Accommodations aboard Skylab were significantly advanced and generally proved to be quite adequate for three astronauts for 84 days. Progressive lengthening of manned space flights of the future will require significantly increased attention to these provisions, especially with the addition of non-astronaut passengers aboard. Specific factors within this area include hygiene, work-rest-sleep cycles, volume requirements, clothing and laundry, housekeeping, furnishings and decor, exercise, and diversions.

There are many elements to be considered within the scope of body hygiene. From the standpoint of morale, it would be wise to maintain a high on board standard of personal appearance, dress, and general cleanliness within the spacecraft. Body cleansing techniques suitable for the weightless environment will require continuing developmental efforts. The control of body odors will be essential. Some effort must be sustained to improve methods for maintaining optimal dental hygiene and carrying out such mundane functions as shaving, nail clipping, and haircutting, so as to minimize particulate contamination of the spacecraft atmosphere. The management of body wastes will require facilities which must be suitable aesthetically as well as hygienically.

Past research in work-rest-sleep cycles has affirmed that the most desirable schedule is the one to which we are accustomed on earth [32]. Although man can adapt to variations, such adaptation is probably not complete, nor does it occur at the same rate for all individuals. The 24-hour schedule which would seem most satisfactory for long-sustained missions would consist of 8 hours of uninterrupted sleep, 8 hours of work interrupted by meals and suitable breaks, and the remaining 8 hours devoted to personal needs, elective activities, and recreation. If the flight team is large enough, it may be advisable to divide it into two groups operating 12 hours out of cycle. Studies indicate that the cycle chosen should be adhered to throughout the mission with as little change as possible.

Circadian research has shown that man is best adjusted to a 24-hour diurnal cycle, by training if not by nature. It is something of a paradox that man's natural rhythm is approximately 25 hours, according to the preponderance of evidence derived from free-running studies. This feature can be used advantageously in situations where it becomes necessary to shift to a new 24 hour day. Indications are that the days may be extended to 25 hours each day without ill effect by increasing sleep periods to 9 hours until the new start point is reached [33].

Currently there are no universally accepted standards of minimum living space for flight crews. This depends a great deal on not only the size of the flight crew, but also such factors as age and sex composition, and duration and kind of mission. A few basic principles are generally accepted, however. The importance of an area of privacy for each individual, even if only a bunk and foot locker, is worthy of emphasis. Generally, it is advisable to separate the recreation area from the work areas. As vehicular size increases, it should be possible to provide room volumes, arrangements, and accommodations approximating those aboard small naval vessels.

Clothing should be comfortable, nonallergenic, nonirritating, nonflammable, and easily cleaned. The cleated shoes developed for Skylab were comfortably functional on the grid floor. However, other forms of flooring in future vehicles will call for a different type of semi-adherent or optionally adherent shoe. Protective gloves should be provided for tasks requiring them. Effective, nonbreakable protective goggles or glasses should also be provided. All clothing materials, like all materials aboard the spacecraft, must be nontoxic. Lint production must be minimized. Laundry facilities, designed to function in weightlessness, must be provided unless trade-off studies favor the alternative of disposable clothing. New principles, such as ultrasonic cleaning, warrant investigation. New principles should also be pursued with respect to trash disposal since housekeeping will pose a major problem in long-term flight.

Furnishings, illumination, and decor should be designed for pleasant, comfortable, and safe living within the spacecraft. For either weightless or rotating space flight modes they may also be designed to aid visual orientation. Room decoration, furniture, and lighting can and should be fashioned to be conducive to the functions intended, whether work, sleep, relaxation, or recreation. The present state-of-the-art is already quite well advanced in these areas.

Exercise is important not only physiologically but also as a recreational activity simply because it makes one feel better. New kinds of competitive and noncompetitive recreational exercise suitable for weightless flight need to be developed.

Books, radio, television, games, playing cards, writing materials, educational courses, and other diversionary activities must be provided. Research in this area should be directed not only to the adaptability of these games and materials to weightlessness, but also toward determination of the kinds of competitive activity which will be helpful, and those which may lead to group disharmony.

Performance Factors

Performance factors may be described as equipment, techniques, and design considerations dedicated to the enhancement of task performance efficiency. This field, also called Human Engineering or Man-Machine Integration, deals with the design of any machine or piece of equipment used or manipulated by man to best fit his anatomical, perceptual, intellectual, and motor characteristics for maximum ease, safety, and productivity. Its major origin and impetus was in aviation, where contributing specialties such as anthropometry were developed to a high level of sophistication. Continued expansion of this type of research in the interest of manned space flight has resulted in a quantity of available information on such factors as optimal sizes and shapes of seats, equipment arrangements, switch buttons and toggles and on operator information devices such as dials, gauges, and viewing screens. Yet there is need for continuing research since much of this knowledge is specific for specific kinds of equipment.

Perhaps a major element of our work in the future will center on the determination of those tasks which can best be carried out by man as opposed to those accomplished better by automated techniques. Remote operation is a special form of automation of extremely promising value. Man's capabilities are hopelessly beyond those of the most sophisticated machines ever conceived. His inventiveness and his judgment are entirely unique. The scope of his perception and quality of his responses cannot be duplicated. On the deficit side, however, he is a fragile entity who requires a great deal of support and supply, and he is a relatively slow traveler compared to transmitted energies. Through automated remote operation from the ground, or even more intriguing, from a manned spacecraft, the best attributes of man and machine can be effectively combined to extend man's intelligence through forbiddingly distant and dangerous zones. The Soviet remote lunar exploration with return of soil samples was a remarkable demonstration of this technology.

Lastly, the enhancement of human performance and task accomplishment in space must continue to be concerned with the design of adequate body restraints, mobility aids, tools and similar devices adapted for use under the particular circumstances required, whether weightless, during spacecraft rotation, or on lunar or planetary surfaces. The importance of these aids has been amply demonstrated in past American and Soviet experience. From the standpoint of future research, work aids of this sort will probably not be developed primarily by the life scientist. Astronomy instrumentation will be developed by the astronomers, geological equipment by geologists, and vehicular repair tools by spacecraft engineers. The role of the life scientist remains prominent, however, in evaluating and prescribing steps to assure optimal form, fit, and function of the instrument to the structure and function of the man.

Artificial Gravity

Now that Skylab flight crews have successfully achieved up to 84 days of continuous weightlessness without serious overt duration-related physical difficulties, the need for artificial gravity to maintain crew well being on missions of extremely long duration has become even less likely than before. It seems increasingly apparent that prevention of the physiological changes which do occur will be amenable to much simpler countermeasures than this cumbersome concept. Nevertheless, it is quite possible that at some time in the future vehicle rotation may be considered desireable for purposes of housekeeping and creature comforts. Such a case might be a very large semi-permanent space station meant to accommodate ordinary unindoctrinated passengers and, perhaps, long term resident crews. For this reason, as well as to add more to our knowledge of human vestibular system function as it relates to the space motion sickness phenomenon, research continues to be indicated to further explore effects, optimum procedures, and methods to counteract symptomatology of artificial gravity in space.

At present, the only practical method of producing artificial gravity is by rotation of the spacecraft. Although rotation of the individual on an on board centrifuge appears to offer a reasonable alternative, the short radius and relatively high rotation rates involved are likely to produce more physiological disturbances than the techniques can resolve. In addition, housekeeping and other problems which would be eased by spacecraft rotation are not affected by the on board centrifuge.

Spacecraft rotation poses a number of human physiological and performance problems as well as those referable to the design, navigation, and operation of the spacecraft. The primary focus of potential physiological difficulty is on equilibrium and the vestibular system, which in turn impact performance and habitability factors. Potential difficulties such as motion sickness, the tendency to fall in one direction while ascending and the opposite while descending ladders, the imposition of greater gravity levels while walking in one direction than the other, as well as head turning, past pointing, and other manipulative problems are well-known. Ground-based research must seek ways of reducing these effects and explore more thoroughly methods of determining optimal gravity levels and rotation rates, and the effects of rapid transitions from one gravity level to another within the artificial gravity field. At the same time, spacecraft-oriented studies should be undertaken to determine design requirements for the most efficient means of providing artificial gravity in-flight. Because the 1 g vector cannot be eradicated on earth, the final resolution of these problems will require at least one well-executed in-flight study on a rotating spacecraft, the value of which will depend heavily on careful ground-based research.

A related problem in the field of space biology requires earlier resolution. The opinion has been responsibly expressed that in order to provide truly adequate controls for flight experiments in gravitational biology, the control group of specimens should be flown aboard the same space flight as the experimental group and exposed to 1 g throughout the weightless period of flight. Furthermore, if artificial g is to be provided for this purpose, additional valuable information can be gained by flying similar specimens at specific gradient levels of g, both below and above 1 g. While this would unquestionably be an ideal protocol, the restriction of our ability to provide these g forces to an on-board centrifuge imposes angular acceleration problems and associated experimental artifacts which could be considerably less than ideal. Specific trade off studies are needed with respect to this important and far reaching experimental problem.

II. LIFE SCIENCES EXPERIMENTS

Medical Experiments

The objectives of the medical experiments program are given in Table 4. The first category of objectives, it will be recognized, is geared toward manned space flight. The purpose of its four constituent objectives is to determine as precisely as possible man's medical and behavioral responses, functional limitations, and supportive requirements in space flight. This kind of information is essential to the planning of future manned space flight. The second category is oriented to the advancement

TABLE 4 - MEDICAL EXPERIMENTS OBJECTIVES

A. To extend man's capabilities in manned space flight by determining:

1. The effect of space flight on man and the time course of these effects.
2. The specific etiologies and mechanisms by which these effects are mediated.
3. Means of predicting the onset and severity of undesirable effects.
4. The most effective means of prevention or correction of undesirable effects.

B. To obtain scientific information of value to conventional medical research and practice.

of earth-based biomedical research by utilizing the unique environmental characteristics of space for scientific information, whether or not the resulting data will be applicable to manned space flight. These experiments use space flight as a scientific opportunity.

Because we are dealing with a largely unknown environment, the medical experiments conducted aboard each mission should be more broadly directed than the exploration of known or anticipated problems. To the extent possible, they must include a "monitoring" of all human systems in as much depth as is practical. All manned space flight missions should provide for medical investigations, because flight opportunities are infrequent and redundant human data is essential for statistical validity. It is especially important that flights of increasing durations be utilized fully, even primarily, for gathering medical information since the length of crew existence in space must be considered the chief variable of medical concern. Of the environmental factors affecting man in space, such as acceleration, radiation, social isolation, confinement, etc., the most unique and unknown is clearly long-duration weightlessness. Yet the effects of all factors must be evaluated, both singly and in combination.

In planning an adequate program of in-flight medical experiments, it is necessary first to formulate the problems to be resolved in order of importance. How specifically these problems are defined will continue to depend on the knowledge derived from space flight and ground-based research. As problem specificity narrows, in-flight medical investigations will in turn focus upon greater levels of detail. In the cardiovascular area, for example, the broad question of responsiveness in and after space flight has now yielded more specific problems such as the roles of reninangiotensin and aldosterone, cardiac stroke volume changes and their role in postflight exercise tolerance recovery, the relative importance of the Gauer-Henry reflex, and the influence of potassium loss on the development of premature contractions. Similar areas in which our experience has led to more refined problem definition include body fluid distribution, red cell mass changes, vestibular effects, musculoskeletal integrity, and the distribution and control of sodium and other electrolytes.

Biomedical findings from more recent U.S. and U.S.S.R. manned space flight experience have been summarized [2, 3, 12]. Now, Skylab findings have added greatly to our understanding of these problem areas and have further amplified problem specificity. Red cell mass losses were significant despite minimal exposure to 100% oxygen. Paradoxically, these losses were greatest and recovery times longest in the Skylab 2 crew (28 day flight), and least and shortest, respectively, in the Skylab 4 crew (84 day flight), a finding which raises new questions concerning the specific etiology and basic mechanisms involved. Cardiovascular responses to lower body negative pressure were characterized by increased compensatory heart rates and decreased pulse pressures approximately as anticipated, and may have reached a plateau during Skylab 4. They varied somewhat during flight to the extent that the LBNP procedure had to be aborted on occasion, but the same individual usually tolerated the full LBNP protocol during the next scheduled test. This demonstrates very well, for the first time during space missions, the point that LBNP tolerance is tangibly influenced by factors other than weightlessness, as one would expect. Generally, the first LBNP responses after return to earth matched quite well those obtained from the last in-flight tests.

Here again, however, the time required to return to preflight values was shorter after the two longer flights than after the 28 day flight, probably reflecting the beneficial influence of the far heavier personal exercise schedules of the last two flight crews. In-flight exercise response tests showed no appreciable changes, but tolerances were significantly reduced after earth return. Once more, postflight recoveries were faster following the two longer flights. Cardiac output and stroke volume were reduced postflight compared with preflight. Despite bicycle and other forms of exercise aboard, calf dimensions and leg volumes were considerably less postflight than preflight. Weight losses were not appreciably influenced by flight duration, but were greater early than later during flight. Similarly, postflight weight gain was sharper within the first one or two days after recovery.

Vestibular effects were manifested as space motion sickness which was severe enough to impair task performance during the first three days of Skylab 3. Although the Skylab 2 crew was untroubled by such symptoms, all three crew members of Skylab 3 were afflicted. Symptoms did respond to anti-motion sickness medication and cleared after the initial three days of flight. Preventive medication was used for the Skylab 4 crew, nevertheless one crew member did develope this syndrome for a short time. He was also symptom free after the first three days of flight. Contrary to expectations, tolerances to head motions during rotation on the litter chair were much greater inflight than preflight, uniformly permitting advancement to the maximum protocol of 150 head motions at a rotation rate of 30 RPM. Postflight vestibular responses consisted of unsteadiness of gait the first day, dizziness on rapid head turning the first 2 to 3 days, which persisted in a few individuals for several days, and decreased rail walking ability with eyes closed. Yet, in all crew members tolerance to head movements during litter chair rotation remained at maximum for several days postflight before gradually diminishing to preflight levels. The concept that vestibular symptomatology may be related to the redistribution of body fluids in-flight has been recently expressed [11].

Sleep responses varied among the individuals evaluated, but quantity and quality appeared to be adequate throughout all Skylab missions. Mineral balance studies revealed losses of calcium and phosphorus approximating those found during bed rest. The same was generally true of bone density changes in that decreases were not observed until the longer duration flights. In-flight sodium and potassium losses were also noted. A variety of endocrine measurements were accomplished, but the data has not yet been sufficiently reduced for uniform trend indications to be discerned at this time.

A detailed evaluation of the voluminous data obtained from Skylab is well beyond the scope of this chapter. After suitable time, for more complete data analysis, a full account of Skylab biomedical findings will be reported elsewhere by the many skilled scientists who participated in this significant and multifaceted scientific achievement. Nine experimental areas are set forth in Table 3. Table 5 is a listing of broad problems to be considered within each of these areas. These tables and the above comments are offered in the hope that they will provide a beginning framework for world wide cooperative participation in in-flight medical investigation. Each problem should be regarded as requiring data on

TABLE 5 – INFLIGHT MEDICAL PROBLEMS REQUIRING EXPERIMENTS

1. Neurophysiology:
   - Effects of space flight on the integrative function of the central nervous system
   - Effects on sleep
   - Effects on the vestibular system, both otoliths and semicircular canals, under conditions of weightlessness and rotation for artificial gravity
   - Effects on sensory perception and spatial orientation

2. Pulmonary Function:
   - Effects on mechanics of breathing
   - Effects on ventilation/perfusion
   - Effects on alveolar gas transfer
   - Effects on control of breathing

3. Cardiovascular function:
   - Effects on cardiac output
   - Effects on arterial pressure control
   - Effects on central venous pressure and venous compliance
   - Effects on intrinsic cardiac function
   - Effects on overall circulatory responsiveness to g loading and 0 g

4. Metabolism and Nutrition
   - Effects on metabolic requirements at rest and during activity
   - Effects on caloric, water, electrolyte, mineral and vitamin requirements
   - Effects on lean body mass
   - Effects on the skeletal system and metabolism of bone mineral
   - Effects on muscular integrity
   - Effects on fluid and electrolyte balance

5. Endocrinology:
   - Effects on endocrine controlling mechanisms of water and electrolyte balance and distribution
   - Effects on vasoactive hormones
   - Effects on endocrine stress responses
   - Effects on calcitonin output, parathyroid, thyroid, and other hormonal controls of mineral metabolism
   - Effects on endocrine control of glucose metabolism
   - Effects on overall balance of the endocrine system

6. Hematology:
   - Effects on red cell mass, rates of red cell production and destruction
   - Effects on clotting factors
   - Effects on inflammatory responses
   - Chromosonal effects
   - Effects on serum proteins

7. Microbiology and Immunology:
   - Effects on spacecraft microbial ecology
   - Effects on distribution and relative dominance of pathogens
   - Effects on microbial genetics
   - Effects on factors of immunity

8. Behavioral Responses:
   - Effects on perception
   - Long term effects on emotional stability
   - Effects on stress tolerance
   - Effects on group integrity

9. Clinical Medicine:
   - Influence of space flight on medical and surgical therapeutic procedures and materials
   - Effects on pharmacological responses
   - Effects on preventive medical requirements inflight and effectiveness of instituted preflight procedures

specific effects and time courses, mechanisms and specific environmental etiologies, predictive indices, and countermeasures.

The ground-based information necessary to adequately investigate these many unresolved questions and prepare to utilize future flight opportunities for medical experiments to maximum advantage will demand an increasingly strong ground-based research program. As problems are defined in greater detail, the pursuit of solutions to them often tends to delve into more fundamental regions, and their component problems may become increasingly difficult to resolve. Although, fortunately, this ramifying sequence need not be pursued *ad infinitum*, the study of the mechanisms by which these observed changes are mediated must be continued at least until practical end points are reached, and should be continued beyond, as basic research, which will ultimately broaden the range of their utility into more and more allied fields. For the purposes of space medicine, these practical end points will consist of the attainment of a sufficient substructure of information on mechanisms to enable us to establish optimal techniques for prediction, for both medical selection and on-board prognosis, and countermeasures for the prevention and correction of ill effects. Among the many approaches which will be required, continuation of both short duration and longer term simulation studies involving human as well as animal subjects will be needed. The repetition of such long term bed rest studies as have already been carried out in the U.S. and U.S.S.R. will continue to be required to shed further light on cardiovascular and musculoskeletal response mechanisms, prognostic indicators and countermeasures [10, 13, 34]. Similarly, short term bed rest, water immersion, animal immobilization, confinement, centrifugation, pressure chamber studies and other simulation techniques, as well as investigations involving all of the basic medical sciences, will need to be brought to bear in order to achieve these goals.

Biology

Biological experiments, like medical experiments, will serve the same two categories of objectives outlined above [9]. In contrast, however, biology tends to place greater emphasis on more fundamental observations applicable to earth-based sciences and less on the extension of manned space flight. As the medical experiments identify operationally significant potential problems and define their component problems, the use of animals in-flight to resolve these questions will prove to be as necessary as animal experiments on earth. Some of these requirements have already become apparent, such as the need for animal surgery in space to work out suitable in-flight techniques. Others, perhaps the majority, have yet to be determined; but these will be defined as more knowledge is gained.

Flight experiments in more fundamental biology can be anticipated in such fields as genetics, growth and development factors, intracellular protoplasmic structures and functions, plant physiology, and enzyme chemistry. Planetary investigations dealing with life on other planets, clues to the origins of life, and studies of earth ecology are highly important fields which require continuing emphasis.

The specific biological experiments to be carried out in space will be determined largely by the needs and desires of active researchers within the scientific community. These, in turn, will be dependent upon the current status of biological research, i.e., the particular array of problems which prevail at any given time and the relative emphasis placed upon them.

Equipment Tests

As new and advanced life-support systems and techniques are developed, components and assemblies may be expected to continually evolve which require in-flight testing. Some of these may involve new principles, others merely new arrangements which may pose unknowns regarding their function in space flight. Any component of advanced environmental control systems, bioinstrumentation, food, water and waste management systems, crew equipment, task aids, restraints and similar apparatus may require such in-flight testing.

Bioinstrumentation

Bioinstrumentation requirements for space flight are predicated, in general, upon four major factors: function in weightlessness, minimal interference with working crew members, ease of accomplishment, and safety. The need for accuracy and reproducibility, although extremely important, cannot be considered unique for space flight. Another consideration should be added, however. In common with other endeavors in the field of environmental medicine is a requirement for high levels of measurement sensitivity and precision, because evaluations of healthy individuals under abnormal conditions can be expected to yield data which may prove to be significant, even though falling within accepted clinical ranges of normal.

Research is needed in the development of noninvasive techniques of physiological measurement, such as cardiac output and peripheral and central venous pressure. In the area of biochemistry, techniques and procedures which avoid the use of liquid reagents will obviate the potential dangers of their toxicity, and problems of handling liquids in the weightless environment. Automated techniques would be of great value in saving crew time. Finally, improved techniques must continually be pursued for the storage, compression, display, and transmission of in-flight data.

Life Sciences Laboratory

One of the research efforts of the U.S. Life Sciences Program during the past few years has been the development of a compact and highly flexible laboratory console system to accommodate the measurement requirements of in-flight medical experiments. This Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS), by virtue of its flexibility, is capable of being expanded to include clinical diagnosis, therapy, and equipment for the conduct of biological experiments.

Beyond the current development of Spacelab for the Shuttle Program by ESRO, it is entirely feasible for future global research to bring about the development and cooperative utilization of a life sciences flight module which can be docked and operated as a part of an orbiting or planetary vehicle. Such a module would make the full potential of space available to the life science community of the world, to provide maximum opportunity for achievements to support the expansion of man's exploration of space, and advance our scientific understanding of life on earth.

SUMMARY AND CONCLUSIONS

In summary, an attempt has been made to define the characteristics of three basic classes of manned space flight missions of the future, and to broadly organize and highlight future research requirements in the life sciences for the support and advancements of these space achievements. Whether or not current planning for the next decade includes missions beyond the earth orbital class or further extensions of flight duration, it is viewed as a certainty that at some time in the future man's intrepid curiosity and irrepressible thirst for knowledge will lead him inevitably to use his hard won gains to further expand his horizons in space. As tangible human benefits become apparent and as such missions become cheaper and easier to carry out, their frequency may be expected to increase progressively.

During the intervening periods, the large amount of ground-based research needed to support, improve and utilize these expanding space explorations can and must be accomplished. In the medical area, our competence to set forth appropriate medical specifications to support man for such missions of the future will be fundamentally dependent upon our knowledge of man's responses, their ranges, and our ability to prognosticate, prevent and correct undesirable effects. Even more fundamental to success, and underlying all of these essential criteria, will be a thorough knowledge of the mechanisms by which these responses are mediated. The more than 26,000 man hours of combined U.S. and U.S.S.R. manned space flight experience to date, have to a large extent served to identify, define and arrange in approximate priority the more apparent medical problem areas and many of their component issues. When reduced, the large amount of medical data derived from Skylabs' 12,300 man hours of this total will significantly increase our information on moderately long term effects and their time courses. We are now in a position to make full use of these gains and augment them by placing strong emphasis on ground based research and shorter duration flight experiments to more fully explore *mechanisms*, i.e., the cellular, tissue, neurologic, endocrine, immunologic, biochemical, and other modalities involved in producing the physiological alterations, adaptations and losses of adaptation which have thus far been measured. By this means we will continue to enhance our ability to support and advance man's future capabilities in space, and at the same time, may expect to derive important new insight into functional human physiology in both health and disease. Similarly, with respect to all of the other elements of the life sciences the periods between expanding flight missions should be regarded as periods of preparation emphasizing strong ground-based research programs to accomplish the multiplicity of diverse tasks required in biotechnology, bioengineering, and experimental biology.

The overall need for research on behalf of man in space is very great, and the welfare, protection, expansion and intellectual growth of man are of common interest to all of man kind. It is, therefore, to be hoped that this need and common interest will result in the structuring of an internationally cooperative research endeavor which truly reflects the global scope of man's ventures away from his home planet into the unknowns of outer space.

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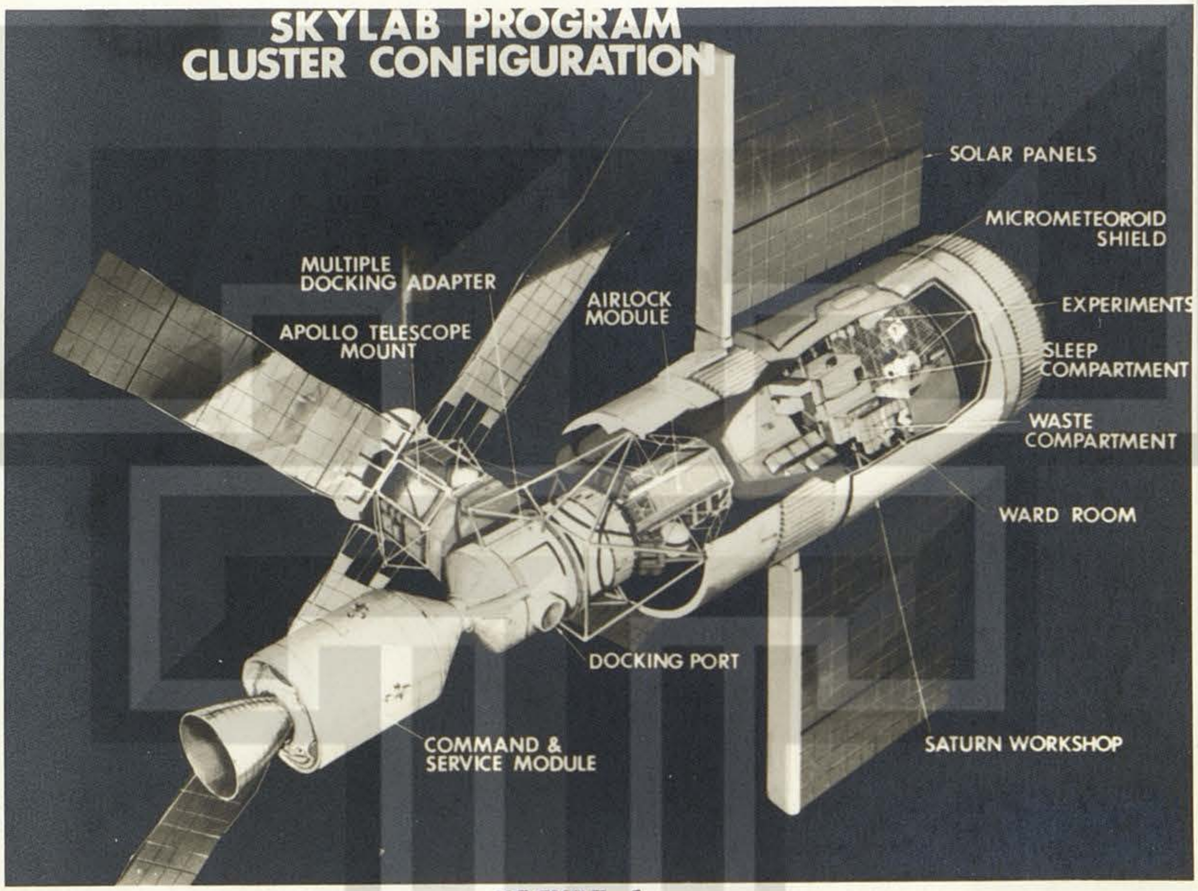
SKYLAB PROGRAM
CLUSTER CONFIGURATION
SOLAR PANELS
MICROMETEOROID SHIELD
EXPERIMENTS
SLEEP COMPARTMENT
WASTE COMPARTMENT
WARD ROOM
MULTIPLE DOCKING ADAPTER
AIRLOCK MODULE
APOLLO TELESCOPE MOUNT
DOCKING PORT
COMMAND & SERVICE MODULE
SATURN WORKSHOP

FIGURE 1

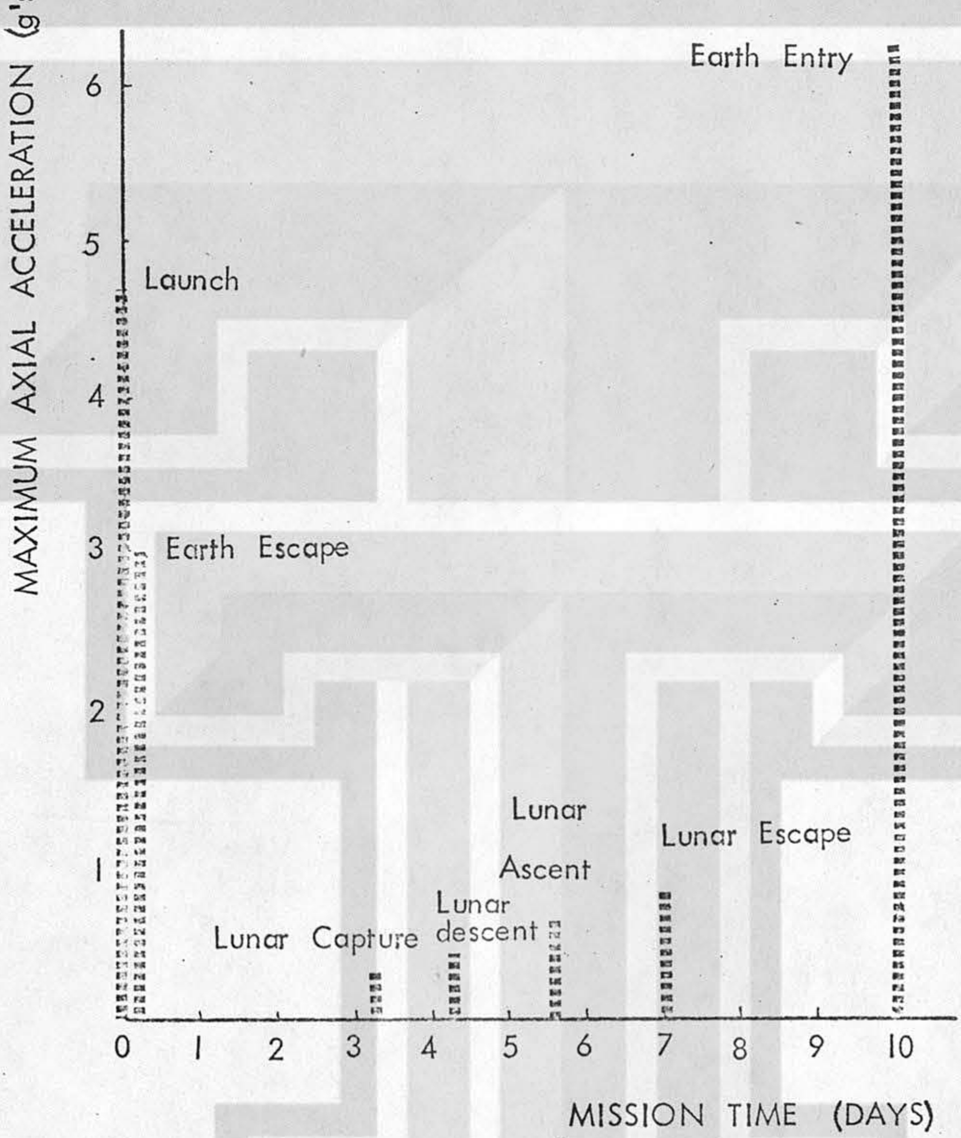

Figure 2 Acceleration Levels during Apollo Type Lunar Missions

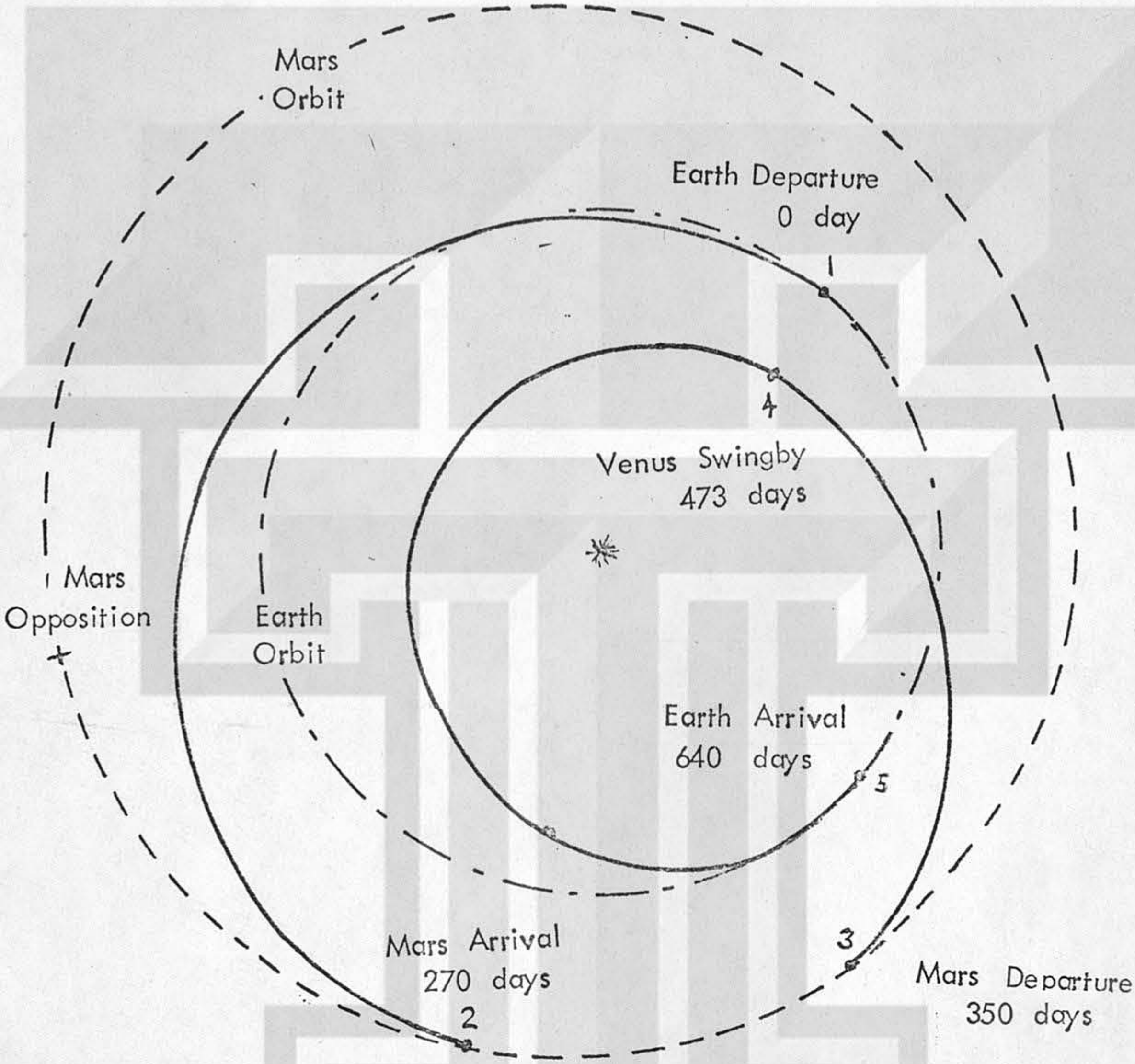

Figure 3 Trajectory of Mars Opposition-Class Manned Mission

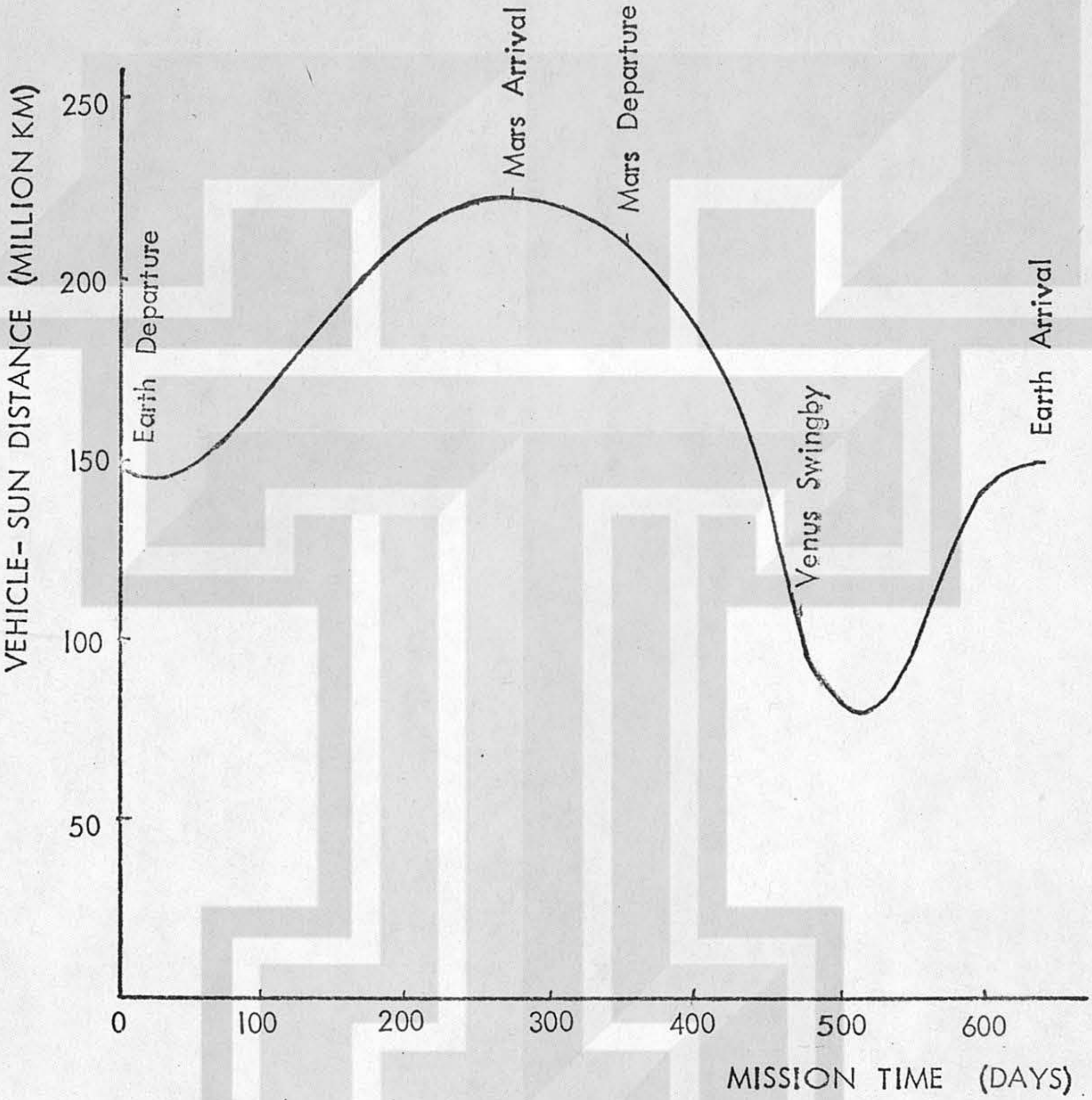

Figure 4 Vehicle-Sun Distances During Mars Mission

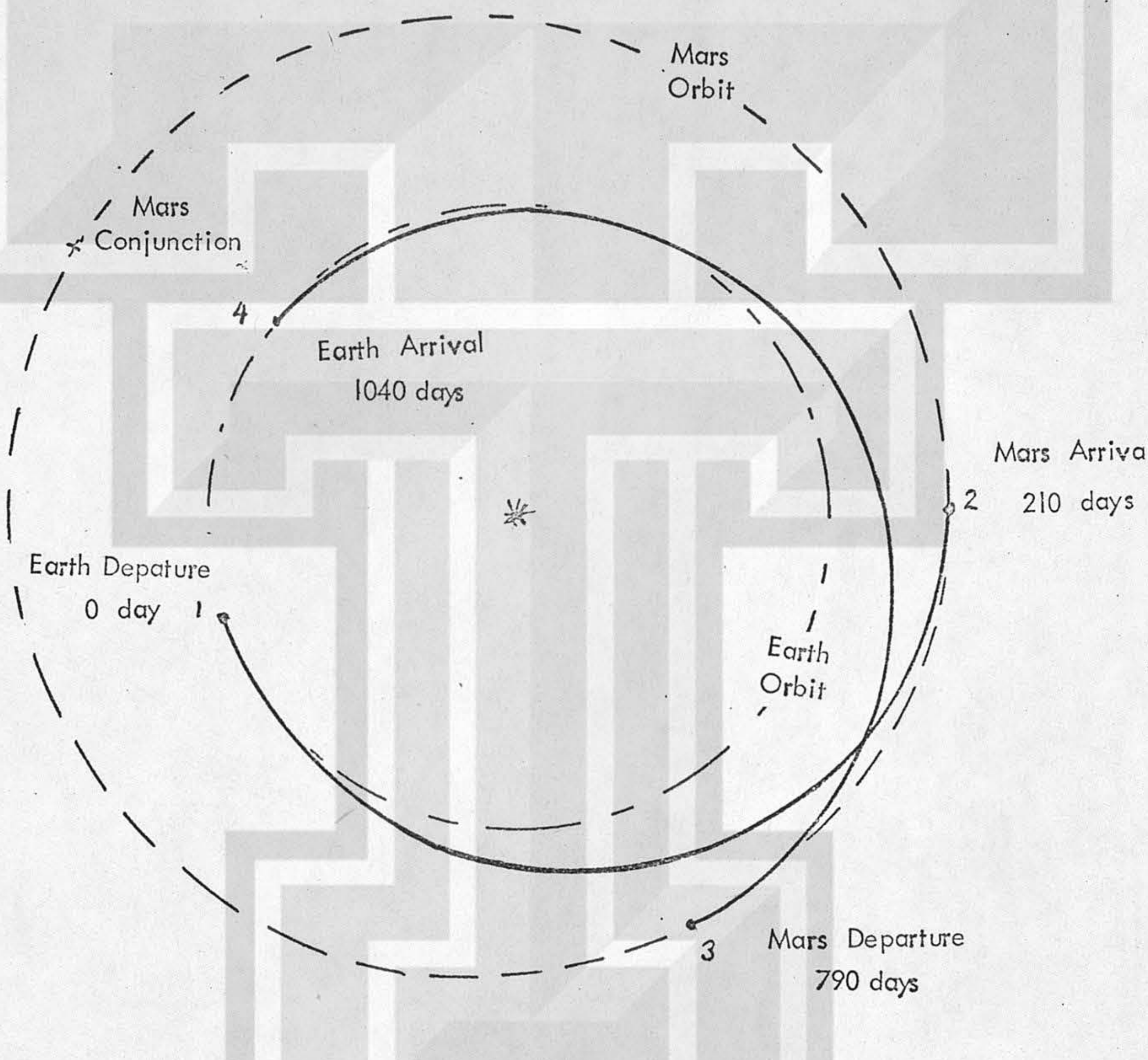

Figure 5 Trajectory of Mars Conjunction-Class Manned Mission

Figure 6 Acceleration Levels for Mars Manned Mission

THE FOUNDATIONS OF

SPACE BIOLOGY AND MEDICINE

Volume 3, Part 5

Chapter 1

Research Toward the Future: An Appraisal of Future Life Sciences Research

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CONTENTS

INTRODUCTION

At the time of this writing, the combined experience of the two countries of the world which have launched man into space have demonstrated that man, supplied with his fundamental organic needs, is capable of existing, functioning, and carrying out his assigned activities normally in an extraterrestrial environment for at least a few months. The United States space flight programs from Mercury through Gemini and the manned lunar landings of Apollo verified man's capabilities for flight durations of up to 14 days, while the Soviet programs from Vostok through Soyuz and and Soyuz-Salut accomplished manned space flights of up to 24 days. With the recent completion of the U.S. Skylab Program, man has now flown successfully in space for almost 3 months.

We are now merging into a new era, one in which manned space flights can be extended to many months and even years; one in which man can expand his investigations of the moon and explore beyond into the solar system; one in which he can advance significantly by gaining new knowledge of his environment, his origins, and himself; and one which holds the opportunity for man to mature in the process, as well, by learning to join forces with his fellows across the earth in positive action to launch and sustain this promising future in space.

From the standpoint of science and technology, new growth will be required not only in the realm of space vehicle systems but also in the development of long-lived systems for the support of man and, most importantly, for the understanding of man, himself, in the environment of space. To a great extent, these requirements will vary according to the type and duration of mission to be undertaken. This chapter will, therefore, begin with a description of three general classes of manned space flight missions of the future: earth orbital, lunar, and planetary; and follow with a broad analysis of biomedical science and technology emphasizing areas of research needed to support future manned space flights and the information to be obtained from them.

FUTURE MANNED SPACE FLIGHT MISSIONS

Three distinct categories of future manned flight missions can be identified: missions in earth orbit, missions to the moon, and missions to the planets, including the minor planets [1, 28].

In earth orbital missions, the astronauts remain in close proximity of the earth, are in instantaneous communication with earth, and can be returned to the surface within hours should medical emergency demand it. Resupply and replacement of spacecraft components are within easy reach of the operations center on earth.

In lunar missions, the target is within a week's travel time from the earth, thus increasing the complexity of resupply and replacement. The systems required for lunar missions are more numerous and complicated since operations now include escape from the earth's gravity field, capture by the lunar gravity field, and landing and take-off from an extraterrestrial body.

Grateful acknowledgement is made to William L. Haberman, Ph.D., formerly of the Advanced Manned Missions Program Office of the NASA Office of Manned Spaceflight, for his compilation of the original section on Future Manned Space Flight Missions.

Finally, for the planetary missions with round trip durations of one year or more, the character and complexity of the mission changes completely. The spacecraft now travels to distances of several hundred million kilometers from the planet earth and, in most instances, the mission cannot be cancelled or aborted once the spaceship has departed from earth orbit. Mission operation and control will, of necessity, be almost autonomous from the earth. Medical emergencies must be handled aboard the spacecraft since fast return to earth generally is not possible (Figures 3 and 5).

The development of spacecraft systems, capable of maintaining the relatively narrow environmental range to which man is accustomed, will depend upon knowledge of the external environment as well as the characteristics of the vehicle and mission. The major features of the natural environment of the moon and several planets are presented in Table 1. Those of the earth are included for purposes of comparison. It is worthwhile to note that the presence of a planetary atmosphere not only has implications with respect to exobiology, life support, and toxicology, but also serves as protection against inherent radiation and micrometeoroid penetration, while an appreciable magnetic field about a planet will tend to trap and retain a radiation belt (Table 1).

Earth Orbital Missions

Manned orbital space flight began with Yuri Gagarin's historic flight in April, 1961. Beginning with John Glenn's flight (MA 6), the first U.S. orbital missions were carried out in 1962 and 1963, when four manned orbital missions were completed during the Mercury program. The maximum flight duration achieved during Mercury was about 34 hours on Gordon Cooper's MA 9. The next orbital manned space flight program in the U.S. spanned the years

TABLE 1. THE LUNAR AND PLANETARY ENVIRONMENT

	Surface Pressure (atmospheres)	Solar Thermal Irradiance (Cal/cm^2 - min)	Surface Temperature (°C)		Solar Illuminance (thousands lux)	Albedo	Day/Night Cycle (Earth days)	Gravity	Magnetic Field Intensity (gammas)	Radiation Belt	Distance from Earth (millions km)
			Max.	Min.							
Earth	1	1.98	50	-30	140	0.34	1	1.00g	62,000 (poles) 31,000 (equator)	Yes	-
Moon	0	1.94	120	-170	140	0.07	27.3	0.17g	36	No	0.4
Mercury	0.001	10.9	340		935	0.058	88	0.35g	Not Available		80 to 220
Venus	90	3.88	475		267	0.76	250	0.90g	70	No	40 to 260
Mars	0.005	0.72 to 1.05	20	-70	60	0.148	1.02	0.38g	50	No	56 to 400
Jupiter	200,000	0.68	-140		5.2	0.51	0.41	2.40g	500,000	Yes	588 to 963

1965 and 1966, when the ten manned missions of the Gemini program accomplished stay times of up to two weeks in earth orbit. In addition to medical monitoring of the astronauts and medical experiments, the Gemini scientific experiments included synoptic earth terrain photography, astronomical photography, micrometeorite collection, and earth vision tests. These flights demonstrated man's capability to live and function under weightless conditions (for at least limited durations) and to perform activities outside a spacecraft with the protection of a spacesuit.

Aside from the relatively short duration Apollo-Soyuz docking mission scheduled for July, 1975, the only currently approved future U.S. manned space flight project is the Shuttle Program which will make a large experiment capacity available for a series of frequently repeated 7 day earth orbital flights during the 1980's. Future orbital missions beyond Shuttle may be carried out in semipermanent to permanent space stations in orbit where men can live and work for extended periods. A brief description of these concepts follows, emphasizing factors relating to the support of man and the environments critical to man.

Skylab, like Salyut, was a dedicated orbiting laboratory which in many aspects can be regarded as a space station prototype. Although its flight missions have now been completed, its data yield will continue to be analyzed for information for some time to come, and its Orbital Workshop will remain in orbit for another 9 or 10 years. It, too, is therefore briefly described.

The Skylab Program was by far the largest and most ambitious earth orbital manned space flight program completed to date. Its three missions of

28, 59, and 84 days, respectively were carried out from May, 1973 to February, 1974. It carried a large complement of medical, astronomy, earth resources and other experiments, all of which were successfully completed by its three three-man crews. One of its major objectives was to evaluate man's ability to live and work in space for durations extending to two to three months [27]. A number of significant physiological changes were measured, but except for a tendency toward severe motion sickness (space motion sickness) during the initial three days of weightlessness, crew well being and task performance during flight were essentially unimpaired. As a result, the data yield from Skylab was very large and a great deal more was learned about crew support and effective operations during long duration space flight.

The Skylab orbital facilities consisted of a workshop, a modified Apollo command and service capsule, a telescope and two interconnecting modules, the multiple docking adapter, and the airlock. The Orbital Workshop is a modified S-IVB stage which was made suitable for long-duration manned habitation in orbit. It contained the necessary crew provisions, living quarters, and food-preparation and waste management facilities to support a crew of three men for the three periods of 28, 59, and 84 days. The Skylab experiments and the necessary support facilities for their operation were also installed (Figure 1).

The Skylab series began with the unmanned launch of the workshop by a Saturn V launch vehicle into a circular orbit of 430 km altitude with an orbital inclination of about 50 degrees. The first crew, which was to be launched the following day aboard an Apollo Saturn IB (SL 2) to dock with the workshop, was delayed for 10 days while studies were carried out to determine the corrective procedures and equipment which the crew would employ to repair the damage to the solar panels and heat shield, which had occurred on launch. The crew demonstrated the importance of the human capability very clearly when they salvaged the entire Skylab Program by affecting the necessary repairs during the first two weeks after docking with the workshop. They returned via their Apollo spacecraft after their successful 28 day mission, to be followed successively by the SL 3 and, later, the SL 4 mission crews. These missions were launched at 3 month intervals although stay times ranged from 28 to 84 days, as indicated above.

The launch atmosphere was that used for the Apollo Program. At and prior to launch it consisted of a 60:40 oxygen:nitrogen ratio at sea level. During ascent the total pressure was reduced to 5 psia (260 mm Hg), and further losses through leakage or after cabin decompression for EVA were replaced with 100% oxygen. On return to earth, the Apollo atmosphere was 100% oxygen at 5 psia (260 mm Hg). In the workshop the atmosphere provided consisted of a nominal 70:30 oxygen:nitrogen mixture at 5 psia (260 mm Hg), although oxygen partial pressures actually ranged slightly higher. CO_2 levels ranged no higher than 5 mm Hg. Once the initial thermal problem was resolved by deployment of the sun shade, temperatures were maintained generally in the range of 70° to 80° F. Relative humidity was kept at 45 to 55%.

The acceleration levels experienced by the crew during launch and return to earth were those of the Saturn IB vehicle, which imposes a maximum acceleration (in the x-axis) of 4 g's during launch, and a maximum of about 3.5 g's during return. The data and samples were returned with the crew after the completion of each of the three missions. Emergency return to earth was feasible after several hours via the command module, and an emergency rescue capability from the ground was made available.

A new space transportation system, the Space Shuttle, is the only U.S. manned space flight program currently approved for the era beyond the 1975 Apollo-Soyuz mission. It was originally conceived as a vehicle to transport personnel, equipment, supplies, etc. to and from a space station [6, 7]. By virtue of its reusability, it is now being pursued as a relatively inexpensive means of greatly facilitating the accomplishment of all varieties of scientific and technological investigations in space. The Shuttle will consist of a booster and an orbiter. The orbiter will carry a two or three man crew, scientist passengers, and supplies and equipment to sustain orbital flights of 7 days. Later, this duration may be expanded to 30 days. It will also carry a large, independently pressurized habitable enclosure for experiments, called Spacelab, as well as non-pressurized pallets for experiments not requiring an atmosphere. These units, to be carried in the orbiter's after section, will be entirely exchangeable on the ground. The booster will supply launch power as a first stage, which will then be jettisoned. After achieving and maintaining earth orbit the orbiter will return, landing on a runway like an airplane. Several flights per year are planned.

There are still many undefined aspects to Shuttle, but some of those that are known have important implications to the life sciences. The sea level atmosphere which is to be provided will require further advancements in suit technology and dysbarism research. Although launch and reentry g levels are not yet known, reentry may for the first time impose g stresses in the long axis (z axis) of the body. It is likely that these g levels will be nominally low, of the order of 1.2 to 2 g's, but their durations may be up to 20 minutes or more. Importantly, they will follow a 7 day period of weightlessness with attendant decreases in human resistance to g stress. Another important "first" will be the flight of scientist passengers for whom medical selection standards, training procedures and supportive requirements must be established. Finally, the frequency of 7 day flight opportunities for biomedical experiments will necessitate preflight emphasis on thorough organization and planning of informational requirements and desires, and on the large amount of ground-based research needed to provide relevant experimental control data. These 7 day flights will afford excellent opportunities to obtain important medical data on mechanisms, and to look for changes in body functional areas which have not yet been examined.

As a long-lasting, general-purpose facility in earth orbit, a permanent space station can provide means of surveying earth resources as well as a base for research in astronomy, astrophysics, biology, space physics, and the technologies of material processing [17, 24]. The space station can also play a major role in the development of future space systems and operations. Its design, therefore, will be dominated by the need to accommodate a broad spectrum of activities which may change markedly over the years. The design keynotes are versatility and maximum exploitation of man's adaptability and talent for decision making.

The space station is thus envisioned as a flexible, multidisciplinary research center for operations in earth orbit. Features such as weightlessness, unlimited vacuum, rapid earth viewing, and unobstructed celestial observation, make a center of this type a unique scientific laboratory capable of many beneficial applications.

Although the space station concept has been studied extensively, it does not now exist as an approved flight program. In concept, it would be launched unmanned into an orbit with an average altitude of 430 km at the equator and an inclination of 55 degrees. This orbital inclination would provide maximum coverage for earth-related experiments. The first logistics flight would bring the crew (about eight men) and be followed by resupply and crew rotation flights several times a year via a space shuttle.

The space station would be designed to have a high degree of on-orbit autonomy, with the crew conducting a variety of experiments and controlling operations with little real-time support from the ground. Operations in orbit would be performed by astronaut-engineers who would control the space station during flight, and by astronaut-scientists who would conduct the many experiments aboard. The tour of duty of each crew member would range from 3 to 6 months.

The interior of the space station would be pressurized to 1 atmosphere with an earthlike oxygen-nitrogen mixture. Cabin temperature levels would be maintained at 18° to 24° C (65° to 75° F), with a relative humidity range of 40 to 60%. Living quarters volume would be about 400 to 1000 cubic feet (10 to 30 cubic meters) per crewmember. Accommodations would include private staterooms for on board personnel, well-appointed wardroom, exercise facilities, large galley, a dispensary for medical and dental care, and well-equipped laboratories. An artificial gravity environment of up to 0.5 g could be provided.

Lunar Missions

The historic first landing of man on an extraterrestrial body was in the summer of 1969, when two American astronauts landed on the moon, fulfilling the primary objective of the Apollo program [15, 18, 19]. During their 24-hour stay they left their spacecraft, clad in pressure suits to carry out experiments on the lunar surface, and to collect samples of lunar soil and rocks to be returned to earth for analysis. Subsequent Apollo missions have expanded these accomplishments. Further exploration and eventual exploitation of the lunar body will require much longer stay times, varying from several weeks to several months. Such missions will involve the establishment of semipermanent or even permanent stations on the moon and means of surface transportation over distances of several hundred kilometers. The lunar shelters would contain living quarters and research laboratories, maintain an earth sea level human environment, and serve as bases for carrying out the objectives of lunar exploration and exploitation, which would be:

1. To improve our understanding of the solar system and its origin through the determination of the physical and chemical nature of the moon and its environment.

2. To obtain a better understanding of the dynamic processes that shaped the earth and led to our present environment, including the development of life.

3. To evaluate the natural resources of the moon and utilize its unique environment for scientific and technological processes.

4. To extend man's ability in space and obtain experience to explore other planetary bodies.

The acceleration characteristics of the manned missions to the moon will depend on the type of launch and earth return vehicles used. A plot of the maximum accelerations (x-axis) during an Apollo-type lunar mission (Figure 2) shows that the greatest accelerations occur during earth launch, earth orbit escape, and maximally during the aerodynamic deceleration of reentry.

In later missions to the moon, advanced transportation systems could be utilized. Such a system might employ the Space Shuttle to transport the astronauts to a permanent space station in earth orbit. From earth orbit, another transportation system would deliver the crew to a lunar orbit station and then to the base on the lunar surface. The acceleration characteristics of such a system need not exceed 2.5 to 3.0 g's (x-axis). The crew size at the lunar base could be as many as 12 men. Emergency return from the surface of the moon could be accomplished within 3 1/2 days. Resupply and data and sample return missions would be flown as needed, averaging perhaps four per year.

Lunar observations and sorties would be conducted from the lunar orbit station, which would be a modified space station, described in the preceding section. Its orbit about the moon would probably be circular to an altitude of about 110 km with a 90-degree inclination (polar orbit). The six-man crews would be rotated at intervals of about 3 months. As in the space station, an artificial gravity environment of up to 0.5 g could be provided, if needed.

Planetary Missions

As our capability and experience with long-life manned space systems aboard a space station grows, as our knowledge of man's ability to survive and function in space is increased, and as the investigation of the surface of the moon progresses, it is likely that manned space exploration missions will turn to the planets in our solar system.

By means of fly-by's and probes, unmanned spacecraft of the Mariner series and similar U.S.S.R. flights have explored the topography and sparse atmosphere of Mars and examined the hot atmosphere of Venus. Recently, Pioneer 10 reached within 81,000 miles of the planet Jupiter transmitting voluminous data and thousands of pictures of its surface before continuing its journey out of the solar system. Viking, which is scheduled for launch in 1975, is planned to land on the Martian surface to perform *in situ* analyses of its soil and surface atmosphere and search for the presence of life. Future unmanned missions may eventually return samples of the Martian soil for detailed analysis on earth. It seems certain that unmanned exploration of the outer planets, Saturn through Pluto, will also be carried out in the future.

The unmanned missions are a necessary prerequisite for man's greatest venture into the unknown: his excursion to another planet many millions of kilometers away. Manned as well as further unmanned exploration of the planets would have as goals:

1. The improvement of our understanding of the solar system, its origin and evolution through the determination of the physical and chemical nature of other planetary bodies and the interplanetary medium.

2. The search for extraterrestrial life on other planets. It is currently thought that the

best planet for this purpose is Mars, where there are some expectations of life existing or having existed.

3. The development of a broader understanding of the earth and life on earth through comparative studies with other planets.

The planets within possible technological reach of manned missions during the next several decades are Mars, Venus, Mercury, and possibly Jupiter [23]. In addition, mission opportunities exist to a number of asteroids, such as Eros, Geographos, Toro, and Icarus. For the surface characteristics of these planets, reference is again made to Table 1. The asteroids have a surface gravity of 0 and no atmosphere. Since manned missions to the asteroids are technically easier to accomplish, they may precede Mars missions. Table 2 lists typical manned mission round trip durations and stopover times at the planets. In general, such manned trips are anticipated to be of 1-year duration and longer.

Because Mars is the most likely first target of a manned planetary mission, details of the probable mission profiles are given. As indicated in Table 2, there exist two classses of Mars missions: opposition and conjunction. Opposition-class missions are, in general, characterized by relatively short durations, short stay time at Mars, and high propulsive performance requirements. Within the opposition-class missions are the Venus swingby missions, which permit observations of both Mars and Venus during a single mission. The conjunction-class missions are, in general, characterized by lower propulsive performance requirements, longer durations, and longer Mars stay times.

A typical Mars opposition-class mission with a Venus inbound swingby (i.e., on the return trip) is shown in Figure 3. Upon departure from

TABLE 2 - TRIP DURATIONS OF MANNED PLANETARY MISSIONS

	Typical Total Mission Duration	Typical Portion Devoted to Stopover at Planet
MARS		
Conjunction	1000 days	460 days
Opposition, Venus Swingby	600 days	Up to 100 days
Opposition	450 days	Up to 30 days
VENUS		
Long Stay	800 days	450 days
Short Stay	400-500 days	40 days
MERCURY		
Direct	350 days	Up to 60 days
Venus Swingby	400 days	Up to 60 days
JUPITER	1500 days	Up to 60 days
ASTEROIDS	360-450 days	30 days

earth orbit, the space vehicle arrives at Mars after a 270-day transit. After an 80-day stay at Mars, the vehicle departs. The return trip to earth includes a swingby past Venus, 123 days after Mars departure. The remaining Venus-to-earth transfer requires 167 days. The total mission duration is 640 days.

The vehicle-sun distance history during the mission is illustrated in Figure 4, which shows that that maximum distance from the sun is 2.2×10^8 km and occurs upon arrival at Mars. The closest distance from the sun (perihelion) is 8×10^7 km and occurs during the vehicle passage between Venus and earth. The maximum distance between the space vehicle and earth is 2.8×10^8 km and occurs during the Mars-Venus leg of the journey.

A typical Mars conjunction-class mission is shown in Figure 5. The transit between earth and Mars requires 210 days. After a 580 day stay at Mars, the vehicle departs from earth. The return transit requires 250 days, making the total mission duration 1040 days. The maximum vehicle-sun distance occurs midway during the Mars stay and is 2.5×10^8 km. The maximum earth-to-vehicle distance of 4×10^8 km occurs at the same time.

A likely example of the acceleration profile of a manned mission to the planet Mars is given in Figure 6. Acceleration during launch into earth orbit will be about that of the space shuttle for which a maximum acceleration of 2.5 to 3 g's is foreseen. While in earth orbit, an artificial gravity of up to 0.5 g could be provided if needed. In the example shown, earth departure is accomplished by means of three propulsive impulses spaced about 18 hours apart. The maximum acceleration during the departure phase amounts to about 0.13 g. During the transit phase to Mars, the acceleration level is practically zero unless artificial gravity is provided. The acceleration loading during entry into the Martian atmosphere is shown at a maximum of 3.5 g's. A different atmospheric entry maneuver could reduce this level to as low as 0.7 g. During ascent from the surface of Mars to orbit, the acceleration will reach a level of about 1 g, while about 0.3 g will be reached during Mars orbit departure. The deceleration for capture into an earth orbit is about 0.2 g. Transfer of the crew from earth orbit is accomplished via space shuttle; there is a maximum deceleration of roughly 2 g's on reentry to earth. The crew size for such a planetary mission would be about 6 to 12, with the volume of crew living quarters about 1000 cubic feet (30 cubic meters) per man.

The capability for emergency return or rescue is very limited. Specifically, within 2 days after departure from earth orbit, a quick emergency return to earth orbit is still possible and would take only 1 or 2 days. During the transit period to the planet Mars, a quick return is no longer feasible, although it would be possible to reduce the nominal return time. For example, 50 days after departure from earth orbit, the return trip would take about 200 days. On the other hand, 120 days after departure the return would require about 350 days. Once the spacecraft has been placed in orbit about Mars, no reduction in return trip time is achievable.

MEDICAL AND BIOLOGICAL FACTORS IN MANNED MISSIONS

The biomedical research which will be needed to support these future missions is a subject of sufficient breadth and variety that it may be of practical benefit to begin by first establishing a serviceable organization of its content.

The outline offered (Table 3) divides the area into two major segments: factors which must be supplied to space flight personnel, and biomedical information to be gained from space missions. While these two basic elements are as distinctive as "intake and output", they are not entirely independent of each other. Information derived from crew responses to the flight environment supplied for a mission may lead to flight experiments. On the other hand, data obtained from flight experiments is often of importance toward improving flight crew support techniques and enhancing man's function in space. Indeed, this is a major purpose of the life sciences space flight experiments.

Both of these elements have in common the requirement for a strong foundation of ground-based research. In terms of the information needed, this total ground-based effort is, of itself, a scientific quest of significant magnitude. Its scope is extremely broad, it requires the inspired activities of many talented individuals of many scientific disciplines, and it is expensive to implement properly. As a fundamental part of the movement of our world to explore other worlds it seems clear that this large body of research would best be accomplished worldwide, both practically and ideally.

In the following paragraphs each of the factors outlined is reviewed, especially in light of research still to be accomplished to prepare for the three classes of missions discussed. Since a thorough review of each subject is the work of these entire volumes, comprehensive detail cannot be attempted. Instead, it is intended that the information needs

TABLE 3. BIOMEDICINE AND BEHAVIOR IN MANNED SPACE FLIGHT

I. Crew/Passenger Support
   1. Atmospheres
   2. Pressure suits and EVA (Extravehicular Activity) equipment
   3. Nutrition and food-water-waste management
   4. Hazard protection
      a. Toxic substances
      b. Particulate contamination
      c. Microbial hazards
      d. Electromagnetic forces
      e. Mechanical forces
      f. Micrometeoroids
      g. Fire hazard
   5. Clinical medicine; Preventive and Therapeutic
   6. Medical selection
   7. Training
   8. Group integrity
   9. Living conditions and standards
      a. Hygiene
      b. Work-rest-sleep cycles
      c. Volume requirements
      d. Clothing and laundry
      e. Furnishing and decor
      f. Exercise
      g. Diversions
   10. Performance factors
   11. Artificial gravity

II. Life Sciences Experiments
   1. Experiment content
      a. Medical
         (1) Neurophysiology
         (2) Pulmonary function
         (3) Cardiovascular function
         (4) Metabolism and nutrition
         (5) Endocrinology
         (6) Hematology
         (7) Microbiology and immunology
         (8) Behavioral response
         (9) Clinical medicine
      b. Biology
      c. Equipment Tests
   2. Experiment Support Equipment
      a. Bioinstrumentation
      b. Life Sciences Laboratory

identified will provoke thoughtful supplementation, planning, approaches to solutions, and constructive research in the direction of an internationally coordinated scientific effort.

I. CREW/PASSENGER SUPPORT

Atmospheres

The provision of a spacecraft atmosphere entails the establishment of desired levels, ranges, and limits of: total pressure, gaseous composition, humidity, temperature, and accumulations of toxic gases. In parallel with this medically oriented research is the hardware design and development to provide new, improved techniques and equipment to meet these specifications.

Although the first three United States manned space flight programs, Mercury, Gemini, and Apollo, provided spacecraft atmospheres of 100% oxygen at one-third sea level total pressure, future trends favor a progressively closer approximation to the sea level earth atmosphere for long-duration flights. There are two primary reasons. First, it is reasonable to assume that the gaseous environment in which man evolved, develops, grows, and lives is the one to which he is optimally adapted by nature. Although approximately 80% of this gaseous envelope is chemically inert, it cannot necessarily be assumed to be physiologically inert. The validation of alternative long-term artificial atmospheres for human physiological and functional normalcy would require a very large research effort, since possible gaseous combinations are virtually infinite and the burden of proof would rest with their proponents. Second, the interpretation of data derived from space flight medical experiments will be greatly facilitated by the removal of an unnatural gaseous environment as an experimental variable. Not only will requirements for expensive and complex long-term ground-based chamber studies be greatly reduced, but also flight findings will be more accurately interpretable.

The 5 psia (260 mm Hg) 100% oxygen atmosphere had the advantage of simplicity, low intrinsic weight, and reduced vehicular structural weight. Very importantly, it eliminated the threat of dysbarism during extravehicular activities in the 3 psia (155 mm Hg) suit. Its major disadvantages were the fire hazard which it imposed and its apparent action to reduce the mass of circulating red blood cells by mechanisms which are still not completely established. These problems, together with the reasons cited above, have resulted in abandonment of the pure oxygen cabin atmosphere for future manned space flights. Currently, increased launch power and vehicular load-carrying capacity have, in fact, devalued all of its advantages except one, elimination of the bends problem.

An appreciable amount of research has been done in several countries in an attempt to identify a gaseous mixture which would retain this advantage without disturbing the integrity of human function or creating new hazards. Helium-oxygen and other air substitutes have been studied but results, although promising in some respects, must be considered incomplete from the standpoint of validating long-term use. In the future, it might be more practical to place greater emphasis on dysbarism research which assumes nitrogen-oxygen cabin atmospheres with normal O_2 partial pressures and total pressures ranging from sea level downward, depending upon the mission characteristics anticipated. Such research would amplify nominal and emergency denitrogenization standards and techniques;

advance suit technology to permit greater freedom of movement at higher pressures; and develop in-flight therapeutic procedures and equipment. This work must be centered about not only the highly physically fit flight crew, but also the less stringently selected space flight passenger. Elucidation of the mechanisms of dysbarism and the effects of long-term exposures to non-sea level atmospheres will also continue to merit attention.

Temperature levels of 21° to 24° C (65° to 75° F), and a relative humidity of approximately 50% appear to be satisfactory. Technology to provide these levels in the spacecraft is currently available, but as new types of environmental control systems are developed, modifications and new component concepts may be required.

The setting of maximum CO_2 limits at 8 mm Hg, and approximately three times that figure for short-term emergencies, appears to be sound for purposes of safety. The extent to which prolonged exposure to such ranges as 4 to 8 mm Hg CO_2 might interfere with in-flight physiological investigations has not been precisely determined, but the probability of significant influence appears small.

Carbon monoxide accumulations should not be permitted to exceed 0.01 mm Hg. Visual effects have been observed at levels as low as 0.013 mm Hg [32]. Little carbon monoxide is produced endogenously but significant amounts may accumulate within the spacecraft over periods of a month or more unless ventilation and scrubbing methods are adequate. Other possible sources such as leakage from Bosch or similar CO_2 removal systems must be rigidly prevented.

Spacecraft ventilation requirements are determined largely by comfort factors and adequacy of flow rates through environmental control systems to permit their operation within established specifications. Ventilation must be pervasive enough to prevent pocketed accumulations of untreated cabin air.

For very long-term missions such as future lunar and planetary flights, increasing emphasis must be placed on regenerative systems. There is great need for continuing progress and innovation in perfecting present concepts and creating new ones. From time to time longer term testing of newly developed components in inhabited integrated systems will continue to be required. By means of careful preplanning such tests can be utilized as excellent sources of ground-based human data in many other areas of biomedical importance, as has been done in the past [5, 26]. The systems selected for any of the three classes of missions will depend on the duration of flight, crew size, power-weight-volume capacity of the vehicle, feasibility of resupply, and the state-of-the-art of regenerative systems. In general, environmental control systems requirements for stations on lunar or planetary surfaces will follow the same principles as those for manned spacecraft.

Pressure Suits and Extravehicular Activity Equipment

The full pressure suit is basically a portable environment essential for the performance of tasks away from the spacecraft. It is also a "cocoon" of refuge in the event of any failure of the spacecraft environment. Although used for relatively short periods, it must have the same protective characteristics as the spacecraft, itself, with modifications that both provide and utilize its mobility. It must supply a gaseous environment to support life and vigorous activity, adequately remove metabolic heat, prevent accumulations of toxic products, and protect against extreme ambient temperatures, micrometeoroids, high-intensity electromagnetic energies, and mechanical wear and tear. It must permit normal bodily functions such as eating and the discharge of wastes, and still afford maximum mobility and manipulative freedom. For EVA activities, it must permit the integration of space maneuvering units and sufficient dexterity for handling tools.

The Apollo Portable Life Support System, thermal garment, micrometeroid protection, ultraviolet filtration, water cooling, and urine management techniques have proven very satisfactory for the time required on the lunar surface as well as in space. For radiation protection, reliance was placed on probabilities of freedom from solar storms and the ability to move quickly to the relative shelter of the lunar module, and from there to the orbiting command module and return to earth. The Skylab EVA system consisted of a slightly modified Apollo suit used with an umbilical. It proved to be fully satisfactory for the tasks assigned.

Present soft suits provide reasonable maneuverability and dexterity if operated at 3 psia (155 mm Hg). At 5 psia (260 mm Hg), these attributes are seriously impaired. At higher pressures, even the most highly trained athlete is helplessly transfixed in a fully supine, doll-like attitude. Research into the capabilities of suits made of harder materials has resulted in the retention of some maneuverability at higher pressures, but movements are somewhat awkward and the suits are excessively bulky and difficult to store.

Among the goals to be achieved in future pressure suit research, foremost is increased ease of coarse and fine movement during operation at significantly higher pressures. Ideally, a suit pressure approximating cabin pressure would eradicate the specter of dysbarism, and a cabin atmosphere approximating sea level would fully satisfy all physiological and experimental requirements of the spacecraft gaseous environment. An easily stored, quickly donned, relatively long-duration suit with all of these utopian attributes need not necessarily remain beyond the range of our rapidly growing technology.

Nutrition and Food, Water and Waste Management

Apollo information indicated that caloric requirements in weightless space will probably be less than those on earth, based on reasoning from the 1/6 g data obtained. By indirect measurement from three forms of data, heart rate, suit coolant-water temperature, and oxygen consumption, metabolic costs of lunar surface activity averaged approximately 1200 Btu/hour (300 kcal/hour), significantly less than with commensurate earth-based work [2, 14]. *Ad libitum* caloric intake showed a wide range of individual variation in the Apollo program, but the reasons varied, and cause-and-effect relationships or even trends cannot yet be established. Skylab data are not yet completely analyzed but in-flight controlled studies will continue to be required in the future, owing to the many factors involved and high degrees of individual variation. The resulting data will have direct bearing on problems of food logistics and the support of man.

Food provisions allowing for an average daily intake of approximately 2800 k calories per day per man should be adequate for planning according to present indications. Skylab menus were planned successfully on the basis of 300 k calories per day less than individual averages on earth, and supplements were provided. The caloric intakes of some crewmen were phenomenally high normally, and were correspondingly high in space. Food composition similar to earth diets proved entirely satisfactory. It differed only where specific dietary controls were needed for experimental purposes. Protein intake of high quality was supplied at approximately 1.5 to 2 grams per kilogram body weight per day which, on the average, matched consumption. Standard vitamin requirements were assured by means of a standard minimum daily requirement tablet taken daily. There is some evidence to consider supplemental Vitamin E if exposure to high oxygen environments are anticipated [8], and mineral and trace mineral supplements if the diet is high in foods processed by chelation [32]. Vitamin D supplementation would seem indicated to compensate for lack of direct exposure to sunlight. There appears to be a valid case for increasing calcium and phosphorus intake to about double the normal daily required levels (i.e., to 2 grams and 3 grams, respectively) on very long missions to decrease the rate of bone demineralization [13]. Salt supplements should be carried in the event of exposures to excessive thermal stress. Skylab metabolic balance experiments required rigid control of the dietary intakes of calcium, phosphorus, sodium and magnesium. Potable water supplies providing for a daily intake for all metabolic purposes (food preparation included) of approximately 3 to 3.5 liters per man per day should be adequate. It would seem advisable to establish a daily minimum intake of about 1.5 liters per day for each crewmember to prevent dehydration and possible nephrolithiasis. Skylab potable water supplies were provided on the basis of 7.5 lbs. (3.5 liters) per man per day. Actual use on Skylab 2 averaged 75% of this amount; 90% on Skylab 3; and 90% on Skylab 4.

From the systems point of view, future research in food, water and waste management should be continued in the same three primary directions to perfect past accomplishments. These are to: provide crew nutritional support with improved ease, palatability, and aesthetic standards; furnish medical experiment requirements with maximum precision and simplicity; and develop improved regenerative systems. Although food storage and logistics problems will be a limiting factor, food systems research should be oriented toward providing nutritional and enjoyable earth-type meals with minimal artificial processing for storage. Ideally, menus should be punctuated with special meals of unprocessed natural food such as frozen poultry or steaks for morale purposes, as well as to provide needed roughage, dental exercise, and trace components. Requirements for containers can be relaxed to some extent since it has been demonstrated on Apollo and Skylab that foods with relatively small cohesive properties are easily handled with a spoon during weightless flight. Development of rather simple mechanical contrivances, such as a glove-box type of food preparation unit, might materially enhance appetite and morale by making it possible for the crew to prepare cooked foods, sandwiches, salads, and snacks.

Convenient techniques for precisely recording intakes of food, food components, and fluid should be available for scientific data. Real time readouts by individual crew members would make possible constant intakes of specific components, such as calcium, where necessary for experimental purposes. In support of medical experiments, urine and fecal outputs should also be recorded by automated means to minimize the need for crew intervention. Similarly, automated methods should be developed for the taking, packaging, and labeling of accurately measured urinary and fecal samples.

The disposal of fecal wastes is perhaps best accomplished by vacuum dehydration or freeze drying. Incineration or possibly some form of reutilization would resolve the problem of storing dried fecal material on long-duration flights. Water reclamation from urine is already within the state-of-the-art, but these techniques must be further perfected. Improved methods of preserving water for long periods and testing it at frequent intervals for chemical and microbial content must continue to be sought.

Hazard Protection

A good deal of forethought and preventive planning will continue to be required to protect crews against the potential environmental hazards which are either uniquely important or inherently unique to space flight. These may be classified as: toxic substances; particulate contamination; microbial hazards; radiation; mechanical forces; micrometeroids; and fire.

In dealing with toxic contamination, attention must be given to potential sources, means of transmission, purifying techniques, maximum acceptable concentrations, and therapeutic procedures. The variety of materials used within the spacecraft makes the range of potentially toxic substances quite broad. Significant levels can develop by simple accumulation, outgassing at sub-sea level pressures, increased rates of oxidation at high oxygen partial pressures, interactions with other spacecraft materials or energies, microbial action, failure of scrubbing devices or techniques, and leakage of contained substances such as coolants or fire extinguishing chemicals. All materials carried aboard the spacecraft must be considered as potential sources of toxicity. This is to include not only the substances of spacecraft systems, supplies and accommodations, but also human endogenous sources, experimental animals and plants, and the reagents, supplies, and various forms of apparatus used for all in-flight experiments. The means of transmission of toxic agents to onboard personnel parallel the three classic portals of entry into the body; the lungs, the gastrointestinal tract, and the skin, either by contact or accidental penetration. The vectors of concern, therefore, are gaseous and particulate contamination of the atmosphere; food, water, and accidental ingestibles; and wash water, soaps, clothes, laundry materials, bedding, and all equipment, materials and substances with which the human occupant will be in living and working contact.

Because the use of potentially toxic materials cannot be completely avoided, technical advancement must continue in developing sensors and purifying techniques for all modes of transmission. Filters, catalytic burners, exchange resins, semipermeable membranes, adsorbants and various combinations of these and other techniques need further investigation.

Maximum acceptable concentrations have been established for an extremely wide range of contaminants on earth, but almost all are based on 8-hour workday exposures. Relatively few limits have been established for 24-hour-a-day living environments. While this task applies less to ingested toxins than to the respiratory and contact vectors, it remains a formidable future research assignment.

The development of therapeutic procedures will continue to be accomplished primarily by nonspace-oriented clinical research. It is anticipated, however, that a few specific therapeutic problems may arise because of substances which may be uniquely produced by interactions within the spacecraft or space suit environment.

The more or less even distribution of particulate matter in the weightless atmosphere is a unique problem of space flight. These particles can be considered to consist of both soluble and insoluble substances, which by virtue of their protean distribution, are potential toxic hazards through all three portals of entry into the body. Insoluble materials such as fiber glass, asbestos, silicone, etc. must be minimized to prevent pneumoconiosis. Even more emphatically, beryllium and cadmium must be entirely eliminated from the spacecraft because of their extreme toxicity. The problems of particulate contamination should be largely preventable by avoiding the use of certain materials within the spacecraft and by providing on board control through effective airflow and filtration systems.

Possible changes in the microbial ecology on long-duration space flight were postulated as a potential problem area several years ago [4]. Ground-based and space flight evidence has been accumulated since, which appears to lend some support to that hypothesis [2, 14, 31]. The distribution of bacteria among crewmembers tends to become homogenous and there is some evidence that the relative dominance of pathogens may change in this closed microcosm. Tenable hypotheses have also been expressed concerning microbial genetic changes as a consequence of the space environment, as well as alterations of host resistance in human occupants who have been removed from the daily microbial assaults of ordinary living [30]. The microbial problem warrants a considerable amount of ground-based as well as in-flight amplification, especially in light of the fact that experimental findings can be expected to be influenced by so many variables, such as initial microbial populations, carrier states, individual resistance, interpersonal proximity, spacecraft or simulator volume, sources of contamination, and personal hygiene. While prevention of infectious disease aboard is a clear requirement, the possibility of microbial shock postflight militates against a sterile spacecraft environment. Consequently, the advancement of such methodologies as microbial filtration, food and water purification and preservation techniques, and perhaps selective destruction of specific kinds of bacteria, viruses, or fungi, in fact, all microbial ecological control and monitoring techniques would best be oriented to the preservation of an earth-simulated microbial environment.

Areas of particular interest within the radiation spectrum are ionizing radiation, and the ultraviolet, visible, and infrared ranges. The three kinds of ionizing radiation with which we must deal in space are now well established. They are the trapped radiation, the protons and electrons trapped by the earth's geomagnetic field to form the belts of radiation enveloping the earth; the solar flares which result in the eruption of protons, alpha-particles, and small fluxes of heavy nuclei into space; and cosmic or galactic radiation containing extremely high-energy particles of protons, alpha-particles, and heavy nuclei ranging through z-numbers of 26 and higher. Our orbital and lunar manned space flights to date have shown that our preflight calculations have tended to err slightly on the high side. Actual doses received by the astronaut flight crews have been extremely small [2, 14, 20, 21, 22]. The timing of lunar flights to avoid solar flares proved to be both well-planned and fortunate, since no flares were encountered.

An observation made by our Apollo lunar crews, however, may well be related to the relatively infrequent strikes of high-energy cosmic primaries (HZE). Similar occurrences have also been reported by Skylab crews. This is the "flashes of light" phenomenon. The relationship has not yet been established conclusively, however, nor the mechanisms which produce the phenomenon.

As flight durations lengthen, much more information will be needed concerning the acute, subacute, and chronic effects of ionizing radiation in terms of both somatic and genetic effects [16]. The relationship between specific dose levels and effects produced (symptoms, signs, pathology, recoverability, etc.) must be discerned for the types and energies of radiation which will be encountered in space. Very importantly, the modifying influence of dose rates, especially low dose rates, requires amplification. Questions concerning the effects of dose fractionation, nonuniform dose distribution, and linear energy transfer (LET) properties on injury and recovery times, and the influence of space flight physiological changes on susceptibility to radiation injury must be investigated. Finally, the technology of radiation dosimetry and the development of preventive or modifying medication are in need of more research. Continuing work in radiation shielding must also be emphasized, but as long as shielding effectiveness is a function of its density (disregarding for the moment its proclivity to produce secondaries), duration of flight as a function of acceptable radiation dosages will vary according to the weight load capacity of the spacecraft.

Protection of the space crews and passengers, particularly eyes and skin, from the potential hazards of ultraviolet, visible light, and infrared radiations of high intensities is of considerable importance. Knowledge of these dangers and protective techniques, however, is in general fairly well established. A special case within the visible light spectrum is the laser, since it is possible that laser technology may be utilized for instrumentation aboard spacecraft of the future. Safety and protective techniques will be required.

The potential hazards of mechanical forces are well-known, having been under study for many years in aviation as well as the relatively recent space program. The field includes the effects of noise and vibration as well as angular and linear acceleration forces of the long-duration, medium, and impact types. Although the general state-of-the-art with respect to tolerance limits and attenuation devices is quite well advanced, this research should continue because specific applications will be required and improvements desired. The acceleration profile of a given class of missions can be controlled as a function of the power of the launch vehicle and return mode, but contingency modes and violent emergencies must be anticipated as well as changes in g tolerance after extended periods of weightlessness. Extensive research into the effects of noise has resulted in the establishment of acceptable limits, but considerably less is known about long-term postexposure effects.

The probability of micrometeoroid penetration is relatively small, but introduces the possibility of decompression and, if the cabin oxygen partial pressure is high, the additional danger of flash fire. It is unlikely that decompression from this source would be explosive in character. Yet, in order to avoid dangerous reductions in pressure and to conserve cabin atmosphere, efforts should be directed toward development of an immediate warning system which would not only indicate a puncture, but also its precise location. Repair techniques, automatic puncture-sealing technology, and puncture prevention by means of lining materials, laminated coats, or other devices, must also be investigated, for space suits as well as cabins and shelters.

The danger of fire is an important threat to the safety of flight crews. Although future U.S. plans no longer call for a spacecraft atmosphere of 100% oxygen, the fire hazard is only reduced, not by any means eliminated. As partial pressures of nitrogen approach those of sea level atmosphere, the danger of fire approaches that at sea level. Although sources of ignition within the spacesuit are very minimal, operation at 100% oxygen, if only at 3 psia (155 mm Hg), still poses a greater potential threat than a mixed gas spacecraft atmosphere. Fire prevention requires the use of materials of very low flammability with relatively high ignition temperatures, low propagation rates, and minimal production of toxic materials on burning. The spacecraft must be scrutinized for ignition sources which must be contained. Volatile substances must be eliminated or scrupulously controlled. An immediate alarm system must be developed, and quick-response, automatic, nontoxic extinguishment techniques developed and employed. The capability of isolating at least one compartment of the spacecraft as a fire and smoke refuge should be seriously considered.

Clinical Medicine, Preventive and Therapeutic

Preventive medical procedures are directed toward maintaining optimal health of flight crews prior to flight, and minimizing possibilities of preflight contact with transmissible diseases which might become manifest during flight. Broadly, this entails attention to adequate nutrition, sleep, exercise, emotional well-being, and group compatibility; the implementation of an adequate schedule of preflight physical examinations; and isolation of the crew to the extent practicable from all other individuals for a reasonably selected incubation period prior to flight. Where feasible, inoculations should be instituted against diseases which may have been carried by suspected contacts. All preflight contacts, of course, must be carefully screened. Research to improve methods for the early detection of communicable disease is particularly important.

In-flight therapy on future extended missions will necessitate a considerably expanded capability, depending upon the characteristics of the mission. The level of sophistication of treatment facilities and personnel will vary as a function of such factors as duration of flight, "space ambulance" availability, and size and makeup of on-board personnel, i.e., age ranges, physical qualifications, inclusion of both sexes, and level of training of on-board medical and dental personnel. For missions of approximately 30 days or more with scientists or other passengers aboard it would seem wise to carry a physician crewmember. His equipment would be the equivalent of a large physician's bag plus that ordinarily found in an emergency room. He would be able to treat discomforts, acute illnesses, and a wide range of injuries, serving to protect the crew and its morale. He would provide the important diagnostic acumen to prevent the unnecessary abort of the mission.

A larger capability would be needed for a larger crew or longer duration mission; but, there is no real need for greater sophistication, as long as the flight is orbital, which can be aborted or reached by a shuttle or its equivalent on relatively short notice.

The most extensive in-flight therapeutic requirement would apply to a distant planetary mission with an intended duration of 1 to 3 years, and a large crew composed of both sexes of ages ranging to 55. Such a flight would require a medical and surgical team capable in all medical specialties as well as dentistry. Appropriate clinical facilities would be the equivalent of a small but fully equipped hospital.

Future research in this area will involve the development of equipment and techniques suited to a full array of medical and surgical procedures in weightless flight.

Although postlunar quarantine is no longer considered necessary, preparations to reinstitute these procedures following other planetary missions must be maintained, and improved techniques must continue to be pursued.

Medical Selection

The basic objectives of medical selection are to prevent, to the greatest extent possible, adverse effects during space flight or space flight training by applying carefully selected principles and techniques to screen out candidates with identifiable predisposing characteristics. It is the first and one of the most important steps in preventive medicine as applied to flight crews. The trend since the beginning of the U.S. manned space flight experience has been to eliminate the extremely rigorous selection tests used originally, such as the thermal and isolation tests. In addition, the training period has come to be increasingly regarded as a part of the selection process. Extensive jet flight experience in pilot astronauts, however, has proven so valuable a selection criterion that even nonaviator scientist-astronauts now routinely receive jet pilot training.

It seems reasonable to believe that the future course of medical selection criteria will parallel the history of aviation medical requirements. As space flight experience increases, as crew protective and supportive equipment is improved, as larger vehicles permit more room for the various niceties of life, and as space flight becomes more routinized in the future, it is envisioned that medical selection requirements will approach the categories and standards of criteria now established for aviation physical examinations. Whereas pilot standards will always remain high, medical standards for other specialized crewmembers will probably become less exacting and those for passengers might eventually become relatively minimal. At the same time, relaxation to the level of standards for present-day commercial passengers will probably not occur for a very long time.

The area warrants continuing reevaluation and considered thought along with the development of new, more relevant diagnostic techniques. The success, pertinence, and specificity of criteria used in the past must be continually reassessed against cumulative experience and modified accordingly.

Training

Training is another area calling for continuing study, for appraising and reappraising the relative values of techniques which have been employed by matching them against the events of each mission. The U.S. experience, overall, has tended to endorse our selection and training procedures. The astronauts have responded uniformly well to both nominal and emergency requirements. One of the greatest problems which has confronted us has been shortness of time. Training schedules are persistently crowded despite the fact that our flight crews have been uniformly avid, retentive, and rapid learners. Considering the complexities of the three classes of future flights under discussion, it may be decidedly advantageous to develop techniques to enhance learning speed without adversely affecting retention or well being.

The training of scientist-astronauts necessitates indoctrinating these highly qualified young scientists in the characteristics, sensations, techniques, procedures, and equipment of space flight, and at the same time providing time and opportunity for them to continue to advance in their respective scientific fields. As noted above, an important part of this training is jet pilot instruction for those not previously qualified, and continuation of jet flight experience afterward on a regular and frequent basis.

The multifaceted missions and relatively small crews of the near future will require considerable cross-disciplinary training. As crews become larger, even greater mission accomplishments will be obtainable through increased crew specialization. Still larger crews will permit redundancy within each specialty. Improved full and partial flight simulators, cross-training methods, and within-discipline training and reinforcement techniques merit continuing research.

Group Integrity

Group integrity may be defined as the efficient and harmonious functioning of a group or team of individuals. Both Soviet and American manned space mission have progressed beyond the initial single-man flight to two, and now three-man crews. Continuing expansion of space flight objectives and capabilities will result in very long missions and larger, more diversely specialized crews. The need for these people to live and work together and depend upon each other for extended periods has unique and important implications with respect to selection, training and on board reenforcement of group harmony. Group performance can be either more or less than the sum of the capabilities of its component personnel, for even highly qualified, strongly motivated, and emotionally stable individuals may form a disharmonious, noncohesive, and inefficient group [32]. Ideally, a well-selected and trained socially isolated team should function harmoniously and with synergistic efficiency under all nominal and emergency conditions, and should resist the deteriorative effects of time.

Although several studies have been carried out under a variety of conditions of group isolation, our current knowledge of the subject is far from adequate [29]. Furthermore, the complexity of variables influencing such studies and the relative infrequency of opportunities for them lead one to expect that significant conclusions will require many years of continuing research. Some of the more prominent component problem areas to be evaluated are: group efficiency as a function of individual contribution and as a function of individual personality characteristics; adaptation of the individual to group stresses and flexibility of adjustment; group function under various adverse conditions and as related to time; identification of group morale factors and preventive, corrective, and maintenance techniques; and the establishment of criteria and, where necessary, more sensitive and discriminating measurement procedures for selection of individuals as group members and leaders. These and related questions will be difficult and time-consuming to resolve. This highly significant research must therefore be strongly emphasized now, if usable conclusions are to be available for the more arduous space journeys of the future.

Living Conditions and Standards

The term, living conditions and standards, is intended to denote an area which gives consideration to the comforts and conveniences of normal human patterns of living with the objective of maintaining normal physical, emotional, motivational, and intellectual aptitudes and enhancing individual and team efficiency. Whereas living conditions aboard early manned space vehicles were considerably austere, these were, after all, initial flight tests of very short duration. As we have progressed, spacecraft comforts and conveniences were only moderately improved through Apollo and Soyuz, since flight durations increased to a maximum of only 2 weeks for U.S. flights and 18 days for the Soviet experience (Soyuz-9) [25]. Accommodations aboard Skylab were significantly advanced and generally proved to be quite adequate for three astronauts for 84 days. Progressive lengthening of manned space flights of the future will require significantly increased attention to these provisions, especially with the addition of non-astronaut passengers aboard. Specific factors within this area include hygiene, work-rest-sleep cycles, volume requirements, clothing and laundry, housekeeping, furnishings and decor, exercise, and diversions.

There are many elements to be considered within the scope of body hygiene. From the standpoint of morale, it would be wise to maintain a high on board standard of personal appearance, dress, and general cleanliness within the spacecraft. Body cleansing techniques suitable for the weightless environment will require continuing developmental efforts. The control of body odors will be essential. Some effort must be sustained to improve methods for maintaining optimal dental hygiene and carrying out such mundane functions as shaving, nail clipping, and haircutting, so as to minimize particulate contamination of the spacecraft atmosphere. The management of body wastes will require facilities which must be suitable aesthetically as well as hygienically.

Past research in work-rest-sleep cycles has affirmed that the most desirable schedule is the one to which we are accustomed on earth [32]. Although man can adapt to variations, such adaptation is probably not complete, nor does it occur at the same rate for all individuals. The 24-hour schedule which would seem most satisfactory for long-sustained missions would consist of 8 hours of uninterrupted sleep, 8 hours of work interrupted by meals and suitable breaks, and the remaining 8 hours devoted to personal needs, elective activities, and recreation. If the flight team is large enough, it may be advisable to divide it into two groups operating 12 hours out of cycle. Studies indicate that the cycle chosen should be adhered to throughout the mission with as little change as possible.

Circadian research has shown that man is best adjusted to a 24-hour diurnal cycle, by training if not by nature. It is something of a paradox that man's natural rhythm is approximately 25 hours, according to the preponderance of evidence derived from free-running studies. This feature can be used advantageously in situations where it becomes necessary to shift to a new 24 hour day. Indications are that the days may be extended to 25 hours each day without ill effect by increasing sleep periods to 9 hours until the new start point is reached [33].

Currently there are no universally accepted standards of minimum living space for flight crews. This depends a great deal on not only the size of the flight crew, but also such factors as age and sex composition, and duration and kind of mission. A few basic principles are generally accepted, however. The importance of an area of privacy for each individual, even if only a bunk and foot locker, is worthy of emphasis. Generally, it is advisable to separate the recreation area from the work areas. As vehicular size increases, it should be possible to provide room volumes, arrangements, and accommodations approximating those aboard small naval vessels.

Clothing should be comfortable, nonallergenic, nonirritating, nonflammable, and easily cleaned. The cleated shoes developed for Skylab were comfortably functional on the grid floor. However, other forms of flooring in future vehicles will call for a different type of semi-adherent or optionally adherent shoe. Protective gloves should be provided for tasks requiring them. Effective, nonbreakable protective goggles or glasses should also be provided. All clothing materials, like all materials aboard the spacecraft, must be nontoxic. Lint production must be minimized. Laundry facilities, designed to function in weightlessness, must be provided unless trade-off studies favor the alternative of disposable clothing. New principles, such as ultrasonic cleaning, warrant investigation. New principles should also be pursued with respect to trash disposal since housekeeping will pose a major problem in long-term flight.

Furnishings, illumination, and decor should be designed for pleasant, comfortable, and safe living within the spacecraft. For either weightless or rotating space flight modes they may also be designed to aid visual orientation. Room decoration, furniture, and lighting can and should be fashioned to be conducive to the functions intended, whether work, sleep, relaxation, or recreation. The present state-of-the-art is already quite well advanced in these areas.

Exercise is important not only physiologically but also as a recreational activity simply because it makes one feel better. New kinds of competitive and noncompetitive recreational exercise suitable for weightless flight need to be developed.

Books, radio, television, games, playing cards, writing materials, educational courses, and other diversionary activities must be provided. Research in this area should be directed not only to the adaptability of these games and materials to weightlessness, but also toward determination of the kinds of competitive activity which will be helpful, and those which may lead to group disharmony.

Performance Factors

Performance factors may be described as equipment, techniques, and design considerations dedicated to the enhancement of task performance efficiency. This field, also called Human Engineering or Man-Machine Integration, deals with the design of any machine or piece of equipment used or manipulated by man to best fit his anatomical, perceptual, intellectual, and motor characteristics for maximum ease, safety, and productivity. Its major origin and impetus was in aviation, where contributing specialties such as anthropometry were developed to a high level of sophistication. Continued expansion of this type of research in the interest of manned space flight has resulted in a quantity of available information on such factors as optimal sizes and shapes of seats, equipment arrangements, switch buttons and toggles and on operator information devices such as dials, gauges, and viewing screens. Yet there is need for continuing research since much of this knowledge is specific for specific kinds of equipment.

Perhaps a major element of our work in the future will center on the determination of those tasks which can best be carried out by man as opposed to those accomplished better by automated techniques. Remote operation is a special form of automation of extremely promising value. Man's capabilities are hopelessly beyond those of the most sophisticated machines ever conceived. His inventiveness and his judgment are entirely unique. The scope of his perception and quality of his responses cannot be duplicated. On the deficit side, however, he is a fragile entity who requires a great deal of support and supply, and he is a relatively slow traveler compared to transmitted energies. Through automated remote operation from the ground, or even more intriguing, from a manned spacecraft, the best attributes of man and machine can be effectively combined to extend man's intelligence through forbiddingly distant and dangerous zones. The Soviet remote lunar exploration with return of soil samples was a remarkable demonstration of this technology.

Lastly, the enhancement of human performance and task accomplishment in space must continue to be concerned with the design of adequate body restraints, mobility aids, tools and similar devices adapted for use under the particular circumstances required, whether weightless, during spacecraft rotation, or on lunar or planetary surfaces. The importance of these aids has been amply demonstrated in past American and Soviet experience. From the standpoint of future research, work aids of this sort will probably not be developed primarily by the life scientist. Astronomy instrumentation will be developed by the astronomers, geological equipment by geologists, and vehicular repair tools by spacecraft engineers. The role of the life scientist remains prominent, however, in evaluating and prescribing steps to assure optimal form, fit, and function of the instrument to the structure and function of the man.

Artificial Gravity

Now that Skylab flight crews have successfully achieved up to 84 days of continuous weightlessness without serious overt duration-related physical difficulties, the need for artificial gravity to maintain crew well being on missions of extremely long duration has become even less likely than before. It seems increasingly apparent that prevention of the physiological changes which do occur will be amenable to much simpler countermeasures than this cumbersome concept. Nevertheless, it is quite possible that at some time in the future vehicle rotation may be considered desireable for purposes of housekeeping and creature comforts. Such a case might be a very large semi-permanent space station meant to accommodate ordinary unindoctrinated passengers and, perhaps, long term resident crews. For this reason, as well as to add more to our knowledge of human vestibular system function as it relates to the space motion sickness phenomenon, research continues to be indicated to further explore effects, optimum procedures, and methods to counteract symptomatology of artificial gravity in space.

At present, the only practical method of producing artificial gravity is by rotation of the spacecraft. Although rotation of the individual on an on board centrifuge appears to offer a reasonable alternative, the short radius and relatively high rotation rates involved are likely to produce more physiological disturbances than the techniques can resolve. In addition, housekeeping and other problems which would be eased by spacecraft rotation are not affected by the on board centrifuge.

Spacecraft rotation poses a number of human physiological and performance problems as well as those referable to the design, navigation, and operation of the spacecraft. The primary focus of potential physiological difficulty is on equilibrium and the vestibular system, which in turn impact performance and habitability factors. Potential difficulties such as motion sickness, the tendency to fall in one direction while ascending and the opposite while descending ladders, the imposition of greater gravity levels while walking in one direction than the other, as well as head turning, past pointing, and other manipulative problems are well-known. Ground-based research must seek ways of reducing these effects and explore more thoroughly methods of determining optimal gravity levels and rotation rates, and the effects of rapid transitions from one gravity level to another within the artificial gravity field. At the same time, spacecraft-oriented studies should be undertaken to determine design requirements for the most efficient means of providing artificial gravity in-flight. Because the 1 g vector cannot be eradicated on earth, the final resolution of these problems will require at least one well-executed in-flight study on a rotating spacecraft, the value of which will depend heavily on careful ground-based research.

A related problem in the field of space biology requires earlier resolution. The opinion has been responsibly expressed that in order to provide truly adequate controls for flight experiments in gravitational biology, the control group of specimens should be flown aboard the same space flight as the experimental group and exposed to 1 g throughout the weightless period of flight. Furthermore, if artificial g is to be provided for this purpose, additional valuable information can be gained by flying similar specimens at specific gradient levels of g, both below and above 1 g. While this would unquestionably be an ideal protocol, the restriction of our ability to provide these g forces to an on-board centrifuge imposes angular acceleration problems and associated experimental artifacts which could be considerably less than ideal. Specific trade off studies are needed with respect to this important and far reaching experimental problem.

II. LIFE SCIENCES EXPERIMENTS

Medical Experiments

The objectives of the medical experiments program are given in Table 4. The first category of objectives, it will be recognized, is geared toward manned space flight. The purpose of its four constituent objectives is to determine as precisely as possible man's medical and behavioral responses, functional limitations, and supportive requirements in space flight. This kind of information is essential to the planning of future manned space flight. The second category is oriented to the advancement

TABLE 4 - MEDICAL EXPERIMENTS OBJECTIVES

A. To extend man's capabilities in manned space flight by determining:

1. The effect of space flight on man and the time course of these effects.
2. The specific etiologies and mechanisms by which these effects are mediated.
3. Means of predicting the onset and severity of undesirable effects.
4. The most effective means of prevention or correction of undesirable effects.

B. To obtain scientific information of value to conventional medical research and practice.

of earth-based biomedical research by utilizing the unique environmental characteristics of space for scientific information, whether or not the resulting data will be applicable to manned space flight. These experiments use space flight as a scientific opportunity.

Because we are dealing with a largely unknown environment, the medical experiments conducted aboard each mission should be more broadly directed than the exploration of known or anticipated problems. To the extent possible, they must include a "monitoring" of all human systems in as much depth as is practical. All manned space flight missions should provide for medical investigations, because flight opportunities are infrequent and redundant human data is essential for statistical validity. It is especially important that flights of increasing durations be utilized fully, even primarily, for gathering medical information since the length of crew existence in space must be considered the chief variable of medical concern. Of the environmental factors affecting man in space, such as acceleration, radiation, social isolation, confinement, etc., the most unique and unknown is clearly long-duration weightlessness. Yet the effects of all factors must be evaluated, both singly and in combination.

In planning an adequate program of in-flight medical experiments, it is necessary first to formulate the problems to be resolved in order of importance. How specifically these problems are defined will continue to depend on the knowledge derived from space flight and ground-based research. As problem specificity narrows, in-flight medical investigations will in turn focus upon greater levels of detail. In the cardiovascular area, for example, the broad question of responsiveness in and after space flight has now yielded more specific problems such as the roles of reninangiotensin and aldosterone, cardiac stroke volume changes and their role in postflight exercise tolerance recovery, the relative importance of the Gauer-Henry reflex, and the influence of potassium loss on the development of premature contractions. Similar areas in which our experience has led to more refined problem definition include body fluid distribution, red cell mass changes, vestibular effects, musculoskeletal integrity, and the distribution and control of sodium and other electrolytes.

Biomedical findings from more recent U.S. and U.S.S.R. manned space flight experience have been summarized [2, 3, 12]. Now, Skylab findings have added greatly to our understanding of these problem areas and have further amplified problem specificity. Red cell mass losses were significant despite minimal exposure to 100% oxygen. Paradoxically, these losses were greatest and recovery times longest in the Skylab 2 crew (28 day flight), and least and shortest, respectively, in the Skylab 4 crew (84 day flight), a finding which raises new questions concerning the specific etiology and basic mechanisms involved. Cardiovascular responses to lower body negative pressure were characterized by increased compensatory heart rates and decreased pulse pressures approximately as anticipated, and may have reached a plateau during Skylab 4. They varied somewhat during flight to the extent that the LBNP procedure had to be aborted on occasion, but the same individual usually tolerated the full LBNP protocol during the next scheduled test. This demonstrates very well, for the first time during space missions, the point that LBNP tolerance is tangibly influenced by factors other than weightlessness, as one would expect. Generally, the first LBNP responses after return to earth matched quite well those obtained from the last in-flight tests.

Here again, however, the time required to return to preflight values was shorter after the two longer flights than after the 28 day flight, probably reflecting the beneficial influence of the far heavier personal exercise schedules of the last two flight crews. In-flight exercise response tests showed no appreciable changes, but tolerances were significantly reduced after earth return. Once more, postflight recoveries were faster following the two longer flights. Cardiac output and stroke volume were reduced postflight compared with preflight. Despite bicycle and other forms of exercise aboard, calf dimensions and leg volumes were considerably less postflight than preflight. Weight losses were not appreciably influenced by flight duration, but were greater early than later during flight. Similarly, postflight weight gain was sharper within the first one or two days after recovery.

Vestibular effects were manifested as space motion sickness which was severe enough to impair task performance during the first three days of Skylab 3. Although the Skylab 2 crew was untroubled by such symptoms, all three crew members of Skylab 3 were afflicted. Symptoms did respond to anti-motion sickness medication and cleared after the initial three days of flight. Preventive medication was used for the Skylab 4 crew, nevertheless one crew member did develope this syndrome for a short time. He was also symptom free after the first three days of flight. Contrary to expectations, tolerances to head motions during rotation on the litter chair were much greater inflight than preflight, uniformly permitting advancement to the maximum protocol of 150 head motions at a rotation rate of 30 RPM. Postflight vestibular responses consisted of unsteadiness of gait the first day, dizziness on rapid head turning the first 2 to 3 days, which persisted in a few individuals for several days, and decreased rail walking ability with eyes closed. Yet, in all crew members tolerance to head movements during litter chair rotation remained at maximum for several days postflight before gradually diminishing to preflight levels. The concept that vestibular symptomatology may be related to the redistribution of body fluids in-flight has been recently expressed [11].

Sleep responses varied among the individuals evaluated, but quantity and quality appeared to be adequate throughout all Skylab missions. Mineral balance studies revealed losses of calcium and phosphorus approximating those found during bed rest. The same was generally true of bone density changes in that decreases were not observed until the longer duration flights. In-flight sodium and potassium losses were also noted. A variety of endocrine measurements were accomplished, but the data has not yet been sufficiently reduced for uniform trend indications to be discerned at this time.

A detailed evaluation of the voluminous data obtained from Skylab is well beyond the scope of this chapter. After suitable time, for more complete data analysis, a full account of Skylab biomedical findings will be reported elsewhere by the many skilled scientists who participated in this significant and multifaceted scientific achievement. Nine experimental areas are set forth in Table 3. Table 5 is a listing of broad problems to be considered within each of these areas. These tables and the above comments are offered in the hope that they will provide a beginning framework for world wide cooperative participation in in-flight medical investigation. Each problem should be regarded as requiring data on

TABLE 5 – INFLIGHT MEDICAL PROBLEMS REQUIRING EXPERIMENTS

1. Neurophysiology:
   - Effects of space flight on the integrative function of the central nervous system
   - Effects on sleep
   - Effects on the vestibular system, both otoliths and semicircular canals, under conditions of weightlessness and rotation for artificial gravity
   - Effects on sensory perception and spatial orientation

2. Pulmonary Function:
   - Effects on mechanics of breathing
   - Effects on ventilation/perfusion
   - Effects on alveolar gas transfer
   - Effects on control of breathing

3. Cardiovascular function:
   - Effects on cardiac output
   - Effects on arterial pressure control
   - Effects on central venous pressure and venous compliance
   - Effects on intrinsic cardiac function
   - Effects on overall circulatory responsiveness to g loading and 0 g

4. Metabolism and Nutrition
   - Effects on metabolic requirements at rest and during activity
   - Effects on caloric, water, electrolyte, mineral and vitamin requirements
   - Effects on lean body mass
   - Effects on the skeletal system and metabolism of bone mineral
   - Effects on muscular integrity
   - Effects on fluid and electrolyte balance

5. Endocrinology:
   - Effects on endocrine controlling mechanisms of water and electrolyte balance and distribution
   - Effects on vasoactive hormones
   - Effects on endocrine stress responses
   - Effects on calcitonin output, parathyroid, thyroid, and other hormonal controls of mineral metabolism
   - Effects on endocrine control of glucose metabolism
   - Effects on overall balance of the endocrine system

6. Hematology:
   - Effects on red cell mass, rates of red cell production and destruction
   - Effects on clotting factors
   - Effects on inflammatory responses
   - Chromosonal effects
   - Effects on serum proteins

7. Microbiology and Immunology:
   - Effects on spacecraft microbial ecology
   - Effects on distribution and relative dominance of pathogens
   - Effects on microbial genetics
   - Effects on factors of immunity

8. Behavioral Responses:
   - Effects on perception
   - Long term effects on emotional stability
   - Effects on stress tolerance
   - Effects on group integrity

9. Clinical Medicine:
   - Influence of space flight on medical and surgical therapeutic procedures and materials
   - Effects on pharmacological responses
   - Effects on preventive medical requirements inflight and effectiveness of instituted preflight procedures

specific effects and time courses, mechanisms and specific environmental etiologies, predictive indices, and countermeasures.

The ground-based information necessary to adequately investigate these many unresolved questions and prepare to utilize future flight opportunities for medical experiments to maximum advantage will demand an increasingly strong ground-based research program. As problems are defined in greater detail, the pursuit of solutions to them often tends to delve into more fundamental regions, and their component problems may become increasingly difficult to resolve. Although, fortunately, this ramifying sequence need not be pursued *ad infinitum*, the study of the mechanisms by which these observed changes are mediated must be continued at least until practical end points are reached, and should be continued beyond, as basic research, which will ultimately broaden the range of their utility into more and more allied fields. For the purposes of space medicine, these practical end points will consist of the attainment of a sufficient substructure of information on mechanisms to enable us to establish optimal techniques for prediction, for both medical selection and on-board prognosis, and countermeasures for the prevention and correction of ill effects. Among the many approaches which will be required, continuation of both short duration and longer term simulation studies involving human as well as animal subjects will be needed. The repetition of such long term bed rest studies as have already been carried out in the U.S. and U.S.S.R. will continue to be required to shed further light on cardiovascular and musculoskeletal response mechanisms, prognostic indicators and countermeasures [10, 13, 34]. Similarly, short term bed rest, water immersion, animal immobilization, confinement, centrifugation, pressure chamber studies and other simulation techniques, as well as investigations involving all of the basic medical sciences, will need to be brought to bear in order to achieve these goals.

Biology

Biological experiments, like medical experiments, will serve the same two categories of objectives outlined above [9]. In contrast, however, biology tends to place greater emphasis on more fundamental observations applicable to earth-based sciences and less on the extension of manned space flight. As the medical experiments identify operationally significant potential problems and define their component problems, the use of animals in-flight to resolve these questions will prove to be as necessary as animal experiments on earth. Some of these requirements have already become apparent, such as the need for animal surgery in space to work out suitable in-flight techniques. Others, perhaps the majority, have yet to be determined; but these will be defined as more knowledge is gained.

Flight experiments in more fundamental biology can be anticipated in such fields as genetics, growth and development factors, intracellular protoplasmic structures and functions, plant physiology, and enzyme chemistry. Planetary investigations dealing with life on other planets, clues to the origins of life, and studies of earth ecology are highly important fields which require continuing emphasis.

The specific biological experiments to be carried out in space will be determined largely by the needs and desires of active researchers within the scientific community. These, in turn, will be dependent upon the current status of biological research, i.e., the particular array of problems which prevail at any given time and the relative emphasis placed upon them.

Equipment Tests

As new and advanced life-support systems and techniques are developed, components and assemblies may be expected to continually evolve which require in-flight testing. Some of these may involve new principles, others merely new arrangements which may pose unknowns regarding their function in space flight. Any component of advanced environmental control systems, bioinstrumentation, food, water and waste management systems, crew equipment, task aids, restraints and similar apparatus may require such in-flight testing.

Bioinstrumentation

Bioinstrumentation requirements for space flight are predicated, in general, upon four major factors: function in weightlessness, minimal interference with working crew members, ease of accomplishment, and safety. The need for accuracy and reproducibility, although extremely important, cannot be considered unique for space flight. Another consideration should be added, however. In common with other endeavors in the field of environmental medicine is a requirement for high levels of measurement sensitivity and precision, because evaluations of healthy individuals under abnormal conditions can be expected to yield data which may prove to be significant, even though falling within accepted clinical ranges of normal.

Research is needed in the development of noninvasive techniques of physiological measurement, such as cardiac output and peripheral and central venous pressure. In the area of biochemistry, techniques and procedures which avoid the use of liquid reagents will obviate the potential dangers of their toxicity, and problems of handling liquids in the weightless environment. Automated techniques would be of great value in saving crew time. Finally, improved techniques must continually be pursued for the storage, compression, display, and transmission of in-flight data.

Life Sciences Laboratory

One of the research efforts of the U.S. Life Sciences Program during the past few years has been the development of a compact and highly flexible laboratory console system to accommodate the measurement requirements of in-flight medical experiments. This Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS), by virtue of its flexibility, is capable of being expanded to include clinical diagnosis, therapy, and equipment for the conduct of biological experiments.

Beyond the current development of Spacelab for the Shuttle Program by ESRO, it is entirely feasible for future global research to bring about the development and cooperative utilization of a life sciences flight module which can be docked and operated as a part of an orbiting or planetary vehicle. Such a module would make the full potential of space available to the life science community of the world, to provide maximum opportunity for achievements to support the expansion of man's exploration of space, and advance our scientific understanding of life on earth.

SUMMARY AND CONCLUSIONS

In summary, an attempt has been made to define the characteristics of three basic classes of manned space flight missions of the future, and to broadly organize and highlight future research requirements in the life sciences for the support and advancements of these space achievements. Whether or not current planning for the next decade includes missions beyond the earth orbital class or further extensions of flight duration, it is viewed as a certainty that at some time in the future man's intrepid curiosity and irrepressible thirst for knowledge will lead him inevitably to use his hard won gains to further expand his horizons in space. As tangible human benefits become apparent and as such missions become cheaper and easier to carry out, their frequency may be expected to increase progressively.

During the intervening periods, the large amount of ground-based research needed to support, improve and utilize these expanding space explorations can and must be accomplished. In the medical area, our competence to set forth appropriate medical specifications to support man for such missions of the future will be fundamentally dependent upon our knowledge of man's responses, their ranges, and our ability to prognosticate, prevent and correct undesirable effects. Even more fundamental to success, and underlying all of these essential criteria, will be a thorough knowledge of the mechanisms by which these responses are mediated. The more than 26,000 man hours of combined U.S. and U.S.S.R. manned space flight experience to date, have to a large extent served to identify, define and arrange in approximate priority the more apparent medical problem areas and many of their component issues. When reduced, the large amount of medical data derived from Skylabs' 12,300 man hours of this total will significantly increase our information on moderately long term effects and their time courses. We are now in a position to make full use of these gains and augment them by placing strong emphasis on ground based research and shorter duration flight experiments to more fully explore *mechanisms*, i.e., the cellular, tissue, neurologic, endocrine, immunologic, biochemical, and other modalities involved in producing the physiological alterations, adaptations and losses of adaptation which have thus far been measured. By this means we will continue to enhance our ability to support and advance man's future capabilities in space, and at the same time, may expect to derive important new insight into functional human physiology in both health and disease. Similarly, with respect to all of the other elements of the life sciences the periods between expanding flight missions should be regarded as periods of preparation emphasizing strong ground-based research programs to accomplish the multiplicity of diverse tasks required in biotechnology, bioengineering, and experimental biology.

The overall need for research on behalf of man in space is very great, and the welfare, protection, expansion and intellectual growth of man are of common interest to all of man kind. It is, therefore, to be hoped that this need and common interest will result in the structuring of an internationally cooperative research endeavor which truly reflects the global scope of man's ventures away from his home planet into the unknowns of outer space.

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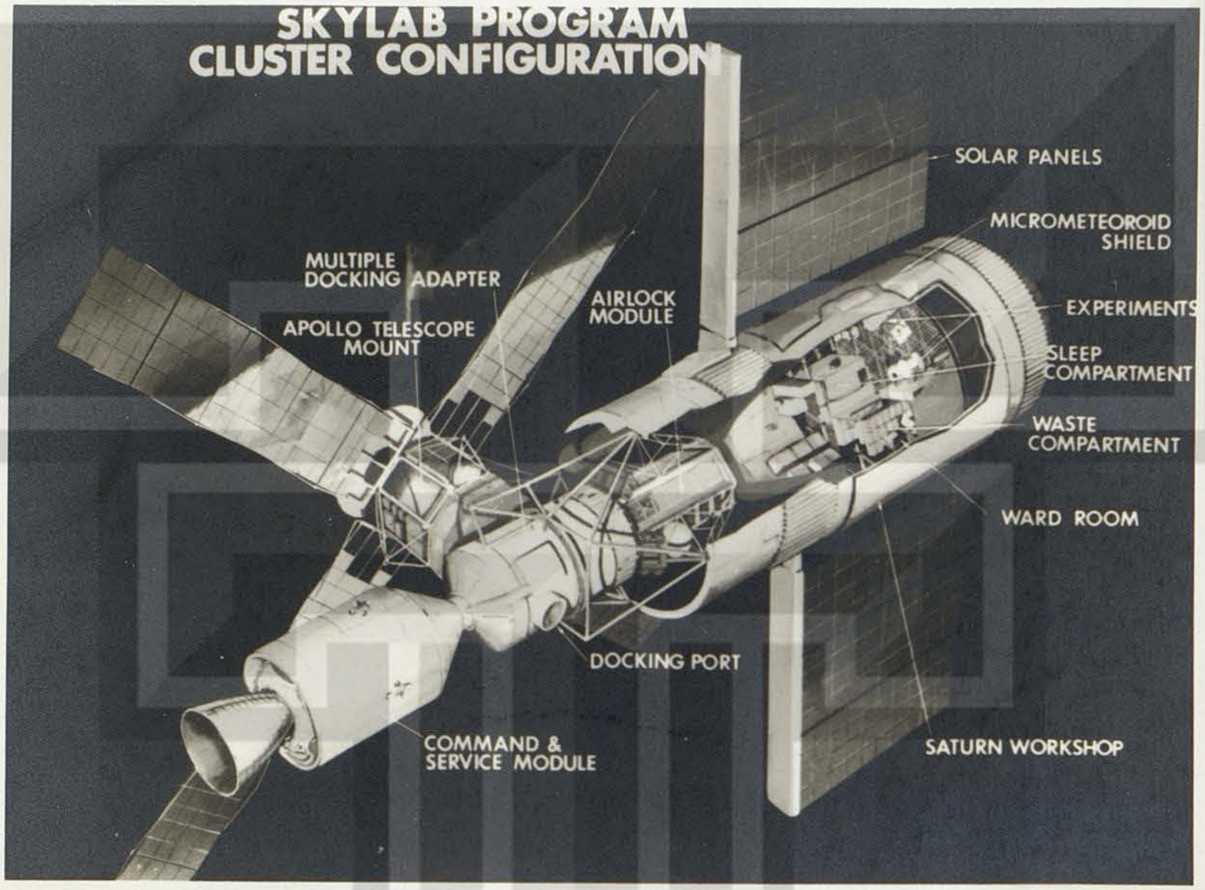
SKYLAB PROGRAM
CLUSTER CONFIGURATION
SOLAR PANELS
MICROMETEOROID SHIELD
MULTIPLE DOCKING ADAPTER
AIRLOCK MODULE
EXPERIMENTS
APOLLO TELESCOPE MOUNT
SLEEP COMPARTMENT
WASTE COMPARTMENT
WARD ROOM
DOCKING PORT
COMMAND & SERVICE MODULE
SATURN WORKSHOP

FIGURE 1

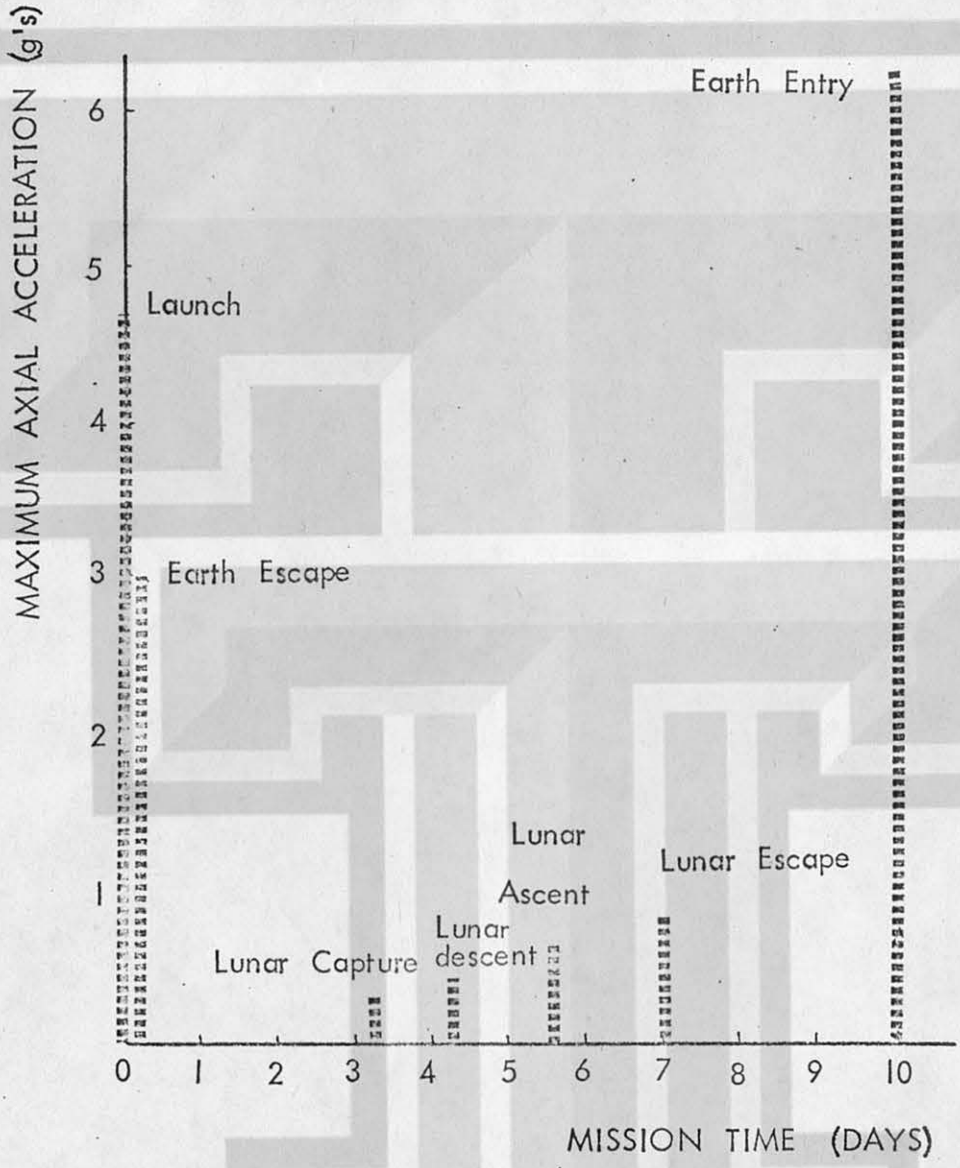

Figure 2 Acceleration Levels during Apollo Type Lunar Missions

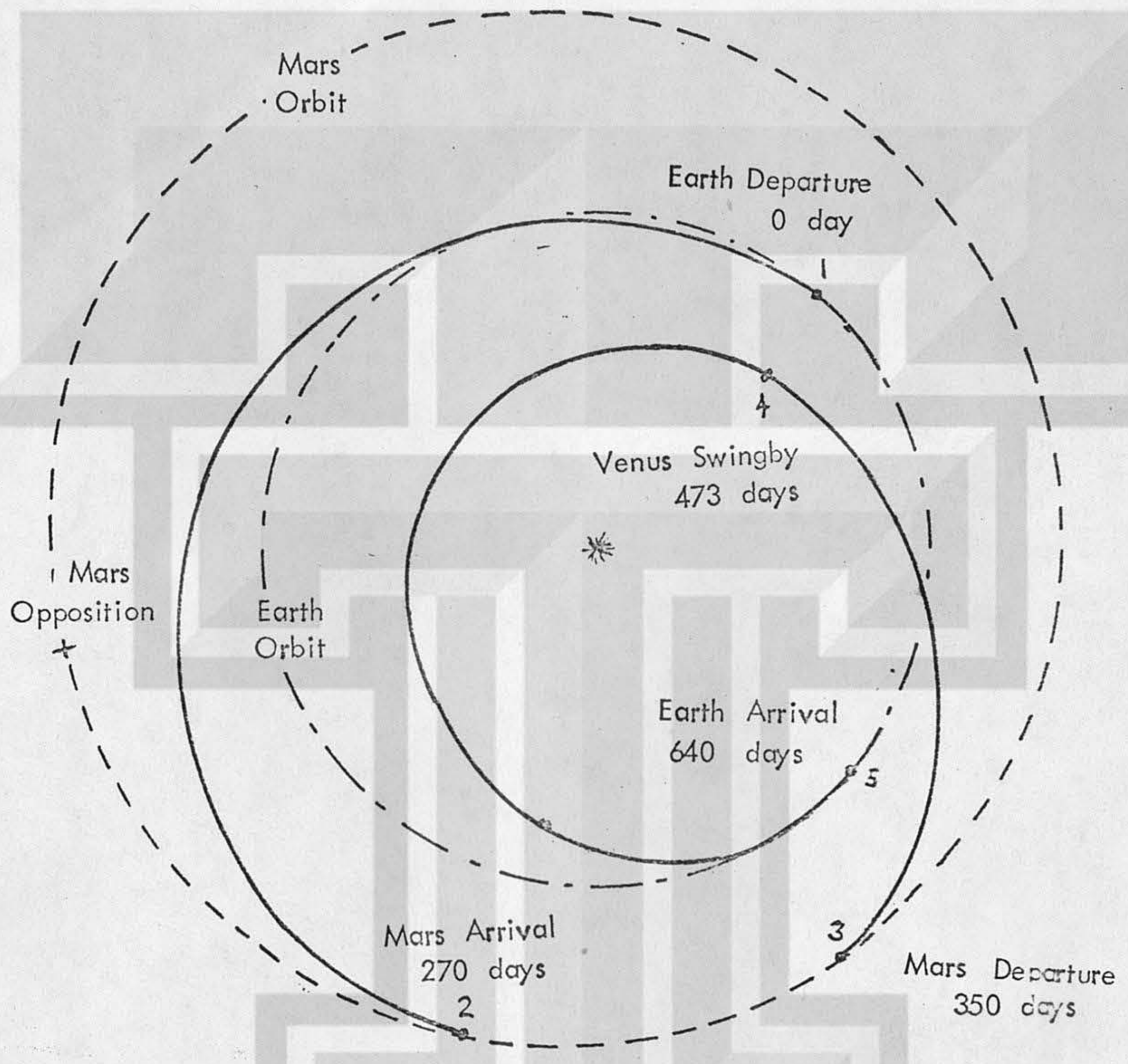

Figure 3 Trajectory of Mars Opposition-Class Manned Mission

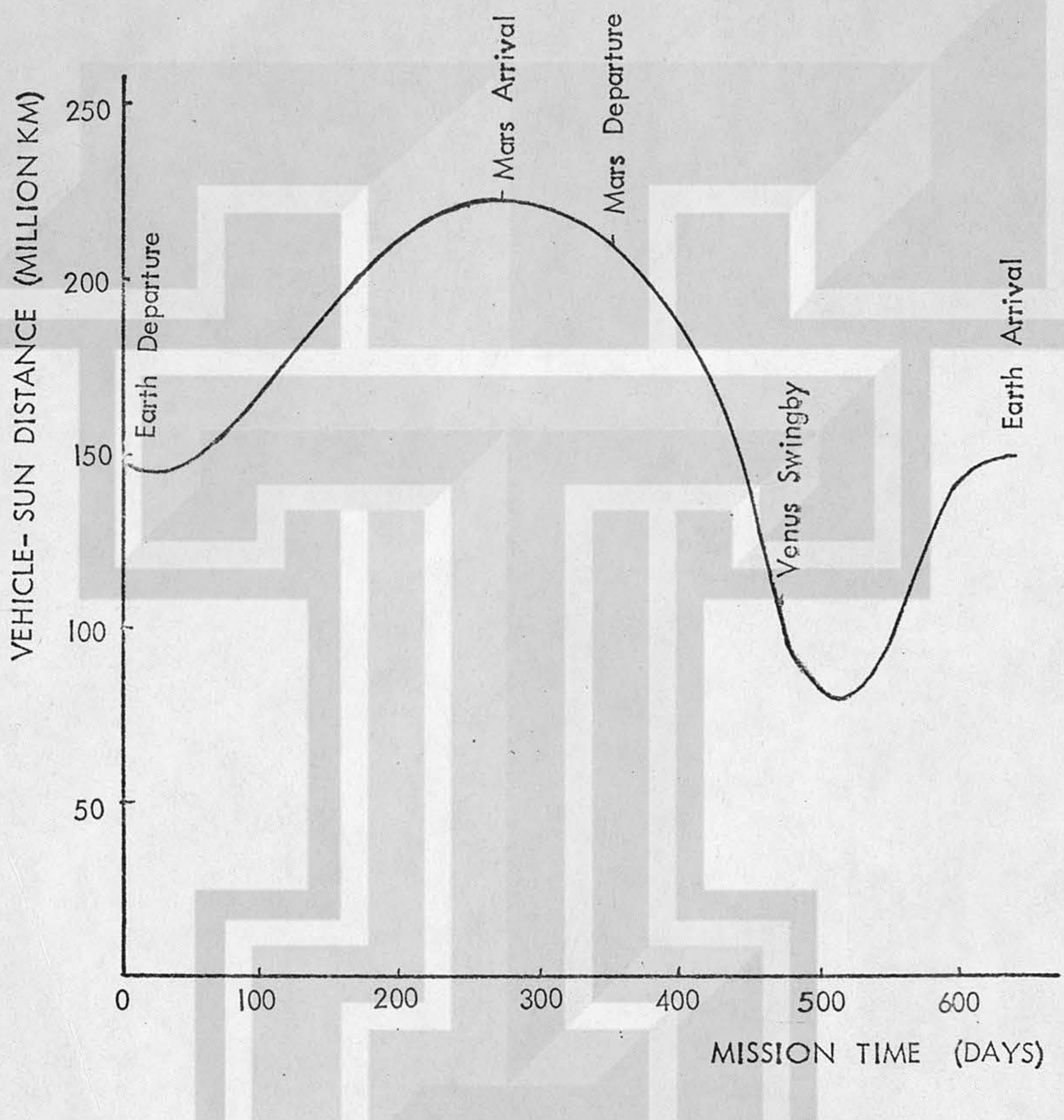

Figure 4 Vehicle-Sun Distances During Mars Mission

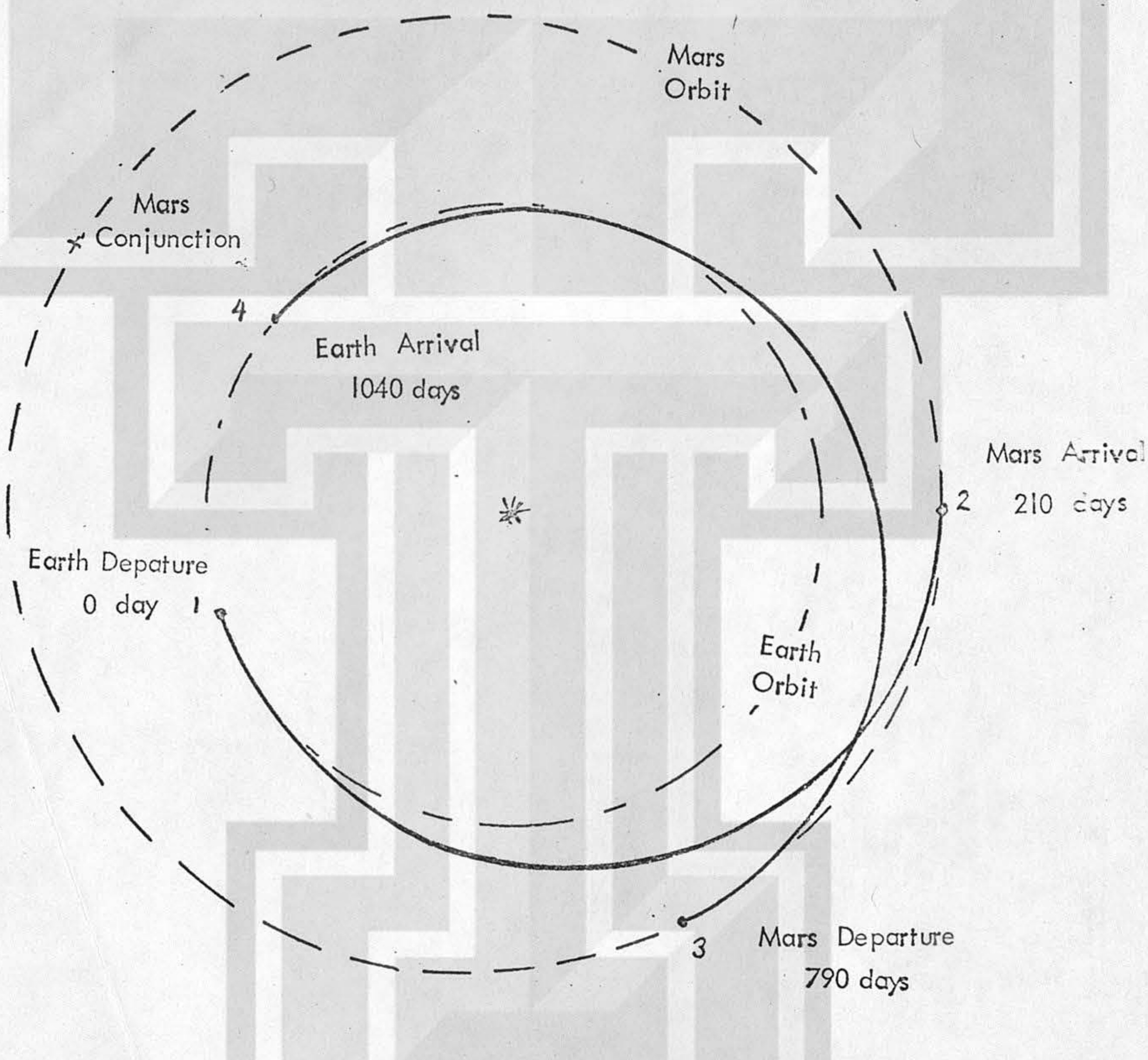

Figure 5 Trajectory of Mars Conjunction-Class Manned Mission

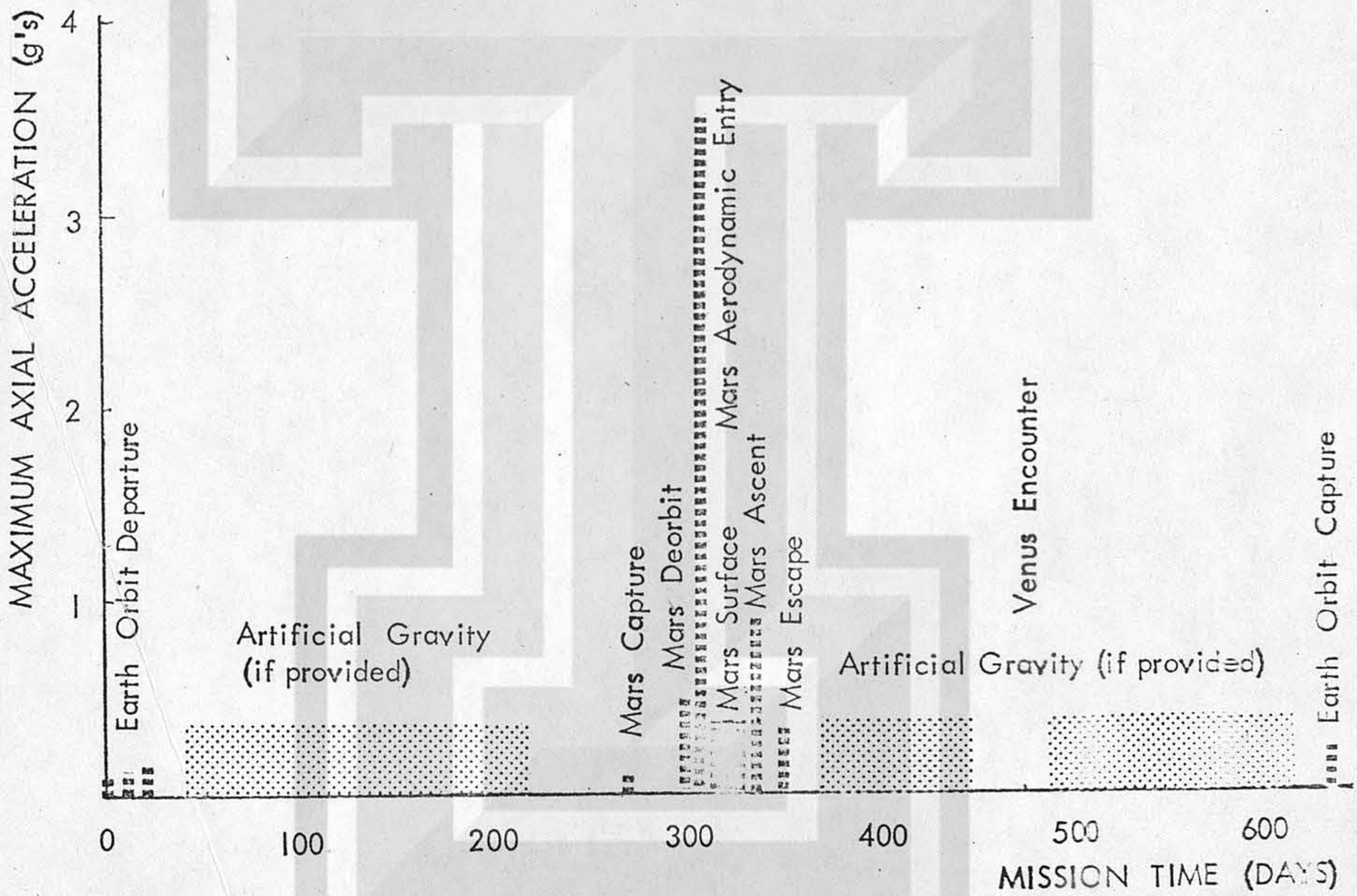

Figure 6 Acceleration Levels for Mars Manned Mission

THE GEORGE WASHINGTON UNIVERSITY
MEDICAL CENTER

Medical and Public Affairs

May 1, 1972

Dr. S.P. Vinograd
Director, Bioresearch
Office of Life Sciences
Hq NASA, Code MMR
Washington, D.C. 20546

Dear Dr. Vinograd:

Under Contract NSR-09-010-027 with the NASA Office of Life Sciences, the Biological Sciences Communication Project (BSCP) of The George Washington University is responsible for the editing and composition of the manuscripts comprising the three volumes of Foundations in Space Biology and Medicine, as well as for negotiating an honorarium with the U.S. authors of each chapter.

We have been informed by Dr. Stanley C. White, NASA, that you have agreed to author Volume 2, Part 5, Chapter 3, consisting of 1-3/4 folios or 35 pages. It is further understood that you have agreed, or will agree on specific deadlines for your chapter with your volume editor, Dr. Marbarger. Also, all manuscript drafts will be submitted to the volume editor, not to the BSCP.

The BSCP is prepared to offer you an honorarium of $875 based upon $25.00 per page of double-spaced manuscript. This amount is intended to reimburse you for your effort, for secretarial assistance, and all other costs incurred in the preparation of your manuscript except travel. Any travel costs to be incurred must be negotiated separately in consultation with Dr. White.

Biological Sciences Communication Project
2001 S Street, N.W., Washington, D.C. 20009
202 – 462-5828

If you are willing to accept the honorarium please address a letter to the undersigned agreeing to the terms of this letter and certifying to your eligibility to receive the honorarium. Since the honorarium will be paid from a government contract, government employees and certain other individuals employed on other government contracts will wish to resolve the matter of eligibility with their organizational superiors.

We appreciate your assistance in this timely project.

Sincerely yours,

Irvin C. Mohler,
Assistant Director

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF: MM

JAN 24 1972

Sherman P. Vinograd, M.D.
Acting Director of Bioresearch (MMR)
NASA Office of Life Sciences
National Aeronautics and Space Administration
Washington, DC 20546

Dear Dr. Vinograd:

The Joint United States/Union of Soviet Socialist Republics Editorial Board for the publication of the volumes, "The Foundations of Space Biology and Medicine," has nominated you to be the United States author for the US/USSR jointly authored chapter entitled, "Biological Indicators for Space Flight Profiles." The author for the Soviet portion of the chapter is Dr. Parfonov, the Soviet compiler for this chapter. As Chairman of the United States segment of the Joint Editorial Board, I am forwarding this letter to you to officially appoint you for this task.

Your portion of the chapter will be Section B, Chapter 3, Part 5 of Volume 2 of this three volume publication. Dr. John Marberger, a member of the US/USSR Joint Editorial Board, has been appointed as the United States Volume Editor for Volume 2. You should work directly with him concerning the details of preparation, content and length of the chapter, schedule for the preparation of the manuscript and the review process for your chapter.

Special requirements or problems being encountered as a result of having this chapter prepared in two parts and by a Soviet and a United States author should be discussed with Dr. Marbarger as soon as possible after identification. This will insure prompt solution for problems. The NASA Executive Secretary for this project has tried to anticipate most problems and is prepared to assist you and Dr. Marbarger in the solution of unique situations.

I am enclosing as background and guidance for your work:

1. A General Outline for the total effort "The Foundations of Space Biology and Medicine."

2. A Detailed or "expanded" Outline of chapter topics for Volume 2.

3. "Instructions to Authors" regarding chapter content, details and copy preparation.

4. Table of chapters, chapter length, authors and country.

A copy of the Soviet compilation material for your chapter is being forwarded under separate cover directly to you by the NASA Executive Secretary for this project.

The Joint Editorial Board seeks to review the first draft manuscripts for all chapters at its next meeting in May 1972. I requested that Dr. Marberger discuss this issue with you and to establish a schedule for the preparations of your chapter. I understand that you and he have agreed on a target date of April 1, 1972, for completing the initial draft of your work. Completion of the chapter manuscripts within this time frame will insure the prompt publication of all volumes on schedule. Thus one author's manuscript would not be held up awaiting another's work.

Dr. Marbarger has also discussed with you the problem of the proper address of the issue of the combined effects of several stresses upon an organism which he faces as Volume 2 editor. Presently there is insufficient data available to permit him to make a recommendation to the Editorial Board concerning whether this issue should be addressed as a separate chapter or as a part of each of the other chapters in Volume 2. As a means of moving ahead on the manuscripts while this decision is being developed by the Editorial Board, I request that you include within your manuscript a discussion of pertinent combined stress effects which are related to your topic. It would be of assistance to the editors if any discussion on the combined stress effects could be incorporated near the end of your chapter.

I want to express my sincere appreciation for your willingness to undertake this task. Although the initial phases of this joint publication have been long and at times quite complex, it is now rapidly moving toward a successful completion.

I am sure all of us who have labored through the preliminary work believe that all of this effort has been worthwhile because it represents a pioneering effort for opening the needed dialogue and scientific exchange with our fellow Soviet Bioscientists.

Sincerely yours,

Melvin Calvin

Melvin Calvin, Ph.D.
Chairman, United States Segment of the
US/USSR Joint Editorial Board
"The Foundations of Space Biology and Medicine"

Enclosures

THE FOUNDATIONS OF SPACE BIOLOGY AND MEDICINE

USA - NASA/USSR - ACADEMY OF SCIENCES

Encl

Preface

This collective scientific work is a survey of the main problems, achievements (mostly during the past 10 years), and prospects for the growth of space biology and medicine (bioastronautics).

The work consists of 3 volumes, each of which is issued in the authentic Russian and English versions.

The first volume begins with a foreword pertaining to the entire work. In the foreword the editors define the basic concepts and terms and outline the significance of bioastronautics in solving scientific and practical problems in astronautics, biology and medicine. They set forth the general characteristics of the work as a whole, justify the classification of the material and method of presentation, and mention the importance of international cooperation in advancing space science. The foreword also includes a chronology of the main events and achievements in the exploration of space and its conquest by man, the historical basis of bioastronautics and its relation to allied scientific disciplines, specifically marine (submarine) and aviation medicine. The role of international organizations such as COSPAR and IAF in the development of bioastronautics is explained.

VOLUME I. SPACE AS A HABITAT

The first volume presents the general physical characteristics of space. It sets forth in some detail data on the nature and conditions prevailing on the planets of the solar system. Separate chapters of the first volume contain the general reference material needed by the biologist to evaluate space and the planets as a unique habitat for terrestrial organisms. There is a discussion of the probability of discovering exotic forms of life.

The Earth's biosphere, the distribution boundaries of life and the conditions limiting its survival, and the ways in which organic matter evolved in the universe are specially considered.

Experimental results of exobiological investigations are summarized under two headings; astrobiological investigations (spectroscopic) and investigations unders simulated (laboratory) conditions of individual or combined space (planetary) factors.

General results reported in publications on sterilization of space objects and on the problem of quarantine are presented as an important applied aspect of exobiological research.

Part I. Physical Properties and Biological Significance of Space

Chapter 1. Theories of the Origin and Nature of the Universe.

Structure, nature, and evolution of the galaxies and the solar system.

Chapter 2. Physical Characteristics of Interplanetary Space

The problem of Sun-Earth relations. Solar radiation (infrared, visible, ionizing, ultraviolet).

Cosmic radiation, radiation fields, X-rays, radioactive particles.

Pressure

Diurnal cycles

Micrometeorites

Gravitation

Part II. Planets and Satellites of the Solar System from the Physical and Ecological Point of View.

The description of the conditions on the planets and Moon includes the characteristics: of the atmosphere (pressure, composition, vertical profile, motion), gravitational fields, temperature on and below the surface, radiation and changes therein in time and space, chemical composition and structure of the environment, chemical substances suitable for use (their availability), magnetic and electric fields, diurnal cycles.

Chapter 1. The Moon and Its Nature.

Chapter 2. Planets of the Inner Solar System (Mercury, Venus and Mars).

Chapter 3. Planets of the Outer Solar System and Their Satellites, Asteroids, Minor Planets, Meteorites (including cosmic dust) and Comets.

Part III. Problems of Exobiology

Chapter 1. Biological Effects of Extreme Environmental Conditions (Including Laboratory Simulation).

Limits of Life on Earth, Earth's biosphere

Examination of the problem should be focused on studying the reactions of living organisms to various environmental conditions. Not only the limits of the activity of living organisms but also, as far as possible, the changes arising when these limits are approached, should be elucidated. Here we should include: temperature, thermophily, hydrophily, and sensitivity to temperature in relation to humidity and other conditions; concentration of hydrogen ions (pH); radiation, including visible, ultraviolet, and ionizing; activity of water, evaporation, estivation; osmotic pressure; hydrostatic pressure; correlation of isotopes; acceleration; composition of atmosphere; magnetic fields; diurnal cycles and other rhythms.

Experimental exobiological investigations under simulated conditions of outer space and planets.

Stimulation of extraterrestrial conditions and exotic biochemical processes, investigation of survivability of terrestrial organisms and stability of ecological systems.

Chapter 2. Theoretical and Experimental Prerequisites of Exobiology.

Ways in which organic matter evolved on Earth and in space (paleobiology and investigations of meteorites).

Abiogenic synthesis of organic chemical substances under conditions simulating the environment of primary planets and space.

Results of astrochemical research (spectroscopic investigations).

Chapter 3. Search for and Investigation of Extraterrestrial Forms of Life.

Methods of searching for and finding forms of life on the other planets.

Suggested methods of investigation in case extraterrestrial forms of life are discovered.

Exploratory observations for the purpose of determining significant forms of mobility, visible reaction to stimuli.

Changes in form, size, color, and growth rate.

Physical changes such as optical activity and pigmentation and spectroscopic properties.

Discovery of catalytic effects such as disappearance of measurable substrates, change in pH, formation of CO_2, heat and other metabolic products as well as isotropic metabolism.

Comparative study of extraterrestril forms of life (in relation to terrestrial forms) by determining the chemical composition, nature of polymers and constituent monomers, discovery of pigments, observations on catalytic processes in the integral organism, its fragments or extracts (if extraterrestrial forms of life are discovered).

Comparison of genetic, metabolic, and functional mechanisms.

Data of prebiological chemistry and paleobiology.

Chapter 4. Planetary quarantine: Principles, Methods, and Problems.

Survey of problems in sterilizing spacecraft (equipment) and dangers of contaminating planets should include the following subjects:

survivability of forms of life after prolonged exposure to deep-space conditions;

control of flora (on the surface and inside);

control of microflora on the spacecraft;

sterilization and methods: heat, radiation, gases, filtration, combination of these methods.

Quarantine of Planets:

prevention of contamination of planets by nonsterile spacecraft or parts of spacecraft;

protection of the Earth from extraterrestrial flora.

VOLUME 2. ECOLOGICAL AND PHYSIOLOGICAL BASES OF SPACE BIOLOGY AND MEDICINE

The second volume deals with problems in space biology, effect on the organism of various flight factors. It presents the general characteristics and classification of flight factors. It examines the effect on the organism of different kinds of space energy, the dynamics of spaceflight factors, the artificial gaseous atmosphere of spacecraft, psychophysiological factors connected with prolonged stays in spacecraft or stations. It discusses the combined effect of flight factors on the human and animal organism, and the activity of astronauts. The volume describes the principal methods of physiological investigations, biotelemetry, and use of mathematical methods in space biology and medicine. It is proposed to compare the results of biological research on human subjects, and the results of flight experiments, as well as the results of corresponding laboratory controls as a function of various parameters.

The volume concludes with a summary of the knowledge gained from studies on the physiology of the organism under conditions of actual space flight. It defines the main problems in and prospects for future research.

General Introduction

Definition of the concept of environmental physiology with a review of the research in this field. General characteristics and classification of flight factors.

Part I. Effect on the Organism of Radiant Energy from Cosmic Space.

Introduction including definitions, characteristics, classification, and a review of the subject.

Chapter 1. Radiofrequencies and Microwaves.

Magnetic and Electric Fields.

Physical characteristics, methods of study, biological role, state of organs and systems, pathophysiological and pathomorphological effects, pathogenesis, state of higher nervous activity, psychic functions, general condition, physical fitness limits and criteria of resistance, genetic effects, prevention and treatment, basis of principles of protection.*

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*Note: The plan for setting forth the material is repeated in the following chapters of Volume 2.

Chapter 2. Ultraviolet, Light, and Infrared Rays.

Chapter 3. Ionizing Radiation including Artificial Sources of Atomic Energy.

Part II. Effect on the Organism of the Artificial Gaseous Atmosphere of Spacecraft and Stations.

Introduction with definitions, characteristics, classification and history of the subject.

Chapter 1. Barometric Pressure. Gas Composition.

Dysbarism. Partial pressure of oxygen (hypoxia and hyperoxia) and carbon dioxide (hypercapnia and hypocapnia). Nitrogen and other inert gases.

Chapter 2. Toxicology of the Air in closed spaces.

Chapter 3. Thermal Properties of the Atmosphere (heat production, convection, radiation). Human resistance and protection against adverse temperature conditions.

Part III. Effect on the Organism of Dynamic Flight Factors.

Introduction with general characteristics, classification and history of the problem.

Chapter 1. Principles of Gravitational Biology.

Gravitation-dependent functions in plants, cells, and small animals.

Experiments on clinostats.

Biological experiments during flights.

Long-term studies on animals exposed to increased gravitation.

Chapter 2. Effect on Man of Prolonged and Brief Linear and Radial Accelerations.

Prolonged and brief linear and radial accelerations.

Experiments on the effects of acceleration and deceleration (various directions and durations of accelerations).

Limits of human tolerance.

Physiological reactions.

Long-term pathology.

Methods of protection.

Chapter 3. Impact Accelerations. Brief Accelerations. Limits of Tolerance.

Chapter 4. Angular Velocities. Angular Accelerations. Coriolis Accelerations.

Effects on man of low-intensity but prolonged accelerations.

Problems of orientation in slowly rotating rooms and during orbital flight.

Chapter 5. Weightlessness.

Immersion investigations and investigations involving the creation of conditions of immobility (bed).

Physiological data (especially biochemical disturbances): calcium-metabolism.

Other chemical and hormonal changes.

Data recently obtained from orbital flights with human beings and animals.

Brief weightlessness.

Prolonged weightlessness.

Conclusions from data of orbital flights and investigation of problems involved in artificial creation of conditions of weightlessness.

Problems in creating artificial gravitation.

Chapter 6. Vibration and Noise.

Part IV. Psychophysiological Problems Connected with Flight and Stays in Spacecraft or Space Stations.

Introduction (definitions, characteristics, classification, history of the subject).

Chapter 1. Psychological Stress of Space Flight.

Limited space.

Hypodynamics.

Limitations of sensory information.

Uniformity of stimuli.

Social isolation, psychophysiological problems of prolonged isolation of small groups of people ("group psychology").

Problems of motivation and emotional reactions during space flight.

Chapter 2. Biological and Physiological Rhythms.

Chapter 3. Physiology of Human Sense Organs Under Space Flight Conditions.

Chapter 4. Astronaut Activity.

Physical fitness:

Indices and methods of studying physical fitness.

Processing of information and decision making by man.

Factors determining the efficiency and reliability of activity (sensations, perception, individual physiological capabilities, skills, training and motivation).

"Man-machine" problem.

Part V. Combined Effect of Space Flight Factors on Man and Animals, Methods of Investigation.

Introduction (definitions, general characteristics, classification, history).

Chapter 1. Combined Effect of Various Flight Factors.

Chapter 2. Methods of Investigation in Space Biology and Medicine.

Chapter 3. Biological Indicators for Space Flight Profiles.

VOLUME 3. SPACE MEDICINE AND BIOTECHNOLOGY

The third volume examines ways and means of maintaining optimum health conditions in spacecraft cabins from the medical and biotechnological standpoints. It presents possible plans for constructing life-support systems and describes physiological-hygienic methods of evaluating their effectiveness in relation to the nature of the flight. Particular attention is paid to protecting the crew from adverse space-flight factors in simple and emergency situations. The volume sets forth the fundamental principles governing the selection and training of astronauts, methods of medical supervision and therapeutic and prophylactic care during flights.

General Introduction

Status and outlook for the development of habitable space vehicles; general classification; chief medical problems.

Part I. Selections and Training of Astronauts.

Criteria for selection and training of astronauts in relation to flight programs are examined. Particular attention is paid to justifying the criteria used.

Chapter 1. Selection.

State of health, mental state, intellect, and previous occupational experience requirements.

Methods of selecting astronauts.

Chapter 2. Training.

Preflight training of astronauts.

Special training on board the spacecraft.

Part II. Methods of Providing Life-Support for Astronauts.

Chapter 1. Basic Data.

Metabolism and energy balance. Oxygen, food, and water requirements of man; final products of vital activity.

Their relation to the nature of the activity and other conditions.

Chapter 2. Physiological Aspects of Food and Water Supply.

The astronauts' food and water requirements in relation to the nature of their activity and other flight conditions.

Ingredients of the rations.

Vitamins and minerals. Technology of food preparation on board a spacecraft. Regenerating water-methods and evaluation of their effectiveness.

Biological and chemical production of food from the final products of human vital activity.

Chapter 3. Air Regenerating and Conditioning.

Methods of supplying oxygen. Methods of removing carbon dioxide and water vapors. Removal of injurious impurities. Means of purifying the air of dust, aerosols, bacteria, and viruses. Air ion composition. Air conditioning with regard to humidity and temperature. Rate of air movement, basis for calculating ventilation values. Hygienic control of atmospheric parameters. Possible arrangements, their economic characteristics and reliability characteristics.

Chapter 4. Astronauts' Clothing and Personal Hygiene.

Chapter 5. Isolation and Removal of Waste Products.

Chapter 6. Habitability of Spacecraft.

Physiological-hygienic aspects of planning cabins, geometric dimensions and arrangement of seating, control panels and units, illumination, layout of interior, cabin and recreational equipment. Objects of personal hygiene.

Clothing. Sanitary facilities. Work and rest routines of the astronauts. Ways and means of the astronauts' moving about the spacecraft.

Ways and means of physical exercise.

Chapter 7. Individual Life-Support Systems Outside a Spacecraft Cabin, Space Suits and Capsules.

Medical Aspects.

Part III. Integrated Characteristics of Life-Support Systems.

Chapter 1. Non-regenerative Life-support Systems for Brief and Moderately Long Flights.

VOLUME II. ECOLOGICAL AND PHYSIOLOGICAL BASES OF SPACE BIOLOGY AND MEDICINE

Expanded Volume II Outline

The second volume deals with problems in space biology, effect on the organism of various flight factors. It presents the general characteristics and classification of flight factors. It examines the effect on the organism of different kinds of space energy, the dynamics of spaceflight factors, the artificial gaseous atmosphere of spacecraft, psychophysiological factors connected with prolonged stays in spacecraft or stations. It discusses the combined effect of flight factors on the human and animal organism, and the activity of astronauts. The volume describes the principal methods of physiological investigations, biotelemetry, and use of mathematical methods in space biology and medicine. It is proposed to compare the results of biological research on human subjects, and the results of flight experiments, as well as the results of corresponding laboratory controls as a function of various parameters.

The volume concludes with a summary of the knowledge gained from studies on the physiology of the organism under conditions of actual space flight. It defines the main problems in and prospects for future research.

Forward

General Introduction

Definition of the concept of environmental physiology with a review of the research in this field. General characteristics and classification of flight factors.

Part I. Effect on the Organism of Radiant Energy from Cosmic Space.

Introduction including definitions, characteristics, classification, and a review of the subject.

Chapter 1. Radiofrequencies and Microwaves, Magnetic and Electric Fields.

Introduction.

1. Physical characteristics of sources of electromagnetic radiation, and of electric and magnetic fields (EMF) during space flight. Natural and artificial EMF in the biosphere.

2. Clinical and physiological aspects of the biological effect of electromagnetic waves (EMW) in the radio frequency band. Questions of occupational hygiene. Standardization.

Encl 2

3. Effect of electric fields on the human body.

4. Effect of magnetic fields on the human body.

5. Mechanism of the effect of EMW and EMF on the human body.

6. Problems requiring future research effort.

Chapter 2. Ultraviolet, Light, and Infrared Rays.

Introduction.

1. Physical characteristics of the sources of light, ultraviolet, and infrared rays.

2. Hygienic and psychophysiological aspects of the light regime. Standardization of illumination for astronaut work and rest sites.

3. Clinical and physiological aspects of the biological effect of ultraviolet rays and their physiological and hygienic importance in flight. Effect on the sight organs. Irradiation standardization. Equipment for protection against ultraviolet rays.

4. Clinical and physiological aspects of the biological effect of infrared rays. Standardization. Protective means.

Chapter 3. Ionizing Radiation including Artificial Sources of Atomic Energy.

Introduction.

1. Physical characteristics. Sources of radiation danger in space flight. Dosimetry.

2. Influence of the magnitude and strength of the dose on the biological effect.

3. Relative biological effectiveness of various types of cosmic radiation.

4. Evaluation of effective doses as a result of long periods of chronic irradiation.

5. Overall clinical and physiological picture of acute and chronic irradiation of man.

6. Present day views of the mechanism of the damaging effect of cosmic radiation.

7. Radiobiological experiments in space.

8. Questions of the standardization and justification for permissible doses of irradiation during short and long term space flights.

Part II. Effect on the Organism of the Artificial Gaseous Atmosphere of Spacecraft and Stations.

Introduction with definitions, characteristics, classification and history of the subject.

Chapter 1. Barometric Pressure. Gas Composition.

Introduction.

1. Physical parameters of the atmosphere and gas composition.

2. Physiological and pathological effects of reduced barometric pressure (caisson disease, altitude tissue emphysema, explosive decompression); protection.

3. Effect on the body of reduced partial pressure of oxygen in inspired air (acute and chronic forms of oxygen starvation).

4. Physiological mechanisms of adaption to hypoxia. Justification for the low limit of oxygen in the artificial gas atmosphere (AGA).

5. Hyperoxia and its effect on the body. Oxygen intoxication. Justification for permissible upper limits of oxygen in the inspired air.

6. Hypercapnia and its effect on the body. Acute and chronic forms of intoxication by high carbon dioxide concentrations. Justification for permissible quantities of carbon dioxide in the AGA.

7. Nitrogen and inert gases in the AGA.

8. General principles of the formation of the AGA in cabins of spacecraft (role of flight conditions in selection of the rational AGA).

9. AGA close to that of normal atmosphere on earth in terms of gas exchange conditions; its advantages and disadvantages. Mono- and multiple component gas mixtures.

10. Active artificial gas atmosphere. Prospects for its use in space flight.

11. Comparative evaluation of various AGA.

12. Current questions and prospects for future research on the problem.

Chapter 2. Toxicology of the Air in closed spaces.

Introduction.

1. Toxic agents in the AGA of closed ecological systems (CES) of spacecraft.

2. Sources of pollution of the AGA in CES. Biological sources (people, food, wastes, etc.); cabin materials (polymers, and others); industrial liquids (lubricants, resins, coolants, etc.); equipment and gear in use in the spacecraft.

3. The combined effect of various chemical agents of anthropotoxins on the human body. Overall response of the body to toxic agents.

4. Principles involved in the establishment of maximum concentrations of toxic agents in the AGA of spacecraft.

Chapter 3. Thermal Properties of the Atmosphere (heat production, convection, radiation). Human resistance and protection against adverse temperature conditions.

Introduction.

1. Physical properties of the environment and their importance in body heat exchange by conduction, convection, evaporation, and radiation:

temperature, humidity, and movement of air;

temperature of surrounding surfaces;

air pressure.

2. Man's capacity to withstand heat loads: man's physiological reactions to heat loads; limits of bearable heat (influence on the tolerance to physical properties of the environment, clothing, and level of physical activity).

3. Methods and equipment for protecting man against heat: physical and physiological bases of protection; passive and active protection (ventilated suits providing protection against heat, suits with water conduction and evaporation cooling).

4. Principal unsolved problems and direction of future research.

Part III. Effect on the Organism of Dynamic Flight Factors.

Introduction with general characteristics, classification and history of the problem.

Chapter 1. Principles of Gravitational Biology.

Introduction.

1. Gravitation as one of the constants of the ecological environment of habitation on earth.

2. The role of gravitation in the occurrence of elementary biological processes and in the evolution of earth organisms.

3. Orientation and locomotion in a gravitational field.

4. Fundamental physiological and biological effects of increased weight.

5. Fundamental physiological and biological effects of reduced weight and of weightlessness.

6. Prospects for the investigation of the biological effect of increased and decreased weight. Ways to build the concept of the biological role of gravitation - of gravitation biology.

Chapter 2. Effect on Man of Prolonged and Brief Linear and Radial Accelerations.

Introduction.

1. Physical parameters of acceleration. Classification and terminology.

2. General symptomatic picture of disturbances characteristic of the effect of long periods of acceleration.

3. Reactions of physiological systems (central nervous system, visual analyzer, cardio-vascular and respiratory systems, gastro-intestinal tract, blood system, excretory system, endocrine organs, etc.).

4. Physiological and pathophysiological mechanisms of the effect of long periods of acceleration on the body.

5. Resistance of man to the effect of long periods of acceleration and factors determining that resistance. Criteria for the evaluation of tolerance.

6. Reaction of the body during the acceleration aftereffect period.

7. Capacity to work under the effects of acceleration.

8. Effects of adaptation and cumulative effect of stress to repeated acceleration.

9. Methods for increasing the resistance of the body to accelerations of space flight.

10. Problems for future research.

Chapter 3. Impact Accelerations. Brief Accelerations. Limits of Tolerance.

Introduction.

1. Physical properties and characteristics of the effect on the body.

2. Procedures and methods for studying the influence on the body. Safety precautions during experiments. Present-day test stands. Terminology.

3. General symptomatic profiles of disturbances. Specific and nonspecific reactions.

4. Reactions of physiological systems (central nervous system, respiration, blood circulation, skeleton-motor apparatus, and others).

5. Mechanisms causing disturbances. Protective-adaptive reactions. Biomechanical reactions. Traumatism.

6. Cumulation effects.

7. Limits of endurable magnitudes. Criteria for evaluation.

8. Methods for increasing tolerance and protective principles.

9. Impact accelerations during catapulting and ground landings.

10. Problems requiring future research effort.

Chapter 4. Angular Velocities. Angular Accelerations. Coriolis Accelerations.

Introduction.

1. Biophysical characteristics of angular velocities, angular accelerations, and Coriolis acceleration encountered in space flight.

2. General symptomatic picture of disturbances observed when small-scale angular velocities, and angular and Coriolis accelerations act on man for long periods of time.

3. Some features of the functional changes that occur when angular velocities and accelerations act for a long period of time.

4. Methods for prevention of the space-type motion sickness:

methods for selection and training to withstand angular velocities and accelerations acting for long periods of time;

pharmacological means for preventing motion sickness.

5. Physiological and hygienic justification for the standardization of permissible levels of angular velocities and accelerations.

6. Problems for future research study.

Chapter 5. Weightlessness.

Introduction.

1. Weightlessness as an extreme factor in space flight. Research avenues. Simulation methods.

2. Mechanisms for the formation of changes in weightlessness condition when simulated in the laboratory:

reactions caused primarily by changes in the activity of the afferent systems;

reactions caused primarily by the absence of hydrostatic pressure of the blood;

reactions caused primarily by the absence of a ponderable load on the skeletal-muscular system.

4. Immunobiological reactions and morbidity during hypodynamia and under weightlessness conditions.

5. Ability to work. Energy consumptions.

6. Effects of adaptation and cumulative effect during a long space flight.

7. Clinical and physiological condition for the period of readaptation (orthostatic stability, physical capacity to do work).

8. Means for prevention of the unfavorable effect of weightlessness on the human body.

9. Problems for future research studies.

Chapter 6. Vibration and Noise.

Introduction.

The noise factor.

1. The general and physical characteristics of audio oscillations (sources of noise, sound waves, stationary and pulse noises, physical scale of noise intensity).

2. Psychophysiological characteristics of the perception of sound.

3. Physiological reactions of the body to noise (reaction of the auditory analyzer, general reactions to noise).

4. Effect of high intensity acoustic energy on the body.

5. Pulse noise and sound impact. Ultra- and infrasonics.

6. Special features of noise effect in space flight.

7. Voice communication when noise is present.

8. Protection against noise.

Vibration

1. General and physical characteristics of vibrational oscillations (sources, range of levels, sinusoidal and random vibrations).

2. Subjective reactions to vibration (thresholds of sensation, scale of tolerance).

3. Physiological reactions of the body to the effects of vibration.

4. Energy theory of the vibration effect.

5. Physiological and hygienic justification for standardization of vibration effect.

6. Complex noise-vibration effect. Protection.

7. Problems for future research investigations.

Part IV. Psychophysiological Problems Connected with Flight and Stays in Spacecraft or Space Stations.

Introduction (definitions, characteristics, classification, history of the subject).

Chapter 1. Psychological Stress of Space Flight.

Introduction.

1. Specific features of space flight causing a high level of nervous and emotional stress:

space limited volumes;

changed sensory information (sometimes distortion);

hypodynamia, monotonous nature of stimuli;

feeling of high degree of responsibility. Risk.

2. Psychophysiological problems of long isolation of a small group of men (group compatibility).

3. Problems of motivation and emotional reactions during space flight.

4. Current problems for future research.

Chapter 2. Biological and Physiological Rhythms.

Introduction.

1. Periodicity of body functions, the universal law of living nature. Basic mechanisms generating rhythms.

2. Psychic, vegetative, and somatic reactions at various times of day. Biological rhythms and resistance to stress stimuli.

3. Man's capacity to work when the circus physiological rhythm is staggered.

4. Questions of adaptation and cumulative effects to changed daily work and rest regimes.

5. Basic principles of construction of optimal and forced work and rest regimes for astronauts (static and migrating days).

6. Prospects and tasks of the study of biological rhythms in space medicine.

Chapter 3. Physiology of Human Sense Organs Under Space Flight Conditions.

Introduction.

1. Status of various types of sensitivity to space flight (vision, hearing, sense of smell, tactile, pain, and proprioceptive senses).

2. Illusory sensations under weightlessness conditions. Nature of illusions and mechanics of their occurrence.

3. Measures for warning and preventing illusory sensations in flight (selection, methods of training on ground test stands, and during flights in aircraft).

4. Current problems and methods for solution.

Chapter 4. Astronaut Activity.

Introduction.

1. Status of capacity to do work:

indices and study methods;

factors determining efficiency and dependability of work (sensation, perception, individual physiological capabilities, skills, training and motivation).

2. Information processing and human decision-making.

3. The "man-machine" problem.

Part V. Combined Effect of Space Flight Factors on Man and Animals, Methods of Investigation.

Introduction (definitions, general characteristics, classification, history).

Chapter 1. Combined Effect of Various Flight Factors.

Introduction.

1. The place of the problem in space biology and medicine.

2. The importance of the original functional condition of the body (system) to the final reaction in a complex effect.

3. Dependence of the effect on the force and nature of the effect of intervals and sequences. A mathematical expression for these relationships.

4. The results of experimental investigations of the complex effect on the body of different flight factors (conditions):

vibration, acceleration, ionizing radiation, weightlessness, change in the gas environment, etc.

5. Analysis of the mechanisms modifying the influence of the various factors on the reaction of the body.

6. Justification of the prospects for future investigation of the problem.

Chapter 2. Methods of Investigation in Space Biology and Medicine. Transmission of Biomedical information.

Introduction.

1. Biological telemetry and information theory.

2. Clinical and physiological examination methods in flight.

3. Biotelemetry installations. Removal and transmission of physiological information to earth during flights of various lengths and types.

4. Analysis and evaluation of physiological data obtained via telemetry channels. Automation of physiological measurements. Forecasts of conditions and diagnoses of illnesses.

5. Current problems. Future improvements in the systems for physiological measurements in space.

Chapter 3 Biological Indicators for Space Flight Profiles.

Introduction.

1. Importance of biological indicators from deep space in the problem of making man's flight safe.

2. Biological objects. Research methods. Conditions for conducting experiments.

3. Results of biological experiments conducted with:

altitude ballons;

ballistic rockets;

satellites-spacecraft (orbits below the earth's radiation belts);

automatic space stations (circling the moon).

4. Evaluation of the contribution of individual flight factors to biological (genetic) effects recorded at submolecular, cell, tissue, and organism levels.

5. Basic problems and directions for future flights when there is a biological indication of new space routes.

FOUNDATIONS OF SPACE BIOLOGY AND MEDICINE

Suggestions to Authors and General Comments

The three Volumes entitled "Foundations of Space Biology and Medicine," represent an intensive joint effort between Soviet and American scientists to produce a collective scientific document. The content of the Volumes include in-depth surveys of scientific and technical problems, achievements in the field, and prospects for growth and development in Space Biology and Medicine.

Extensive work by compilers both in Russia and the United States, has progressed very well and all compilers should be complimented for their fine efforts. Most of the material presented by all compilers is in the style of a complete bibliography but generally does not present sufficient detail to be useful except for reference. It will be the responsibility of the authors to prepare from these compilations, a critical review and summary of data for each chapter. Authors are requested to adhere to the guidelines presented herein.

This publication is designed for a wide circle of readers. Students in the health sciences and specialists in aerospace biology and medicine will receive an in-depth treatment of the subject. Specialists in related fields will receive information about a problem in which they are not directly involved. Engineers and health scientists working in areas providing direct support to aerospace programs will obtain recent reference material.

The production of any book with multiple authors having varied disciplines within a broad field offers problems for a variety of editorial reasons. The Joint Editorial Board is aware of these problems and appreciates the fact that the three Volumes should, when published in Russian and English, contain a continuity of style and format so that the material will not only be factual, but in its final organization, will achieve a high level of scientific literary excellence and usefulness. Consequently, the goal of the author(s) for each chapter should not be to prepare just an annotated bibliography, not just a review, but a critical presentation of the present state of knowledge on each chapter topic.

The authors of each chapter shall include the reference material prepared by the foreign compiler. He shall acknowledge the compiler(s) in the introduction to the chapter.

Authors shall give preference to inclusion of references to published review material and thereby avoid listing of unusually lengthy bibliographies. Authors should cite references in the text rather than inclusion of extensive direct quotations. Authors are advised to present data in tabular and graphic form whenever possible.

Encl 3

Each author is supplied with an outline detailing all chapters, including his, so that he may observe the topic content of each chapter to indicate the relationship of his chapter to the other chapters in the Volumes.

The Volumes combine the basic work of the authors. Hence, certain minimal instructions to the authors will serve as guidelines and thereby provide a certain style continuity with regard to the source documents prepared by each author or group of authors.

The information presented below is not original. It contains selected items from popular scientific journals "tailored" to meet the unique requirements of the three Volumes.

MANUSCRIPT

General Manuscripts should be typewritten, double spaced, with margins four to five cm., on non-erasable bond paper 20-22 by 28-30 cm. Two copies, an original and one carbon copy with figures and tables should be submitted. Figures should be no larger than 22 x 30 cm. A title page should be prepared separately and have the title of the paper, name(s) of author(s), laboratory or institute of origin with the city, state (where applicable) and country. The bottom of the title page should include the exact mailing address for galley proofs. All references, footnotes, acknowledgments of compilers, legends for illustrations and figures should be typed on separate sheets, double spaced. Figures and photographic illustrations should be identified on the reverse side with the figure number, the author's name, the volume, part and chapter numbers. The top of each figure should be clearly marked. Tables should be typed, double spaced on a separate sheet of non-erasable bond paper. Authors should use the accepted INTERNATIONAL SYSTEM OF UNITS (SI) and standard nomenclature throughout the chapters. It is understood that in certain areas, conventional units may be used. Specifically, measurements of pressure including blood pressure, partial pressures of gases and osmotic pressures may be given in millimeters mercury or atmospheres and heat and energy values may be given in calories. Other exceptions require authorization of the volume editors. Conversion factors, tables and nomograms will be included at the back of each printed volume.

New terms which perhaps may be unfamiliar, arbitrary abbreviations, and ambiguous names should be defined when they are first used. The chemical names of drugs should be used. When the chemical name of a drug or pharmaceutical is unknown, the tradenames should be followed by the name of the manufacturer or producer.

References All references cited in the text of the chapter should be listed in alphabetical order according to the family name of the senior author on a separate sheet of paper at the end of a manuscript. These should then be sequentially numbered with only one reference to a number and cited (in the text) according to number. Journal citations and the lists of references should contain family names, initials of authors and co-authors (note: the family name of the first author precedes the initials; initials precede the family names of all co-authors), title of article, title of journal, (journal abbreviations according to the list of abbreviations in the 1961 Edition of Chemical Abstracts List of Periodicals) volume number, inclusive pages, and year. The following is an example:

White, H. L., I. T. Rosen, S. S. Fischer, G. H. Wood
The influence of posture on renal activity. Am. J. Physiol.
78: 185-200, 1926.

References to books should be complete, including author, title, page numbers or chapters where applicable, place of publication, name of publisher, and year of publication. In multi-author publications, the name of editor(s) followed by the abbreviation ed. or eds., should be included; following is an example:

Greaves, R. I. N. Some Factors Which Influence the Stability of Freeze Dried Cultures. In, Parkes, A. S. and Smith, A. U., Eds/ Recent Research in Freeze Drying, pp. 203-215 Philadelphia, Davis, 1960.

References to all chapters shall be presented in two groups, including the Cyrilic in one and Latin alphabet in the other. The references in the original language should be numbered consecutively throughout the entire list. In translation, numbers for references will remain unchanged, although, the list will be alphabetized. In the English volumes, Russian names, titles of papers, and books will be translated into English. Titles of journals will be transposed to Latin characters. In the Russian volumes, foreign references will be included in the original language.

Citations to technical publications and government documents may be included as references and should be treated as a periodical reference. A footnote should indicate where these can be procured or purchased (Government Printing Office etc.). References to "Unpublished Observations," "Manuscript in Preparation," "To be Published," "Personal Communications," should not be included in the list of references, but may be noted as footnotes in the texts. These should be held to a minimum.

Tables and Figures   Tables should be typed double spaced and should be numbered with Arabic numerals and referred to in the text. Each table should have a brief, concise title and the content should not duplicate material contained in figures. Column headings should be brief and abbreviated where possible. Explanatory information concerning the table should be included as a footnote to the table, not as part of the title. The content of each table such as statistical measures of variation, etc. should be identified so that the table could "stand alone" and present a meaningful bit of scientific information.

Figures include line drawings, photographs of personnel or equipment, tracings of biological signals such as EEG, ECG, etc., block diagrams, flow charts, photomicrographs, etc. They should be submitted as sharp, contrasty, unmounted photographs of the illustrations on glossy paper. Original drawings should not be submitted. Drawings for reduction should be drawn and lettered on the same scale. The actual magnification of all photomicrographs should be indicated on the back of the figure. Whenever possible all lettering should be within the framework of the figure and key symbols should be on the face of the chart if space is provided. If the figure is filled, put the explanatory symbols in the legend.

For a family of curves, it is suggested that the following characters be used in the graphs: open square, closed square, open circle, closed circle, half-closed circle, open triangle, closed triangle and x. The illustration with its title and legend should be prepared concisely so that it will "stand alone" and provide a unit of scientific information.

Locations of Figures and Tables The approximate location of each figure and table in the text of the manuscript should be indicated by a marginal notation. This information will be of considerable assistance during construction of page proofs.

Formulas and Equations Formulas and equations should be typewritten wherever possible, with subscripts and superscripts clearly indicated. Text equations should be expressed so that they can be set in line.

Abbreviations It is suggested that abbreviations (except for title of journal abbreviations noted earlier) follow the general style outlined in the book, Style Manual for Biological Journals, Second Edition, Washington, D. C., AIBS, 1964. The manual may be obtained for $3.00 from the American Institute of Biological Sciences, 3900 Wisconsin Avenue, Washington, D. C., 20016.

Footnotes It is suggested that footnotes be kept at a minimum and noted by using a numerical superscript.

GENERAL COMMENTS

It is essential to obtain appropriate translation of certain technical terms and their usage. To achieve this, each author(s) should identify and prepare, at the end of his chapter, a glossary of technical terms with a brief definition of their meaning. Ambiguity and misinterpretation of terminology will thereby be minimized. The accumulated glssary shall be included at the end of each volume.

The inclusion of extensive appendices should be discouraged.

If it is necessary to include an appendix to one of the chapters, it should be located at the end of the chapter just before the references.

It is suggested that each volume contain a complete author index for the volume and that a subject index be prepared for each volume.

Each author and co-author will be supplied with copies of reprints of chapters prepared by him.

Volume 2

Chapters Designation, Chapter Length, Selected Authors

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2	1	2	1.5		
2	1	3	4.0	Tobias and Grigoriev	USA-USSR
2	2	1	3.0	Malkin	USSR
2	2	2	2.0	Wands	USA
2	2	3	3.0	Webb	USA
2	3	1	1.5	Smith	USA
2	3	2	3.0	Vasilyev	USSR
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2	3	6	3.0	von Gierke	USA
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2	4	4	2.0		
2	5	1	1.5		
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Encl 4