III. PROVIDING ACCESS TO SPACE FOR LIFE SCIENCES BASIC RESEARCH

A. Basic Science Not Immediately Applicable to Moon and Mars Missions

Throughout its evolution, life on Earth has been exposed to the constant force of gravity. Therefore, it is axiomatic that gravity helped shape and continues to influence the structure, function, and ongoing evolution of all living organisms. Because of its pervasive influence, understanding the effects of gravity on life is a fundamental question of substantial, inherent scientific value in our quest to understand life. Knowledge of the effects of gravity on lower organisms, plants, humans, and other animals, as well as elucidation of the basic mechanisms by which these effects occur, will be of direct benefit to: (1) the quality of life on Earth through applications in medicine, agriculture, industrial biotechnolgy, environmental management, and other human activities dependent on understanding biological resources; (2) understanding the impact of, and providing countermeasures for, long-term exposure of humans to the microgravity of space flight and the partial gravity of Moon and planetary bases; and (3) development of bioregenerative life support systems for use on human exploration missions.

Space flight provides the only environment in which the force of gravity can be removed or discrete levels of gravitational force between 0 and 1 g can be provided to address critical scientific questions. Variable g hardware will allow control of gravity as a variable analogous to the way in which light intensity and quality, temperature, nutrient levels, drug dosages, etc., have always been manipulated to elucidate the fundamental mechanisms and processes involved in the structure and function of living systems. Also, space is the only environment in which other fundamental biological processes and mechanisms can be studied in the absence of coupled and sometimes overwhelming effects of gravity.

The closed environment of spacecrafts provides a unique opportunity to conduct controlled experiments to investigate the impacts of environmental factors such as atmosphere, light, confined space, radiation, and their interaction with gravitational force. Twenty-two percent (22%) of the critical questions in the Life Sciences Discipline Science Plans (Volume II, Table 2) address research which is not applicable to MFPE missions. The existing Life Sciences Program provides appropriately balanced support for this research consistent with NASA goals.

Moon and Mars missions will provide both the opportunity to conduct research, foster science and math education, and spark the imagination of scientists and the American public, adding impetus for space sciences research in general. The Life Sciences Program must maintain its balanced approach.

B. Inherent Scientific Merit of the Science and Technology Research that Supports Moon and Mars Missions

Most of the science required for Moon and/or Mars missions has inherent scientific value and is justifiable on its own merit. In many instances the experimental data necessary to understand the structure and function of living systems is the same fundamental data required for applications that would improve "quality of life on Earth," or which would allow design of spacecraft, space bases, and space suits that will enable human exploration of our solar system. Both "science for the sake of science," (including understanding of the origin, evolution and distribution of life in the universe) and "human health and well-being in space" and will undoubtedly benefit from the understanding of physico-chemical processes, and biological perception and transduction of gravity.

C. Science Enabled by Moon and Mars Missions

Moon and Mars missions will provide broad impetus for science and accelerate acquisition of knowledge in gravitational biology across all disciplines. The following discussion focuses only on those areas of science which will be specifically facilitated or enhanced by Moon and Mars missions, immediately applicable to enabling those missions.

1. Introduction

The Exobiology Program, the scientific study of Mars, and the enabled science that can be accomplished on such a mission are among the primary justifications for going to Mars. The Synthesis Group Report and NASA Office of Exploration planning (Appendix G) emphasize that "planning for scientific investigations shall be an integral part of operations and exploration missions." Mars and Moon missions enable activities that offer promising and unique science opportunities. Of twelve Life Sciences Division disciplines, seven have critical questions[1] enabled by these missions.

Table III-1
Life Sciences Disciplines Enabled by Mars and Moon Missions

Exobiology
Cell and Developmental Biology
Neuroscience
Regulatory Physiology
Cardiopulmonary
Musculoskeletal
Behavior, Performance and Human Factors

Footnote 1. 12% of the critical questions identified in Life Sciences Division Discipline Science Plans are enabled by Mars and or Moon missions. See Volume II Table 2.

2. Exobiology

The Exobiology Program seeks to understand the origin, evolution, and distribution of life and life-related molecules in the universe. It is a highly interdisciplinary program encompassing such diverse research areas as chemical evolution (the history of carbon and carbon-containing molecules in the universe), microbiology, paleomicrobiology, organic geochemistry, geology, planetology, radio astronomy, and the Search for Extraterrestrial Intelligence (SETI), to name a few. The program requires extensive ground-based research in all of the areas mentioned, as well as the opportunity for long-term orbital research (e.g., on SSF) and studies of interstellar molecules and extraterrestrial bodies, such as comets, asteroids, meteorites, and planets. All evidence suggests that the origin and evolution of life is inextricably woven into the history and evolution of planets. The Earth is an example of such a planet — teeming with life, so much so that terrestrial life has completely reworked and devoured its own earlier history. It is clear that other planets have evolved differently from Earth. We need to understand the differences and why they occur. Life on Earth began between 3.5 to 4 billion years ago. During this time frame, while life on Earth was originating, the environment on Mars was warmer and wetter than at present, and it was probably more hospitable to living processes. Planets, such as Mars, may or may not have produced the appropriate organic molecules leading to life, and that life, if it arose, may or may not have survived and evolved as the planet evolved — we do not know! Only by exploration and research can we resolve the multitude of questions associated with the very profound issues of life's origin(s), evolution, and distribution.

The Planetary Protection Program, discussed in Section IV, is essential to ensure that the scientific value of Mars is protected from biological and chemical (organic) contamination from the Earth until our key scientific objectives are met. That program encompasses the development of technology to clean, and if necessary, sterilize spacecraft searching for the record of life, in order to avoid masking or even destruction of important evidence on Mars by introducing terrestrial life forms and organic molecules. The constituents most sensitive to such contamination are (if they exist):

- Indigenous life forms
- Fossil organisms
- Organic molecules.

Table III-2
Sites Within Solar System Likely to Contain Evidence of the Origin of Life*

1. Mars	4. Titan
2. Comets	5. Cosmic Dust
3. Meteorites	

*Approximate priority order

Approach. The search for evidence of life (extant or extinct), life related organic molecules, and water are the principal NASA objectives of a series of missions to Mars that began with the Viking missions in the mid 1970s. The search continues with a series of unmanned robotic precursor probes designed to further characterize the chemistry of the Mars atmosphere and planetary surface, geology, seismology, and climatology. The Viking mission searched for indigenous life forms and organic molecules but found none in two small localized sites. It is important to study a far larger portion of the planet (i.e., equator to poles), in sites more representative of the variety of Mars geographies, and in sites with characteristics of particular interest from an exobiological point of view. This work can be done with orbiters, landers, and rovers which can be cleaned and sterilized so that the planet is not contaminated and future study compromised. Such a program accomplishes two things:

- We will learn much more about Mars, the solar system, and the universe so that future experiments can be better designed and more desirable sites for scientific investigation can be identified.

- We will have more confidence in the selection of human landing sites with concerns for safety and the scientific potential of the area for detailed human exploration. Human exploration will inevitably contaminate the planet; therefore, from a scientific point of view the key data concerning life should be obtained before that time.

While the likelihood of extant life on Mars is very remote, it is not zero, and the likelihood of ancient (fossil) life is much greater. Human exploration will eventually greatly facilitate the search for and study of ancient life — an undertaking which may be impossible to accomplish robotically.

Unmanned precursor missions, Moon bases, and SSF offer important opportunities for research, such as long-term cosmic dust collection for organic analysis or simulations of gas-grain interactions, which are scientific objectives of exobiology. Furthermore, Moon missions can also provide significant opportunity for exobiology science experiments, particularly those dealing with the record of chemical evolution in the early solar system.

3. Other Specifically Enabled Science

Although the Exobiology Program has been identified as uniquely enabled by Mars missions, unmanned precursor missions, Moon bases, and SSF offer exciting opportunities to conduct other life science experiments. Microgravity research will also be enabled by accelerated plant research required for long-term bioregenerative life support (CELSS) on SSF. Basic science studies of muscle physiology, cardiovascular function, vestibular and other neuroscience, regulatory physiology, and behavioral and performance studies will also be enhanced.

A Moon base that can serve as a waystation and research base for Mars missions will offer unique opportunities to conduct cellular and developmental biology experiments within the reduced gravity of the Moon. In particular, it will be of great value to assess reproduction and development (i.e., egg to egg) in this 0.16g environment compared to that in 1g centrifuges on site. In order to evaluate the impact of hypogravity on human, animal and plant systems, studies should include a variety of species over the phylogenic range (including, but not limited to, the well understood systems of mice, insects, and roundworms). Many basic science questions included in Section III-A, and Mars mission questions included in Sections IV, V, and VI can be addressed in Moon or Mars bases, and could provide beneficial crew activity and exciting scientific results in a Mars transit vehicle.

Cell and Developmental Biology. Questions focusing on gravity sensing responses of cellular systems and the affect of gravity on the development of anatomical structures of animals would be uniquely enabled by Moon and Mars missions.

Neuroscience. Uniquely enabled science focuses on understanding basic mechanisms of gravity perception, effects of altered gravity on changes in biological rhythms, definition of appropriate neuronal models for understanding central processing in altered gravity, and understanding how signals from different receptors are involved in orienting in altered states of gravity and motion.

Cardiopulmonary. Uniquely enabled questions focus on a basic understanding of the cardiovascular function in the microgravity environment. For example, cellular changes in the function of the heart, morphological changes involving the cardiovascular system, and understanding of pulmonary aging and pathology caused by space flight. Neuroscience studies in relation to autonomic control of cardiovasuclar action may be of great significance, both for spaceflight and medical treatment on Earth.

Regulatory Physiology. Further flight and ground-based investigations into the changes in the major regulatory systems of the body (the nervous, endocrine and immune systems) induced by exposure to the space environment will be required to support Mission to Planet Earth (MTPE).

Human Factors. Studies of the effect of space flight on sleep architecture, quality and quantity would be specifically enabled by long-duration Moon base studies.

Musculoskeletal. Long-duration studies facilitated by Moon and or Mars missions would help determine the effects of weight-bearing on development.

D. Educational Opportunities

The reason for voyages of discovery are tied to humankind's insatiable desire to investigate the unknown and learn. The natural fuel for learning is inquisitiveness, motivation and desire of students to learn. The spark that ignites the process is excitement. History is replete with examples of the positive benefits of exploration on technology and scientific knowledge. The Apollo Program had a dramatic impact on the development of microelectronics, materials, microminiaturization and the plethora of other "terrestrial applications" that NASA refers to by the term "spinoff." Most importantly, the Apollo Program captured the interest of a generation of Americans and motivated unprecedented numbers of young minds to pursue careers in space science and engineering.

The most critical factors in great endeavors such as MTPE and MFPE include visionary planners, committed sponsors, capable managers, daring explorers and large numbers of dedicated, skilled, and experienced scientists and engineers. By far the most important resources are trained minds. The availability of men and women with these skills requires a nation-wide educational system that attracts and retains capable disciplined minds to the "hard sciences" and engineering fields. The current trend of fewer and fewer students, particularly ethnic minorities and women, choosing careers in these fields is alarming, is not in the best interest of NASA or the United States, and must be reversed.

NASA life sciences educational programs include the Space Life Sciences Training Program at field centers, a SETI education initiative (co-sponsored by NSF) focusing Life in the Universe as an Integrated Science Teaching Program, the Planetary Biology Intern Program, the Space Biology Research Associate Program, the Planetary Biology and Microbial Ecology Program, the Aerospace Medicine Residency Program, NASA Specialized Centers of Research and Training, and Spacelab Life Science Curriculum Supplements. These efforts should be strengthened and further integrated with the educational programs in other OSSA divisions, throughout NASA, and across federal agencies. Participation with private industry and the university community must be enhanced.

The Moon and Mars missions are a unique opportunity to spark the interest of students throughout the world. The plan to get there must include resources and people dedicated to communicating both the knowledge and the excitement, thereby ushering in a new era in education.

E. Robust Program

It is impossible to address a robust science program within the bounds of robust and constrained as defined in this report. Robustness of the science program depends on the availability of flight research equipment, crew time, power, volume, etc. It also depends on a broadly based ground research program and the availability of research funds for principal investigators. It requires a spirit of openness to a diversity of hypotheses across the extraordinarily broad area called life sciences. AMAC encourages the development and implementation of a very robust science program.