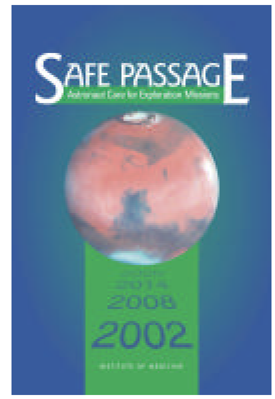
INSTITUTE OF MEDICINE

Shaping the Future for Health

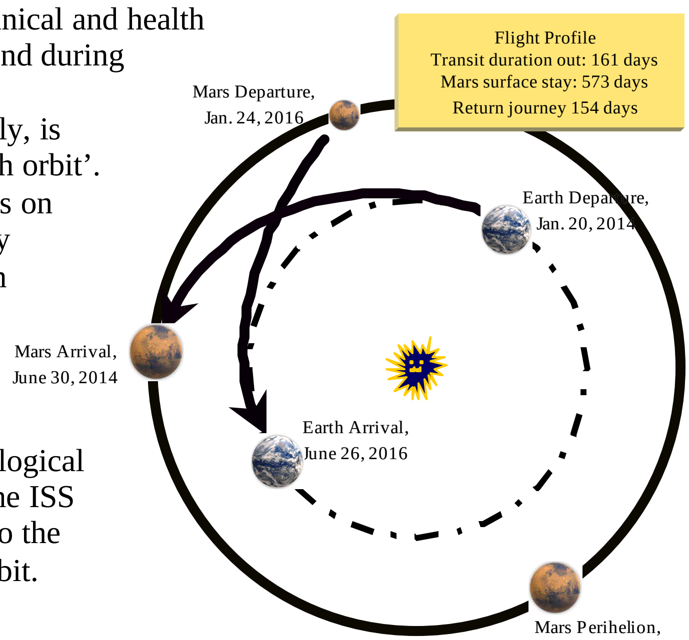


SAFE PASSAGE:

ASTRONAUT CARE FOR EXPLORATION-MISSIONS

Space travel is inherently risky. From the early days of orbital flight through the longer-duration missions first on the Russian space station *MIR* and now an the International Space Station (ISS), a number of health hazards have been identified; the loss of bone calcium, radiation exposure, and difficulty in behavioral adaptation to confined living conditions are a few of the most serious. And as the National Aeronautics and Space Administration (NASA) prepares to face its next challenge—long-duration missions beyond Earth orbit—questions about the health risks associated with prolonged exposure to the unique environment of deep space have gained importance. In response to a request from NASA, the Institute of Medicine convened a committee to address the need and methods for getting answers to questions about astronaut health. The Committee on Creating a Vision for Space Medicine During Travel Beyond Earth Orbit was charged with making recommendations regarding the infrastructure for a health system in space, defining the principles that should guide such a system to provide an appropriate standard of care for astronauts, and identifying the nature of clinical and health services research that will be required before and during long-duration missions.

To begin, we must identify what, exactly, is meant by 'long-duration missions beyond Earth orbit'. The description refers to missions with humans on boardinto deep space, such as an interplanetary mission, which would require multiple years in space. A mission to Mars, for example, would take three years. Shuttle missions, in comparison, generally last 1-2 weeks, and an assignment to the ISS may last for several months. The physiological and psychological effects noted above are of greater concern to the ISS astronaut stationed for 3 months in orbit than to the shuttle astronaut who will spend 2 weeks in orbit. Therefore, it is reasonable to conclude that the



Trajectory of a human mission to Mars in 2014.

health risks would be quantitatively increased, and perhaps qualitatively different as well, for a 3-year mission.

…everything reasonable should be done to gain the necessary information before humans are sent on missions of space exploration.

The basic findings of the committee are these: (1) not enough is yet known about the risks to humans of long-duration missions, such as to Mars, or about what can effectively mitigate those risks to enable humans to travel and work safely in the environment of deep space and (2) everything reasonable should be done to gain the necessary information before humans are sent on missions of space exploration.

Given these findings, how should NASA proceed toward designing a contemporary, practical, and portable astronaut health care diagnosis and delivery system? Such a system will rely on clinical research to determine what types of risks should be addressed in training, the ability of astronauts to provide day-to-day health care for one another during a long-term mission, and the development of an infrastructure that can provide the necessary support.

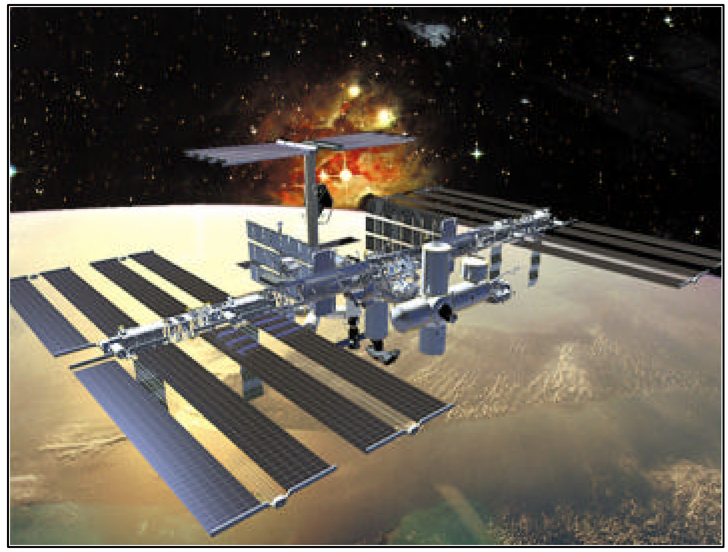
HEALTH RISKS AND CLINICAL RESEARCH

Risks and Research

The three most important health issues for long-duration missions have already been identified during short-term missions: radiation, loss of bone mineral density, and behavioral adaptation. The radiation risk of deep space, for example, is difficult to quantify. The character of radiation in space is quite different from that to which we are regularly exposed on Earth. In addition, unpredictable solar outbursts cause a spike in radiation levels. Currently, there is no practical way to protect astronauts from them. The potential effects of radiation are increased during acute exposure related to extravehicular activity (so-called space walks) and during the chronic exposure experienced by residents of the ISS. Longer-duration missions will increase the risk at least arithmetically (if not exponentially) due to increased length of chronic exposure time and the changing character of radiation in the environment. Reducing radiation exposure by physical shielding represents an engineering challenge that should be met before assigning astronauts to long-term missions in deep space.

The loss of bone mineral density, which can result in brittle bones and increased susceptibility to fractures, occurs at an average rate of 1 percent per month in microgravity. The loss is relatively manageable on the short-duration missions of the space shuttle, but it becomes problematic during extended residence on the ISS. The ISS, therefore, is perhaps the best setting for expanded research on this topic. If no medical remedy can be devised, an engineering countermeasure, such as artificial gravity, will be necessary. If no method is found to mitigate the loss of bone density, which could be as great as 50% or more if left untreated over a 3-year period, long-duration interplanetary missions will be impossible.

Behavioral adaptation and human interactions aboard a confined spacecraft, isolated both temporally and spatially from Earth, may well be one of the most serious challenges to human exploratory missions. The habitability of the spacecraft, marginalized from the outset by the need to restrict weight, will be further compromised by the need to carry all necessary equipment and nourishment at least for the voyage to Mars (if supplies have been stockpiled there), if not for the entire 3-year duration of the mission. Current designs are plagued by high noise levels, less that optimal light, and diminished privacy. In addition, an interplanetary mission would likely be staffed by an international crew; differences in social and cultural backgrounds and politics could increase tension on board. To an already tense environment, add several factors of isolation. Real-time communication with Earth will be impossible; at the farthest distance from Earth, radio and even more advanced messages will take 20 minutes to reach their destination. Likewise, a timely return to Earth will be impossible during an interplanetary flight; a return trip could take months to plan and execute.



The success of the mission and the lives of the astronauts will depend on every member of the crew functioning appropriately, both physically and emotionally. Understanding the behavior of individuals in such environments and understanding the interactions of members of a team in prolonged isolation are necessary prerequisites to preventing disruptive behaviors and to dealing adequately with them should they occur.

Data Collection and Analysis

There is a profound professional and ethical responsibility to evaluate honestly the risk to human life that accompanies long-duration space travel. This risk should be evaluated in the context of the benefit of such exploration to humans but should be identified in terms of individual lives and explained in a way that can be plainly understood. Unfortunately, current data are not adequate for a risk assessment.

Over the 40 years that humans have flown in space, several types of clinical data have been collected: health-related data (personal medical data), supplemental data (mission-based data and responses to space travel), and integrated test regimen data (research data from studies with astronauts as participants). Health-related data are considered private, while supplemental and integrated test regimen data are available for analysis, although they are nonattributable. The reality is, however, that the astronaut is (in most cases) the only individual from whom clinical information relevant to space travel can be collected. A tailored application of occupational health principles, in which the safety and health of the group are balanced with the rights of the individual, would therefore be a useful and appropriate model for the collection and analysis of all astronaut clinical data.

The reality is, however, that the astronaut is (in most cases) the only individual from whom clinical information relevant to space travel can be collected.

The primary goal of NASA-sponsored health care research is to learn how to send and keep humans safely in space, then have them return to Earth in good health.

The primary goal of NASA-sponsored health care research is to learn how to send and keep humans safely in space, then have them return to Earth in good health. This requires a comprehensive system that will enable the collection of all clinical information relevant to space travel. Combined with a strategic health care research plan that would enable the analysis of those data, such a system would foster data-driven decisions about health risks, prevention, and mitigation. Both the intramural and extramural research programs of NASA, especially the research conducted through the National Space Biomedical Research Institute, are mechanisms for addressing the two principal issues: the relative paucity of relevant clinical data and the heretofore relatively closed clinical research environment that has characterized NASA. A far more basic understanding of fundamental processes is needed, however, and investigator-initiated research in broad areas is an appropriate strategy for the development of such an understanding.

HEALTH CARE

The known risks of space travel, such as those identified previously, are enough to indicate that regular monitoring of health status during an extended mission will be critical to its success. In addition to monitoring activities, however, several astronauts will need to be trained to provide diagnosis and treatment of a broad spectrum of health problems—it is not far-fetched to consider that the mission's medical officer could become incapacitated. It is also critical to recognize that not all of the risks that could be encountered during an interplanetary mission are known, and that the environment will be more extreme than anything modern planners, practitioners, and patients have yet encountered. A continuing review of all available data from missions in space and extreme, isolated Earth environments (e.g., Antarctica and extended submarine missions) will help determine what training should be provided, what resources should be made available, and what pharmaceuticals and equipment should be on-board to ensure the highest possible standard of clinical care during extended missions. The goals of the health care system should be to maximize the astronaut's ability to function as a productive member of the crew while in deep space and to maintain or to restore normal function in the pre-mission and the post-mission phases of space travel.

Knowledge of the pre-flight health status of individual astronauts—especially of the organs and systems likely to be most stressed by an extended mission in deep space—will also be critical. These data can contribute meaningfully to both the crew selection and in-flight monitoring processes. Again, the application of an occupational health model to relevant medical data is a policy shift that will result in better care and better health for astronauts on long-duration missions.

INFRASTRUCTURE AND ORGANIZATION

Engineering and Biology

The technical aspects of space flight, such as the mechanics and function of the spacecraft, have always represented NASA's greatest achievements. The human aspect has often been less well appreciated, perhaps because short-duration missions have statistically fewer human problems than mechanical ones. In response to technical risks, NASA has developed an elaborate system of 'countermeasures'—the engineering solution for each technical failure. But this 'one-problem, one-solution' model is insufficient to address the range of human health responses to various risks. Instead, a model that relies on developing an understanding of the nature and causes of particular risks and the diversity of possible responses is needed.

The theory and practice of engineering are converging with those of biology in new ways, and NASA could derive great benefit from facilitating that transition within NASA. Taking advantage of these developments, however, will require organizational integration within NASA and coordination with external resources. Similar efforts of integration and coordination are recommended to facilitate the development of a comprehensive health care system for astronauts.

The theory and practice of engineering are converging with those of biology in new ways, and NASA could derive great benefit from facilitating that transition within NASA.

Organization

This comprehensive system must encompass both health care and an effective health care research strategy. Such a framework requires leadership in the form of accountability for and authority over all aspects of astronaut health, including the funding needed to make all pertinent decisions with respect to the health of the astronaut corps. Such leadership could best be provided by a single organizational unit, either internal or external to NASA, charged with (1) development of the system along with standards for performance; (2) coordination of all related external and internal resources, including basic, translational, and clinical biomedical and behavioral research; and (3) administration of the unit's policies and procedures. The fragmentation of these system components works against the integration of astronaut health with other elements, such as spacecraft design and function, of an exploratory mission.

CONCLUSION

In a 1997 report, NASA characterized the human exploration of Mars as a goal that "currently lies at the ragged edge of achievability" (Hoffman and Kaplan, 1997). Human exploration of this scope requires optimum functioning of both spacecraft and astronauts—of both the engineering and the human components. Failure of either could result in mission failure. Success, therefore, requires close integration of both throughout the design, planning, and implementation process. By developing and instituting a comprehensive health care system for astronauts, NASA can create a knowledge base for decision-making that will allow long-duration exploration of deep space to go forward.

Summary of the Committee's Recommendations

Managing and Communicating Risks to Astronaut Health

Recommendation 1. NASA should give increased priority to understanding, mitigating, and communicating to the public the health risks of long-duration missions beyond Earth orbit.

Comprehensive Astronaut Health Care System

Recommendation 2. NASA should develop a comprehensive health care system for astronauts for the purpose of collecting and analyzing data while providing the full continuum of health care to ensure astronaut health.

Strategic Health Care Research Plan

Recommendation 3. NASA should develop a strategic health care research plan designed to increase the knowledge base about the risks to astronaut health.

Understanding Behavioral, Social and Cultural Issues and Challenges

Recommendation 4. NASA should give priority to increasing the knowledge base of the effects of living conditions and behavioral interactions on the health and performance of astronauts on long-duration space mission.

Astronaut Health and Safety Data Collection and Access

Recommendation 5. NASA should develop and use an occupational health model for the collection and analysis of astronaut health-related data, giving priority to the creation and maintenance of a safe work environment.

Integration of Engineering and Health Sciences

Recommendation 6. NASA should accelerate integration of its engineering and health sciences cultures.

Authority and Accountability for Astronaut Health

Recommendation 7. NASA should establish an organizational component headed by an official who has authority over and accountability for all aspects of astronaut health, including appropriate policy-making, operational, and budgetary authority.

For More Information…

Copies of *Safe Passage: Astronaut Care for Exploration-Missions* are available for sale from the National Academy Press; call (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area), or visit the NAP home page at **www.nap.edu.**

This study was funded by the United States National Aeronautics and Space Administration.

The Institute of Medicine is a private, nonprofit organization that provides health policy advice under a congressional charter granted to the National Academy of Sciences. For more information about the Institute of Medicine, visit the IOM home page at **www.iom.edu.**

COMMITTEE ON CREATING A VISION FOR SPACE MEDICINE DURING TRAVEL BEYOND EARTH ORBIT

JOHN R. BALL (*Chair*), Executive Vice President Emeritus, American College of Physicians, Havre de Grace, MD

JOSEPH V. BRADY, Director, Behavioral Biology Research Center, The Johns Hopkins University, Baltimore, MD

BRUCE M. COULL, Head, Department of Neurology, University of Arizona College of Medicine, Tucson, AZ

N. LYNN GERBER, Chief, Department of Rehabilitation Medicine, National Institutes of Health, Bethesda, MD

BERNARD A. HARRIS, President, The Harris Foundation, Houston, TX

CHRISTOPH R. KAUFMANN, Colonel MC (USA), Division of Surgery for Trauma, Uniformed Services University of the Health Sciences, Bethesda, MD

JAY M. McDONALD, Professor and Chair, Department of Pathology, University of Alabama at Birmingham, Birmingham, AL

RONALD D. MILLER, Professor and Chair of Anesthesia and Perioperative Care, University of California at San Francisco, San Francisco, CA

ELIZABETH G. NABEL, Scientific Director, National Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, MD

TOM S. NEUMAN, Professor of Medicine and Surgery, Associate Director, Department of Emergency Medicine, University of California at San Diego, San Diego, CA

DOUGLAS H. POWELL, Senior Partner, Powell and Wagner Associates, Cambridge, MA, and Clinical Instructor in Psychology, Harvard Medical School, Boston, MA

WALTER M. ROBINSON, Assistant Professor of Pediatrics and Medical Ethics, Harvard Medical School, Boston, MA

CAROL SCOTT-CONNER, Professor and Head, Department of Surgery, University of Iowa College of Medicine, Iowa City, IA

JUDITH E. TINTINALLI, Professor and Chair, Department of Emergency Medicine, University of North Carolina at Chapel Hill, Chapel Hill, NC

Committee Liaisons

Institute of Medicine Board on Health Sciences Policy

GLORIA E. SARTO, Professor of Obstetrics and Gynecology, National Center of Excellence in Women's Health, University of Wisconsin, Madison, WI

Institute of Medicine Board on Neuroscience and Behavioral Health

STEVEN M. MIRIN, Medical Director, American Psychiatric Association, Washington, DC

National Research Council Space Studies Board

MARY JANE OSBORN, Professor and Head, Department of Microbiology, University of Connecticut, Farmington, CT

Institute of Medicine Staff

CHARLES H. EVANS, JR., Study Director and Institute Senior Adviser for Biomedical and Clinical Research

MELVIN H. WORTH, JR., Scholar–in–Residence

JUDITH RENSBERGER, Senior Program Officer

VERONICA SCHREIBER, Research Assistant

SETH M. KELLY, Project Assistant to August 2000

TANYA M. LEE, Project Assistant from August 2000

GREG T. SHERR, National Research Council Intern (Summer 2000)

Institute of Medicine Board on Health Sciences Policy Staff

ANDREW POPE, Director

CARLOS GABRIEL, Financial Associate

ALDEN CHANG, Administrative Assistant

Institute of Medicine Auxiliary Staff

MICHAEL EDINGTON, Managing Editor to March 2001

PAIGE BALDWIN, Managing Editor from March 2001

SUSAN FOURT, Librarian to December 2000

WILLIAM McCLOUD, Librarian from December 2000

Copy Editor

MICHAEL K. HAYES