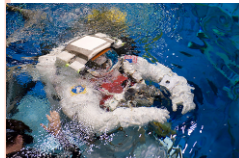
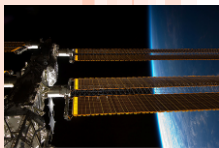


# RECAPTURING A FUTURE FOR SPACE EXPLORATION: LIFE AND PHYSICAL SCIENCES RESEARCH FOR A NEW ERA

WHAT ARE THE KEY SCIENTIFIC CHALLENGES THAT LIFE AND PHYSICAL SCIENCES RESEARCH IN SPACE MUST ADDRESS IN THE NEXT 10 YEARS?

**“In the context of extraordinary advances in the life and physical sciences and with the realization that national policy decisions will continue to shift near-term exploration goals, the committee focused on surveying broadly and intensively the scientific issues necessary to advance knowledge in the next decade. Such a task is never easy; it relies on interpolation and extrapolation from existing knowledge sources and educated assumptions about new developments. The committee grappled with all of these issues as well as the thorny problem of how to organize the scientific efforts themselves procedurally so that they would flourish in the next decade”.**



**Betsy Cantwell  
Wendy Kohrt**

Decadal Survey on Biological and Physical Sciences in Space  
National Academy of Sciences

## THE DECADAL SURVEY FOR LIFE & PHYSICAL SCIENCES RESEARCH IN MICROGRAVITY AND PARTIAL GRAVITY ENVIRONMENTS

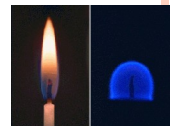
NASA asked the National Academy of Sciences to:

- Define research areas that enable and are enabled by exploration missions
- Define and prioritize an integrated life and physical sciences research portfolio and associated objectives;
- Develop a timeline for the next decade for these research objectives and identify dependencies between the objectives;
- Explain how the objectives could enable exploration activities, produce knowledge, or provide benefits to space and other applications;
- Identify terrestrial, airborne, and space-based platforms and facilities that could most effectively achieve the objectives;
- Identify potential research synergies between NASA and other US government agencies, as well as with commercial entities and international partners; and
- Identify potential research objectives beyond 2020.



# STEERING COMMITTEE MEMBERSHIP

- **Elizabeth R. Cantwell**, *co-chair*  
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- **Wendy M. Kohrt**, *co-chair*  
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# THE DECADAL SURVEY ON BIOLOGICAL AND PHYSICAL SCIENCES IN SPACE

- This Decadal Survey was mandated by Congress and requested of the NRC by the Exploration Missions Directorate in 2009
  - “The survey should focus on the aforementioned tasks and should not recommend budgetary levels.”
- Input was dependent on re-engaging a disenfranchised community
  - Assembled 7 advisory panels
  - Received approximately 150 white papers
  - Held 4 Town Hall meetings
- A major challenge was to continue to move forward in deliberations in the face of policy changes and uncertainty
  - Developed a research portfolio that is adaptable to future policies



# PANELS FOR THIS DECADAL STUDY

## Steering Committee

### Life Sciences

- Plant and Microbial Biology
- Behavior and Mental Health
- Animal and Human Biology

### Translational Science

- Cross-cutting Issues for Humans in the Space Environment
- Translation to Space Exploration Systems

### Physical Sciences

- Fundamental Physical Sciences in Space
- Applied Physical Sciences in Space

<http://www7.nationalacademies.org/ssb/microgravdecadal.html>



## PANEL CHAIRS

- **Dr. Terri Lomax** – Plant and Microbial Biology  
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- **Dr. Thomas J. Balkin** – Behavior and Mental Health  
Walter Reed Army Institute of Research
- **Dr. Kenneth M. Baldwin** – Animal and Human Biology  
University of California, Irvine
- **Dr. James A. Pawelczyk** - Cross-Cutting Issues for Humans in the Space Environment  
Pennsylvania State University
- **Dr. Robert V. Duncan** - Fundamental Physical Sciences in Space  
Missouri University of Science and Technology
- **Dr. Peter W. Voorhees** - Applied Physical Sciences in Space  
Northwestern University
- **Dr. James P. Bagian** - Translation to Space Exploration Systems  
Veterans Health Administration



## THE BOTTOM LINE

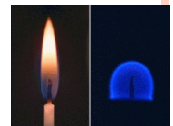
“Although its review has left it deeply concerned about the current state of NASA’s life and physical sciences research, the Committee for the Decadal Survey on Biological and Physical Sciences in Space is nevertheless convinced that a focused science and engineering program can achieve successes that will bring the space community, the U.S. public, and policymakers to an understanding that we are ready for the next significant phase of human space exploration. The goal of this report is to lay out steps whereby NASA can reinvigorate its partnership with the life and physical sciences research community and develop a forward-looking portfolio of research that will provide the basis for recapturing the excitement and value of human spaceflight—thereby enabling the U.S. space program to deliver on new exploration initiatives that serves the nation, excite the public, and place the United States again at the forefront of space exploration for the global good.”





# REPORT SYNOPSIS

- The report is a highly integrated effort by the committee and its panels, drawing on extensive input from the scientific community.
- Each panel worked from a common template for organizing the chapters, but these were revised to fit the demands of the subject material. Accordingly, each panel chapter (Chapters 4 through 10) contains:
  - review of the current status of knowledge
  - assessment of gaps in knowledge
  - recommendations to address gaps
  - recommendations considered to be of the highest priority; and
  - discussion of the timeframe, facilities, and platforms needed to support the recommended research.
- Common prioritization metrics were discussed but each panel applied metrics that were most appropriate for its discipline
- The metrics were aggregated and synthesized into a common set of criteria against which all of the highest priority recommendations were mapped
- Although the report recognizes the powerful advantages of the ISS in carrying out critical research, the research was selected independently of the consideration of what platform should be used and whether that platform was available. Platform needs were identified after high-priority research was identified.



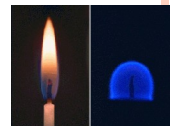
# REPORT ORGANIZATION – OVERARCHING CHAPTERS

- Certain themes arose repeatedly in discussions with the community and within the panels and committee regarding programmatic barriers to establishing a successful research program. The results of those discussions, presented in **Chapter 12**, are considered by the committee and its panels to be at least equal in importance to the selection of research.
- The final high-priority recommendations evolved from interactions of the advisory panels with each other and with the study committee and form the research portfolio in **Chapter 13**. The committee was cognizant of the role that both budget and policy direction will play in implementing the recommended portfolio and therefore provided guidance and examples for how NASA can utilize the recommendations.



# TABLE OF CONTENTS

- CHAPTER 1 INTRODUCTION
- CHAPTER 1 HISTORY OF MICROGRAVITY LIFE AND PHYSICAL SCIENCES RESEARCH
- CHAPTER 3 U.S. AND INTERNATIONAL FACILITIES
- CHAPTER 4 PLANT AND MICROBIAL BIOLOGY
- CHAPTER 5 BEHAVIOR AND MENTAL HEALTH
- CHAPTER 6 ANIMAL AND HUMAN BIOLOGY
- CHAPTER 7 CROSS-CUTTING ISSUES FOR HUMANS IN THE SPACE ENVIRONMENT
- CHAPTER 8 FUNDAMENTAL PHYSICAL SCIENCES IN SPACE
- CHAPTER 9 APPLIED PHYSICAL SCIENCES IN SPACE
- CHAPTER 10 TRANSLATION TO SPACE EXPLORATION SYSTEMS
- CHAPTER 11 THE ROLE OF THE INTERNATIONAL SPACE STATION
- CHAPTER 12 ESTABLISHING A LIFE AND PHYSICAL SCIENCES RESEARCH PROGRAM:  
PROGRAMMATIC ISSUES
- CHAPTER 13 ESTABLISHING A LIFE AND PHYSICAL SCIENCES RESEARCH PROGRAM: AN  
INTEGRATED MICROGRAVITY RESEARCH PORTFOLIO



# PROGRAMMATIC ISSUES<sub>1</sub>

The committee identified critical needs for the successful renewal of research endeavors in life and physical sciences. These include:

- Elevating the priority of life and physical sciences research in space exploration
  - central to NASA's exploration mission and embraced throughout the agency as an essential translational step in the execution of space exploration missions
  - integral component of spaceflight operations, including astronaut participation
  - collection and analysis of a broad array of astronaut data; legal concerns about confidentiality could be addressed by the DHHS SACHRP
- Establishing a stable and sufficient funding base
  - balanced between intramural and extramural activities to support a sufficiently robust extramural research program
  - sustained and strengthened collaborations with other sponsoring agencies



# PROGRAMMATIC ISSUES<sub>2</sub>

- Improving the process for solicitation and review of high-quality research
  - regularly issued solicitations including broad research announcements, targeted research announcements, and team research announcements that specifically foster multidisciplinary translational research
  - a review process for extramural and intramural research that is transparent and accountable for prioritization of intra- and extramural investigations
- Rejuvenating a strong pipeline of intellectual capital through training and mentoring programs
  - educational programs and training opportunities to expand the pool of graduate students, scientists, and engineers who will be prepared to improve the translational application of fundamental and applied life and physical sciences research to space exploration needs



# PROGRAMMATIC ISSUES<sub>3</sub>

- Linking science to mission capabilities through multidisciplinary translational programs
  - long-term strategic plan for maximizing team research opportunities to accelerate the trajectory of research discoveries and improve the translation to solutions for the complex problems associated with space exploration
  - improved central information networks to facilitate data sharing with and analysis by the life and physical science communities
  - improved access of the scientific community to samples and data collected from astronauts; concerns regarding the confidentiality could be addressed by the DHHS SACHRP
- Developing commercial sector interactions to advance science, technology, and economic growth
  - foster interactions with the commercial sector, particularly commercial in a manner that addresses research needs, with attention to such issues as control of intellectual property, technology transfer, conflicts of interest, and data integrity



# PROGRAMMATIC ISSUES<sub>4</sub>

- Administrative oversight of life and physical sciences research
  - Leadership with both true scientific gravitas and a sufficiently high level in the overall organizational structure at NASA is needed to ensure that there will be a “voice at the table” when the agency engages in difficult deliberations about prioritizing resources and engaging in new activities.
  - The successful renewal of a life and physical sciences research program will depend on strong leadership with a unique authority over a dedicated and enduring research funding stream.
  - It is important that the positioning of leadership within the agency allows both the conduct of the necessary research programs as well as interactions, integration, and influence within the mission-planning elements that develop new exploration options.



# ESTABLISHING AN INTEGRATIVE RESEARCH PORTFOLIO

- The Committee synthesized the highest priority research recommendations from each of the Discipline chapters and mapped them to 8 prioritization criteria
- The prioritization criteria can be used to develop relevant research portfolios aligned with future space exploration goals
  - Bounding examples are given for a human mission to Mars and for a science policy that places strongest emphasis on fundamental scientific discovery
- Interdependencies and timelines are then discussed for the integrated set of highest priority recommendations in the context of the 8 criteria at a more granular level





# Highest Priority Research Recommendations

## Plant and Microbial Biology

- Establish a “microbial observatory” program on the ISS to conduct a long term multi-generational studies of microbial population dynamics.
- Establish a robust spaceflight program of research analyzing plant and microbial growth and physiological responses to the multiple stimuli encountered in spaceflight environments.
- Develop a research program aimed at demonstrating the roles of microbial-plant systems in long-term life support systems.



# Highest Priority Research Recommendations

## Behavior and Mental Health

- Develop sensitive, meaningful, and valid measures of mission-relevant performance for both astronauts and ground crew.
- Conduct integrated translational research in which long duration missions are simulated specifically for the purpose of studying the interrelationship between individual functioning, cognitive performance, sleep and group dynamics.
- Determine the genetic, physiological and psychological underpinnings of individual differences in resilience to stressors likely encountered during extended space missions, with emphasis to develop a personalized approach to sustaining astronauts during such missions.
- Conduct research to enhance cohesiveness, team performance, and effectiveness of multinational crews, especially under conditions of extreme isolation and autonomy.



# Highest Priority Research Recommendations

## Animal and Human Biology<sub>1</sub>

### Musculoskeletal

- The **efficacy of bisphosphonates** should be tested in an adequate population of astronauts on the ISS during a 6- month mission.
- The **preservation/reversibility of bone structure/strength** should be evaluated when assessing countermeasures.
- **Bone loss studies of genetically altered mice** exposed to weightlessness are strongly recommended.
- **New osteoporosis drugs** under clinical development should be tested in animal models of weightlessness.
- Conduct studies to identify underlying **mechanisms regulating net skeletal muscle protein balance** and protein turnover during states of unloading and recovery.
- Studies should be done to **develop and test new prototype exercise devices**, and to optimize physical activity paradigms/prescriptions targeting multi-system countermeasures.
- **Determine the daily levels and pattern of recruitment of flexor and extensor muscles** of the neck, trunk, arms and legs at 1 g and after being in a novel gravitational environment for up to 6 months.



# Highest Priority Research Recommendations

## Animal and Human Biology<sub>2</sub>

### Cardiopulmonary

- Determine the **basic mechanisms, adaptations, and clinical significance of changes in regional vascular/interstitial pressures** (Starling forces) during long duration space missions.
- Investigate the effect of prolonged periods of microgravity and partial (3/8 or 1/6 G) gravity on the **determinants of task specific, enabling levels of work capacity**.
- Determine the **integrative mechanisms of orthostatic intolerance** after restoration of gravitational gradients (both 1 g and 3/8 g).
- Collaborative studies among flight medicine and cardiovascular epidemiologists are recommended to **determine the best screening strategies to avoid flying astronauts with subclinical coronary heart disease** that could become manifest during a long duration exploration class mission (3 years).
- Determine the **amount and site of the deposition of aerosols** of different sizes in the lungs of humans and animals in microgravity.



# Highest Priority Research Recommendations

## Animal and Human Biology<sub>3</sub>

### Immune function, developmental biology

- Multiple **parameters of T cell activation** in cells should be obtained from astronauts before and after re-entry to establish which parameters are altered during flight.
- To both address the **mechanism(s) of the changes in the immune system** and to develop measures to limit the changes, data from multiple “organ/system-based” studies need to be integrated.
- Perform **mouse studies, including immunization and challenge**, with immune samples acquired both prior to and immediately upon re-entry on the ISS to establish the biological relevance of the changes observed in the immune system. Parameters examined need to be aligned with those influenced by flight in humans.
- Studies should be conducted on **transmission across generations of structural and functional changes** induced by exposure to space during development. Ground-based studies are needed to develop specialized habitats to support reproducing and developing rodents in space.



# Highest Priority Research Recommendations

## Cross-Cutting Issues for Humans in the Space Environment<sub>1</sub>

- To ensure the safety of future commercial orbital and exploration crews, **post-landing vertigo and orthostatic intolerance should be quantified** in a sufficiently large sample of returning ISS crews, as part of the immediate post-flight medical exam.
- **Determine whether artificial gravity is needed** as a multi-system countermeasure, and whether continuous large radius AG is needed, or intermittent short radius AG is sufficient. Human studies in ground labs are essential to establish dose response relationships, and adequate gravity level, gradient, RPM, duration and frequency.
- Studies on humans are needed to **determine whether there is an effect of gravity on micronucleation and/or intrapulmonary shunting**, or whether the unexpectedly low DCS prevalence on Shuttle/ISS is due to underreporting and to determine operationally acceptable low suit pressure and hypobaric hypoxia limits.



# Highest Priority Research Recommendations

## Cross-Cutting Issues for Humans in the Space Environment<sub>2</sub>

- Optimizing **dietary strategies** for crews and **food preservation strategies** that will maintain bioavailability for 12 or more months.
- Initiate a robust food science program focused on **preserving nutrient stability** for three or more years.
- Include **food and energy intake as an outcome variable** in intervention in studies in humans.
- Studies of astronauts for **cataract incidence, quality, and pathology related to radiation exposures** to understand risk from cataracts and to understand radiation-induced late tissue toxicities in humans.
- Conduct **animal studies to assess radiation risks** from cancer, cataracts, cardiovascular disease, neurologic dysfunction, degenerative diseases, and acute toxicities such as fever, nausea, bone marrow suppression, and others.
- Cellular **ground-based studies to develop endpoints and markers that can be used to define acute and late radiation toxicities** using radiation facilities that are able to mimic space radiation exposures.



# Highest Priority Research Recommendations

## Cross-Cutting Issues for Humans in the Space Environment<sub>3</sub>

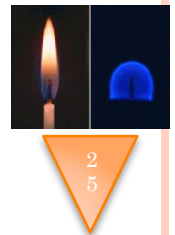
- **Expand our understanding of gender differences** in adaptation to the spaceflight environment through flight and ground based research, including potential differences in bone, muscle and cardiovascular function and long-term radiation risks.
- **Investigate the biophysical principles of thermal balance** to determine whether microgravity reduces the threshold for thermal intolerance.





# Highest Priority Research Recommendations Fundamental Physical Sciences in Space

- Research on complex fluids and soft matter
- Understanding of the fundamental forces and symmetries of Nature
- Research related to the physics and applications of quantum gases
- Investigations of matter near a critical phase transition



# Highest Priority Research Recommendations Applied Physical Sciences in Space<sub>1</sub>

- **Reduced-gravity multiphase flows, cryogenics and heat transfer database and modeling**, including phase separation and distribution (i.e., flow regimes), phase change heat transfer, pressure drop, and multiphase system stability.
- **Interfacial flows and phenomena** (including induced and spontaneous multiphase flows with or without phase change) relevant to storage and handling systems for cryogenics and other liquids, life support systems, power generation, thermal control systems, and other important multiphase systems.
- **Dynamic granular material behavior and subsurface geotechnics** to enable advanced human and robotic planetary surface exploration and habitation.
- Development of **fundamentals-based strategies and methods for dust mitigation** to enable advanced human and robotic exploration of planetary bodies.
- **Experiments to understand complex fluid physics** in a zero-gravity environment enabled by the ISS platform.



# Highest Priority Research Recommendations

## Applied Physical Sciences in Space<sub>2</sub>

- Fire safety research to improve methods for **screening materials in terms of flammability and fire suppression** in space environments.
- **Combustion processes research**, including reduced gravity experiments with longer durations, larger scales, new fuels, and practical aerospace materials relevant to future missions.
- Numerical simulation of combustion research to **develop and validate detailed single and multiphase numerical combustion models**.
- **Materials synthesis and processing and control of microstructure and properties** to improve the properties of existing and new materials on the ground.
- Design and **develop advanced materials that meet new property requirements to enable human exploration at reduced cost** using both current and novel materials synthesis and processing techniques and computational methods.
- Fundamental and applied research is required in developing **technologies for extraction, synthesis, and processing of minerals, metals, and other materials** available on extraterrestrial surfaces.



# Highest Priority Research Recommendations Translation to Space Exploration Systems<sub>1</sub>

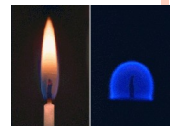
- Research should be conducted to **address active two-phase flow questions** relevant to thermal management.
- Research should be conducted in support of **zero-boiloff propellant storage and cryogenic fluid management**. Physical sciences research includes advanced insulation materials research, active cooling, multi-phase flows, and capillary effectiveness, as well as active and passive storage, fluid transfer, gauging, pressurization, pressure control, leak detection, and mixing destratification.
- NASA should **enhance surface mobility**; relevant research includes suited astronaut computational modeling, biomechanics analysis for partial gravity, robotic-human testing of advanced spacesuit joints and full body suits, and musculoskeletal modeling and suited range-of-motion studies (T4), and studies of the humanrobot interaction (including teleoperations) or the construction and operation of planetary surface habitats.



# Highest Priority Research Recommendations

## Translation to Space Exploration Systems<sub>2</sub>

- NASA should **develop and demonstrate technologies to mitigate the effects of dust on EVA systems and suits, life support systems, and surface construction systems**. Supporting research includes impact mechanics of particulates, design of outer layer dust garments, advanced material and design concepts, magnetic repulsive technologies, and the quantification of plasma electrodynamic interactions with EVA systems; electrostatic coupling; and regolith mechanics and gravity-dependent soil models.
- NASA should **define requirements for thermal control, micrometeoroid and orbital debris impact and protection, and radiation protection** for EVA systems, rovers, and habitats and develop a plan for radiation shelters.
- NASA should conduct research for the **development and demonstration of closed-loop life support systems and supporting technologies**. Fundamental research includes heat and mass transfer in porous media under microgravity conditions and understanding the effect of variable gravity on multi-phase flow systems.
- NASA should **develop and demonstrate technologies to support thermoregulation** of habitats, rovers, and spacesuits on the lunar surface.



# Highest Priority Research Recommendations

## Translation to Space Exploration Systems<sub>3</sub>

- NASA should **perform critical fire safety research to develop new standards to qualify materials for flight and to improve fire and particle detectors**. Supporting research is necessary in materials qualification for ignition, flame spread, and generation of toxic and/or corrosive gases and in the characterization of particle size from smoldering and flaming fires in microgravity.
- NASA should **characterize the effectiveness of fire suppression and post-fire recovery strategies**. Specific research is needed to develop and implement a standard methodology for qualifying fire suppression systems and to assess and restore a post-fire environment.
- Research should be conducted to allow **regenerative fuelcell technologies** to be demonstrated in reduced gravity environments.
- Research is needed to support the **development of new energy conversion technologies**. In particular, research is required for more efficient primary basepower and to enable the arrays for Solar Electric Propulsion to transfer large masses of propellant and cargo to distant locations.



# Highest Priority Research Recommendations Translation to Space Exploration Systems<sub>4</sub>

- Research is needed in **high-temperature, low-weight materials for power conversion and radiators** to enable fission surface power systems.
- Development and demonstration of **ascent and descent system technologies** are needed, including ascent/descent propulsion technologies, inflatable aerodynamic decelerators, and supersonic retro propulsion system technologies. Research is needed in propellant ignition, flame stability, and active thermal control; lightweight flexible materials; and dynamics and control.
- Research is required to support the **development and demonstration of space nuclear propulsion systems**, including liquid-metal cooling under reduced gravity, thawing under reduced gravity, and system dynamics.
- Research is needed to identify and adapt excavation, extraction, preparation, handling, and processing techniques for a **lunar water/oxygen extraction system**.
- NASA should establish plans for **surface operations, particularly ISRU capability development and surface habitats**. Research is needed to characterize resources available at lunar and martian surface destinations and to define surface habitability systems design requirements.



# PRIORITIZATION CRITERIA – not weighted

- **Criterion 1:** The extent to which the results of the research will reduce uncertainty about both the benefits and the risks of space exploration (positive impact on exploration efforts, improved access to data and samples, risk reduction)
- **Criterion 2:** The extent to which the results of the research will reduce the costs of space exploration (potential to enhance mission options or to reduce mission costs)
- **Criterion 3:** The extent to which the results of the research may lead to entirely new options for exploration missions (positive impact on exploration efforts, improved access to data and samples)
- **Criterion 4:** The extent to which the results of the research will provide full or partial answers to grand science challenges that the space environment provides a unique means to address (relative impact within research field)
- **Criterion 5:** The extent to which the results of the research are uniquely needed by NASA, as opposed to any other agencies (needs unique to NASA exploration programs)
- **Criterion 6:** The extent to which the results of the research can be synergistic with needs of other agencies (research programs that could be dual-use)
- **Criterion 7:** The extent to which the research must use the space environment to achieve useful knowledge (research value of using reduced-gravity environment)
- **Criterion 8:** The extent to which the results of the research could lead to either faster or better solutions to terrestrial problems or to terrestrial economic benefit (ability to Translate results to terrestrial needs)





TABLE 13.1 Summary of Highest-Priority Recommendations

Recommendation Identifier <sup>a</sup>	Recommendation	Enabled by (E/B) and/or enabling (E) space exploration
AH1	Efficacy of bisphosphonates should be tested in an adequate population of astronauts on the ISS during a 6-month mission	EB/E
AH2	Preservation/reversibility of bone structure/strength should be evaluated when assessing countermeasures	EB/E
AH3	Bone loss studies of genetically altered mice exposed to weightlessness are strongly recommended	E
AH4	New osteoporosis drugs under clinical development should be tested in animal models of weightlessness	E

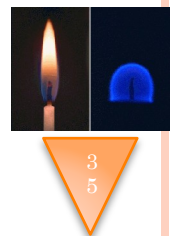
**TABLE 13.2 Highest-Priority Recommendations That Provide High Support in Meeting Each of Eight Specific Prioritization Criteria**

	Prioritization Criteria							
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Life sciences	P2, P3, B1, B2, B3, B4, AH1, AH2, AH3, AH5, AH6, AH7, AH8, AH9, AH10, AH11	P3, B1, B2, B3, B4, AH6, AH9, AH10, AH11	P3, B4, AH1, AH2, AH3, AH5, AH6, AH7, AH8, AH9, AH10, AH11	P1, P2, B3, B4, AH9, AH10, AH11, AH16	P1, P2, P3, AH1, AH2, AH3, AH4, AH5, AH6, AH7, AH8, AH9, AH10, AH11, AH16	B1, B2, B3, B4, AH1, AH2, AH3, AH4, AH5, AH6, AH7, AH9, AH10	P1, B1, B4, AH12, AH16	B1, B2, B3, B4, AH1, AH2, AH3, AH4, AH5, AH6, AH7

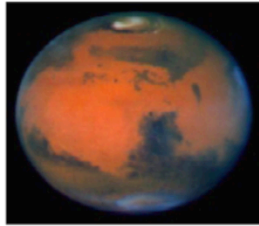


TABLE 13.3 Level of Support Provided by High-Priority Recommendations for Each of Eight Prioritization Criteria

	Prioritization Criteria							
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
AH1	<b>High</b>	Medium	<b>High</b>	Medium	<b>High</b>	<b>High</b>	Medium	<b>High</b>
AH2	<b>High</b>	Medium	<b>High</b>	Medium	<b>High</b>	<b>High</b>	Medium	<b>High</b>
AH3	<b>High</b>	Medium	<b>High</b>	Medium	<b>High</b>	<b>High</b>	Medium	<b>High</b>
AH4	Medium	Medium	Medium	Medium	<b>High</b>	<b>High</b>	Medium	<b>High</b>



## Goal: send humans to Mars



Prioritization Criteria #1 and #2 will be the most important functions in prioritizing the research to support this policy, and the recommendations associated with these priorities must find a way to be supported in an integrated program with clear translational end-points. Secondly, Prioritization Criteria #3 and #5 will also have to be taken into consideration to achieve the science necessary for this policy goal.

**Criterion #1:** The extent to which research developments will reduce uncertainty about both benefits and risks of space exploration (Impact on Exploration Efforts, Results in Improved Access to Data or to Samples, Risk Reduction)

Relevant research recommendations

Life sciences: P2, P3, B1, B2, B3, B4, AH1, AH2, AH3, AH5, AH6, AH7, AH8, AH9, AH10, AH11  
Life sciences translational: CCH2, CCH4, CCH7  
Physical sciences: AP1, AP4, AP6, AP8  
Physical sciences translational: TSES1, TSES2, TSES3, TSES14

The efficacy of bisphosphonates should be tested in an adequate population of astronauts on the ISS during a 6-month mission.

**Criterion #2:** The extent to which information gained from investment in research funding will reduce the costs of space exploration (Potential to Enhance Mission Options or Mission Costs)

Relevant research recommendations

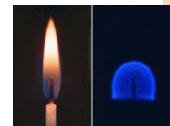
Research should be conducted in support of zero-boiloff propellant storage and cryogenic fluid management. Physical sciences research includes advanced insulation materials research, active cooling, multi-phase flows, and capillary effectiveness (T2), as well as active and passive storage, fluid transfer, gauging, pressurization, pressure control, leak detection, and mixing destratification (T3).

**Criterion #3:** The extent to which information may lead to broad knowledge about exploration mission options (Impact on Exploration Efforts, Results in Improved Access to Data or to Samples)

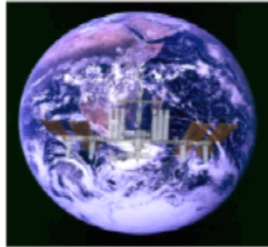
Relevant research recommendations

**Criterion #5:** The extent to which the information gained is uniquely needed by NASA, as opposed to any other agencies (Needs Unique to NASA Exploration Programs)

Relevant research recommendations



## Goal: Develop new capabilities by advancing leading edge science



The second policy option is a decision to hold off on advanced human mission until we have developed a new base of capability with which to plan. This goal would focus near-term on advancing leading edge science and the value of our space assets to terrestrial needs. In this case, Prioritization Criteria #4 and #5 and #3 will have primary importance, and Prioritization Criteria #6 and #7 may also be of importance in building the integrated research portfolio which best supports this policy goal.

**Criterion #4:** The extent to which the information gained will fully or partially provide answers to grand science challenges for which the space environment provides a unique means to address (Relative Impact Within Research Field)

Establish a "microbial observatory" program on the ISS to conduct a long term multi-generational studies of microbial population dynamics.

### Relevant research recommendations

Life sciences: P1, P2, B3, B4, AH9, AH10, AH11, AH16  
 Life sciences translational: CCH2, CCH6  
 Physical sciences: FP1, FP2, FP3, AP5, AP7, AP8, AP9  
 Physical sciences translational:

**Criterion #5:** The extent to which the information gained is uniquely needed by NASA, as opposed to any other agencies (Needs Unique to NASA Exploration Programs)

Microgravity provides a unique opportunity to study long-time dynamics of colloids, polymer and colloidal gels, foams, emulsions, and soap solutions free from gravitational interference

### Relevant research recommendations

**Criterion #8:** The extent to which the information could result in either faster or better solutions to terrestrial problems or in terrestrial economic benefit (Ability to Translate Results to Terrestrial Needs)

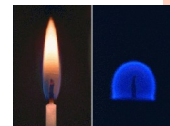
### Relevant research recommendations

**Criterion #6:** The extent to which the information gained can be synergistic with other agencies needs

### Relevant research recommendations

**Criterion #7:** The extent to which the research must use the space environment to achieve useful information (Research Value of Using Reduced Gravity Environment)

### Relevant research recommendations



# FINAL Comments

The committee and advisory panels have

- defined the next decade of a science-based program that addresses, in an integrated fashion:
  - Plant and Microbial Biology
  - Behavior and Mental Health
  - Animal and Human Biology
  - Cross-cutting Issues for Humans in the Space Environment
  - Fundamental Physical Sciences in Space
  - Applied Physical Sciences in Space
  - Translation to Space Exploration Systems
- developed metrics for prioritizing that research, and for creating timelines appropriate to policy decisions
- addressed factors to strengthen the microgravity life and physical science enterprise and the translation of science to human exploration
- recommended an integrated life and physical sciences research portfolio that:
  - identifies facility and platform requirements
  - provides rationale for all suggested program elements
  - is adaptable to changes in policy and budget as they occur

