The NASA Office of Biological and Physical Research (OBPR) Physical Sciences Research Program carries out basic and applied research to enable the NASA Vision “to improve life here, to extend life to there, and to find life beyond.” Two primary research thrusts are implemented: 1) utilization of the space environment to advance the understanding of physical, chemical, and biophysical processes that are relevant to both Earth and space exploration applications, 2) research pre-requisite to the implementation of enabling technologies for human space exploration. Cross-disciplinary teaming across research areas is strongly encouraged in order to address scientific and technological challenges in complex engineering and living systems. The current areas of emphasis are focused on enabling technologies for space exploration:

1. Biophysics and Bioengineering research and development targeting the understanding of low-gravity physiological effects and the deployment of distributed biomedical sensors for targeted diagnostics;

2. Advanced materials fundamental research and development for spacecraft structure, power and propulsion, radiation shielding, and advanced sensors;

3. Micro and reduced-gravity engineering systems for closed-loop life support, power generation and propulsion, fire research, detection, and suppression; and

4. In situ resources development for in-space fabrication and for extra-terrestrial exploration and habitation, including the development of advanced biology-inspired approaches for novel space technologies and robotic enhancement of human capabilities.

Sub Topics:

**B1.01 Exploiting Gravitational Effects for Combustion, Fluids, Synthesis, and Vibration Technology**

**Lead Center:** GRC  
**Participating Center(s):** MSFC

In preparation for future human exploration we must advance our ability to live and work safely in space, and at the same time, develop technologies to reach the Moon and other planets. The objective of this subtopic is to introduce new technology in the form of devices, models, and/or instruments for use in microgravity, extraterrestrial habitats, and/or for commercial applications on Earth. Research should target spacecraft and planetary life-support systems (such as Extra-Vehicular Activity suits, extraterrestrial habitats, oxygen generation, and waste disposal), environmental monitors, and hazard controls (contaminants, fire safety, etc.). For Biofluids, please see subtopic B1.04 Bioscience and Engineering.
Innovations are sought in the following areas:

- Understanding the effects of microgravity on fluid behaviors.

- Using the mechanics of granular materials to determine how the reduced gravity environment affects transport and mixing of granular solids, with application to in situ resource utilization (ISRU) and more efficient terrestrial processes.

- Pool and flow boiling systems or subsystems that enable safe, efficient, and reliable heat transfer technologies for space application of advanced power and thermal control systems.

- Multiphase flow and fluid management to provide designers key information on controlling the location and dynamics of liquid–vapor interfaces in microgravity. This is needed for safe and reliable fluid handling and transport in microgravity.

- Innovative concepts for phase separation and condensation over a wide range of vapor content and gravity levels ranging from 0–1g.

- Measuring the residual accelerations on spacecraft or in ground-based low-gravity facilities. Emphasis is placed on MEMS or nanoscale devices capable of measuring quasi-steady (low frequency ~0–0.1 Hz) microgravity levels.

- Improving in-space system performance that relies on fluid or combustion phenomena, principally spacecraft fire safety, especially fire prevention, smoke, precursor, and fire detection and fire suppression.

- Characterization of ignitability, flame spread, and spacecraft material selection.

- Micropumps and microvalves, individual as well as simultaneous diagnostics for determining fluid movement through microscale devices for the aforementioned applications, and identifying specific chemical or biological elements of interest.

- Micropower systems for EVA operations, including power, heating, and cooling.

- Robust sensors for detection of hazards (fire, spills, leaks) in spacecraft, extraterrestrial habitats, and EVA systems.

- Partial and low-gravity compliant reactors for waste stabilization, as well as for oxygen and water recovery on extraterrestrial habitats.

- Understanding the effects of microgravity on combustion behaviors.

- Pollution reduction and improvement of the efficiency of liquid fueled combustors.

- Microfluidics for fuel cells and other power systems.
Participating Center(s): ARC

NASA is interested in the development of science and experiments that support strategic aspects of exploration, as well as develop the technologies to extend humanity's reach to the Moon, Mars, and beyond. Preparing for exploration and research will accelerate the development of technologies that are important to the economy and national security, as well as accelerate critical technologies such as biotechnology.

Plans are to support research and development to investigate the influence of the space environment, radiation, and reduced gravity on biotechnology processes, and human factors at the biomolecular level. Areas of interest include factors that influence bone and muscle biochemistry, protein crystal growth and structural analysis techniques, separation science and technology, and biomaterials. Examples of the types of research include but are not limited to:

- Technologies designed to improve our understanding of the effect of gravity on expression of biological macromolecules.
- Technologies to determine the relationships between material substrates, bone and muscle tissue and cell culture conditions, and subsequent cell protein expression and differentiation.
- Development of high-throughput technologies to determine gene and protein expression and differentiation.
- Biotechnology and instrumentation to help enable safe human exploration beyond Earth orbit for extended periods.
- Environmental monitoring and control for human life support.

B1.03 Materials Science for In-Space Fabrication and Radiation Protection

Lead Center: MSFC
Participating Center(s): ARC

Methods for conducting materials science and technology research required to enable humans to safely and effectively live and work in space are needed. Other areas of interest are the development of reduced gravity materials processing technology for in-space fabrication, repair, and resource development. Equipment that can operate with the limited resources of the Space Station Glovebox and in existing Space Station racks to perform demonstration experiments of strategic interest for in-space fabrication and repair, and for development of in situ resources, would also be of interest. Innovative developments are sought in the following research areas and their enabling technologies, including commercial applications on Earth.

In-Space Fabrication

NASA needs the development of techniques and processes that permit in-space fabrication of critical path components of future major projects. Developmental studies of materials and processes of direct strategic significance to the exploration of space are appropriate. In addition, the manufacture or repair of components during a mission is essential to human exploration and the development of space. Fabrication and repair beyond low-Earth orbit is required to reduce resource requirements and spare parts inventory, and to enhance mission
security. Also being sought are enabling technologies that can lead to materials and/or processes for the reduced gravity (micro-g, 1/6g, and 3/8g) in-space fabrication of *in situ* space resources. Of particular interest is the effect of reduced gravity and the space environment on these processes. Examples of the types of research include but are not limited to the following:

- Application of rapid prototyping technology to low gravity, 3/8 and 1/6 g level free-form fabrication of near-net shapes from metals, ceramics and polymers for fabricating spare parts and repairs.
- Development of space resources into raw materials and feedstock for use with rapid prototyping technology.
- Novel and innovative methods for processing materials in reduced gravity, in-space fabrication and repair including microwave processing, sintering, welding, and joining.
- Development of an improved lunar and Martian regolith simulant material more suitable for materials experiments with not just an average composition, but also the mineralogical analysis, particle shape, size, and distribution of the individual particle grains being more representative of actual lunar and Martian soils.
- Basic research, theoretical modeling, and experimental development of extractive and reactive processes, materials purification and characterization in a reduced gravity (3/8g and 1/6g) space environment and fundamental studies of in-space fabrication with *in situ* resources. For example: *in situ* fabrication of solar cells; metallic wire suitable for electrical conductors, antennas and rectifying-antennas; glass formation from *in situ* resources with minimal terrestrial components.

**Radiation Protection Materials**

NASA needs materials and novel concepts for effective radiation shielding in support of human exploration of space. These materials must be capable of attenuating exposure levels due to galactic cosmic rays and solar energetic particles, as well as their secondaries, to acceptable limits. Specific areas of interest include:

- Development of multi-functional and/or smart structural materials for radiation hardening/shielding;
- *In situ* regolith radiation shielding research;
- Development of light-weight, hydrogenated epoxy and preimpregnates (prepregs);
- Development of hydrogen filled, carbon nanostructures for both radiation shielding and as structural elements for spacecraft and habitat; and
- Methods for monitoring/dosimetry for space radiation.

**B1.04 Bioscience and Engineering**

**Lead Center: GRC**

NASA recognizes the critical role that fluid mechanics and transport processes, along with their supporting technologies, play in many biological and physiological events. A wide variety of fundamental problems in the
categories of physiological systems, cellular systems, and biotechnology may be addressed. The objective of this research is to deliver new technology in the form of devices and instruments of use in microgravity missions to the Moon and Mars and/or for commercial application on Earth in the areas discussed below.

Micro-Optical Technology for Interdisciplinary and Biological Research

Technologies are sought for measuring and manipulating Space Station and long-duration mission experiments, and for monitoring and managing astronaut health and the health of structures and systems affecting astronauts’ environments. Areas of innovative technology development include:

- Diagnostic methods to assess the performance of labs-on-a-chip, including detecting the presence of bubbles and particles and removing or characterizing them;
- Measurements for fluids including spatially and temporally resolved chemical composition and physical state variables;
- Optically-based biomimetics for self-aware, self-reconfiguring measurement systems;
- Measurement and micro-control technologies for health monitoring and health management of experiments, astronauts, and astronauts’ environments;
- Optical quantum technologies for measurement systems including signal detection and transmission; and
- Technologies enabling optically-based mobile sensor platforms for detection and maintenance, using optical sensing, control, power, and/or communication.

Biological Fluid Mechanics (Biofluids)

Biofluids, an intersection of fluid physics and biology, is a new area of emphasis within NASA’s Office of Biological and Physical Research (OBPR). Fluid mechanics and transport processes play a critical role in many biological and physiological systems and processes. An adequate understanding of the underlying fluid physics and transport phenomena can provide new insight and techniques for analyzing and designing systems that are critical to NASA’s mission. The microgravity environment modifies vascular fluid distribution on a short time scale, because of the loss of hydrostatic pressure, and on a longer time scale, because of the shift of intercellular flows. This fluid shift could modify transport processes throughout the body. For example, modification of flow and resulting stresses within blood vessels could modify vascular endothelial cell structure and permeability, which may be detrimental in long-term inter-planetary space flight. Furthermore, reintroduction of gravity causes large-scale fluid shifts in the body, which can influence cardiac output and induce faintness. Studies of macro- and microscale biofluid mechanics of the vascular system in the microgravity environment may be important to understanding these physiological events. Innovations sought include but are not limited to the following:

- Studies of biological fluid mechanics that seek answers to questions related to effect of long-term exposure to microgravity on human physiology;
- Understanding the role of fluid physics and transport phenomena in the “fluid shift” observed in the human body when exposed to prolonged microgravity; and
- Understanding the role fluid physics plays in human physiological processes such as cardiovascular flows and its effect on arteriosclerosis, and pulmonary flows and asthma.

BioMicroFluidics
Many biotechnology applications need manipulation of fluids moving through micro channels. As a result, microfluidic devices are becoming increasingly useful for biological/biotechnological applications. Because capillary forces can have a significant effect on the flow at this scale, a strong similarity with microgravity flows exists. Innovations sought include but are not limited to the following:

- Understanding of fluid mechanics underlying the operations of microfluidic devices crucial to their successful operation and continued miniaturization; and
- Tools for prediction, measurement, and control of fluid flow in microchannels and microchannel network.

Models of Cellular Behavior

The simplest living cell is so complex that models may never be able to provide a perfect simulation of its behavior, however, even imperfect models could provide information that could shake the very foundations of biology. We are now at the point where we can consider models of molecular, cellular and developmental biological systems that, when coupled to experiments, result in an increased understanding of biology. Quantitative models of cellular processes require. Innovations sought include but are not limited to the following:

- New methods for better handling of large numbers of coupled reactions, increases in computing power, and the ability to transition among different levels of resolution associated with quantitative models of cellular processes; and
- Development of models to form the basis of tools to aid in optimization of existing biological systems and design of new ones, enabling engineers to evolve biological systems by rounds of variation and selection for any function they choose.

Functional Imagery

Research on-orbit has demonstrated that the microgravity environment affects the skeletal, cardiovascular, and immune systems of the body. Few of the investigations to date examined functional changes due to microgravity at either the cellular or molecular scale. NASA, therefore, seeks innovations that would lead to an enhanced capability to image functioning biological systems at either length scale. All proposals should recognize the power, volume, and mass constraints of orbital facilities. Examples of possible innovations include but are not limited to the following:

- Development of novel fluorophores that tag proteins mediating cellular function, particularly those that can be excited using solid-state lasers;
- Systems that can simultaneously image multiple fluorophores following different processes at standard video frame rates;
- Devices that enable three-dimensional imagery of the sample; and
- Imaging hardware that can follow a metabolic process in a turbulent system.

Understanding Living Systems Through Microgravity Fluid Physics

Developing strategies for long-duration space flight requires an understanding of the effects of the microgravity environment on biological processes. Interdisciplinary fundamental and applied research is required in biology,
physiology, and microbiology to human, and microbial systems from the standpoint of physics. Of particular interest are studies with technology development that develop theoretical, numerical, and/or experimental understanding of the effects of acceleration, and other factors in microgravity environments on these systems. Exploring the effects of Martian and lunar gravity and the quasi-steady, oscillatory, and transient accelerations that are typical of a space laboratory are of great interest, as well as fundamental studies with technology development of acceleration sensitivity. The knowledge obtained should contribute to related agency activities, such as the development of self-sustaining ecosystems and treatment of bacterial infection in space. Moreover, we expect that the knowledge and technologies derived will also provide ground-based economic and societal benefits. Major research disciplines include the fluid transport in microbiology, human physiology, hematology, and drug delivery systems. Innovations are sought in a number of areas.

Delineation of the effects of acceleration and environment at the macro- and microscale levels on processes such as bacterial growth, growth rates, resistance to antibiotics and disinfectants, interactions among microbes, microbial locomotion and interaction with the surrounding fluid or solid medium, transport through cell membranes, electro-osmotic flows, and cytoplasmic streaming, as well as quantification of metabolic processes and other phenomena that permit the examination of these problems:

- Effects of bulk fluid flows on biofilms and liposome formation.
- Transendothelial transport.
- Microscale modeling of fluid flows and mass transfer for drug delivery systems.

Fundamental Space Biology Topic B2

The NASA mission to explore the universe and search for life includes the goal of exploring the principles of biology through research in the unique natural laboratory of space. Important is the biological and physical research organizing question which asks: How does life respond to gravity and space environments? It includes four sub-questions:

1. How do space environments affect life at molecular and cellular levels?
2. How do space environments affect organisms throughout their lives?
3. How do space environments influence interactions between organisms?
4. How can life be sustained and thrive in space across generations?
through space flight as well as ground-based research that supports the NASA mission. Proposals are sought for research that:

1. Effectively make use of microgravity and other characteristics of space environments to enhance our understanding of fundamental biological processes;

2. Develop the scientific and technological foundations for a safe, productive human presence in space for extended periods and in preparation for exploration; and

3. Apply this knowledge and technology to improve our nation’s competitiveness, education, and quality of life on Earth.

Ground-based and flight research is conducted on a broad spectrum of biological topics including cell and molecular biology, developmental and physiological biology, and how the space environment affects whole organisms and their interactions.

Sub Topics:

**B2.01 Understanding and Utilizing Gravitational Effects on Plants and Animals**

**Lead Center: ARC**

**Participating Center(s): KSC**

This subtopic area focuses on technologies that support the NASA Fundamental Biology Program in understanding the effects of gravity on plants and animals. The program supports investigations into the ways in which fundamental biological processes function in space, compared to their function on the ground. Given the Exploration Initiative newly assigned to NASA, this area of work and discovery is important to achieve the goals to explore the planets and allow plant, animal, and human habitation. To conduct these investigations, the program supports both ground and space flight research. The improved understanding of the role of gravity on plants requires innovative support equipment for observing, measuring, and manipulating the responses of plants to environmental variables. Areas of innovative technology development include:

- Measuring the atmospheric and radiation environment and optimizing the lighting and nutrient delivery systems for plants;

- Storage, transportation, maintenance, and *in situ* analyses of seeds and growing plants;

- Sensors with low power requirements and low mass to monitor the atmosphere and water (nutrient) environment, as well as automated control and data logging systems for the experiment containers to measure performance indicators, such as respiration (whole plant, shoot, root), evapotranspiration, photosynthesis, and other variables in plants;

- Data analysis and control;

- Modular seeding and/or planting units to minimize labor;

- Sensors for atmospheric, liquid, and solid analyses, including atmospheric and liquid contaminants, such as ethylene and other biogenic compounds, as well as analyses of hydroponic and solid media for N, P, K, Cu, Mg, and micronutrients;

- Remote sensors to identify biological stress; and
The improved understanding of the role of gravity on animals requires innovative instrumentation that tracks and analyzes from organism development, including gametogenesis through fertilization, embryonic development and maturation, through ecological system stability. Technologies may incorporate a variety of processes such as metabolism and metabolic control, through genetic expression and the control of development. Of particular interest are technologies that require minimal power and can noninvasively measure physical, chemical, metabolical, and developmental parameters. Such measurements will ultimately be made in environments at one or more of several gravity ranges, e.g., "microgravity" (0.01 to 0.00001 g), "planetary" gravity (1 g; 0.38 g or 0.12 g) or hypergravity (up to 2 g). Refined and stable measurements, however, are as important as gravity independence. Of interest are sustained instrument sensitivity, accuracy and stability, and reductions in the need for frequent measurement standardization. Parameters requiring measurement include pH, temperature, pressure, ionic strength, gas concentration (O\(_2\), CO\(_2\), CO, etc.), and solute concentration (e.g., Na\(^+\), K\(^+\), etc.). In the case of new techniques and instruments, a clear path toward miniaturization, reduction in power demands and increased space worthiness should be identified. Technologies applicable to plant, microorganism, and animal study applications include the following areas:

- Live support and energy management;
- Expert data management systems;
- Capabilities for specimen storage, manipulation and dissection;
- Video-image analysis for specimen (cell, animal, plant) health and maintenance;
- Sensors for primary environmental parameters and microbial organisms; and
- Electrophysiology sensors, biotelemetry systems and biological monitors carried on spacecraft.

**B2.02 Biological Instrumentation**

*Lead Center: ARC*

*Participating Center(s): JPL*

The Fundamental Biology (FB) Program is the Agency lead for biological research and biological instrumentation and technology development, and focuses on research designed to develop our understanding of the role of gravity in the evolution, development, and function of biological processes. Increasingly, the research thrusts are directed at incorporating the most advanced technologies from the fields of cell and molecular biology, genomics, and biotechnology, to provide researchers with the most up-to-date methods to conduct their biological research. For these requirements, the capability to perform autonomous, *in situ* acquisition, and preparation and analysis of samples to determine the presence and composition of biological components is a highly desired objective. As the size of flight payloads becomes increasingly smaller, and information technologies permit smarter and more independent payload and device control and management, the realization of completely autonomous *in situ* biological laboratories (ISBL) on spacecraft platforms and planetary surfaces will become more desirable.
Biological and biomolecular, microbiological, and genomic research is enabling unprecedented insight into the structure and function of cells, organisms, and subcellular components and elements, and a window into the inner workings and machinations of living things. Techniques and technologies, which have evolved from the microelectronics and biological revolutions, have permitted the emergence of a new class of instruments and devices. Many devices, techniques, and products are now available or emerging, which allow measurement, imaging, analysis, and interpretation of the biological composition at the molecular level, and which permit determination of DNA/RNA and other analytes of interest. Advances in information systems and technologies, and bioinformatics, provide the capability to understand, simulate, and interpret the large amounts of complex data being made available from these biological-physical hybrid systems. These synergistic relationships are facilitating the development of revolutionary technologies in many areas.

Biological instrumentation technologies to support FB objectives are grouped into the solicited categories below.

**Biological Sample Management and Handling:**

- Technologies for remote, automated biosample and biospecimen collection, handling, preservation/fixation, and processing; and
- Modular, embeddable systems and subsystems capable of supporting a variety of tissue, liquid, and/or cellular specimens, from a wide range of biological subjects, including cells, nematodes, plants, fish, avians, mice, rats, and humans.

**In situ Measurement and Control:**

- Technology development for sensors, signal processors, biotelemetry systems, sample management and handling systems, and other instruments and platforms for real-time monitoring and characterization of biological and physiological phenomena.

**Genomics Technologies:**

- Technologies to enhance and augment research in genomics, proteomics, cell and molecular biology, including molecular and nanotechnologies, cDNA arrays, gene array technologies, and cell culture and related habitat systems.

**Bio-Imaging Systems:**

- Advanced, real-time capabilities for visualization, imaging, and optical characterization of biological systems. Technologies include multidimensional fluorescent microscopy, spectroscopy systems, and multi- and hyperspectral imaging.

**Biological Information Processing**
• Capability for automated acquisition, processing, analysis, communication, and archival and retrieval of biological data, and interface and transfer to advanced bioinformatics and biocomputation systems.

**Integrated Biological Research Systems and Subsystems**

• Integrated, experiment- and subject-specific biolaboratory modules and systems, providing complete flight prototype capability to support the above five categories.

**B2.03 Understanding and Utilizing Gravitational Effects on Molecular Biology and for Medical Applications**

**Lead Center:** JSC

**Participating Center(s):** ARC

Microgravity allows unique studies of the effects of gravitational effects on cell and tissue development and behavior. These studies use novel and advanced technologies to culture and nurture cells and tissues. Additionally, the ability to manipulate and/or exploit the form and function of living cells and tissues has significant potential to enhance the quality of life on Earth and in space through novel products and services, as well as through new science knowledge generated and communicated. This capability may lead to new products and services for medicine and biology. Current space research includes the development of space bioreactors for culturing fragile cells, which has applications in biomedical and cancer research; tissue engineering systems which take advantage of microgravity to grow 3-D tissue constructs; testing the effectiveness of drugs and biomodulators on growth and physiology of normal and transformed cells, and methods for measuring specific cellular and systemic immune functions of persons under physiological stress. Biotechnology research systems also are being developed for microgravity research on the International Space Station and future space-based laboratories. Studies of this nature are critical to our understanding of how the space environment affects astronaut health, and for maintaining a healthy environment for astronauts during missions of exploration.

Specific areas of interest are:

• New methods for culturing mammalian cells in bioreactors, including advanced bioreactor design and support systems; microprocessor controllers; and miniature sensors for measurement of pH, oxygen, carbon-dioxide, glucose, glutamine, and metabolites. Neural fuzzy logic network systems for the control of mammalian cell culture systems. Methods to minimize biofilm formation on fluid-handling components, sensors and bioreactors. Spectroscopic and biochemical analysis of biofilm formed in bioreactors. Micro-scale bioreactors for biomonitoring of radiation and other external stressors.

• Technologies that allow automated biosampling and bio-specimen collection, handling, preservation/fixation, and processing in cellular systems. Methods for separation and purification of living cells, proteins, and biomaterials, especially those using electrokinetic or magnetic fields that obviate thermal convection and sedimentation, enhance phase partitioning, or use laser light and other force fields to manipulate target cells or biomaterials.
• Techniques or apparatus for macro-molecular assembly of biological membranes, biopolymers, and molecular bio-processing systems; bio-compatible materials, devices, and sensors for implantable medical applications including molecular diagnostics, *in vivo* physiological monitoring and microprocessor control of prosthetic devices.

• Methods and apparatus that allow microscopic imaging including hyperspectral fluorescent, scattering and absorption imaging, and biophysical measurements of cell functions; effects of electric or magnetic fields, photoactivation, and testing of drugs or biocompatible polymers on live tissues. Integrated instrumentation for separation and purification of RNA, DNA, and proteins from cells and tissues.

• Quantitative applications of molecular biology, fluorescence imaging and flow cytometry, and new methods for measurement of cell metabolism, cytogenetics, immune cell functions, DNA, RNA, oligonucleotides, intracellular proteins, secretory products, and cytokine or other cell surface receptors. Small scale mass spectrometers. Means to enhance and augment genomics/proteomics techniques, including molecular and nano-scale tools. Development of novel fluorophores that tag proteins mediating cellular function, particularly those that can be excited using solid-state lasers.

• Micro-encapsulation of drugs, radiocontrast agents, crystals, and development of novel drug delivery systems wherein immiscible liquid interactions, electrostatic coating methods, and drug release kinetics from microcapsules or liposomes can be altered under microgravity to better understand and improve manufacturing processes on Earth.

• Miniature bioprocessing systems that allow for precise control of multiple environmental parameters such as low level fluid shear, thermal, pH, conductivity, external electromagnetic fields, and narrow-band light for fluorescence or photoactivation of biological systems.

• Novel low temperature sample storage methods (-80°C and -180°C) and biological sample preservation methods. Methods to reduce launch/return mass of biological samples and support reagents.

• DNA template for molecular wiring that permits macro- to nanoscale connectivity. Nanoscale electronics based on self-assembling protein-based molecular structures.

• Computer models and software that better handle large numbers of coupled reactions in cell science systems.

• Tools and techniques to study mechanical properties of the cell: subcellular rheology, cell adhesion, affect of shear flow, affects of direct mechanical perturbation. Tools and techniques to facilitate multiple simultaneous probing and analyzing of a cell or sub-cellular region (examples include atomic force microscope coupled with microelectrode or micro-Raman, Optical trap)

• Nanosensors for sub-cellular measurements: ultra-microelectrodes with less than 1µ diameter including cladding, nanoparticle reporters that provide spectroscopic information, and other novel intracellular sensor devices to provide spectroscopic data on intracellular processes.
NASA has the enabling goal to extend the duration and boundaries of human space flight to create new opportunities for exploration and discovery. In order to reach this goal, the Biological and Physical Research (BPR) Enterprise is seeking the answers to several “organizing” questions. Two of the questions related to biomedical and human support research are as follows: (1) How can we assure the survival of humans traveling far from Earth? and (2) What technologies must we create to enable the next explorers to go beyond where we have been? (More details on these questions can be found in the BPR Bioastronautics Strategy ([http://spaceresearch.nasa.gov/](http://spaceresearch.nasa.gov/)) and the Bioastronautics Critical Path Roadmap ([http://criticalpath.jsc.nasa.gov](http://criticalpath.jsc.nasa.gov)). Proposals are sought that support the objectives of the enabling goal including supporting the biomedical and human support research necessary to ensure the health, safety, and performance of humans living and working in space.

Sub Topics:

**B3.01 Environmental Control of Spacecraft Cabin Atmosphere**

**Lead Center:** JSC  
**Participating Center(s):** ARC, GRC, KSC, MSFC

Advanced life support and thermal systems are essential to enable human planetary exploration. Requirements include safe operability in micro- and partial-gravity, ambient and reduced-pressure environments, high reliability, minimal use of expendables, ease of maintenance, and low-system volume, mass and power. Innovative, efficient, and practical concepts are needed for regenerative air revitalization, ventilation, temperature, and humidity control. Advanced active thermal control technologies in the areas of heat acquisition, transport, and rejection are also needed. In addition to long-duration space applications, innovative approaches that could have terrestrial application are encouraged. Proposals should include estimates for power, volume, mass, logistics, and crew time requirements as they relate to the technology concepts. More information on advanced life support systems can be found at [http://advlifesupport.jsc.nasa.gov](http://advlifesupport.jsc.nasa.gov). Innovations are solicited in the areas that follow below.

**Air Revitalization**

Oxygen, carbon dioxide, water vapor, and trace gas contaminant concentration, separation, and control techniques for space vehicle applications (International Space Station, Moon, or Mars transit vehicle) and long-duration planetary mission applications.

- Separation of carbon dioxide from a mixture primarily of nitrogen, oxygen, and water vapor to maintain carbon dioxide concentrations below 0.3% by volume.
- The recovery of oxygen from carbon dioxide with some focus on an approach to deal with the by-products of the process, if any, keeping in mind the above mass, power, and expendables goals.
- Removal of trace contaminant gases from cabin air and/or a gas product stream from another system (e.g., water reclamation, waste management, etc.) using advanced regenerable sorbent materials, improved oxidation techniques, or other methods.
- Alternate methods of storage and delivery of atmospheric gases to reduce mass and volume and improve safety.
- Novel approaches to integrating atmosphere revitalization processes to achieve energy and logistics mass reductions.
- Alternate methods of atmospheric humidity control that do not use liquid-to-air heat exchanger technology (dependent on the spacecraft active thermal control system) or mechanical refrigeration technology.
Environmental Control and Thermal Systems

Thermal control is an essential part of any space vehicle, as it provides the necessary thermal environment for the crew and equipment to operate efficiently during the mission. A primary goal is to provide advanced thermal system technologies, which are highly reliable and possess low mass, size, and power requirements (i.e., reduced cost) for spacecraft cabin temperature and humidity control. Offerors should indicate explicitly how their research is expected to improve the mass, power, volume, safety, reliability, and/or design and analyses techniques for future thermal control systems for human space missions as compared to state-of-the-art technologies. Areas in which innovations are solicited include the following:

- Liquid-to-liquid heat exchangers that provide two physical barriers preventing interpath leakage.
- Advanced technologies to control cabin temperature and humidity in microgravity. Condensate that is collected must be able to be recovered and transported to the water recovery system.
- Technologies to inhibit microbial growth on wetted surfaces. Applications include condensate collection surfaces for humidity control and heat exchangers resident in water loops.
- Lightweight, versatile and efficient heat acquisition devices including flexible cold plates. Devices would provide cooling to electronics, motors, and other types of heat producing equipment that is internal to the cabin.
- Lightweight, controllable evaporative heat rejection devices that can operate in environments ranging from space, Mars’ atmosphere, and Earth’s atmosphere.
- Alternative heat transfer fluids that are non-toxic, non-flammable, and have a low freezing temperature.
- Energy storage devices that maintain the integrity of food or science samples. Temperatures of -20°C, -40°C, -80°C or -180°C are desired.
- Highly accurate, remotely monitored, in situ, non-intrusive thermal instrumentation.
- Advanced analytical tools for thermal and fluid systems design and analyses, which are amenable to concurrent engineering processes.

Component Technologies

Energy efficient, low mass, low noise, low vibration or vibration isolating, fail-safe and reliable components for handling gases and fluids applicable to spacecraft environmental control and air revitalization, including actuators, fans, pumps, compressors, coolers, tubing, ducts, fittings, tanks, heat exchangers, couplings, quick disconnects, and valves that operate under varied levels of gravity, pressure, and vacuum. Mass flow monitoring and control devices that have similar attributes and that are easily calibrated and serviced.
The long-term goal for this subtopic is to enable planning, designing, and carrying out human space missions of up to 5 years with crew independence, without resupply and without real-time communications to Earth. Specifically, this subtopic's focus is the development of innovations in crew equipment; and the development of technologies for assessment, modeling, and enhancement of human performance; and the development of design tools for engineers to incorporate human factors engineering requirements into hardware and software.

Proposals are solicited that seek to develop technologies that address these specific needs:

- Monitoring and maintaining human performance nonintrusively. Specifically, minimally invasive and unobtrusive devices and techniques to monitor the behavior and performance (physical, cognitive, perceptual, etc.) of individuals and teams during long-duration space flights or analog missions. Technologies to track locations of individuals within habitats, and report on physiological or other state information. Methods and models for human performance prediction, including physical performance, as affected by encumbrances of clothing, space suits, etc.

- Predictive modeling of effects on the crew due to potential spacecraft environments and operational procedures. Develop computational models of the crew environment and of human performance and behavior to simulate the effects of factors that contribute to (or degrade) long-term performance capabilities. Such models of the environment, individual, and group behaviors and performance can be used to simulate and explore the conditions that influence human performance (e.g., fatigue, noise, CO₂, microgravity, group dynamics, etc.). Such capabilities would include digital models of human operators and routine and emergency tasks that interact in the context of the long-duration human exploration environment.

- Tools to aid in design and evaluation of human-system interfaces for speed, accuracy, and acceptability in a cost-effective and reliable manner: Automated analysis of computer-user interfaces for complex display systems to conduct objective review of displays and controls, and to determine compliance with guidelines and standards. Quantitative measures of the effectiveness of user interfaces to be used for task-sensitive evaluations.

- Tools that facilitate the user interface design for human computer interfaces, and for facilitators, such as procedures, labels, and instructions. Tools should assist the designer in incorporating contextual information such as the user's task, the user's knowledge, and the system limitations.

- Tools to build just-in-time system and operational information software to aid human users conducting routine and emergency operations and activities. Such tools might include effective and efficient job aids (e.g., "intelligent" manuals, checklists, warnings) and support for designing flexible interfaces between users and large information systems. Methods for development of facilitators (procedures, labels, etc.) adapted for the development of space vehicle and payload applications.

- Rapid don/doff launch-and-entry and survival suit: a personal ambient environment and individual health and safety protective garment system with antigravity protection, metabolic-cooling and heating, breathing air, thermal protection, zero-atmospheric pressure protection, land and water survival gear, etc. An integrated suit (providing all desired protective functions), as well as a modular suit (allowing user to select ahead of time any of the array of required protection and survival subsystems) approach should be considered. The emphasis for this innovation should be to achieve the desired levels of protection for space travel, as well as for survival on Earth after landing at an unplanned site—all while affording rapid donning in microgravity through one-gravity (1g) environments on the order of 60 s and rapid doffing on the order of 300 s or less. Include accommodation for using the suit for ill, injured, or incapacitated crewmembers, meeting the don/doff goals while providing access for medical monitoring and ongoing treatment.
B3.03 Human Adaptation and Countermeasures

Lead Center: JSC
Participating Center(s): ARC

In order for humans to live and function safely and efficiently in space or in the hypogravity of the Moon (1/6g) or Mars (3/8g), a good understanding of the effects of micro- and hypogravity and other factors associated with the space environment on human physiology and human responses to the space and extraplanetary environments is required. A variety of countermeasures must be developed to oppose the deleterious changes that occur in space and upon subsequent exposure to other gravitational fields. The ability to monitor the effectiveness of countermeasures and alterations in human physiology during space exploration missions, particularly when several countermeasures are used concurrently, is equally important. This subtopic seeks innovative technologies in several very specific key areas.

As launch costs relate directly to mass and volume, instruments and sensors must be small and lightweight with an emphasis on multi-functional capabilities. Low power consumption is a major factor, as are design enhancements to improve the operation, design reliability, and maintainability of these instruments in the environment of space and on planetary surfaces. As the efficient use of time is extremely important, innovative instrumentation setup, ease of usage, improved astronaut (patient) comfort, noninvasive sensors, and easy-to-read information displays are also very important considerations. Extended shelf-life and ambient storage conditions of consumables are also key necessities. Ability to operate in 0g, 1g, and 3/8g become more important as we push for future human Moon and Mars missions.

Immersive Virtual Scene Display System

Development of an immersive visual display system is required to be interfaced with treadmill exercise devices. This system would not be head-mounted but would be free standing and provide at least a 180° field of view. This visual display would allow visual flow patterns to be displayed to a non-encumbered subject during inflight or on-surface treadmill exercise. Ultra-long duration missions to the Moon or Mars will especially benefit from such technology that encourages crew to spend more time exercising by enriching the environment and contribute to psychological well being by mimicking the terrestrial exercise experience.

Measurement of Emboli in the Brain

A small Doppler ultrasound device (need not be oxygen compatible), emboli recognition system/software, and solid-state recorder of detected events. This would be worn in a fashion similar to a Holter monitor and help to monitor blood clots in the brain for those at risk for embolic stroke. This is especially valuable for ensuring the safety of Extra-Vehicular Activity (EVA) on planetary surfaces, as well as during orbital flight.

Noninvasive Pharmacotherapy and Monitoring

Development of innovative technologies resulting in noninvasive methods for diagnosis, treatment, and therapeutic drug monitoring is needed to facilitate effective pharmacotherapy of humans in space. Many questions remain about the effectiveness of pharmaceuticals in micro- and hypogravity environments, which may interfere with their
activity by sensitizing or desensitizing the crew member or interfering in other ways with the desired physiological effect.

**MEMS-Based Human Blood Cell Analyzer**

Development of a small, automated, micro- and hypogravity capable, lightweight, low power instrument that will analyze a small sample (microliter quantity) of human whole blood and provide a complete blood cell count (RBC, WBC, platelet, hemoglobin concentration, hematocrit, WBC differential, and calculated RBC indices) that correlates with traditional ground-based impedance or light-scattering technologies is needed. Likely devices based on MEMS will employ a biocompatible combination of microfluidics, micromechanics, micro-optics, microelectronics, and data telemetry capabilities in an integrated handheld package with a simple, user-friendly operator interface. Such technologies will be critical to the implementation of future missions beyond low-Earth orbit to the Moon or Mars. Proper medical care and valuable research contributions will be dependent on such technologies in these exploration class missions.

**Human-Worn Whole Body Biomechanical and Movement Analysis Suit**

A whole-body suit and analysis system worn by human subjects is needed, which records and measures biomechanical movements and biomechanical characteristics in order to provide an assessment of total body physical activity during human space missions, especially missions to hypogravity environments such as the Moon or Mars. Measurements to be made and recorded would include upper and lower limb segment displacements along with related joint angular velocities and accelerations. The system would allow entry of limb segment and trunk mass and center-of-mass data specific to the individual wearing the suit and then would provide data analysis related to work and power across different body segments and for the whole body based on analytical algorithms. Other capabilities include storage of raw data and the ability to download the data to other computer-based storage and data analysis systems through either hardwired connections or via telemetry. Many differences may be noted in the way humans move in micro- and hypogravity environments. These differences may suggest better ways to perform work or to design tools, workstations, or procedures for accomplishing critical tasks in the future beyond low-Earth orbit missions.

**Body Composition Hardware for Spaceflight**

Development of on-orbit instrumentation for determining body composition. Specific parameters of interest include lean body mass, total fat mass, and total body water. Validation data will be required using the current gold-standard techniques in this field. This information will be used in conjunction with nutritional status protocols to assess crew health. The effects of the hypogravity environment of planetary surfaces on body composition are not known. Any future mission to the Moon or Mars will certainly measure these changes to detect and combat potential adverse changes. Such an instrument must work in 0g, 1/6g, and 3/8g environments.

**Device for Providing Increased Neuromuscular Activation During Spaceflight**

Astronauts returning from spaceflight exhibit post-flight postural and gait instabilities that are a result of neural adaptation to microgravity. A small, lightweight countermeasure device is required to stimulate somatosensory receptors on the plantar surface of the feet during in-flight exercise with the goal of increasing neuromuscular activation and enhancing sensorimotor integration. This system would integrate with in-flight exercise hardware and coupled with visual stimulation systems would allow a more complete sense of immersion to enhance in-flight postural and locomotor training.
B3.04 Food and Galley

Lead Center: JSC

As NASA begins to look beyond low-Earth orbit and to plan for future exploration missions, such as to the Moon or Mars, new food science technologies will be needed. The impossibility of regularly resupplying a Mars crew means that the prepackaged shelf-stable food, ingredients, and equipment to provide a complete diet for six crewmembers for more than three years will have to be carried with them. As the crew remains on the Moon or Mars surface, crops will be grown to supplement the crew’s diet, using plants to revitalize the air and water supply. Methods are needed, therefore, for processing potential food crops. Areas in which innovations are solicited follow below.

Long-Duration, Shelf-Stable Food

An initial trip to the Moon or Mars will require a stored food system that is nutritious, palatable, and provides a sufficient variety of foods to support significant crew activities on a mission of at least three years duration. Development of highly acceptable, shelf-stable food items that use high-quality ingredients is important to maintaining a healthy diet. Foods should maintain safety, acceptability, and nutrition, for the entire shelf life of 3–5 years. Shelf-life extension may be attained through new food preservation methods and/or packaging. Once on the lunar or planetary surface, it may be possible to use bulk packaging of meals or snack items. These food products will require specialized processing conditions and packaging materials.

Advanced Packaging

The current food packaging technologies represent a potentially significant trash-management problem for exploration-class missions to the Moon or Mars. New food packaging technology is needed that minimizes waste by using packaging with less mass and volume and/or by using packaging that is biodegradable or recyclable. Another opportunity would be development of a packaging material that can readily be reused by the crew to make objects of value to the space flight mission.

Food Processing

Advanced life-support systems, which use chemical, physical, and biological processes, are being developed to support future human planetary exploration. One such system might grow crops hydroponically and then process them into edible food ingredients or table-ready products. Variations in crop quality, crop yield, and nutrient content may occur over the course of long-duration missions, posing further requirements to the food processing and storage system. Such variations might affect the shelf stability and functional properties of the bulk ingredients and ultimately, the quality of the final food products.

Equipment to process crops on missions to the Moon and Mars should be highly reliable, safe, automated, and should minimize crew time, power, water, mass, and volume. Equipment for processing raw materials must be suitable for use in hypogravity (e.g., 1/6g on Moon, 3/8g on Mars) and in hermetically sealed habitats. Some potential crops for advanced life-support systems include minimally processed crops such as lettuce, spinach, carrots, tomatoes, onions, cabbage, bell peppers, strawberries, fresh herbs, and radishes. Other baseline crops that require processing would be wheat, soybeans, white potatoes, sweet potatoes, peanuts, dried beans, rice, and tomatoes. There is a need to develop one or more pieces of food processing equipment for each of these crops.
Food Safety

Assurances of food quality and food safety are essential components in the maintenance of crew health and well-being. Food quality and safety efforts should be focused on monitoring the shelf stability of processed food ingredients and on identification and control of microbial agents of food spoilage, including the development of countermeasures to ameliorate their effects. Determination of radiation on crop functionality and the stored food system shelf life is also needed in the development of the food system. For all food production and processing procedures, Hazard Analysis Critical Control Points (HACCP) must be established.

B3.05 Biomedical R&D of Noninvasive, Unobtrusive Medical Devices for Future Flight Crews

Lead Center: GRC

Human presence in space requires an understanding of the effects of the space environment on the physiological systems of the body. The objective of this subtopic is to sponsor applied research leading to the development of noninvasive, unobtrusive medical devices that will mitigate crew health, safety, and performance risks during future flight missions to the Moon and Mars. Medical diagnostic and monitoring devices are critical for providing health care and medical intervention during missions, particularly extended-duration spaceflight to the Moon and Mars. Of particular interest are devices with minimized mass, volume, and power consumption, and capable of multiple functions. Design enhancements that improve the operation, design reliability, and maintainability of medical devices in the space environment are also sought. Of additional consideration are innovative instrumentation automation, ease of use, improved astronaut comfort, and easy-to-read information displays.

Major research disciplines include endocrinology, hematology, microbiology, muscle physiology, pharmacology, drug delivery systems, and mechanistic changes in neurovestibular physiology.

Innovations in the following areas are sought:

- Biomedical monitoring, sensing, and analysis (including the acquisition, processing, communication, and display) of electrical, physical, or chemical aspects of a human's health or physiological state.
- Instrumentation to be used for in-flight and ground-based studies for reliable and accurate noninvasive monitoring of human physiological functions such as the musculoskeletal, neurological, gastrointestinal, and hematological systems.
- Noninvasive biosensors for real-time monitoring of blood and urine chemistry including gases, calcium ions, electrolytes, proteins, lipids, and hormones.
- In-flight specimen analysis to evaluate physiological, metabolic, and pharmacological responses of astronauts.
- Instrumentation to provide quantitative data to establish the effectiveness of an exercise regimen in ground-based research, and to measure bone strain in the hip, heel, and lumbar spine during exercise.
- Assessment of gas bubble formation or growth in the body after in-flight or ground-based decompression,
and to prevent or minimize associated decompression sickness.

- In-flight assessment of the metabolism of proteins, carbohydrates, lipids, vitamins, and minerals.
- Smart sensors capable of sensor data processing and sensor reconfiguration.
- Small, portable, medical imaging diagnostic instrumentation.

B3.06 Waste and Water Processing for Spacecraft Advanced Life Support

Lead Center: JSC
Participating Center(s): ARC, GRC, KSC, MSFC

Regenerative closed-loop life-support systems will be essential to enable human planetary exploration. Efforts are currently focused on missions ranging from a return to the Moon and through an initial Mars mission, including using the International Space Station as a test bed for research and technology validation. These future life-support systems must provide additional mass balance closure to further reduce logistics requirements and to promote self-sufficiency. Requirements include safe operability in micro- and partial-gravity, ambient and reduced-pressure environments, high reliability, minimal use of expendables, ease of maintenance, and low-system volume, mass, and power. Recovery of useful resources from liquid and solid wastes will be essential. Innovative, efficient, practical concepts are needed in all areas of resource recovery processes, providing the basic life-support functions of water reclamation and waste management. In addition to these long-duration space applications, innovative regenerative life-support approaches that could have terrestrial application are encouraged. Phase-I proof of concept should lead to Phase-II hardware development that could be integrated into a life-support system test bed. Proposals should include estimates for power, volume, mass, logistics, and crew time requirements as they relate to the technology concepts. More information on advanced life support systems can be found at [http://advlifesupport.jsc.nasa.gov](http://advlifesupport.jsc.nasa.gov) [3]. Areas in which innovations are solicited in the following areas:

Water Reclamation

Efficient, direct treatment of wastewater consisting of urine, wash water, and condensates, to produce potable and hygienic waters.

- Physicochemical methods for primary treatment to reduce the total organic carbon concentration of the wastewater from 1000 mg/L to less than 50 mg/L and/or the total dissolved solids from 1000 mg/L to less than 100 mg/L.
- Post-treatment methods to reduce total organic carbon from 100 mg/L to less than 0.25 mg/L in the presence of 50 mg/L bicarbonate ions, 25 mg/L ammonium ions and 25 ppm other inorganic ions.
- Methods for the phase separation of solids, gases, and liquids in a microgravity environment that are insensitive to fouling mechanisms.
- Methods for the treatment of brine solutions including water recovery.
- Methods to eliminate or manage solids precipitation in wastewater lines.
Disinfection technologies, both for potable water storage and point-of-use. Development of residual disinfectants that can be consumed by crewmembers. Techniques to minimize or eliminate biofilm or microbial contamination from potable water systems and water treatment systems, including fluid handling components such as pipes, tanks, flow meters, check valves, regulators, etc.

Solid Waste Management

Concepts and methods to safely and effectively manage wastes for all future human space missions are required to perform the following functions: acceptance/collection, transport, storage, processing, disposal, and associated monitoring and control. Actual types and quantities of wastes generated during missions are highly mission dependent. For sizing purposes, however, the "maximum" waste streams have been estimated as follows, based on a 6-person crew: trash (0.56 kg/day), food packaging (7.91 kg/day), human fecal wastes (0.72 kg/day dry, 3.0 kg/day wet), inedible plant biomass (2.25 kg/day), paper (1.16 kg/day), tape (0.25 kg/day), filters (0.33 kg/day), water recovery brine concentrates (3.54 kg/day), clothing (3.6 kg/day), and hygiene wipes (1.0 kg/day). Wastes can also be assumed to be source-separated because this requirement has been identified for a majority of waste processing equipment:

- Microgravity- and hypogravity-compatible solid waste management technologies;
- Volume reduction of wet and dry solid wastes;
- Small and compact fecal treatment and/or collection system;
- Water recovery from wet wastes (including human fecal wastes, food packaging, brines, etc.);
- Stabilization, sterilization, and/or microbial control technologies to minimize or eliminate biological hazards associated with waste;
- Storage devices needed for the containment of solid waste that incorporates an odor abatement technology.
- Microgravity-compatible technologies for the jettison of solid wastes in space; and
- Other novel waste management technologies for storage, transport, processing, resource recovery, and disposal that satisfy a critical need for the referenced missions (e.g., recovery of critical resources).

Component Technologies

Energy efficient, low mass, low noise, low vibration or vibration isolating, fail-safe and reliable components for handling fluids, slurries and/or solids applicable to wastewater treatment and solid waste management. Components include actuators, pumps, conveyors, compressors, coolers, tubing, tanks, bins, fittings, couplings, quick disconnects, and valves which operate under varied levels of gravity, pressure, and vacuum. Mass flow monitoring and control devices that have similar attributes and that are easily calibrated and serviced.

B3.07 Biomass Production for Planetary Missions

Lead Center: KSC
Participating Center(s): ARC, JSC
The production of biomass (in the form of edible food crops) in closed or nearly-closed environments is essential for the future of long-term planetary exploration and human settlement in Moon and Mars base applications. These technologies will lead not only to food production, but also to the reclamation of water, purification of air, and recovery of inedible plant resources in the comprehensive exploration of interplanetary regions. Innovations are solicited in the following areas:

**Crop Lighting**

- Sources for plant lighting such as, but not limited to, light emitting diodes, high-efficiency lamps or solar collectors suitable for orbital space, interplanetary space, lunar or Martian surface;
- Transmission and distribution systems for plant lighting including, but not limited to, luminaries, light pipes, fiber optics, and optical filters; and
- Heat removal techniques for the plant growth lighting such as, but not limited to, water-jackets, water barriers, and wavelength-specific filters and reflectors.

**Water and Nutrient Management Systems**

- Technologies for production of crops using hydroponics or solid substrates suitable for orbital space, interplanetary space, lunar or Martian surface;
- Water and nutrient delivery systems;
- Regenerable media for seed germination plant support; and
- Separation and recovery of usable minerals from wastewater and solid waste products for use as a source of mineral nutrients for plant growth.

**Environmental Monitoring and Control**

Innovations in monitoring and control approaches for plant-production environments, including temperature, humidity, gas composition, and pressure. Gases of interest could include carbon dioxide, oxygen, nitrogen, water vapor, and ethylene. Development of autonomous control systems integrated with predictive modeling for crop production optimization.

**Mechanization and Automation**

Innovations in propagation, seeding, and plant biomass processing. Plant biomass processing includes harvesting, separation of inedibles from edibles, cleaning and storage of edibles (seed, vegetable, and tubers) and removal of inedibles for resource-recovery processing.

**Facility or System Sanitation**

Methods or technologies to identify and prevent excessive build-up of microorganisms within closed plant
production systems with emphasis on nutrient delivery systems. Processes to insure pathogen free products through HACCP food safety protocols.

**Health Measurement**

Remote, direct, and indirect methods of measuring plant health and development using canopy (leaf) spectral signatures or fluorescence to quantify parameters such as rate of photosynthesis, transpiration, respiration, and nutrient uptake. Data acquisition should be noninvasive or remotely sensed using spectral, spatial, and image analysis. System modeling and decision making algorithms may be included.

**Sensor Technologies**

Innovations are required for development of sensors using miniature, micro- and nanotechnologies for evaluation of the physical and biological parameters in all phases of biomass production. Such sensor arrays include wide-ranging applications of gas and liquid sensors, as well as photo sensors and microbiological community indicators. Innovations are required in all phases of sensor development, including biomass fouling, miniaturization, wireless transmission, multiple-phase and multiple-tasking sensors, and interface with artificial intelligence (AI) data collection systems.

**Flight Equipment Support**

Innovative hardware and components developed to support life support and biological research in the Space Shuttle, on board the International Space Station, and exploration missions to the Moon, Mars, and beyond. Biomass production investigations using flight-support equipment will be required to meet the demanding requirements for space flight operations, meet the rigorous scientific data collection standards, and produce plants in a controlled environment for research purposes and food. Innovative methods to perform in-flight biomass analyses, including equipment miniaturization, are requested in order to perform remote analyses and to minimize requirements to return in-flight samples. Innovations in whole-package design and in component designs will be required.

**Structures**

Innovative concepts and designs for autonomous or human tended plant production structures that might be deployed in space habitats, including flight, planetary transit, or planetary surfaces systems. Systems would need to accommodate the capture and distribution of solar light or generated light (e.g., electric lamps) and meet the mass and stowage challenges for spaceflight delivery.

**B3.08 Software Architectures and Integrated Control Strategies for Advanced Life Support Systems**

**Lead Center:** JSC  
**Participating Center(s):** ARC, JPL, KSC  

The purpose of this subtopic is to develop advanced control system technologies that can support an integrated
approach to the command and control of Advanced Life Support (ALS) for future long-duration human space missions, including a permanent human presence on the Moon and Mars. The control strategies for ALS systems must deal with continuous and discrete processes and with dynamic interactions between subsystems such as air revitalization, water recovery, food production, solids processing, and the crew. The goal of autonomously controlling an ALS system challenges many areas of technology, including distributed data management and control, sensor interpretation, planning and scheduling, modeling and simulation, and validation and verification of autonomous control systems. These various technology areas must eventually be integrated into a coherent system that runs day after day for years and that can effectively interact with crewmembers who place their lives in its hands. The control strategy must be able to reach “across” the system and “down” into its parts to gather all data necessary to achieve its control objectives. Interfaces to crew, ground control, and other spacecraft systems must allow for insight into control strategies, choices, and pending actions and allow for manual control at any level.

The challenges of controlling regenerative life support for an enclosed crew environment involve the ALS goals to minimize expendables, to minimize crew and ground involvement, and to incorporate biological systems for recycling air, water and solids. The interdependence of environmental processing systems, and the need for reducing operations support costs are included. There is a need for the development and evaluation of control architectures and strategies which meet these challenges, both by building on current advances in distributed, modular, object-based protocols, and by new advances in integration of agent technology, planning, and resource management across heterogeneous systems. This includes:

**New Control Strategies for Closed-Loop Systems**

Advanced Life Support consists of a combination of physico-chemical systems with biological systems to recycle air, water, solid waste, plants, and food. The system is closed with respect to hydrogen, oxygen, and carbon in order to reduce the amount of consumable air water and food necessary for extended human presence on other planets. Closed systems and biological systems have different constraints and control paradigms than conventional processes. There is a need for new control algorithms, analyses, strategies, and techniques that can accommodate this architecture.

**Distributed Network Protocols, Including Support for Fieldbus and Intelligent Controllers**

The robustness of the control and data paths for equipment and subsystems is determined by the fieldbus protocols that connect them. Fieldbus protocols have been developed for the special needs of the aerospace and process control industries. There is a need for investigation and adaptation of these protocols, and the development of new protocols to support the type of distributed intelligent systems and networks envisioned for human exploration missions. These protocols need to be robust and fault-tolerant, and to support a large number of heterogeneous systems. Ideally, these protocols should support both local and interplanetary connectivity.

**Development of Ontologies for Communication Among Autonomous Systems or Control Agents**

Human exploration missions involve hundreds of systems developed by dozens of organizations. To develop software that can integrate across these systems and integrate with operations requires the use of common terminology across multiple disciplines. A common taxonomy or common ontology needs to be developed for the types of control problems associated with integrated control of advanced life support systems.

**Software Development Methodologies for Autonomous Systems**

This includes requirements management, testing, performance metrics, and long-term maintenance support, including development for growth and support for model-based simulations. There is a need for new tools to
support the development of distributed autonomous control systems throughout the program life cycle. This includes tools for managing prototyping, requirements, design, design knowledge capture, testing, and growth and maintenance across multiple development teams.

**Approaches for Integration of New Controls Technology (both hardware and software) with Existing Legacy Systems**

Some space technologies are relatively mature. New controls technology must be compatible with legacy fieldbuses and operations concepts in addition to providing new functionality. There is a need for tools and development methodologies that can accommodate growth in system functionality.

**Fault Detection, Isolation and Recovery (FDIR) Across Multiple Systems; Sharing of Parameters and Data Between Heterogeneous Systems**

The majority of FDIR approaches focuses on single subsystems and depend on a homogeneous platform and software architecture, often using a blackboard or shared memory model to share data between modules. There is a need to perform FDIR across multiple heterogeneous systems across networks. Ideally, FDIR should support cooperative efforts between group operations and planetary systems.

**Control System Failure Tolerance**

Critical systems provide functional redundancy in the case of failure or performance degradation. There is a need for new approaches to providing failure tolerance for both hardware and software components of the control systems. Of particular importance is the reduction of crew time for maintenance, and reduction of dependence on re-supplying hardware, as these are the most expensive constraints on these systems.

**Planning and Scheduling**

This includes reactions to system faults, supporting adjustments to operations, inventory, and logistics because of planned and unplanned maintenance. There is a need for tools to support development and deployment of applications that support planning and scheduling. Developed applications should support the integration of both planet-side and Earth-side activities.

**Development and Integration of Autonomous System and Intersystem Control with Crew and Ground Operations**

There is a need for tools, architectures, and technology that can support integration of operations between crew, ground operators, ground applications, and onboard applications.

**Development of Architectures that Support a Range of Autonomy, from Fully Autonomous to Fully Manual, with the Corresponding Range of Support for Human Interaction**

Autonomous systems for human exploration missions must provide visibility, situational awareness, and an ability to change the level of autonomy based on both situation and human input. As unexpected situations arise that are outside the scope of design, autonomous control systems must interact with crew and ground operators at varying levels of transparency. Unlike Earth-based systems, the planet-side crew will not be subsystem experts and may be isolated from ground support. Local systems must safely and robustly aid the crew in both troubleshooting and
nominal operations. There is a need for software architectures and development methodologies, including system and crew modeling, to provide such capabilities.

B3.09 Radiation Shielding to Protect Humans

Lead Center: LaRC

Revolutionary advances in radiation shielding technology are needed to protect humans from the hazards of space-radiation during NASA missions. All space-radiation environments in which humans may travel in the foreseeable future are considered, including low-Earth orbit, geosynchronous orbit, Moon, Mars, etc. All radiations are considered, including particulate radiation (electrons; protons; neutrons; alpha; light-to-heavy ions, with particular emphasis on ions up to iron; mesons; etc.) and including electromagnetic radiation (ultraviolet, x-rays, gamma rays, etc.). Technologies of specific interest include, but are not limited to, the following:

- Advanced computer codes are needed to model and predict the transport of radiation through materials.
- Advanced computer codes are needed to model and predict the effects of radiation on the physiological performance, health, and well-being of humans in space radiation environments.
- Innovative lightweight radiation shielding materials are needed to shield humans in aerospace transportation vehicles, large space structures such as space stations, orbiters, landers, rovers, habitats, space suits, etc. The materials emphasis should be on non-parasitic radiation shielding materials, or multifunctional materials, where one of the functions is radiation shielding.
- Non-materials and "out-of-the-box" radiation shielding technologies are also of interest.
- Laboratory and space flight data are needed to validate the accuracy of radiation transport codes.
- Laboratory and space flight data are needed to validate the effectiveness of radiation-shielding materials and non-materials solutions.
- Comprehensive radiation-shielding databases and design tools are also sought to enable designers to incorporate and optimize radiation shielding into space systems during the initial design phases.
- Accurate and reliable theoretical and phenomenological models are needed for the collision of radiation ions to generate the input database for transport phenomena. The models that give comprehensive results in a fast manner for broader (preferably whole) ranges of colliding ions, for ion energies from a few mega-electron volts to a few giga-electron volts are desirable. The information needed is as follows:
  - Total, elastic, absorption, and fragmentation cross sections
  - Spectral and angular distributions of producing particles
  - Multiparticle fragmentations
  - Cluster effects
B3.10 Sensors for Advanced Human Support Technology

Lead Center: JPL
Participating Center(s): ARC, GRC, JSC, KSC, MSFC

Monitoring technologies are employed to assure that the chemical and microbial content of the air and water environment of the astronaut crew habitat falls within acceptable limits, and that the chemical or biological life support system is functioning properly. The sensors may also provide data to automated control systems.

Significant improvements are sought in miniaturization, accuracy, precision, and operational reliability, as well as long life, real-time multiple measurement functions, in-line operation, self-calibration, reduction of expendables, low energy consumption, and minimal operator time/maintenance for monitoring and controlling the life-support processes.

- For water monitoring, sensitive, fast response, online analytical sensors to monitor suspended liquid droplets, dispersed gas bubbles, and water quality, particularly total organic carbon.

- Other species of interest include dissolved gases and ions, and polar organic compounds such as methanol, ethanol, isopropanol, butanol, and acetone in water reclamation processes; and particulate matter, major constituents (such as oxygen, carbon dioxide, and water vapor) and trace gas contaminants (such as ammonia, formaldehyde, ethylene) in air revitalization processes. Both invasive and noninvasive techniques will be considered.

- Monitoring of microbial species, especially pathogens, primarily in water, is important. Enabling technologies may include proper sample preparation and handling, with minimal operator effort and minimal or no reagent usage.

- Significant mass savings and ease of use may be enabled by approaches that detect more than one species at a time. Proposals that seek to develop new technologies or combine existing technologies to simultaneously monitor several major constituents and/or trace constituents are of interest.
Partnerships and Market Driven Research Topic B4

NASA’s Space Product Development (SPD) division supports the strategic missions to understand and protect our home planet and to explore the universe and search for life. It also seeks to find answers to the biological and physical research organizing sub-question that asks: How can research partnerships—both market driven and interagency—support our national goals, such as contributing to economic growth and sustaining human capital in science and technology? Innovative proposals are sought for market driven technologies and processes that will support NASA’s goals and include dual-use market needs on Earth. There are four initiative areas where NASA space research has strong potential for dual market use on Earth:

1. Self-calibrating and self-repairing bio-MEMS devices for such uses as monitoring crew health in space along with dual applications on Earth for monitoring biological/physical interfaces;

2. Space resource utilization techniques that enable the use of \textit{in situ} planetary resources along with dual applications on Earth that create products by combustion synthesis of materials, extraction of volatiles, separation of solids;

3. Spacecraft technologies that enhance spacecraft inspections, robotic processing, or Free Flyer experiments with dual applications on Earth, such as high density video and advanced sensor networks;

4. Life support technologies that enable health monitoring, provide functional foods and nutraceuticals and environmentally clean habitats with dual applications on Earth, such as high-resolution wireless ultrasound for patient monitoring, improved crop productions, and new forms of drug delivery. Small business applicants must have strong intentions of becoming a part of NASA’s Research Partnering Center initiatives leading to partnered Phase III contracts for products to be used in space and on the Earth.

Sub Topics:

\textbf{B4.01 Space Market Driven Research}

\textbf{Lead Center: MSFC}

The commercial development of space offers enabling benefits to space exploration for NASA. In accordance with the Space Act, as amended, to “seek and encourage to the maximum extent possible the fullest commercial use of space,” NASA facilitates the use of space and microgravity for the development of commercial products and services. The products may use information from in-space activities to enhance an Earth-based effort, or may require in-space use. This subtopic has three goals. The first goal is the commercial demonstration of pivotal technologies or processes, for example, self-calibrating and self-repairing bio-MEMS devices for such uses as monitoring crew health in space along with dual applications on Earth for monitoring biological-physical interfaces. The second goal is the development of associated infrastructure equipment for commercial experimentation and operations in space, or the transfer of these technologies to industry in space or on Earth. An example of this is the automated processes and hardware (robotics), which will reduce crew exposure and time, and which are a priority. The third goal is the commercial research and technologies pursued and developed in the program often have direct applicability to NASA priority mission areas. This dual-use strategy for research and technology has the potential to greatly expand what the NASA scientific and engineering communities can do in advancing exploration mission requirements. All Agency activity in microgravity, including those in life science and microgravity sciences, which lead to commercial products and services as well as benefits to the mission requirements of exploration objectives, are of interest. Below are some specific areas for which proposals are sought.
Biotechnology

This category comprises biotechnology, biomedical, and agricultural instrumentation or techniques that exploit space-derived capabilities or data to support the commercial development of space by the agricultural, medical, or pharmaceutical industry.

- Portable biological sensors: The need for sensing devices that can detect and identify biological pathogens (airborne or in vivo) is desired to support NASA's mission for a permanent presence of man in space.

- Development of noninvasive health monitoring systems and models: Application to NASA's crew health program for extended duration missions. For example, (1) novel in vitro cell-matrix models for studying the effects of microgravity on human tissue repair and wound healing, (2) novel orga-notypic skin models that simulate physiological changes found in humans under a microgravity environment, and (3) functional models for delineating the MG-inducible or MG-responsive pathways of human tissue angiogenesis (new blood vessel formation).

- Physiological measurement in microgravity of bone growth and the immune system in microgravity.

- Innovative research in plant-derived pharmaceuticals using microgravity.

- Agricultural research, i.e., genetic manipulation of plants using microgravity.

- Instrumentation or technology to explore the use of microgravity in genetic assay, analysis, and manipulation.

- Instrumentation to analyze cell reactor systems and characterize cell structure in microgravity in order to develop enhanced drug therapies that can also be applied to pharmaceutical development and commercialization.

- Innovative techniques for dynamic control and cryogenic preservation of protein crystals.

- Innovations in preparation of protein crystals for x-ray diffraction experiments without the use of frangible materials.

- Innovation of low-technology temperature control chambers requiring little or no power for bringing temperature sensitive experiments up to, or back from, the International Space Station.

Materials Science

Areas in which Materials Science innovations are sought include the following:

- Applications using space-grown semiconductor crystals, including epitaxially grown materials for commercial electronic devices. The applications will also attempt to use the knowledge of the space-grown material behavior to enhance ground processing of the materials to achieve equivalent performance of space-grown materials in electronic circuitry.

- Applications using space-grown optical electronic materials such as fluoride glasses and nonlinear optical compounds for commercial optical electronic devices and to achieve equivalent performance of space-grown materials in ground processing.

- Innovations using nonlinear optical material to be processed in space.
• Innovations for new space-processed glasses for optical electronic applications.

B4.02 Market Driven Space Exploration Payloads

Lead Center: MSFC

NASA has an interest in the development of science and experiments that support strategic aspects of exploration, as well as the development of technologies to extend humanity’s reach to the Moon, Mars, and beyond. This includes designing exploration microgravity payloads. For example, life support technologies that enable health monitoring, provide functional foods and nutraceuticals, and environmentally clean habitats with dual applications on Earth such as high-resolution wireless ultrasound for patient monitoring, improved crop productions, and new forms of drug delivery. Preparing for exploration and research will accelerate the development of technologies that are important to the economy and national security as well as accelerate critical technologies.

Microgravity Payloads

• Design and develop microgravity payloads for space station applications that lead to commercial products or services.

• Enabling commercial technologies that promote the human exploration and development of space.

• Enabling commercial technologies through the use of ISS as a commercial test bed for hardware, products, or processes.

• Enabling technology designed to reduce crew work loads and/or facilitate commercial investigations or processing through automation, robotics, or nanotechnology.

Combustion Science

Innovative applications in combustion research that will lead to developing commercial products or improved processes through the unique properties of space or through enhanced or innovative techniques on the ground.

Food Technology

Innovative applications of space research in food technology that will lead to developing commercial food products or improved food processes through the unique properties of space or through enhanced or innovative techniques on the ground.

Biomedical Materials
Innovative materials where microgravity promotes structures such as biodegradable polymers for use in wound healing and orthopedic applications.

Entertainment Value Missions

Innovative approaches for commercial economic benefit from space research involving broadcasting, e-business, or other activities that have entertainment value.

B4.03 Market Driven Space Infrastructure

Lead Center: MSFC

In accordance with the Space Act, as amended, to "seek and encourage to the maximum extent possible the fullest commercial use of space," NASA facilitates the use of space for commercial products and services. For example, space resource utilization techniques that enable the use of in situ planetary resources along with dual applications on Earth that create products by combustion synthesis of materials, extraction of volatiles, and separation of solids; also, spacecraft technologies that enhance spacecraft inspections, robotic processing or Free Flyer experiments with dual applications on Earth, such as high density video and advanced sensor networks. The products may use information from in-space activities to enhance an Earth-based effort or may require in-space manufacturing. This subtopic's goal is the development of infrastructure technology that will enable or enhance commercial space operations. Processes and hardware that have a clear utilization plan are a priority. All space activities that lead to commercial use in space are of interest. Some specific areas for which proposals are sought include the following:

Power and Thermal Management

Power and thermal management technologies that enable or enhance commercial satellites or space systems are sought.

Communications

Broadband, data compression, and imaging that can enable or enhance commercial operations in space or commercial satellites. This includes use of hyperspectral imagery and remote sensing.

Space Vehicles and Platforms

Improved technologies are sought for autonomous commercial vehicles and platforms. These technologies include autonomous rendezvous and docking, structures, and avionics.

Space Resources Utilization

Advanced commercial space activities will benefit from using nonterrestrial resources. These resources include
propellants, power, and structural materials.

B4.04 Partnering Innovations for Security and Safety

Lead Center: MSFC

NASA also has the goal to protect its assets, on Earth and in space, as well as our home planet and better understand the use of technologies that improve the quality of life in space and on Earth. By investing in space research and by collaborating with other agencies, industry, and academia, NASA has the opportunity to contribute to the creation of a more secure environment in space and on Earth. By leveraging resources in support of research in the unique environment of space, NASA goals and national priorities, such as security, as well as market needs, may be achieved. This dual use with good potential for commercial product development is strongly encouraged. Following are some example areas for which proposals are sought:

- Sensors and detection systems to improve processes and operations in support of NASA space research and exploration goals, national security, and industrial processes.

- Improved communication systems to effectively and efficiently gather information from space-based research and provide better communication capabilities in support of NASA; its space and ground-based research and exploration goals are a priority. These systems could also be used to disseminate warnings and other critical information, in the event of a national disaster.

- Innovative devices and procedures for the use of technologies to protect NASA's personnel and assets as well as citizens from various threats to their personal security and/or property. These devices and procedures for the use of technologies would also provide protection to personnel carrying out NASA space research and exploration operations, both in space and on Earth.

- Countermeasure systems and/or devices to better effect rescue, recovery, treatment, and environmental safety during and after the occurrence of a disaster or a related accident.

Exploiting Gravitational Effects for Combustion, Fluids, Synthesis, and Vibration Technology Topic B1.01

In preparation for future human exploration we must advance our ability to live and work safely in space, and at the same time, develop technologies to reach the Moon and other planets. The objective of this subtopic is to introduce new technology in the form of devices, models, and/or instruments for use in microgravity, extraterrestrial habitats,
and/or for commercial applications on Earth. Research should target spacecraft and planetary life-support systems (such as Extra-Vehicular Activity suits, extraterrestrial habitats, oxygen generation, and waste disposal), environmental monitors, and hazard controls (contaminants, fire safety, etc.). For Biofluids, please see subtopic B1.04 Bioscience and Engineering.

Innovations are sought in the following areas:

- Understanding the effects of microgravity on fluid behaviors.
- Using the mechanics of granular materials to determine how the reduced gravity environment affects transport and mixing of granular solids, with application to in situ resource utilization (ISRU) and more efficient terrestrial processes.
- Pool and flow boiling systems or subsystems that enable safe, efficient, and reliable heat transfer technologies for space application of advanced power and thermal control systems.
- Multiphase flow and fluid management to provide designers key information on controlling the location and dynamics of liquid–vapor interfaces in microgravity. This is needed for safe and reliable fluid handling and transport in microgravity.
- Innovative concepts for phase separation and condensation over a wide range of vapor content and gravity levels ranging from 0–1g.
- Measuring the residual accelerations on spacecraft or in ground-based low-gravity facilities. Emphasis is placed on MEMS or nanoscale devices capable of measuring quasi-steady (low frequency ~0–0.1 Hz) microgravity levels.
- Improving in-space system performance that relies on fluid or combustion phenomena, principally spacecraft fire safety, especially fire prevention, smoke, precursor, and fire detection and fire suppression.
- Characterization of ignitability, flame spread, and spacecraft material selection.
- Micropumps and microvalves, individual as well as simultaneous diagnostics for determining fluid movement through microscale devices for the aforementioned applications, and identifying specific chemical or biological elements of interest.
- Micropower systems for EVA operations, including power, heating, and cooling.
- Robust sensors for detection of hazards (fire, spills, leaks) in spacecraft, extraterrestrial habitats, and EVA systems.
- Partial and low-gravity compliant reactors for waste stabilization, as well as for oxygen and water recovery on extraterrestrial habitats.
- Understanding the effects of microgravity on combustion behaviors.
- Pollution reduction and improvement of the efficiency of liquid fueled combustors.
- Microfluidics for fuel cells and other power systems.

Sub Topics:
Gravitational Effects on Biotechnology Topic B1.02

NASA is interested in the development of science and experiments that support strategic aspects of exploration, as well as develop the technologies to extend humanity's reach to the Moon, Mars, and beyond. Preparing for exploration and research will accelerate the development of technologies that are important to the economy and national security, as well as accelerate critical technologies such as biotechnology.

Plans are to support research and development to investigate the influence of the space environment, radiation, and reduced gravity on biotechnology processes, and human factors at the biomolecular level. Areas of interest include factors that influence bone and muscle biochemistry, protein crystal growth and structural analysis techniques, separation science and technology, and biomaterials. Examples of the types of research include but are not limited to:

- Technologies designed to improve our understanding of the effect of gravity on expression of biological macromolecules.
- Technologies to determine the relationships between material substrates, bone and muscle tissue and cell culture conditions, and subsequent cell protein expression and differentiation.
- Development of high-throughput technologies to determine gene and protein expression and differentiation.
- Biotechnology and instrumentation to help enable safe human exploration beyond Earth orbit for extended periods.
- Environmental monitoring and control for human life support.

Sub Topics:
Materials Science for In-Space Fabrication and Radiation Protection Topic B1.03

Methods for conducting materials science and technology research required to enable humans to safely and effectively live and work in space are needed. Other areas of interest are the development of reduced gravity materials processing technology for in-space fabrication, repair, and resource development. Equipment that can operate with the limited resources of the Space Station Glovebox and in existing Space Station racks to perform demonstration experiments of strategic interest for in-space fabrication and repair, and for development of in situ resources, would also be of interest. Innovative developments are sought in the following research areas and their enabling technologies, including commercial applications on Earth.

In-Space Fabrication

NASA needs the development of techniques and processes that permit in-space fabrication of critical path components of future major projects. Developmental studies of materials and processes of direct strategic significance to the exploration of space are appropriate. In addition, the manufacture or repair of components during a mission is essential to human exploration and the development of space. Fabrication and repair beyond low-Earth orbit is required to reduce resource requirements and spare parts inventory, and to enhance mission security. Also being sought are enabling technologies that can lead to materials and/or processes for the reduced gravity (micro-g, 1/6g, and 3/8g) in-space fabrication of in situ space resources. Of particular interest is the effect of reduced gravity and the space environment on these processes. Examples of the types of research include but are not limited to the following:
Application of rapid prototyping technology to low gravity, 3/8 and 1/6 g level free-form fabrication of near-net shapes from metals, ceramics and polymers for fabricating spare parts and repairs.

Development of space resources into raw materials and feedstock for use with rapid prototyping technology.

Novel and innovative methods for processing materials in reduced gravity, in-space fabrication and repair including microwave processing, sintering, welding, and joining.

Development of an improved lunar and Martian regolith simulant material more suitable for materials experiments with not just an average composition, but also the mineralogical analysis, particle shape, size, and distribution of the individual particle grains being more representative of actual lunar and Martian soils.

Basic research, theoretical modeling, and experimental development of extractive and reactive processes, materials purification and characterization in a reduced gravity (3/8g and 1/6g) space environment and fundamental studies of in-space fabrication with in situ resources. For example: in situ fabrication of solar cells; metallic wire suitable for electrical conductors, antennas and rectifying-antennas; glass formation from in situ resources with minimal terrestrial components.

Radiation Protection Materials

NASA needs materials and novel concepts for effective radiation shielding in support of human exploration of space. These materials must be capable of attenuating exposure levels due to galactic cosmic rays and solar energetic particles, as well as their secondaries, to acceptable limits. Specific areas of interest include:

- Development of multi-functional and/or smart structural materials for radiation hardening/shielding;
- In situ regolith radiation shielding research;
- Development of light-weight, hydrogenated epoxy and preimpregnates (prepregs);
- Development of hydrogen filled, carbon nanostructures for both radiation shielding and as structural elements for spacecraft and habitat; and
- Methods for monitoring/dosimetry for space radiation.

Sub Topics:
Bioscience and Engineering Topic B1.04

NASA recognizes the critical role that fluid mechanics and transport processes, along with their supporting technologies, play in many biological and physiological events. A wide variety of fundamental problems in the categories of physiological systems, cellular systems, and biotechnology may be addressed. The objective of this research is to deliver new technology in the form of devices and instruments of use in microgravity missions to the Moon and Mars and/or for commercial application on Earth in the areas discussed below.

Micro-Optical Technology for Interdisciplinary and Biological Research

Technologies are sought for measuring and manipulating Space Station and long-duration mission experiments, and for monitoring and managing astronaut health and the health of structures and systems affecting astronauts’ environments. Areas of innovative technology development include:
- Diagnostic methods to assess the performance of labs-on-a-chip, including detecting the presence of bubbles and particles and removing or characterizing them;

- Measurements for fluids including spatially and temporally resolved chemical composition and physical state variables;

- Optically-based biomimetics for self-aware, self-reconfiguring measurement systems;

- Measurement and micro-control technologies for health monitoring and health management of experiments, astronauts, and astronauts’ environments;

- Optical quantum technologies for measurement systems including signal detection and transmission; and

- Technologies enabling optically-based mobile sensor platforms for detection and maintenance, using optical sensing, control, power, and/or communication.

**Biological Fluid Mechanics (Biofluids)**

Biofluids, an intersection of fluid physics and biology, is a new area of emphasis within NASA’s Office of Biological and Physical Research (OBPR). Fluid mechanics and transport processes play a critical role in many biological and physiological systems and processes. An adequate understanding of the underlying fluid physics and transport phenomena can provide new insight and techniques for analyzing and designing systems that are critical to NASA’s mission. The microgravity environment modifies vascular fluid distribution on a short time scale, because of the loss of hydrostatic pressure, and on a longer time scale, because of the shift of intercellular flows. This fluid shift could modify transport processes throughout the body. For example, modification of flow and resulting stresses within blood vessels could modify vascular endothelial cell structure and permeability, which may be detrimental in long-term inter-planetary space flight. Furthermore, reintroduction of gravity causes large-scale fluid shifts in the body, which can influence cardiac output and induce faintness. Studies of macro- and microscale biofluid mechanics of the vascular system in the microgravity environment may be important to understanding these physiological events. Innovations sought include but are not limited to the following:

- Studies of biological fluid mechanics that seek answers to questions related to effect of long-term exposure to microgravity on human physiology;

- Understanding the role of fluid physics and transport phenomena in the “fluid shift” observed in the human body when exposed to prolonged microgravity; and

- Understanding the role fluid physics plays in human physiological processes such as cardiovascular flows and its effect on arteriosclerosis, and pulmonary flows and asthma.

**BioMicroFluidics**

Many biotechnology applications need manipulation of fluids moving through micro channels. As a result, microfluidic devices are becoming increasingly useful for biological/biotechnological applications. Because capillary forces can have a significant effect on the flow at this scale, a strong similarity with microgravity flows exists. Innovations sought include but are not limited to the following:

- Understanding of fluid mechanics underlying the operations of microfluidic devices crucial to their successful operation and continued miniaturization; and

- Tools for prediction, measurement, and control of fluid flow in microchannels and microchannel network.
Models of Cellular Behavior

The simplest living cell is so complex that models may never be able to provide a perfect simulation of its behavior, however, even imperfect models could provide information that could shake the very foundations of biology. We are now at the point where we can consider models of molecular, cellular and developmental biological systems that, when coupled to experiments, result in an increased understanding of biology. Quantitative models of cellular processes require. Innovations sought include but are not limited to the following:

- New methods for better handling of large numbers of coupled reactions, increases in computing power, and the ability to transition among different levels of resolution associated with quantitative models of cellular processes; and
- Development of models to form the basis of tools to aid in optimization of existing biological systems and design of new ones, enabling engineers to evolve biological systems by rounds of variation and selection for any function they choose.

Functional Imagery

Research on-orbit has demonstrated that the microgravity environment affects the skeletal, cardiovascular, and immune systems of the body. Few of the investigations to date examined functional changes due to microgravity at either the cellular or molecular scale. NASA, therefore, seeks innovations that would lead to an enhanced capability to image functioning biological systems at either length scale. All proposals should recognize the power, volume, and mass constraints of orbital facilities. Examples of possible innovations include but are not limited to the following:

- Development of novel fluorophores that tag proteins mediating cellular function, particularly those that can be excited using solid-state lasers;
- Systems that can simultaneously image multiple fluorophores following different processes at standard video frame rates;
- Devices that enable three-dimensional imagery of the sample; and
- Imaging hardware that can follow a metabolic process in a turbulent system.

Understanding Living Systems Through Microgravity Fluid Physics

Developing strategies for long-duration space flight requires an understanding of the effects of the microgravity environment on biological processes. Interdisciplinary fundamental and applied research is required in biology, physiology, and microbiology to human, and microbial systems from the standpoint of physics. Of particular interest are studies with technology development that develop theoretical, numerical, and/or experimental understanding of the effects of acceleration, and other factors in microgravity environments on these systems. Exploring the effects of Martian and lunar gravity and the quasi-steady, oscillatory, and transient accelerations that are typical of a space laboratory are of great interest, as well as fundamental studies with technology development of acceleration sensitivity. The knowledge obtained should contribute to related agency activities, such as the development of self-sustaining ecosystems and treatment of bacterial infection in space. Moreover, we expect that the knowledge and technologies derived will also provide ground-based economic and societal benefits. Major research disciplines include the fluid transport in microbiology, human physiology, hematology, and drug delivery systems. Innovations are sought in a number of areas.
Delineation of the effects of acceleration and environment at the macro- and microscale levels on processes such as bacterial growth, growth rates, resistance to antibiotics and disinfectants, interactions among microbes, microbial locomotion and interaction with the surrounding fluid or solid medium, transport through cell membranes, electro-osmotic flows, and cytoplasmic streaming, as well as quantification of metabolic processes and other phenomena that permit the examination of these problems:

- Effects of bulk fluid flows on biofilms and liposome formation.
- Transendothelial transport.
- Microscale modeling of fluid flows and mass transfer for drug delivery systems.

Sub Topics:
Understanding and Utilizing Gravitational Effects on Plants and Animals Topic B2.01
This subtopic area focuses on technologies that support the NASA Fundamental Biology Program in understanding the effects of gravity on plants and animals. The program supports investigations into the ways in which fundamental biological processes function in space, compared to their function on the ground. Given the Exploration Initiative newly assigned to NASA, this area of work and discovery is important to achieve the goals to explore the planets and allow plant, animal, and human habitation. To conduct these investigations, the program supports both ground and space flight research. The improved understanding of the role of gravity on plants requires innovative support equipment for observing, measuring, and manipulating the responses of plants to environmental variables. Areas of innovative technology development include:

- Measuring the atmospheric and radiation environment and optimizing the lighting and nutrient delivery systems for plants;
- Storage, transportation, maintenance, and in situ analyses of seeds and growing plants;
- Sensors with low power requirements and low mass to monitor the atmosphere and water (nutrient) environment, as well as automated control and data logging systems for the experiment containers to measure performance indicators, such as respiration (whole plant, shoot, root), evapotranspiration, photosynthesis, and other variables in plants;
- Data analysis and control;
- Modular seeding and/or planting units to minimize labor;
- Sensors for atmospheric, liquid, and solid analyses, including atmospheric and liquid contaminants, such as ethylene and other biogenic compounds, as well as analyses of hydroponic and solid media for N, P, K, Cu, Mg, and micronutrients;
- Remote sensors to identify biological stress; and
- Expert control systems for environmental chambers.
The improved understanding of the role of gravity on animals requires innovative instrumentation that tracks and analyzes from organism development, including gametogenesis through fertilization, embryonic development and maturation, through ecological system stability. Technologies may incorporate a variety of processes such as metabolism and metabolic control, through genetic expression and the control of development. Of particular interest are technologies that require minimal power and can noninvasively measure physical, chemical, metabolical, and developmental parameters. Such measurements will ultimately be made in environments at one or more of several gravity ranges, e.g., "microgravity" (0.01 to 0.000001 g), "planetary" gravity (1 g ; 0.38 g or 0.12 g) or hypergravity (up to 2 g). Refined and stable measurements, however, are as important as gravity independence. Of interest are sustained instrument sensitivity, accuracy and stability, and reductions in the need for frequent measurement standardization. Parameters requiring measurement include pH, temperature, pressure, ionic strength, gas concentration (O₂, CO₂, CO, etc.), and solute concentration (e.g., Na⁺, K⁺, etc.). In the case of new techniques and instruments, a clear path toward miniaturization, reduction in power demands and increased space worthiness should be identified. Technologies applicable to plant, microorganism, and animal study applications include the following areas:

- Live support and energy management;
- Expert data management systems;
- Capabilities for specimen storage, manipulation and dissection;
- Video-image analysis for specimen (cell, animal, plant) health and maintenance;
- Sensors for primary environmental parameters and microbial organisms; and
- Electrophysiology sensors, biotelemetry systems and biological monitors carried on spacecraft.

Sub Topics:

 Biological Instrumentation Topic B2.02

The Fundamental Biology (FB) Program is the Agency lead for biological research and biological instrumentation and technology development, and focuses on research designed to develop our understanding of the role of gravity in the evolution, development, and function of biological processes. Increasingly, the research thrusts are directed at incorporating the most advanced technologies from the fields of cell and molecular biology, genomics, and biotechnology, to provide researchers with the most up-to-date methods to conduct their biological research. For these requirements, the capability to perform autonomous, in situ acquisition, and preparation and analysis of samples to determine the presence and composition of biological components is a highly desired objective. As the size of flight payloads becomes increasingly smaller, and information technologies permit smarter and more independent payload and device control and management, the realization of completely autonomous in situ biological laboratories (ISBL) on spacecraft platforms and planetary surfaces will become more desirable.

Biological and biomolecular, microbiological, and genomic research is enabling unprecedented insight into the structure and function of cells, organisms, and subcellular components and elements, and a window into the inner workings and machinations of living things. Techniques and technologies, which have evolved from the microelectronics and biological revolutions, have permitted the emergence of a new class of instruments and devices. Many devices, techniques, and products are now available or emerging, which allow measurement, imaging, analysis, and interpretation of the biological composition at the molecular level, and which permit determination of DNA/RNA and other analytes of interest. Advances in information systems and technologies, and
bioinformatics, provide the capability to understand, simulate, and interpret the large amounts of complex data being made available from these biological-physical hybrid systems. These synergistic relationships are facilitating the development of revolutionary technologies in many areas.

Biological instrumentation technologies to support FB objectives are grouped into the solicited categories below.

**Biological Sample Management and Handling:**

- Technologies for remote, automated biosample and biospecimen collection, handling, preservation/fixation, and processing; and
- Modular, embeddable systems and subsystems capable of supporting a variety of tissue, liquid, and/or cellular specimens, from a wide range of biological subjects, including cells, nematodes, plants, fish, avians, mice, rats, and humans.

**In situ Measurement and Control:**

- Technology development for sensors, signal processors, biotelemetry systems, sample management and handling systems, and other instruments and platforms for real-time monitoring and characterization of biological and physiological phenomena.

**Genomics Technologies:**

- Technologies to enhance and augment research in genomics, proteomics, cell and molecular biology, including molecular and nanotechnologies, cDNA arrays, gene array technologies, and cell culture and related habitat systems.

**Bio-Imaging Systems:**

- Advanced, real-time capabilities for visualization, imaging, and optical characterization of biological systems. Technologies include multidimensional fluorescent microscopy, spectroscopy systems, and multi- and hyperspectral imaging.

**Biological Information Processing**

- Capability for automated acquisition, processing, analysis, communication, and archival and retrieval of biological data, and interface and transfer to advanced bioinformatics and biocomputation systems.

**Integrated Biological Research Systems and Subsystems**
Integrated, experiment- and subject-specific biolaboratory modules and systems, providing complete flight prototype capability to support the above five categories.

Sub Topics:
Understanding and Utilizing Gravitational Effects on Molecular Biology and for Medical Applications Topic B2.03

Microgravity allows unique studies of the effects of gravitational effects on cell and tissue development and behavior. These studies use novel and advanced technologies to culture and nurture cells and tissues. Additionally, the ability to manipulate and/or exploit the form and function of living cells and tissues has significant potential to enhance the quality of life on Earth and in space through novel products and services, as well as through new science knowledge generated and communicated. This capability may lead to new products and services for medicine and biology. Current space research includes the development of space bioreactors for culturing fragile cells, which has applications in biomedical and cancer research; tissue engineering systems which take advantage of microgravity to grow 3-D tissue constructs; testing the effectiveness of drugs and biomodulators on growth and physiology of normal and transformed cells, and methods for measuring specific cellular and systemic immune functions of persons under physiological stress. Biotechnology research systems also are being developed for microgravity research on the International Space Station and future space-based laboratories. Studies of this nature are critical to our understanding of how the space environment affects astronaut health, and for maintaining a healthy environment for astronauts during missions of exploration.

Specific areas of interest are:

- New methods for culturing mammalian cells in bioreactors, including advanced bioreactor design and support systems; microprocessor controllers; and miniature sensors for measurement of pH, oxygen, carbon-dioxide, glucose, glutamine, and metabolites. Neural fuzzy logic network systems for the control of mammalian cell culture systems. Methods to minimize biofilm formation on fluid-handling components, sensors and bioreactors. Spectroscopic and biochemical analysis of biofilm formed in bioreactors. Micro-scale bioreactors for biomonitors of radiation and other external stressors.

- Technologies that allow automated biosampling and bio-specimen collection, handling, preservation/fixation, and processing in cellular systems. Methods for separation and purification of living cells, proteins, and biomaterials, especially those using electrokinetic or magnetic fields that obviate thermal convection and sedimentation, enhance phase partitioning, or use laser light and other force fields to manipulate target cells or biomaterials.

- Techniques or apparatus for macro-molecular assembly of biological membranes, biopolymers, and molecular bio-processing systems; bio-compatible materials, devices, and sensors for implantable medical applications including molecular diagnostics, in vivo physiological monitoring and microprocessor control of prosthetic devices.

- Methods and apparatus that allow microscopic imaging including hyperspectral fluorescent, scattering and absorption imaging, and biophysical measurements of cell functions; effects of electric or magnetic fields, photoactivation, and testing of drugs or biocompatible polymers on live tissues. Integrated instrumentation for separation and purification of RNA, DNA, and proteins from cells and tissues.

- Quantitative applications of molecular biology, fluorescence imaging and flow cytometry, and new methods for measurement of cell metabolism, cytogenetics, immune cell functions, DNA, RNA, oligonucleotides, intracellular proteins, secretory products, and cytokine or other cell surface receptors. Small scale mass
spectrometers. Means to enhance and augment genomics/proteomics techniques, including molecular and nano-scale tools. Development of novel fluorophores that tag proteins mediating cellular function, particularly those that can be excited using solid-state lasers.

- Micro-encapsulation of drugs, radiocontrast agents, crystals, and development of novel drug delivery systems wherein immiscible liquid interactions, electrostatic coating methods, and drug release kinetics from microcapsules or liposomes can be altered under microgravity to better understand and improve manufacturing processes on Earth.

- Miniature bioprocessing systems that allow for precise control of multiple environmental parameters such as low level fluid shear, thermal, pH, conductivity, external electromagnetic fields, and narrow-band light for fluorescence or photoactivation of biological systems.

- Novel low temperature sample storage methods (-80°C and -180°C) and biological sample preservation methods. Methods to reduce launch/return mass of biological samples and support reagents.

- DNA template for molecular wiring that permits macro- to nanoscale connectivity. Nanoscale electronics based on self-assembling protein-based molecular structures.

- Computer models and software that better handle large numbers of coupled reactions in cell science systems.

- Tools and techniques to study mechanical properties of the cell: subcellular rheology, cell adhesion, affect of shear flow, affects of direct mechanical perturbation. Tools and techniques to facilitate multiple simultaneous probing and analyzing of a cell or sub-cellular region (examples include atomic force microscope coupled with microelectrode or micro-Raman, Optical trap)

- Nanosensors for sub-cellular measurements: ultra-microelectrodes with less than 1µ diameter including cladding, nanoparticle reporters that provide spectroscopic information, and other novel intracellular sensor devices to provide spectroscopic data on intracellular processes.

Sub Topics:
Environmental Control of Spacecraft Cabin Atmosphere Topic B3.01

Advanced life support and thermal systems are essential to enable human planetary exploration. Requirements include safe operability in micro- and partial-gravity, ambient and reduced-pressure environments, high reliability, minimal use of expendables, ease of maintenance, and low-system volume, mass and power. Innovative, efficient, and practical concepts are needed for regenerative air revitalization, ventilation, temperature, and humidity control. Advanced active thermal control technologies in the areas of heat acquisition, transport, and rejection are also needed. In addition to long-duration space applications, innovative approaches that could have terrestrial application are encouraged. Proposals should include estimates for power, volume, mass, logistics, and crew time requirements as they relate to the technology concepts. More information on advanced life support systems can be found at [http://advlifesupport.jsc.nasa.gov](http://advlifesupport.jsc.nasa.gov) [3]. Innovations are solicited in the areas that follow below.

**Air Revitalization**

Oxygen, carbon dioxide, water vapor, and trace gas contaminant concentration, separation, and control techniques for space vehicle applications (International Space Station, Moon, or Mars transit vehicle) and long-duration
• Separation of carbon dioxide from a mixture primarily of nitrogen, oxygen, and water vapor to maintain carbon dioxide concentrations below 0.3% by volume.

• The recovery of oxygen from carbon dioxide with some focus on an approach to deal with the by-products of the process, if any, keeping in mind the above mass, power, and expendables goals.

• Removal of trace contaminant gases from cabin air and/or a gas product stream from another system (e.g., water reclamation, waste management, etc.) using advanced regenerative sorbent materials, improved oxidation techniques, or other methods.

• Alternate methods of storage and delivery of atmospheric gases to reduce mass and volume and improve safety.

• Novel approaches to integrating atmosphere revitalization processes to achieve energy and logistics mass reductions.

• Alternate methods of atmospheric humidity control that do not use liquid-to-air heat exchanger technology (dependent on the spacecraft active thermal control system) or mechanical refrigeration technology.

Environmental Control and Thermal Systems

Thermal control is an essential part of any space vehicle, as it provides the necessary thermal environment for the crew and equipment to operate efficiently during the mission. A primary goal is to provide advanced thermal system technologies, which are highly reliable and possess low mass, size, and power requirements (i.e., reduced cost) for spacecraft cabin temperature and humidity control. Offerors should indicate explicitly how their research is expected to improve the mass, power, volume, safety, reliability, and/or design and analyses techniques for future thermal control systems for human space missions as compared to state-of-the-art technologies. Areas in which innovations are solicited include the following:

• Liquid-to-liquid heat exchangers that provide two physical barriers preventing interpath leakage.

• Advanced technologies to control cabin temperature and humidity in microgravity. Condensate that is collected must be able to be recovered and transported to the water recovery system.

• Technologies to inhibit microbial growth on wetted surfaces. Applications include condensate collection surfaces for humidity control and heat exchangers resident in water loops.

• Lightweight, versatile and efficient heat acquisition devices including flexible cold plates. Devices would provide cooling to electronics, motors, and other types of heat producing equipment that is internal to the cabin.

• Lightweight, controllable evaporative heat rejection devices that can operate in environments ranging from space, Mars’ atmosphere, and Earth’s atmosphere.

• Alternative heat transfer fluids that are non-toxic, non-flammable, and have a low freezing temperature.

• Energy storage devices that maintain the integrity of food or science samples. Temperatures of -20°C, -40°C, -80°C or -180°C are desired.

• Highly accurate, remotely monitored, in situ, non-intrusive thermal instrumentation.
• Advanced analytical tools for thermal and fluid systems design and analyses, which are amenable to concurrent engineering processes.

**Component Technologies**

Energy efficient, low mass, low noise, low vibration or vibration isolating, fail-safe and reliable components for handling gases and fluids applicable to spacecraft environmental control and air revitalization, including actuators, fans, pumps, compressors, coolers, tubing, ducts, fittings, tanks, heat exchangers, couplings, quick disconnects, and valves that operate under varied levels of gravity, pressure, and vacuum. Mass flow monitoring and control devices that have similar attributes and that are easily calibrated and serviced.

Sub Topics:
Space Human Factors and Human Performance Topic B3.02

The long-term goal for this subtopic is to enable planning, designing, and carrying out human space missions of up to 5 years with crew independence, without resupply and without real-time communications to Earth. Specifically, this subtopic's focus is the development of innovations in crew equipment; and the development of technologies for assessment, modeling, and enhancement of human performance; and the development of design tools for engineers to incorporate human factors engineering requirements into hardware and software.

Proposals are solicited that seek to develop technologies that address these specific needs:

• Monitoring and maintaining human performance nonintrusively. Specifically, minimally invasive and unobtrusive devices and techniques to monitor the behavior and performance (physical, cognitive, perceptual, etc.) of individuals and teams during long-duration space flights or analog missions. Technologies to track locations of individuals within habitats, and report on physiological or other state information. Methods and models for human performance prediction, including physical performance, as affected by encumbrances of clothing, space suits, etc.

• Predictive modeling of effects on the crew due to potential spacecraft environments and operational procedures. Develop computational models of the crew environment and of human performance and behavior to simulate the effects of factors that contribute to (or degrade) long-term performance capabilities. Such models of the environment, individual, and group behaviors and performance can be used to simulate and explore the conditions that influence human performance (e.g., fatigue, noise, CO₂, microgravity, group dynamics, etc.). Such capabilities would include digital models of human operators and routine and emergency tasks that interact in the context of the long-duration human exploration environment.

• Tools to aid in design and evaluation of human-system interfaces for speed, accuracy, and acceptability in a cost-effective and reliable manner: Automated analysis of computer-user interfaces for complex display systems to conduct objective review of displays and controls, and to determine compliance with guidelines and standards. Quantitative measures of the effectiveness of user interfaces to be used for task-sensitive evaluations.

• Tools that facilitate the user interface design for human computer interfaces, and for facilitators, such as procedures, labels, and instructions. Tools should assist the designer in incorporating contextual information such as the user’s task, the user’s knowledge, and the system limitations.
• Tools to build just-in-time system and operational information software to aid human users conducting routine and emergency operations and activities. Such tools might include effective and efficient job aids (e.g., "intelligent" manuals, checklists, warnings) and support for designing flexible interfaces between users and large information systems. Methods for development of ‘facilitators’ (procedures, labels, etc.) adapted for the development of space vehicle and payload applications.

• Rapid don/doff launch-and-entry and survival suit: a personal ambient environment and individual health and safety protective garment system with antigravity protection, metabolic-cooling and heating, breathing air, thermal protection, zero-atmospheric pressure protection, land and water survival gear, etc. An integrated suit (providing all desired protective functions), as well as a modular suit (allowing user to select ahead of time any of the array of required protection and survival subsystems) approach should be considered. The emphasis for this innovation should be to achieve the desired levels of protection for space travel, as well as for survival on Earth after landing at an unplanned site—all while affording rapid donning in microgravity through one-gravity (1g) environments on the order of 60 s and rapid doffing on the order of 300 s or less. Include accommodation for using the suit for ill, injured, or incapacitated crewmembers, meeting the don/doff goals while providing access for medical monitoring and ongoing treatment.

Sub Topics:
Human Adaptation and Countermeasures Topic B3.03

In order for humans to live and function safely and efficiently in space or in the hypogravity of the Moon (1/6g) or Mars (3/8g), a good understanding of the effects of micro- and hypogravity and other factors associated with the space environment on human physiology and human responses to the space and extraplanetary environments is required. A variety of countermeasures must be developed to oppose the deleterious changes that occur in space and upon subsequent exposure to other gravitational fields. The ability to monitor the effectiveness of countermeasures and alterations in human physiology during space exploration missions, particularly when several countermeasures are used concurrently, is equally important. This subtopic seeks innovative technologies in several very specific key areas.

As launch costs relate directly to mass and volume, instruments and sensors must be small and lightweight with an emphasis on multi-functional capabilities. Low power consumption is a major factor, as are design enhancements to improve the operation, design reliability, and maintainability of these instruments in the environment of space and on planetary surfaces. As the efficient use of time is extremely important, innovative instrumentation setup, ease of usage, improved astronaut (patient) comfort, noninvasive sensors, and easy-to-read information displays are also very important considerations. Extended shelf-life and ambient storage conditions of consumables are also key necessities. Ability to operate in 0g, 1g, and 3/8g become more important as we push for future human Moon and Mars missions.

Immersive Virtual Scene Display System

Development of an immersive visual display system is required to be interfaced with treadmill exercise devices. This system would not be head-mounted but would be free standing and provide at least a 180° field of view. This visual display would allow visual flow patterns to be displayed to a non-encumbered subject during inflight or on-surface treadmill exercise. Ultra-long duration missions to the Moon or Mars will especially benefit from such technology that encourages crew to spend more time exercising by enriching the environment and contribute to psychological well being by mimicking the terrestrial exercise experience.

Measurement of Emboli in the Brain
A small Doppler ultrasound device (need not be oxygen compatible), emboli recognition system/software, and solid-state recorder of detected events. This would be worn in a fashion similar to a Holter monitor and help to monitor blood clots in the brain for those at risk for embolic stroke. This is especially valuable for ensuring the safety of Extra-Vehicular Activity (EVA) on planetary surfaces, as well as during orbital flight.

**Noninvasive Pharmacotherapy and Monitoring**

Development of innovative technologies resulting in noninvasive methods for diagnosis, treatment, and therapeutic drug monitoring is needed to facilitate effective pharmacotherapy of humans in space. Many questions remain about the effectiveness of pharmaceuticals in micro- and hypogravity environments, which may interfere with their activity by sensitizing or desensitizing the crew member or interfering in other ways with the desired physiological effect.

**MEMS-Based Human Blood Cell Analyzer**

Development of a small, automated, micro- and hypogravity capable, lightweight, low power instrument that will analyze a small sample (microliter quantity) of human whole blood and provide a complete blood cell count (RBC, WBC, platelet, hemoglobin concentration, hematocrit, WBC differential, and calculated RBC indices) that correlates with traditional ground-based impedance or light-scattering technologies is needed. Likely devices based on MEMS will employ a biocompatible combination of microfluidics, micromechanics, micro-optics, microelectronics, and data telemetry capabilities in an integrated handheld package with a simple, user-friendly operator interface. Such technologies will be critical to the implementation of future missions beyond low-Earth orbit to the Moon or Mars. Proper medical care and valuable research contributions will be dependent on such technologies in these exploration class missions.

**Human-Worn Whole Body Biomechanical and Movement Analysis Suit**

A whole-body suit and analysis system worn by human subjects is needed, which records and measures biomechanical movements and biomechanical characteristics in order to provide an assessment of total body physical activity during human space missions, especially missions to hypogravity environments such as the Moon or Mars. Measurements to be made and recorded would include upper and lower limb segment displacements along with related joint angular velocities and accelerations. The system would allow entry of limb segment and trunk mass and center-of-mass data specific to the individual wearing the suit and then would provide data analysis related to work and power across different body segments and for the whole body based on analytical algorithms. Other capabilities include storage of raw data and the ability to download the data to other computer-based storage and data analysis systems through either hardwired connections or via telemetry. Many differences may be noted in the way humans move in micro- and hypogravity environments. These differences may suggest better ways to perform work or to design tools, workstations, or procedures for accomplishing critical tasks in the future beyond low-Earth orbit missions.

**Body Composition Hardware for Spaceflight**

Development of on-orbit instrumentation for determining body composition. Specific parameters of interest include lean body mass, total fat mass, and total body water. Validation data will be required using the current gold-standard techniques in this field. This information will be used in conjunction with nutritional status protocols to assess crew health. The effects of the hypogravity environment of planetary surfaces on body composition are not known. Any future mission to the Moon or Mars will certainly measure these changes to detect and combat potential adverse changes. Such an instrument must work in 0g, 1/6g, and 3/8g environments.
Device for Providing Increased Neuromuscular Activation During Spaceflight

Astronauts returning from spaceflight exhibit post-flight postural and gait instabilities that are a result of neural adaptation to microgravity. A small, lightweight countermeasure device is required to stimulate somatosensory receptors on the plantar surface of the feet during in-flight exercise with the goal of increasing neuromuscular activation and enhancing sensorimotor integration. This system would integrate with in-flight exercise hardware and coupled with visual stimulation systems would allow a more complete sense of immersion to enhance in-flight postural and locomotor training.

Sub Topics:
Food and Galley Topic B3.04
As NASA begins to look beyond low-Earth orbit and to plan for future exploration missions, such as to the Moon or Mars, new food science technologies will be needed. The impossibility of regularly resupplying a Mars crew means that the prepackaged shelf-stable food, ingredients, and equipment to provide a complete diet for six crewmembers for more than three years will have to be carried with them. As the crew remains on the Moon or Mars surface, crops will be grown to supplement the crew's diet, using plants to revitalize the air and water supply. Methods are needed, therefore, for processing potential food crops. Areas in which innovations are solicited follow below.

Long-Duration, Shelf-Stable Food

An initial trip to the Moon or Mars will require a stored food system that is nutritious, palatable, and provides a sufficient variety of foods to support significant crew activities on a mission of at least three years duration. Development of highly acceptable, shelf-stable food items that use high-quality ingredients is important to maintaining a healthy diet. Foods should maintain safety, acceptability, and nutrition, for the entire shelf life of 3–5 years. Shelf-life extension may be attained through new food preservation methods and/or packaging. Once on the lunar or planetary surface, it may be possible to use bulk packaging of meals or snack items. These food products will require specialized processing conditions and packaging materials.

Advanced Packaging

The current food packaging technologies represent a potentially significant trash-management problem for exploration-class missions to the Moon or Mars. New food packaging technology is needed that minimizes waste by using packaging with less mass and volume and/or by using packaging that is biodegradable or recyclable. Another opportunity would be development of a packaging material that can readily be reused by the crew to make objects of value to the space flight mission.

Food Processing

Advanced life-support systems, which use chemical, physical, and biological processes, are being developed to support future human planetary exploration. One such system might grow crops hydroponically and then process them into edible food ingredients or table-ready products. Variations in crop quality, crop yield, and nutrient content may occur over the course of long-duration missions, posing further requirements to the food processing and storage system. Such variations might affect the shelf stability and functional properties of the bulk ingredients and ultimately, the quality of the final food products.

Equipment to process crops on missions to the Moon and Mars should be highly reliable, safe, automated, and should minimize crew time, power, water, mass, and volume. Equipment for processing raw materials must be
suitable for use in hypogravity (e.g., 1/6g on Moon, 3/8g on Mars) and in hermetically sealed habitats. Some potential crops for advanced life-support systems include minimally processed crops such as lettuce, spinach, carrots, tomatoes, onions, cabbage, bell peppers, strawberries, fresh herbs, and radishes. Other baseline crops that require processing would be wheat, soybeans, white potatoes, sweet potatoes, peanuts, dried beans, rice, and tomatoes. There is a need to develop one or more pieces of food processing equipment for each of these crops.

**Food Safety**

Assurances of food quality and food safety are essential components in the maintenance of crew health and well-being. Food quality and safety efforts should be focused on monitoring the shelf stability of processed food ingredients and on identification and control of microbial agents of food spoilage, including the development of countermeasures to ameliorate their effects. Determination of radiation on crop functionality and the stored food system shelf life is also needed in the development of the food system. For all food production and processing procedures, Hazard Analysis Critical Control Points (HACCP) must be established.

Sub Topics:

Biomedical R&D of Noninvasive, Unobtrusive Medical Devices for Future Flight Crews Topic B3.05

Human presence in space requires an understanding of the effects of the space environment on the physiological systems of the body. The objective of this subtopic is to sponsor applied research leading to the development of noninvasive, unobtrusive medical devices that will mitigate crew health, safety, and performance risks during future flight missions to the Moon and Mars. Medical diagnostic and monitoring devices are critical for providing health care and medical intervention during missions, particularly extended-duration spaceflight to the Moon and Mars. Of particular interest are devices with minimized mass, volume, and power consumption, and capable of multiple functions. Design enhancements that improve the operation, design reliability, and maintainability of medical devices in the space environment are also sought. Of additional consideration are innovative instrumentation automation, ease of use, improved astronaut comfort, and easy-to-read information displays.

Major research disciplines include endocrinology, hematology, microbiology, muscle physiology, pharmacology, drug delivery systems, and mechanistic changes in neurovestibular physiology.

Innovations in the following areas are sought:

- Biomedical monitoring, sensing, and analysis (including the acquisition, processing, communication, and display) of electrical, physical, or chemical aspects of a human's health or physiological state.
- Instrumentation to be used for in-flight and ground-based studies for reliable and accurate noninvasive monitoring of human physiological functions such as the musculoskeletal, neurological, gastrointestinal, and hematological systems.
- Noninvasive biosensors for real-time monitoring of blood and urine chemistry including gases, calcium ions, electrolytes, proteins, lipids, and hormones.
- In-flight specimen analysis to evaluate physiological, metabolic, and pharmacological responses of astronauts.
- Instrumentation to provide quantitative data to establish the effectiveness of an exercise regimen in ground-
based research, and to measure bone strain in the hip, heel, and lumbar spine during exercise.

- Assessment of gas bubble formation or growth in the body after in-flight or ground-based decompression, and to prevent or minimize associated decompression sickness.

- In-flight assessment of the metabolism of proteins, carbohydrates, lipids, vitamins, and minerals.

- Smart sensors capable of sensor data processing and sensor reconfiguration.

- Small, portable, medical imaging diagnostic instrumentation.

Sub Topics:
Waste and Water Processing for Spacecraft Advanced Life Support Topic B3.06

Regenerative closed-loop life-support systems will be essential to enable human planetary exploration. Efforts are currently focused on missions ranging from a return to the Moon and through an initial Mars mission, including using the International Space Station as a test bed for research and technology validation. These future life-support systems must provide additional mass balance closure to further reduce logistics requirements and to promote self-sufficiency. Requirements include safe operability in micro- and partial-gravity, ambient and reduced-pressure environments, high reliability, minimal use of expendables, ease of maintenance, and low-system volume, mass, and power. Recovery of useful resources from liquid and solid wastes will be essential. Innovative, efficient, practical concepts are needed in all areas of resource recovery processes, providing the basic life-support functions of water reclamation and waste management. In addition to these long-duration space applications, innovative regenerative life-support approaches that could have terrestrial application are encouraged. Phase-I proof of concept should lead to Phase-II hardware development that could be integrated into a life-support system test bed. Proposals should include estimates for power, volume, mass, logistics, and crew time requirements as they relate to the technology concepts. More information on advanced life support systems can be found at http://advlifesupport.jsc.nasa.gov [3]. Areas in which innovations are solicited in the following areas:

Water Reclamation

Efficient, direct treatment of wastewater consisting of urine, wash water, and condensates, to produce potable and hygienic waters.

- Physicochemical methods for primary treatment to reduce the total organic carbon concentration of the wastewater from 1000 mg/L to less than 50 mg/L and/or the total dissolved solids from 1000 mg/L to less than 100 mg/L.

- Post-treatment methods to reduce total organic carbon from 100 mg/L to less than 0.25 mg/L in the presence of 50 mg/L bicarbonate ions, 25 mg/L ammonium ions and 25 ppm other inorganic ions.

- Methods for the phase separation of solids, gases, and liquids in a microgravity environment that are insensitive to fouling mechanisms.

- Methods for the treatment of brine solutions including water recovery.

- Methods to eliminate or manage solids precipitation in wastewater lines.

- Disinfection technologies, both for potable water storage and point-of-use. Development of residual disinfectants that can be consumed by crewpersons. Techniques to minimize or eliminate biofilm or
microbial contamination from potable water systems and water treatment systems, including fluid handling components such as pipes, tanks, flow meters, check valves, regulators, etc.

**Solid Waste Management**

Concepts and methods to safely and effectively manage wastes for all future human space missions are required to perform the following functions: acceptance/collection, transport, storage, processing, disposal, and associated monitoring and control. Actual types and quantities of wastes generated during missions are highly mission dependent. For sizing purposes, however, the "maximum" waste streams have been estimated as follows, based on a 6-person crew: trash (0.56 kg/day), food packaging (7.91 kg/day), human fecal wastes (0.72 kg/day dry, 3.0 kg/day wet), inedible plant biomass (2.25 kg/day), paper (1.16 kg/day), tape (0.25 kg/day), filters (0.33 kg/day), water recovery brine concentrates (3.54 kg/day), clothing (3.6 kg/day), and hygiene wipes (1.0 kg/day). Wastes can also be assumed to be source-separated because this requirement has been identified for a majority of waste processing equipment:

- Microgravity- and hypogravity-compatible solid waste management technologies;
- Volume reduction of wet and dry solid wastes;
- Small and compact fecal treatment and/or collection system;
- Water recovery from wet wastes (including human fecal wastes, food packaging, brines, etc.);
- Stabilization, sterilization, and/or microbial control technologies to minimize or eliminate biological hazards associated with waste;
- Storage devices needed for the containment of solid waste that incorporates an odor abatement technology.
- Microgravity-compatible technologies for the jettison of solid wastes in space; and
- Other novel waste management technologies for storage, transport, processing, resource recovery, and disposal that satisfy a critical need for the referenced missions (e.g., recovery of critical resources).

**Component Technologies**

Energy efficient, low mass, low noise, low vibration or vibration isolating, fail-safe and reliable components for handling fluids, slurries and/or solids applicable to wastewater treatment and solid waste management. Components include actuators, pumps, conveyors, compressors, coolers, tubing, tanks, bins, fittings, couplings, quick disconnects, and valves which operate under varied levels of gravity, pressure, and vacuum. Mass flow monitoring and control devices that have similar attributes and that are easily calibrated and serviced.

**Sub Topics:**
Biomass Production for Planetary Missions Topic B3.07

The production of biomass (in the form of edible food crops) in closed or nearly-closed environments is essential for the future of long-term planetary exploration and human settlement in Moon and Mars base applications. These technologies will lead not only to food production, but also to the reclamation of water, purification of air, and recovery of inedible plant resources in the comprehensive exploration of interplanetary regions. Innovations are solicited in the following areas:
Crop Lighting

- Sources for plant lighting such as, but not limited to, light emitting diodes, high-efficiency lamps or solar collectors suitable for orbital space, interplanetary space, lunar or Martian surface;
- Transmission and distribution systems for plant lighting including, but not limited to, luminaries, light pipes, fiber optics, and optical filters; and
- Heat removal techniques for the plant growth lighting such as, but not limited to, water-jackets, water barriers, and wavelength-specific filters and reflectors.

Water and Nutrient Management Systems

- Technologies for production of crops using hydroponics or solid substrates suitable for orbital space, interplanetary space, lunar or Martian surface;
- Water and nutrient delivery systems;
- Regenerable media for seed germination plant support; and
- Separation and recovery of usable minerals from wastewater and solid waste products for use as a source of mineral nutrients for plant growth.

Environmental Monitoring and Control

Innovations in monitoring and control approaches for plant-production environments, including temperature, humidity, gas composition, and pressure. Gases of interest could include carbon dioxide, oxygen, nitrogen, water vapor, and ethylene. Development of autonomous control systems integrated with predictive modeling for crop production optimization.

Mechanization and Automation

Innovations in propagation, seeding, and plant biomass processing. Plant biomass processing includes harvesting, separation of inedibles from edibles, cleaning and storage of edibles (seed, vegetable, and tubers) and removal of inedibles for resource-recovery processing.

Facility or System Sanitation

Methods or technologies to identify and prevent excessive build-up of microorganisms within closed plant production systems with emphasis on nutrient delivery systems. Processes to insure pathogen free products through HACCP food safety protocols.

Health Measurement

Remote, direct, and indirect methods of measuring plant health and development using canopy (leaf) spectral
signatures or fluorescence to quantify parameters such as rate of photosynthesis, transpiration, respiration, and nutrient uptake. Data acquisition should be noninvasive or remotely sensed using spectral, spatial, and image analysis. System modeling and decision making algorithms may be included.

Sensor Technologies

Innovations are required for development of sensors using miniature, micro- and nanotechnologies for evaluation of the physical and biological parameters in all phases of biomass production. Such sensor arrays include wide-ranging applications of gas and liquid sensors, as well as photo sensors and microbiological community indicators. Innovations are required in all phases of sensor development, including biomass fouling, miniaturization, wireless transmission, multiple-phase and multiple-tasking sensors, and interface with artificial intelligence (AI) data collection systems.

Flight Equipment Support

Innovative hardware and components developed to support life support and biological research in the Space Shuttle, on board the International Space Station, and exploration missions to the Moon, Mars, and beyond. Biomass production investigations using flight-support equipment will be required to meet the demanding requirements for space flight operations, meet the rigorous scientific data collection standards, and produce plants in a controlled environment for research purposes and food. Innovative methods to perform in-flight biomass analyses, including equipment miniaturization, are requested in order to perform remote analyses and to minimize requirements to return in-flight samples. Innovations in whole-package design and in component designs will be required.

Structures

Innovative concepts and designs for autonomous or human tended plant production structures that might be deployed in space habitats, including flight, planetary transit, or planetary surfaces systems. Systems would need to accommodate the capture and distribution of solar light or generated light (e.g., electric lamps) and meet the mass and stowage challenges for spaceflight delivery.

Sub Topics:

Software Architectures and Integrated Control Strategies for Advanced Life Support Systems Topic B3.08
The purpose of this subtopic is to develop advanced control system technologies that can support an integrated approach to the command and control of Advanced Life Support (ALS) for future long-duration human space missions, including a permanent human presence on the Moon and Mars. The control strategies for ALS systems must deal with continuous and discrete processes and with dynamic interactions between subsystems such as air revitalization, water recovery, food production, solids processing, and the crew. The goal of autonomously controlling an ALS system challenges many areas of technology, including distributed data management and control, sensor interpretation, planning and scheduling, modeling and simulation, and validation and verification of autonomous control systems. These various technology areas must eventually be integrated into a coherent system that runs day after day for years and that can effectively interact with crewmembers who place their lives in its hands. The control strategy must be able to reach “across” the system and “down” into its parts to gather all data necessary to achieve its control objectives. Interfaces to crew, ground control, and other spacecraft systems must allow for insight into control strategies, choices, and pending actions and allow for manual control at any level.
The challenges of controlling regenerative life support for an enclosed crew environment involve the ALS goals to minimize expendables, to minimize crew and ground involvement, and to incorporate biological systems for recycling air, water and solids. The interdependence of environmental processing systems, and the need for reducing operations support costs are included. There is a need for the development and evaluation of control architectures and strategies which meet these challenges, both by building on current advances in distributed, modular, object-based protocols, and by new advances in integration of agent technology, planning, and resource management across heterogeneous systems. This includes:

**New Control Strategies for Closed-Loop Systems**

Advanced Life Support consists of a combination of physico-chemical systems with biological systems to recycle air, water, solid waste, plants, and food. The system is closed with respect to hydrogen, oxygen, and carbon in order to reduce the amount of consumable air water and food necessary for extended human presence on other planets. Closed systems and biological systems have different constraints and control paradigms than conventional processes. There is a need for new control algorithms, analyses, strategies, and techniques that can accommodate this architecture.

**Distributed Network Protocols, Including Support for Fieldbus and Intelligent Controllers**

The robustness of the control and data paths for equipment and subsystems is determined by the fieldbus protocols that connect them. Fieldbus protocols have been developed for the special needs of the aerospace and process control industries. There is a need for investigation and adaptation of these protocols, and the development of new protocols to support the type of distributed intelligent systems and networks envisioned for human exploration missions. These protocols need to be robust and fault-tolerant, and to support a large number of heterogeneous systems. Ideally, these protocols should support both local and interplanetary connectivity.

**Development of Ontologies for Communication Among Autonomous Systems or Control Agents**

Human exploration missions involve hundreds of systems developed by dozens of organizations. To develop software that can integrate across these systems and integrate with operations requires the use of common terminology across multiple disciplines. A common taxonomy or common ontology needs to be developed for the types of control problems associated with integrated control of advanced life support systems.

**Software Development Methodologies for Autonomous Systems**

This includes requirements management, testing, performance metrics, and long-term maintenance support, including development for growth and support for model-based simulations. There is a need for new tools to support the development of distributed autonomous control systems throughout the program life cycle. This includes tools for managing prototyping, requirements, design, design knowledge capture, testing, and growth and maintenance across multiple development teams.

**Approaches for Integration of New Controls Technology (both hardware and software) with Existing Legacy Systems**

Some space technologies are relatively mature. New controls technology must be compatible with legacy fieldbuses and operations concepts in addition to providing new functionality. There is a need for tools and development methodologies that can accommodate growth in system functionality.
Fault Detection, Isolation and Recovery (FDIR) Across Multiple Systems; Sharing of Parameters and Data Between Heterogeneous Systems

The majority of FDIR approaches focuses on single subsystems and depend on a homogeneous platform and software architecture, often using a blackboard or shared memory model to share data between modules. There is a need to perform FDIR across multiple heterogeneous systems across networks. Ideally, FDIR should support cooperative efforts between group operations and planetary systems.

Control System Failure Tolerance

Critical systems provide functional redundancy in the case of failure or performance degradation. There is a need for new approaches to providing failure tolerance for both hardware and software components of the control systems. Of particular importance is the reduction of crew time for maintenance, and reduction of dependence on re-supplying hardware, as these are the most expensive constraints on these systems.

Planning and Scheduling

This includes reactions to system faults, supporting adjustments to operations, inventory, and logistics because of planned and unplanned maintenance. There is a need for tools to support development and deployment of applications that support planning and scheduling. Developed applications should support the integration of both planet-side and Earth-side activities.

Development and Integration of Autonomous System and Intersystem Control with Crew and Ground Operations

There is a need for tools, architectures, and technology that can support integration of operations between crew, ground operators, ground applications, and onboard applications.

Development of Architectures that Support a Range of Autonomy, from Fully Autonomous to Fully Manual, with the Corresponding Range of Support for Human Interaction

Autonomous systems for human exploration missions must provide visibility, situational awareness, and an ability to change the level of autonomy based on both situation and human input. As unexpected situations arise that are outside the scope of design, autonomous control systems must interact with crew and ground operators at varying levels of transparency. Unlike Earth-based systems, the planet-side crew will not be subsystem experts and may be isolated from ground support. Local systems must safely and robustly aid the crew in both troubleshooting and nominal operations. There is a need for software architectures and development methodologies, including system and crew modeling, to provide such capabilities.

Sub Topics:
Radiation Shielding to Protect Humans Topic B3.09

Revolutionary advances in radiation shielding technology are needed to protect humans from the hazards of space-radiation during NASA missions. All space-radiation environments in which humans may travel in the foreseeable future are considered, including low-Earth orbit, geosynchronous orbit, Moon, Mars, etc. All radiations are considered, including particulate radiation (electrons; protons; neutrons; alpha; light-to-heavy ions, with particular...
emphasis on ions up to iron; mesons; etc.) and including electromagnetic radiation (ultraviolet, x-rays, gamma rays, etc.). Technologies of specific interest include, but are not limited to, the following:

- Advanced computer codes are needed to model and predict the transport of radiation through materials.
- Advanced computer codes are needed to model and predict the effects of radiation on the physiological performance, health, and well-being of humans in space radiation environments.
- Innovative lightweight radiation shielding materials are needed to shield humans in aerospace transportation vehicles, large space structures such as space stations, orbiters, landers, rovers, habitats, space suits, etc. The materials emphasis should be on non-parasitic radiation shielding materials, or multifunctional materials, where one of the functions is radiation shielding.
- Non-materials and "out-of-the-box" radiation shielding technologies are also of interest.
- Laboratory and space flight data are needed to validate the accuracy of radiation transport codes.
- Laboratory and space flight data are needed to validate the effectiveness of radiation-shielding materials and non-materials solutions.
- Comprehensive radiation-shielding databases and design tools are also sought to enable designers to incorporate and optimize radiation shielding into space systems during the initial design phases.
- Accurate and reliable theoretical and phenomenological models are needed for the collision of radiation ions to generate the input database for transport phenomena. The models that give comprehensive results in a fast manner for broader (preferably whole) ranges of colliding ions, for ion energies from a few mega-electron volts to a few giga-electron volts are desirable. The information needed is as follows:
  - Total, elastic, absorption, and fragmentation cross sections
  - Spectral and angular distributions of producing particles
  - Multiparticle fragmentations
  - Cluster effects
  - Meson production

Sub Topics:
Sensors for Advanced Human Support Technology Topic B3.10

Monitoring technologies are employed to assure that the chemical and microbial content of the air and water environment of the astronaut crew habitat falls within acceptable limits, and that the chemical or biological life support system is functioning properly. The sensors may also provide data to automated control systems.

Significant improvements are sought in miniaturization, accuracy, precision, and operational reliability, as well as long life, real-time multiple measurement functions, in-line operation, self-calibration, reduction of expendables, low
energy consumption, and minimal operator time/maintenance for monitoring and controlling the life-support processes.

- For water monitoring, sensitive, fast response, online analytical sensors to monitor suspended liquid droplets, dispersed gas bubbles, and water quality, particularly total organic carbon.

- Other species of interest include dissolved gases and ions, and polar organic compounds such as methanol, ethanol, isopropanol, butanol, and acetone in water reclamation processes; and particulate matter, major constituents (such as oxygen, carbon dioxide, and water vapor) and trace gas contaminants (such as ammonia, formaldehyde, ethylene) in air revitalization processes. Both invasive and noninvasive techniques will be considered.

- Monitoring of microbial species, especially pathogens, primarily in water, is important. Enabling technologies may include proper sample preparation and handling, with minimal operator effort and minimal or no reagent usage.

- Significant mass savings and ease of use may be enabled by approaches that detect more than one species at a time. Proposals that seek to develop new technologies or combine existing technologies to simultaneously monitor several major constituents and/or trace constituents are of interest.

Sub Topics:
Space Market Driven Research Topic B4.01

The commercial development of space offers enabling benefits to space exploration for NASA. In accordance with the Space Act, as amended, to “seek and encourage to the maximum extent possible the fullest commercial use of space,” NASA facilitates the use of space and microgravity for the development of commercial products and services. The products may use information from in-space activities to enhance an Earth-based effort, or may require in-space use. This subtopic has three goals. The first goal is the commercial demonstration of pivotal technologies or processes, for example, self-calibrating and self-repairing bio-MEMS devices for such uses as monitoring crew health in space along with dual applications on Earth for monitoring biological-physical interfaces. The second goal is the development of associated infrastructure equipment for commercial experimentation and operations in space, or the transfer of these technologies to industry in space or on Earth. An example of this is the automated processes and hardware (robotics), which will reduce crew exposure and time, and which are a priority. The third goal is the commercial research and technologies pursued and developed in the program often have direct applicability to NASA priority mission areas. This dual-use strategy for research and technology has the potential to greatly expand what the NASA scientific and engineering communities can do in advancing exploration mission requirements. All Agency activity in microgravity, including those in life science and microgravity sciences, which lead to commercial products and services as well as benefits to the mission requirements of exploration objectives, are of interest. Below are some specific areas for which proposals are sought.

Biotechnology

This category comprises biotechnology, biomedical, and agricultural instrumentation or techniques that exploit space-derived capabilities or data to support the commercial development of space by the agricultural, medical, or
pharmaceutical industry.

- Portable biological sensors: The need for sensing devices that can detect and identify biological pathogens (airborne or in vivo) is desired to support NASA's mission for a permanent presence of man in space.

- Development of noninvasive health monitoring systems and models: Application to NASA's crew health program for extended duration missions. For example, (1) novel in vitro cell-matrix models for studying the effects of microgravity on human tissue repair and wound healing, (2) novel orga-notypic skin models that simulate physiological changes found in humans under a microgravity environment, and (3) functional models for delineating the MG-inducible or MG-responsive pathways of human tissue angiogenesis (new blood vessel formation).

- Physiological measurement in microgravity of bone growth and the immune system in microgravity.

- Innovative research in plant-derived pharmaceuticals using microgravity.

- Agricultural research, i.e., genetic manipulation of plants using microgravity.

- Instrumentation or technology to explore the use of microgravity in genetic assay, analysis, and manipulation.

- Instrumentation to analyze cell reactor systems and characterize cell structure in microgravity in order to develop enhanced drug therapies that can also be applied to pharmaceutical development and commercialization.

- Innovative techniques for dynamic control and cryogenic preservation of protein crystals.

- Innovations in preparation of protein crystals for x-ray diffraction experiments without the use of frangible materials.

- Innovation of low-technology temperature control chambers requiring little or no power for bringing temperature sensitive experiments up to, or back from, the International Space Station.

Materials Science

Areas in which Materials Science innovations are sought include the following:

- Applications using space-grown semiconductor crystals, including epitaxially grown materials for commercial electronic devices. The applications will also attempt to use the knowledge of the space-grown material behavior to enhance ground processing of the materials to achieve equivalent performance of space-grown materials in electronic circuitry.

- Applications using space-grown optical electronic materials such as fluoride glasses and nonlinear optical compounds for commercial optical electronic devices and to achieve equivalent performance of space-grown materials in ground processing.

- Innovations using nonlinear optical material to be processed in space.

- Innovations for new space-processed glasses for optical electronic applications.
NASA has an interest in the development of science and experiments that support strategic aspects of exploration, as well as the development of technologies to extend humanity’s reach to the Moon, Mars, and beyond. This includes designing exploration microgravity payloads. For example, life support technologies that enable health monitoring, provide functional foods and nutraceuticals, and environmentally clean habitats with dual applications on Earth such as high-resolution wireless ultrasound for patient monitoring, improved crop productions, and new forms of drug delivery. Preparing for exploration and research will accelerate the development of technologies that are important to the economy and national security as well as accelerate critical technologies.

**Microgravity Payloads**

- Design and develop microgravity payloads for space station applications that lead to commercial products or services.
- Enabling commercial technologies that promote the human exploration and development of space.
- Enabling commercial technologies through the use of ISS as a commercial test bed for hardware, products, or processes.
- Enabling technology designed to reduce crew work loads and/or facilitate commercial investigations or processing through automation, robotics, or nanotechnology.

**Combustion Science**

Innovative applications in combustion research that will lead to developing commercial products or improved processes through the unique properties of space or through enhanced or innovative techniques on the ground.

**Food Technology**

Innovative applications of space research in food technology that will lead to developing commercial food products or improved food processes through the unique properties of space or through enhanced or innovative techniques on the ground.

**Biomedical Materials**

Innovative materials where microgravity promotes structures such as biodegradable polymers for use in wound healing and orthopedic applications.

**Entertainment Value Missions**

Innovative approaches for commercial economic benefit from space research involving broadcasting, e-business, or other activities that have entertainment value.
Sub Topics:
Market Driven Space Infrastructure Topic B4.03

In accordance with the Space Act, as amended, to "seek and encourage to the maximum extent possible the fullest commercial use of space," NASA facilitates the use of space for commercial products and services. For example, space resource utilization techniques that enable the use of in situ planetary resources along with dual applications on Earth that create products by combustion synthesis of materials, extraction of volatiles, and separation of solids; also, spacecraft technologies that enhance spacecraft inspections, robotic processing or Free Flyer experiments with dual applications on Earth, such as high density video and advanced sensor networks. The products may use information from in-space activities to enhance an Earth-based effort or may require in-space manufacturing. This subtopic's goal is the development of infrastructure technology that will enable or enhance commercial space operations. Processes and hardware that have a clear utilization plan are a priority. All space activities that lead to commercial use in space are of interest. Some specific areas for which proposals are sought include the following:

**Power and Thermal Management**

Power and thermal management technologies that enable or enhance commercial satellites or space systems are sought.

**Communications**

Broadband, data compression, and imaging that can enable or enhance commercial operations in space or commercial satellites. This includes use of hyperspectral imagery and remote sensing.

**Space Vehicles and Platforms**

Improved technologies are sought for autonomous commercial vehicles and platforms. These technologies include autonomous rendezvous and docking, structures, and avionics.

**Space Resources Utilization**

Advanced commercial space activities will benefit from using nonterrestrial resources. These resources include propellants, power, and structural materials.

Sub Topics:
Partnering Innovations for Security and Safety Topic B4.04

NASA also has the goal to protect its assets, on Earth and in space, as well as our home planet and better understand the use of technologies that improve the quality of life in space and on Earth. By investing in space research and by collaborating with other agencies, industry, and academia, NASA has the opportunity to contribute to the creation of a more secure environment in space and on Earth. By leveraging resources in support of research in the unique environment of space, NASA goals and national priorities, such as security, as well as
market needs, may be achieved. This dual use with good potential for commercial product development is strongly encouraged. Following are some example areas for which proposals are sought:

- Sensors and detection systems to improve processes and operations in support of NASA space research and exploration goals, national security, and industrial processes.

- Improved communication systems to effectively and efficiently gather information from space-based research and provide better communication capabilities in support of NASA; its space and ground-based research and exploration goals are a priority. These systems could also be used to disseminate warnings and other critical information, in the event of a national disaster.

- Innovative devices and procedures for the use of technologies to protect NASA's personnel and assets as well as citizens from various threats to their personal security and/or property. These devices and procedures for the use of technologies would also provide protection to personnel carrying out NASA space research and exploration operations, both in space and on Earth.

- Countermeasure systems and/or devices to better effect rescue, recovery, treatment, and environmental safety during and after the occurrence of a disaster or a related accident.

Sub Topics:
Telescience and Flight Payload Operations Topic B5.01

NASA has interest in the development of science and experiments that support strategic aspects of exploration, as well as to develop the technologies to extend humanity's reach to the Moon, Mars, and beyond. Preparing for exploration and research will require the acceleration of the development of new technologies that will be imperative to future telescience and payload operations. It is important that the space missions and experiments for biological and physical research be managed using new tools, models, and procedures that improve telescience and flight payload operations. In addition, NASA wants to make available data and information associated with microgravity research investigations and results.

The ability for developers to access existing and new tools and collaborate in the design, simulation, modeling, building, and testing will be crucial to the success of NASA’s new initiative. New methods of computing, accessing disparate data spread over wide geographical areas will require new approaches to computing, data storage and communications.

There are many potential users for NASA services and data located throughout the U.S. There are three general types of users of these services and data. The first type is the principal investigator (PI)/payload developer (PD) who is responsible for the payload, experiment, and attendant science, and who commands the payload or experiment. The second type is the secondary investigator(s) who participates in analysis of the science and its control, but does not send commands. The third type is the educational user, from secondary school students up to graduate students. These users will receive either data processed by the PI or unprocessed data. Commercial investigations require the ability to receive, process, and display telemetry, view video from science sources,
including the ISS, and interact with NASA concerning the science and operations. To conduct or be involved in
general science activities, including the ISS science operations, a user will require various services from the
Payload Operations Integration Center (POIC) located at the Marshall Space Flight Center near Huntsville,
Alabama, or from other control centers located at various NASA facilities. These services are required to enable the
experiment to be controlled using the inputs from various video sources, telemetry, and the crew. The input allows
the experimenter to send to his/her payload or experiment commands to change various experiment operations.
Before an experiment can get underway, an experimenter must participate in the payload planning process to
schedule onboard services such as power, crew time, and cryogenics. This planning process is integral to the
entire payload/carrier operation and requires the PI/PD or his/her representatives to participate via voice or video
teleconferencing. To enable a user to operate from his/her home base, whether located in a laboratory, office, or
home; these services (commensurate to the level of operation) must be provided at the user's location at a
reasonable cost. Costs include both the platform upon which these services will run, and the communications
required to provide these services to the experimenter's location.

Proposals are sought for innovative ideas and efficiencies for systems to better effect communication and handling
of data and information for scientific and commercial research on the International Space Station payloads and on
manned exploration missions, and at the same time, for general use as applicable.

Sub Topics:
Flight Payload Logistics, Integration, Processing, and Crew Activities Topic B5.02
In preparation for future human exploration, we must advance our ability to live and work safely in space, and at the
same time, develop technologies to reach the Moon, Mars, and other planets. These new technologies will improve
the Nation's other space activities and may provide applications that could be used to address problems on Earth.
The objective of this subtopic is to introduce new technology in the form of new tools, models, and procedures. It is
important that the space missions and experiments for biological and physical research be managed using new
tools, models, and procedures that improve flight payload integration and associated activities. Proposals are
sought for more effective and efficient flight payload logistics, integration, processing, and crew activities. As
experiment hardware is developed, concurrent planning for logistics, processing, and for both analytical and
physical payload integration must take place. One objective is to minimize crew time required for experiment
handling, transfer, installation, and operation through automation, procedural efficiencies, and other means. Some
potential areas for payload improvements include, but are not limited to, the following:

- Acoustics, i.e., noise level reduction
- Power requirement reduction
- Electro Magnetic Interference/Electro Magnetic Compatibility (EMI/EMC) reduction
- Thermal control
- Materials usage
- Data control/handling
- Safety
- Test and checkout
- Systems integration
U.S. achievements in space have lead to the development of technologies that have widespread applications to address problems on Earth, as well as in space. In preparation for future human exploration of space, we must advance our ability to live and work safely in space and at the same time develop technologies to extend our reach to the Moon, Mars, and beyond. Outreach is a critical part of this process. This subtopic places emphasis on the effective implementation and analysis of outreach activities.

The Biological and Physical Research enterprise (BPR) seeks to use its research activities to encourage educational excellence and to improve scientific literacy from elementary school through the university level and beyond. The Enterprise delivers value to the American people by facilitating access to the experience and excitement of space research. NASA wants to provide access to information and data about microgravity research experiments and commercial investigations to schools, industry, and the general public.

Proposals are sought that provide a system, or systems, based on commercial solutions to develop outreach products for the improvement of education and public outreach planning and implementation. These systems should allow outreach participation in NASA programs, including the science and operational levels. Systems could provide for the general public and the educational community access to NASA and commercial science activities and operations through low-cost technologies, and outreach and education activities. The systems should be capable of facilitating secondary and college-level students’ access to, and the ability to participate in, science activities. Similarly, the systems should be able to accommodate institutions and organizations that promote the use of science and technologies, e.g., museums and space camps. Examples of potential outreach activities include, but are not limited to the following:

- Exhibits and educational/informational material for conferences, workshops, and schools.
- Development and distribution of outreach brochures, newsletters to the general public, and student flight experiment programs.
- Adult Ambassador Program, e.g., advocacy speakers for community education and outreach events, alliance with Collegiate Alumni Learning Weekend Programs, development of a partnership with retirement organizations for the planning and implementation of a program with appropriate learning experiences, development and implementation of “learning laboratories” for science centers and museums, publication of articles in general interest periodicals, publication of articles and reports in scientific journals, multimedia outreach products, outreach Web sites, education briefs, fact sheets, and press releases.
- In addition to the development of new tools for planning and implementation, BPR seeks to evaluate the effectiveness of outreach activities. Systems are sought to assess and analyze the implementation and effectiveness of education and outreach activities and goals associated with BPR research. Assessment of
available learning venues for varied age groups and priority order of attendance would be valuable in helping to formulate which venues and audiences to target.

Sub Topics: