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.

**Subtopics**

**B1.01 Exploiting Gravitational Effects for Combustion, Fluids, Synthesis, and Vibration Technology**
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.
B1.02 Gravitational Effects on Biotechnology

Lead Center: MSFC
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

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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.