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/) and the Bioastronautics Critical Path Roadmap (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.

Subtopics

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. Innovations are solicited in the areas that follow below.
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.

- 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.

**B3.02 Space Human Factors and Human Performance**

*Lead Center:* JSC  
*Participating Center(s):* ARC

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, \( \text{CO}_2 \), 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. 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.

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.

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**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
- Meson production

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.