Life support and habitation encompasses the process technologies and equipment necessary to provide and maintain a livable environment within the pressurized cabin of crewed spacecraft. Functional areas of interest to this solicitation include thermal control and ventilation, atmosphere resource management and particulate control, water recovery systems, solid waste management, habitation systems, environmental monitoring and fire protection systems. Technologies must be directed at long duration missions in microgravity, including earth orbit and planetary transit. Requirements include operation in microgravity and compatibility with cabin atmospheres of up to 34% O$_2$ by volume and pressures ranging from 1 atmosphere to as low as 7.6 psia. Systems external to the spacecraft will be at vacuum. Special emphasis is placed on developing technologies that will fill existing gaps, reduce requirements for consumables and other resources including mass, power, volume and crew time, and which will increase safety and reliability with respect to the state-of-the-art. Non-venting processes may be of interest for technologies that have future applicability to planetary protection. Results of a Phase I contract should show feasibility of the technology and approach. A resulting Phase II contract should lead to development, evaluation and delivery of prototype hardware. Specific technologies of interest to this solicitation are addressed in each subtopic.

Subtopics

**X3.01 Process Technologies for Life Support System Loop Closure**

**Lead Center:** MSFC

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

**Atmosphere Revitalization Process Technologies**

**Regenerative CO$_2$ Reduction Reactors:** Carbon dioxide reduction processes based on the Bosch series of reactions suffer from catalyst coking and subsequent deactivation. A novel process where the catalyst is either resistant to coking and/or may be regenerated in-situ is sought.

**Alternatives to Pyrolysis for CH$_4$ Management:** Process technologies are sought that convert CH$_4$ into either elemental products (carbon and H$_2$) or other useful commodities (fuel, organic synthesis precursor, or other) by reaction with available cabin resources such as O$_2$, N$_2$, or other readily available reactant.
Gas Separations: CO₂ reduction processes involve complex feed, recycle, and effluent gas mixtures. Process technologies and techniques for separating H₂, CH₄, and CO from complex effluent gas streams to facilitate their recycle and further reaction are sought.

Regenerable Particulate Matter Filters and Separators: Efficient methods of regenerating particulate filters and separators are sought to reduce crew maintenance time and eliminate the need for consumable filter elements. These units should be self-cleaning in-place (preferable) or off-line. Targeted technologies should be compact and lightweight, easily integrated with the spacecraft life support system, and provide viable methods for disposing of collected particulate matter while minimizing or eliminating direct contact by the crew.

Water Recovery Process Technologies

Efficient technologies are desired for recovering and purifying wastewater to potable quality. Emphasis is on the development of technology that is capable of operation in microgravity. In addition, the use of power and consumable components or chemicals should be minimized. Wastewater requiring treatment on spacecraft may consist of one or more waste streams including urine, brines, humidity condensate, hygiene water, and/or laundry water. Areas of emphasis are the following:

Removal of Dissolved and Suspended Solids from Wastewater: Process technologies suitable for serving as primary or secondary treatment stages to provide alternative treatment options to the vacuum compression distillation process equipment used on the International Space Station are sought. The dissolved and suspended solids may be composed of organic or inorganic compounds. The wastewater may have a total organic carbon concentration as high as 2000 mg-C/l and conductivity up to 12 mS/cm. Performance of proposed process technologies should be insensitive to solids precipitation.

Water Recovery from Brines: Many systems used for wastewater recovery produce clean water while concentrating contaminants into a highly concentrated brine waste. Microgravity-compatible process technologies capable of recovering a product water containing

Oxidation Technologies for Disinfection of Recovered Potable Water: Techniques for reducing the concentration of bacteria in potable water to less than 50 CFU/ml are sought that require minimal consumables resupply and are demonstrated to be compatible with the spacecraft cabin environment and life support systems.

X3.02 Human Accommodations and Interfaces with Spacecraft Life Support

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

Clothing

The requirements for crew clothing are balanced between appearance, comfort, wear, flammability and toxicity. Ideally, crew clothing should have durable flame resistance in a 34% O₂ (by volume) enriched atmospheric environment. Fabrics must enable multiple crew wear cycles before cleaning/disposal.
Laundry

The laundry system should remove/stabilize combined perspiration salt, organic, dander and planetary dust contaminants, preserve flame resistance properties of the fabrics, and use cleaning agents compatible with water recovery technologies including biological processes. Proposals using water for cleaning should use significantly less than 10 kg of water per kg of clothing cleaned.

Human Metabolic Waste Collection and Processing

Advanced methods of collection (human interfaces) and management are needed. Microgravity technology is needed to collect, provide odor control, stabilize, process for water recovery, reduce volume and dispose of feces. Areas of emphasis include: stabilization, water removal and recovery, and volume reduction. Human urine or water collection systems that require minimal/no airflow and allow >99% capture efficiency with non-contact crew interfaces are needed. Systems should include ability to separate liquid and air without rotary separators and be tolerant of urine precipitates and particulates from the crew cabin (originating from the crew, clothing, and equipment).

Quiet Ventilation Fans

Ventilation fans with inherent minimal acoustic generation in the range of human hearing are desired. Fans must not rely on passive acoustic mufflers, duct treatments, or mass for acoustic attenuation. Fans must have intrinsic aero-mechanical, rotary support, and electrical drive elements that reduce acoustic generation and provide high efficiency. Fans should be tolerant (prevent deterioration of flow performance or be periodically self cleaning) of particulates from the crew cabin (originating from the crew, clothing and equipment).

X3.03 Monitoring and Control for Spacecraft Environmental Quality and Fire Protection

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

Monitoring and Control Technology Needs

Long duration human missions far from Earth and operation of closed loop life support systems have critical needs for monitoring and control for environmental quality and certifying recycled life support consumables. 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 life support system is functioning properly and efficiently. The sensors may also provide data to automated control systems. All proposed technologies should have a 3 year shelf-life, including any calibration materials (liquid or gas). The technologies will need to function in microgravity and low pressure environments (~8 psi), and may see unpressurized storage. Significant improvements are sought in miniaturization and operational reliability, as well as long life, in-line operation, self-calibration, reduction of expendables, low energy consumption, and minimal operator time/maintenance for monitoring and controlling the life-support processes.
• Process control sensors for closed loop life support systems: Targeted sensors include humidity in gases such as \( \text{O}_2 \), \( \text{H}_2 \), and \( \text{CO}_2 \); volatile organic compounds in \( \text{O}_2 \) and \( \text{CO}_2 \) (VOCs in \( \text{CO}_2 \) would be in the \( \text{CO}_2 \) removal/concentration product that would feed to any \( \text{CO}_2 \) reduction process); composition of \( \text{CO}_2 \) reduction effluent gases (\( \text{CO}_2 \), \( \text{CO} \), \( \text{CH}_4 \), and \( \text{H}_2\text{O} \)) from either a Sabatier- or Bosch-based \( \text{CO}_2 \) reduction process; and combustible gas sensors for \( \text{H}_2 \) in an \( \text{O}_2 \) background and \( \text{O}_2 \) in an \( \text{H}_2 \) background from electrolysis.

• Trace toxic metals in water.

• Microbial monitoring of water and surfaces using minimal consumables.

• Optimal system control methods. Operate the life support system with optimal efficiency and reliability, using a carefully chosen suite of feedback and health monitors, and the associated control system.

• Sensor suites. Develop an approach for selecting number, types and placement of sensors in a distributed network for optimal environmental monitoring. Develop an approach to efficiently analyze data from a suite of sensors within a distributed network for optimal environmental monitoring.

Spacecraft Fire Protection Technology Needs

The overheating or combustion of spacecraft materials can introduce many types of particulate and gaseous contaminants into the cabin atmosphere. Technologies that not only detect smoke particulate but identify important characteristics such as particulate size and composition would be extremely useful for rapid identification of the fire source. These must be of suitable size, mass, and volume for a distributed sensor array in spacecraft systems. Also, catalytic or sorbent technologies suitable for the rapid removal of gases, especially CO, and particulate during a contingency response are desired.

X3.04 Thermal Control Systems for Human Spacecraft

Lead Center: JSC

Participating Center(s): GRC, GSFC, JPL, LaRC, MSFC