Environmental Control and Life Support (ECLS) encompasses the process technologies and equipment necessary to provide and maintain a livable environment within a crewed spacecraft or surface habitat cabin. Functional areas of interest to this solicitation include atmospheric resource management; airborne particulate matter removal and disposal; water recovery systems; waste management; fire protection systems; and environmental monitoring. Technologies are needed for crewed space exploration missions supporting the Vision for Space Exploration with emphasis on missions to the lunar surface, including short duration lunar sortie and long duration lunar outpost missions. Vehicles of interest include the Lunar Lander and Lunar Outpost (LO). Requirements include operation in micro- and/or partial-gravity as well as ambient and reduced-pressure cabin environments. Special emphasis is placed on developing technologies that will fill existing gaps; have a significant impact on reduction of mass, power, volume and crew time; and increase safety and reliability.

Subtopics

X3.01 Spacecraft Cabin Atmospheric Resource Management and Particulate Matter Removal

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

Atmospheric resource management and particulate matter removal systems supporting critical needs for lunar mission architectures are requested. Vehicles and habitats are expected to be significantly restricted with respect to habitable volume and may operate at reduced atmospheric pressure with elevated oxygen concentrations. Improved non-regenerative and regenerative processes technologies for atmospheric quality control must be developed. The ability to economically supply atmospheric gases and refill storage tanks in flight will be needed. Isolating habitable volumes from surface dust and disposing of accumulated particulate matter will be challenges. Systems must be innovative and extremely efficient with respect to volume, mass, energy and thermal requirements.

Atmospheric Resource Management

Atmospheric resource management encompasses process technologies and equipment to supply, store, and condition atmospheric gases; provide gaseous oxygen at pressures at or above 3,000 psia; and achieve mass closure by recycling resources and using in situ resources. Typical process technologies employed for achieving these needs may include reduction of carbon dioxide to carbon, sub-critical gas storage, and electrolytic oxygen...
production with compression. Techniques for enhancing NASA's present capabilities and filling technology gaps are sought. The ability to provide early computer-based process technology predictive performance models for application scale-up and scale-down is desirable. Areas of emphasis include:

- **Carbon Dioxide Removal and Reduction for Recovery of Oxygen:** Process technologies for removing and sequestering carbon dioxide from cabin atmospheric gases (via means other than adsorption or chemisorption) and conditioning carbon dioxide for use in reduction processes to facilitate cabin mass balance closure are sought. Technologies to reduce carbon dioxide to a carbon product with high efficiency that yields a high percentage mass balance closure are also of interest.

- **Gas Supply and Storage:** Novel means for supplying and storing oxygen and nitrogen under sub-critical conditions that lead to enhancements in energy efficiency, reduced mass and volume, and mission flexibility are sought. Further, process technologies leading to a ready, in-flight renewable source of 3,000-psia gaseous oxygen are of interest.

### Particulate Matter Removal and Disposal

Dust and particulate matter contamination are challenges that must be overcome for lunar surface exploration. Particulate contamination originating from the external surface environment or from internal sources are both of concern. Development of process technologies and equipment to minimize the impacts of surface dust on crew health and equipment inside the habitable volume are sought, including novel approaches to remove dust from spacecraft cabin atmosphere and isolate habitable volumes from surface dust. Candidate technology solutions should provide high efficiency and long-lived removal capacity. Technologies must be tolerant to the abrasive effects of dust particles. Performance should be demonstrated with appropriate lunar dust analogs or simulants. Areas of emphasis include:

- **Removal of Fine Atmospheric Dust Particulates:** Fine airborne lunar dust will be detrimental to crew health. Filtration technologies are sought that will provide significantly improved capture efficiency of both fines (10 nm to 2 microns) and ultra-fines.

- **Regenerative Processes and Filters:** Regeneration techniques and regenerable filters are sought that effectively handle a broad particulate size range from larger-sized particles down to fine particle sizes. These techniques must be able to separate and dispose of lunar dust to the lunar surface, and/or dispose of and collect all other particulate matter to highly compacted units/states. Salient features for this application include capability for regeneration in place, long-lived and large bulk removal capacity, and high efficiency. Operational modes of continuous regeneration or long interval regeneration cycles using either single or multi-stage regeneration processes will be considered. Methods for determining and annunciating the loading and unloading status of the regenerative unit and for automated regeneration are of interest.

- **Isolation Technologies:** Process technologies and design concepts to isolate habitable volumes from surface dust are sought. Such process technologies and design concepts may employ a variety of techniques to prevent surface dust from being transported through an airlock into the habitable part of the spacecraft or habitat cabin.
X3.02 Water Processing and Waste Management Systems

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

Water processing and waste management systems supporting critical needs for lunar mission architectures are requested. Improved technologies for recovery of water and other resources as well as safe long term stabilization and storage of residuals inside and outside the habitat are needed. Water processes collect, store, recycle, and disinfect water for reuse as both drinking water and hygiene water. Waste processes collect, process, recover resources, stabilize, and store residuals. Although this solicitation is directed at technologies for lunar missions, crosscutting technologies that are also applicable to human missions to Mars are of interest. Proposals should explicitly describe the weight, power, and volume advantages of the proposed technology.

Water Reclamation

Efficient treatment of wastewater from a variety of sources is critical to long-term exploration missions. Sources of water to be recovered may include urine, wash water, humidity condensate, and/or water derived from in situ planetary resources. Treatment processes should produce potable and hygiene water supplies. Treatment methods for long duration missions should seek high levels of mass closure. Systems targeted for planetary surface applications must be designed to function in hypogravity environments but need not be microgravity compatible. Areas of emphasis include:

- Disinfection and residual disinfectant technologies that are compatible with both biological and physicochemical wastewater processing systems;
- Techniques to minimize or eliminate biofilms, microbial contamination and/or solids precipitation from potable water, wastewater and water treatment system components;
- Post-treatment methods to reduce total organic carbon from 100 mg/L to less than 1 mg/L in the presence of 50 mg/L bicarbonate ions, 25 mg/L ammonium ions and 25 ppm other inorganic ions.

Waste Management

Wastes (trash, food packaging, feces, paper, tape, filters, water brines, clothing, hygiene wipes, etc.) must be managed to protect crew health, safety, and quality of life, to avoid harmful contamination of planetary surfaces, and to recover useful resources. Areas of emphasis include:

- Solid waste stabilization including water removal and recovery of water from wet wastes (including human fecal wastes, food packaging, brines, etc.);
- Solid waste storage and odor control (e.g., catalytic and adsorptive systems);
- Energy efficient/internal heat recycling waste pyrolysis systems for mineralization of wastes.

Clothing Systems

Low mass reusable or long usage clothing options that meet flammability, out gassing, and crew comfort requirements. Cleaning and drying systems for re-use of clothing that have low-water usage, non-toxic cleaning agents compatible with physicochemical or biological water reclamation systems, or that do not require water.
X3.03 Spacecraft Cabin Environmental Monitoring and Control

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.

Technologies should be appropriate for a small crewed mission to the Moon, of duration no more than a few weeks. Emphasis is on major constituents in the air and lunar dust. Extendibility to trace monitoring for longer missions is a plus. 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. Proposals should be for either new technologies or combine existing technologies in a new way to simultaneously monitor several major constituents and dust, and/or trace constituents.

Substances from an external environment such as lunar surface dust may be encountered during astronaut excursions and may be a mechanical or chemical threat both during the external encounter and if brought inside. Monitoring technologies are needed to assess and quantify these threats.

For longer missions, water monitoring will be required. Needs will include sensitive, fast response, online analytical sensors to monitor suspended liquid droplets, dispersed gas bubbles, and water quality, particularly total organic carbon. A desire is for an immersible water quality sensor that is reversible; i.e., it tracks analyte changes in water without having to replace any sensor chemistry element.

Monitoring of 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, will be important for longer missions. Enabling technologies may include proper sample preparation and handling, with minimal operator effort and minimal or no reagent usage.

Crew members will employ software tools to help them interpret sensor data. Methods are sought which will assist the crew in using sensor data to detect and predict failures.
Results of a Phase 1 contract should show feasibility of the technology and approach. A resulting Phase 2 contract should produce at least a prototype demonstration and test of the environmental monitor.

X3.04 Spacecraft Fire Protection

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

The objective of fire protection strategies on exploration spacecraft is to quantitatively reduce the likelihood of a fire and reduce the impact to the mission should a fire occur. NASA's fire protection strategy includes: strict control of ignition sources and flammable material, early detection and annunciation of fire signatures, and effective fire suppression and response procedures. While proposals describing innovations in all of these areas are applicable, they are particularly sought in the following areas:

- Advanced fire detection strategies are desired that respond uniquely to one or more fire or pre-fire characteristics such as thermal radiation, smoke, or gaseous product. These sensors and detector systems should be appropriate for the unique fire behavior in low- and partial-gravity environments yet effectively discriminate between fire signatures and relevant spacecraft nuisance sources. Fire detection systems particularly attractive for long-duration exploration missions will have reduced mass, power, and volume requirements and exhibit high degrees of reliability, minimal maintenance, and self-calibration.

- Fire suppression technologies for exploration spacecraft and habitats must be applicable for use in a confined habitable volume having an atmosphere of up to 34% O₂ by volume and pressures as low as 7.6 psia. These systems would be effective in low- and partial-gravity environments and have minimal mass and volume requirements. Applicable technologies would be highly reliable with little or no maintenance, have multi-use capability and/or be replenishable during a mission, and be compatible with the spacecraft environmental control and life support system.

Results of a Phase 1 contract should show feasibility of the technology and approach. A plan for the demonstration of a prototype to be developed in Phase 2 should also be produced at the end of Phase 1. The Phase 2 contract should produce at least a prototype demonstration and test of the fire detection or suppression system.