The purpose of In-Situ Resource Utilization (ISRU) is to harness and utilize resources at the site of exploration to create products and services, which can enable and significantly reduce the mass, cost, and risk of near-term and long-term space exploration. The ability to make propellants, life support consumables, fuel cell reagents, and radiation shielding can significantly reduce the cost, mass, and risk of sustained human activities beyond Earth. The ability to modify the landscape for safer landing and transfer of payloads, creation of habitat and power infrastructure, and extraction of resources for construction, power, and in-situ manufacturing can also enable long-term, sustainable exploration of the solar system. Since ISRU can be performed wherever resources may exist, both natural and discarded, ISRU systems will need to operate in a variety of environments and gravitations. Also, because ISRU systems and operations have never been demonstrated before in missions, it is important that ISRU concepts and technologies be evaluated under relevant conditions (gravity, environment, and vacuum) as well as anchored through modeling to regolith/soil and environmental conditions. While the discipline of ISRU can encompass a large variety of different concept areas, resources, and products, the ISRU Topic has been divided into two subtopics dealing with the fundamental difference in technologies associated with solid in-situ material handling and processing versus gaseous and gaseous/solid processing. An attempt was made to minimize the potential overlap in technologies and processes between the two subtopics.

Sub Topics:

**X1.01 Regolith/Soil Transfer, Handling, & Processing of Extraterrestrial Material**

**Lead Center:** JSC

**Participating Center(s):** GRC, KSC, MSFC

**Regolith/Soil Transfer and Handling**

- Long-life, light-weight, and minimum consumable technologies to move feedstock material from the surface or a collection hopper to processing reactors (at least 3m); High separation efficiency gas/solid particle separation techniques and regenerable particle filters
- Granular materials mixing and size separation for reactor feedstock conditioning: remove material > 0.5 cm diameter before dumping into storage bin during excavation operation for oxygen extraction from regolith
- Granular flow computer models, devices, and instruments to evaluate material flow and manipulation under low and micro-gravity flight and ground vacuum experimental conditions
- Mineral beneficiation concepts to separate iron oxide-bearing material from bulk regolith; up to 20 kg/hr based on hydrogen reduction

**Regolith/Soil Processing To Extract Resources and Products of Interest**
- Regolith/soil valve/seal concepts for processing systems with no gas leakage after 1000’s of operating cycles with material. For processes that require elevated temperatures, thermal isolation or minimum heat loss is required

- Regolith/soil processing reactor concepts for extracting volatiles and water/ice

- Regolith/soil processing reactor concepts for extracting metals through electrolysis and/or metal/waste/salt removal and separation techniques.

- High temperature (=1000 C), high efficiency insulation for regolith/soil processing reactors

- High temperature (=1000 C) pressure sensors and instruments for process control and performance assessment

- Alternative thermal, chemical, and/or biological processing concepts for oxygen (and potentially metal) extraction from regolith/soil besides

### Hydrogen Reduction and Carbothermal Reduction Processes

- Light-weight, deployable solar concentrator concepts and solar energy transfer methods into regolith/soil processing reactors

- Low energy loss methods for redirecting solar energy from concentrators and fiber optic cables to allow multiple users in series

### Regolith/Soil Processing for Protection, Construction, and Energy

- Thermal energy storage and utilization using bulk or processed regolith

- Techniques for hardening or modifying in-situ materials so that landing pads and roads can be constructed to prevent landing plume debris damage and wear on surface mobility platforms

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**X1.02 Gas, Liquid, and Solid Processing to Produce Oxygen and Fuels from In-Situ Resources**

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

### Solid/Gas Processing to Support Oxygen and Fuel Production

- Gas Separators for lunar oxygen extraction from regolith that provide low pressure drop separation of the system and product gas streams from impurities (e.g. HCl, HF, H₂S, SO₂); the process should be regenerable and the output contaminant concentration should be less than 50 ppb

- Hydrogen gas pumps with rates (up to 6 scfm) for recirculation and pneumatic transport
• Carbon dioxide collection and separation from Mars atmosphere

• High efficiency carbon dioxide/carbon monoxide separation concepts with high quality carbon dioxide produced

• Long-life carbon dioxide electrolysis/dissociation into carbon monoxide and oxygen concepts with high conversion efficiency at pressures greater than or equal to 1 bar

**Water Processing**

• Water/gas separators that use the space environment for water condensation/separation with minimal energy usage; concepts that can operate in both low-gravity (1/6-g and 3/8-g) and micro-gravity are of greatest interest

• Removal of dissolved ions in water by methods other than de-ionization resins to meet water electrolysis purity requirements (minimum resistivity of 1M-Ohms-cm). Ions of interested are dissolved metal ions (Fe, Cr, Co, Ni, Zn) at concentration of 0.01% and dissolved anions (Cl, F, S) at concentrations of 0.01%-2%. The process should be regenerable, minimize consumables, and minimize water loss.

• Contaminate resistant, high temperature water electrolysis concepts

**Trash/Waste Processing for Fuel Production**

• Processing concepts for production of carbon monoxide, carbon dioxide, water, and methane from plastic trash and dried crew solid waste. Proposals must define use of solar or electrical energy during processing, and any reagents/consumables; recycling schemes for reactants/reagents used in the processing should be evaluated

• Methods for waste/trash transfer and handling before and after processing

Advanced Propulsion Topic X2

Human Exploration require advances in propulsion to get to the moon, Mars, and beyond. A major thrust of this research and development activity will be related to space launch propulsion technologies. This effort will include first stage engine development, non-toxic in-space engine demonstrations, and foundational propulsion research in areas such as new or largely untested propellants that can result in more capable and less expensive future rockets. NASA is interested in conducting foundational research to study the requirements and potential designs for advanced high-energy in-space propulsion systems to support exploration and to reduce travel time. These technologies could include nuclear propulsion and electric propulsion.

Sub Topics:

**X2.01 Earth-to-Orbit Propulsion**
NASA is interested in innovative Earth-to-Orbit (ETO) propulsion systems and component technologies, as well as design and analysis tools used to support the assessment of the technical viability of those systems. Next generation launch systems will require propulsion systems that deliver high thrust-to-weight ratios, increased trajectory averaged specific impulse, reliable overall vehicle systems performance, low recurring costs, and other innovations required to achieve cost and crew safety goals.

Proposals should address technical issues related to Earth-to-Orbit (ETO) LOX/Hydrocarbon engines and LOX/Hydrogen second stage engines including engine and main propulsion systems design and integration, turbomachinery, combustion devices, valves, actuators, and ducts. Areas of specific interest for technology advancement and innovations include the following:

- Advancements in design and analysis tools applicable to assessment of ETO propulsion systems including engine systems, turbomachinery, valves, and combustion device concepts. Of particular interest are design and analysis tools that provide improved understanding and quantification of component, subsystem, and system operating environments and that significantly enhance the overall systems engineering evaluation of potential ETO propulsion concepts. Examples include low and high fidelity tools suitable for component and parameter sensitivity analysis and optimization, dynamic environment prediction, quantification of system benefits to changes.

- Improved propulsion systems stability prediction analysis and design tools, along with stability aid concepts and demonstration of approaches (i.e., rotordynamic coefficients, turbopump cavitation, instabilities, combustion stabilities, structural-acoustic, propellant management, and fluid dampers.)

- Innovative tools for predicting the complex fluid and structural interactions within rocket nozzles and experimental methods and data for validating these tools. Specific areas of interest include nozzle side loads induced by nozzle flow separation during engine start and shutdown transients and the effect of fluctuating pressure during engine main stage.

- Improvements to tools that predict the environments in and around the engine during booster operation.

- Data to validate the accuracy of high fidelity design and analysis tools used for the prediction of internal rocket engine environments.

- Design concepts that improve performance, reduce cost, reduce weight or improve reliability of the propellant feed systems, valves. Of particular interest are:
  - Design concepts for high power density turbines,
  - Design concepts for low net positive suction pressure pumps,
  - Design concepts for low cost, reliable valves and their actuation system,
  - Demonstration of robust bearing design concepts for large, high speed rotors,
  - Identification and demonstration of high strength materials that are resistant to combustion in a high pressure, oxygen rich environment.
X2.02 Non-Toxic In-Space Propulsion

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

This solicitation intends to examine a range of key technology options associated with cryogenic and non-toxic storable propellant space engines. Non-toxic engine technology is desired for use in lieu of the currently operational NTO/MMH engine technology. Safety concerns with toxic propellants drive mission planners to the use of more costly propulsion modules that are fueled and sealed on the ground. Non-toxic engine technologies could range from reaction control class of 25-1000 lbf to main engines of up to 60,000 lbf with both pump fed or pressure fed systems.

Specific technologies of interest to meet proposed engine requirements include:

- Non-toxic bipropellant or monopropellants that meet performance targets (as indicated by high specific impulse and high specific impulse density) while improving safety and reducing handling operations as compared to current state-of-the-art storable propellants.

- Low-mass propellant injectors that provide stable, uniform combustion over a wide range of propellant inlet temperature and pressure conditions.

- High temperature materials, coatings and/or ablatives for injectors, combustion chambers, nozzles, and nozzle extensions.

- Combustion chamber thermal control technologies such as regenerative, transpiration, swirl or other cooling methods, which offer improved performance and adequate chamber life.

- Technologies are also solicited that enable deep-throttling turbopumps to operate at off-design flow coefficients while eliminating flow instabilities such as cavitating surge.

- Highly-reliable, long-life, fast-acting propellant valves that tolerate long duration space mission environments with reduced volume, mass, and power requirements is also desirable.

- Cryogenic instrumentation such as pressure and temperature sensors that will operate for months/years instead of hours.

Note to Proposer: Subtopic S3.04 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.04.

X2.03 Nuclear Thermal Propulsion

Lead Center: GRC
Participating Center(s): JPL, MSFC

NASA is interested in the development of critical technologies for first in-space applications of solid core nuclear
thermal propulsion (NTP) systems for use in future exploration missions. For short round trip missions to MARS, NTP systems may be enabling by helping to reduce launch mass to reasonable values and by also increasing the payload delivered for Mars exploration missions.

Preliminary solid core NTP system concepts could be based on a high thrust/high ISP (~850-950s) NTP system that would use a fission reactor with U-235 fuel as its source of thermal energy. During the short primary propulsion maneuvers of a typical conceptual mission, large quantities of thermal power (100's of MW) would be produced within the NTP system and removed using liquid hydrogen propellant that is pumped through the engine's reactor core. The superheated hydrogen gas is then exhausted out the engine's nozzle to generate thrust. Representative ranges of engine performance include: (1) hydrogen exhaust temperatures ~2500 - 2900K, (2) propellant flowrates ~7 - 13 kg/s, (3) chamber pressures ~500 - 1500 psi, and (4) nozzle expansion area ratios ~200:1 - 500:1.

Proposals are sought to further improve factors contributing to safety, performance, reliability, and life as well as reduce projected weight and costs for the first in-space NTP systems, subsystems, and components beyond that in previously achieved ground test systems. Proposals are solicited in the following key technology/concept areas:

- High temperature, low burn-up carbide- and ceramic-metallic (cermet)-based nuclear fuels with improved coatings and /or claddings to reduce fission product gas release into the engine's hydrogen exhaust stream;
- Reliable, high temperature materials, fabrication techniques, and concepts for non-reactor portions of NTP systems;
- Light-weight, multi-use shielding materials and designs;
- High temperature, radiation tolerant instrumentation and avionics for engine health monitoring. Non-invasive designs for measuring neutron flux (outside of reactor), chamber temperature, operating pressure, and liquid hydrogen propellant flow rates over wide range of temperatures desired;
- Long life, lightweight, reliable hydrogen turbopump designs and technologies;
- Lightweight, long life, heat flux thrust chambers, regenerative-cooled nozzles and radiation-cooled skirt extensions that are compatible with hot hydrogen;
- Radiation tolerant materials compatible with above engine subsystem applications and operating environments.

X2.04 Electric Propulsion Systems

Lead Center: GRC
Participating Center(s): JPL, MSFC

The goal of this subtopic is to develop innovations in high-power (100 kW to MW-class) electric propulsion systems. High-power (high-thrust) electric propulsion may enable dramatic mass and cost savings for lunar and Mars cargo missions, including Earth escape and near-Earth space maneuvers. At very high power levels, electric propulsion may enable piloted exploration missions as well. Improved performance of propulsion systems that are integrated
with associated power and thermal management systems and that exhibit minimal adverse spacecraft-thruster interaction effects are of interest. Innovations are sought that increase system efficiency, increase system and/or component life, increase system and/or component durability, reduce system and/or component mass, reduce system complexity, reduce development issues, or provide other definable benefits. Desired specific impulses range from a value of 2000 s for Earth-orbit transfers to over 6000 s for planetary missions. System efficiencies in excess of 50% and system lifetimes of at least 5 years (total impulse > 1 x10^7 N-sec) are desired. Specific technologies of interest in addressing these challenges include:

- Long-life, high-current cathodes (100,000 hours);
- Electric propulsion designs employing fuels that are more readily available (whether from Earth or in situ space resources) and easy to store/handle;
- Electrode thermal management technologies;
- Innovative plasma neutralization concepts;
- Metal propellant management systems and components;
- Cathodes for metal propellants;
- Low-mass, high-efficiency power electronics for RF and DC discharges;
- Lightweight, low-cost, high-efficiency power processing units;
- Low-voltage, high-temperature wire for electromagnets;
- High-temperature permanent magnets and/or electromagnets;
- Application of advanced materials for electrodes and wiring;
- Highly accurate propellant control devices/schemes;
- Miniature propellant flow meters;
- Lightweight, long-life storage systems for krypton and/or hydrogen;
- Fast-acting, very long-life valves and switches for pulsed inductive thrusters;
- Superconducting magnets;
- Lightweight thrust vector control for high-power thrusters; and
- High fidelity methods of determining the thrust of ion, Hall, and advanced plasma engines without using conventional thrust-stands.

Note to Proposer: Subtopic S3.04 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.04.
Life Support and Habitation Systems Topic X3

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\textsubscript{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.

Sub Topics:

**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\textsubscript{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\textsubscript{4} Management:** Process technologies are sought that convert CH\textsubscript{4} into either elemental products (carbon and H\textsubscript{2}) or other useful commodities (fuel, organic synthesis precursor, or other) by reaction with available cabin resources such as O\textsubscript{2}, N\textsubscript{2}, or other readily available reactant.

**Gas Separations:** CO\textsubscript{2} reduction processes involve complex feed, recycle, and effluent gas mixtures. Process technologies and techniques for separating H\textsubscript{2}, CH\textsubscript{4}, 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% O<sub>2</sub> (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 O₂, H₂, and CO₂; volatile organic compounds in O₂ and CO₂ (VOCs in CO₂ would be in the CO₂ removal/concentration product that would feed to any CO₂ reduction process); composition of CO₂ reduction effluent gases (CO₂, CO, CH₄, and H₂O) from either a Sabatier- or Bosch-based CO₂ reduction process; and combustible gas sensors for H₂ in an O₂ background and O₂ in an H₂ 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

Extra-Vehicular Activity Technology Topic X4

Advanced Extra Vehicular Activity (EVA) systems are necessary for the successful support of the International Space Station (ISS) beyond 2020 and future human space exploration missions. Advanced EVA systems include the space suit pressure garment, airlocks, the Portable Life Support System (PLSS), Avionics and Displays, and EVA Integrated Systems. Future human space exploration missions will require innovative approaches for maximizing human productivity and for providing the capability to perform useful tasks, such as assembling and servicing large in-space systems and exploring surfaces of the Moon, Mars, and small bodies. Top level requirements include reduction of system weight and volume, low or non-consuming systems, increased hardware reliability, durability, operating life, increased human comfort, and less restrictive work performance in the space environment. All proposed Phase I research must lead to specific Phase II experimental development that could be integrated into a functional EVA system.

Sub Topics:

X4.01 Space Suit Pressure Garment and Airlock Technologies

Lead Center: JSC
Participating Center(s): GRC
X4.02 Space Suit Life Support Systems

Lead Center: JSC
Participating Center(s): GRC

X4.03 Space Suit Radio, Displays, Cameras, and Integrated Systems

Lead Center: JSC
Participating Center(s): GRC

Tunable RF Front End and Transceiver

A major impetus behind the MEMS technology stems from compactness, which leads to lower power dissipation, higher levels of integration, lower weight, volume, and cost. To shrink form factor and enable efficient surface operations, one of the cornerstone components of this radio is the tunable filter. Recent advances in RF MEMs filters and resonator technology have permitted very high quality factors (>1000) at GHz frequencies. Achieving high and excellent tuning range (>2:1) to bandwidth ratio without cryogenic cooling is now viable for the S-band frequency. For reliability, the tunable filter should employ a contact-less tuning scheme.

Power-Aware Processing

To support Quality of Service (QoS) of different applications, it's inadequate to optimize power at design time, but dynamic power management must be employed to ensure power efficiency. To maximize power efficiency, the radio must be able to adjust power and update rates to suit for diverse missions. Users should have the ability to specify QoS for different data streams. The radio must have the capability to scale power, select optimum modes of operation, and minimum energy profiles. During low-rate-processing intensive modes, including local processing and compression of telemetry data and voice, highly energy-efficient low-voltage, low-performance modes must be used. For high-rate-processing intensive modes, like advance signal encoding of high definition imagery, medium performance modes must be used; and during active communication modes (which may have a low duty-cycle), ultra-high-performance modes must be used. Accordingly, the digital platform must be highly agile and use-case aware to continuously minimize energy. Below are some desirable features to consider:

Variation-Tolerant, Performance-Scalable Architectures

Hardware must sense its own limitation at a dynamically varying, performance-driven optimal energy operating point, and reconfigure accordingly. If variability is stressed at the low-voltage operating point, redundant hardware should be used to improve reliability; if throughput is stressed at the high-performance operating point, redundant hardware should be used to increase parallelism.

Energy-Aware Algorithms for Adaptive Hardware

Algorithms must be aware of the different hardware operating-points and associated architecture. For instance, during low-power modes targeting voice and data (for telemetry), occasional high through-put applications (like high-
rate imagery) should dynamically switch to algorithms employing extreme parallelism in order to support a minimum operating voltage.

**Modularity and Extensibility**

Enabling platform must support open architecture and accommodate rapid upgrades, multiple protocols, new technology advances, complete re-configurability of functionality, and evolution of planetary communications and network infrastructure.

**Phase I Deliverables**: Given maximum range of 4km, telemetry, voice at 8 kbps, high definition imagery at 20 Mbps, and S-band frequency operating at 2.4 - 2.483 GHz, assess radio ultimate mass, size, and power. This should be backed with analyses and simulation to ensure achievable performance and power targets.

One significant prerequisite to Phase II is the development of a promising and novel MEMS-based radio architecture that comprises: a highly programmable frontend and highly programmable digital basebands with the MAC implementation of multiple protocols and Advanced Encryption Standard (AES) encryption. The offeror must demonstrate the ability to achieve significant advantages in compactness, power efficiency, and reliability.

**Phase II Deliverables**: Develop a reliable, intelligent, and power-efficient MEMS-based EVA radio prototype unit that demonstrates robust RF performance, frequency agility, re-configurability, and dynamic power management for voice, telemetry, and high definition imagery under power budget constraints.

Demonstrate a highly programmable frontend and digital basebands with the MAC implementation for multiple open standard protocols. Consider a three-node network configuration for interoperability.

Integrate AES encryption as well as power-aware technologies and ensure QoS applications fall within prescribed power constraints.

**Displays**

To surmount geometric constraints, compact external flat panel or helmet-mounted display technologies are needed to improve situational awareness, mobility, suit monitoring, and task management. Hands-free interactive control of visual information (text, graphics, images, and video) using conversational spoken dialogue can improve work efficiency over audio communications as well as increase productivity and safety. High resolution suit displays must be able to operate outside the protection of the suit in bright surroundings, thermal, radiation, and vacuum environments as well as internally without imposing ignition hazards due to 100 percent oxygen environment.

**Sensors**

Crew health and suit monitoring require advancement of lightweight CO₂, biomedical (heart rate, blood OX, EKG) and core temperature sensors with reduced size, increased reliability, and greater packaging flexibility.
Consequently, technologies are needed to provide high accuracy, low mass, and low-power sensors that measure flow rate, pressure, temperature, and relative humidity or dew point. All sensors must operate in a low pressure 100% O$_2$ environment with high humidity and may be exposed to liquid condensate.

Because missions must be designed with appropriate radiation shielding and adjusted to keep the radiation doses within tolerable limits, real-time, accurate, instantaneous and integrated radiation dose measurements and readout are needed such as novel dosimeter sensors. Given sufficient warning, astronauts can move to a more shielded part of the space vehicle and lessen dose impact. As cosmic rays impinge upon the vehicle leaving the magnetosphere, sensors are needed to determine the type of radiation and dose as well as reduce the potential risk of biological tissue damage.

### High Definition (HD) Cameras

Ultra-compact, low-power, HD cameras are needed to support both high definition motion and high resolution still imagery, providing low loss compressed digital data output for transmission over RF and/or IP networks. Key features include advanced wireless networking for transmitting video at high bandwidth, high-quality image compression algorithms, radiation tolerant image sensor and processing platform capable of running video compression in near real time. The cameras must provide excellent situational awareness for crew members and quality imagery for remote viewing, scientific research, exploration, and public relations. They will be mounted on space and planetary vehicles (e.g. rovers), so remote operation (pan, tilt, focus, zoom, light level controls) can be controlled by astronaut in a suit, and the image projected onto a helmet display or remotely for Earth-based operations.

### Integrated Systems

A complete system of displays, cameras, sensors must be integrated under a common interface. A key enabler will be advanced spoken dialogs. Typing or using a touch menu is too cumbersome with space suit gloves. Voice commands are much more natural for the suited astronaut and can increase situational awareness. In case of voice failure, a backup system can be implemented to perform all critical functions. Not only can this capability reduce crew workload, but it can immensely enhance operational efficiency. Such functions can alert crew about progressive deterioration of equipment preceding failures. Sensor data can be read out to determine the heart rate, body temperature, and CO$_2$ levels. Cameras can be turned on, aimed at precise locations, and either still or motion imagery can be taken.

Rather than separate control interfaces, a total solution is needed for integrating a suite of space suit functions: displays, cameras, sensors, audio, and voice. Hands-free interaction requires automated planning, scheduling, consumable management, suit monitoring, and display presentation. Advanced spoken dialogue system which works in an acoustic environment of the space suit and provides an interface to control all space suit, display, camera, sensor, and audio functions will allow a natural operation of complex suite of space suit capabilities.
Lightweight Spacecraft Materials and Structures Topic X5

The SBIR topic area of Lightweight Spacecraft Materials and Structures centers on developing lightweight expandable structures, advanced manufacturing technologies for metallic and composite materials, structural sensing techniques, in-situ non-destructive evaluation systems, and low-temperature mechanisms. Applications are expected to include space exploration vehicles including launch vehicles, crewed vehicles, and surface and habitat systems.

The area of expandable structures solicits innovative concepts to support the development of lightweight-structure technologies that would be viable solutions to high packaging efficiency and increasing the usable primary pressurized volume in habitats, airlocks, and other crewed vessels. Technologies are needed to minimize launch mass, size and costs, while maintaining the required structural performance for loads and environments.

Advanced fabrication and manufacturing of lightweight structures focuses on the development of metallic alloys and hybrid materials, processing and fabrication technologies related to near-net shape forming. The goal is to reduce structural weight, assembly steps, and minimize welds, resulting in increased reliability and reduced cost. Research should evaluate material compatibility with forming methods and establish fundamental microstructure/processing/property correlations to guide full-scale fabrication. Laboratory scale test methods are needed to accurately simulate the deformation modes experienced in large-scale manufacturing.

Polymer matrix composite (PMC) materials have been identified as a critical need for launch and in-space vehicles. The reduction of structural mass translates directly to additional performance, increased payload mass and reduced cost. PMC materials are also critical for other structures, such as cryogenic propellant tanks. Advances in PMC materials, automated manufacturing processes, non-autoclave curing methods, advances in damage-tolerant/repairable structures, and PMC materials with high resistance to microcracking at cryogenic temperatures are sought. The objective is to advance technology readiness levels of PMC materials and manufacturing for launch vehicle and in-space applications resulting in structures having affordable, reliable, and predictable performance.

Practical modular structural sensor systems and NDE technologies are sought for spaceflight missions. Smart, lightweight, low-volume, and stand-alone sensor systems should reduce the complexities of standard wires and connectors and enable sensing in locations not normally accessible. NDE sensor system technology should include modular, low-volume systems and have the ability to perform inspections with minimal human interaction. Systems need to provide the location and extent of damage with the minimal data transfer between the flight system and Earth. Mission application areas include space transportation vehicles, pressure vessels, ISS modules, inflatable structures, EVA suits, MMOD shields, and thermal protection structures.

Low-temperature mechanism technology is being developed for reliable and efficient operation of mechanisms in low temperature environments at -230°C and sustained performance thru temperature cycles of -230°C to +120°C. The goal is to enhance operation of mechanized parts by lowering the operating temperature of the component, and by improving performance at cold conditions under vacuum over the life of the mechanism. The targeted application of the technology is to provide for operation of motors and drive systems, lubricated mechanisms, and actuators of rovers, mobility systems, and robotic mechanisms.
Research under this topic should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a full-scale demonstration unit for functional and environmental testing at the completion of the Phase II contract.

Sub Topics:

**X5.01 Expandable Structures**

**Lead Center: LaRC**

The Expandable Structures subtopic solicits innovative structural concepts that support the development of lightweight structures technologies for expandable exploration space modules and surface based habitats. The targeted structural concepts are desired for utilization in primary pressurized volumes and in secondary structures internal to the deployed primary volume. Innovations in expandable structures technology is desired to minimize launch mass, volume, and costs, while maximizing operational volume and structural performance of a crewed or material transfer pressure vessel.

Inflatable structures is a research area within expandable structures, which offers a viable solution for increasing the volume of habitats, airlocks, and other crewed vessels. Inflatable structure concerns, due to the low level of maturity include: consistent and reproducible mechanical behavior, durability in the presence of micrometeoroid impact, incorporation of material for radiation shielding, crew-induced damage, and repair techniques for long term survivability. Other areas of concern include, pre-integration solutions, storage of a pressurized volume within an expandable structure, and deployment techniques. Solicitations which address topics in these areas would be welcomed.

One remaining area of interest is the development of innovative deployable secondary structures that have minimal mass, high packaging efficiency, and multi-functional utilization. One simple example of a secondary structure could be a walkway internal to a lunar surface habitat, which could be reconfigured as a storage container or a radiation shield during a major solar flare event. These secondary multi-functional structures should provide highly robust, stiff and mass efficient surfaces that enable the useful outfitting and pre-integration of subsystems within the primary structural volume.

In general, development of structural concepts can include structural components, methods of validation, and/or predictive analysis capabilities. Analytical and numerical methods to analyze the behavior of soft-goods from a global scale, down to the fabric and strap level are desired. Methods and designs for integrating instrumentation into soft-goods, including the ability to detect damage, creep (strains), loads in the primary restraint layers, and temperatures are also desired. Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

**X5.02 Advanced Fabrication and Manufacturing of Metallic and Hybrid Materials for Lightweight Structures**

**Lead Center: LaRC**

**Participating Center(s): MSFC**
X5.03 Manufacturing of Polymer Matrix Composite (PMC) Structures
Lead Center: MSFC
Participating Center(s): ARC, GRC, KSC, LaRC

X5.04 Spaceflight Structural Sensor Systems and NDE
Lead Center: LaRC
Participating Center(s): ARC, JSC, MSFC

Spaceflight Structural Sensor Systems

Technologies sought include: modular/low mass-volume systems, stand-alone smart sensor systems that provide answers as close to the sensor as practical, Surface Acoustic Wave (SAW)-based sensors, passive wireless sensor-tags, flexible sensors for highly curved surfaces and direct-write film sensors. These systems allow for additions or changes in instrumentation late in the design/development process and enable relocation or upgrade on orbit. They reduce the complexities of standard wires and connectors and enable sensing functions in locations not normally accessible with previous technologies. They allow NASA to gain insight into performance and safety of NASA vehicles as well as commercial launchers, vehicles and payloads supporting NASA missions.

Mission Application Areas (Interior or Exterior):

(1) Add-on in-space modular sensors for:

- Commercial human-rated transportation systems
- Composite Overwrapped Pressure Vessels (COPVs) and other pressure-vessels
- International Space Station (ISS) habitable modules and exterior structure
- Inflatable habitat modules

(2) Built-in flight monitoring systems for:

- New COPV and other pressure vessels
- New manned and unmanned spacecraft
- New propulsion system tankage and transfer systems
- New heavy-lift vehicles: fairings, transition sections, engines, Thermal Protection Systems (TPS), tanks
• New transformational habitats and structures like inflatables

(3) Mobile sensor interrogation systems - robotic, wireless network or interrogation which can:

• Program and download data from smart systems without wires
• Acquire active/passive sensor-tag data
• Determine real-time position/orientation for other sensors or tools

Performance Goals/Metrics:

Ability to establish new functionality in one of the 3 areas above, and:

• Increase number of sensor locations per pound of monitoring weight by 50%
• Decrease the system monitoring electronics weight by 50%
• Decrease total wiring required for monitoring by 50%
• Decrease the time to plan and install monitoring by 50%
• Decrease the overall life-cycle cost per sensor by 50%
• Decrease total data rate required from sensor data acquisition location by 50%
• Decrease the expected cost of instrumentation changes/upgrades by 50%

NDE Systems for use during Spaceflight

Technologies sought include: modular/low mass/volume smart NDE sensors systems and associated software that enable effective use with minimum crew training or re-familiarization after extended periods of no use. Systems should include ability to perform inspections with minimal human interaction. These systems need to provide reliable assessments of the location and extent of damage with the minimal data transfer between vehicle and Earth. Methods are desired to perform inspections in areas with difficult access in pressurized habitable compartments and external environments. Many applications require the ability to see through conductive and/or thermal insulating materials without contacting the surface. Sensors that can dynamically and accurately determine position and orientation of the NDE sensor are needed to automatically register NDE results to precise locations on the structure. Structural design and material configurations are sought that can enhance NDE and monitoring. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who may only use the NDE tool infrequently, but need to make important assessments quickly. Micro-miniature, low power NDE inspection sensors are needed for potential use on free-flying inspection platforms. Integration of wireless systems with NDE may be of significant utility.
Mission Application Areas:

Enabling NDE (Interior and Exterior):

(1) On-orbit NDE sensor systems (e.g., Visual, Laser, Micro-wave, Terrahertz, Infra-red, X-ray backscatter, eddy current or other) that have high resolution and small form-factor to inspect:

- Thermal protection - Multi-Layer Insulation (MLI) and TPS) structures
- Inflatable habitats, Extra-Vehicular Activity (EVA) suits and visiting vehicles
- Electronic systems, environmental control systems, and other vehicle systems
- Conductive structures, Micro-Meteoroid and Orbital Debris (MMOD) shields, primary structure, pressure vessels
- Structures (COPV, module walls) under MLI/MMOD shielding
- Be deployed/used without the need for robotic manipulators or EVA crew

(2) On-orbit NDE sensor systems that can be used:

- In difficult access areas: flexible borescopes, micro-robots, smart sensors
- To identify, locate and quantify potential damage areas: MMOD damage, module and pressure vessel leaks, corrosion, etc.
- On robotically operated platforms: free-flyers, micro-robots, dexterous robots, or remote manipulators

Performance Goals/Metrics:

Ability to establish new functionality in one of the 2 areas above, and:

- Decrease total data-rate required from the NDE sensor by 50%
- Decrease time to perform NDE inspections by 50%
- Decrease the size, weight and power of NDE systems by 50%
X5.05 Low Temperature Mechanisms
Lead Center: GSFC
Participating Center(s): GRC, JPL, JSC, LaRC

Autonomous Systems and Avionics Topic X6

NASA invests in the development of advanced avionics, automation software, integrated system health management, and robust software technology capabilities for the purpose of enabling complex missions and technology demonstrations. The avionics and software elements requested within this topic are critical to enhancing flight system functionality, reducing system vulnerability to extreme radiation and thermal environments, reducing system risk, and increasing autonomy and system reliability through processes, operations, and system management. As a cross-cutting technology area, avionics and software are applicable to broad areas of technology emphasis, including heavy lift launch vehicle technologies, robotic precursor platforms, utilization of the International Space Station, and flagship technology demonstrations performed to enable long duration space missions. All of these flight applications will require unique advances in avionic and software technologies such as integrated systems health management, autonomous systems for the crew and mission operations, radiation hardened processors, and reliable, dependable software. Exploration requires the best of the nation’s technical community to step up to providing the technologies, engineering, and systems to regain the frontiers of the Moon, to extend our reach to Mars, and to explore the beyond.

Sub Topics:

X6.01 Automation for Vehicle and Crew Operations
Lead Center: ARC
Participating Center(s): JSC

Automation will be instrumental for decreasing workload, reducing dependence on Earth-based support staff, enhancing response time, and releasing crew and operators from routine tasks to focus on those requiring human judgment, leading to increased efficiency and reduced mission risk. To enable the application of intelligent automation and autonomy techniques, the technologies need to address two significant challenges: adaptability and software validation. Proposals are solicited in the areas of:

- **Automation Support Tools:** Support tools are needed to facilitate the authoring and validation of plans and execution scripts. Tools that are not tied specifically to one executive would provide NASA the most flexibility. Examples include: Graphical tool for monitoring and debugging plan execution and for creating and editing execution scripts; Tools for authoring and validating execution plans; User friendly abstraction of low-level execution languages by adding syntactic enhancements.
• **Decision Support:** Systems Decision support systems amplify the efficiency of operators by providing the information they need when and where they need it. Examples: Command and supervise complex tasks while projecting the outcome and identify potential problems; Understand system state, including visualization and summarization; Allow the system to interact with a user when generating the plan and allow evaluation of alternate courses of action; Integration of a planning and scheduling system as part of an on-board, closed loop controller.

• **Trustable Systems:** Systems that support or interact with crew require a very high level of reliability. Tools are needed that improve the reliability and trustworthiness of autonomous systems. These include: Ability to predict what the system will do; Guarantees of behavioral properties; Other properties that increase the operator’s trust; Verifiability (e.g., restricted executive languages that facilitate model-based verification).

**X6.02 Radiation Hardened/Tolerant and Low Temperature Electronics and Processors**

**Lead Center:** MSFC

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

Exploration flight projects, robotic precursors, and technology demonstrators that are designed to operate beyond low-earth orbit require avionic systems, components, and controllers that are capable of enduring the extreme temperature and radiation environments of deep space, the lunar surface, and eventually the Martian surface. Spacecraft vehicle electronics will be required to operate across a wide temperature range and must be capable of enduring frequent (and often rapid) thermal-cycling. Packaging for these electronics must be able to accommodate the mechanical stress and fatigue associated with the thermal cycling. Spacecraft vehicle electronics must be radiation hardened for the target environment. They must be capable of operating through a minimum total ionizing dose (TID) of 300 krad (Si), provide fewer Single Event Upsets (SEUs) than 10⁻¹⁰ to 10⁻¹¹ errors/bit-day, and provide single event latchup (SEL) immunity at linear energy transfer (LET) levels of 100 MeV cm²/mg (Si) or more. Electronics hardened for thermal cycling and extreme temperature ranges should perform beyond the standard military specification range of -55°C to 125°C, running as low as -230°C or as high as 350°C.

Considering these target environment performance parameters for thermal and radiation extremes, proposals are sought in the following specific areas:

• Low power, high efficiency, radiation-hardened processor technologies.

• Technologies and techniques for environmentally hardened Field Programmable Gate Array (FPGA)

• Innovative radiation hardened volatile and nonvolatile memory technologies.

• Tightly-integrated electronic sensor and actuator modules that include power, command and control, and processing.

• Radiation hardened analog application specific integrated circuits (ASICs) for spacecraft power management and other applications.
• Radiation hardened DC-to-DC converters and point-of-load power distribution circuits.

• Computer Aided Design (CAD) tools for predicting the electrical performance, reliability, and life cycle for low-temperature and wide-temperature electronic systems and components.

• Physics-based device models valid at temperature ranging from -230°C to +130°C to enable design, verification and fabrication of custom mixed-signal and analog circuits.

• Circuit design and layout methodologies/techniques that facilitate improved radiation hardness and low-temperature (-230°C) analog and mixed-signal circuit performance.

• Packaging capable of surviving numerous thermal cycles and tolerant of the extreme temperatures on the Moon and Mars. This includes the use of appropriate materials including substrates, die-attach, encapsulants, thermal compounds, etc.

Human-Robotic Systems Topic X7

This call for technology development is in direct support of the Exploration Systems Mission Directorate (ESMD). The purpose of this research is to develop component and subsystem level technologies to support robotic precursor exploration missions. To that end, it is the intent of this Topic to capitalize on advanced technologies that allow humans and robots to interact seamlessly and significantly increase their efficiency and productivity in space. The objective is to produce new technologies that will reduce the total mass-volume-power of equipment and materials required to support both short and long duration planetary missions. The proposals must focus on component and subsystem level technologies in order to maximize the return from current SBIR funding levels and timelines. Doing so increases the likelihood of successfully producing a technology that can be readily infused into existing robotic system designs. This research focuses on technology development for the critical functions that will ultimately enable surface exploration for the advancement of scientific research. Surface exploration begins with short duration missions to establish a foundation, which leads to extensible functional capabilities. Successive buildup missions establish a continuous operational platform from which to conduct scientific research while on the planetary surface. Reducing risk and ensuring mission success depends on the coordinated interaction of many functional surface systems including power, communications infrastructure, mobility and ground operations. This topic addresses technology needs associated with planetary surface systems infrastructure, interaction of humans and machines, mobility systems, payload and resource handling, and mitigation of environmental contaminations. Sub Topics:

X7.01 Robotic Systems for Human Exploration

Lead Center: JSC
Participating Center(s): ARC, GRC, JPL, JSC
High-Efficiency Space Power Systems Topic X8

This topic solicits technology development for high-efficiency power systems to be used for the human exploration of space. Technologies applicable to both space exploration and clean and renewable energy for terrestrial applications are of particular importance. Power system needs include: electric energy generation and storage for human-rated vehicles, electrical energy generation for in-space propulsion systems, and electric energy generation, storage, and transmission for planetary and lunar surface applications. Technology development is sought in: Electrochemical systems including fuel cells and electrolysers; Battery technology including components for improved performance and safety; Nuclear power systems including fission and radioisotope power generation; Photovoltaic power generation including solar cell, blanket/component and array technology; Power conversion and management technologies including solar dynamic and high conversion efficiency thermodynamic systems; reliable, radiation tolerant devices, and wireless power transmission.

Sub Topics:

X8.01 Fuel Cells and Electrolysers for Space Applications

Lead Center: GRC
Participating Center(s): JPL, JSC

Fuel Cells and Electrolysers for Space Applications

Advanced primary fuel cell and regenerative fuel cell energy storage systems are enabling for various aspects of future Exploration missions. Proton Exchange Membrane (PEM) and Solid Oxide Based systems are of particular interest.

Proton Exchange Membrane (PEM) Fuel Cells and Electrolysers

Proposals that address technology advances related to the following issues for PEM fuel cell, electrolysis, and regenerative fuel cell systems are desired.

Oxidation resistant gas diffusion layers (GDLs) for PEM fuel cell membrane-electrode-assemblies (MEAs) GDLs are integral to PEM fuel cell MEAs. Traditional carbon or graphite based GDLs are very susceptible to oxidation under certain operating conditions in the pure oxygen environment of space fuel cell systems. This results in MEA degradation and shortened life. Proposals addressing the development of oxidation resistant GDLs that remain stable to oxidation in a pure oxygen environment, and provide improved performance and longer life are desired.

Passive liquid-feed high-pressure PEM electrolysis technology - Water electrolysis technology is critical for water utilization and hydrogen/oxygen generation. Standard liquid-feed PEM electrolysis technology requires numerous mechanical ancillary components for reactant management functions, including pumps and two-phase water/gas separators. These components present life and reliability issues in addition to their inherent mass and volume penalties, and also require parasitic power for operation. Vapor-feed PEM electrolysis technology avoids the necessity of these ancillary components, but suffers from reduced electrochemical performance and operational constraints. Development of passive liquid-feed PEM electrolysis technology could offer the benefits of both aforementioned systems without the drawbacks. This would yield an electrolysis system with strong
electrochemical performance and a minimum of ancillary components with their inherent system penalties.

**Oxidation resistant, electrically conductive, hydrophilic coatings** for internal cell components within PEM fuel cells and electrolyzers. Liquid water is produced within the reactant cavities of PEM fuel cells and consumed within the reactant cavities of PEM electrolyzers. In the case of a non-flow-through PEM fuel cell, the liquid product water moves across an open but supported gas cavity and through a water/gas separation barrier into a liquid cavity. If the supporting cell components within the gas cavity are hydrophobic, the water will be transported as droplets, which could impede gas flow and subsequently reduce electrochemical performance. If these supporting components are hydrophilic, the water is more likely to be transported as a film along the support structure and not impede gas flow. In the case of a PEM electrolyzer, water is moving in the opposite direction and therefore into the reactant cavity. A hydrophilic support structure would allow a flowing film of liquid water to reach the cell MEA while still maintaining an open reactant cavity relative to gas flow. In essence, an electrolysis cell assembly designed for vapor-feed operation could operate in a liquid-feed mode. This would yield a system with strong electrochemical performance and a minimum of ancillary components with their inherent system penalties.

**Stable, highly efficient, long-life MEAs and catalysts for PEM fuel cells and electrolyzers** - PEM fuel cells and electrolyzers are key technologies for space systems utilizing hydrogen, oxygen, or water as reactants. In order to improve the life and reliability of the electrochemical stacks within these systems, as well as to reduce overall system mass/volume and cost, development of MEAs and catalysts that are stable and highly efficient is critical. Techniques to accomplish this goal include, but are not limited to, alternative noble metal and mixed oxide catalysts with increased surface areas, advanced binders and catalyst layer application techniques, alternative ionomer formulations, and high-temperature membrane compatibility.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

**Solid Oxide Fuel Cells and Electrolyzers**

Advanced primary Solid Oxide Fuel Cells (SOFC) and Electrolyzers offer notable advantages in certain space applications when integrated with, respectively, \( \text{CH}_4/\text{O}_2 \) propulsion systems and systems for producing oxygen from planetary resources. Technology advances that reduce the weight and volume, improve the efficiency, life, safety, system simplicity and reliability of Solid Oxide Fuel Cells and Electrolyzers are desired. Proposals are sought which address the following areas:

**Advanced Primary SOFC Systems**: Their high temperature heat rejection and high efficiency power generation from methane and oxygen make primary SOFC’s attractive for application to spacecraft with \( \text{CH}_4/\text{O}_2 \) propulsion systems. Research directed towards improving the durability, efficiency, and reliability of SOFC systems fed by propellant-grade methane and oxygen is desired.

Primary SOFC components and systems of interest:

- Have power outputs in the 1 to 3 kW range.
• Offer thermodynamic efficiencies of at least 70% (fuel source-to-DC output) when operating at the current draw corresponding to optimized specific power.

• Operate as specified after at least 300 start-up cycles (from cold to operating temperature within 5 minutes) and 300 shut-down cycles (from operating temperature to cold within 5 minutes).

• Operate as specified after at least 2500 hours of steady state operation on propellant-grade methane and oxygen.

• Are cooled by way of conduction through the stack to a radiator exposed to space.

**Advanced Solid Oxide Electrolyzers:** Their high temperature heat rejection and operation, along with high efficiency, make solid oxide electrolyzers attractive as the final step of producing oxygen from Lunar regolith by way of hydrogen or carbothermal reduction. They are also attractive components for Sabatier reactors producing methane from the Martian atmosphere. Research directed towards improving the durability, efficiency, and reliability of solid oxide electrolyzers is desired.

Solid oxide electrolysis systems of interest:

• Require power inputs in the 1 to 3 kW range.

• Operate as specified after 10,000 hours of operation fed by water with mild contamination

• Operate as specified after 100 start-up cycles (from cold to operating temperature within 5 minutes) and 100 shut-down cycles (from operating temperature to cold within 5 minutes).

• Offer thermodynamic efficiencies of at least 70% (DC-input to Lower Heating Value H\textsubscript{2} output) when operating at the current feed corresponding to rated power.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

**X8.02 Advanced Space-Rated Batteries**

*Lead Center: GRC*

* Participating Center(s): JPL, JSC

**X8.03 Space Nuclear Power Systems**
X8.04 Advanced Photovoltaic Systems

Lead Center: GRC
Participating Center(s): JPL, JSC

- Solar cell, blanket component and advanced solar array technology with high operating efficiency (>30%), low mass (>200W/kg), and low stowed volume;
- PV technology capable of long-term, reliable of planetary surface operation under dust, temperature extreme (high and low), radiation, and other space environmental conditions;
- Advanced concepts for array packaging, autonomous deployment, retraction and redeployment;
- Modular, high power (10s to 100s kWe) concepts with lifetimes greater than 10 years;
- High voltage (>200 Volts) array designs capable of reliable operation under space environmental conditions.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. A major focus will be on the demonstration of dual-use technologies for clean and renewable energy for terrestrial applications.

X8.05 Advanced Power Conversion, Management, and Distribution (PMAD) for High Power Space Exploration Applications

Lead Center: GRC

Advanced power conversion technologies are sought for improvements in efficiency and reliability of power conversion for space exploration missions. Power levels for applications are expected to be in the range of 10s to 100s of kWe. System and component technologies are sought that can deliver efficiency and reliability improvements in this power range in the space environment.

In addition, advanced Power Management and Distribution (PMAD) technologies are required for the electrical components and systems on future high power platforms to address size, mass, efficiency, capacity, durability, and reliability improvements Of importance are improvements in energy density, speed, efficiency, and wide temperature (-125°C to over 450°C) with a number of thermal cycles.
Power conversion and PMAD technologies must enable or enhance the ability to provide low-cost, abundant power for deep space missions, with requirements from 10s to 100s of kWe and months to years of mission duration.

Examples of Power Conversion technology areas:

- High conversion efficiency for Brayton, Stirling or Rankine power converters;
- High efficiency solar dynamic deployable solar concentrators and collectors;
- Research into advanced Power Conversion system concepts.

Examples of PMAD technology areas:

- Highly reliable devices and components;
- Radiation tolerance;
- Advanced power bus solutions;
- Technologies for high pulse power applications such as advanced energy storage devices;
- Efficient wireless power transmission.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. A major focus will be on the demonstration of dual-use technologies for clean and renewable energy for terrestrial applications.
The Thermal Protection System (TPS) protects a spacecraft from the severe heating encountered during hypersonic flight through a planetary atmosphere. In general, there are two classes of TPS: reusable and ablative. Typically, reusable TPS applications are limited to relatively mild entry environments like that of Space Shuttle. No change in the mass or properties of the TPS material results from entry with a significant amount of energy being re-radiated from the heated surface and the remainder conducted into the TPS material. Typically, a surface coating with high emissivity (to maximize the amount of energy re-radiated) and with low surface catalycity (to minimize convective heating by suppressing surface recombinination of dissociated boundary layer species) is employed. The primary insulation has low thermal conductivity to minimize the mass of material required to insulate the primary structure. Ablative TPS materials, in contrast, accommodate high heating rates and heat loads through phase change and mass loss. All NASA planetary entry probes to date have used ablative TPS. Most ablative TPS materials are reinforced composites employing organic resins as binders. When heated, the resin pyrolyzes producing gaseous products that are heated as they percolate toward the surface thus transferring some energy from the solid to the gas. Additionally, the injection of the pyrolysis gases into the boundary layer alters the boundary layer properties resulting in reduced convective heating. However, the gases may undergo chemical reactions with the boundary layer gases that could return heat to the surface. Furthermore, chemical reactions between the surface material and boundary layer species can result in consumption of the surface material leading to surface recession. Those reactions can be endothermic (vaporization, sublimation) or exothermic (oxidation) and will have an important impact on net energy to the surface. Clearly, in comparison to reusable TPS materials, the interaction of ablative TPS materials with the surrounding gas environment is much more complex as there are many more mechanisms to accommodate the entry heating. NASA has successfully tackled the complexity of thermal protection systems for numerous missions to inner and outer planets in our solar system in the past; the knowledge gained has been invaluable but incomplete. Future missions will be more demanding. Better performing ablative TPS than currently available is needed to satisfy requirements of the most severe missions, e.g., Mars Landing with 8 km/s entry and Mars Sample Return with 12-15 km/s Earth entry. Beyond the improvement needed in ablative TPS materials, more demanding future missions such as large payload missions to Mars will require novel entry system designs that consider different vehicle shapes, deployable or inflatable configurations and integrated approaches of TPS materials with the entry system sub-structure.

Sub Topics:

X9.01 Ablative Thermal Protection Systems
Lead Center: ARC
Participating Center(s): GRC, JPL, JSC, LaRC

X9.02 Advanced Integrated Hypersonic Entry Systems
Lead Center: ARC
Participating Center(s): GRC, JPL, JSC, LaRC

Cryogenic Propellant Storage and Transfer Topic X10
The Exploration Systems architecture presents cryogenic storage, distribution, and fluid handling challenges that require new technologies to be developed. Reliable knowledge of low-gravity cryogenic fluid management behavior is lacking and yet is critical for future manned and robotic exploration in the areas of storage, distribution, and low-gravity propellant management. Additionally, Earth-based and planetary surface missions will require success in
storing and transferring liquid and gas commodities in applications. Some of the technology challenges are for long-term space use cryogenic propellant storage and distribution; cryogenic fluid ground processing and fluid conditioning; liquid hydrogen and liquid oxygen liquefaction processes on the lunar surface. Furthermore, specific technologies are required in valves, regulators, instrumentation, modeling, mass gauging, cryocoolers, and passive and active thermal control techniques. The technical focus for component technologies are for accuracy, reduced mass, minimal heat leak, minimal leakage, and minimal power consumption. The anticipated technologies proposed are expected to increase safety, reliability, economic efficiency over current state-of-the-art cryogenic system performance, and are capable of being made flight qualified and/or certified for the flight systems and dates to meet Exploration Systems mission requirements.

Sub Topics:

**X10.01 Cryogenic Fluid Management Technologies**

**Lead Center:** GRC

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

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**Exploration Crew Health Capabilities Topic X11**

Human space flight is associated with losses in muscle strength, bone mineral density and aerobic capacity. Crewmembers returning from the International Space Station (ISS) can lose as much as 10-20% of their strength in weight bearing and postural muscles. Likewise, bone mineral density is decreased at a rate of ~1% per month. During future exploration missions such physiological decrements represent the potential for a significant loss of human performance which could lead to mission failure and/or a threat to crewmember health and safety. The ability to perform motion capture and kinematic analysis on-orbit to understand the similarities and differences of exercising in microgravity, estimate the physical cost of exploration tasks, monitor crew health and fitness, and to provide effective hardware for exercise countermeasures use will be valuable in supporting safe and successful space exploration. In this solicitation, Exercise Systems is seeking technologies to enable 3-D kinematic analysis of exercise sessions in-flight, and analyzed by research teams on the ground. Visit the following for additional information: [http://hacd.jsc.nasa.gov/projects/ecp.cfm](http://hacd.jsc.nasa.gov/projects/ecp.cfm) [1], [http://hacd.jsc.nasa.gov/projects/eva.cfm](http://hacd.jsc.nasa.gov/projects/eva.cfm) [2].

Sub Topics:

**X11.01 Crew Exercise System**

**Lead Center:** GRC

**Participating Center(s):** JSC

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**Exploration Medical Capability Topic X12**

Further human exploration of the solar system will present significant new challenges to crew health including...
hazards created by traversing the terrain of lunar or planetary surfaces and the effects of variable gravity environments. The limited communications with ground-based personnel for diagnosis and consultation of medical events creates additional challenges. Providing health care capabilities for the moon and mars will require the definition of new medical requirements and development of technologies to ensure the safety and success of Exploration missions, pre-, in-, and post-flight. This SBIR Topic addresses some key medical technology and gaps that NASA will need to solve in order to proceed with exploration missions.

Sub Topics:

**X12.01 Spaceflight Auscultation Capability**

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

Analysis of body sounds for abnormalities is standard medical practice for diagnosing a medical condition. This call is for technology that can isolate internal body sounds (heart beating, breathing, etc.) in a potentially noisy ambient environment (up to 70 dBA) and capture the auscultation data to be managed and transmitted digitally to the appropriate destination for analysis.

Current commercially available systems have two main issues. Some systems pick up all sounds without filtering out the sounds of interest. Other systems use technology (e.g. doppler) that produce sounds that are not readily familiar to clinicians—thereby necessitating retraining.

**Phase I Deliverable:** Technical Feasibility Report; Draft Requirements Document  
**Phase II Deliverable:** Prototype Hardware

**X12.02 Quantifying Bone Degradation with High Resolution Ultrasound**

**Lead Center:** GRC

Loss of bone strength, mass and density are known medical complications of space flight, where the static load of gravity is no longer present. The process of bone demineralization begins almost immediately upon an astronaut's arrival into a microgravity environment and appears to continue unabated. The losses occur particularly in weight bearing bone regions of the lower spine, hip and legs. NASA will eventually require diagnostics techniques that can perform in vivo quantitative evaluations of bone mineral density (BMD) and trabecular micro-architecture (i.e., porosity, trabecular size and geometry) during manned Exploration class missions. As an incremental step toward this end, a high-resolution diagnostic or imaging device is required for performing the quantitative evaluations identified above ex vivo with a technology that shows significant promise for adaptability to long duration human space flight. The device should be capable of resolving the trabecular micro-structure for analysis. The device should also demonstrate sufficient penetration depth in the body to eventually adapt the technology for in vivo evaluations of the calcaneus and lumbar spine, at a minimum. Efforts should be made to minimize the volume, mass, electromagnetic emissions and power draw of the device and its associated peripheral equipment. The use of ionizing radiation is not restricted, but its use is considered highly undesirable in a manned space flight environment and should, therefore, be minimized. This technology is desired for possible demonstration on ISS and for targeted deployment on future Exploration class vehicles supporting long duration missions.
X12.03 Lab to Marketplace: Commercializing Spaceflight Biomedical and Behavioral Research Tools

Lead Center: JSC

NASA and SBIR invest a significant amount of funds in the development of new technologies to study human physiology and behavior during spaceflight. This investment has produced a large number of technologies that include hardware (e.g., instruments, devices, etc.) and software (e.g., computational models, informatics tools, data analytic methods, etc.) While these technologies are put to good use by their developers, such non-commercial developers devote little attention to making their tools robust and easy to use by the broad research or clinical communities. Consequently, the promise of these advanced technologies is often realized only by the tool's developers and their close associates. Moreover, ongoing support to maintain and update technologies in non-commercial settings is difficult to obtain.

In contrast, tools that are commercially available need to be sturdy and easy to use, and commercial success often provides the means for continued maintenance and improvements of the underlying technology. This call is intended to formulate business plans that will move useful technologies from non-commercial laboratories into the commercial marketplace by inviting SBIR grant applications for further development of such technologies that are relevant to the missions of the NASA’s Human Research Program. The supported research and development will likely include making the tools more robust and easy to use, advancing the Technology Readiness Levels (TRLs) from TRL 3-4 to TRL 6-7 and will likely require close collaboration between the original developers of these technologies and commercial partners.

Biomedical devices currently being developed that this will be focused on are: assisted medical procedure viewer, physiological and medical models, minimally invasive laboratory analysis capabilities, medical imaging techniques and procedures.

Phase I Deliverables: 5 business plans for current NASA/SBIR technology projects. These should include: market analysis; gap analyses reports between current state of 5 NASA biomedical technologies and what would be needed for commercialization/venture capital funding.

Phase II Deliverables: Updated business plans to include the following strategies: FDA regulatory; reimbursement; product adoption; competitive analysis; manufacturing costs; sales; use of proceeds; marketing; clinical trials.

X12.04 Batteries for Oxygen Concentrators

Lead Center: GRC

Advanced high energy battery systems are sought for use in Exploration Medical Capabilities mission applications such as power for mobile oxygen concentrators. There are only a few battery chemistries with a reasonable chance of achieving the target specific energies. Metal/air battery systems are the most likely candidates. The most common type of commercial metal/air battery utilizes zinc/air chemistry and has a practical specific energy of ~370 Wh/kg. While this battery chemistry has a theoretical specific energy of 1350 Wh/kg, it is not possible for this chemistry to meet the specific energy goals for these applications (>2000 Wh/kg). In addition to zinc/air batteries, aluminum/air batteries are also available in the commercial market, although only in a limited fashion. Aluminum/air batteries have a much greater theoretical specific energy (8140 Wh/kg) and although they currently have a practical specific energy of ~350 Wh/kg, the potential for significant near-term improvement exists. The highest theoretical
specific energy for a metal/air battery chemistry is lithium/air at 11,500 Wh/kg giving it and aluminum/air batteries the best potential to realize the high specific energy values needed for Exploration Medical Capabilities mission applications.

The focus of this solicitation is on the development of a high specific energy battery that can meet the following goals:

- Specific energy (battery level) >2000 Wh/kg;
- Operating Temperature Range from 0°C to 35°C;
- Shelf life >2 years.

All classes of metal-air batteries (aqueous, non-aqueous, and solid state) as well as other battery chemistries will be considered if they fall within the guidelines of performance. Additionally, the battery system will be used inside a crewed space vehicle and must meet the requisite safety guidelines stated in "Crewed Space Vehicle Battery Safety Requirements".

Phase I research should be conducted to demonstrate technical feasibility and deliver multiple cell-level demonstration units at the conclusion of the contract. Additionally, a path toward a Phase II hardware demonstration should be shown which leads to the delivery of multiple module-level demonstration units mid-way through the phase II contract and multiple TRL 4 battery-level demonstration units for TRL 5/6 validation and verification testing at the end of the phase II contract.

Behavioral Health and Performance Topic X13

The Behavioral Health and Performance topic is interested in developing strategies, tools, and technologies to mitigate Behavioral Health and Performance risks. The Behavioral Health and Performance topic is seeking tools and technologies to prevent performance degradation, human errors, or failures during critical operations resulting from: fatigue or work overload; deterioration of morale and motivation; interpersonal conflicts or lack of team cohesion, coordination, and communication; team and individual decision-making; performance readiness factors (fatigue, cognition, and emotional readiness); and behavioral health disorders. For 2010, the Behavioral Health and Performance topic is interested in the following technologies: Unobtrusive behavioral health monitoring tools:
specifically a tool(s) which would monitor physiological markers of stress and emotional states. Proposals should respond in this area: [http://humanresearch.jsc.nasa.gov/elements/bhp/asp](http://humanresearch.jsc.nasa.gov/elements/bhp/asp) [3], [http://www.nsbri.org/Research/Psycho.html](http://www.nsbri.org/Research/Psycho.html) [4].

Sub Topics:

**X13.01 Behavioral Health Monitoring Tools**

**Lead Center: JSC**

The NASA Behavioral Health and Performance Program Element (BHP) identifies and characterizes the behavioral health and performance risks associated with training, living and working in Space, and return to Earth. BHP develops strategies, tools, and technologies to mitigate these risks. Currently, BHP has the need for behavioral health monitoring tools specific to the long duration Exploration Mission environment. The aim of the current task is to provide a non-invasive technology that would unobtrusively monitor and detect physiological markers of chronic stress that could lead to behavioral or performance decrements. Factors may include the changes in Central Nervous System, Autonomic Nervous System, emotional state, environment, gestures, and speech. The stress monitoring system would automatically generate meaningful feedback for the user regarding their individual behavioral health status based on measures of physiological, psychological and emotional state.

**Requirements:** The stress assessment tool shall:

- Be unobtrusive;
- Require minimal crew time or effort;
- Monitor physiological markers of stress and emotional state;
- Provide meaningful feedback to user regarding individual behavioral health status;
- If decrements are detected, the measure shall provide meaningful feedback to user regarding recommended course of action or treatment.

**Phase I Deliverables:** A final report summarizing current accepted methods and measures of physiological markers of stress as they relate to performance, the current state of technologies, recommendations regarding enhancements to current technology or the development of a new technology with the technology enhancement or development concept fully described. A draft requirements document for the recommended technology.
The emphasis on developing new, innovative technologies to enable future Space Exploration encompasses a need for new approaches in the areas of Space Human Factors and Food Systems. Operations in confined, isolated, and foreign environments can lead to impairments of human performance. Research and development activities in this topic address challenges that are fundamental to design, development, and operation of the next generation crewed space vehicles. These challenges include: (1) technologies to unobtrusively and non-invasively measure crew task performance in real time, and (2) a need to develop, evaluate, and deliver food technologies for human spacecraft that allow for food processing or preparation in a reduced gravity and reduced pressure environment to support crews on missions beyond low earth orbit, and efficiently balance vehicle resources such as mass, volume, water, air, waste, power, and crew time.


Sub Topics:

X14.01 Technologies for Non-Invasive Measurement and Analysis of Human Task Performance

Lead Center: ARC  
Participating Center(s): JSC

X14.02 Advanced Food Technologies

Lead Center: JSC

The purpose of the Advanced Food Technology Project is to develop, evaluate and deliver food technologies for human centered spacecraft that will support crews on missions beyond low earth orbit. A safe, nutritious, acceptable, and varied food system will be required to support the crew during future exploration missions. Concurrently, the food system must efficiently balance appropriate vehicle resources such as mass, volume, water, air, waste, power, and crew time. For example, it would require approximately 10,000 kg of packaged food with a 5-year shelf life for a 6-crew, 1000 day mission to Mars.

It has been proposed to use a food system which incorporates processing of raw ingredients into edible ingredients and uses these edible ingredients in recipes in the galley to produce meals. This type of food system will require technologies that will allow these raw ingredients to maintain their functionality and nutrition for 5-years. This food system would also require food processing and food preparation equipment. The equipment should be miniaturized, multipurpose and efficiently use vehicle resources such as mass, volume, water, and power.

There are some unique parameters that need to be considered when developing the technologies. The Moon's gravity is 1/6 of Earth's gravity, and that of Mars is 3/8 of Earth's. In addition, it is proposed that the habitat will have an atmospheric pressure of 8 psia, equivalent to being on a 16,000 foot mountain top. These two factors will affect heat and mass transfer during food processing and food preparation.

The response to this subtopic should include a plan to develop a technology that will enable safe and timely food processing and food preparation in reduced pressure and reduced gravity. Phase I should concentrate on the scientific, technical, and commercial merit and feasibility of the proposed innovation resulting in a feasibility report and concept, complete with analyses and top-level drawings.
Deliverables: Conceptual designs for food preparation or food processing equipment that can be used in partial gravity while efficiently balancing appropriate vehicle resources such as mass, volume, waste, and crew time.

Space Radiation Topic X15

The goal of the NASA Space Radiation Research Program is to assure that we can safely live and work in the space radiation environment, anywhere, any time. Space radiation is different from forms of radiation encountered on Earth. Radiation in space consists of high-energy protons, heavy ions and secondary products created when the protons and heavy ions interact with matter such as a spacecraft, surface of a planet, moon or asteroid. NASA requires instruments that can reliably measure these radiations. For exploration class missions, there is extraordinary premium on compact and reliable active radiation detection systems to meet very stringent size and power requirements. NASA needs compact, low power, active monitors that can measure charged particle spectrum and flux separately from neutrons and other radiations. NASA also needs compact active neutron spectrometers that can measure the neutron component of the dose separate from the charged particles. Advanced technologies up to technology readiness level (TRL) 4 are requested in the following areas: Charged particle spectrometer that is capable of measuring charge and energy spectra of ions with energies, linear energy transfer (LET) characteristics, and dose-rate parameters specified here. Neutron spectrometer that is capable of measuring neutrons with energies, dose rates, and other performance parameters specified here.

Sub Topics:

X15.01 Active Charged Particle and Neutron Measurement

Lead Center: ARC

For exploration class missions, there is extraordinary premium on compact and reliable active radiation detection systems to meet very stringent size and power requirements. NASA needs compact, low power, active monitors that can measure charged particle spectrum and flux separately from neutrons and other radiations. NASA also needs compact active neutron spectrometers that can measure the neutron component of the dose separate from the charged particles. Advanced technologies up to technology readiness level (TRL) 4 are requested in the following areas:

Charged Particle Spectrometer

Measure charge and energy spectra of protons and other ions (Z = 2 to 26) and be sensitive to charged particles with linear energy transfer (LET) of 0.2 to 1000 keV/micrometer. For Z less than 3, the spectrometer should detect energies in the range 30 MeV/n to 400 MeV/n. For Z = 3 to 26, the spectrometer should detect energies in the range 50 MeV/n to 1 GeV/n. Design goals for mass should be 2 kg and for volume, 3000 cm³. The spectrometer should be able to measure charged particles at both ambient conditions in space (0.01 mGy/hr) and during a large solar particle event (100 mGy/hr). The time resolution should be less than or equal to 1 minute. The spectrometer
shall be able to perform data reduction internally and provide processed data.

**Neutron Spectrometer**

Measure neutron energy spectra in the range of 0.5 MeV to 150 MeV. Measure neutrons at ambient conditions such that proton/ion veto capability should be approaching 100% at solar minimum GCR rates; measure ambient dose equivalent of 0.02 mSv in a 1 hour measurement period, using ICRP 74 (1997) conversion factors; store all necessary science data for post measurement data evaluation. Design goals for mass and volume should be 5 kg and 6000 cm$^3$.

**Inflight Biological Sample Preservation and Analysis Topic X16**

Flight resources such as the International Space Station are essential assets for the Human Research Program goals of quantifying the human health and performance risks for crews during exploration missions. However, the resources for carrying supplies and returning biological samples to/from these assets are limited. Thus, the Human Research Program must identify the means for inflight sample analysis or unique sample processing techniques that minimize the need to return conditioned human samples for analysis. The Inflight Biological Sample Preservation and Analysis topic is seeking innovative technologies or techniques to: provide On Orbit Ambient Biological Sample Preservation Techniques and On Orbit Biologic Sample Analysis capabilities.

Sub Topics:

**X16.01 Alternative Methods for Ambient Preservation of Human Biological Samples During Extended Spaceflight and Planetary Operations**

*Lead Center: JSC*

*Participating Center(s): ARC*

Measurement of blood, plasma, and urine analytes is a common clinical medicine practice used for differential disease diagnosis and determination of the therapeutic response to treatment. Accurate biochemical results depend on maintaining the integrity of blood and urine samples until analyses can be completed. Improper sample collection, handling, or preservation may lead to critical errors in diagnostic interpretation of analytical results. Traditional methods have been developed that include the use of sample component separation by means of centrifugation, refrigeration, freezing or the addition of preservatives to maintain the integrity of biological samples. While such techniques are easily achieved in a routine clinical setting, the spaceflight environment presents unique challenges to sample processing and stowage. Thus, novel on-orbit methods for the ambient preservation of biological samples are critical for scientific research, monitoring of crew health and evaluation of countermeasure efficacy. The development of alternative innovative techniques with advantages over currently used methods for processing and preserving biological samples at ambient temperatures during spaceflight that provide a high level of reliability in maintaining a wide array of both blood and urine analytes over a long period of ambient stowage is highly desirable.
Phase I expectations include at a minimum a fully developed concept with feasibility analyses. A prototype is highly desirable.

Regolith/Soil Transfer, Handling, & Processing of Extraterrestrial Material Topic X1.01

Regolith/Soil Transfer and Handling

- Long-life, light-weight, and minimum consumable technologies to move feedstock material from the surface or a collection hopper to processing reactors (at least 3m); High separation efficiency gas/solid particle separation techniques and regenerable particle filters
- Granular materials mixing and size separation for reactor feedstock conditioning: remove material > 0.5 cm diameter before dumping into storage bin during excavation operation for oxygen extraction from regolith
- Granular flow computer models, devices, and instruments to evaluate material flow and manipulation under low and micro-gravity flight and ground vacuum experimental conditions
- Mineral beneficiation concepts to separate iron oxide-bearing material from bulk regolith; up to 20 kg/hr based on hydrogen reduction

Regolith/Soil Processing To Extract Resources and Products of Interest

- Regolith/soil valve/seal concepts for processing systems with no gas leakage after 1000’s of operating cycles with material. For processes that require elevated temperatures, thermal isolation or minimum heat loss is required
- Regolith/soil processing reactor concepts for extracting volatiles and water/ice
- Regolith/soil processing reactor concepts for extracting metals through electrolysis and/or metal/waste/salt removal and separation techniques.
- High temperature (=1000 C), high efficiency insulation for regolith/soil processing reactors
- High temperature (=1000 C) pressure sensors and instruments for process control and performance assessment
- Alternative thermal, chemical, and/or biological processing concepts for oxygen (and potentially metal) extraction from regolith/soil besides
Hydrogen Reduction and Carbothermal Reduction Processes

- Light-weight, deployable solar concentrator concepts and solar energy transfer methods into regolith/soil processing reactors
- Low energy loss methods for redirecting solar energy from concentrators and fiber optic cables to allow multiple users in series

Regolith/Soil Processing for Protection, Construction, and Energy

- Thermal energy storage and utilization using bulk or processed regolith
- Techniques for hardening or modifying in-situ materials so that landing pads and roads can be constructed to prevent landing plume debris damage and wear on surface mobility platforms

Sub Topics:
Gas, Liquid, and Solid Processing to Produce Oxygen and Fuels from In-Situ Resources Topic X1.02

Solid/Gas Processing to Support Oxygen and Fuel Production

- Gas Separators for lunar oxygen extraction from regolith that provide low pressure drop separation of the system and product gas streams from impurities (e.g. HCl, HF, H₂S, SO₂); the process should be regenerable and the output contaminant concentration should be less than 50 ppb
- Hydrogen gas pumps with rates (up to 6 scfm) for recirculation and pneumatic transport
- Carbon dioxide collection and separation from Mars atmosphere
- High efficiency carbon dioxide/carbon monoxide separation concepts with high quality carbon dioxide produced
- Long-life carbon dioxide electrolysis/dissociation into carbon monoxide and oxygen concepts with high conversion efficiency at pressures greater than or equal to 1 bar

Water Processing

- Water/gas separators that use the space environment for water condensation/separation with minimal energy usage; concepts that can operate in both low-gravity (1/6-g and 3/8-g) and micro-gravity are of greatest interest
- Removal of dissolved ions in water by methods other than de-ionization resins to meet water electrolysis purity requirements (minimum resistivity of 1M-Ohms-cm). Ions of interest are dissolved metal ions (Fe, Cr, Co, Ni, Zn) at concentration of 0.01% and dissolved anions (Cl, F, S) at concentrations of 0.01%-2%. The process should be regenerable, minimize consumables, and minimize water loss.
- Contaminate resistant, high temperature water electrolysis concepts
Trash/Waste Processing for Fuel Production

- Processing concepts for production of carbon monoxide, carbon dioxide, water, and methane from plastic trash and dried crew solid waste. Proposals must define use of solar or electrical energy during processing, and any reagents/consumables; recycling schemes for reactants/reagents used in the processing should be evaluated.

- Methods for waste/trash transfer and handling before and after processing.

Sub Topics:

Earth-to-Orbit Propulsion Topic X2.01

NASA is interested in innovative Earth-to-Orbit (ETO) propulsion systems and component technologies, as well as design and analysis tools used to support the assessment of the technical viability of those systems. Next generation launch systems will require propulsion systems that deliver high thrust-to-weight ratios, increased trajectory averaged specific impulse, reliable overall vehicle systems performance, low recurring costs, and other innovations required to achieve cost and crew safety goals.

Proposals should address technical issues related to Earth-to-Orbit (ETO) LOX/Hydrocarbon engines and LOX/Hydrogen second stage engines including engine and main propulsion systems design and integration, turbomachinery, combustion devices, valves, actuators, and ducts. Areas of specific interest for technology advancement and innovations include the following:

- Advancements in design and analysis tools applicable to assessment of ETO propulsion systems including engine systems, turbomachinery, valves, and combustion device concepts. Of particular interest are design and analysis tools that provide improved understanding and quantification of component, subsystem, and system operating environments and that significantly enhance the overall systems engineering evaluation of potential ETO propulsion concepts. Examples include low and high fidelity tools suitable for component and parameter sensitivity analysis and optimization, dynamic environment prediction, quantification of system benefits to changes.

- Improved propulsion systems stability prediction analysis and design tools, along with stability aid concepts and demonstration of approaches (i.e., rotordynamic coefficients, turbopump cavitation, instabilities, combustion stabilities, structural-acoustic, propellant management, and fluid dampers.)

- Innovative tools for predicting the complex fluid and structural interactions within rocket nozzles and experimental methods and data for validating these tools. Specific areas of interest include nozzle side loads induced by nozzle flow separation during engine start and shutdown transients and the effect of fluctuating pressure during engine main stage.

- Improvements to tools that predict the environments in and around the engine during booster operation.
Data to validate the accuracy of high fidelity design and analysis tools used for the prediction of internal rocket engine environments.

Design concepts that improve performance, reduce cost, reduce weight or improve reliability of the propellant feed systems, valves. Of particular interest are:

- Design concepts for high power density turbines,
- Design concepts for low net positive suction pressure pumps,
- Design concepts for low cost, reliable valves and their actuation system,
- Demonstration of robust bearing design concepts for large, high speed rotors,
- Identification and demonstration of high strength materials that are resistant to combustion in a high pressure, oxygen rich environment.

Sub Topics:
Non-Toxic In-Space Propulsion Topic X2.02
This solicitation intends to examine a range of key technology options associated with cryogenic and non-toxic storable propellant space engines. Non-toxic engine technology is desired for use in lieu of the currently operational NTO/MMH engine technology. Safety concerns with toxic propellants drive mission planners to the use of more costly propulsion modules that are fueled and sealed on the ground. Non-toxic engine technologies could range from reaction control class of 25-1000 lbf to main engines of up to 60,000 lbf with both pump fed or pressure fed systems.

Specific technologies of interest to meet proposed engine requirements include:

- Non-toxic bipropellant or monopropellants that meet performance targets (as indicated by high specific impulse and high specific impulse density) while improving safety and reducing handling operations as compared to current state-of-the-art storable propellants.
- Low-mass propellant injectors that provide stable, uniform combustion over a wide range of propellant inlet temperature and pressure conditions.
- High temperature materials, coatings and/or ablatives for injectors, combustion chambers, nozzles, and nozzle extensions.
- Combustion chamber thermal control technologies such as regenerative, transpiration, swirl or other cooling methods, which offer improved performance and adequate chamber life.
- Technologies are also solicited that enable deep-throttling turbopumps to operate at off-design flow coefficients while eliminating flow instabilities such as cavitating surge.
- Highly-reliable, long-life, fast-acting propellant valves that tolerate long duration space mission environments with reduced volume, mass, and power requirements is also desirable.
- Cryogenic instrumentation such as pressure and temperature sensors that will operate for months/years instead of hours.

Note to Proposer: Subtopic S3.04 under the Science Mission Directorate also addresses in-space propulsion.
Proposals more aligned with science mission requirements should be proposed in S3.04.

Sub Topics:
Nuclear Thermal Propulsion Topic X2.03
NASA is interested in the development of critical technologies for first in-space applications of solid core nuclear thermal propulsion (NTP) systems for use in future exploration missions. For short round trip missions to MARS, NTP systems may be enabling by helping to reduce launch mass to reasonable values and by also increasing the payload delivered for Mars exploration missions.

Preliminary solid core NTP system concepts could be based on a high thrust/high ISP (~850-950s) NTP system that would use a fission reactor with U-235 fuel as its source of thermal energy. During the short primary propulsion maneuvers of a typical conceptual mission, large quantities of thermal power (100's of MWt) would be produced within the NTP system and removed using liquid hydrogen propellant that is pumped through the engine’s reactor core. The superheated hydrogen gas is then exhausted out the engine's nozzle to generate thrust. Representative ranges of engine performance include: (1) hydrogen exhaust temperatures ~2500 - 2900K, (2) propellant flowrates ~7 - 13 kg/s, (3) chamber pressures ~500 - 1500 psi, and (4) nozzle expansion area ratios ~200:1 - 500:1.

Proposals are sought to further improve factors contributing to safety, performance, reliability, and life as well as reduce projected weight and costs for the first in-space NTP systems, subsystems, and components beyond that in previously achieved ground test systems. Proposals are solicited in the following key technology/concept areas:

- High temperature, low burn-up carbide- and ceramic-metallic (cermet)-based nuclear fuels with improved coatings and/or claddings to reduce fission product gas release into the engine's hydrogen exhaust stream;
- Reliable, high temperature materials, fabrication techniques, and concepts for non-reactor portions of NTP systems;
- Light-weight, multi-use shielding materials and designs;
- High temperature, radiation tolerant instrumentation and avionics for engine health monitoring. Non-invasive designs for measuring neutron flux (outside of reactor), chamber temperature, operating pressure, and liquid hydrogen propellant flow rates over wide range of temperatures desired;
- Long life, lightweight, reliable hydrogen turbopump designs and technologies;
- Lightweight, long life, heat flux thrust chambers, regenerative-cooled nozzles and radiation-cooled skirt extensions that are compatible with hot hydrogen;
- Radiation tolerant materials compatible with above engine subsystem applications and operating environments.

Sub Topics:
Electric Propulsion Systems Topic X2.04
The goal of this subtopic is to develop innovations in high-power (100 kW to MW-class) electric propulsion systems. High-power (high-thrust) electric propulsion may enable dramatic mass and cost savings for lunar and Mars cargo missions, including Earth escape and near-Earth space maneuvers. At very high power levels, electric propulsion may enable piloted exploration missions as well. Improved performance of propulsion systems that are integrated with associated power and thermal management systems and that exhibit minimal adverse spacecraft-thruster interaction effects are of interest. Innovations are sought that increase system efficiency, increase system and/or component life, increase system and/or component durability, reduce system and/or component mass, reduce system complexity, reduce development issues, or provide other definable benefits. Desired specific impulses range from a value of 2000 s for Earth-orbit transfers to over 6000 s for planetary missions. System efficiencies in excess of 50% and system lifetimes of at least 5 years (total impulse > 1 x 10^7 N-sec) are desired. Specific technologies of interest in addressing these challenges include:

- Long-life, high-current cathodes (100,000 hours);
- Electric propulsion designs employing fuels that are more readily available (whether from Earth or in situ space resources) and easy to store/handle;
- Electrode thermal management technologies;
- Innovative plasma neutralization concepts;
- Metal propellant management systems and components;
- Cathodes for metal propellants;
- Low-mass, high-efficiency power electronics for RF and DC discharges;
- Lightweight, low-cost, high-efficiency power processing units;
- Low-voltage, high-temperature wire for electromagnets;
- High-temperature permanent magnets and/or electromagnets;
- Application of advanced materials for electrodes and wiring;
- Highly accurate propellant control devices/schemes;
- Miniature propellant flow meters;
- Lightweight, long-life storage systems for krypton and/or hydrogen;
- Fast-acting, very long-life valves and switches for pulsed inductive thrusters;
- Superconducting magnets;
- Lightweight thrust vector control for high-power thrusters; and
- High fidelity methods of determining the thrust of ion, Hall, and advanced plasma engines without using conventional thrust-stands.

Note to Proposer: Subtopic S3.04 under the Science Mission Directorate also addresses in-space propulsion.
Proposals more aligned with science mission requirements should be proposed in S3.04.

Sub Topics:

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

Atmosphere Revitalization Process Technologies

Regenerative CO\textsubscript{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\textsubscript{4} Management: Process technologies are sought that convert CH\textsubscript{4} into either elemental products (carbon and H\textsubscript{2}) or other useful commodities (fuel, organic synthesis precursor, or other) by reaction with available cabin resources such as O\textsubscript{2}, N\textsubscript{2}, or other readily available reactant.

Gas Separations: CO\textsubscript{2} reduction processes involve complex feed, recycle, and effluent gas mixtures. Process technologies and techniques for separating H\textsubscript{2}, CH\textsubscript{4}, 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.

Sub Topics:

Human Accommodations and Interfaces with Spacecraft Life Support Topic X3.02

**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% O_2 (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).
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 O₂, H₂, and CO₂; volatile organic compounds in O₂ and CO₂ (VOCs in CO₂ would be in the CO₂ removal/concentration product that would feed to any CO₂ reduction process); composition of CO₂ reduction effluent gases (CO₂, CO, CH₄, and H₂O) from either a Sabatier- or Bosch-based CO₂ reduction process; and combustible gas sensors for H₂ in an O₂ background and O₂ in an H₂ 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.
Tunable RF Front End and Transceiver

A major impetus behind the MEMS technology stems from compactness, which leads to lower power dissipation, higher levels of integration, lower weight, volume, and cost. To shrink form factor and enable efficient surface operations, one of the cornerstone components of this radio is the tunable filter. Recent advances in RF MEMs filters and resonator technology have permitted very high quality factors (>1000) at GHz frequencies. Achieving high and excellent tuning range (>2:1) to bandwidth ratio without cryogenic cooling is now viable for the S-band frequency. For reliability, the tunable filter should employ a contact-less tuning scheme.

Power-Aware Processing

To support Quality of Service (QoS) of different applications, it's inadequate to optimize power at design time, but dynamic power management must be employed to ensure power efficiency. To maximize power efficiency, the radio must be able to adjust power and update rates to suit for diverse missions. Users should have the ability to specify QoS for different data streams. The radio must have the capability to scale power, select optimum modes of operation, and minimum energy profiles. During low-rate-processing intensive modes, including local processing and compression of telemetry data and voice, highly energy-efficient low-voltage, low-performance modes must be used. For high-rate-processing intensive modes, like advance signal encoding of high definition imagery, medium performance modes must be used; and during active communication modes (which may have a low duty-cycle), ultra-high-performance modes must be used. Accordingly, the digital platform must be highly agile and use-case aware to continuously minimize energy. Below are some desirable features to consider:

Variation-Tolerant, Performance-Scalable Architectures

Hardware must sense its own limitation at a dynamically varying, performance-driven optimal energy operating point, and reconfigure accordingly. If variability is stressed at the low-voltage operating point, redundant hardware should be used to improve reliability; if throughput is stressed at the high-performance operating point, redundant hardware should be used to increase parallelism.

Energy-Aware Algorithms for Adaptive Hardware

Algorithms must be aware of the different hardware operating-points and associated architecture. For instance, during low-power modes targeting voice and data (for telemetry), occasional high through-put applications (like high-rate imagery) should dynamically switch to algorithms employing extreme parallelism in order to support a minimum operating voltage.
Modularity and Extensibility

Enabling platform must support open architecture and accommodate rapid upgrades, multiple protocols, new technology advances, complete re-configurability of functionality, and evolution of planetary communications and network infrastructure.

Phase I Deliverables: Given maximum range of 4km, telemetry, voice at 8 kbps, high definition imagery at 20 Mbps, and S-band frequency operating at 2.4 - 2.483 GHz, assess radio ultimate mass, size, and power. This should be backed with analyses and simulation to ensure achievable performance and power targets.

One significant prerequisite to Phase II is the development of a promising and novel MEMS-based radio architecture that comprises: a highly programmable frontend and highly programmable digital basebands with the MAC implementation of multiple protocols and Advanced Encryption Standard (AES) encryption. The offeror must demonstrate the ability to achieve significant advantages in compactness, power efficiency, and reliability.

Phase II Deliverables: Develop a reliable, intelligent, and power-efficient MEMS-based EVA radio prototype unit that demonstrates robust RF performance, frequency agility, re-configurability, and dynamic power management for voice, telemetry, and high definition imagery under power budget constraints.

Integrate AES encryption as well as power-aware technologies and ensure QoS applications fall within prescribed power constraints.

Displays

To surmount geometric constraints, compact external flat panel or helmet-mounted display technologies are needed to improve situational awareness, mobility, suit monitoring, and task management. Hands-free interactive control of visual information (text, graphics, images, and video) using conversational spoken dialogue can improve work efficiency over audio communications as well as increase productivity and safety. High resolution suit displays must be able to operate outside the protection of the suit in bright surroundings, thermal, radiation, and vacuum environments as well as internally without imposing ignition hazards due to 100 percent oxygen environment.

Sensors

Crew health and suit monitoring require advancement of lightweight CO₂, biomedical (heart rate, blood O₂, EKG) and core temperature sensors with reduced size, increased reliability, and greater packaging flexibility. Consequently, technologies are needed to provide high accuracy, low mass, and low-power sensors that measure flow rate, pressure, temperature, and relative humidity or dew point. All sensors must operate in a low pressure 100% O₂ environment with high humidity and may be exposed to liquid condensate.
Because missions must be designed with appropriate radiation shielding and adjusted to keep the radiation doses within tolerable limits, real-time, accurate, instantaneous and integrated radiation dose measurements and readout are needed such as novel dosimeter sensors. Given sufficient warning, astronauts can move to a more shielded part of the space vehicle and lessen dose impact. As cosmic rays impinge upon the vehicle leaving the magnetosphere, sensors are needed to determine the type of radiation and dose as well as reduce the potential risk of biological tissue damage.

High Definition (HD) Cameras

Ultra-compact, low-power, HD cameras are needed to support both high definition motion and high resolution still imagery, providing low loss compressed digital data output for transmission over RF and/or IP networks. Key features include advanced wireless networking for transmitting video at high bandwidth, high-quality image compression algorithms, radiation tolerant image sensor and processing platform capable of running video compression in near real time. The cameras must provide excellent situational awareness for crew members and quality imagery for remote viewing, scientific research, exploration, and public relations. They will be mounted on space and planetary vehicles (e.g. rovers), so remote operation (pan, tilt, focus, zoom, light level controls) can be controlled by astronaut in a suit, and the image projected onto a helmet display or remotely for Earth-based operations.

Integrated Systems

A complete system of displays, cameras, sensors must be integrated under a common interface. A key enabler will be advanced spoken dialogs. Typing or using a touch menu is too cumbersome with space suit gloves. Voice commands are much more natural for the suited astronaut and can increase situational awareness. In case of voice failure, a backup system can be implemented to perform all critical functions. Not only can this capability reduce crew workload, but it can immensely enhance operational efficiency. Such functions can alert crew about progressive deterioration of equipment preceding failures. Sensor data can be read out to determine the heart rate, body temperature, and CO$_2$ levels. Cameras can be turned on, aimed at precise locations, and either still or motion imagery can be taken.

Rather than separate control interfaces, a total solution is needed for integrating a suite of space suit functions: displays, cameras, sensors, audio, and voice. Hands-free interaction requires automated planning, scheduling, consumable management, suit monitoring, and display presentation. Advanced spoken dialogue system which works in an acoustic environment of the space suit and provides an interface to control all space suit, display, camera, sensor, and audio functions will allow a natural operation of complex suite of space suit capabilities.
The Expandable Structures subtopic solicits innovative structural concepts that support the development of lightweight structures technologies for expandable exploration space modules and surface based habitats. The targeted structural concepts are desired for utilization in primary pressurized volumes and in secondary structures internal to the deployed primary volume. Innovations in expandable structures technology is desired to minimize launch mass, volume, and costs, while maximizing operational volume and structural performance of a crewed or material transfer pressure vessel.

Inflatable structures is a research area within expandable structures, which offers a viable solution for increasing the volume of habitats, airlocks, and other crewed vessels. Inflatable structure concerns, due to the low level of maturity include: consistent and reproducible mechanical behavior, durability in the presence of micrometeoroid impact, incorporation of material for radiation shielding, crew-induced damage, and repair techniques for long term survivability. Other areas of concern include, pre-integration solutions, storage of a pressurized volume within an expandable structure, and deployment techniques. Solicitations which address topics in these areas would be welcomed.

One remaining area of interest is the development of innovative deployable secondary structures that have minimal mass, high packaging efficiency, and multi-functional utilization. One simple example of a secondary structure could be a walkway internal to a lunar surface habitat, which could be reconfigured as a storage container or a radiation shield during a major solar flare event. These secondary multi-functional structures should provide highly robust, stiff and mass efficient surfaces that enable the useful outfitting and pre-integration of subsystems within the primary structural volume.

In general, development of structural concepts can include structural components, methods of validation, and/or predictive analysis capabilities. Analytical and numerical methods to analyze the behavior of soft-goods from a global scale, down to the fabric and strap level are desired. Methods and designs for integrating instrumentation into soft-goods, including the ability to detect damage, creep (strains), loads in the primary restraint layers, and temperatures are also desired. Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

Sub Topics:
Advanced Fabrication and Manufacturing of Metallic and Hybrid Materials for Lightweight Structures Topic X5.02

Sub Topics:
Manufacturing of Polymer Matrix Composite (PMC) Structures Topic X5.03

Sub Topics:
Spaceflight Structural Sensor Systems and NDE Topic X5.04

**Spaceflight Structural Sensor Systems**

Technologies sought include: modular/low mass-volume systems, stand-alone smart sensor systems that provide answers as close to the sensor as practical, Surface Acoustic Wave (SAW)-based sensors, passive wireless sensor-tags, flexible sensors for highly curved surfaces and direct-write film sensors. These systems allow for additions or changes in instrumentation late in the design/development process and enable relocation or upgrade on orbit. They reduce the complexities of standard wires and connectors and enable sensing functions in locations not normally accessible with previous technologies. They allow NASA to gain insight into performance and safety of
NASA vehicles as well as commercial launchers, vehicles and payloads supporting NASA missions.

Mission Application Areas (Interior or Exterior):

(1) Add-on in-space modular sensors for:

- Commercial human-rated transportation systems
- Composite Overwrapped Pressure Vessels (COPVs) and other pressure-vessels
- International Space Station (ISS) habitable modules and exterior structure
- Inflatable habitat modules

(2) Built-in flight monitoring systems for:

- New COPV and other pressure vessels
- New manned and unmanned spacecraft
- New propulsion system tankage and transfer systems
- New heavy-lift vehicles: fairings, transition sections, engines, Thermal Protection Systems (TPS), tanks
- New transformational habitats and structures like inflatables

(3) Mobile sensor interrogation systems - robotic, wireless network or interrogation which can:

- Program and download data from smart systems without wires
- Acquire active/passive sensor-tag data
- Determine real-time position/orientation for other sensors or tools

Performance Goals/Metrics:

Ability to establish new functionality in one of the 3 areas above, and:
• Increase number of sensor locations per pound of monitoring weight by 50%
• Decrease the system monitoring electronics weight by 50%
• Decrease total wiring required for monitoring by 50%
• Decrease the time to plan and install monitoring by 50%
• Decrease the overall life-cycle cost per sensor by 50%
• Decrease total data rate required from sensor data acquisition location by 50%
• Decrease the expected cost of instrumentation changes/upgrades by 50%

NDE Systems for use during Spaceflight

Technologies sought include: modular/low mass/volume smart NDE sensors systems and associated software that enable effective use with minimum crew training or re-familiarization after extended periods of no use. Systems should include ability to perform inspections with minimal human interaction. These systems need to provide reliable assessments of the location and extent of damage with the minimal data transfer between vehicle and Earth. Methods are desired to perform inspections in areas with difficult access in pressurized habitable compartments and external environments. Many applications require the ability to see through conductive and/or thermal insulating materials without contacting the surface. Sensors that can dynamically and accurately determine position and orientation of the NDE sensor are needed to automatically register NDE results to precise locations on the structure. Structural design and material configurations are sought that can enhance NDE and monitoring. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who may only use the NDE tool infrequently, but need to make important assessments quickly. Micro-miniature, low power NDE inspection sensors are needed for potential use on free-flying inspection platforms. Integration of wireless systems with NDE may be of significant utility.

Mission Application Areas:

Enabling NDE (Interior and Exterior):

(1) On-orbit NDE sensor systems (e.g. Visual, Laser, Micro-wave, Terrahertz, Infra-red, X-ray backscatter, eddy current or other) that have high resolution and small form-factor to inspect:

• Thermal protection - Multi-Layer Insulation (MLI) and TPS) structures
• Inflatable habitats, Extra-Vehicular Activity (EVA) suits and visiting vehicles
• Electronic systems, environmental control systems, and other vehicle systems
• Conductive structures, Micro-Meteoroid and Orbital Debris (MMOD) shields, primary structure, pressure
vessels

- Structures (COPV, module walls) under MLI/MMOD shielding
- Be deployed/used without the need for robotic manipulators or EVA crew

(2) On-orbit NDE sensor systems that can be used:

- In difficult access areas: flexible borescopes, micro-robots, smart sensors
- To identify, locate and quantify potential damage areas: MMOD damage, module and pressure vessel leaks, corrosion, etc.
- On robotically operated platforms: free-flyers, micro-robots, dexterous robots, or remote manipulators

Performance Goals/Metrics:

Ability to establish new functionality in one of the 2 areas above, and:

- Decrease total data/rate required from the NDE sensor by 50%
- Decrease time to perform NDE inspections by 50%
- Decrease the size, weight and power of NDE systems by 50%

Sub Topics:
- Low Temperature Mechanisms Topic X5.05

Sub Topics:
- Automation for Vehicle and Crew Operations Topic X6.01
  Automation will be instrumental for decreasing workload, reducing dependence on Earth-based support staff, enhancing response time, and releasing crew and operators from routine tasks to focus on those requiring human judgment, leading to increased efficiency and reduced mission risk. To enable the application of intelligent automation and autonomy techniques, the technologies need to address two significant challenges: adaptability and software validation. Proposals are solicited in the areas of:
• **Automation Support Tools:** Support tools are needed to facilitate the authoring and validation of plans and execution scripts. Tools that are not tied specifically to one executive would provide NASA the most flexibility. Examples include: Graphical tool for monitoring and debugging plan execution and for creating and editing execution scripts; Tools for authoring and validating execution plans; User friendly abstraction of low-level execution languages by adding syntactic enhancements.

• **Decision Support:** Systems Decision support systems amplify the efficiency of operators by providing the information they need when and where they need it. Examples: Command and supervise complex tasks while projecting the outcome and identify potential problems; Understand system state, including visualization and summarization; Allow the system to interact with a user when generating the plan and allow evaluation of alternate courses of action; Integration of a planning and scheduling system as part of an on-board, closed loop controller.

• **Trustable Systems:** Systems that support or interact with crew require a very high level of reliability. Tools are needed that improve the reliability and trustworthiness of autonomous systems. These include: Ability to predict what the system will do; Guarantees of behavioral properties; Other properties that increase the operator’s trust; Verifiability (e.g., restricted executive languages that facilitate model-based verification).

Sub Topics:

- Radiation Hardened/Tolerant and Low Temperature Electronics and Processors Topic X6.02
- Exploration flight projects, robotic precursors, and technology demonstrators that are designed to operate beyond low-earth orbit require avionic systems, components, and controllers that are capable of enduring the extreme temperature and radiation environments of deep space, the lunar surface, and eventually the Martian surface. Spacecraft vehicle electronics will be required to operate across a wide temperature range and must be capable of enduring frequent (and often rapid) thermal-cycling. Packaging for these electronics must be able to accommodate the mechanical stress and fatigue associated with the thermal cycling. Spacecraft vehicle electronics must be radiation hardened for the target environment. They must be capable of operating through a minimum total ionizing dose (TID) of 300 krad (Si), provide fewer Single Event Upsets (SEUs) than 10-10 to 10-11 errors/bit-day, and provide single event latchup (SEL) immunity at linear energy transfer (LET) levels of 100 MeV cm²/mg (Si) or more. Electronics hardened for thermal cycling and extreme temperature ranges should perform beyond the standard military specification range of -55°C to 125°C, running as low as -230°C or as high as 350°C.

Considering these target environment performance parameters for thermal and radiation extremes, proposals are sought in the following specific areas:

- Low power, high efficiency, radiation-hardened processor technologies.
- Technologies and techniques for environmentally hardened Field Programmable Gate Array (FPGA)
- Innovative radiation hardened volatile and nonvolatile memory technologies.
- Tightly-integrated electronic sensor and actuator modules that include power, command and control, and
processing.

- Radiation hardened analog application specific integrated circuits (ASICs) for spacecraft power management and other applications.
- Radiation hardened DC-to-DC converters and point-of-load power distribution circuits.
- Physics-based device models valid at temperature ranging from -230°C to +130°C to enable design, verification and fabrication of custom mixed-signal and analog circuits.
- Circuit design and layout methodologies/techniques that facilitate improved radiation hardness and low-temperature (-230°C) analog and mixed-signal circuit performance.
- Packaging capable of surviving numerous thermal cycles and tolerant of the extreme temperatures on the Moon and Mars. This includes the use of appropriate materials including substrates, die-attach, encapsulants, thermal compounds, etc.

Sub Topics:
Robotic Systems for Human Exploration Topic X7.01

Sub Topics:
Fuel Cells and Electrolyzers for Space Applications Topic X8.01

**Fuel Cells and Electrolyzers for Space Applications**

Advanced primary fuel cell and regenerative fuel cell energy storage systems are enabling for various aspects of future Exploration missions. Proton Exchange Membrane (PEM) and Solid Oxide Based systems are of particular interest.

**Proton Exchange Membrane (PEM) Fuel Cells and Electrolyzers**

Proposals that address technology advances related to the following issues for PEM fuel cell, electrolysis, and
regenerative fuel cell systems are desired.

Oxidation resistant gas diffusion layers (GDLs) for PEM fuel cell membrane-electrode-assemblies (MEAs) are integral to PEM fuel cell MEAs. Traditional carbon or graphite based GDLs are very susceptible to oxidation under certain operating conditions in the pure oxygen environment of space fuel cell systems. This results in MEA degradation and shortened life. Proposals addressing the development of oxidation resistant GDLs that remain stable to oxidation in a pure oxygen environment, and provide improved performance and longer life are desired.

Passive liquid-feed high-pressure PEM electrolysis technology - Water electrolysis technology is critical for water utilization and hydrogen/oxygen generation. Standard liquid-feed PEM electrolysis technology requires numerous mechanical ancillary components for reactant management functions, including pumps and two-phase water/gas separators. These components present life and reliability issues in addition to their inherent mass and volume penalties, and also require parasitic power for operation. Vapor-feed PEM electrolysis technology avoids the necessity of these ancillary components, but suffers from reduced electrochemical performance and operational constraints. Development of passive liquid-feed PEM electrolysis technology could offer the benefits of both aforementioned systems without the drawbacks. This would yield an electrolysis system with strong electrochemical performance and a minimum of ancillary components with their inherent system penalties.

Oxidation resistant, electrically conductive, hydrophilic coatings for internal cell components within PEM fuel cells and electrolyzers - Liquid water is produced within the reactant cavities of PEM fuel cells and consumed within the reactant cavities of PEM electrolyzers. In the case of a non-flow-through PEM fuel cell, the liquid product water moves across an open but supported gas cavity and through a water/gas separation barrier into a liquid cavity. If the supporting cell components within the gas cavity are hydrophobic, the water will be transported as droplets, which could impede gas flow and subsequently reduce electrochemical performance. If these supporting components are hydrophilic, the water is more likely to be transported as a film along the support structure and not impede gas flow. In the case of a PEM electrolyzer, water is moving in the opposite direction and therefore into the reactant cavity. A hydrophilic support structure would allow a flowing film of liquid water to reach the cell MEA while still maintaining an open reactant cavity relative to gas flow. In essence, an electrolysis cell assembly designed for vapor-feed operation could operate in a liquid-feed mode. This would yield a system with strong electrochemical performance and a minimum of ancillary components with their inherent system penalties.

Stable, highly efficient, long-life MEAs and catalysts for PEM fuel cells and electrolyzers - PEM fuel cells and electrolyzers are key technologies for space systems utilizing hydrogen, oxygen, or water as reactants. In order to improve the life and reliability of the electrochemical stacks within these systems, as well as to reduce overall system mass/volume and cost, development of MEAs and catalysts that are stable and highly efficient is critical. Techniques to accomplish this goal include, but are not limited to, alternative noble metal and mixed oxide catalysts with increased surface areas, advanced binders and catalyst layer application techniques, alternative ionomer formulations, and high-temperature membrane compatibility.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

Solid Oxide Fuel Cells and Electrolyzers

Advanced primary Solid Oxide Fuel Cells (SOFC) and Electrolyzers offer notable advantages in certain space applications when integrated with, respectively, CH₄/O₂ propulsion systems and systems for producing oxygen from
planetary resources. Technology advances that reduce the weight and volume, improve the efficiency, life, safety, system simplicity and reliability of Solid Oxide Fuel Cells and Electrolyzers are desired. Proposals are sought which address the following areas:

**Advanced Primary SOFC Systems:** Their high temperature heat rejection and high efficiency power generation from methane and oxygen make primary SOFC's attractive for application to spacecraft with CH₄/O₂ propulsion systems. Research directed towards improving the durability, efficiency, and reliability of SOFC systems fed by propellant-grade methane and oxygen is desired.

Primary SOFC components and systems of interest:

- Have power outputs in the 1 to 3 kW range.
- Offer thermodynamic efficiencies of at least 70% (fuel source-to-DC output) when operating at the current draw corresponding to optimized specific power.
- Operate as specified after at least 300 start-up cycles (from cold to operating temperature within 5 minutes) and 300 shut-down cycles (from operating temperature to cold within 5 minutes).
- Operate as specified after at least 2500 hours of steady state operation on propellant-grade methane and oxygen.
- Are cooled by way of conduction through the stack to a radiator exposed to space.

**Advanced Solid Oxide Electrolyzers:** Their high temperature heat rejection and operation, along with high efficiency, make solid oxide electrolyzers attractive as the final step of producing oxygen from Lunar regolith by way of hydrogen or carbothermal reduction. They are also attractive components for Sabatier reactors producing methane from the Martian atmosphere. Research directed towards improving the durability, efficiency, and reliability of solid oxide electrolyzers is desired.

Solid oxide electrolysis systems of interest:

- Require power inputs in the 1 to 3 kW range.
- Operate as specified after 10,000 hours of operation fed by water with mild contamination
- Operate as specified after 100 start-up cycles (from cold to operating temperature within 5 minutes) and 100 shut-down cycles (from operating temperature to cold within 5 minutes).
- Offer thermodynamic efficiencies of at least 70% (DC-input to Lower Heating Value H₂ output) when operating at the current feed corresponding to rated power.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a
Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

Sub Topics:
Advanced Space-Rated Batteries Topic X8.02

Sub Topics:
Space Nuclear Power Systems Topic X8.03

Sub Topics:
Advanced Photovoltaic Systems Topic X8.04

- Solar cell, blanket component and advanced solar array technology with high operating efficiency (>30%), low mass (>200W/kg), and low stowed volume;
- PV technology capable of long-term, reliable of planterary surface operation under dust, temperature extreme (high and low), radiation, and other space enviromental conditions;
- Advanced concepts for array packaging, autonomous deployment, retraction and redeployment;
- Modular, high power (10s to 100s kWe) concepts with lifetimes greater than 10 years;
- High voltage (>200 Volts) array designs capable of reliable operation under space environmental conditions.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. A major focus will be on the demonstration of dual-use technologies for clean and renewable energy for terrestrial applications.

Sub Topics:
Advanced Power Conversion, Management, and Distribution (PMAD) for High Power Space Exploration Applications Topic X8.05

Advanced power conversion technologies are sought for improvements in efficiency and reliability of power conversion for space exploration missions. Power levels for applications are expected to be in the range of 10s to 100s of kWe. System and component technologies are sought that can deliver efficiency and reliability improvements in this power range in the space environment.

In addition, advanced Power Management and Distribution (PMAD) technologies are required for the electrical components and systems on future high power platforms to address size, mass, efficiency, capacity, durability, and reliability improvements. Of importance are improvements in energy density, speed, efficiency, and wide temperature (-125°C to over 450°C) with a number of thermal cycles.
Power conversion and PMAD technologies must enable or enhance the ability to provide low-cost, abundant power for deep space missions, with requirements from 10s to 100s of kWe and months to years of mission duration.

Examples of Power Conversion technology areas:

- High conversion efficiency for Brayton, Stirling or Rankine power convertors;
- High efficiency solar dynamic deployable solar concentrators and collectors;
- Research into advanced Power Conversion system concepts.

Examples of PMAD technology areas:

- Highly reliable devices and components;
- Radiation tolerance;
- Advanced power bus solutions;
- Technologies for high pulse power applications such as advanced energy storage devices;
- Efficient wireless power transmission.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. A major focus will be on the demonstration of dual-use technologies for clean and renewable energy for terrestrial applications.
Analysis of body sounds for abnormalities is standard medical practice for diagnosing a medical condition. This call is for technology that can isolate internal body sounds (heart beating, breathing, etc.) in a potentially noisy ambient environment (up to 70 dBA) and capture the auscultation data to be managed and transmitted digitally to the appropriate destination for analysis.

Current commercially available systems have two main issues. Some systems pick up all sounds without filtering out the sounds of interest. Other systems use technology (e.g. doppler) that produce sounds that are not readily familiar to clinicians—thereby necessitating retraining.

Phase I Deliverable: Technical Feasibility Report; Draft Requirements Document

Phase II Deliverable: Prototype Hardware

Loss of bone strength, mass and density are known medical complications of space flight, where the static load of gravity is no longer present. The process of bone demineralization begins almost immediately upon an astronaut's arrival into a microgravity environment and appears to continue unabated. The losses occur particularly in weight bearing bone regions of the lower spine, hip and legs. NASA will eventually require diagnostics techniques that can
perform in vivo quantitative evaluations of bone mineral density (BMD) and trabecular micro-architecture (i.e., porosity, trabecular size and geometry) during manned Exploration class missions. As an incremental step toward this end, a high-resolution diagnostic or imaging device is required for performing the quantitative evaluations identified above ex vivo with a technology that shows significant promise for adaptability to long duration human space flight. The device should be capable of resolving the trabecular micro-structure for analysis. The device should also demonstrate sufficient penetration depth in the body to eventually adapt the technology for in vivo evaluations of the calcaneus and lumbar spine, at a minimum. Efforts should be made to minimize the volume, mass, electromagnetic emissions and power draw of the device and its associated peripheral equipment. The use of ionizing radiation is not restricted, but its use is considered highly undesirable in a manned space flight environment and should, therefore, be minimized. This technology is desired for possible demonstration on ISS and for targeted deployment on future Exploration class vehicles supporting long duration missions.

Sub Topics:
Lab to Marketplace: Commercializing Spaceflight Biomedical and Behavioral Research Tools Topic X12.03

NASA and SBIR invest a significant amount of funds in the development of new technologies to study human physiology and behavior during spaceflight. This investment has produced a large number of technologies that include hardware (e.g., instruments, devices, etc.) and software (e.g., computational models, informatics tools, data analytic methods, etc.) While these technologies are put to good use by their developers, such non-commercial developers devote little attention to making their tools robust and easy to use by the broad research or clinical communities. Consequently, the promise of these advanced technologies is often realized only by the tool's developers and their close associates. Moreover, ongoing support to maintain and update technologies in non-commercial settings is difficult to obtain.

In contrast, tools that are commercially available need to be sturdy and easy to use, and commercial success often provides the means for continued maintenance and improvements of the underlying technology. This call is intended to formulate business plans that will move useful technologies from non-commercial laboratories into the commercial marketplace by inviting SBIR grant applications for further development of such technologies that are relevant to the missions of the NASA's Human Research Program. The supported research and development will likely include making the tools more robust and easy to use, advancing the Technology Readiness Levels (TRLs) from TRL 3-4 to TRL 6-7 and will likely require close collaboration between the original developers of these technologies and commercial partners.

Biomedical devices currently being developed that this will be focused on are: assisted medical procedure viewer, physiological and medical models, minimally invasive laboratory analysis capabilities, medical imaging techniques and procedures.

Phase I Deliverables: 5 business plans for current NASA/SBIR technology projects. These should include: market analysis; gap analyses reports between current state of 5 NASA biomedical technologies and what would be needed for commercialization/venture capital funding.

Phase II Deliverables: Updated business plans to include the following strategies: FDA regulatory; reimbursement; product adoption; competitive analysis; manufacturing costs; sales; use of proceeds; marketing; clinical trials.

Sub Topics:
Batteries for Oxygen Concentrators Topic X12.04
Advanced high energy battery systems are sought for use in Exploration Medical Capabilities mission applications such as power for mobile oxygen concentrators. There are only a few battery chemistries with a reasonable chance of achieving the target specific energies. Metal/air battery systems are the most likely candidates. The most common type of commercial metal/air battery utilizes zinc/air chemistry and has a practical specific energy of ~370 Wh/kg. While this battery chemistry has a theoretical specific energy of 1350 Wh/kg, it is not possible for this chemistry to meet the specific energy goals for these applications (>2000 Wh/kg). In addition to zinc/air batteries, aluminum/air batteries are also available in the commercial market, although only in a limited fashion. Aluminum/air batteries have a much greater theoretical specific energy (8140 Wh/kg) and although they currently have a practical specific energy of ~350 Wh/kg, the potential for significant near-term improvement exists. The highest theoretical specific energy for a metal/air battery chemistry is lithium/air at 11,500 Wh/kg giving it and aluminum/air batteries the best potential to realize the high specific energy values needed for Exploration Medical Capabilities mission applications.

The focus of this solicitation is on the development of a high specific energy battery that can meet the following goals:

- Specific energy (battery level) >2000 Wh/kg;
- Operating Temperature Range from 0°C to 35°C;
- Shelf life >2 years.

All classes of metal-air batteries (aqueous, non-aqueous, and solid state) as well as other battery chemistries will be considered if they fall within the guidelines of performance. Additionally, the battery system will be used inside a crewed space vehicle and must meet the requisite safety guidelines stated in "Crewed Space Vehicle Battery Safety Requirements".

Phase I research should be conducted to demonstrate technical feasibility and deliver multiple cell-level demonstration units at the conclusion of the contract. Additionally, a path toward a Phase II hardware demonstration should be shown which leads to the delivery of multiple module-level demonstration units mid-way through the phase II contract and multiple TRL 4 battery-level demonstration units for TRL 5/6 validation and verification testing at the end of the phase II contract.

Sub Topics:
- Behavioral Health Monitoring Tools Topic X13.01

The NASA Behavioral Health and Performance Program Element (BHP) identifies and characterizes the behavioral
health and performance risks associated with training, living and working in Space, and return to Earth. BHP develops strategies, tools, and technologies to mitigate these risks. Currently, BHP has the need for behavioral health monitoring tools specific to the long duration Exploration Mission environment. The aim of the current task is to provide a non-invasive technology that would unobtrusively monitor and detect physiological markers of chronic stress that could lead to behavioral or performance decrements. Factors may include the changes in Central Nervous System, Autonomic Nervous System, emotional state, environment, gestures, and speech. The stress monitoring system would automatically generate meaningful feedback for the user regarding their individual behavioral health status based on measures of physiological, psychological and emotional state.

Requirements: The stress assessment tool shall:

- Be unobtrusive;
- Require minimal crew time or effort;
- Monitor physiological markers of stress and emotional state;
- Provide meaningful feedback to user regarding individual behavioral health status;
- If decrements are detected, the measure shall provide meaningful feedback to user regarding recommended course of action or treatment.

Phase I Deliverables: A final report summarizing current accepted methods and measures of physiological markers of stress as they relate to performance, the current state of technologies, recommendations regarding enhancements to current technology or the development of a new technology with the technology enhancement or development concept fully described. A draft requirements document for the recommended technology.

Sub Topics:
Technologies for Non-Invasive Measurement and Analysis of Human Task Performance Topic X14.01

Sub Topics:
Advanced Food Technologies Topic X14.02
The purpose of the Advanced Food Technology Project is to develop, evaluate and deliver food technologies for human centered spacecraft that will support crews on missions beyond low earth orbit. A safe, nutritious, acceptable, and varied food system will be required to support the crew during future exploration missions. Concurrently, the food system must efficiently balance appropriate vehicle resources such as mass, volume, water, air, waste, power, and crew time. For example, it would require approximately 10,000 kg of packaged food with a 5-year shelf life for a 6-crew, 1000 day mission to Mars.
It has been proposed to use a food system which incorporates processing of raw ingredients into edible ingredients and uses these edible ingredients in recipes in the galley to produce meals. This type of food system will require technologies that will allow these raw ingredients to maintain their functionality and nutrition for 5-years. This food system would also require food processing and food preparation equipment. The equipment should be miniaturized, multipurpose and efficiently use vehicle resources such as mass, volume, water, and power.

There are some unique parameters that need to be considered when developing the technologies. The Moon’s gravity is 1/6 of Earth’s gravity, and that of Mars is 3/8 of Earth’s. In addition, it is proposed that the habitat will have an atmospheric pressure of 8 psia, equivalent to being on a 16,000 foot mountain top. These two factors will affect heat and mass transfer during food processing and food preparation.

The response to this subtopic should include a plan to develop a technology that will enable safe and timely food processing and food preparation in reduced pressure and reduced gravity. Phase I should concentrate on the scientific, technical, and commercial merit and feasibility of the proposed innovation resulting in a feasibility report and concept, complete with analyses and top-level drawings.

Deliverables: Conceptual designs for food preparation or food processing equipment that can be used in partial gravity while efficiently balancing appropriate vehicle resources such as mass, volume, waste, and crew time.

Sub Topics:

Active Charged Particle and Neutron Measurement Topic X15.01
For exploration class missions, there is extraordinary premium on compact and reliable active radiation detection systems to meet very stringent size and power requirements. NASA needs compact, low power, active monitors that can measure charged particle spectrum and flux separately from neutrons and other radiations. NASA also needs compact active neutron spectrometers that can measure the neutron component of the dose separate from the charged particles. Advanced technologies up to technology readiness level (TRL) 4 are requested in the following areas:

**Charged Particle Spectrometer**

Measure charge and energy spectra of protons and other ions (Z = 2 to 26) and be sensitive to charged particles with linear energy transfer (LET) of 0.2 to 1000 keV/micrometer. For Z less than 3, the spectrometer should detect energies in the range 30 MeV/n to 400 MeV/n. For Z = 3 to 26, the spectrometer should detect energies in the
range 50 MeV/n to 1 GeV/n. Design goals for mass should be 2 kg and for volume, 3000 cm$^3$. The spectrometer should be able to measure charged particles at both ambient conditions in space (0.01 mGy/hr) and during a large solar particle event (100 mGy/hr). The time resolution should be less than or equal to 1 minute. The spectrometer shall be able to perform data reduction internally and provide processed data.

**Neutron Spectrometer**

Measure neutron energy spectra in the range of 0.5 MeV to 150 MeV. Measure neutrons at ambient conditions such that proton/ion veto capability should be approaching 100% at solar minimum GCR rates; measure ambient dose equivalent of 0.02 mSv in a 1 hour measurement period, using ICRP 74 (1997) conversion factors; store all necessary science data for post measurement data evaluation. Design goals for mass and volume should be 5 kg and 6000 cm$^3$.

Sub Topics:

- Alternative Methods for Ambient Preservation of Human Biological Samples During Extended Spaceflight and Planetary Operations Topic X16.01

Measurement of blood, plasma, and urine analytes is a common clinical medicine practice used for differential disease diagnosis and determination of the therapeutic response to treatment. Accurate biochemical results depend on maintaining the integrity of blood and urine samples until analyses can be completed. Improper sample collection, handling, or preservation may lead to critical errors in diagnostic interpretation of analytical results. Traditional methods have been developed that include the use of sample component separation by means of centrifugation, refrigeration, freezing or the addition of preservatives to maintain the integrity of biological samples. While such techniques are easily achieved in a routine clinical setting, the spaceflight environment presents unique challenges to sample processing and stowage. Thus, novel on-orbit methods for the ambient preservation of biological samples are critical for scientific research, monitoring of crew health and evaluation of countermeasure efficacy. The development of alternative innovative techniques with advantages over currently used methods for processing and preserving biological samples at ambient temperatures during spaceflight that provide a high level of reliability in maintaining a wide array of both blood and urine analytes over a long period of ambient stowage is highly desirable.

Phase I expectations include at a minimum a fully developed concept with feasibility analyses. A prototype is highly desirable.