NASA SBIR 2012 Phase I Solicitation

Human Exploration and Operations

In-Situ Resource Utilization Topic H1

The purpose of In-Situ Resource Utilization (ISRU) is to harness and utilize resources (both natural and discarded material) 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 from in-situ resources can significantly reduce the cost, mass, and risk of sustained human activities beyond Earth. Since ISRU may be performed wherever resources exist, ISRU systems need to operate in a variety of environments and gravities. 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, atmosphere, and environmental conditions. While the discipline of ISRU can encompass a large variety of different concept areas, resources, and products, the ISRU Topic will focus on technologies and capabilities associated with atmospheric and trash/waste resource collection, transfer, and processing.

Sub Topics:

H1.01 In-Situ Resource Utilization

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

Converting in-situ resources into propellants, energy storage reactants, or other useful products at the site of exploration, known as in-situ resource utilization (ISRU), versus transporting from Earth can significantly reduce the cost and risk of human exploration while at the same time enabling new mission concepts and long term exploration sustainability. Potential in-situ resources of interest include extraterrestrial atmospheres, soils/regolith, and discarded mission materials such as trash (food, wipes, paper, etc.), packaging materials, and crew waste. Technologies and innovative approaches are sought related to the collection, transfer, and processing of these in-situ resources into intermediate (carbon monoxide/carbon dioxide, water, hydrogen, and hydrocarbons) and final products (methane and oxygen) for propulsion and energy generation applications. The subtopic seeks proposals for the design and subsequent building of synergistic hardware that can support Mars atmosphere capture and processing and mission trash/waste conversion. Technologies of interest include:

- Trash feed into high temperature reactors with tight cabin leakage specs.
- Trash gasification reactors (steam and/or partial oxidation) with minimum tar and ash generation and subsequent tar/liquid hydrocarbon reduction.
- Highly efficient reactors for carbon monoxide/carbon dioxide (CO/CO₂) conversion into methane (CH₄).
- Highly efficient gas/gas and gas/liquid-vapor separation devices.
- Fine particle/gas separation (regenerative or continuous) technologies for Mars dust and gasification ash particles.
The proposed technology should address benefits in system mass, conversion and power efficiency, and intermediate/final product generation compared to current approaches. Proposed technologies need be able to operate in microgravity. Mars ISRU technologies need to involve separation and processing of 0.5 to 2 kg/hr of carbon dioxide. Trash processing technologies need to be capable of feeding and processing 12 kg of waste material per day.

Technology Readiness Levels (TRL) of 2 to 5 or higher are sought.

Potential NASA Customers include:

- Office of Chief Technologist/ISRU Program.
- Advanced Exploration Systems Logistics.
- Advanced Exploration Systems Mars Program.

Space Transportation Topic H2
Achieving space flight remains a challenging enterprise. It is an undertaking of great complexity, requiring numerous technological and engineering disciplines and a high level of organizational skill. Human Exploration requires advances in operations, testing, and propulsion for transport to the earth orbit, the moon, Mars, and beyond. NASA is interested in making space transportation systems more capable and less expensive. NASA is interested in technologies for advanced in-space propulsion systems to support exploration, reduce travel time, reduce acquisition costs, and reduce operational costs. The goal is a breakthrough in cost and reliability for a wide range of payload sizes and types (including passenger transportation) supporting future orbital flight vehicles.

Lower cost and reliable space access will provide significant benefits to civil space (human and robotic exploration beyond Earth as well as Earth science), to commercial industry, to educational institutions, for support to the International Space Station National Laboratory, and to national security. While other strategies can support frequent, low-cost and reliable space access, this topic focuses on the technologies that dramatically alter acquisition, reusability, reliability, and operability of space transportation systems.

Sub Topics:

H2.01 Cryogenic Fluid Management Technologies

Lead Center: GRC

Participating Center(s): ARC, GSFC, JSC, KSC

This subtopic solicits technologies related to cryogenic propellant storage, transfer, and instrumentation to support NASA's exploration goals. Proposed technologies should feature enhanced safety, reliability, long-term space use, economic efficiency over current state-of-the-art, or enabling technologies to allow NASA to meet future space exploration goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions. Specifically:
Innovative concepts for cryogenic fluid instrumentation are solicited to enable accurate measurement of propellant mass in low-gravity storage tanks, sensors to detect in-space and on-pad leaks from the storage system, and minimally invasive cryogenic liquid mass flow measurement sensors, including cryogenic two-phase flow.

- Passive thermal control for Zero Boil-Off (ZBO) storage of cryogens for both long term (>200 days) and short term (~14 days) in all mission environments. Insulation systems that can also serve as Micrometeoroid/orbital debris (MMOD) protection and are self-healing are also desired.
- Cryogenic storage technologies for alternate propellants such as xenon.
- Active thermal control for long term ZBO storage for space applications. Technologies include 20K cryocoolers and integration techniques, heat exchangers, distributed cooling, and circulators.
- Zero gravity cryogenic control devices including thermodynamic vent systems, spray bars, mixers, and liquid acquisition devices.
- Advanced spacecraft valve actuators using piezoelectric ceramics. Actuator should reduce the size and power while minimizing heat leak and increasing reliability.
- Propellant conditioning and densification technologies for propellant storage and transfer. Specific component technologies include compact, efficient and economical cryogenic compressors, pumps, Joule-Thompson orifices and heat exchangers. Also, subcooling of propellants for ground processing and long-term in-space cryogen storage and transfer.
- Liquefaction of oxygen for in space applications. This includes passive cooling with radiators, cryocooler liquefaction, or open cycle systems that work with high-pressure electrolysis.
- Efficient small to medium scale hydrogen liquefaction technologies (1-10k gal/day) including domestically produced wet cryogenic turboexpanders.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II demonstration, and delivering a demonstration package for NASA testing at the completion of the Phase II contract.

**Phase I Deliverables** - Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a demonstration. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL range of 3-4.

**Phase II Deliverables** - Emphasis should be placed on developing and demonstrating the technology under simulated mission conditions. The proposal shall outline a path showing how the technology could be developed into mission-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL range of 4-5.

Potential NASA Customers include:

- **Cryogenic Propulsion Storage and Transfer Technology Demonstration Mission.**
- **Office of Chief Technologist - Game Changing Development Cryogenic Propulsion Stage Program.**

**H2.02 In-Space Propulsion Systems**

**Lead Center:** GRC

**Participating Center(s):** JSC, MSFC

**OCT Technology Area:** TA02 [1]

This solicitation intends to examine a range of key technology options associated with cryogenic, non-toxic storable, and solid core nuclear thermal propulsion (NTP) systems for use in future exploration missions.
Non-toxic engine technology, including new mono and bipropellants, is desired for use in lieu of the currently operational NTO/MMH engine technology. Handling and safety concerns with toxic chemical propellants can lead to more costly propulsion systems. NTP systems using nuclear fission reactors may enable future short round trip missions to Mars, by helping to reduce launch mass to reasonable values and thereby increasing the payload delivered for Mars exploration missions.

Non-toxic and cryogenic engine technologies could range from pump fed or pressure fed reaction control engines of 25-1000 lbf up to 60,000 lbf primary propulsion engines. Pump fed NTP engines in the 15,000-25,000 lbf class, used individually or in clusters, would be used for primary propulsion.

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.
- Manufacturing techniques that lower the cost of manufacturing complex components such as injectors and coolant channels. Examples include, but are not limited to, development and demonstration of rapid prototype techniques for metallic parts, powder metallurgy techniques, and application of nano-technology for near net shape manufacturing.
- High temperature materials, coatings and/or ablatives or injectors, combustion chambers, nozzles, and nozzle extensions.
- Long life, lightweight, reliable turbo-pump designs and technologies include seals, bearing and fluid system components. Hydrogen technologies are of particular interest.
- 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.
- High temperature, low burn-up carbide- and ceramic-metallic (cermet) based nuclear fuels with improved coatings and/or claddings to maximize hydrogen propellant heating and to reduce fission product gas release into the engine's hydrogen exhaust stream.
- High temperature and cryogenic 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 are desired. Sensors need to operate for months/years instead of hours.

Note to Proposer: Subtopic S3.03 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.03.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II demonstration, and delivering a demonstration package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables - Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a demonstration. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL range of 3-4.
**Phase II Deliverables** - Emphasis should be placed on developing and demonstrating the technology under simulated mission conditions. The proposal shall outline a path showing how the technology could be developed into mission-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL range of 4-6.

Potential NASA Customers include:

- Office of Chief Technologist/Game Changing Development Program - In-Space Propulsion Project.
- Office of Chief Technologist/Game Changing Development Program - Manufacturing Innovation (MIP).
- Cryogenic Propulsion Stage/Advanced Upper Stage Engine Program.
- Human Exploration and Operations Directorate/Advanced Exploration Systems - Nuclear Cryogenic Propulsion Stage.

**H2.03 Advanced Technologies for Propulsion Testing**

**Lead Center: SSC**

Nuclear Thermal Propulsion (NTP), Rocket Based Combined Cycle (RBCC) and Turbine Based Combined Cycle (TBCC) propulsion systems have been identified as high priority NASA technology areas by the United States National Research Council. The goal of this subtopic is to foster development of advanced technologies with commercialization potential that will be needed for component and system level ground testing of these systems during the development and certification phases of their life-cycle.

NTP could be an enabling technology to reduce transit time and mission risk to Near-Earth Objects, Mars, and other deep space destinations. Nuclear power and propulsion technologies are key enabling technologies for future NASA exploration missions. Technology development to facilitate ground testing of NTP is required in the following areas:

- Advanced high-temperature and hydrogen resistant materials for use in a hot hydrogen environment (3000 °F).
- Efficient non-nuclear generation of high flow rate (100 lb/sec), high temperature hydrogen.
- High temperature fluid and thermal management systems.
- High temperature flow control and relief systems.
- High temperature power conversion systems.
High temperature process piping systems and associated components.

High temperature instrumentation.

RBCC and TBCC could be enabling technologies to reduce cost for and increase frequency of access to space and allow for rapid transit within the Earth's atmosphere, far exceeding our nation's current capabilities. Technology development to facilitate ground testing of RBCC and TBCC is required in the following areas:

- Thrust take-out and thrust measurement systems that address the unique challenges of a RBCC / TBCC test facility design.
- Non-intrusive velocity / temperature / pressure profile measurement of inlet and exhaust flows.

For the above technology subject areas, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward hardware and/or material development as appropriate which occurs during Phase II and culminates in a proof-of-concept system.

**Phase I Deliverables** - Phase I deliverables shall include a final report describing design studies and analyses, system, sensor, or instrumentation concepts, prospective material formulations, testing, etc. Prototype systems, components, sensors, instruments or materials can be developed in Phase I as well. The designs or concepts should have commercialization potential. For Phase II consideration, the final report should include a detailed path towards Phase II hardware proof-of-concept system or component or material manufacturing and testing as applicable. The technology concept at the end of Phase I should be at a TRL of 3-4.

**Phase II Deliverables** - Phase II deliverables shall consist of working proof-of-concept systems, tested material formulations with samples, tested component, sensor, or instrumentation hardware, etc. which have been successfully demonstrated in a relevant environment and delivered to NASA for testing and verification. The technology at the end of Phase II should be at a TRL of 6-7.

Potential NASA Customers include:

- Rocket Propulsion Test Program.
- Nuclear Thermal Propulsion Program.
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 atmosphere revitalization and particulate control, environmental monitoring and fire protection systems, crew accommodations, water recovery systems, solid waste management and thermal control. 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% oxygen by volume and pressures ranging from 1 atmosphere to as low as 7.6 psi (52.4 kPa). 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 demonstrate proof of concept and feasibility of the technical 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:

H3.01 Advanced Technologies for Atmosphere Revitalization

Lead Center: MSFC

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

Advancing process technologies for key atmosphere revitalization (AR) functions will be essential for enabling future efforts to extend crewed space exploration beyond low Earth orbit. Specific process technology advancements are sought in the technical areas of regenerative CO$_2$ removal, process gas drying, regenerable particulate matter filtration and separation techniques, and photocatalytic processes for removing trace volatile organic compounds (VOCs) from cabin atmospheric gases. Specifics pertaining to each technical area are the following:

- **Advanced Sorbents for CO$_2$ Removal** - Development of robust, high capacity, regenerable CO$_2$ adsorbents that substantially reduce the energy required for regeneration, are resistant to material degradation (i.e., dusting, spalling) and are highly selective to CO$_2$ over moisture. Candidate sorbents must be capable of operating in either CO$_2$ venting (open loop) or CO$_2$ processing (closed loop) modes.

- **Passive Moisture Removal** - Development of advanced water vapor removal techniques from air streams that operate at near-ambient pressure and temperatures and with little to no energy costs. This may include the development of water-selective materials (e.g., membranes, adsorbents) that exhibit significantly higher efficiencies than current commercial products. Very dry air (-65 °C dew point) can be assumed to be available to aid in drying process stream (1:1 ratio). Candidate process technologies must be capable of either venting moisture to space or returning moisture to the cabin for subsequent recovery for crew use.

- **Particulate Management** - Long-life and self-cleaning particulate pre-filters are required to reduce crew maintenance time and eliminate the need for consumable filter elements. These units should be able to handle large surges of particles and operate over very long periods. They should also be self-cleaning in-place or off-line (in-place is preferable, and provide viable methods for disposing of collected particulate matter while minimizing or eliminating direct contact by the crew. Complete (100%) capture of particles 20 microns and larger is required. Targeted technologies should be compact and lightweight, and easily integrated with the spacecraft Environmental Control and Life Support Systems (ECLSS).

- **Photocatalytic Oxidation (PCO) for Trace Contaminant Control** - Technologies are of interest for photocatalytic oxidation of Volatile Organic Carbon (VOCs) completely to CO$_2$ and H$_2$O (i.e., complete "mineralization") without producing partial oxidation products such as aldehydes and/or organic acids. Catalysts that are activated not only by UV, but also the visible region of the solar spectrum to capitalize on the highly efficient blue LEDs or solar energy are desired. Concepts should minimize PCO reactor volume via improved catalysts and catalyst activity, improved UV illumination scheme and/or improved illuminated catalyst surface area-to-volume ratio.

Technology Readiness Levels (TRL) of 2 to 3 or higher are sought.
Potential NASA Customers include:

- Human exploration missions include: Low-Earth orbit, Earth's neighborhood (Earth-moon libration points, lunar orbit and surface, geosynchronous orbits, etc), Near-Earth Asteroids, Mars Missions (transit, orbit, moons and surface).

(http://www.nasa.gov/exploration/home/index.html [2])

H3.02 Environmental Monitoring and Fire Protection for Spacecraft Autonomy

Lead Center: JPL

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

Environmental Monitoring

Technologies are desired to ensure that the chemical content of the air and water environment of the crew habitat falls within acceptable limits and the life support system is functioning properly and efficiently. Required technology characteristics include: 2 year shelf-life; functionality in microgravity and low pressure environments (~8 psi). The technologies require significant improvements in miniaturization, reliability, life-time, self-calibration, and reduction of expendables. Examples of desired analytes are:

- Trace silver (0.05-15 mg/L) and trace organics in water (acetone: 0.05-5 mg/L; aldehydes: 0.4-60 mg/L; alcohols: 1-100 mg/L).

Technologies for quantification and identification of microbial species are requested within an alternative subtopic, ISS Utilization.

Spacecraft Fire Protection

A first response crew mask capable of protecting the crew from ammonia, hydrazine, and combustion products is desired. A suitable first response mask should be quick to don, protect the wearer from environmental contaminants and elevated temperature hazards, and provide breathable air during prolonged emergency response activities. This mask would be one-size fits all and be effective for a minimum of 1 hour. While wearing the mask, the crew should have excellent freedom of motion and positive indication of effectiveness.

A portable, self-contained fire and toxic atmosphere cleanup system is desired that can rapidly remove contaminants from a spacecraft volume
Technology Readiness Levels (TRL) of 3 to 4 or higher are sought.

H3.03 Crew Accommodations and Water Recovery for Long Duration Missions

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

Spacecraft crew accommodations requires volumetrically reconfigurable and hygienic crew interiors that maintain crew productivity. Advancements are required to reduce logistical packaging mass residual, repurpose logistical items for outfitting, provide extended wear clothing, clothes laundering, and metabolic waste collection/processing. Advancements in technology for water recovery are required to exceed existing 85% recovery from urine and humidity condensate. It is expected that both the variety of wastewater sources and the total volume of wastewater will increase with increasing mission duration. Technologies that increase closure of the water system and reduce expendables will enable future missions. Specific focus areas include:

Human Fecal & Waste Management:

- Technology is needed to collect, dry, process, and recover useful materials, and to safely store human feces, trash, and processed residuals. Technologies for micro-gravity collection of urine and feces should have modes that allow for operation even if active components fail, by relying on or being aided by passive processes for function, such as capillary forces. Minimal crew interaction, low energy, contamination tolerant waste processing systems that recover water, methane, or other useful materials are desired.

Logistical Repurposing:

- Novel alternatives to existing launch foam packaging materials that are light weight, have low frangibility, and can be compressed or heated to achieve low residual volume after launch.

- Launch packaging systems (bags, nets, hard structures) that can be repurposed or reconfigured on orbit to provide interior crew accommodations (sleep areas, exercise, hygiene, thermal/sound control) with minimal mass penalty.

- Logistical materials that can be readily processed or reformulated on orbit to provide atmospheric gases, water, or material for in-space fabrication processes with minimal power requirements.

Mixed Brine Water Recovery:
• Recovery of water from mixed waste stream brines with 12% or higher dissolved solids are desired. Low energy, microgravity, low expendable systems should be tolerant of urine stabilization chemicals such as oxone, sulfuric acid and hexavalent chromium.

Biocide Delivery Systems:

• Technologies to replace the use of iodine for potable water disinfection. This may include techniques to replenish silver ions to a concentration of 0.4 mg/l in potable water or techniques to minimize the loss of silver ions in a potable water system. In addition, alternative disinfection technologies to inhibit biofilm formation on surfaces and provide residual disinfectant to maintain potable water quality would be considered.

Technology Readiness Levels (TRL) of 3 or higher are sought.

Potential NASA Customers include:

• Mission elements and vehicles:
  • Orion Multi-Purpose Crew Vehicle.
  • Multi-Mission Space Exploration Vehicle.
  • Deep Space Habitat.
  • Pressurized Rovers and Planetary Surface Systems.
  • International Space Station.

Human exploration missions include:

• Low-Earth orbit, Earth's neighborhood (Earth-moon libration points, lunar orbit and surface, geosynchronous orbits, etc).
• Near-Earth Asteroids.
• Mars Missions (transit, orbit, moons and surface).

(http://www.nasa.gov/exploration/home/index.html [2])
H3.04 Thermal Control Systems

Lead Center: JSC

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

Future human spacecraft will venture far beyond the relatively benign environment of low Earth orbit. They will transit through the deep space, but they may encounter warm transient environments such as low lunar orbit. Some spacecraft elements may be launched untended and would operate at relatively low power levels as they transit to their final destination. The combination of extreme environments and high turndown capability will be a major challenge for spacecraft Active Thermal Control Systems (ATCSs). Sophisticated thermal control systems will be required that can dissipate a wide range of heat loads in widely varying environments while using fewer of the limited spacecraft mass, volume and power resources. Advances are sought for microgravity room temperature thermal control in the areas of:

- Innovative thermal components and system architectures that are capable of operating over a wide range of heat loads in varying environments (for example, a 5:1 heat load range in environments ranging from 0 to 275 K).

- Two-phase heat transfer components and system architectures will allow the efficient acquisition, transport, and rejection of waste heat.

- Heat rejection strategies and hardware for transient, cyclical applications - e.g., phase change material heat exchangers, heat pumps, or efficient evaporative heat sinks.

- Smaller, lighter, high performance heat exchangers and coldplates.

- Low temperature external working fluids (a temperature limit approaching 150K) with favorable thermophysical properties - e.g., high specific heat, high thermal conductivity, and viscosity that does not dramatically increase at lower temperatures.

- Internal working fluids that are non-toxic, have favorable thermophysical properties, and are compatible with aluminum tubing (i.e., no corrosion for up to 10 years). Low temperature limits (~150 K) and favorable thermophysical properties would allow their use externally in a single loop ATCS.

- Low mass, high conductance ratio thermal switches.

- Long-life, light-weight, efficient single-phase pumps capable of producing relatively high pressure heads (~4 atm).

- Variable area radiators (e.g., variable conductance heat pipe radiators or drainable radiators).

- New thermal design tools to reduce the time and costs required for analysis, design, integration, and testing of the spacecraft. In particular, an innovative thermal design tool capable of fast and accurate spacecraft thermal modeling with significantly reduced effort and cost is needed.

Technology Readiness Levels (TRL) of 2 to 4 or higher are sought.
Potential NASA Customers include:


Future Human Space Missions - [http://www.nasa.gov/exploration/home/index.html](http://www.nasa.gov/exploration/home/index.html)

Extra-Vehicular Activity Technology Topic H4

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 for in-space microgravity EVA and for planetary surface exploration. 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. Advanced EVA system must also provide the capability to perform useful tasks safely, such as assembling and servicing large in-space systems and exploring surfaces of the Moon, Mars, and small bodies. Top-level requirements for advanced EVA systems include reduction of system weight and volume, minimization of consumables usage, 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:

**H4.01 Space Suit Pressure Garment and Airlock Technologies**

**Lead Center:** JSC

**Participating Center(s):** GRC

Advanced space suit pressure garment and airlock technologies are necessary for the successful support of the International space Station (ISS) and future human space exploration missions for in-space microgravity EVA and planetary surface operations. The space suit pressure garment requires innovative technologies focused on performance, environmental protection, and mass reduction. Two of the critical performance characteristics of a suit are mobility and durability. Improved mobility typically competes against durability and suit component life. Materials that enable both highly mobile and durable designs would negate the need for compromise in one of these areas. Other key suit performance enhancements include materials that enable improved fit and sizing, such as shape change materials that increase the ease of suit don/doff or facilitate adaptable fit for specific functional tasks. Space suit environmental protection includes protection from thermal extremes, vacuum, cuts, abrasion and micrometeoroid and orbital debris (MMOD). Additional environmental protection is desired for plasma, radiation,
electrical shock, antimicrobials and dust. It is desirable to provide protection in as few material layers as possible; therefore, multi-functional materials are desired. Self-healing materials and materials that alert the inspector to wear/maintenance needs are also of interest. Mass reduction of the space suit system is highly desirable for many reasons, with arguably the biggest drivers being launch mass and on-back mass during EVA. New materials that can lead to reductions in suit component mass, for example, lightweight materials for bearings and hard structures, are therefore desirable.

Due to the expected large number of space walks that will be performed on the ISS beyond 2020 and during future human space exploration missions, innovative technologies and designs for both microgravity and surface airlocks will be needed. Technology development is needed to decrease the time associated with egressing and ingressing the vehicle or habitat, reducing the gas loss during depressurization, and decreasing the potential of contaminating the cabin due to bringing in dust or CO₂. These enhancements could be achieved with a suitport, suitlock or some type of advanced airlock.

Technology Readiness Levels (TRL) of 4 to 6 or higher are sought.

Potential NASA Customers include:

- EVA Project Office.
- International Space Station.
- Office of Chief Technologist.

**H4.02 Space Suit Life Support and Avionics Systems**

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

Space Suit Life Support Systems

Advanced space suit life support systems are necessary for the successful support of the International Space Station (ISS) and future human space exploration missions for in-space microgravity EVA and planetary surface operations. Exploration missions will require a robust, lightweight, and maintainable Primary Life Support System (PLSS). The PLSS attaches to the space suit pressure garment and provides approximately an 8 hour supply of oxygen for breathing, suit pressurization, ventilation and CO₂ removal, and a thermal control system for crew member metabolic heat rejection. Innovative technologies are needed for high-pressure O₂ delivery, crewmember cooling, heat rejection, and removal of expired CO₂ and water vapor.
Future generations of advanced space suit avionics will be far superior to those on the current generation of space suits. They will be more capable, configurable, lightweight, and low power with a footprint that will rival current consumer electronic devices, but survive the harsh space environment. They must be self-contained, so that maintenance on the devices can be performed on-orbit or they can be easily swapped for functioning or upgraded devices. Those considered will be radio, displays, and cameras.

Future advanced radios will be configurable and, potentially, software-defined and/or re-configurable to support future communications network-based architectures in addition to the point-to-point communications links that are prevalent today. The next-generation EVA radios will need to support voice, telemetry, and standard/high definition video data flows (up to 20 Mbps) and the radio architecture will need to be lightweight and power efficient while managing data in a seamless and lossless manner between multiple interfaces. Radios should support space-based or terrestrial-based protocols to enable communications between multiple entities across a communications link and have an open and modular architecture.

The current generation of Head-Mounted Displays (HMDs) and Near-to-Eye (NTE) Displays are not viable, since it is desirable for the display to be decoupled from the user's head for improved safety, comfort, and alignment. The decoupling makes the specifications for the eyebox (tolerance to misalignment before image goes out of focus), field of view (angle of the image created by the optics), and eye relief (working distance from the eye to the last optical element) difficult. Key performance targets include:

- **Graphical Data Presentation:** SXGA @ 40 °FOV (possibly biocular).
- **Decoupled from User's Head - Large Eyebox:** 100 mm x 100mm x 50mm (D).
- **Sunlight Readability:** 500 fL inside visor, 1800 fL outside visor (>10 to 1 contrast).

Display technologies must ensure that suit displays can operate outside the suit environment in thermal, radiation, and vacuum as well as internally without imposing ignition hazards due to 100% oxygen environment.

Cameras will not only provide the crewmember the ability for still and motion image, but also situational awareness, which enhances safety for the crewmember. The cameras should be capable of recording high definition motion and high-resolution imagery with the ability to compress the data for transmission over a variety of RF transmissions and/or IP networks with varying bandwidths. Hemispherical and dynamic cameras are desired. Dynamic cameras can take still images and motion video in variable bandwidths, capture images based on link quality, and change frame rates. Hemispherical cameras record 360 ° video views of a crewmember, distort views through optics and then undistort the views via software on the ground to pan/zoom for total situational awareness. Cameras should be low-power and lightweight with a number of mounting options for optimal placement on the suit.

Technology Readiness Levels (TRL) of 4 to 6 or higher are sought.

Potential NASA Customers include:
Lightweight Spacecraft Materials and Structures Topic H5

The SBIR topic area of Lightweight Spacecraft Materials and Structures centers on developing lightweight inflatable structures, solar array structures, and advanced manufacturing technologies for metallic materials. Applications are expected to include space exploration vehicles including launch vehicles, crewed vehicles, and surface and habitat systems, and solar electric propulsion tugs. The subtopic Expandable/Deployable Structures solicits innovative concepts to support the development of lightweight-structure technologies that would be viable solutions to high packaging efficiency, and of deployment mechanisms. Technologies are needed to minimize launch mass, volume and costs, while maintaining the required structural performance for the loads and environments. Of particular interest for expandable/inflatable systems are high-tenacity fibrous materials for the restraint layer of inflatable structures, and bladder materials with limited air permeation and good flexure properties at low temperatures. Analysis and test methods that verify the performance of highly loaded inflated structures are highly desired. For large solar arrays systems, mass-efficient solar array designs with a scalable path from 20-30 kW up to 300 kW and beyond are needed. Advanced analysis and test techniques to ensure reliable deployment of large solar array structures are of special interest. Novel design and packaging concepts, analysis techniques, and both ground and in-space test methods are sought for large deployable solar arrays as well as for individual components such as lightweight booms, ribs, or frames; flexible substrate materials; and mechanisms. The overall objective of the subtopic on Advanced Manufacturing and Material Development for Lightweight Metallic Structures is to advance technology readiness levels of lightweight metals and manufacturing techniques for launch vehicles and in-space applications resulting in structures having affordable, reliable, predictable performance with reduced costs. Proposals are sought that offer innovative manufacturing processes and/or materials to locally increase the stiffness and strength of structural elements added to NNS components. Manufacturing methods of interest include additive manufacturing methods that employ wire feedstock, fusion and friction stir welding. Of specific interest in materials are advances in aluminum wire and tape feedstock materials, including customized alloy chemistry and metal matrix composites (MMCs) incorporating either discontinuous or continuous reinforcements. Of specific interest in manufacturing and processing are proposals that address issues such as residual stress and distortion control, post-deposition processing to develop service mechanical properties, and energy source/reinforcement interactions. 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:

**H5.01 Expandable/Deployable Structures**

*Lead Center: LaRC*

*Participating Center(s): JSC*

The SBIR subtopic area of Lightweight Expandable/Deployable Structures solicits innovative concepts to support the development of primary pressurized inflatable modules or large solar array structures for space exploration.
environments. Concepts should illustrate simple designs, low launch-to-deployed dimension ratios, efficient packaging and deployment techniques. Robustness, damage tolerance, and minor repair capabilities should also be considered in concept submittals. Development of advanced analysis and test methods that verify the performance of highly loaded inflated structures or large solar array systems are highly desired.

Of particular interest for expandable/inflatable systems are high-tenacity fibrous materials for the restraint layer of inflatable structures. Proposed materials should have well-characterized long-term creep behavior or a characterization plan for determination thereof. Also of significant interest are bladder materials with an air permeation rate no greater than 1.5 cc/100 in²/day/atm that remain sufficiently flexible at -50 °F to be deployed on orbit without external heating. Permeation rate should show no increase upon fold/flex testing at -50 °F.

For large solar arrays systems, mass-efficient solar array designs with a scalable path from 20-30 kW up to 300 kW and beyond are needed. Advanced analysis and test techniques to ensure reliable deployment of large solar array structures are of special interest. Novel design and packaging concepts, analysis techniques, and both ground and in-space test methods are sought for large deployable solar arrays as well as for individual components such as lightweight booms, ribs, or frames; flexible substrate materials; and mechanisms.

Technology Readiness Levels (TRL) of 3 to 4 or higher are sought.

Potential NASA Customers include:

- International Space Station.
- Advanced Exploration Systems - Deep Space Habitat.
- Office of Chief Technology - Game Changing Technology Division, and Technology Demonstration Missions.

**H5.02 Advanced Manufacturing and Material Development for Lightweight Metallic Structures**

**Lead Center:** LaRC

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

The overall objective of this subtopic is to advance technology readiness levels of lightweight metals and manufacturing techniques for launch vehicles and in-space applications resulting in structures having affordable, reliable, predictable performance with reduced costs.

The current state-of-the-art for fabrication of launch vehicle structure is multi-piece welded and riveted construction to assemble parts that are heavily machined from thick wrought products. Fabrication of single-piece launch vehicle structure using near-net shape (NNS) manufacturing methods can reduce mass and cost while increasing safety and reliability, primarily through elimination of welds and parasitic weld land weight and reduction in the number of
manufacturing steps. However, to fully realize the benefits of these NNS manufactured components, methods to add structural elements and/or locally enhance material properties of these structural elements are needed. Structural elements added by welding or deposited by additive manufacturing methods typically have dissimilar microstructures and reduced mechanical properties compared with the NNS fabricated component. Materials of construction are typically aluminum and aluminum lithium (Al-Li) alloys. Some examples where this technology would be applied include adding stiffeners to thin-walled single-piece monocoque shells such as cylinders, bulkheads, domes, and frustums, and for reinforcing cut outs and windows.

Proposals are sought that offer innovative manufacturing processes and/or materials to locally increase the stiffness and strength of structural elements added to NNS components. Manufacturing methods of interest include additive manufacturing methods that employ wire feedstock, fusion and friction stir welding. Of specific interest in materials are advances in aluminum wire and tape feedstock materials, including customized alloy chemistry and metal matrix composites (MMCs) incorporating either discontinuous or continuous reinforcements. Of specific interest in manufacturing and processing are proposals that address issues such as residual stress and distortion control, post-deposition processing to develop service mechanical properties, and energy source / reinforcement interactions.

Research should be conducted to demonstrate technical feasibility in Phase I and show a path toward demonstration in Phase II of material fabrication and/or manufacturing process improvement. When possible proposals should include delivery of sample material for test and evaluation by NASA and/or a component demonstration article.

Technology Readiness Levels (TRL) of 4 to 6 or higher are sought.

Potential NASA Customers include:

- Office of Chief Technology - Integrated Manufacturing Modeling with Experiment.
- Space Launch System.
- Multi Purpose Crew Vehicle.
- Fundamental Aeronautics - Fixed Wing, High Speed, Aerosciences Projects.

Autonomous and Robotic Systems Topic H6

NASA invests in the development of autonomous systems, advanced avionics, and robotics technology capabilities for the purpose of enabling complex missions and technology demonstrations supporting the Human
Exploration and Operations Mission Directorate (HEOMD). The software, avionics, and robotics elements requested within this topic are critical to enhancing human spaceflight system functionality. These elements increase autonomy and system reliability; reduce system vulnerability to extreme radiation and thermal environments; and support human exploration missions with robotic assistants, precursors and caretaker robots. As key and enabling technology areas, autonomous systems, avionics and robotics are applicable to broad areas of technology use, including heavy lift launch vehicle technologies, robotic precursor platforms, utilization of the International Space Station, and spacecraft technology demonstrations performed to enable long duration space missions. All of these flight applications will require unique advances in software, robotic technologies and avionics. The exploration of space requires the best of the nation’s technical community to provide the technologies, engineering, and systems to enable human exploration beyond LEO, to visit asteroids and the Moon, and to extend our reach to Mars.

Sub Topics:

**H6.01 Spacecraft Autonomy and Space Mission Automation**

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

Future human spaceflight missions will place crews at large distances and light-time delays from Earth, requiring novel capabilities for crews and ground to manage spacecraft consumables such as power, water, propellant and life support systems to prevent Loss of Mission (LOM) or Loss of Crew (LOC). This capability is necessary to handle events such as leaks or failures leading to unexpected expenditure of consumables coupled with lack of communications. If crews in the spacecraft must manage, plan and operate much of the mission themselves, NASA must migrate operations functionality from the flight control room to the vehicle for use by the crew. Migrating flight controller tools and procedures to the crew on-board the spacecraft would, even if technically possible, overburden the crew. Enabling these same monitoring, tracking, and management capabilities on-board the spacecraft for a small crew to use will require significant automation and decision support software. Required capabilities to enable future human spaceflight to distant destinations include:

- Enable on-board crew management of vehicle consumables that are currently flight controller responsibilities.
- Increase the onboard capability to detect and respond to unexpected consumables-management related events and faults without dependence on ground.
- Reduce up-front and recurring software costs to produce flight-critical software.
- Provide more efficient and cost effective ground based operations through automation of consumables management processes, and up-front and recurring mission operations software costs.

The same capabilities for enabling human spaceflight missions are directly applicable to efforts to automate the operation of unmanned aircraft flying in the National Airspace (NAS) and robotic planetary explorers.

**Mission Operations Automation:**

- Peer-to-peer mission operations planning.
- Mixed initiative planning systems.
- Elicitation of mission planning constraints and preferences.
- Planning system software integration.
Space Vehicle Automation:

- Autonomous rendezvous and docking software.
- Integrated discrete and continuous control software.
- Long-duration high-reliability autonomous system.
- Power aware computing.

Spacecraft Systems Automation:

- Multi-agent autonomous systems for mapping.
- Safe proximity operations (including astronauts).
- Uncertainty management for proximity ops, movement, etc.

Emphasis of proposed efforts:

- Software proposals only, but emphasize hardware and operating systems the proposed software will run on (e.g., processors, sensors).
- In-space or Terrestrial applications (e.g., UAV mission management) are acceptable.
- Proposals must demonstrate mission operations cost reduction by use of standards, open source software, staff reduction, and/or decrease of software integration costs.
- Proposals must demonstrate autonomy software cost reduction by use of standards, demonstration of capability especially on long-duration missions, system integration, and/or use of open source software.

Technology Readiness Levels (TRL) of 4 to 6 or higher are sought.

Potential NASA Customers include:

- Habitation Systems Project.
  - ([http://www.nasa.gov/exploration/analogs/hdu_project.html](http://www.nasa.gov/exploration/analogs/hdu_project.html) [5])
- Mission Operations Directorate
- Human Exploration Telerobotics Project
H6.02 Radiation Hardened/Tolerant and Low Temperature Electronics and Processors

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

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. All three characteristics for radiation hardened electronics of TID, SEU and SEL are needed.

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.

Using the 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 radiation hardness and low-temperature (-230 °C) analog and mixed-signal circuit performance.

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

Technology Readiness Levels (TRL) of 3 to 5 or higher are sought.

Potential NASA Customers include:

- Autonomous Landing Systems.
- Mars Science Lab Instrumentation.
- Tele-robotics.
- Surface Mobility.
- Nuclear Systems.
- Robotic Satellite Servicing.
- In-Space propulsion.
- Deep Space Optical Communications.
- Mars Sample Return.
- Europa Orbiter.
- Near Earth Objects and Primitive Body Missions.
- Space Launch System.
- Extra-Vehicular Activity Suits

**H6.03 Human-Robotic Systems - Manipulation Subsystem**

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

This call for technology development is in direct support of the Human Exploration and Operations Mission Directorate (HEOMD). 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 Subtopic 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 Subtopic addresses robotic manipulation and related technology needs associated with planetary surface systems infrastructure, interaction of humans and machines, mobility systems, payload and resource handling, and mitigation of environmental contaminations.

The objective of this Subtopic is to create human-robotic technologies (hardware and software) to improve the exploration of space.

Robots can perform tasks to assist and off-load work from astronauts. Robots may perform this work before, in support of, or after humans.

Ground controllers and astronauts will remotely operate robots using a range of control modes (teleoperation to supervised autonomy), over multiple spatial ranges (shared-space, line-of-sight, in orbit, and interplanetary), and with a range of time-delay and communications bandwidth.

Proposals are sought that address the following technology needs:

- Subsystems that improve handling and maintenance of payloads and assets.
- Enable crew and ground controllers to better operate, monitor, and supervise robots.
- Improve the transport of crew, instruments, and payloads on planetary surfaces, asteroids, as well as in space.

This includes:

- Robot user interfaces.
- Automated performance monitoring.
- Tactical planning software.
- Ground data system tools.
- Command planning and sequencing.
- Real-time visualization/notification.
- Software for situational awareness, as well as, subsystems to improve handling and maintenance of payloads and assets.
- Tactile sensors.
- Human-safe actuation.
- Active structure.
- Dexterous grasping.
- Modular "plug and play" mechanisms for deployment and setup.
- Standardized interfaces for structural loads & commodity transfer.
- Novel robotic manipulation methods.
- Small/lightweight devices to provide subsurface access and sampling.
- Small/lightweight regolith excavation, handling & delivery devices.
- Regolith anchoring methods for near Earth objects (neo).
- Subsystems to improve the transport of crew, instruments, and payloads on planetary surfaces, asteroids, and in-space.
- Hazard detection sensors/perception.
- Active suspension.
- Grappling/anchoring.
- Legged locomotion.
- Sub-surface locomotion.
- Robot navigation.
- Infrastructure-free localization.

Technology Readiness Levels (TRL) of 2 to 6 are sought.

Potential NASA Customers include:

- Software Robotics and Simulation Division (JSC-ER).
- International Space Station.
- Habitat Development Unit (AES Project).
- Multi-Mission Space Exploration Vehicle (MMSEV-AES Project).
- MPCV Orion Project.
Entry, Descent and Landing Technology Topic H7

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 recombination 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., Near Earth Object Earth Return with velocities exceeding 11.5 km/s and Heavy Mass Mars Landing with 8 km/s entry. In addition, new low ballistic coefficient deployable systems may require flexible ablative TPS materials that can protect systems experiencing heat fluxes ranging from 30 W/cm² to 300 W/cm², depending on their missions. 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:

**H7.01 Ablative Thermal Protection Systems**

Lead Center: ARC

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

The technologies described below support the goal of developing higher performance ablative TPS materials for higher performance future Exploration missions. Developments are sought for ablative TPS materials and heat shield systems that exhibit maximum robustness, reliability and survivability while maintaining minimum mass requirements, and capable of enduring severe combined convective and radiative heating. In addition, in order to adequately test and design with these materials, advancements in instrumentation, inspection, and modeling of ablative TPS materials is also sought.
Areas of interest include improvements in the reinforcement materials as follows:

- Advancements in carbon felts including thickness (>1.0-in), density (>0.12 g/cm³), uniformity to use as reinforcement for high strain-to-failure ablative TPS materials.

- Advancements in thin (~0.1-in) three dimensional woven carbon materials to act as stress bearing structure for deployable aeroshells.

- Advancements in thick (>1.0-in) three dimensional woven carbon materials to use as reinforcement for high heat flux mid-to-high density ablative TPS materials.

TPS Materials advancements sought in felts or woven materials impregnated with polymers to improve ablation performance. Areas of interest include:

- One class of materials, for planetary aerocapture and entry for a rigid mid L/D (lift to drag ratio) shaped vehicle, will need to survive a dual heating exposure, with the first at heat fluxes of 400-500 W/cm² (primarily convective) and integrated heat loads of up to 55 kJ/cm², and the second at heat fluxes of 100-200 W/cm² and integrated heat loads of up to 25 kJ/cm². These materials or material systems must improve on the current state-of-the-art recession rates of 0.25 mm/s at heating rates of 200 W/cm² and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 1.0 g/cm² required to maintain a bondline temperature below 250 °C.

- The second class of materials, for planetary aerocapture and entry for a deployable aerodynamic decelerator, will need to survive a single or dual heating exposure, with the first (or single pulse) at heat fluxes of 50-150 W/cm² (primarily convective) and integrated heat loads of 10 kJ/cm² and the second at heat fluxes of 30-50 W/cm² and heat loads of 5 kJ/cm². These materials may be either flexible or deployable.

- The third class of materials, for higher velocity (>11.5km/s) Earth return, will need to survive heat fluxes of 1500-2500 W/cm², with radiation contributing up to 75% of that flux, and integrated heat loads from 75-150 kJ/cm². These materials, or material systems must improve on the current state-of-the-art recession rates of 1.00 mm/s at heating rates of 2000 W/cm² and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 4.0 g/cm², required to maintain a bondline temperature below 250 °C.

Development of in-situ heat flux sensors, surface recession diagnostics, and in-depth or interface thermal response measurement devices for use on rigid and/or flexible ablative materials. In-situ heat flux sensors and surface recession diagnostics tools are needed for flight systems to provide better traceability from the modeling and design tools to actual performance. The resultant data will lead to higher fidelity design tools, risk reduction, decreased heat shield mass and increases in direct payload. The heat flux sensors should be accurate within 20%, surface recession diagnostic sensors should be accurate within 10%, and any temperature sensors should be accurate within 5% of actual values.

Non Destructive Evaluation (NDE) tools for evaluation of bondline and in-depth integrity for light weight rigid and/or flexible ablative materials. Non Destructive Evaluation (NDE) tools are sought to verify design requirements are met during manufacturing and assembly of the heat shield, e.g., verifying that anisotropic materials have been installed in their proper orientation, that the bondline as well as the TPS materials have the proper integrity and are free of voids or defects. Void and/or defect detection requirements will depend upon the materials being inspected. Typical internal void detection requirements are on the order of 6mm, and bondline defect detection requirements are on the order of 25.4mm by 25.4mm by the thickness of the adhesive.
Advances are sought in ablation modeling, including radiation, convection, gas surface interactions, pyrolysis, coking, and charring for low and mid-density fiber based (woven or felt) ablative materials. There is a specific need for improved models for low and mid density as well as multi-layered charring ablators (with different chemical composition in each layer). Consideration of the non-equilibrium states of the pyrolysis gases and the surface thermochemistry, as well as the potential to couple the resulting models to a computational fluid dynamics solver, should be included in the modeling efforts.

Technology Readiness Levels (TRL) of 2-3 or higher are sought.

Potential NASA Customers include:

- Human Exploration and Operations Mission Directorate.
  - Multi Purpose Crewed Vehicle (MPCV) heatshield and backshell projects.
  - Asteroid Sample Return projects.
  - Future design of low Ballistic Coefficient entry vehicles using Hypersonic Inflatable Aerodynamic Decelerator (HIAD) or Adaptive Deployable Entry and Placement Technology (ADEPT) systems.
- Science Mission Directorate - Planetary Exploration Entry, Decent and Landing heatshield and backshell projects and Planetary Sample Return projects.
- NASA Commercial Orbital Transportation Services (COTS) projects.

High Efficiency Space Power Systems Topic H8

This topic solicits technology development for high-efficiency power systems to be used for the human exploration of space. Power system needs include:

- Batteries for extravehicular activity suits.
- Electrical power for in-space propulsion systems.
- Electric power generation and energy storage for planetary and lunar surface applications.

H8.01 Fuel Cells and Electrolyzers:
- Ion-exchange membranes for PEM electrolyzers, emphasizing low acid generation to meet a critical ISS need and low permeability to increase the efficiency of high pressure systems for surface systems.

- Solid oxide fuel cell technology to spark the next-generation of fuel cell technology that will enable operation with multiple fuels including methane for landers and hydrocarbons generated from ISRU processes.

H8.02 Ultra High Specific Energy Batteries:

- Cathodes compatible with silicon-composite anodes to address the key obstacle to current lithium ion battery development for extravehicular activities.

- High-risk battery chemistries offering performance well beyond Li-ion.

H8.03 Space Nuclear Power Systems:

- 10 kWe-class power conversion devices and 450K radiators to support the Technology Demonstration Unit for surface power and 100kW-class electric vehicles.

- 100 kWe-class power conversion devices, > 500K radiators, and high temperature fuels, materials, and heat transport to support fission power systems for MW-class electric vehicles.

- 1 kW-class fission power systems concepts to support science missions and small-scale surface power systems.

H8.04 Advanced Photovoltaic Systems:

- Solar cell, blanket, and interconnect technologies consistent with the needs of solar electric propulsion systems:
  - Flexible blankets.
  - High voltage and high power operation.
  - Low cost, high volume fabrication techniques.

- Modular panel concepts that emphasize low mass and cost reduction.

Sub Topics:

**H8.01 Fuel Cells and Electrolyzers**

**Lead Center:** GRC

**Participating Center(s):** JPL, JSC, KSC

Ion-Exchange Membranes for PEM Electrolyzers
During high-pressure electrolysis operation, hydrogen permeation through the ion-exchange membrane acts to reduce the current efficiency within the cell. This permeation increases with increasing pressure. Technological approaches are sought that significantly reduce this permeation. Areas of interest include:

- Demonstrated hydrogen permeability reduction >50% for Nafion membranes.
- Concurrent conductivity reductions
- Additionally, such membranes should have low acid generation rates to avoid degrading other elements within the cell stack, and must maintain good water transfer capability, bubble point, and tensile strength for use with cathode liquid-feed systems.

Solid Oxide Fuel Cell Systems

Technologies are sought that improve the durability, efficiency, and reliability of SOFC systems fed by oxygen and fuels such as propellant-grade methane and those generated by ISRU systems (e.g., CO, syngas). Primary SOFC components and systems of interest:

- Power outputs in the 1 to 3 kW range.
- Offer thermodynamic efficiencies of 70% (fuel source-to-DC output) when operating at the current draw corresponding to optimized specific power.
- Operate as specified after at least 50 start-up cycles (from cold to operating temperature within 20 minutes) and 50 shut-down cycles.
- Operate as specified after at least 2500 hours of steady state operation on propellant-grade methane and oxygen. System should startup dry but after reaching operating conditions an amount of water/H$_2$ consistent with what can be obtained from anode recycle can be used. Amounts must be justified.
- Minimal cooling required as obtained by way of conduction through the stack to a radiator exposed to space and/or by anode exhaust flow.

Technology Readiness Levels (TRL) of 3 to 4 or higher are sought.

Potential NASA Customers include:

- International Space Station.
- Human Exploration and Operations Mission Directorate.
Ultra High Specific Energy Batteries

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

Advanced rechargeable batteries are sought for future NASA missions.

For near-term missions, advanced lithium-ion (Li-ion) systems are being developed with the goal to achieve 265 Wh/kg and 675 Wh/L on a cell level. Advanced cathodes are sought, which when integrated into a full cell with a silicon-carbon composite anode, can enable a Li-ion cell to achieve the stated goals at practical voltage levels at a C/10 discharge rate when operating at 10 °C. The cathode should retain 80% of its initial capacity after 250 cycles. In addition, because the cathodes must be manufactured practically, cathodes must achieve a tap density of >1.5 g/cc, should possess qualities that can enable loading of at least 15 mg/square cm per side, and should utilize synthesis approaches that are readily scalable and are amenable to large scale electrode processing utilizing standard battery component equipment. The anode will achieve a reversible capacity of 1000 mAh/g and operate between 50 millivolts and 1 volt versus lithium. The cathode should have no detrimental impact on anode electrochemical performance, cycle-ability or cycle life, should possess a high degree of thermal stability, should have low toxicity, and should be stable against typical carbonate-based electrolytes at voltage levels and material loadings that are practical for the proposed system.

For far-term missions, proposals are sought for advanced next generation rechargeable chemistries that go beyond Li-ion and have the potential to offer >500 Wh/kg and >700 Wh/L on the cell level. Advanced next generation chemistries will be required for human missions, therefore specific energy and energy density goals must be met while simultaneously delivering a high level of safety. Applications may include Extravehicular Activities (spacesuit) and robotic landers and rovers for missions to outer planets, moons and asteroids.

Phase I proposals must include analysis and numerical/quantitative evidence to justify the choice of cathode or advanced chemistry that clearly shows how the proposed component/system has the potential to meet the projected specific energy and energy density goals at the end of a Phase II effort. Additionally, Phase I proposals should describe the technical path that will be followed to achieve the desired specific energy and energy density.

Technology Readiness Levels (TRL) of 4 or higher are sought.

Potential NASA Customers include:

- *Technology is cross-cutting &amp;#150; applicable to any mission or application that requires low mass, low volume, safe batteries. Some examples:*
  - Office of Chief Technologist.
  - Human Exploration and Operations Directorate (EVA suits, landers, rovers, habitats, vehicle power).
  - Aeronautics Research Directorate (electric aircraft).
  - Science Directorate (power for payloads).
H8.03 Space Nuclear Power Systems

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

NASA is developing fission power system technology for future space transportation and surface power applications using a stepwise approach. Early systems are envisioned in the 10 to 100 kWe range that utilize a 900 K liquid metal cooled reactor, dynamic power conversion, and water-based heat rejection. The anticipated design life is 8 to 15 years with no maintenance. Candidate mission applications include initial power sources for human outposts on the Moon or Mars, and nuclear electric propulsion systems (NEP) for Mars cargo transport. A non-nuclear system ground test in thermal-vacuum is planned by NASA to validate technologies required to transfer reactor heat, convert the heat into electricity, reject waste heat, process the electrical output, and demonstrate overall system performance. 1-10 kWe systems are also envisioned for power for robotic science missions to fill the gap between radioisotope power systems and higher power systems.

The primary goals for the early systems are low cost, high reliability, and long life. Proposals are solicited that could help supplement or augment the planned NASA system test. Specific areas for development include:

- 10 kWe-class Stirling and Brayton power conversion devices.
- 450 K radiator panels with embedded heat pipes.
- Kilowatt-class fission power systems concepts and technologies

The NASA non-nuclear system ground test is expected to provide the foundation for later systems in the multi-hundred kilowatt or megawatt range that utilize higher operating temperatures, alternative materials, and advanced components to improve system performance. For the later systems, specific power will be a key performance metric with goals of 30 kg/kWe at 100 kWe and 10 kg/kWe at 1 MWe. Possible mission applications include large NEP cargo vehicles, NEP piloted vehicles, and surface-based resource production plants. In addition to low cost, high reliability, and long life, the later systems should address the low system specific mass goal. Proposals are solicited that identify novel system concepts and methods to reduce mass and increase power output. Specific areas for development include:

- 100 kWe-class Brayton and Rankine power conversion devices.
- Waste heat rejection technologies for 500 K and above.
- High temperature reactor fuels, structural materials and heat transport technologies.

Technology Readiness Levels (TRL) of 3 to 5 or higher are sought.

Potential NASA Customers include:
The primary customer is the Office of Chief Technologist (OCT).

Game Changing Development Program.

Nuclear Systems Project.

Secondary customers include:

- Advanced Exploration Systems (AES) under the Human Exploration and Operations Mission Directorate.
- Planetary Science Division under the Science Mission Directorate.

H8.04 Advanced Photovoltaic Systems

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

Advanced photovoltaic (PV) power generation and enabling power system technologies are sought for improvements in capability and reliability of PV power generation for space exploration missions. Power levels for PV applications may reach 100s of kW. System and component technologies are sought that can deliver efficiency, cost, reliability, mass and volume improvements under various operating conditions. Compatibility with solar cells having at least 29% efficiency and flexible blankets is required.

PV technologies must enable or enhance the ability to provide low-cost, low mass and higher efficiency for power systems with particular emphasis on high power arrays to support solar electric propulsion spacecraft operating at high voltage in the deep space environment. Technologies can address recurring and non-recurring costs for flight units or development units. Examples include technologies that reduce the solar cell cost, modular panel designs, automated blanket/cell/integration and interconnects, low cost/low mass coverglass/coatings, etc.

Areas of particular emphasis for 2012 include:

- Advanced PV blanket and component technology/ designs that support very high power and high voltage (> 200 V) applications.
- PV module/ component technologies that emphasize low mass and cost reduction (in materials, fabrication and testing).
- Improvements to solar cell efficiency that are consistent with low cost, high volume fabrication techniques.
- Automated/ modular fabrication methods for PV panels/ modules on flexible blankets (includes cell laydown, interconnects, shielding and high voltage operation mitigation techniques).

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.

Technology Readiness Levels (TRL) of 2 to 6 or higher are sought.

Potential NASA Customers include:

- Solar Electric Propulsion Technology Demonstration Project in the Office of the Chief Technologist.
- Human Exploration and Operations Mission Directorate; Science Mission Directorate.

Space Communications and Navigation Topic H9

The Space Communication and Navigation Technology Area supports all NASA space missions with the development of new capabilities and services that make our missions possible. Communication links are the lifelines to our spacecraft that provide the command, telemetry, and science data transfers as well as navigation support. Advancement in communication and navigation technology will allow future missions to implement new and more capable science instruments, greatly enhance human missions beyond Earth orbit, and enable entirely new mission concepts. NASA's communication and navigation capability is based on the premise that communications shall enable and not constrain missions. Today our communication and navigation capabilities, using Radio Frequency technology, can support our spacecraft to the fringes of the solar system and beyond. As we move into the future, we are challenged to increase current data rates- 300 Mbps in LEO to about 6 Mbps at Mars- to support the anticipated numerous missions for space science, Earth science and exploration of the universe. Technologies such as optical communications, RF including antennas and ground based Earth stations, surface networks, cognitive networks, access links, reprogrammable communications systems, advanced antenna technology, transmit array concepts, and communications in support of launch services are very important to the future of exploration and science activities of the Agency. Additionally, innovative, relevant research in the areas of positioning, navigation, and timing (PNT) are desirable. NASA's Space Communication and Navigation (SCaN) Office considers the three elements of PNT to represent distinct, constituent capabilities:

- Positioning, by which we mean accurate and precise determination of an asset's location and orientation referenced to a coordinate system.
- Navigation, by which we mean determining an asset's current and/or desired absolute or relative position and velocity state, and applying corrections to course, orientation, and velocity to attain achieve the desired state.
- Timing, by which we mean an assets acquiring from a standard, maintaining within user-defined parameters, and transferring where required, an accurate and precise representation of time, minimize the impact of latency on overall system performance.
This year, the following technology areas are being solicited to meet increasing data throughput and accuracy needs: Optical communications, RF communications, experiments involving reprogrammable communications systems, flight dynamics and breakthrough or high impact communication technologies. Emphasis is placed on size, weight and power improvements. Innovative solutions centered on operational issues are needed in all of the aforementioned areas. All technologies developed under this topic area to be aligned with the Architecture Definition Document and technical direction as established by the NASA SCaN Office. For more details, see [http://ti.arc.nasa.gov/tech/asr/intelligent-robotics/haughton-field/](http://ti.arc.nasa.gov/tech/asr/intelligent-robotics/haughton-field/).

Sub Topics:

**H9.01 Long Range Optical Communications**

*Lead Center: JPL*

*Participating Center(s): GRC, GSFC*

This subtopic seeks innovative technologies for long range Optical Telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- **Isolation platforms** - Compact, lightweight, space-qualifiable vibration isolation platforms for payloads massing between 3 and 50 kg that require less than 15 W of power and mass less than 3 kg that will attenuate an integrated angular disturbance of 150 micro-radians to less than 0.5 micro-radians (1-sigma), from

- **Laser Transmitters** - Space-qualifiable, >20% DC-to-optical (wall-plug) efficiency, 0.2 to 16 nanosecond pulse-width 1550-nm laser transmitter for pulse-position modulated data with from 16 to 320 slots per symbol, less than 35 picosecond pulse rise and fall times, near transform limited spectral width, single polarization output with at least 20 dB polarization extinction ratio, amplitude extinction ratio greater than 38 dB, average power of 5 to 20 Watt, massing less than 500 grams per Watt. Also of interest for the laser transmitter are: robust and compact packaging with radiation tolerant electronics inherent in the design, and high speed electrical interface to support output of pulse position modulation encoding of sub nanosecond pulses and inputs such as Spacewire, Firewire or Gigabit Ethernet. Detailed description of approaches to achieve the stated efficiency is a must.

- **Photon counting near-infrared detectors arrays for ground receivers** - Hexagonal close packed kilo-pixel arrays sensitive to 1000 to 1650 nm wavelength range with single photon detection efficiencies greater than 60% and single photon detection jitters less than 40 picoseconds 1-sigma, active diameter greater than 15 microns/pixel, and 1 dB saturation rates of at least 10 mega-photons (detected) per pixel and dark count rates of less than 1 MHz/square-mm.

- **Photon counting near-infrared detectors arrays for flight receivers** - For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation rates of at least 1 mega-photons/pixel and operational temperatures above 220K and dark count rates of

- **Ground-based telescope assembly** - Telescope/photon-buckets with primary mirror diameter ~2.5 meter, f-number of ~1.1 and Cassegrain focus to be used as optical communication receiver/transmitter optics at 1000-1600nm. Produce a maximum image spot size of ~20 micro-radian, and field-of-view will be ~50 micro-radian. Telescope shall be positioned with a two-axis gimbal capable of 0.25 milli-radian pointing. Desired manufacturing cost for combined telescope, gimbal and dome in quantity (tens) is ~$3 M each.

Research should be conducted to convincingly prove technical feasibility during Phase I - ideally through hardware development, with clear pathways to demonstrating and delivering functional hardware, meeting all objectives and specifications, in Phase II.
Phase I Deliverables - Phase I deliverables shall include a final report describing design studies and analyses, system, sensor, or instrumentation concepts, prospective material formulations, testing, etc. Prototype systems, components, sensors, instruments or materials can be developed in Phase I as well. The designs or concepts should have commercialization potential. For Phase II consideration, the final report should include a detailed path towards Phase II hardware proof-of-concept system or component or material manufacturing and testing as applicable. The technology concept at the end of Phase I should be at a TRL of 4.

Phase II Deliverables - Phase II deliverables shall consist of working proof-of-concept systems, tested material formulations with samples, tested component, sensor, or instrumentation hardware, etc. which have been successfully demonstrated in a relevant environment and delivered to NASA for testing and verification. The technology at the end of Phase II should be at a TRL of 5-6.

Potential NASA Customers include:

- Deep Space Planetary Missions.
- Deep Space Optical Terminal (DOT) Project.
- Space Communications and Navigation (SCaN) Program.

H9.02 Long Range Space RF Communications

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC

This subtopic seeks to develop innovative long-range RF telecommunications technologies supporting the needs of space missions.

In the future, spacecraft with increasingly capable instruments producing large quantities of data will be visiting the Moon and the planets. These spacecraft will also support long term missions, such as to the outer planets, or extended missions with new objectives. They will possess reconfigurable avionics and communication subsystems and will be designed to require less intervention from earth during periods of low activity. The communication needs of these missions motivate higher data rate capabilities on the uplink and downlink as well as more reliable RF and timing subsystems. Innovative long-range telecommunications technologies that maximize power efficiency, reliability, receiver capability, transmitted power and data rate, while minimizing size, mass and DC power consumption are required. The current state-of-the-art in long-range RF space telecommunications is 6 Mbps from Mars using microwave communications systems (X-Band and Ka-Band) with output power levels in the low tens of Watts and DC-to-RF efficiencies in the range of 10-25%.

Technologies of interest:
This subtopic seeks innovative technologies in the following areas:

- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders and components, incorporating MMICs, MEMs and Bi-CMOS circuits.

- MMIC modulators with drivers to provide a wide range of linear phase modulation (greater than 2.5 rad), high-data rate (10 - 200 Mbps) BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (26 GHz, 32 GHz and 38 GHz).

- High DC-to-RF-efficiency (> 60%), low mass Solid-State Power Amplifiers (SSPAs), of both medium output power (10 W-50 W) and high-output power (150 W-1 KW), using power combining and/or wide band-gap semiconductors at X-band (8.4 GHz) and Ka-band (26 GHz, 32 GHz and 38 GHz).

- Utilization of nano-materials and/or other novel materials and techniques for improving the power efficiency or reducing the mass and cost of reliable vacuum electronics amplifier components (e.g., TWTAs and Klystrons).

- Ultra low-noise amplifiers (MMICs or hybrid, uncooled) for RF front-ends (High dynamic range (> 65 dB), data rate receivers (> 20 Mbps) supporting BPSK/QPSK modulations.

- MEMS-based integrated RF subsystems that reduce the size and mass of space transceivers and transponders. Frequencies of interest include UHF, X- and Ka-Band. Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.

- Novel approaches to mitigate RF component susceptibility to radiation and EMI effects.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

**Phase I Deliverables** - Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4). Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

**Phase II Deliverables** - Working engineering model of proposed product, along with full report of development and measurements, including populated verification matrix from Phase I (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

Potential NASA Customers include:

- Deep Space Planetary Missions such as Mars 2018, Mars Sample Return, Jupiter Outer Planet Missions.

- Human Space Exploration Missions such as missions to Asteroids, Mars or various Earth-Moon Libration Waypoints.
**H9.03 CoNNeCT Experiments**

**Lead Center:** GRC

**Participating Center(s):** JPL

NASA has developed an on-orbit, reprogrammable, software defined radio-based (SDR) testbed facility aboard the International Space Station (ISS), to conduct a suite of experiments to advance technologies, reduce risk, and enable future mission capabilities. The Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) Project provides SBIR recipients and through other mechanisms NASA, large business, other Government agencies, and academic partners the opportunity to develop and field communications, navigation, and networking technologies in the laboratory and space environment based on reconfigurable, software defined radio platforms. Each SDR is compliant with the Space Telecommunications Radio System (STRS) Architecture, NASA’s common architecture for SDRs. The Testbed is installed on the truss of ISS and communicates with both NASA’s Space Network via Tracking Data Relay Satellite System (TDRSS) at S-band and Ka-band and direct to/from ground systems at S-band. One SDR is capable of receiving L-band at the GPS frequencies of L1, L2, and L5.

NASA seeks innovative software applications and experiments to run aboard the Testbed to demonstrate and enable future mission capability using the reconfigurable features of the software defined radios. Experiment software/firmware can run in the flight SDRs, the flight avionics computer, and on a corresponding ground SDR at the Space Network, White Sands Complex. Unique experimenter ground hardware equipment may also be used.

Experimenters will be provided with appropriate documentation (e.g., flight SDR, avionics, ground SDR) to aid their experiment application development, and may be provided access to the ground-based and flight SDRs to prepare and conduct their experiment. Access to the ground and flight system will be provided on a best effort basis and will be based on their relative priority with other approved experiments. Please note that selection for award does not guarantee flight opportunities on the ISS.

Desired capabilities include, but are not limited to, the examples below:

- Demonstration of mission applicability of SDR.
- Aspects of reconfiguration:
  - Unique/efficient use of processor, FPGA, DSP resources.
  - Inter-process communications.
- Spectrum efficient technologies.
- Space internetworking:
  - Disruption Tolerant Networking.
- Position, navigation and timing (PNT) technology.
- Technologies/waveforms for formation flying.
- High data rate communications.
- Uplink antenna arraying technologies.
- Multi-access communication.
- RF sensing applications (science emulation).
- Cognitive applications.

Experimenters using ground or flight systems will be required to meet certain pre-conditions for flight including:

- Provide software/firmware deliverables (software/firmware source, executables, and models) suitable for flight.
- Document development and build environment and tools for waveform/applications.
- Provide appropriate documentation (e.g., experimenter requirements, waveform/software user's guide, ICD's) throughout the development and code delivery process.
- Software/firmware deliverables compliant to the Space Telecommunications Radio System (STRS) Architecture, Release 1.02.1 and submitted to waveform repository for reuse by other users.
- Verification of performance on ground based system prior to operation on the flight system.

Methods and tools for the development of software/firmware components that is portable across multiple platforms and standards-based approaches are preferred.

Documentation for both the CoNNeCT system and STRS Architecture may be found at the following link:

(http://spaceflightsystems.grc.nasa.gov/SpaceOps/CoNNeCT/) [8]

These documents will provide an overview of the CoNNeCT flight and ground systems, ground development and test facilities, and experiment flow. Documentation providing additional detail on the flight SDRs, hardware suite, development tools, and interfaces will be made available to successful SBIR award recipients. Note that certain documentation available to SBIR award recipients is restricted by export controls and available to U.S. citizens only.

For all above technologies, Phase I will provide experimenters time to develop and advance waveform/application architectures and designs along with detailed experiment plans. The subtopic will seek to leverage more mature waveform developments to reduce development risk in subsequent phases, due to the timeframe of the on-orbit Testbed. The experiment plan will show a path toward Phase II software/firmware completion, ground verification process, and delivering a software/firmware and documentation package for NASA space demonstration aboard the flight SDR. Phase II will allow experimenters to complete the waveform development and demonstrate technical feasibility and basic operation of key algorithms on CoNNeCT ground-based SDR platforms and conduct their flight
system experiment. Opportunities and plans should also be identified and summarized for potential commercialization.

Phase I Deliverables:

- Waveform/application architecture and detailed design document, including plan/approach for STRS compliance.
- Experiment Reference Design Mission Concept of Operations.
- Experiment Plan (according to provided template).
- Demonstrate simulation or model of key waveform/application functions.
- Plan and approach for Commercialization of the technology (part of final report).
- Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product. Early software/firmware application source and binary code and documentation. Source/binary code will be run on engineering models and/or SDR breadboards (at TRL-3-4).

Phase II Deliverables:

- Applicable Experiment Documents (e.g., requirements, design, management plans).
- Simulation or model of waveform application.
- Demonstration of waveform/application in the laboratory on CoNNeCT breadboards and engineering models.
- Results of implementing the Commercialization Plan outlined in Phase I.
- Software/firmware application source and binary code and documentation (waveform contribution to STRS Repository for reuse by others). Source/binary code will be run on engineering models and/or demonstrated on-orbit in flight system (at TRL-5-7) SDRs.

Potential NASA Customers include:

- Deep Space Planetary Missions.
- Extra Vehicular Activity Office.
- Space Communications and Navigation (SCaN) Program.
NASA’s current Position, Navigation, and Timing (PNT) state-of-the-art relies on both ground-based and space-based radiometric tracking, laser ranging, and optical navigation techniques. Post-processed GPS position determination performance accuracy is at the cm-level at Near-Earth distances and at meter-level at High-Earth Orbit distances; while autonomous real-time GPS performance, such as provided by GPS-Enhanced Onboard Navigation System (GEONS) can achieve accuracy performance of 20 meters. For missions at Mars, Deep Space Network navigation services provide performance accuracy of 1km, while optical navigation methodologies obtain performance accuracy of 10s of km at this distance.

Future NASA missions will require precision landing, rendezvous, formation flying, cooperative robotics, proximity operations, and coordinated platform operations. As such, the need for increased precision in absolute and relative navigation solutions increases. As operations occur further from Earth and more complex navigational maneuvers are performed, it will be necessary to reduce the reliance on Earth-based systems for real-time decisions. Investments in technologies to implement autonomous on-board navigation and maneuvering will permit a reduction in dependence on ground-based tracking, ranging, trajectory/orbit/attitude determination, and maneuver planning and support functions. Therefore, the early focus for NASA will be to improve PNT through increasing real-time PNT accuracy and precision, as well as achieving this performance in autonomously on-board the spacecraft.

Technologies and software should support a broad range of spaceflight customers. Technologies and software specifically focused on a particular mission's or mission set's needs are the subject of other solicitations by the relevant sponsoring organizations and should not be submitted in response to this solicitation. In the context of this solicitation, flight dynamics technologies and software are algorithms and software that may be used in ground support facilities, or onboard a spacecraft, so as to provide PNT services that reduce the need for ground tracking and ground navigation support. Flight dynamics technologies and software also provide critical support to pre-flight mission design, planning, and analysis activities.

This solicitation is primarily focused on NASA’s flight dynamics software and technology needs in the following focused areas:

- Next generation of multi-purpose ground-based and on-board autonomous navigation filtering techniques, such as adaptive filtering where measurements are selectively weighted, or filters that monitor state noise and measurement noise processes.
- Algorithms for real-time multi-platform relative navigation (relative position, velocity, attitude/pose).
- Algorithms which process clock measurements and estimate and/or propagate the timekeeping model (which generates the time and frequency signal output) and timekeeping system architectures in which outputs of an ensemble of clocks are weighed and software filtered to synthesize an optimized time estimate.
- Sensor measurement models and processing algorithms for next generation sensors, including (but not limited to): optical navigation sensors (high resolution flash LIDAR, visible cameras, infrared cameras), radar sensors, radiometrics, fine guidance sensors, laser rangefinders, high volume/high speed FPGA-based electronics for LIDAR.
- Algorithms for real-time vision processing, path planning and optimization, constraint handling, integrated system health management, fault management (FDIR), event sequencing, optimal resource allocations, collaborative sensor fusion, sensor image motion compensation and processing, pattern
recognition/matching, hazard search and detection, feature location and mapping, high performance inertial and celestial sensor models, accurate and fast converging vehicle state estimation filters and adaptive flight control systems.

- Applications of advanced dynamical theories to space mission design and analysis for ground-based and on-board autonomous algorithms, especially in the context of unstable orbital trajectories in the vicinity of small bodies, libration points, and Near-Earth objects.

- Autonomous navigational planning, detection, and filter optimization, as well as attitude control systems for autonomous platform orientation, using sensor measurement fault detection & management and/or fault-tolerant filtering algorithms.

- Addition of novel estimation techniques and/or orbit determination capabilities to existing NASA mission design software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.

Proposals that leverage state-of-the-art capabilities already developed by NASA are especially encouraged, such as:

- GPS-Enhanced Onboard Navigation Software:  
  - (http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtm) [9]


- General Mission Analysis Tool (http://sourceforge.net/projects/gmat) [10]

- GPS-Inferred Positioning System and Orbit Analysis Simulation Software:  

- Optimal Trajectories by Implicit Simulation (http://otis.grc.nasa.gov) [12]

Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

**Phase I Deliverables** - Phase I research should be conducted to demonstrate technical feasibility (to reach TRL 3), with preliminary software being delivered for NASA testing at the end of the Phase I contract, as well as show a plan towards Phase II integration. Phase I Deliverables include:


- Preliminary Software at end of Phase I contract.

- Final Phase I Technical Feasibility Report with a Phase II Integration Path.

**Phase II Deliverables** - Phase II efforts should build on Phase I research towards a Phase II software demonstration and delivering a software package for NASA testing at the completion of the Phase II contract (to reach TRL 5). Also, prototype software should be delivered to NASA at the end of the first year of the contract, to be reviewed and iterated upon towards the development of the final software demonstration and delivery. Phase II
efforts should also include development of proper documentation, which includes a thorough Algorithm Specification document. Phase II Deliverables include:

- Prototype Software at end of first year of Phase II contract.
- Final Phase II Technical Report.
- Algorithm Specification at end of Phase II contract.
- Delivery of software package at end of Phase II contract.
- Demonstration of software package at end of Phase II contract.

Potential NASA Customers include:

- Space Communications and Navigation (SCaN) Program

**H9.05 Game Changing Technologies**

**Lead Center:** GRC

**Participating Center(s):** ARC, GSFC, JPL

NASA seeks revolutionary, highly innovative, game changing communications technologies that have the potential to enable order of magnitude performance improvements for space operations, exploration systems, and/or science mission applications. As NASA moves towards an integrated network architecture, infusion of critical, enabling technologies will be key to meeting user needs and offering standardized services. Emphasis for this subtopic is on the mid - (3-8 yrs.), and far-term (>8 yrs.) with focused research in the following areas:

Develop novel techniques for size, weight, and power (SWAP) of communications systems by addressing digital processing and logic implementation tradeoffs, dynamic power management, hardware and software partitioning. Address reliability, robustness, and radiation tolerance for missions beyond low Earth orbit. Investigate and demonstrate unique, innovative electronic or optical technologies to alleviate demanding mission requirements (at least 10X improvement over state-of-the-art) in areas such as chip speed, compression, encoding/decoding, etc. Communication systems optimized for energy efficiency (information bits per unit energy) will be increasingly important for low energy communication systems.

Small spacecraft, due to their limited surface area, are typically power constrained, limiting small spacecraft communications systems to low bandwidth architectures. Technologies and architectures that can exploit commercial or other terrestrial communication infrastructures to enable novel small satellite (e.g., CubeSat) missions are desired. Identify advanced solutions for higher density integration techniques and packaging. Address how existing communications architectures can be adapted and utilized to provide higher bandwidth communications capabilities with better performance and at lower cost for spacecraft to ground, and spacecraft to spacecraft applications.
Novel approaches to addressing extremely high bandwidth, high data rate signaling using RF, mm-wave (Ka- to W-band), and/or optical (1550 nm) links.) Purely optical links are subject to atmospheric interference (clouds, rain, snow, fog, etc.) and can restrict operations for Earth-based optical terminals, so hybrid RF/optical systems are intriguing. Technologies that address flexible, scalable digital/optical core processing topologies to support both RF and optical communications in a single dual-feed terminal, such as: programmable modulation/coding, multi-rate clocking and data recovery, system-on-a-chip integration, memory management, multi-processor architectures, etc. are sought to mitigate risk of such a system.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II demonstration with delivery of a demonstration unit or package for NASA testing at the completion of the Phase II contract.

Opportunities and plans should also be identified and summarized for potential commercialization.

**Phase I Deliverables** - Phase I deliverables shall include a final report describing design studies and analyses, system, sensor, or instrumentation concepts, prospective formulations, testing, etc. Prototype systems, components, sensors, instruments or materials can be developed in Phase I as well. The designs or concepts should have commercialization potential. For Phase II consideration, the final report should include a detailed path towards Phase II proof-of-concept system or component or testing as applicable. The technology concept at the end of Phase I should be at a TRL range of 2-3.

**Phase II Deliverables** - Phase II deliverables shall consist of working proof-of-concept systems, samples, component, sensor, or instrumentation hardware, etc. which have been successfully demonstrated in a relevant environment and delivered to NASA for testing and verification. The technology at the end of Phase II should be at a TRL range of 3-4.

Potential NASA Customers include:

- Deep Space Planetary Missions.
- Extra Vehicular Activity Office.
- Space Suit Communications.
- Space Communications and Navigation (SCaN) Program.
Ground Processing and ISS Utilization Topic H10

The Human Exploration and Operations Mission Directorate (HEOMD) provides mission critical space exploration services to both NASA customers and to other partners within the U.S. and throughout the world: assembling and operating the International Space Station; ensuring safe and reliable access to space; maintaining secure and dependable communications between platforms across the solar system; and ensuring the health and safety of our Nation’s astronauts. Activities include ground-based and in-flight processing and operations tasks, along with support that ensures these tasks are accomplished efficiently and accurately, enables successful missions and healthy crews. This topic area, while largely focused on operational space flight activities, is broad in scope. NASA is seeking technologies that address how to improve and lower costs related to ground and flight assets, and maximize the utilization of the International Space Station. A typical flight focused approach would include:

- Phase I - Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Bench or lab-level demonstrations are desirable.
- Phase II - Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions.

The proposal shall outline a path showing how the technology could be developed into space-worthy systems. For ground processing and operations tasks, the proposal shall outline a path showing how the technology could be developed into ground or flight systems. The contract shall deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract and, if possible, demonstrate earth based uses or benefits.

Sub Topics:

**H10.01 Ground Processing Optimization and Technology Infusion**

**Lead Center:** KSC

**Participating Center(s):** ARC, SSC

This subtopic seeks innovative concepts and solutions for both addressing long-term ground processing and test complex operational challenges and driving down the cost of government and commercial access to space. Technology infusion and optimization of existing and future operational programs, while concurrently maintaining continued operations, are paramount for cost effectiveness, safety assurance, and supportability.

Strategies to optimize and support changes in operations concepts should consider:

- The needs of geographically distributed and mobile teams.
- Efficient configuration changes to support operations of different customers.
- Protection of information for the different customers.
- Infrastructure availability.
- Increased situational awareness for operators.

Technology areas of Interest include:
• Strategies, technology innovations, and technology maturation of control room services to provide cost effective data handling and storage and standardized interfaces for data generated by dissimilar systems. Methods for rapid prototype of control and data systems software from engineering data, ensuring scalability of data presentation and streamlined communication, and methods to address and inform consumers of time delays in data transmission:

  ◦ Cost effective solutions to connect control and data system software to facility models that provide for ease of use and maximize the return on investment for concurrent test and launch complex environments.

  ◦ Approaches, such as a single console to perform command and control for a set of test resources or provisions for model-based diagnostic methods to provide rapid feedback on the test and launch complex environment state, can be explored.

• Methodologies for benchmarking, migrating, upgrading, and/or enhancing tools and control and data system architectures to lower the cost of technology infusion concurrently with the operational environment while reducing sustaining costs:

  ◦ Focus should also be on system maintenance concepts for a highly COTS intensive environment to ensure configuration management and control, verification and validation approaches, technology refresh and security updates.

  ◦ Innovative capabilities in information technology are required to provide robust and highly efficient information security for maintaining customer-specific intellectual property while providing a collaborative environment for launch and testing services.

• Optimization of ground controller and test conductor staffing and roles requirements through robust, innovative, and operator-infused simulation/training capabilities to efficiently train ground and test controllers in a collaborative environment. Objectives should focus on skills proficiency and maintenance for troubleshooting, decision making, and time management in critical situations.

• Migration of models used in the design and development of infrastructure to the operations/training phase (e.g., Model-Based System Engineering (MBSE) process).

• Cost effective solutions for operations automation including peer-to-peer planning, mixed initiatives, elicitation of constraints and preferences, and system software integration. Focus should be on the use of standards and open source software enabling staff reduction, fault isolation and recovery methods, and decrease of software integration costs. Additionally, on understanding the interfaces of planning/mixed initiative systems with diagnostic systems, as diagnostic systems will inform the planning system of the available resources.

• Prognostic technologies to optimize component maintenance, support, mission and test planning, evaluation of system component redundancy, monitoring of performance and safety margins, and critical decision making.

Proposed concepts would benefit from clean, well-defined, unambiguous interfaces that account for configuration changes over the ground processing and test complex timeline; such proposals will receive higher consideration. All concepts must place an emphasis on how the interfaces in the system behave. Approaches to model, verify, and validate interfaces will be of interest.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II demonstration, and delivering a demonstration package for NASA testing at the completion of the Phase II contract.
**Phase I Deliverables** - Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a demonstration. Concept methodology, infusion strategies (including risk trades), and business model. Identify improvements over the current state of the art and the feasibility of the approach in a multi-customer environment. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL of 4.

**Phase II Deliverables** - Emphasis should be placed on developing and demonstrating the technology under simulated mission conditions, including the mission of engine testing. The proposal shall outline a path showing how the technology could be developed into mission-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL of 7.

---

**H10.02 ISS Demonstration & Development of Improved Exploration Technologies**

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

The focus of this subtopic is on technologies and techniques which may advance the state of the art of spacecraft systems by utilizing the International Space Station as a technology test bed.

Successful proposals will address using the long duration environment of the ISS to demonstrate component or system characteristics that extend beyond the current state of the art by:

- Increasing capability/operating time including overall operational availability.
- Reducing logistics and maintenance efforts.
- Reducing operational efforts, minimizing crew interaction with both systems and the ground.
- Reducing known spacecraft/spaceflight technical risks and needs.
- Providing information on the long term space environment needed in the development of future spacecraft technologies through model development, simulations or ground testing verified by on orbit operational data.

These demonstrations should focus on increasing the TRL in the following fields:

- Power generation and energy storage (e.g., regenerative fuel cells and battery).
- Robotics Tele-robotics and Autonomous (RTA) Systems.
• Communication and Navigation (e.g., autonomous rendezvous and docking advancements).

• Human health, Life Support and Habitation Systems (e.g. closed loop aspects of environmental control and life support systems).

• Science Instruments, Observatories and Sensor Systems.

• Nanotechnology.

• Materials, Structures, Mechanical Systems and Manufacturing.

• Thermal Management Systems (e.g., cryogenic propellant storage and transfer).

• Environmental control systems, including improved carbon dioxide removal.

• On-orbit trash processing/recycling.

• Radiation.

• Providing Engineering Motion Imagery "smart" imaging systems that reduce bandwidth but maintain high quality imaging in areas of interest; maintenance of window clarity on optical systems without creating a debris source; data storage and retrieval for instances when bandwidth is constrained or the rocket or spacecraft will not be retrieved; compression and/or modulation techniques to maximize efficiency of constrained telemetry downlinks; and imaging system components that are radiation and electromagnetic interference tolerant.

For the above technology subject areas, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward hardware and/or material development as appropriate which occurs during Phase II and culminates in a proof-of-concept system.

Phase I Deliverables - Phase I Deliverables: Research to identify and evaluate candidate technologies applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL of 3-6.

Phase II Deliverables - Phase II Deliverables: Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions. The proposal shall outline a path showing how the technology could be developed into space-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology at the end of Phase II should be at a TRL of 6-7.
Radiation Protection Topic H11

The SBIR topic area of Radiation Protection focuses on the development and testing of mitigation concepts to protect astronaut crews and exploration vehicles from the harmful effects of space radiation, both in Low Earth Orbit (LEO) and while conducting long-duration missions beyond LEO. Advances are needed in mitigation schema for the next generation of exploration vehicles inclusive of radiation shielding materials and structures technologies to protect humans from the hazards of space radiation during NASA missions. As NASA continues to form plans for long duration exploration, it has also become increasingly clear that the ability to mitigate the risks posed to both crews and vehicle systems by the space weather environment are also of central importance. This Radiation Protection Topic will concentrate on the Alert and Warning Systems. This area of interest is ways in which SBIR-developed technologies can contribute to NASA's overall mission requirements are advances in the understanding and predictability of space weather science. Current operational space weather support utilizes both inter- and extra-agency assets to maintain situational awareness and mitigate radiation risks associated with agency missions. Operational space weather support consists in the most basic terms of maintaining situational awareness of both the state of the Sun as a physical system and the radiation environment and its dynamics within the Heliosphere, and altering in real-time, a mission in order to minimize their effects. Therefore, advances are needed in the development of scientific research products for real-time operational forecasting tools to mitigate mission risk. Research under this topic should be conducted to demonstrate technical feasibility during Phase I and show a path forward to 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:

**H11.01 Radiation Prediction (Integrated Advanced Alert/Warning Systems for Solar Proton Events)**

**Lead Center:** JSC

**Participating Center(s):** LaRC

Advances are needed in alerts/warnings and risk assessment models that give mission planners, flight control teams and crews sufficient advanced warning of impending Solar Proton Event (SPE) impact. Research and development should be targeted which leverages modeling techniques used throughout terrestrial weather for extreme event assessment. There is particular interest in development of models capable of delivering the probability of no SPE occurrence in a 24-hour time period, i.e., an "All-Clear" forecast.

Forecast techniques should utilize the historical record of archived SPEs to characterize model forecast validity in terms accepted metrics, i.e., skill score, false alarm rates, etc. Specific areas in which SBIR-developed technologies can contribute to NASA's overall mission requirements include the following:

- Innovative forecasting solutions that leverage model development in other areas such as ensemble forecasting of hurricane tracks, flooding, financial market behavior, and earthquake prediction.

- Innovative methods that integrate historical trending, real-time data, and fundamental physics-based models into advance warning and detection systems.

Technology Readiness Levels (TRL) of 2 to 4 or higher are sought.

Potential NASA Customers include:

- Human Exploration and Operations Mission Directorate.
Human Research and Health Maintenance Topic H12

NASA’s Human Research Program (HRP) investigates and mitigates the highest risks to astronaut health and performance in exploration missions. The goal of the HRP is to provide human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration, and to ensure safe and productive human spaceflight. The scope of these goals includes both the successful completion of exploration missions and the preservation of astronaut health over the life of the astronaut. HRP developed an Integrated Research Plan (IRP) to describe the requirements and notional approach to understanding and reducing the human health and performance risks. The IRP describes the Program’s research activities that are intended to address the needs of human space exploration and serve HRP customers. The IRP illustrates the program’s research plan through the timescale of early lunar missions of extended duration. The Human Research Roadmap (http://humanresearchroadmap.nasa.gov [13]) is a web-based version of the IRP that allows users to search HRP risks, gaps, and tasks. The HRP is organized into Program Elements:

- Human Health Countermeasures.
- Behavioral Health & Performance.
- Exploration Medical Capability.
- Space Human Factors and Habitability.
- Space Radiation and ISS Medical Projects.

Each of the HRP Elements address a subset of the risks, with ISS Medical Projects responsible for the implementation of the research on various space and ground analog platforms. The overview and responsibilities of each of the Elements is described within the Human Research Roadmap (referenced above). With the exception of Space Radiation, the SBIR subtopics in this solicitation align with the HRP Program Elements:

- H12.02 Exploration Medical Capability - Medical Suction Capability addresses a specific Exploration Medical Capability technology gap.
• H12.04 Advanced Food Systems Technology helps address the Space Human Factors and Habitability food system risks.

• H12.05 In-Flight Biological Sample Analysis helps address an ISS Medical Project technology need to allow on-orbit biological sample analysis, limiting the need for biological sample return.

Sub Topics:

H12.01 Exploration Countermeasure Capability - Portable Activity Monitoring System

Lead Center: JSC

Participating Center(s): GRC

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 physiologic 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. NASA is conducting research to enhance and optimize exercise countermeasure hardware and protocols for these missions. In this solicitation, we are seeking portable technologies to collect foot ground reaction force data from current exercise hardware deployed on the International Space Station to be analyzed by research teams on the ground.

NASA seeks a portable, force/load measurement system capable of being integrated into existing ISS exercise systems and suitable for use in future transfer and exploration vehicles. During long duration spaceflight, exercise is prescribed to mitigate bone and muscle loss. Advancement of these exercise prescriptions may require biomechanical analysis of exercise on orbit. Output parameters from the proposed device must be valid in the bandwidth from 0-100Hz and be able to be synchronized with existing analog data systems. 3-D force, torque, acceleration, and turn rates are required. Must include a portable data logging system or wireless interface compatible with the Windows platform or Apple iPad. On-board data processing, activity recognition and display is desirable. The portable system should be low-maintenance, durable, easy to set-up and calibrate, non-disruptive to exercise form or gait, accurate ( NASA Deliverables) - Fully developed concept complete with feasibility and top-level drawings as well as computational methodology as applicable. A breadboard or prototype system is highly desired.

HRP IRP Risks - Risk of Impaired Performance Due to Reduced Muscle Mass, Strength, and Endurance; Risk Of Early Onset Osteoporosis Due To Spaceflight

Technology Readiness Levels (TRL) of 6 or higher are sought.

Potential NASA Customers include:

• Human Health Countermeasures Element in Human Research Program:

  ○ (http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-hhc.html [14])
H12.02 Exploration Medical Capability - Medical Suction Capability

Lead Center: JSC

Participating Center(s): GRC

The existing in-space medical suction system (used on ISS) provides insufficient medical suction capability. Medical suction clears the airway, empties the stomach, decompresses the chest, and keeps the operative field clear. The existing design provides limited operational flexibility in providing airway management support, oropharyngeal suction, and chest tube drainage during an exploration mission due to limitations in suction performance, usability, patient interfaces, and reusability. It is restricted for use by a trained medical doctor and has several design limitations including:

- It can only be used to clear the airway. It would be insufficient/incapable to perform other types of medical suction.
- Device consists of several pieces that are only held together by a friction fit/seal and may come apart unless handled carefully.
- Device does not meet flow rate requirement since it is limited by operator speed.
- Device can only collect about 1 liter total volume. This volume includes volume of air since there is no gas separator.

The Phase I technology developed under this SBIR should demonstrate proof of concept medical suction capability in a space operational environment and should focus on the following aspects:

- Phase separation.
- Range of flow rates.
- Range of applied vacuum pressure.
- Continuous and intermittent operation.
- Variety of operational conditions including micro, partial and normal gravity; and in-space and post-landing usage.
- Minimize mass, volume, and power usage.

Minimum specifications that should be in the design:

- Airway Management and Oropharyngeal Suction:
  - Suction pressure - at least 500 mmHg
  - Flow rate - at least 25 liters per minute
- Duration - at least 30 minutes

- Chest tube drainage:
  - Suction pressure - between 150-180 mmHg
  - Duration - at least 24 hours

- Biological waste cleanup:
  - Suction pressure - at least 500 mmHg
  - Flow rate - at least 35 liters per minute
  - Duration - at least 30 minutes

**NASA Deliverable** - Prototype functional system in a proof of concept demonstration

**HRP IRP Risk** - Inability to Adequately Recognize or Treat an Ill or Injured Crew Member

Technology Readiness Levels (TRL) of 3 or higher are sought.

Potential NASA Customers include:

- Exploration Medical Capability Element in Human Research Program:

**H12.03 Behavioral Health and Performance - Innovative Technologies for A Virtual Social Support System for Autonomous Exploration Missions**

**Lead Center:** JSC

NASA wants to identify how virtual worlds (i.e., interactive games, avatars, social networks) could be used for long-duration space exploration missions. This subtopic is aimed at developing a virtual social support system for crews of such missions.

During these missions, the crews, by virtue of their distance from Earth, are separated from their significant others and will no longer have access to social support currently provided to the ISS crews. They are living in a confined and isolated environment devoid of normal Earth settings as they venture to distant destinations. Long communication delays between Earth and vehicle are also anticipated. Expanding the crew's social connectivity to
friends, family, and colleagues back home through a variety of virtual platforms will help mitigate the stressors inherent to living and working in such an isolated, confined, and extreme environment.

During the actual mission, the tool could provide a more homelike "virtual world" to augment the constrained physical habitat the crew lives and works. It could also help the crews maintain connections and provide the needed social support. As a design tool, the insight gained into the crew members' interaction with the outside world would be valuable for developing new mission training regimens and design concepts for future long-duration missions.

The proposal shall describe:

- The virtual environment to be developed.
- Plans to provide adaptive systems to deal with communication latencies.
- How the tool could enhance and measure behavioral health and performance, including perceived closeness to home.
- Ways to assess habitability issues.

**NASA Deliverables** - Phase I deliverable shall yield a proof of concept that includes both an evidence review that encompasses an assessment of current knowledge of virtual reality technologies and their use in supporting this topic.

In addition, the following deliverables shall be required:

- A requirements document for such a support system that fits the needs of a NASA exploration mission.
- A plan for evaluating the effectiveness of the tool as a behavioral health countermeasure, training, and habitability assessment.

The subsequent Phase II deliverable shall provide a prototype of specific modules that can demonstrate improved communication and perceived social support by utilizing these technologies.

**HRP IRP Risks** - Risk of Adverse Behavioral Conditions and Psychiatric Disorders; Risk of Performance Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team; Risk of an Incompatible Vehicle/Habitat Design

Technology Readiness Levels (TRL) of 4 or higher are sought.

Potential NASA Customers include:
H12.04 Advanced Food Systems Technology

Lead Center: JSC

The purpose of the NASA Advanced Food Technology Project is to develop, evaluate and deliver food technologies for human centered spacecraft that will support crews on long duration missions beyond low-Earth orbit. Safe, nutritious, acceptable, and varied shelf-stable foods with a shelf life of 5 years will be required to support the crew during these exploration missions. Concurrently, the food system must efficiently balance appropriate vehicle resources such as mass, volume, water, air, waste, power, and crew time.

Refrigeration and freezing require significant vehicle resource utilization, so NASA provisions consist solely of shelf stable foods. Stability is achieved by thermal or irradiative processing to kill the microorganisms in the food, or drying to prevent viability of the microorganisms. These methods do impact the micronutrients within the food substrate. Environmental factors (such as moisture ingress and oxidation) are also capable of compromising the nutrient content over the shelf life of the food. Since the food system is the sole source of nutrition to the crew, a significant loss in nutrient availability could significantly jeopardize the health and performance of the crew. Optimal nutritional content of the food for five years will ensure that the food can support crew performance and help protect their bodies from deficiencies that cause disease.

Vitamin content in NASA foods, such as vitamin C, vitamin A, thiamin, and folic acid, is degraded during processing and as the product ages in storage. The goal is to develop a system that either increases the bioavailability of the nutrients or protects the vitamins from this biological or chemical degradation at ambient temperatures over a five year duration. Possible technologies that could be investigated include novel food ingredients, protective or stabilizing technologies (e.g., encapsulation), biosensors, and controlled-release systems.

*Phase I Requirements* - 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.

*NASA Deliverables* - A system which will result in higher nutrient content in shelf stable foods.

*HRP IRP risk* - Risk of Inadequate Food System

Technology Readiness Levels (TRL) of 4 to 5 or higher are sought.
Potential NASA Customers include:

- Space Human Factors and Habitability Element in Human Research Program:

H12.05 In-Flight Biological Sample Analysis

Lead Center: JSC
Participating Center(s): ARC

Although crewmembers undergo intensive medical screening, the possibility of crew injury or illness can never be completely eliminated. A mission could be jeopardized or compromised by reduction of able crewmembers, both directly and indirectly if an incapacitated crewmember requires nursing or care. Mission architecture limits the amount of equipment, consumables, and procedures that will be available to treat medical problems. Mission allocation and technology development must be performed to ensure that the limited mass, volume, power, and crew training time are used efficiently to provide the broadest possible treatment capability. There is also a gap in knowledge in how the spaceflight environment affects the effectiveness of drug therapies. This subtopic aims to mitigate those space mission constraints by means of innovative approaches for addressing the knowledge gap in the area of drug stability during long duration spaceflight.

This subtopic seeks proposals for novel approaches to develop an in-flight tool capable of monitoring stability of pharmaceuticals (ideally, solids, liquids and creams) under low gravity conditions. Such a device must be able to determine percentage of active ingredients with a preference to also characterize degradation of products while minimizing the amount of pharmaceutical sample consumed in the test. The technology will need to address approaches and methodologies for handling the different forms of pharmaceuticals (pills, liquids, creams) through the use of a flexible sample preparation front-end amenable to the space environment. The proposed technology should be low-resource, low-footprint, and should involve a low volume of supplies/consumables, which do not require refrigeration or freezing for storage. Also, the technological innovation should be user-friendly, requiring minimal training and operating via uncomplicated protocols.

The Phase I technology developed under this SBIR should investigate one or more one or more of the following drugs:

- Acetaminophen.
- Azithromycin.
- Injectable epinephrine.
- Lidocaine topical gel.
In the Phase I effort, the proof of concept analysis should be demonstrated by the innovative technology and provide comparable results to drug stability laboratory USP standards (i.e., high performance liquid chromatography, differential scanning calorimetry, UV/FTIR spectroscopy). Phase II will seek to optimize these results for additional drugs as well as sensitivity, compound identification, drug degradation products, analysis time and facilitated end-user protocols.

NASA Deliverables: Prototype functional system in a proof of concept analysis demonstrated by the innovative technology producing drug stability characterization including integrity and percentage of active ingredients and characterization/degradation of products (in Phase I). Drugs to be demonstrated in Phase I include: Acetaminophen, Azithromycin, Injectable epinephrine and Lidocaine topical gel.

**HRP IRP Risks** - Inability to Adequately Recognize or Treat an Ill or Injured Crew Member; Risk of Therapeutic Failure Due to Ineffectiveness of Medication

Technology Readiness Levels (TRL) of 5 or higher are sought.

Potential NASA Customers include:

- ISS Medical Project Element in Human Research Program:
- Trash feed into high temperature reactors with tight cabin leakage specs.
- Trash gasification reactors (steam and/or partial oxidation) with minimum tar and ash generation and subsequent tar/liquid hydrocarbon reduction.
- Highly efficient reactors for carbon monoxide/carbon dioxide (CO/CO\textsubscript{2}) conversion into methane (CH\textsubscript{4}).
- Highly efficient gas/gas and gas/liquid-vapor separation devices.
- Fine particle/gas separation (regenerative or continuous) technologies for Mars dust and gasification ash particles.

The proposed technology should address benefits in system mass, conversion and power efficiency, and intermediate/final product generation compared to current approaches. Proposed technologies need be able to operate in microgravity. Mars ISRU technologies need to involve separation and processing of 0.5 to 2 kg/hr of carbon dioxide. Trash processing technologies need to be capable of feeding and processing 12 kg of waste material per day.

Technology Readiness Levels (TRL) of 2 to 5 or higher are sought.

Potential NASA Customers include:

- Office of Chief Technologist/ISRU Program.
- Advanced Exploration Systems Logistics.
- Advanced Exploration Systems Mars Program.

Sub Topics:

**Cryogenic Fluid Management Technologies Topic H2.01**

This subtopic solicits technologies related to cryogenic propellant storage, transfer, and instrumentation to support NASA’s exploration goals. Proposed technologies should feature enhanced safety, reliability, long-term space use, economic efficiency over current state-of-the-art, or enabling technologies to allow NASA to meet future space exploration goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions. Specifically:

- Innovative concepts for cryogenic fluid instrumentation are solicited to enable accurate measurement of propellant mass in low-gravity storage tanks, sensors to detect in-space and on-pad leaks from the storage system, and minimally invasive cryogenic liquid mass flow measurement sensors, including cryogenic two-phase flow.
- Passive thermal control for Zero Boil-Off (ZBO) storage of cryogens for both long term (>200 days) and short term (~14 days) in all mission environments. Insulation systems that can also serve as
Micrometeoroid/orbital debris (MMOD) protection and are self-healing are also desired.

- Cryogenic storage technologies for alternate propellants such as xenon.
- Active thermal control for long term ZBO storage for space applications. Technologies include 20K cryocoolers and integration techniques, heat exchangers, distributed cooling, and circulators.
- Zero gravity cryogenic control devices including thermodynamic vent systems, spray bars, mixers, and liquid acquisition devices.
- Advanced spacecraft valve actuators using piezoelectric ceramics. Actuator should reduce the size and power while minimizing heat leak and increasing reliability.
- Propellant conditioning and densification technologies for propellant storage and transfer. Specific component technologies include compact, efficient and economical cryogenic compressors, pumps, Joule-Thompson orifices and heat exchangers. Also, subcooling of propellants for ground processing and long-term in-space cryogen storage and transfer.
- Liquefaction of oxygen for in space applications. This includes passive cooling with radiators, cryocooler liquefaction, or open cycle systems that work with high-pressure electrolysis.
- Efficient small to medium scale hydrogen liquefaction technologies (1-10k gal/day) including domestically produced wet cryogenic turboexpanders.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II demonstration, and delivering a demonstration package for NASA testing at the completion of the Phase II contract.

**Phase I Deliverables** - Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a demonstration. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL range of 3-4.

**Phase II Deliverables** - Emphasis should be placed on developing and demonstrating the technology under simulated mission conditions. The proposal shall outline a path showing how the technology could be developed into mission-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL range of 4-5.

Potential NASA Customers include:

- Cryogenic Propulsion Storage and Transfer Technology Demonstration Mission.
- Office of Chief Technologist - Game Changing Development Cryogenic Propulsion Stage Program.

Sub Topics:
- In-Space Propulsion Systems Topic H2.02

**OCT Technology Area:** TA02 [1]

This solicitation intends to examine a range of key technology options associated with cryogenic, non-toxic storable, and solid core nuclear thermal propulsion (NTP) systems for use in future exploration missions.

Non-toxic engine technology, including new mono and bipropellants, is desired for use in lieu of the currently operational NTO/MMH engine technology. Handling and safety concerns with toxic chemical propellants can lead to more costly propulsion systems. NTP systems using nuclear fission reactors may enable future short round trip missions to Mars, by helping to reduce launch mass to reasonable values and thereby increasing the payload delivered for Mars exploration missions.

Non-toxic and cryogenic engine technologies could range from pump fed or pressure fed reaction control engines of 25-1000 lbf up to 60,000 lbf primary propulsion engines. Pump fed NTP engines in the 15,000-25,000 lbf class,
used individually or in clusters, would be used for primary propulsion.

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.

- Manufacturing techniques that lower the cost of manufacturing complex components such as injectors and coolant channels. Examples include, but are not limited to, development and demonstration of rapid prototype techniques for metallic parts, powder metallurgy techniques, and application of nano-technology for near net shape manufacturing.

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

- Long life, lightweight, reliable turbo-pump designs and technologies include seals, bearing and fluid system components. Hydrogen technologies are of particular interest.

- 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.

- High temperature, low burn-up carbide- and ceramic-metallic (cermet) based nuclear fuels with improved coatings and/or claddings to maximize hydrogen propellant heating and to reduce fission product gas release into the engine's hydrogen exhaust stream.

- High temperature and cryogenic 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 are desired. Sensors need to operate for months/years instead of hours.

Note to Proposer: Subtopic S3.03 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.03.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II demonstration, and delivering a demonstration package for NASA testing at the completion of the Phase II contract.

**Phase I Deliverables** - Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a demonstration. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL range of 3-4.

**Phase II Deliverables** - Emphasis should be placed on developing and demonstrating the technology under simulated mission conditions. The proposal shall outline a path showing how the technology could be developed into mission-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL range of 4-6.
Potential NASA Customers include:

- Office of Chief Technologist/Game Changing Development Program - In-Space Propulsion Project.
- Office of Chief Technologist/Game Changing Development Program - Manufacturing Innovation (MIP).
- Cryogenic Propulsion Stage/Advanced Upper Stage Engine Program.
- Human Exploration and Operations Directorate/Advanced Exploration Systems - Nuclear Cryogenic Propulsion Stage.

Sub Topics:

Advanced Technologies for Propulsion Testing Topic H2.03

Nuclear Thermal Propulsion (NTP), Rocket Based Combined Cycle (RBCC) and Turbine Based Combined Cycle (TBCC) propulsion systems have been identified as high priority NASA technology areas by the United States National Research Council. The goal of this subtopic is to foster development of advanced technologies with commercialization potential that will be needed for component and system level ground testing of these systems during the development and certification phases of their life-cycle.

NTP could be an enabling technology to reduce transit time and mission risk to Near-Earth Objects, Mars, and other deep space destinations. Nuclear power and propulsion technologies are key enabling technologies for future NASA exploration missions. Technology development to facilitate ground testing of NTP is required in the following areas:

- Advanced high-temperature and hydrogen resistant materials for use in a hot hydrogen environment (3000 °F).
- Efficient non-nuclear generation of high flow rate (100 lb/sec), high temperature hydrogen.
- High temperature fluid and thermal management systems.
- High temperature flow control and relief systems.
- High temperature power conversion systems.
- High temperature process piping systems and associated components.
- High temperature instrumentation.

RBCC and TBCC could be enabling technologies to reduce cost for and increase frequency of access to space and allow for rapid transit within the Earth's atmosphere, far exceeding our nation's current capabilities. Technology development to facilitate ground testing of RBCC and TBCC is required in the following areas:

- Thrust take-out and thrust measurement systems that address the unique challenges of a RBCC / TBCC test facility design.
- Non-intrusive velocity / temperature / pressure profile measurement of inlet and exhaust flows.

For the above technology subject areas, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward hardware and/or material development as appropriate which occurs during Phase II and culminates in a proof-of-concept system.

**Phase I Deliverables** - Phase I deliverables shall include a final report describing design studies and analyses, system, sensor, or instrumentation concepts, prospective material formulations, testing, etc. Prototype systems, components, sensors, instruments or materials can be developed in Phase I as well. The designs or concepts should have commercialization potential. For Phase II consideration, the final report should include a detailed path towards Phase II hardware proof-of-concept system or component or material manufacturing and testing as applicable. The technology concept at the end of Phase I should be at a TRL of 3-4.

**Phase II Deliverables** - Phase II deliverables shall consist of working proof-of-concept systems, tested material formulations with samples, tested component, sensor, or instrumentation hardware, etc. which have been successfully demonstrated in a relevant environment and delivered to NASA for testing and verification. The technology at the end of Phase II should be at a TRL of 6-7.

Potential NASA Customers include:

- Rocket Propulsion Test Program.
- Nuclear Thermal Propulsion Program.

**Sub Topics:**

Advanced Technologies for Atmosphere Revitalization Topic H3.01
Advancing process technologies for key atmosphere revitalization (AR) functions will be essential for enabling future efforts to extend crewed space exploration beyond low Earth orbit. Specific process technology advancements are sought in the technical areas of regenerative CO\text{2} removal, process gas drying, regenerable particulate matter filtration and separation techniques, and photocatalytic processes for removing trace volatile organic compounds (VOCs) from cabin atmospheric gases. Specifics pertaining to each technical area are the following:

- Advanced Sorbents for CO\text{2} Removal - Development of robust, high capacity, regenerable CO\text{2} adsorbents that substantially reduce the energy required for regeneration, are resistant to material degradation (i.e., dusting, spalling) and are highly selective to CO\text{2} over moisture. Candidate sorbents must be capable of operating in either CO\text{2} venting (open loop) or CO\text{2} processing (closed loop) modes.
- **Passive Moisture Removal** - Development of advanced water vapor removal techniques from air streams that operate at near-ambient pressure and temperatures and with little to no energy costs. This may include the development of water-selective materials (e.g., membranes, adsorbents) that exhibit significantly higher efficiencies than current commercial products. Very dry air (-65 °C dew point) can be assumed to be available to aid in drying process stream (1:1 ratio). Candidate process technologies must be capable of either venting moisture to space or returning moisture to the cabin for subsequent recovery for crew use.

- **Particulate Management** - Long-life and self-cleaning particulate pre-filters are required to reduce crew maintenance time and eliminate the need for consumable filter elements. These units should be able to handle large surges of particles and operate over very long periods. They should also be self-cleaning in-place or off-line (in-place is preferable, and provide viable methods for disposing of collected particulate matter while minimizing or eliminating direct contact by the crew. Complete (100%) capture of particles 20 microns and larger is required. Targeted technologies should be compact and lightweight, and easily integrated with the spacecraft Environmental Control and Life Support Systems (ECLSS).

- **Photocatalytic Oxidation (PCO) for Trace Contaminant Control** - Technologies are of interest for photocatalytic oxidation of Volatile Organic Carbon (VOCs) completely to CO2 and H2O (i.e., complete "mineralization") without producing partial oxidation products such as aldehydes and/or organic acids. Catalysts that are activated not only by UV, but also the visible region of the solar spectrum to capitalize on the highly efficient blue LEDs or solar energy are desired. Concepts should minimize PCO reactor volume via improved catalysts and catalyst activity, improved UV illumination scheme and/or improved illuminated catalyst surface area-to-volume ratio.

Technology Readiness Levels (TRL) of 2 to 3 or higher are sought.

Potential NASA Customers include:

- Human exploration missions include: Low-Earth orbit, Earth's neighborhood (Earth-moon libration points, lunar orbit and surface, geosynchronous orbits, etc), Near-Earth Asteroids, Mars Missions (transit, orbit, moons and surface).

([http://www.nasa.gov/exploration/home/index.html](http://www.nasa.gov/exploration/home/index.html) [2])

Sub Topics:
- Environmental Monitoring and Fire Protection for Spacecraft Autonomy Topic H3.02
- Environmental Monitoring

Technologies are desired to ensure that the chemical content of the air and water environment of the crew habitat falls within acceptable limits and the life support system is functioning properly and efficiently. Required technology characteristics include: 2 year shelf-life; functionality in microgravity and low pressure environments (~8 psi). The technologies require significant improvements in miniaturization, reliability, life-time, self-calibration, and reduction of expendables. Examples of desired analytes are:

- Trace silver (0.05-15 mg/L) and trace organics in water (acetone: 0.05-5 mg/L; aldehydes: 0.4-60 mg/L; alcohols: 1-100 mg/L).

Technologies for quantification and identification of microbial species are requested within an alternative subtopic, ISS Utilization.
Spacecraft Fire Protection

A first response crew mask capable of protecting the crew from ammonia, hydrazine, and combustion products is desired. A suitable first response mask should be quick to don, protect the wearer from environmental contaminants and elevated temperature hazards, and provide breathable air during prolonged emergency response activities. This mask would be one-size fits all and be effective for a minimum of 1 hour. While wearing the mask, the crew should have excellent freedom of motion and positive indication of effectiveness.

A portable, self-contained fire and toxic atmosphere cleanup system is desired that can rapidly remove contaminants from a spacecraft volume

Technology Readiness Levels (TRL) of 3 to 4 or higher are sought.

Sub Topics:

Crew Accommodations and Water Recovery for Long Duration Missions Topic H3.03
Spacecraft crew accommodations requires volumetrically reconfigurable and hygienic crew interiors that maintain crew productivity. Advancements are required to reduce logistical packaging mass residual, repurpose logistical items for outfitting, provide extended wear clothing, clothes laundering, and metabolic waste collection/processing. Advancements in technology for water recovery are required to exceed existing 85% recovery from urine and humidity condensate. It is expected that both the variety of wastewater sources and the total volume of wastewater will increase with increasing mission duration. Technologies that increase closure of the water system and reduce expendables will enable future missions. Specific focus areas include:

Human Fecal & Waste Management:

- Technology is needed to collect, dry, process, and recover useful materials, and to safely store human feces, trash, and processed residuals. Technologies for micro-gravity collection of urine and feces should have modes that allow for operation even if active components fail, by relying on or being aided by passive processes for function, such as capillary forces. Minimal crew interaction, low energy, contamination tolerant waste processing systems that recover water, methane, or other useful materials are desired.

Logistical Repurposing:

- Novel alternatives to existing launch foam packaging materials that are light weight, have low frangibility, and can be compressed or heated to achieve low residual volume after launch.
• Launch packaging systems (bags, nets, hard structures) that can be repurposed or reconfigured on orbit to provide interior crew accommodations (sleep areas, exercise, hygiene, thermal/sound control) with minimal mass penalty.

• Logistical materials that can be readily processed or reformulated on orbit to provide atmospheric gases, water, or material for in-space fabrication processes with minimal power requirements.

Mixed Brine Water Recovery:

• Recovery of water from mixed waste stream brines with 12% or higher dissolved solids are desired. Low energy, microgravity, low expendable systems should be tolerant of urine stabilization chemicals such as oxone, sulfuric acid and hexavalent chromium.

Biocide Delivery Systems:

• Technologies to replace the use of iodine for potable water disinfection. This may include techniques to replenish silver ions to a concentration of 0.4 mg/l in potable water or techniques to minimize the loss of silver ions in a potable water system. In addition, alternative disinfection technologies to inhibit biofilm formation on surfaces and provide residual disinfectant to maintain potable water quality would be considered.

Technology Readiness Levels (TRL) of 3 or higher are sought.

Potential NASA Customers include:

• Mission elements and vehicles:
  • Orion Multi-Purpose Crew Vehicle.
  • Multi-Mission Space Exploration Vehicle.
  • Deep Space Habitat.
  • Pressurized Rovers and Planetary Surface Systems.
  • International Space Station.

Human exploration missions include:
Low-Earth orbit, Earth's neighborhood (Earth-moon libration points, lunar orbit and surface, geosynchronous orbits, etc).

Near-Earth Asteroids.

Mars Missions (transit, orbit, moons and surface).

(http://www.nasa.gov/exploration/home/index.html [2])

Sub Topics:

Thermal Control Systems Topic H3.04

Future human spacecraft will venture far beyond the relatively benign environment of low Earth orbit. They will transit through the deep space, but they may encounter warm transient environments such as low lunar orbit. Some spacecraft elements may be launched untended and would operate at relatively low power levels as they transit to their final destination. The combination of extreme environments and high turndown capability will be a major challenge for spacecraft Active Thermal Control Systems (ATCSs). Sophisticated thermal control systems will be required that can dissipate a wide range of heat loads in widely varying environments while using fewer of the limited spacecraft mass, volume and power resources. Advances are sought for microgravity room temperature thermal control in the areas of:

- Innovative thermal components and system architectures that are capable of operating over a wide range of heat loads in varying environments (for example, a 5:1 heat load range in environments ranging from 0 to 275 K).

- Two-phase heat transfer components and system architectures will allow the efficient acquisition, transport, and rejection of waste heat.

- Heat rejection strategies and hardware for transient, cyclical applications - e.g., phase change material heat exchangers, heat pumps, or efficient evaporative heat sinks.

- Smaller, lighter, high performance heat exchangers and coldplates.

- Low temperature external working fluids (a temperature limit approaching 150K) with favorable thermophysical properties - e.g., high specific heat, high thermal conductivity, and viscosity that does not dramatically increase at lower temperatures.

- Internal working fluids that are non-toxic, have favorable thermophysical properties, and are compatible with aluminum tubing (i.e., no corrosion for up to 10 years). Low temperature limits (~150 K) and favorable thermophysical properties would allow their use externally in a single loop ATCS.

- Low mass, high conductance ratio thermal switches.

- Long-life, light-weight, efficient single-phase pumps capable of producing relatively high pressure heads (~4 atm).

- Variable area radiators (e.g., variable conductance heat pipe radiators or drainable radiators).
• New thermal design tools to reduce the time and costs required for analysis, design, integration, and testing of the spacecraft. In particular, an innovative thermal design tool capable of fast and accurate spacecraft thermal modeling with significantly reduced effort and cost is needed.

Technology Readiness Levels (TRL) of 2 to 4 or higher are sought.

Potential NASA Customers include:

• Orion Multipurpose Crew Vehicle ([http://www.nasa.gov/mission_pages/constellation/orion/index.html][3])

Future Human Space Missions - ([http://www.nasa.gov/exploration/home/index.html][2])

Sub Topics:
  Space Suit Pressure Garment and Airlock Technologies Topic H4.01
Advanced space suit pressure garment and airlock technologies are necessary for the successful support of the International space Station (ISS) and future human space exploration missions for in-space microgravity EVA and planetary surface operations. The space suit pressure garment requires innovative technologies focused on performance, environmental protection, and mass reduction. Two of the critical performance characteristics of a suit are mobility and durability. Improved mobility typically competes against durability and suit component life. Materials that enable both highly mobile and durable designs would negate the need for compromise in one of these areas. Other key suit performance enhancements include materials that enable improved fit and sizing, such as shape change materials that increase the ease of suit don/doff or facilitate adaptable fit for specific functional tasks. Space suit environmental protection includes protection from thermal extremes, vacuum, cuts, abrasion and micrometeoroid and orbital debris (MMOD). Additional environmental protection is desired for plasma, radiation, electrical shock, antimicrobials and dust. It is desirable to provide protection in as few material layers as possible; therefore, multi-functional materials are desired. Self-healing materials and materials that alert the inspector to wear/maintenance needs are also of interest. Mass reduction of the space suit system is highly desirable for many reasons, with arguably the biggest drivers being launch mass and on-back mass during EVA. New materials that can lead to reductions in suit component mass, for example, lightweight materials for bearings and hard structures, are therefore desirable.

Due to the expected large number of space walks that will be performed on the ISS beyond 2020 and during future human space exploration missions, innovative technologies and designs for both microgravity and surface airlocks will be needed. Technology development is needed to decrease the time associated with egressing and ingressing the vehicle or habitat, reducing the gas loss during depressurization, and decreasing the potential of contaminating
the cabin due to bringing in dust or CO$_2$. These enhancements could be achieved with a suitport, suitlock or some type of advanced airlock.

Technology Readiness Levels (TRL) of 4 to 6 or higher are sought.

Potential NASA Customers include:

- EVA Project Office.
- International Space Station.
- Office of Chief Technologist.

Sub Topics:
Space Suit Life Support and Avionics Systems Topic H4.02
Space Suit Life Support Systems

Advanced space suit life support systems are necessary for the successful support of the International Space Station (ISS) and future human space exploration missions for in-space microgravity EVA and planetary surface operations. Exploration missions will require a robust, lightweight, and maintainable Primary Life Support System (PLSS). The PLSS attaches to the space suit pressure garment and provides approximately an 8 hour supply of oxygen for breathing, suit pressurization, ventilation and CO$_2$ removal, and a thermal control system for crew member metabolic heat rejection. Innovative technologies are needed for high-pressure O$_2$ delivery, crewmember cooling, heat rejection, and removal of expired CO$_2$ and water vapor.

Space Suit Avionics Systems

Future generations of advanced space suit avionics will be far superior to those on the current generation of space suits. They will be more capable, configurable, lightweight, and low power with a footprint that will rival current consumer electronic devices, but survive the harsh space environment. They must be self-contained, so that maintenance on the devices can be performed on-orbit or they can be easily swapped for functioning or upgraded devices. Those considered will be radio, displays, and cameras.

Future advanced radios will be configurable and, potentially, software-defined and/or re-configurable to support future communications network-based architectures in addition to the point-to-point communications links that are prevalent today. The next-generation EVA radios will need to support voice, telemetry, and standard/high definition video data flows (up to 20 Mbps) and the radio architecture will need to be lightweight and power efficient while managing data in a seamless and lossless manner between multiple interfaces. Radios should support space-based or terrestrial-based protocols to enable communications between multiple entities across a communications
link and have an open and modular architecture.

The current generation of Head-Mounted Displays (HMDs) and Near-to-Eye (NTE) Displays are not viable, since it is desirable for the display to be decoupled from the user's head for improved safety, comfort, and alignment. The decoupling makes the specifications for the eyebox (tolerance to misalignment before image goes out of focus), field of view (angle of the image created by the optics), and eye relief (working distance from the eye to the last optical element) difficult. Key performance targets include:

- Graphical Data Presentation: SXGA @ 40 °FOV (possibly biocular).
- Decoupled from User's Head - Large Eyebox: 100 mm x 100mm x 50mm (D).
- Sunlight Readability: 500 fL inside visor, 1800 fL outside visor (>10 to 1 contrast).

Display technologies must ensure that suit displays can operate outside the suit environment in thermal, radiation, and vacuum as well as internally without imposing ignition hazards due to 100% oxygen environment.

Cameras will not only provide the crewmember the ability for still and motion image, but also situational awareness, which enhances safety for the crewmember. The cameras should be capable of recording high definition motion and high-resolution imagery with the ability to compress the data for transmission over a variety of RF transmissions and/or IP networks with varying bandwidths. Hemispherical and dynamic cameras are desired. Dynamic cameras can take still images and motion video in variable bandwidths, capture images based on link quality, and change frame rates. Hemispherical cameras record 360 ° video views of a crewmember, distort views through optics and then undistort the views via software on the ground to pan/zoom for total situational awareness. Cameras should be low-power and lightweight with a number of mounting options for optimal placement on the suit.

Technology Readiness Levels (TRL) of 4 to 6 or higher are sought.

Potential NASA Customers include:

- EVA Project Office.
- International Space Station.
- Office of Chief Technologist.
Sub Topics:
Expandable/Deployable Structures Topic H5.01
The SBIR subtopic area of Lightweight Expandable/Deployable Structures solicits innovative concepts to support the development of primary pressurized inflatable modules or large solar array structures for space exploration environments. Concepts should illustrate simple designs, low launch-to-deployed dimension ratios, efficient packaging and deployment techniques. Robustness, damage tolerance, and minor repair capabilities should also be considered in concept submittals. Development of advanced analysis and test methods that verify the performance of highly loaded inflated structures or large solar array systems are highly desired.

Of particular interest for expandable/inflatable systems are high-tenacity fibrous materials for the restraint layer of inflatable structures. Proposed materials should have well-characterized long-term creep behavior or a characterization plan for determination thereof. Also of significant interest are bladder materials with an air permeation rate no greater than 1.5 cc/100 in²/day/atm that remain sufficiently flexible at -50 °F to be deployed on orbit without external heating. Permeation rate should show no increase upon fold/flex testing at -50 °F.

For large solar arrays systems, mass-efficient solar array designs with a scalable path from 20-30 kW up to 300 kW and beyond are needed. Advanced analysis and test techniques to ensure reliable deployment of large solar array structures are of special interest. Novel design and packaging concepts, analysis techniques, and both ground and in-space test methods are sought for large deployable solar arrays as well as for individual components such as lightweight booms, ribs, or frames; flexible substrate materials; and mechanisms.

Technology Readiness Levels (TRL) of 3 to 4 or higher are sought.

Potential NASA Customers include:

- International Space Station.
- Advanced Exploration Systems - Deep Space Habitat.
- Office of Chief Technology - Game Changing Technology Division, and Technology Demonstration Missions.

Sub Topics:
Advanced Manufacturing and Material Development for Lightweight Metallic Structures Topic H5.02
The overall objective of this subtopic is to advance technology readiness levels of lightweight metals and manufacturing techniques for launch vehicles and in-space applications resulting in structures having affordable, reliable, predictable performance with reduced costs.

The current state-of-the-art for fabrication of launch vehicle structure is multi-piece welded and riveted construction to assemble parts that are heavily machined from thick wrought products. Fabrication of single-piece launch vehicle structure using near-net shape (NNS) manufacturing methods can reduce mass and cost while increasing safety and reliability, primarily through elimination of welds and parasitic weld land weight and reduction in the number of manufacturing steps. However, to fully realize the benefits of these NNS manufactured components, methods to
Proposals are sought that offer innovative manufacturing processes and/or materials to locally increase the stiffness and strength of structural elements added to NNS components. Manufacturing methods of interest include additive manufacturing methods that employ wire feedstock, fusion and friction stir welding. Of specific interest in materials are advances in aluminum wire and tape feedstock materials, including customized alloy chemistry and metal matrix composites (MMCs) incorporating either discontinuous or continuous reinforcements. Of specific interest in manufacturing and processing are proposals that address issues such as residual stress and distortion control, post-deposition processing to develop service mechanical properties, and energy source / reinforcement interactions.

Research should be conducted to demonstrate technical feasibility in Phase I and show a path toward demonstration in Phase II of material fabrication and / or manufacturing process improvement. When possible proposals should include delivery of sample material for test and evaluation by NASA and / or a component demonstration article.

Technology Readiness Levels (TRL) of 4 to 6 or higher are sought.

Potential NASA Customers include:

- Office of Chief Technology - Integrated Manufacturing Modeling with Experiment.
- Space Launch System.
- Multi Purpose Crew Vehicle.
- Fundamental Aeronautics - Fixed Wing, High Speed, Aerosciences Projects.

Sub Topics:
Spacecraft Autonomy and Space Mission Automation Topic H6.01
Future human spaceflight missions will place crews at large distances and light-time delays from Earth, requiring novel capabilities for crews and ground to manage spacecraft consumables such as power, water, propellant and life support systems to prevent Loss of Mission (LOM) or Loss of Crew (LOC). This capability is necessary to handle events such as leaks or failures leading to unexpected expenditure of consumables coupled with lack of communications. If crews in the spacecraft must manage, plan and operate much of the mission themselves, NASA must migrate operations functionality from the flight control room to the vehicle for use by the crew. Migrating flight
controller tools and procedures to the crew on-board the spacecraft would, even if technically possible, overburden the crew. Enabling these same monitoring, tracking, and management capabilities on-board the spacecraft for a small crew to use will require significant automation and decision support software. Required capabilities to enable future human spaceflight to distant destinations include:

- Enable on-board crew management of vehicle consumables that are currently flight controller responsibilities.
- Increase the onboard capability to detect and respond to unexpected consumables-management related events and faults without dependence on ground.
- Reduce up-front and recurring software costs to produce flight-critical software.
- Provide more efficient and cost effective ground based operations through automation of consumables management processes, and up-front and recurring mission operations software costs.

The same capabilities for enabling human spaceflight missions are directly applicable to efforts to automate the operation of unmanned aircraft flying in the National Airspace (NAS) and robotic planetary explorers.

Mission Operations Automation:

- Peer-to-peer mission operations planning.
- Mixed initiative planning systems.
- Elicitation of mission planning constraints and preferences.
- Planning system software integration.

Space Vehicle Automation:

- Autonomous rendezvous and docking software.
- Integrated discrete and continuous control software.
- Long-duration high-reliability autonomous system.
- Power aware computing.

Spacecraft Systems Automation:

- Multi-agent autonomous systems for mapping.
- Safe proximity operations (including astronauts).
- Uncertainty management for proximity ops, movement, etc.
Emphasis of proposed efforts:

- Software proposals only, but emphasize hardware and operating systems the proposed software will run on (e.g., processors, sensors).
- In-space or Terrestrial applications (e.g., UAV mission management) are acceptable.
- Proposals must demonstrate mission operations cost reduction by use of standards, open source software, staff reduction, and/or decrease of software integration costs.
- Proposals must demonstrate autonomy software cost reduction by use of standards, demonstration of capability especially on long-duration missions, system integration, and/or use of open source software.

Technology Readiness Levels (TRL) of 4 to 6 or higher are sought.

Potential NASA Customers include:

- Habitation Systems Project.
  - ([http://www.nasa.gov/exploration/analogs/hdu_project.html](http://www.nasa.gov/exploration/analogs/hdu_project.html) [5])
- Mission Operations Directorate
- Human Exploration Telerobotics Project

Sub Topics:

Radiation Hardened/Tolerant and Low Temperature Electronics and Processors Topic H6.02

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. All three characteristics for radiation hardened electronics of TID, SEU and SEL are needed.
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.

Using the 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 radiation hardness and low-temperature (-230 °C) analog and mixed-signal circuit performance.
- Packaging capable of surviving numerous thermal cycles, tolerant of the extreme temperatures, and the ionizing radiation environment on the Moon and Mars. This includes the use of appropriate materials including substrates, die-attach, encapsulants, thermal compounds, etc.

Technology Readiness Levels (TRL) of 3 to 5 or higher are sought.

Potential NASA Customers include:

- Autonomous Landing Systems.
- Mars Science Lab Instrumentation.
- Tele-robotics.
- Surface Mobility.
- Nuclear Systems.
- Robotic Satellite Servicing.
Sub Topics:

Human-Robotic Systems - Manipulation Subsystem Topic H6.03

This call for technology development is in direct support of the Human Exploration and Operations Mission Directorate (HEOMD). 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 Subtopic 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 Subtopic addresses robotic manipulation and related technology needs associated with planetary surface systems infrastructure, interaction of humans and machines, mobility systems, payload and resource handling, and mitigation of environmental contaminations.

The objective of this Subtopic is to create human-robotic technologies (hardware and software) to improve the exploration of space.

Robots can perform tasks to assist and off-load work from astronauts. Robots may perform this work before, in support of, or after humans.

Ground controllers and astronauts will remotely operate robots using a range of control modes (teleoperation to supervised autonomy), over multiple spatial ranges (shared-space, line-of-sight, in orbit, and interplanetary), and with a range of time-delay and communications bandwidth.
Proposals are sought that address the following technology needs:

- Subsystems that improve handling and maintenance of payloads and assets.
- Enable crew and ground controllers to better operate, monitor, and supervise robots.
- Improve the transport of crew, instruments, and payloads on planetary surfaces, asteroids, as well as in space.

This includes:

- Robot user interfaces.
- Automated performance monitoring.
- Tactical planning software.
- Ground data system tools.
- Command planning and sequencing.
- Real-time visualization/notification.
- Software for situational awareness, as well as, subsystems to improve handling and maintenance of payloads and assets.
- Tactile sensors.
- Human-safe actuation.
- Active structure.
- Dexterous grasping.
- Modular “plug and play” mechanisms for deployment and setup.
- Standardized interfaces for structural loads & commodity transfer.
- Novel robotic manipulation methods.
- Small/lightweight devices to provide subsurface access and sampling.
- Small/lightweight regolith excavation, handling & delivery devices.
- Regolith anchoring methods for near Earth objects (neo).
- Subsystems to improve the transport of crew, instruments, and payloads on planetary surfaces, asteroids, and in-space.
- Hazard detection sensors/perception.
- Active suspension.
- Grappling/anchoring.
- Legged locomotion.
- Sub-surface locomotion.
- Robot navigation.
- Infrastructure-free localization.

Technology Readiness Levels (TRL) of 2 to 6 are sought.

Potential NASA Customers include:

- Software Robotics and Simulation Division (JSC-ER).
- International Space Station.
- Habitat Development Unit (AES Project).
- Multi-Mission Space Exploration Vehicle (MMSEV-AES Project).
- MPCV Orion Project.
- R2 (Robonaut Project).

Sub Topics:

Ablative Thermal Protection Systems Topic H7.01

The technologies described below support the goal of developing higher performance ablative TPS materials for higher performance future Exploration missions. Developments are sought for ablative TPS materials and heat shield systems that exhibit maximum robustness, reliability and survivability while maintaining minimum mass requirements, and capable of enduring severe combined convective and radiative heating. In addition, in order to adequately test and design with these materials, advancements in instrumentation, inspection, and modeling of ablative TPS materials is also sought.

Areas of interest include improvements in the reinforcement materials as follows:

- Advancements in carbon felts including thickness (>1.0-in), density (>0.12 g/cm³), uniformity to use as reinforcement for high strain-to-failure ablative TPS materials.
- Advancements in thin (~0.1-in) three dimensional woven carbon materials to act as stress bearing structure for deployable aeroshells.
Advancements in thick (>1.0-in) three dimensional woven carbon materials to use as reinforcement for high heat flux mid-to-high density ablative TPS materials.

TPS Materials advancements sought in felts or woven materials impregnated with polymers to improve ablation performance. Areas of interest include:

- One class of materials, for planetary aerocapture and entry for a rigid mid L/D (lift to drag ratio) shaped vehicle, will need to survive a dual heating exposure, with the first at heat fluxes of 400-500 W/cm² (primarily convective) and integrated heat loads of up to 55 kJ/cm², and the second at heat fluxes of 100-200 W/cm² and integrated heat loads of up to 25 kJ/cm². These materials or material systems must improve on the current state-of-the-art recession rates of 0.25 mm/s at heating rates of 200 W/cm² and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 1.0 g/cm² required to maintain a bondline temperature below 250 ºC.

- The second class of materials, for planetary aerocapture and entry for a deployable aerodynamic decelerator, will need to survive a single or dual heating exposure, with the first (or single pulse) at heat fluxes of 50-150 W/cm² (primarily convective) and integrated heat loads of 10 kJ/cm² and the second at heat fluxes of 30-50 W/cm² and heat loads of 5 kJ/cm². These materials may be either flexible or deployable.

- The third class of materials, for higher velocity (>11.5km/s) Earth return, will need to survive heat fluxes of 1500-2500 W/cm², with radiation contributing up to 75% of that flux, and integrated heat loads from 75-150 kJ/cm². These materials, or material systems must improve on the current state-of-the-art recession rates of 1.00 mm/s at heating rates of 2000 W/cm² and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 4.0 g/cm², required to maintain a bondline temperature below 250 ºC.

Development of in-situ heat flux sensors, surface recession diagnostics, and in-depth or interface thermal response measurement devices for use on rigid and/or flexible ablative materials. In-situ heat flux sensors and surface recession diagnostics tools are needed for flight systems to provide better traceability from the modeling and design tools to actual performance. The resultant data will lead to higher fidelity design tools, risk reduction, decreased heat shield mass and increases in direct payload. The heat flux sensors should be accurate within 20%, surface recession diagnostic sensors should be accurate within 10%, and any temperature sensors should be accurate within 5% of actual values.

Non Destructive Evaluation (NDE) tools for evaluation of bondline and in-depth integrity for light weight rigid and/or flexible ablative materials. Non Destructive Evaluation (NDE) tools are sought to verify design requirements are met during manufacturing and assembly of the heat shield, e.g., verifying that anisotropic materials have been installed in their proper orientation, that the bondline as well as the TPS materials have the proper integrity and are free of voids or defects. Void and/or defect detection requirements will depend upon the materials being inspected. Typical internal void detection requirements are on the order of 6mm, and bondline defect detection requirements are on the order of 25.4mm by 25.4mm by the thickness of the adhesive.

Advances are sought in ablation modeling, including radiation, convection, gas surface interactions, pyrolysis, coking, and charring for low and mid-density fiber based (woven or felt) ablative materials. There is a specific need for improved models for low and mid density as well as multi-layered charring ablators (with different chemical composition in each layer). Consideration of the non-equilibrium states of the pyrolysis gases and the surface thermochemistry, as well as the potential to couple the resulting models to a computational fluid dynamics solver, should be included in the modeling efforts.
Technology Readiness Levels (TRL) of 2-3 or higher are sought.

Potential NASA Customers include:

- **Human Exploration and Operations Mission Directorate**.
  - Multi Purpose Crewed Vehicle (MPCV) heatshield and backshell projects.
  - Asteroid Sample Return projects.
  - Future design of low Ballistic Coefficient entry vehicles using Hypersonic Inflatable Aerodynamic Decelerator (HIAD) or Adaptive Deployable Entry and Placement Technology (ADEPT) systems.

- **Science Mission Directorate - Planetary Exploration Entry, Decent and Landing heatshield and backshell projects and Planetary Sample Return projects**.

- **NASA Commercial Orbital Transportation Services (COTS) projects**.

**Sub Topics:**
- Fuel Cells and Electrolyzers Topic H8.01
- Ion-Exchange Membranes for PEM Electrolyzers

During high-pressure electrolysis operation, hydrogen permeation through the ion-exchange membrane acts to reduce the current efficiency within the cell. This permeation increases with increasing pressure. Technological approaches are sought that significantly reduce this permeation. Areas of interest include:

- Demonstrated hydrogen permeability reduction >50% for Nafion membranes.
- Concurrent conductivity reductions
- Additionally, such membranes should have low acid generation rates to avoid degrading other elements within the cell stack, and must maintain good water transfer capability, bubble point, and tensile strength for use with cathode liquid-feed systems.

**Solid Oxide Fuel Cell Systems**

Technologies are sought that improve the durability, efficiency, and reliability of SOFC systems fed by oxygen and fuels such as propellant-grade methane and those generated by ISRU systems (e.g., CO, syngas). Primary SOFC components and systems of interest:
• Power outputs in the 1 to 3 kW range.

• Offer thermodynamic efficiencies of 70% (fuel source-to-DC output) when operating at the current draw corresponding to optimized specific power.

• Operate as specified after at least 50 start-up cycles (from cold to operating temperature within 20 minutes) and 50 shut-down cycles.

• Operate as specified after at least 2500 hours of steady state operation on propellant-grade methane and oxygen. System should startup dry but after reaching operating conditions an amount of water/H\textsubscript{2} consistent with what can be obtained from anode recycle can be used. Amounts must be justified.

• Minimal cooling required as obtained by way of conduction through the stack to a radiator exposed to space and/or by anode exhaust flow.

Technology Readiness Levels (TRL) of 3 to 4 or higher are sought.

Potential NASA Customers include:

• International Space Station.

• Human Exploration and Operations Mission Directorate.

Sub Topics:
Ultra High Specific Energy Batteries Topic H8.02
Advanced rechargeable batteries are sought for future NASA missions.

For near-term missions, advanced lithium-ion (Li-ion) systems are being developed with the goal to achieve 265 Wh/kg and 675 Wh/L on a cell level. Advanced cathodes are sought, which when integrated into a full cell with a silicon-carbon composite anode, can enable a Li-ion cell to achieve the stated goals at practical voltage levels at a C/10 discharge rate when operating at 10 °C. The cathode should retain 80% of its initial capacity after 250 cycles. In addition, because the cathodes must be manufactured practically, cathodes must achieve a tap density of >1.5 g/cc, should possess qualities that can enable loading of at least 15 mg/square cm per side, and should utilize synthesis approaches that are readily scalable and are amenable to large scale electrode processing utilizing standard battery component equipment. The anode will achieve a reversible capacity of 1000 mAh/g and operate between 50 millivolts and 1 volt versus lithium. The cathode should have no detrimental impact on anode electrochemical performance, cycle-ability or cycle life, should possess a high degree of thermal stability, should have low toxicity, and should be stable against typical carbonate-based electrolytes at voltage levels and material loadings that are practical for the proposed system.

For far-term missions, proposals are sought for advanced next generation rechargeable chemistries that go beyond Li-ion and have the potential to offer >500 Wh/kg and >700 Wh/L on the cell level. Advanced next generation chemistries will be required for human missions, therefore specific energy and energy density goals must be met while simultaneously delivering a high level of safety. Applications may include Extravehicular Activities (spacesuit) and robotic landers and rovers for missions to outer planets, moons and asteroids.
Phase I proposals must include analysis and numerical/quantitative evidence to justify the choice of cathode or advanced chemistry that clearly shows how the proposed component/system has the potential to meet the projected specific energy and energy density goals at the end of a Phase II effort. Additionally, Phase I proposals should describe the technical path that will be followed to achieve the desired specific energy and energy density.

Technology Readiness Levels (TRL) of 4 or higher are sought.

Potential NASA Customers include:

- Technology is cross-cutting and applicable to any mission or application that requires low mass, low volume, safe batteries. Some examples:
  - Office of Chief Technologist.
  - Human Exploration and Operations Directorate (EVA suits, landers, rovers, habitats, vehicle power).
  - Aeronautics Research Directorate (electric aircraft).
  - Science Directorate (power for payloads).

Sub Topics:

**Space Nuclear Power Systems Topic H8.03**

NASA is developing fission power system technology for future space transportation and surface power applications using a stepwise approach. Early systems are envisioned in the 10 to 100 kWe range that utilize a 900 K liquid metal cooled reactor, dynamic power conversion, and water-based heat rejection. The anticipated design life is 8 to 15 years with no maintenance. Candidate mission applications include initial power sources for human outposts on the Moon or Mars, and nuclear electric propulsion systems (NEP) for Mars cargo transport. A non-nuclear system ground test in thermal-vacuum is planned by NASA to validate technologies required to transfer reactor heat, convert the heat into electricity, reject waste heat, process the electrical output, and demonstrate overall system performance. 1-10 kWe systems are also envisioned for power for robotic science missions to fill the gap between radioisotope power systems and higher power systems.

The primary goals for the early systems are low cost, high reliability, and long life. Proposals are solicited that could help supplement or augment the planned NASA system test. Specific areas for development include:

- 10 kWe-class Stirling and Brayton power conversion devices.
- 450 K radiator panels with embedded heat pipes.
- Kilowatt-class fission power systems concepts and technologies

The NASA non-nuclear system ground test is expected to provide the foundation for later systems in the multi-
hundred kilowatt or megawatt range that utilize higher operating temperatures, alternative materials, and advanced components to improve system performance. For the later systems, specific power will be a key performance metric with goals of 30 kg/kWe at 100 kWe and 10 kg/kWe at 1 MWe. Possible mission applications include large NEP cargo vehicles, NEP piloted vehicles, and surface-based resource production plants. In addition to low cost, high reliability, and long life, the later systems should address the low system specific mass goal. Proposals are solicited that identify novel system concepts and methods to reduce mass and increase power output. Specific areas for development include:

- 100 kWe-class Brayton and Rankine power conversion devices.
- Waste heat rejection technologies for 500 K and above.
- High temperature reactor fuels, structural materials and heat transport technologies.

Technology Readiness Levels (TRL) of 3 to 5 or higher are sought.

Potential NASA Customers include:

- The primary customer is the Office of Chief Technologist (OCT).
- Game Changing Development Program.
- Nuclear Systems Project.

Secondary customers include:

- Advanced Exploration Systems (AES) under the Human Exploration and Operations Mission Directorate.
- Planetary Science Division under the Science Mission Directorate.

Sub Topics:
Advanced Photovoltaic Systems Topic H8.04
Advanced photovoltaic (PV) power generation and enabling power system technologies are sought for improvements in capability and reliability of PV power generation for space exploration missions. Power levels for PV applications may reach 100s of kWe. System and component technologies are sought that can deliver efficiency, cost, reliability, mass and volume improvements under various operating conditions. Compatibility with solar cells having at least 29% efficiency and flexible blankets is required.

PV technologies must enable or enhance the ability to provide low-cost, low mass and higher efficiency for power systems with particular emphasis on high power arrays to support solar electric propulsion spacecraft operating at high voltage in the deep space environment. Technologies can address recurring and non-recurring costs for flight units or development units. Examples include technologies that reduce the solar cell cost, modular panel designs, automated blanket/cell/integration and interconnects, low cost/low mass coverglass/coatings, etc.
Areas of particular emphasis for 2012 include:

- Advanced PV blanket and component technology/designs that support very high power and high voltage (> 200 V) applications.
- PV module/component technologies that emphasize low mass and cost reduction (in materials, fabrication and testing).
- Improvements to solar cell efficiency that are consistent with low cost, high volume fabrication techniques.
- Automated/modular fabrication methods for PV panels/modules on flexible blankets (includes cell laydown, interconnects, shielding and high voltage operation mitigation techniques).

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.

Technology Readiness Levels (TRL) of 2 to 6 or higher are sought.

Potential NASA Customers include:

- Solar Electric Propulsion Technology Demonstration Project in the Office of the Chief Technologist.
- Human Exploration and Operations Mission Directorate; Science Mission Directorate.

Sub Topics:

Long Range Optical Communications Topic H9.01
This subtopic seeks innovative technologies for long range Optical Telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

Systems and technologies relating to acquisition, tracking and sub-micro-radian pointing of the optical communications beam under typical deep-space ranges (to 40 AU) and spacecraft micro-vibration environments.

- **Isolation platforms** - Compact, lightweight, space-qualifiable vibration isolation platforms for payloads massing between 3 and 50 kg that require less than 15 W of power and mass less than 3 kg that will
attenuate an integrated angular disturbance of 150 micro-radians to less than 0.5 micro-radians (1-sigma), from

- **Laser Transmitters** - Space-qualifiable, >20% DC-to-optical (wall-plug) efficiency, 0.2 to 16 nanosecond pulse-width 1550-nm laser transmitter for pulse-position modulated data with from 16 to 320 slots per symbol, less than 35 picosecond pulse rise and fall times, near transform limited spectral width, single polarization output with at least 20 dB polarization extinction ratio, amplitude extinction ratio greater than 38 dB, average power of 5 to 20 Watt, massing less than 500 grams per Watt. Also of interest for the laser transmitter are: robust and compact packaging with radiation tolerant electronics inherent in the design, and high speed electrical interface to support output of pulse position modulation encoding of sub nanosecond pulses and inputs such as Spacewire, Firewire or Gigabit Ethernet. Detailed description of approaches to achieve the stated efficiency is a must.

- **Photon counting near-infrared detectors arrays for ground receivers** - Hexagonal close packed kilo-pixel arrays sensitive to 1000 to 1650 nm wavelength range with single photon detection efficiencies greater than 60% and single photon detection jitters less than 40 picoseconds 1-sigma, active diameter greater than 15 microns/pixel, and 1 dB saturation rates of at least 10 mega-photons (detected) per pixel and dark count rates of less than 1 MHz/square-mm.

- **Photon counting near-infrared detectors arrays for flight receivers** - For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation rates of at least 1 mega-photons/pixel and operational temperatures above 220K and dark count rates of

- **Ground-based telescope assembly** - Telescope/photon-buckets with primary mirror diameter ~2.5 meter, f-number of ~1.1 and Cassegrain focus to be used as optical communication receiver/transmitter optics at 1000-1600nm. Produce a maximum image spot size of ~20 micro-radian, and field-of-view will be ~50 micro-radian. Telescope shall be positioned with a two-axis gimbal capable of 0.25 milli-radian pointing. Desired manufacturing cost for combined telescope, gimbal and dome in quantity (tens) is ~$3 M each.

Research should be conducted to convincingly prove technical feasibility during Phase I - ideally through hardware development, with clear pathways to demonstrating and delivering functional hardware, meeting all objectives and specifications, in Phase II.

**Phase I Deliverables** - Phase I deliverables shall include a final report describing design studies and analyses, system, sensor, or instrumentation concepts, prospective material formulations, testing, etc. Prototype systems, components, sensors, instruments or materials can be developed in Phase I as well. The designs or concepts should have commercialization potential. For Phase II consideration, the final report should include a detailed path towards Phase II hardware proof-of-concept system or component or material manufacturing and testing as applicable. The technology concept at the end of Phase I should be at a TRL of 4.

**Phase II Deliverables** - Phase II deliverables shall consist of working proof-of-concept systems, tested material formulations with samples, tested component, sensor, or instrumentation hardware, etc. which have been successfully demonstrated in a relevant environment and delivered to NASA for testing and verification. The technology at the end of Phase II should be at a TRL of 5-6.

Potential NASA Customers include:

- Deep Space Planetary Missions.
- Deep Space Optical Terminal (DOT) Project.
- Space Communications and Navigation (SCaN) Program.
Sub Topics:
Long Range Space RF Communications Topic H9.02
This subtopic seeks to develop innovative long-range RF telecommunications technologies supporting the needs of space missions.

In the future, spacecraft with increasingly capable instruments producing large quantities of data will be visiting the Moon and the planets. These spacecraft will also support long term missions, such as to the outer planets, or extended missions with new objectives. They will possess reconfigurable avionics and communication subsystems and will be designed to require less intervention from earth during periods of low activity. The communication needs of these missions motivate higher data rate capabilities on the uplink and downlink as well as more reliable RF and timing subsystems. Innovative long-range telecommunications technologies that maximize power efficiency, reliability, receiver capability, transmitted power and data rate, while minimizing size, mass and DC power consumption are required. The current state-of-the-art in long-range RF space telecommunications is 6 Mbps from Mars using microwave communications systems (X-Band and Ka-Band) with output power levels in the low tens of Watts and DC-to-RF efficiencies in the range of 10-25%.

Technologies of interest:

This subtopic seeks innovative technologies in the following areas:

- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders and components, incorporating MMICs, MEMs and Bi-CMOS circuits.

- MMIC modulators with drivers to provide a wide range of linear phase modulation (greater than 2.5 rad), high-data rate (10 - 200 Mbps) BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (26 GHz, 32 GHz and 38 GHz).

- High DC-to-RF-efficiency (> 60%), low mass Solid-State Power Amplifiers (SSPAs), of both medium output power (10 W-50 W) and high-output power (150 W-1 KW), using power combining and/or wide band-gap semiconductors at X-band (8.4 GHz) and Ka-band (26 GHz, 32 GHz and 38 GHz).

- Utilization of nano-materials and/or other novel materials and techniques for improving the power efficiency or reducing the mass and cost of reliable vacuum electronics amplifier components (e.g., TWTAs and Klystrons).

- Ultra low-noise amplifiers (MMICs or hybrid, uncooled) for RF front-ends (High dynamic range (> 65 dB), data rate receivers (> 20 Mbps) supporting BPSK/QPSK modulations.

- MEMS-based integrated RF subsystems that reduce the size and mass of space transceivers and transponders. Frequencies of interest include UHF, X- and Ka-Band. Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.

- Novel approaches to mitigate RF component susceptibility to radiation and EMI effects.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and
show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

**Phase I Deliverables** - Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4). Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

**Phase II Deliverables** - Working engineering model of proposed product, along with full report of development and measurements, including populated verification matrix from Phase I (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

Potential NASA Customers include:

- Deep Space Planetary Missions such as Mars 2018, Mars Sample Return, Jupiter Outer Planet Missions.
- Human Space Exploration Missions such as missions to Asteroids, Mars or various Earth-Moon Libration Waypoints.

Sub Topics:

CoNNeCT Experiments Topic H9.03

NASA has developed an on-orbit, reprogrammable, software defined radio-based (SDR) testbed facility aboard the International Space Station (ISS), to conduct a suite of experiments to advance technologies, reduce risk, and enable future mission capabilities. The Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) Project provides SBIR recipients and through other mechanisms NASA, large business, other Government agencies, and academic partners the opportunity to develop and field communications, navigation, and networking technologies in the laboratory and space environment based on reconfigurable, software defined radio platforms. Each SDR is compliant with the Space Telecommunications Radio System (STRS) Architecture, NASA's common architecture for SDRs. The Testbed is installed on the truss of ISS and communicates with both NASA’s Space Network via Tracking Data Relay Satellite System (TDRSS) at S-band and Ka-band and direct to/from ground systems at S-band. One SDR is capable of receiving L-band at the GPS frequencies of L1, L2, and L5.

NASA seeks innovative software applications and experiments to run aboard the Testbed to demonstrate and enable future mission capability using the reconfigurable features of the software defined radios. Experiment software/firmware can run in the flight SDRs, the flight avionics computer, and on a corresponding ground SDR at the Space Network, White Sands Complex. Unique experimenter ground hardware equipment may also be used.

Experimenterers will be provided with appropriate documentation (e.g., flight SDR, avionics, ground SDR) to aid their experiment application development, and may be provided access to the ground-based and flight SDRs to prepare and conduct their experiment. Access to the ground and flight system will be provided on a best effort basis and will be based on their relative priority with other approved experiments. Please note that selection for award does not guarantee flight opportunities on the ISS.
Desired capabilities include, but are not limited to, the examples below:

- Demonstration of mission applicability of SDR.
- Aspects of reconfiguration:
  - Unique/efficient use of processor, FPGA, DSP resources.
  - Inter-process communications.
- Spectrum efficient technologies.
- Space internetworking:
  - Disruption Tolerant Networking.
- Position, navigation and timing (PNT) technology.
- Technologies/waveforms for formation flying.
- High data rate communications.
- Uplink antenna arraying technologies.
- Multi-access communication.
- RF sensing applications (science emulation).
- Cognitive applications.

Experimenters using ground or flight systems will be required to meet certain pre-conditions for flight including:

- Provide software/firmware deliverables (software/firmware source, executables, and models) suitable for flight.
- Document development and build environment and tools for waveform/applications.
- Provide appropriate documentation (e.g., experimenter requirements, waveform/software user's guide, ICD's) throughout the development and code delivery process.
- Software/firmware deliverables compliant to the Space Telecommunications Radio System (STRS) Architecture, Release 1.02.1 and submitted to waveform repository for reuse by other users.
- Verification of performance on ground based system prior to operation on the flight system.

Methods and tools for the development of software/firmware components that is portable across multiple platforms and standards-based approaches are preferred.

Documentation for both the CoNNeCT system and STRS Architecture may be found at the following link:
These documents will provide an overview of the CoNNeCT flight and ground systems, ground development and test facilities, and experiment flow. Documentation providing additional detail on the flight SDRs, hardware suite, development tools, and interfaces will be made available to successful SBIR award recipients. Note that certain documentation available to SBIR award recipients is restricted by export controls and available to U.S. citizens only.

For all above technologies, Phase I will provide experimenters time to develop and advance waveform/application architectures and designs along with detailed experiment plans. The subtopic will seek to leverage more mature waveform developments to reduce development risk in subsequent phases, due to the timeframe of the on-orbit Testbed. The experiment plan will show a path toward Phase II software/firmware completion, ground verification process, and delivering a software/firmware and documentation package for NASA space demonstration aboard the flight SDR. Phase II will allow experimenters to complete the waveform development and demonstrate technical feasibility and basic operation of key algorithms on CoNNeCT ground-based SDR platforms and conduct their flight system experiment. Opportunities and plans should also be identified and summarized for potential commercialization.

Phase I Deliverables:

- Waveform/application architecture and detailed design document, including plan/approach for STRS compliance.
- Experiment Reference Design Mission Concept of Operations.
- Experiment Plan (according to provided template).
- Demonstrate simulation or model of key waveform/application functions.
- Plan and approach for Commercialization of the technology (part of final report).
- Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product. Early software/firmware application source and binary code and documentation. Source/binary code will be run on engineering models and/or SDR breadboards (at TRL-3-4).

Phase II Deliverables:

- Applicable Experiment Documents (e.g., requirements, design, management plans).
- Simulation or model of waveform application.
- Demonstration of waveform/application in the laboratory on CoNNeCT breadboards and engineering models.
- Results of implementing the Commercialization Plan outlined in Phase I.
• Software/firmware application source and binary code and documentation (waveform contribution to STRS Repository for reuse by others). Source/binary code will be run on engineering models and/or demonstrated on-orbit in flight system (at TRL-5-7) SDRs.

Potential NASA Customers include:

• Deep Space Planetary Missions.
• Extra Vehicular Activity Office.
• Space Communications and Navigation (SCaN) Program.

Sub Topics:
Flight Dynamics Technologies and Software Topic H9.04
NASA’s current Position, Navigation, and Timing (PNT) state-of-the-art relies on both ground-based and space-based radiometric tracking, laser ranging, and optical navigation techniques. Post-processed GPS position determination performance accuracy is at the cm-level at Near-Earth distances and at meter-level at High-Earth Orbit distances; while autonomous real-time GPS performance, such as provided by GPS-Enhanced Onboard Navigation System (GEONS) can achieve accuracy performance of 20 meters. For missions at Mars, Deep Space Network navigation services provide performance accuracy of 1km, while optical navigation methodologies obtain performance accuracy of 10s of km at this distance.

Future NASA missions will require precision landing, rendezvous, formation flying, cooperative robotics, proximity operations, and coordinated platform operations. As such, the need for increased precision in absolute and relative navigation solutions increases. As operations occur further from Earth and more complex navigational maneuvers are performed, it will be necessary to reduce the reliance on Earth-based systems for real-time decisions. Investments in technologies to implement autonomous on-board navigation and maneuvering will permit a reduction in dependence on ground-based tracking, ranging, trajectory/orbit/attitude determination, and maneuver planning and support functions. Therefore, the early focus for NASA will be to improve PNT through increasing real-time PNT accuracy and precision, as well as achieving this performance in autonomously on-board the spacecraft.

Technologies and software should support a broad range of spaceflight customers. Technologies and software specifically focused on a particular mission's or mission set's needs are the subject of other solicitations by the relevant sponsoring organizations and should not be submitted in response to this solicitation. In the context of this solicitation, flight dynamics technologies and software are algorithms and software that may be used in ground support facilities, or onboard a spacecraft, so as to provide PNT services that reduce the need for ground tracking and ground navigation support. Flight dynamics technologies and software also provide critical support to pre-flight mission design, planning, and analysis activities.

This solicitation is primarily focused on NASA’s flight dynamics software and technology needs in the following focused areas:

• Next generation of multi-purpose ground-based and on-board autonomous navigation filtering techniques,
such as adaptive filtering where measurements are selectively weighted, or filters that monitor state noise and measurement noise processes.

- Algorithms for real-time multi-platform relative navigation (relative position, velocity, attitude/pose).

- Algorithms which process clock measurements and estimate and/or propagate the timekeeping model (which generates the time and frequency signal output) and timekeeping system architectures in which outputs of an ensemble of clocks are weighed and software filtered to synthesize an optimized time estimate.

- Sensor measurement models and processing algorithms for next generation sensors, including (but not limited to): optical navigation sensors (high resolution flash LIDAR, visible cameras, infrared cameras), radar sensors, radiometrics, fine guidance sensors, laser rangefinders, high volume/high speed FPGA-based electronics for LIDAR.

- Algorithms for real-time vision processing, path planning and optimization, constraint handling, integrated system health management, fault management (FDIR), event sequencing, optimal resource allocations, collaborative sensor fusion, sensor image motion compensation and processing, pattern recognition/matching, hazard search and detection, feature location and mapping, high performance inertial and celestial sensor models, accurate and fast converging vehicle state estimation filters and adaptive flight control systems.

- Applications of advanced dynamical theories to space mission design and analysis for ground-based and on-board autonomous algorithms, especially in the context of unstable orbital trajectories in the vicinity of small bodies, libration points, and Near-Earth objects.

- Autonomous navigational planning, detection, and filter optimization, as well as attitude control systems for autonomous platform orientation, using sensor measurement fault detection & management and/or fault-tolerant filtering algorithms.

- Addition of novel estimation techniques and/or orbit determination capabilities to existing NASA mission design software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.

Proposals that leverage state-of-the-art capabilities already developed by NASA are especially encouraged, such as:

- GPS-Enhanced Onboard Navigation Software:
  - [http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtm](http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtm) [9])


- GPS-Inferred Positioning System and Orbit Analysis Simulation Software:


Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.
Phase I Deliverables - Phase I research should be conducted to demonstrate technical feasibility (to reach TRL 3), with preliminary software being delivered for NASA testing at the end of the Phase I contract, as well as show a plan towards Phase II integration. Phase I Deliverables include:

- Preliminary Software at end of Phase I contract.
- Final Phase I Technical Feasibility Report with a Phase II Integration Path.

Phase II Deliverables - Phase II efforts should build on Phase I research towards a Phase II software demonstration and delivering a software package for NASA testing at the completion of the Phase II contract (to reach TRL 5). Also, prototype software should be delivered to NASA at the end of the first year of the contract, to be reviewed and iterated upon towards the development of the final software demonstration and delivery. Phase II efforts should also include development of proper documentation, which includes a thorough Algorithm Specification document. Phase II Deliverables include:

- Prototype Software at end of first year of Phase II contract.
- Final Phase II Technical Report.
- Algorithm Specification at end of Phase II contract.
- Delivery of software package at end of Phase II contract.
- Demonstration of software package at end of Phase II contract.

Potential NASA Customers include:

- Space Communications and Navigation (SCaN) Program

Sub Topics:
Game Changing Technologies Topic H9.05
NASA seeks revolutionary, highly innovative, game changing communications technologies that have the potential to enable order of magnitude performance improvements for space operations, exploration systems, and/or science mission applications. As NASA moves towards an integrated network architecture, infusion of critical, enabling technologies will be key to meeting user needs and offering standardized services. Emphasis for this subtopic is on the mid - (3-8 yrs.), and far-term (>8 yrs.) with focused research in the following areas:

Develop novel techniques for size, weight, and power (SWAP) of communications systems by addressing digital processing and logic implementation tradeoffs, dynamic power management, hardware and software partitioning. Address reliability, robustness, and radiation tolerance for missions beyond low Earth orbit. Investigate and demonstrate unique, innovative electronic or optical technologies to alleviate demanding mission requirements (at least 10X improvement over state-of-the-art) in areas such as chip speed, compression, encoding/decoding, etc.
Communication systems optimized for energy efficiency (information bits per unit energy) will be increasingly important for low energy communication systems.

Small spacecraft, due to their limited surface area, are typically power constrained, limiting small spacecraft communications systems to low bandwidth architectures. Technologies and architectures that can exploit commercial or other terrestrial communication infrastructures to enable novel small satellite (e.g., CubeSat) missions are desired. Identify advanced solutions for higher density integration techniques and packaging. Address how existing communications architectures can be adapted and utilized to provide higher bandwidth communications capabilities with better performance and at lower cost for spacecraft to ground, and spacecraft to spacecraft applications.

Novel approaches to addressing extremely high bandwidth, high data rate signaling using RF, mm-wave (Ka- to W- band), and/or optical (1550 nm) links.) Purely optical links are subject to atmospheric interference (clouds, rain, snow, fog, etc.) and can restrict operations for Earth-based optical terminals, so hybrid RF/optical systems are intriguing. Technologies that address flexible, scalable digital/optical core processing topologies to support both RF and optical communications in a single dual-feed terminal, such as: programmable modulation/coding, multi-rate clocking and data recovery, system-on-a-chip integration, memory management, multi-processor architectures, etc. are sought to mitigate risk of such a system.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II demonstration with delivery of a demonstration unit or package for NASA testing at the completion of the Phase II contract.

Opportunities and plans should also be identified and summarized for potential commercialization.

*Phase I Deliverables* - Phase I deliverables shall include a final report describing design studies and analyses, system, sensor, or instrumentation concepts, prospective formulations, testing, etc. Prototype systems, components, sensors, instruments or materials can be developed in Phase I as well. The designs or concepts should have commercialization potential. For Phase II consideration, the final report should include a detailed path towards Phase II proof-of-concept system or component or testing as applicable. The technology concept at the end of Phase I should be at a TRL range of 2-3.

*Phase II Deliverables* - Phase II deliverables shall consist of working proof-of-concept systems, samples, component, sensor, or instrumentation hardware, etc. which have been successfully demonstrated in a relevant environment and delivered to NASA for testing and verification. The technology at the end of Phase II should be at a TRL range of 3-4.

Potential NASA Customers include:

- Deep Space Planetary Missions.
- Extra Vehicular Activity Office.
Sub Topics:

**Ground Processing Optimization and Technology Infusion Topic H10.01**
This subtopic seeks innovative concepts and solutions for both addressing long-term ground processing and test complex operational challenges and driving down the cost of government and commercial access to space. Technology infusion and optimization of existing and future operational programs, while concurrently maintaining continued operations, are paramount for cost effectiveness, safety assurance, and supportability.

Strategies to optimize and support changes in operations concepts should consider:

- The needs of geographically distributed and mobile teams.
- Efficient configuration changes to support operations of different customers.
- Protection of information for the different customers.
- Infrastructure availability.
- Increased situational awareness for operators.

Technology areas of Interest include:

- Strategies, technology innovations, and technology maturation of control room services to provide cost effective data handling and storage and standardized interfaces for data generated by dissimilar systems. Methods for rapid prototype of control and data systems software from engineering data, ensuring scalability of data presentation and streamlined communication, and methods to address and inform consumers of time delays in data transmission:
  - Cost effective solutions to connect control and data system software to facility models that provide for ease of use and maximize the return on investment for concurrent test and launch complex environments.
  - Approaches, such as a single console to perform command and control for a set of test resources or provisions for model-based diagnostic methods to provide rapid feedback on the test and launch complex environment state, can be explored.
- Methodologies for benchmarking, migrating, upgrading, and/or enhancing tools and control and data system architectures to lower the cost of technology infusion concurrently with the operational environment while reducing sustaining costs:
  - Focus should also be on system maintenance concepts for a highly COTS intensive environment to
ensure configuration management and control, verification and validation approaches, technology refresh and security updates.

- Innovative capabilities in information technology are required to provide robust and highly efficient information security for maintaining customer-specific intellectual property while providing a collaborative environment for launch and testing services.

- Optimization of ground controller and test conductor staffing and roles requirements through robust, innovative, and operator-infused simulation/training capabilities to efficiently train ground and test controllers in a collaborative environment. Objectives should focus on skills proficiency and maintenance for troubleshooting, decision making, and time management in critical situations.

- Migration of models used in the design and development of infrastructure to the operations/training phase (e.g., Model-Based System Engineering (MBSE) process).

- Cost effective solutions for operations automation including peer-to-peer planning, mixed initiatives, elicitation of constraints and preferences, and system software integration. Focus should be on the use of standards and open source software enabling staff reduction, fault isolation and recovery methods, and decrease of software integration costs. Additionally, on understanding the interfaces of planning/mixed initiative systems with diagnostic systems, as diagnostic systems will inform the planning system of the available resources.

- Prognostic technologies to optimize component maintenance, support, mission and test planning, evaluation of system component redundancy, monitoring of performance and safety margins, and critical decision making.

Proposed concepts would benefit from clean, well-defined, unambiguous interfaces that account for configuration changes over the ground processing and test complex timeline; such proposals will receive higher consideration. All concepts must place an emphasis on how the interfaces in the system behave. Approaches to model, verify, and validate interfaces will be of interest.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II demonstration, and delivering a demonstration package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables - Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a demonstration. Concept methodology, infusion strategies (including risk trades), and business model. Identify improvements over the current state of the art and the feasibility of the approach in a multi-customer environment. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL of 4.

Phase II Deliverables - Emphasis should be placed on developing and demonstrating the technology under simulated mission conditions, including the mission of engine testing. The proposal shall outline a path showing how the technology could be developed into mission-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL of 7.
Sub Topics:
ISS Demonstration & Development of Improved Exploration Technologies Topic H10.02
The focus of this subtopic is on technologies and techniques which may advance the state of the art of spacecraft systems by utilizing the International Space Station as a technology test bed.

Successful proposals will address using the long duration environment of the ISS to demonstrate component or system characteristics that extend beyond the current state of the art by:

- Increasing capability/operating time including overall operational availability.
- Reducing logistics and maintenance efforts.
- Reducing operational efforts, minimizing crew interaction with both systems and the ground.
- Reducing known spacecraft/spaceflight technical risks and needs.
- Providing information on the long term space environment needed in the development of future spacecraft technologies through model development, simulations or ground testing verified by on orbit operational data.

These demonstrations should focus on increasing the TRL in the following fields:

- Power generation and energy storage (e.g., regenerative fuel cells and battery).
- Robotics Tele-robotics and Autonomous (RTA) Systems.
- Communication and Navigation (e.g., autonomous rendezvous and docking advancements).
- Human health, Life Support and Habitation Systems (e.g. closed loop aspects of environmental control and life support systems).
- Science Instruments, Observatories and Sensor Systems.
- Nanotechnology.
- Materials, Structures, Mechanical Systems and Manufacturing.
- Thermal Management Systems (e.g., cryogenic propellant storage and transfer).
- Environmental control systems, including improved carbon dioxide removal.
- On-orbit trash processing/recycling.
- Radiation.
- Providing Engineering Motion Imagery "smart" imaging systems that reduce bandwidth but maintain high quality imaging in areas of interest; maintenance of window clarity on optical systems without creating a debris source; data storage and retrieval for instances when bandwidth is constrained or the rocket or spacecraft will not be retrieved; compression and/or modulation techniques to maximize efficiency of constrained telemetry downlinks; and imaging system components that are radiation and electromagnetic interference tolerant.
For the above technology subject areas, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward hardware and/or material development as appropriate which occurs during Phase II and culminates in a proof-of-concept system.

**Phase I Deliverables** - Phase I Deliverables: Research to identify and evaluate candidate technologies applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL of 3-6.

**Phase II Deliverables** - Phase II Deliverables: Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions. The proposal shall outline a path showing how the technology could be developed into space-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology at the end of Phase II should be at a TRL of 6-7.

Sub Topics:
Radiation Prediction (Integrated Advanced Alert/Warning Systems for Solar Proton Events) Topic H11.01 Advances are needed in alerts/warnings and risk assessment models that give mission planners, flight control teams and crews sufficient advanced warning of impending Solar Proton Event (SPE) impact. Research and development should be targeted which leverages modeling techniques used throughout terrestrial weather for extreme event assessment. There is particular interest in development of models capable of delivering the probability of no SPE occurrence in a 24-hour time period, i.e., an "All-Clear" forecast.

Forecast techniques should utilize the historical record of archived SPEs to characterize model forecast validity in terms accepted metrics, i.e., skill score, false alarm rates, etc. Specific areas in which SBIR-developed technologies can contribute to NASA's overall mission requirements include the following:

- Innovative forecasting solutions that leverage model development in other areas such as ensemble forecasting of hurricane tracks, flooding, financial market behavior, and earthquake prediction.
- Innovative methods that integrate historical trending, real-time data, and fundamental physics-based models into advance warning and detection systems.

Technology Readiness Levels (TRL) of 2 to 4 or higher are sought.
Potential NASA Customers include:

- Human Exploration and Operations Mission Directorate.
- International Space Station Program.
- Science Mission Directorate.

Sub Topics:
- Exploration Countermeasure Capability - Portable Activity Monitoring System Topic H12.01

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 physiologic 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. NASA is conducting research to enhance and optimize exercise countermeasure hardware and protocols for these missions. In this solicitation, we are seeking portable technologies to collect foot ground reaction force data from current exercise hardware deployed on the International Space Station to be analyzed by research teams on the ground.

NASA seeks a portable, force/load measurement system capable of being integrated into existing ISS exercise systems and suitable for use in future transfer and exploration vehicles. During long duration spaceflight, exercise is prescribed to mitigate bone and muscle loss. Advancement of these exercise prescriptions may require biomechanical analysis of exercise on orbit. Output parameters from the proposed device must be valid in the bandwidth from 0-100Hz and be able to be synchronized with existing analog data systems. 3-D force, torque, acceleration, and turn rates are required. Must include a portable data logging system or wireless interface compatible with the Windows platform or Apple iPad. On-board data processing, activity recognition and display is desirable. The portable system should be low-maintenance, durable, easy to set-up and calibrate, non-disruptive to exercise form or gait, accurate (NASA Deliverables - Fully developed concept complete with feasibility and top-level drawings as well as computational methodology as applicable. A breadboard or prototype system is highly desired.

HRP IRP Risks - Risk of Impaired Performance Due to Reduced Muscle Mass, Strength, and Endurance; Risk Of Early Onset Osteoporosis Due To Spaceflight

Technology Readiness Levels (TRL) of 6 or higher are sought.

Potential NASA Customers include:
Sub Topics:

Exploration Medical Capability - Medical Suction Capability Topic H12.02

The existing in-space medical suction system (used on ISS) provides insufficient medical suction capability. Medical suction clears the airway, empties the stomach, decompresses the chest, and keeps the operative field clear. The existing design provides limited operational flexibility in providing airway management support, oropharyngeal suction, and chest tube drainage during an exploration mission due to limitations in suction performance, usability, patient interfaces, and reusability. It is restricted for use by a trained medical doctor and has several design limitations including:

- It can only be used to clear the airway. It would be insufficient/incapable to perform other types of medical suction.
- Device consists of several pieces that are only held together by a friction fit/seal and may come apart unless handled carefully.
- Device does not meet flow rate requirement since it is limited by operator speed.
- Device can only collect about 1 liter total volume. This volume includes volume of air since there is no gas separator.

The Phase I technology developed under this SBIR should demonstrate proof of concept medical suction capability in a space operational environment and should focus on the following aspects:

- Phase separation.
- Range of flow rates.
- Range of applied vacuum pressure.
- Continuous and intermittent operation.
- Variety of operational conditions including micro, partial and normal gravity; and in-space and post-landing usage.
- Minimize mass, volume, and power usage.

Minimum specifications that should be in the design:

- Airway Management and Oropharyngeal Suction:
  - Suction pressure - at least 500 mmHg
- Flow rate - at least 25 liters per minute
- Duration - at least 30 minutes

- Chest tube drainage:
  - Suction pressure - between 150-180 mmHg
  - Duration - at least 24 hours

- Biological waste cleanup:
  - Suction pressure - at least 500 mmHg
  - Flow rate - at least 35 liters per minute
  - Duration - at least 30 minutes

**NASA Deliverable** - Prototype functional system in a proof of concept demonstration

**HRP IRP Risk** - Inability to Adequately Recognize or Treat an Ill or Injured Crew Member

Technology Readiness Levels (TRL) of 3 or higher are sought.

Potential NASA Customers include:

- Exploration Medical Capability Element in Human Research Program:

Sub Topics:

  Behavioral Health and Performance - Innovative Technologies for A Virtual Social Support System for Autonomous Exploration Missions Topic H12.03

NASA wants to identify how virtual worlds (i.e., interactive games, avatars, social networks) could be used for long-duration space exploration missions. This subtopic is aimed at developing a virtual social support system for crews of such missions.

During these missions, the crews, by virtue of their distance from Earth, are separated from their significant others and will no longer have access to social support currently provided to the ISS crews. They are living in a confined and isolated environment devoid of normal Earth settings as they venture to distant destinations. Long communication delays between Earth and vehicle are also anticipated. Expanding the crew's social connectivity to friends, family, and colleagues back home through a variety of virtual platforms will help mitigate the stressors inherent to living and working in such an isolated, confined, and extreme environment.
During the actual mission, the tool could provide a more homelike "virtual world" to augment the constrained physical habitat the crew lives and works. It could also help the crews maintain connections and provide the needed social support. As a design tool, the insight gained into the crew members' interaction with the outside world would be valuable for developing new mission training regimens and design concepts for future long-duration missions.

The proposal shall describe:

- The virtual environment to be developed.
- Plans to provide adaptive systems to deal with communication latencies.
- How the tool could enhance and measure behavioral health and performance, including perceived closeness to home.
- Ways to assess habitability issues.

*NASA Deliverables* - Phase I deliverable shall yield a proof of concept that includes both an evidence review that encompasses an assessment of current knowledge of virtual reality technologies and their use in supporting this topic.

In addition, the following deliverables shall be required:

- A requirements document for such a support system that fits the needs of a NASA exploration mission.
- A plan for evaluating the effectiveness of the tool as a behavioral health countermeasure, training, and habitability assessment.

The subsequent Phase II deliverable shall provide a prototype of specific modules that can demonstrate improved communication and perceived social support by utilizing these technologies.

*HRP IRP Risks* - Risk of Adverse Behavioral Conditions and Psychiatric Disorders; Risk of Performance Decrement Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team; Risk of an Incompatible Vehicle/Habitat Design

Technology Readiness Levels (TRL) of 4 or higher are sought.

Potential NASA Customers include:
The purpose of the NASA Advanced Food Technology Project is to develop, evaluate and deliver food technologies for human centered spacecraft that will support crews on long duration missions beyond low-Earth orbit. Safe, nutritious, acceptable, and varied shelf-stable foods with a shelf life of 5 years will be required to support the crew during these exploration missions. Concurrently, the food system must efficiently balance appropriate vehicle resources such as mass, volume, water, air, waste, power, and crew time.

Refrigeration and freezing require significant vehicle resource utilization, so NASA provisions consist solely of shelf stable foods. Stability is achieved by thermal or irradiative processing to kill the microorganisms in the food, or drying to prevent viability of the microorganisms. These methods do impact the micronutrients within the food substrate. Environmental factors (such as moisture ingress and oxidation) are also capable of compromising the nutrient content over the shelf life of the food. Since the food system is the sole source of nutrition to the crew, a significant loss in nutrient availability could significantly jeopardize the health and performance of the crew. Optimal nutritional content of the food for five years will ensure that the food can support crew performance and help protect their bodies from deficiencies that cause disease.

Vitamin content in NASA foods, such as vitamin C, vitamin A, thiamin, and folic acid, is degraded during processing and as the product ages in storage. The goal is to develop a system that either increases the bioavailability of the nutrients or protects the vitamins from this biological or chemical degradation at ambient temperatures over a five year duration. Possible technologies that could be investigated include novel food ingredients, protective or stabilizing technologies (e.g., encapsulation), biosensors, and controlled-release systems.

**Phase I Requirements** - 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.

**NASA Deliverables** - A system which will result in higher nutrient content in shelf stable foods.

**HRP IRP risk** - Risk of Inadequate Food System

Technology Readiness Levels (TRL) of 4 to 5 or higher are sought.

Potential NASA Customers include:

- Space Human Factors and Habitation Element in Human Research Program:
Sub Topics:

In-Flight Biological Sample Analysis Topic H12.05

Although crewmembers undergo intensive medical screening, the possibility of crew injury or illness can never be completely eliminated. A mission could be jeopardized or compromised by reduction of able crewmembers, both directly and indirectly if an incapacitated crewmember requires nursing or care. Mission architecture limits the amount of equipment, consumables, and procedures that will be available to treat medical problems. Mission allocation and technology development must be performed to ensure that the limited mass, volume, power, and crew training time are used efficiently to provide the broadest possible treatment capability. There is also a gap in knowledge in how the spaceflight environment affects the effectiveness of drug therapies. This subtopic aims to mitigate those space mission constraints by means of innovative approaches for addressing the knowledge gap in the area of drug stability during long duration spaceflight.

This subtopic seeks proposals for novel approaches to develop an in-flight tool capable of monitoring stability of pharmaceuticals (ideally, solids, liquids and creams) under low gravity conditions. Such a device must be able to determine percentage of active ingredients with a preference to also characterize degradation of products while minimizing the amount of pharmaceutical sample consumed in the test. The technology will need to address approaches and methodologies for handling the different forms of pharmaceuticals (pills, liquids, creams) through the use of a flexible sample preparation front-end amenable to the space environment. The proposed technology should be low-resource, low-footprint, and should involve a low volume of supplies/consumables, which do not require refrigeration or freezing for storage. Also, the technological innovation should be user-friendly, requiring minimal training and operating via uncomplicated protocols.

The Phase I technology developed under this SBIR should investigate one or more one or more of the following drugs:

- Acetaminophen.
- Azithromycin.
- Injectable epinephrine.
- Lidocaine topical gel.

In the Phase I effort, the proof of concept analysis should be demonstrated by the innovative technology and provide comparable results to drug stability laboratory USP standards (i.e., high performance liquid chromatography, differential scanning calorimetry, UV/FTIR spectroscopy). Phase II will seek to optimize these results for additional drugs as well as sensitivity, compound identification, drug degradation products, analysis time and facilitated end-user protocols.

NASA Deliverables: Prototype functional system in a proof of concept analysis demonstrated by the innovative technology producing drug stability characterization including integrity and percentage of active ingredients and characterization/degradation of products (in Phase I). Drugs to be demonstrated in Phase I include: Acetaminophen, Azithromycin, Injectable epinephrine and Lidocaine topical gel.
HRP IRP Risks - Inability to Adequately Recognize or Treat an Ill or Injured Crew Member; Risk of Therapeutic Failure Due to Ineffectiveness of Medication

Technology Readiness Levels (TRL) of 5 or higher are sought.

Potential NASA Customers include:

- ISS Medical Project Element in Human Research Program:
  - (http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-issmp.html [18])

Sub Topics: