



## NASA SBIR 2014 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 new approaches for exploration and significantly reduce the mass, cost, and risk of near-term and long-term space exploration. The ability to make propellants, life support consumables, fuel cell reagents, and radiation shielding can provide significant benefits for sustained human activities beyond Earth very early in exploration architectures. Since ISRU can be performed wherever resources may exist, ISRU systems will need to operate in a variety of environments and gravities and need to consider a wide variety of potential resource physical and mineral characteristics. 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 gas, water, and Mars atmosphere processing.

Sub Topics:

#### H1.01 In-Situ Resource Utilization - Mars Atmosphere/Gas Chemical Processing

Lead Center: JSC

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

In-Situ Resource Utilization (ISRU) involves collecting and converting local resources into products that can reduce mission mass, cost, and/or risk of human exploration. ISRU products that provide significant mission benefits with minimal infrastructure required are propellants, fuel cell reactants, and life support consumable. Innovative technologies and approaches are sought related to ISRU processes associated with collecting, separating, pressurizing, and processing gases collected from in-situ resources including the Mars atmosphere, trash processing, and volatiles released from in-situ soil/regolith resources, into oxygen, methane, and water. State of the art (SOA) technologies for these ISRU processes either do not exist or are too complex, heavy, inefficient, or consume too much power. The innovative technologies and process sought must operate in low and micro-gravity environments, must be scalable from low demonstration processing and production flow rates of 0.045 kg/hr of carbon dioxide (CO<sub>2</sub>) and 0.015 kg/hr of oxygen (O<sub>2</sub>) to utilization flow rates of 2.25 kg/hr for CO<sub>2</sub> and 0.75 kg/hr for O<sub>2</sub>. Chemical processing technologies must operate between 15 to 75 psia.

Technologies of specific interest include:

- Regenerative dust filtration, especially Mars dust, that is: scalable, has minimum pressure drop, can operate at low inlet pressures, and provides 99% @ 0.3 um collection efficiency, with >95% regeneration capability for multiple cleaning cycles. SOA filters are replaced by the crew or sized for the complete mission. Since Mars ISRU operations will occur without a crew present and between 100 and 480 days in duration, cleaning and regeneration of filtration approaches is required.
- Dust/particle measurement device that allows for size and particle density measurements before and after filtration. Optional additional capabilities including electrostatic and or mineral characterization are also of interest. Dust measurement devices must integrate into limited volume areas and interface with atmosphere-inlets/trash processing outlet tubing.
- Lightweight, low-power device to deliver fresh Mars 'air' (0.1 psia) to the plant with small head pressure capability (10's torr). SOA blowers currently do not exist which can effectively move the low pressure Mars atmosphere efficiently (power and mass) for long-periods of time. Thermal management and/or use must be

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clearly defined for proposed devices.

- Lightweight, lower power device to collect and pressurize CO<sub>2</sub> from 0.1 psia to >15 psia; maximum 75 psia. SOA mechanical compressors are heavy, power intensive, and have limited life. Mars atmosphere CO<sub>2</sub> collection devices will need to operate for a minimum of 100 days and up to 480 days. Thermal management and/or use must be clearly defined for proposed devices.
- High throughput water separation from gas streams. SOA devices utilize water tanks and chillers which are potentially large, heavy, and power intensive. Highly efficient, low power, and compact membrane and adsorption based separation devices allowing for very low dew point exhaust are sought.
- High throughput carbon monoxide/carbon dioxide separation and recycling concepts for processes with only partial conversion of CO<sub>2</sub> into usable products. Highly efficient, low power, and compact membrane and adsorption based separation devices are sought with minimum pressure drop.
- Highly efficient chemical reactors and heat exchangers based on modular/stackable microchannel plate architectures. SOA catalyst bed type reactors are inefficient in mass and volume and are not easily scalable to higher processing rates without reactor bed redesigns and thermal management changes. Thermal management and/or use must be clearly defined for proposed devices.

Proposals must identify and provide clear benefits compared to state of the art technologies and processes in the areas of mass, volume, and/or power reduction as well as define the expected impact of changing gravity orientation and strength. SOA for most processing technologies are terrestrial applications or space life support systems. Phase I proposals for innovative technologies and processes must include the design and test of critical attributes or high risk areas associated with the proposed technology or process. Phase II proposals must further Phase I efforts leading to the design, build, test, and delivery of hardware (at rates specified above) that can be integrated into breadboard ISRU systems for testing with other technologies and processes (Technology Readiness Level 4 to 6).

## 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 High Power Electric Propulsion**

**Lead Center:** GRC

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

The goal of this subtopic is to develop innovative technologies that can lead to high-power (>50 kW to MW-class) electric propulsion systems. High-power (high-thrust) electric propulsion (>50kW per thruster) may enable dramatic mass and cost savings for lunar and Mars cargo missions, including Earth escape and near-Earth space maneuvers. At very high power levels, electric propulsion may enable piloted exploration missions.

Innovations and advancements leading to improvements in the end to end performance of high power electric propulsion systems are of interest. Technologies are sought that increase system efficiency; increase system and/or component life or durability; reduce system and/or component mass, complexity, or development issues; or provide other definable benefits. In general, thruster system efficiencies exceeding 60% and providing total impulse values greater than 10<sup>7</sup>. Desired specific impulses range from a value of 2000 s for Earth-orbit transfers to over 6000 s for planetary missions.

Specific technologies of interest in addressing these challenges include:

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- Electric propulsion systems and components for alternate fuels such as the use of in-situ resources, condensable or metal propellants, and alternatives to Xenon.
  - Novel methods for fabricating large refractory metal parts with complex shapes, with integrated heat pipes. Particular figures of merit include low cost, rapid turnaround, and ability to incorporate internal flow passages.
  - Long life cathodes for high power electrostatic or electromagnetic thrusters capable of extended operation at required temperature and current levels for appropriate mission durations.
  - Innovative plasma neutralization concepts.
  - Highly accurate flow controllers and fast acting valves for pulsed thruster systems High current (MA), high repetition rate (up to 1-kHz), long life (greater than  $10^9$  pulses) solid state switches for high power inductive pulsed plasma thrusters.
  - High-temperature permanent magnets and/or electromagnets; low-voltage, high-temperature wire for electromagnets; superconducting magnets.

Note to Proposer: Subtopic S3.02 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.02.

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.

## **H2.02 In-Space Chemical Propulsion**

**Lead Center: GRC**

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

This solicitation intends to examine a range of key technology options associated with non-toxic storable liquid propulsion systems for use in future exploration missions. Efficient propulsive performance and long duration storage attributes have made the use of hydrazine widespread across the aerospace community. However, hydrazine is highly corrosive and toxic, creating a need for non-toxic, high performance propellants for NASA, other government agencies, academia, and the commercial space industry.

Non-toxic engine liquid mono- and bi-propellants technologies are desired for use in lieu of the currently operational hydrazine based engine technologies. Handling and safety concerns with the current toxic chemical propellants can lead to more costly propulsion systems. The use of new non-toxic propellants has the potential to reduce the cost of access to space by lowering overall life cycle costs.

Demonstrations of a hydrazine alternative in a storable liquid mono- or bi-propellant chemical propulsion system implementation relevant to at least one of the following applications are desired: in-space reaction control propulsion, in-space primary propulsion, and launch vehicle reaction control propulsion. Non-toxic technologies could range from pump fed or pressure fed thruster systems from 1 to 1000 lbf.

Specific technologies of interest to meet proposed engine requirements include:

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- Non-toxic mono- and bi-propellants 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.
  - Alternate catalysts, ignition technologies to ignite advanced monopropellants.
  - Advanced materials capable of withstanding hot and corrosive combustion environment of advanced mono- and bi-propellants.
  - Techniques that lower the cost of manufacturing complex components such as injectors, catalysts, and combustion chambers. 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.

Note to Proposer: Subtopic S3.02 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.02.

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.

## **H2.03 Nuclear Thermal Propulsion (NTP)**

**Lead Center: MSFC**

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

This subtopic seeks to develop innovative NTP technologies supporting the needs of future space exploration.

Solid core NTP has been identified as an advanced propulsion concept which could provide the fastest trip times with fewer SLS launches than other propulsion concepts for human missions to Mars over a variety of mission years. The current NASA Strategic Space Technology Investment Plan states NTP is a high priority technology needed for future human exploration of Mars. NTP had major technical work done between 1955-1973 as part of the Rover and Nuclear Engine for Rocket Vehicle Application (NERVA) programs. A few other NTP programs followed including the Space Nuclear Thermal Propulsion (SNTP) program in the early 1990's. The NTP concept is similar to a liquid chemical propulsion system, except instead of combustion in the thrust chamber, a monopropellant is heated with a fission reactor (heat exchanger) in the thrust chamber. In addition, the engine components and surrounding structures are exposed to a radiation environment formed by the reactor during operation.

This solicitation will examine a range of modern technologies associated with NTP using solid core nuclear fission reactors. The engines are pump fed ~15,000-35,000 lbf with a specific impulse goal of 900 seconds (using hydrogen), and are used individually or in clusters for the spacecraft's primary propulsion system. The NTP can have multiple start-ups (>4) with cumulative run time >100 minutes in a single mission, which can last a few years.

Specific technologies of interest to meet the proposed requirements include:

- High temperature (> 2600K), low burn-up composite, carbide, and/or ceramic-metallic (cermet) based nuclear fuels with improved coatings and/or claddings to maximize hydrogen propellant heating and to reduce fission product gas release and particulates into the engine's hydrogen exhaust stream.

- Long life, lightweight, reliable turbopump modeling, designs and technologies including seals, bearing and fluid system components. Throttle ability is also considered. Zero net positive suction head (NPSH) hydrogen inducers have been demonstrated that can ingest 20-30% vapor by volume. The goal would be to develop inducers that can ingest 55% vapor by volume for up to 8 hours with less than 10 percent head fall off at the design point. Develop the capability to model (predict) turbopump cavitation dynamics. This includes first order rotating and alternating cavitation (1.1X 2X) and higher (6X-10X) order cavitation dynamics.
- Highly-reliable, long-life, fast-acting propellant valves with ultra-low hydrogen leakage that tolerate long duration space mission environments with reduced volume, mass, and power requirements are also desirable. Large propellant tank bottom valves can be expected to leak in the order of 1cc per minute of hydrogen measured at standard temperature and pressure (STP). For deep space missions valve leakage will need to be <.01 cc per minute at STP. Demonstrate a large tank bottom valve that can maintain a .01 cc per minute at STP. The valve should be able to cycle 10 times and maintain that leak rate. Valve cycle time can be on the order of one minute or more.
- 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. Robonaut type inspections for prototype flight test considered.
- Concepts to cool down the reactor decay heat after shutdown to minimize the amount of open cycle propellant used in each engine shutdown. Depending on the engine run time for a single burn, cool-down time can take many hours.
- Technology needed to store the NTP propellant for multiple years in-space as liquid hydrogen with almost zero boil-off for 900 days (includes time from first launch to final trans earth injection burn). Innovations are needed in thermal control materials and design, mechanical refrigeration systems, and vehicle design.

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 2-3). 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 component and/or breadboard validation measurements, including populated verification matrix from Phase I (TRL 4-5). Opportunities and plans should also be identified and summarized for potential commercialization.

## **H2.04 Nuclear Thermal Propulsion (NTP) Ground Test Technologies**

**Lead Center: SSC**

**Participating Center(s): MSFC**

A nuclear rocket engine uses a nuclear reactor to heat hydrogen to very high temperatures, which expands through a nozzle to generate thrust. This topic area seeks to develop advanced technology components and system level ground test systems that support Nuclear Thermal Propulsion (NTP) technology development and certification.

Solid core NTP has been identified as an advanced propulsion concept which could provide the fastest trip times with fewer SLS launches than other propulsion concepts for human missions to Mars over a variety of mission years. The current NASA Strategic Space Technology Investment Plan states NTP is a high priority technology needed for future human exploration of Mars. The NTP concept is similar to a liquid chemical propulsion system, except instead of combustion in the thrust chamber, a monopropellant is heated with a fission reactor (heat exchanger) in the thrust chamber. In addition, the engine components and surrounding structures are exposed to a radiation environment formed by the reactor during operation. The NTP had ground testing done between 1955-1973 as part of the Rover and Nuclear Engine for Rocket Vehicle Application (NERVA) programs. The Rover/NERVA ground tested a variety of engine sizes, for a variety of burn durations and start-ups. These ground tests were mostly exhausted in the open air. Information on the NERVA program can be found at

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(<http://history.nasa.gov/SP-4533/Plum%20Brook%20Complete.pdf> [1]).

Current regulations require exhaust filtering of any radioactive noble gases and particulates released to stay within the current environmental regulations. The NTP ground testing requires the development of robust materials, advanced instruments and monitoring systems capable of operating in extreme temperature, pressure and radiation environments. This topic area will investigate large scale engine exhaust scrubber technologies and options for integrating it to the NTP engine for ground tests. The NTP engines are pump fed ~15,000-35,000 lbf with a specific impulse goal of 900 seconds (using hydrogen). The NTP primary test requirements can have multiple start-ups (>8) with the longest single burn time ~50 minutes.

This subtopic seeks innovative technologies in the following areas to facilitate NTP ground testing:

- Advanced high-temperature and hydrogen embrittlement resistant materials for use in a hot hydrogen environment (<4400 °F).
- Efficient non-nuclear generation of high temperature, high flowrate hydrogen (<60 lb/sec).
- Devices for measurement of radiation, pressure, temperature and strain in a high temperature and radiation environment.
- Effluent scrubber technologies for efficient filtering and management of high temperature, high flow hydrogen exhausts.
- Innovative refractory materials which use nano-particle additives and/or unconventional non-cement based refractories that can withstand the extreme plume heating environments experienced during rocket propulsion testing.

Specific interests include:

- Filtering of radioactive particles and debris from exhaust stream having an efficiency rating greater than 99.9%.
- Removal of radioactive halogens, noble gases and vapor phase contaminants from a high flow exhaust stream with an efficiency rating greater than 99.5%.
- Applicable Integrated System Health Monitoring and autonomous test operations control systems.
- Modern robotics which can be used to inspect the ground test system exposed to a radiation environment.

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 2-3). 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 component and/or breadboard validation measurements, including populated verification matrix from Phase I (TRL 4-5). Opportunities and plans should also be identified and summarized for potential commercialization.

### Life Support and Habitation Systems Topic H3

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, environmental monitoring and fire protection systems, crew accommodations, water recovery systems 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

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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 Thermal Control for Future Human Exploration Vehicles**

**Lead Center:** JSC

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

Future human spacecraft will require more sophisticated thermal control systems that can operate in severe environments ranging from full sun to deep space and can dissipate a wide range of heat loads. The systems must perform their function while using fewer spacecraft resources, including mass, volume and power. Advances are sought for microgravity thermal control in the following areas:

- Heat rejection systems and/or radiators that can operate at low fractions of their design heat load in the cold environments that are required for deep space missions. Systems that can maintain setpoint control and operate stably at 25% of their design heat load in a deep space (0 K) environment are sought. Innovative components, working fluids, and systems may be needed to achieve this goal.
- Lightweight non-venting phase change heat exchangers are sought to ameliorate the environmental transients that would be seen in planetary (or lunar) orbit. Heat exchangers that have minimal structural mass and good thermal performance are sought. The goal is a ratio exceeding 2/3 phase change material mass and 1/3 structural mass.
- Two-phase heat transfer components and system architectures that will allow the acquisition, transport, and rejection of waste heat loads in the range of 100 kW to 10 megawatts are sought.
- Nontoxic working fluids are needed that are compatible with aluminum components and combine low operating temperature limits (<250K) and favorable thermophysical properties - e.g., viscosity and specific heat.

Technologies are expected to be raised from TRL2 to TRL 3/4 during Phase I. Minimum deliverables at the end of Phase I are analysis/test reports, but delivery of development hardware for further testing is desirable. In addition, the necessity and usefulness of a follow-on Phase II should be demonstrated.

Technologies would be expected to be matured from TRL 3/4 to TRL 5 during a potential Phase II effort. Expected deliverables for a Phase II effort are analysis/test reports and prototypic hardware.

For more detailed relevant information:

([http://www.nasa.gov/pdf/501320main\\_TA14-Thermal-DRAFT-Nov2010-A.pdf](http://www.nasa.gov/pdf/501320main_TA14-Thermal-DRAFT-Nov2010-A.pdf) [2]).

### **H3.02 Atmosphere Revitalization and Fire Recovery for Future Exploration Missions**

**Lead Center:** MSFC

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

This topic seeks to develop targeted process technologies and equipment to advance the operability and reliability of atmosphere revitalization (AR) subsystems that enable crewed deep space exploration objectives.

Highly reliable AR subsystem equipment and process technologies, supplemented by atmosphere decontamination equipment and methods, are necessary components to crewed deep space exploration mission success. While the International Space Station (ISS) AR subsystem equipment approaches many of the functional goals necessary for deep space exploration mission success, flight operational experience has identified areas for improvement in resource recovery and rapid atmosphere decontamination capabilities. Technologies related to resource recovery include gas compression and management as well as gas separations. Rapid atmosphere decontamination capabilities are needed to remove the functional burden for recovering from a contamination event, such as a fire or chemical spill, from the primary AR subsystem equipment. Details in each functional area of interest are provided by the following:

- *Gas Compression and Management* - NASA is seeking safe, compact, quiet, long-lived, and efficient ways to compress, store, and deliver gaseous oxygen and carbon dioxide within an AR subsystem. Also, methods to store, condition, and deliver reactant gases, primarily carbon dioxide, to carbon dioxide reduction process equipment are sought. Present AR equipment aboard ISS consists of power-intensive, noisy compressors that have service lives less than 2 years. Significant acoustic treatment is necessary to achieve NC-40 criteria. Applications for deep space exploration missions include but are not limited to production of high pressure oxygen for EVA use, and compression and storage of carbon dioxide for use in carbon dioxide reduction systems. Improvements in service life, reliability, and mechanical compression for atmospheric gas recharge to pressures up to 3,600 psia, including long life and reliability, and novel methods to increase tank storage capacity at lower pressures are of particular interest.
- *Hydrogen Purification for Resource Recovery* - Resource recovery and recycling is an enabling functional area for the AR subsystems needed for long-duration missions. For this purpose, NASA is interested in a regenerative separation technology to enable maximum hydrogen recovery from a stream containing water vapor (saturated), carbon monoxide (CO), and hydrocarbons including methane, acetylene, ethane, and ethylene, among others. While a high quantity of methane in the hydrogen product stream is acceptable, and even desirable, the presence of CO, water, and other hydrocarbons is highly undesirable. Final gas composition must be >99% hydrogen with some allowable methane and the dewpoint must be less than -60 °C. System concepts must strive to minimize power, mass, and consumable requirements while maximizing efficiency, operational life, and reliability.
- *Post-Fire Cabin Atmosphere Cleanup* - A portable, self-contained fire and toxic atmosphere cleanup system is desired that can rapidly remove contaminants from a spacecraft volume, to quickly and effectively decontaminate cabin atmosphere after a fire. The capability to reduce starting concentrations by >80% within 15 minutes for a 100-m<sup>3</sup> volume is desired. Methods have involved either deploying a filter assembly to the commode after a fire and using the commode fan as the source of airflow or attaching a series of filters to a portable fan using an adapter kit. Both methods result in low atmospheric scrubbing flow rates and significant time for deployment as well as limited capacity and non-specific scrubbing. Russian-provided portable equipment aboard the ISS provides 65 m<sup>3</sup>/h flow through a replaceable cartridge. The equipment's mass is 17 kg and the power consumption is 150 W. Filter service life is 7.5 hours. The dimensions are approximately 33 cm diameter and 35 cm tall. Future equipment must provide the rapid contamination reduction within the characteristic size and performance envelope of the Russian-developed portable scrubbing device.

For each technical area, projects are sought to research and demonstrate technical feasibility during Phase I that will develop a clear technical maturation path towards Phase II hardware development and demonstration. Phase II products must include a demonstration unit suitable for testing by NASA.

Phase I Deliverables - Documentation, data, and feasibility assessment proving the proposed approach is suitable to develop the proposed product (at least TRL 3 at completion according to NPR 7123.1 TRL definition). A breadboard developmental unit is desirable.

Phase II Deliverables - Functional engineering development unit at a minimum high fidelity breadboard (brassboard fidelity preferred), defined by NPR 7120.8, and technical maturity level 4 (TRL 4 defined by NPR 7123.1) of the proposed product, along with a full report of developmental and performance results, including drawings, analyses, and models as applicable. Opportunities and plans should also be identified and summarized for potential commercialization.

### **H3.03 Human Accommodations and Habitation Systems for Future Exploration Missions**

**Lead Center:** JSC

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

Habitation systems that are dispersed throughout a spacecraft volume need to be investigated as a system to improve future human accommodations. Current spacecraft interiors exceed acoustic limits from a wide range of equipment; have manual inventory tracking and no capability for assistance of lost items; and require substantial crew time and wipes for cleaning common crew surfaces (hand rails and panels) and water/solids hygiene surfaces. Future spacecraft interiors will need to be reconfigurable to meet changing crew needs as a mission moves from launch, transit, and exploration-destination phases. Adaptable distributed habitation technologies are



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needed in the following areas.

- *Quiet Crew Cabin Environments* - Smaller future vehicles will unlikely have dedicated quiet volumes for crew rest so maintaining a quiet cabin is required. Crew cabin acoustic noise mitigation needs to control noise levels to enable improved voice communication, alarm signal to noise ratio, and reduce crew fatigue from long duration noise exposure. There is need for non-wearable active and passive noise cancellation/reduction strategies for open crew cabin environment that do not impede voice or alarms. Need for adaptive broad coverage area to accommodate changing crew cabin layout and volume.
- *Crew Item Location Capability* - Significant crew time is lost in tracking or locating items at the piece part level in space habitat environment that serves both as living quarters and laboratory. Items are sometimes misplaced or simply float away in the microgravity environment. Innovative approaches are sought for automatic location and tracking of a large number of individual crew items as they move from their original launch configuration to any area in the crew cabin. Crew items range in size from pill size, hand tools, clothing, and spare equipment and vary in material composition from non-metallic, metallic, to fluid containing. There is a need for low-power, and miniature Radio Frequency Identification (RFID) readers for dense storage and sparse tag environments. Flexible reader deployment that allows individual item autonomous logistics management tracking and precise 3-D locating are desired. Solutions providing enhanced localization utilizing the EPCglobal UHF reader-tag protocols (Class 1 Gen2 or advanced classes) are of high interest. Similar types of reader-tag communication protocols at higher frequencies that enable more accurate spatial localization are also of interest. Innovative algorithmic solutions for finding lost items, based on RFID or similar sensory information, are also of interest. All solutions must accommodate a highly reflective and complex scattering environment such as a conductive habitat cylindrical volume of ~ 3.5 m diameter ~6 m in length.
- *Crew Cabin Surfaces* - Crew activity and surface contact of fabric and solid surfaces result in generation and accumulation of particulate, moisture, organic, and salt. Surface treatments for fabrics and solid surfaces to prevent this accumulation of contaminants are needed to reduce crew time and the large number of wipes used for cleaning. Innovative low out gassing, super hydrophobic, super hydrophilic, antistatic, and antimicrobial treatments are needed for crew hygiene areas and waste collection hardware is needed. Non-mechanical fastener/non-particle generating removable physical connections are needed for repeated reconfiguring of interior volumes on longer missions. Examples of the types of temporary and reversible physical connections include crew restraints (e.g., hand rails), close out panels, and the hook-and-loop type fasteners present on most crew items.

Phase I Deliverables - Detailed analysis, proof of concept test data, material test coupons, key algorithms/subroutines, and predicted performance comparison to industry state of the art.

Phase II Deliverables - Comparison of analysis to prototype test data in representative environment, sufficient material samples/components for independent evaluation, functional software, functional breadboard component hardware and/or system, and operations documentation.

### **H3.04 Development of Treatment Technologies and Process Monitoring for Water Recovery**

**Lead Center:** JSC

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

The capability to recover potable water from wastewater is critical to enable space exploration missions beyond low Earth orbit. A major focus of technology development is to increase reliability of water recovery systems, so these systems require less crew intervention and a lower risk of failure with longer operational lifetimes. With these goals in mind, two areas of interest have been identified for further focus:

- *Water Recovery Post-Processing Systems* - Technologies are needed to increase the reliability of systems for polishing of partially-treated wastewater. The current state of the art uses catalytic oxidation to remove dissolved organic carbon contaminants. Technologies that operate below 100 °C or ambient pressure are desirable. Examples of these technologies include low-temperature catalytic oxidation, photolysis, or photocatalysis.

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- *Monitoring Systems for Mineral Species in Water & Wastewater* - A capability is needed to measure dissolved mineral ions in water and wastewater, including polyatomic ions (could encompass organic ions) and the alkaline, alkaline-earth and transition metals. Multi-analyte capability is needed, such as that available from ion chromatography and plasma spectroscopy. Potential applications include measurement of typical ionic species in humidity condensate, potable water, wastewater, byproducts of water treatment such as brines, and biomedical and science samples. Desirable attributes should include minimal sample preparation, minimal consumables, in situ calibration, and operation in microgravity and partial gravity.

At the completion of Phase I, the technology should be TRL 3. The expected deliverable for Phase I is a detailed report describing experimental methods and results, with a clear feasibility demonstration of critical technology components. The equivalent system mass, including consumables, power, volume and mass, should be estimated for the technology and be included in the report. Phase II deliverables should have completed TRL 4 and be approaching TRL 5. The Phase II deliverable should include a prototype system suitable for additional testing at a NASA center as well as a detailed report of testing and development demonstrating TRL 4.

#### Extra-Vehicular Activity Technology Topic H4

Extra-Vehicular Activity (EVA) system technology advancements are required to enable forecasted microgravity and planetary human exploration mission scenarios and to support potential extension of the International Space Station (ISS) mission beyond 2020. Advanced EVA systems include the space suit pressure garment systems; the portable life support system (PLSS); the power, avionics and software systems including communications, controls, and informative displays; the common suit system interfaces; and airlock alternatives in varying host vehicles. More durable, longer-life and higher-reliability technologies for Lunar and Martian environment service as well as those suitable for working on and around near earth asteroids (NEAs) are needed, as are technologies that enable the range and difficulty of tasks beyond those experienced to date to encompass those anticipated for exploration, with improved comfort and productivity, less fatigue and lower injury risk. Reductions in commodity and life-limited part consumption rates and the size/weight/power of worn systems are needed. 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

Space suit pressure garment and airlock technology advancements are needed to accomplish future human space exploration missions and support ISS operations. EVA and crew survival pressure garments are addressed in this subtopic. Exploration destinations include deep-space microgravity objectives such as near-earth asteroids and Mars moons as well as lunar and Martian surface objectives involving gravitational forces and local environments. Innovative space suit technologies that improve performance and prevent injuries, extend service life and eliminate or reduce overhead, provide better environmental protection, and reduce suit system mass are required to enable a robust and flexible exploration capability. Innovative airlock technologies that protect habitable environments and reduce operational and logistical overhead are required to integrate with deep space and surface EVA-hosting systems to enable and operationally optimize achievement of exploration objectives. Key innovations sought include, in priority order:

- Reduction of suit mass, emphasizing light-weight structural components and bearings and the use of multi-function materials to reduce environmental protection layers.
- Improved mobility for enhanced task performance that also reduces injury risk.
- Improved material durability and extended service life (time and cycles).
- Improved accommodation of crew size variations for a suit system and an individual crew member.
- Reduction of crew time for maintenance and logistical support.
- Improved protection from natural and induced environments including vacuum/atmosphere, thermal, loads and dynamics, radiation, plasma and conventional shock hazards.
- Includes thin atmosphere thermal protection.
- Elimination/reduction of dust-caused failure or degradation and intrusion/contamination of habitable volumes.
- Innovative data collection techniques to define and improve methods for the human-to-suit interface.
- Improved occupant thermal comfort management.

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- Improved ability to don and doff pressurized rear-entry suits.
  - Self-diagnosing and repair technologies for suit wear and damage.
  - Long-duration (week or longer) suited survival concepts, including nutrition delivery and hygiene maintenance.
  - Low power, consumable, overhead and light-weight airlocks.
  - Suitport designs reduce the impact to the pressure garment and crewmember (on-back mass during EVA).

#### Lightweight Spacecraft Materials and Structures Topic H5

The SBIR topic area of Lightweight Spacecraft Materials and Structures centers on developing lightweight structures and advanced materials technologies for enabling launch vehicles and spacecraft for the Human Exploration Missions. Lightweight structures and advanced materials have been identified as a critical need since the reduction of structural mass translates directly to additional up and down mass capability in exploration missions. The technology drivers are:

- Lower mass.
- Improve efficient packaging of launch volume.
- Improve performance to reduce risk and extend life.
- Improve manufacturing and processing to reduce costs.

Applications are expected to include space exploration vehicles including launch vehicles, crewed vehicles and habitat systems, and in-space transfer vehicles. The focus areas targeted in this topic are:

- Additive Manufacturing of Lightweight Metallic Structures.
- Deployable Structures.
- Advanced Fabrication and Manufacturing of Polymer Matrix Composite (PMC) Structures.Hot Structures.

Metallic additive manufacturing (AM) technology builds near-net shape components one layer at a time using metal powder bed or wire fed processes and data from 3-D CAD models. This technology enables the direct fabrication of net or near-net shape components without the need for tooling and with minimal or no machining thereby reducing component lead-time, manufacturing cost, and material waste. The purpose of the Additive Manufacturing of Lightweight Metallic Structures subtopic is to invest in mid- and long-term research to establish rigorous, systematic, scalable, and repeatable verification and validation methods for additive manufacturing (AM) using the EBF3 system. Nearly all spacecraft flown to date are powered by deployable solar arrays, having up to 100 m<sup>2</sup> of solar cell area and 25 kW of electrical power. NASA has a vital interest in developing much larger arrays over the next 20 years. The Deployable Structures subtopic seeks innovative structures and materials technologies and capabilities for the next generation of lightweight solar arrays beyond 50 kW. The subtopic area for Polymer Matrix Composite (PMC) Materials and Manufacturing concentrates on developing lightweight structures, using advanced materials technologies and new manufacturing processes. The objective of the subtopic is to advance technology readiness levels of PMC materials and manufacturing for launch vehicles and in-space applications resulting in structures having affordable, reliable and predictable performance. The subtopic will address two areas, manufacturing of structures and highly damage-tolerant materials for use in cryogenic environments. NASA has developed hot structure technology for several hypersonic vehicles. Significant reductions in vehicle weight can be achieved with the application of hot structures, which do not require parasitic thermal protection systems (TPS). The most significant technical issue that must be addressed in hot structure design is the development of cost effective, environmentally durable and manufacturable material systems capable of operating at temperatures from 1500 °C to 3000 °C, while maintaining structural integrity. The Hot Structures subtopic seeks to develop innovative low cost, mass and structurally efficient high temperature materials for hot structures applications. The metrics and specific needs of each of these focus areas of technology development are described in the subtopic descriptions. 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 Additive Manufacturing of Lightweight Metallic Structures**

Lead Center: LaRC

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

The 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. Technologies developed under this subtopic are of interest to NASA programs such as Space Launch System (SLS), Multi-Purpose Crew Vehicle (MPCV), Orion, and commercial launch providers.

Metallic additive manufacturing (AM) technology builds near-net shape components one layer at a time using metal powder bed or wire fed processes and data from 3-D CAD models. Metallic AM technologies like Selective Laser Melting (SLM), Direct Metal Laser Sintering (DMLS), Electron Beam Freeform Fabrication (EBF3), and Laser Engineered Net Shaping (LENS) are of interest to NASA for fabrication of advanced metallic aerospace components and in-space fabrication and repair. These technologies enable the direct fabrication of net or near-net shape components without the need for tooling and with minimal or no machining thereby reducing component lead time, manufacturing cost, and material waste. Metallic AM also has the potential to enable novel product designs that could not be fabricated using conventional subtractive machining processes and extends the life of in-service parts through innovative repair methodologies. Currently, some metallic AM systems use sensors for process control but not for in-situ quality assurance (QA) or flaw detection.

The purpose of this subtopic is to invest in mid- and long-term research to establish rigorous, systematic, and scalable verification and validation methods for metallic AM. Beam tracking errors, part distortion, feedstock nozzle stand-off distance variability, excessive heat build-up in the deposit, stuck or unmelted feedstock, etc. can contribute to build deposit geometric anomalies and discontinuities. The objective would be to achieve a capability to have in-situ assessment during the deposition process to provide immediate feedback to the operator or a closed loop control system to enable real-time process correction or remedial actions to correct for defects. Although the technologies developed may be specific to one metallic AM system, it is desired that they have cross cutting capabilities to other metallic AM technologies. Proposals are invited that:

- Explore new and improved sensors and sensor systems for monitoring of the metallic AM build deposit.
- Offer technologies to use the signals generated by the energy beam (either electron beam or laser) or beam / substrate emissions for in-situ process monitoring and quality assurance.
- Propose additional devices to support real-time geometric part inspection and identification of flaws (voids, cracks, lack of fusion defects or other discontinuities).

Technologies should enable determination of the boundaries of the molten pool within 0.001" (in order to define the size and shape), measurement of temperature over the range from 700 °F to 3000 °F (representative of the molten pool and surrounding regions) to within 25 °F, measurement of geometric features to within +0.005", detect flaws in the range of 0.010 - 0.001", and determine chemical composition within 1 weight percent. Technologies should be compatible with standard high speed computer communication protocols and sensors should be able to update at frequencies on the order of 10 Hz. Highly desirable attributes are that technologies enable non-contact sensing and measurement, are vacuum compatible, and are relatively insensitive to contamination. Desirable attributes include that technologies are non-hazardous, do not require the use of additional consumables, and do not introduce contaminants into the process.

Research should be conducted to demonstrate technical feasibility in Phase I and show a path toward demonstration in Phase II of in-situ process monitoring and quality assurance. Phase II proposals should include delivery of a prototype system for test and evaluation in environments representative of NASA's metallic AM systems. Expected Technology Readiness Levels (TRL) at the completion of Phase I projects are 2-3 and 4-5 at the end of Phase II projects.

Links to information about NASA's additive manufacturing development projects can be found at:

- Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS).
  - (<http://www.nasa.gov/exploration/systems/sls/3dprinting.html> [3]).
- Electron Beam Freeform Fabrication (EBF3)
  - (<http://www.sciencedaily.com/releases/2009/11/091110071535.htm> [4]).
  - ([http://www.nmc.ctc.com/useruploads/file/events/PA\\_Karen\\_Taminger.pdf](http://www.nmc.ctc.com/useruploads/file/events/PA_Karen_Taminger.pdf) [5]).
- Laser Engineered Net Shaping (LENS).

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- (<http://www.sandia.gov/mst/pdf/LENS.pdf> [6]).

## H5.02 Deployable Structures

Lead Center: LaRC

Participating Center(s): GRC, JPL

Nearly all spacecraft flown to date are powered by deployable solar arrays, having up to 100 m<sup>2</sup> of solar cell area and 25 kW of electrical power. NASA has a vital interest in developing much larger arrays over the next 20 years with up to 4000 m<sup>2</sup> of deployed area (1 MW) for exploration missions using solar electric propulsion (SEP). Scaling up solar array deployed surface area by more than an order-of-magnitude will require game changing innovations. In particular, novel flexible-substrate designs are needed that minimize structural mass and packaging volume while maximizing deployment reliability, deployed stiffness, deployed strength, and longevity. Most of the mass savings in these very large future arrays will probably come from improvements to solar array supporting structures, not from improvements in the solar cells mounted on the arrays.

NASA is currently developing solar array systems for SEP in the 30-50 kW power range. This SBIR subtopic seeks innovative structures and materials technologies and capabilities for the next generation of lightweight solar arrays beyond 50 kW. Technologies are needed for the design and verification of large deployable solar arrays with:

- 200-400 m<sup>2</sup> of deployed area (50-100 kW) in 3-5 years.
- 400-1200 m<sup>2</sup> of deployed area (100-300 kW) in 5-10 years.
- 1200-4000 m<sup>2</sup> of deployed area (300-1000 kW) in 10-20 years.

These deployed areas are typically divided between two solar array wings, with each wing requiring half of the specified area.

This subtopic seeks innovations in the following areas for future large solar array structures:

- Novel design, packaging, deployment, and in-space manufacturing and assembly concepts.
- Lightweight, compact components including booms, ribs, substrates, and mechanisms.
- Validated modeling, analysis, and simulation techniques.
- Ground and in-space test methods.
- Load alleviation, damping, and stiffening techniques.
- High-fidelity, functioning laboratory models.

Nominal solar array requirements for large-scale SEP applications are:

- Mass specific power > 120 W/kg at beginning of life (BOL).
- Stowed volume specific power > 40 kW/m<sup>3</sup> BOL.
- Deployment reliability > 0.999.
- Deployed stiffness > 0.1 Hz.
- Deployed strength > 0.2 g (all directions).
- Lifetime > 5 years.

Variations of NASA's in-house large solar array concept referred to as the Government Reference Array (GRA) could be used for design, analysis, and hardware studies. Improved packaging, joints, deployment methods, etc. to enable GRA-type solar arrays up to 4000 m<sup>2</sup> in size (1 MW) with up to 250 W/kg and 60 kW/m<sup>3</sup> BOL are of special interest. The GRA is described in Reference 2.

In Phase I, contractors should prove the feasibility of proposed innovations using suitable analyses and tests. In Phase II, significant hardware or software capabilities should be developed and demonstrated to advance their Technology Readiness Level (TRL). TRLs at the end of Phase II of 3-4 or higher are desired.

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References:

- “Concept Design of High Power Solar Electric Propulsion Vehicles for Human Exploration”

([http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120000068\\_2011025608.pdf](http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120000068_2011025608.pdf) [7]).

- Pappa, R. S. et al., “Solar Array Structures for 300 kW-Class Spacecraft,” Presented at the Space Power Workshop, April 24, 2013.

### **H5.03 Advanced Fabrication and Manufacturing of Polymer Matrix Composite (PMC) Structures**

**Lead Center: MSFC**

**Participating Center(s): LaRC**

The subtopic area for Polymer Matrix Composite (PMC) Materials and Manufacturing concentrates on developing lightweight structures, using advanced materials technologies and new manufacturing processes. The objective of the subtopic is to advance technology readiness levels of PMC materials and manufacturing for launch vehicles and in-space applications resulting in structures having affordable, reliable and predictable performance. The subtopic will address two areas, manufacturing of structures and highly damage-tolerant materials for use in cryogenic environments. Proposals to each area will be considered separately. Areas of interest include: advances in PMC materials for large-scale structures and for in-space applications; innovative automated manufacturing processes (e.g., fiber placement); advanced non-autoclave curing; damage-tolerant/repairable structures; low-cost, durable tooling; high temperature PMC materials for high performance composite structures (high temperature applications); and materials with high resistance to micro cracking at cryogenic temperatures. Reliable, affordable, and practical joining techniques for large segmented composite structures are desired.

Lightweight structures and PMC materials have been identified as a critical need for launch vehicles since the reduction of structural mass translates directly to vehicle additional performance, reduced cost, and increased payload mass capacity. Reliable large-scale (approximately 8 meters or greater in diameter) PMC structures will be critical to the "heavy lift" of America's next-generation space fleet. The capability to transfer and store for long-term propellant, particularly cryogenic propellants in orbit, can significantly increase the nation's ability to conduct complex and extended exploration missions beyond Earth's orbit. The use of PMC materials for cryotanks offers the potential of significant weight savings. Applications include storage of cryogenic propellants on an Earth Departure Stage, a lunar or asteroid descent vehicle, long-term cryogen storage on the Moon, and propellant tanks for a heavy lift launch vehicle. Consideration shall be made for manufacturability in the sense of either using out of autoclave cure or autoclave cure and, in made in sections, novel and reliable approaches to join sections of composite structures to take advantage of the high strength to weight properties so that the joining methods do not significantly increase the complexity or weight of the overall structure. Novel approaches from cradle to grave will be considered in the sense that these very large structures required robust and lightweight tooling and transportation methods for minimal modifications to existing facilities and use of existing transportation or minimal modifications to such infrastructures.

Performance metrics for manufacturing structures include: achieving adequate structural and weight performance; manufacturing and life cycle affordability analysis; verifiable practices for scale-up; validation of confidence in design, materials performance, and manufacturing processes; low-cost, durable tooling; and quantitative risk reduction capability. Research should be conducted to demonstrate novel approaches, technical feasibility, and basic performance characterization for polymer matrix composite structures or low-cost, durable tooling during Phase I, and show a path toward a Phase II design allowables and prototype demonstration. Emphasis should be on demonstrable manufacturing technology that can be scaled up for very large structures.

Performance metrics for materials developed for cryotanks are: temperature-dependent material properties including strength, modulus, CTE, and fracture toughness; and demonstrated improved resistance over present SOA of multi-directional laminates to microcracking under cryogenic temperature cycling. Initial property characterization would be done at the coupon level in Phase I. Generation of design allowables, characterization of long-term material durability, and fabrication of larger panels would be part of follow-on efforts.

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High temperature polymer matrices for high performance composite structures (high temperature applications) with ease of manufacturing using the current composite manufacturing techniques.

#### **H5.04 Hot Structures**

**Lead Center: LaRC**

This subtopic seeks to develop innovative low cost, mass and structurally efficient high temperature materials for hot structures applications.

The National Aeronautics and Space Administration (NASA) has developed hot structure technology for several hypersonic vehicles. Significant reductions in vehicle weight can be achieved with the application of hot structures, which do not require parasitic thermal protection systems (TPS). The most significant technical issue that must be addressed in hot structure design is the development of cost effective, environmentally durable and manufacturable material systems capable of operating at temperatures from 1500 °C to 3000 °C, while maintaining structural integrity. The development of these durable and affordable material systems is critical to technology advances and to enabling future economical hypersonic vehicles. Atmospheric re-entry from cis-lunar space will push the boundaries of thermal structures system technical capabilities. Advanced hot structures are required to enable these future missions.

This subtopic seeks innovative technologies in the following areas:

- Light-weight, low-cost, composite material systems that include continuous fibers.
- Significant improvements of in-plane and thru the thickness mechanical properties, compared to current high temperature laminated composites.
- Decreased processing time and increased consistency for high temperature materials.
- Low conductivity, low thermal expansion, high impact resistance.
- High temperature performance improved with oxidation resistant coatings.

Overall looking for 20% or greater reduction in mass and an order of magnitude reduction in cost.

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

Phase I Deliverables – Test coupons and characterization samples for demonstrating the proposed approach to develop the hot structure material product (TRL 2-3). Matrix of verification/characterization testing to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables – Test coupons and manufacturing demonstration unit for proposed material product. A full report of the material development process will be provided along with the results of the conducted verification matrix from Phase I (TRL 3-4). Opportunities and plans should also be identified and summarized for potential commercialization.

#### **Autonomous & 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

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spacecraft technology demonstrations performed to enable complex or long duration space missions. All of these flight applications will require unique advances in autonomy, 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, JSC

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:

- Mutli-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.

Proposals will mature technology from TRL 4 to TRL 5 or 6 by the end of Phase II work. Phase I proposals must demonstrate the viability of the maturation.

Proposal deliverables must include:

- Software (source code, build instructions, and dependencies are ideal, but binaries may be acceptable under some circumstances).
- Software interface description documents, software architecture descriptions, and other documentation.
- Demonstrations of software systems on relevant applications.
- Quantification of software performance on relevant problems, documented in a report.

#### Entry, Descent, and Landing Technologies Topic H7

In order to explore other planets or return to Earth, NASA requires various technologies to facilitate entry, descent and landing. This topic, at this time, is supported by a single subtopic that calls for the development, modeling, testing, monitoring, and inspection of ablative thermal protection materials and/or systems that will support planetary entry. There is interest in ablative materials that can support aerocapture, requiring them to protect the spacecraft during two heating pulses. There is interest in developing flexible and/or deployable ablative materials. There is also interest in mid to high density composites that are capable replacements to chop-molded or tape-wrapped carbon phenolic composites that were used on Venus entry vehicles in the past. Work is needed on improved reinforcement materials for composites, as well as new formulations of polymers in composites. As new materials are developed, improved analytical tools are required to more accurately predict material response in entry conditions. Instrumentation for measuring the actual surface heating, in-depth temperatures, surface recession rates during testing and/or flight is required to verify the response of the materials and to monitor the health of flight hardware. Inspection of thermal protection material/aeroshell interfaces is critical to assure quality and is extremely difficult for porous, low density composites.

Sub Topics:

#### **H7.01 Advanced Thermal Protection Systems Technologies**

**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 or integration techniques such as joining or attachment for such materials as follows:
  - Advancements in carbon felts including thickness (>1.0-in), density (>0.10 g/cm<sup>3</sup>), 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. If advances in integration techniques are proposed, NASA may provide materials GFE to use in the development effort.
  - Advances in ceramic felts including thickness (>1.0-in) and uniformity to use as reinforcement for flexible TPS in heating up to ~150 W/cm<sup>2</sup>.

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- 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. If advances in integration techniques are proposed, NASA may provide materials GFE to use in the development effort.
  - TPS Materials advancements sought in felts or woven materials impregnated with polymers and/or additives to improve ablation and insulative 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/cm<sup>2</sup> (primarily convective) and integrated heat loads of up to 55 kJ/cm<sup>2</sup>, and the second at heat fluxes of 100-200 W/cm<sup>2</sup> and integrated heat loads of up to 25 kJ/cm<sup>2</sup>. 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/cm<sup>2</sup> and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 1.0 g/cm<sup>2</sup> 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/cm<sup>2</sup> (primarily convective) and integrated heat loads of 10 kJ/cm<sup>2</sup> and the second at heat fluxes of 30-50 W/cm<sup>2</sup> and heat loads of 5 kJ/cm<sup>2</sup>. 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/cm<sup>2</sup>, with radiation contributing up to 75% of that flux, and integrated heat loads from 75-150 kJ/cm<sup>2</sup>. 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/cm<sup>2</sup> and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 4.0 g/cm<sup>2</sup>, 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 6 mm, and bondline defect detection requirements are on the order of 25.4 mm by 25.4 mm 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.

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

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). Small samples and initial test data may be provided to demonstrate feasibility. Development of the 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 4-5). Opportunities and plans should also be identified and summarized for potential commercialization.

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## High Efficiency Space Power Systems Topic H8

This topic solicits technology for power systems to be used for the human exploration of space. Power system needs consistent with human spaceflight include:

- Fuel cells compatible with methane-fueled landers, and electrolyzers and fuel cells compatible with materials extracted from lunar regolith and/or the Martian soil or atmosphere.
- Nuclear fission systems to power electric spacecraft and/or surface space power systems.

Solid oxide technology is of interest for fuel cells and electrolyzers to enable:

- The operation of fuel cells using hydrocarbon reactants, including methane and fuels generated on-site at the Moon or Mars.
- Electrolysis systems capable of generating oxygen by electrolyzing CO<sub>2</sub> (from the Mars atmosphere, trash processing, life support, or volatiles released from soils), and/or water from either extraterrestrial soils or from life support systems.

Both component and system level technologies are of interest. Technologies to enable space-based nuclear fission systems are sought for three power classes:

- Kilowatt-class to support robotic missions as precursors to human exploration.
- 10 kWe-class power conversion devices and 400-500K radiators to support large surface power and 100 kWe-class electric propulsion vehicles.
- 100 kWe-class power conversion devices, >500K radiators, and high temperature fuels, materials, and heat transport to support MW-class electric vehicles.

Sub Topics:

### **H8.01 Solid Oxide Fuel Cells and Electrolyzers**

**Lead Center: GRC**

**Participating Center(s): JSC**

Solid oxide technology for fuel cells and electrolyzers to enable:

- The operation of fuel cells using hydrocarbon reactants, including methane and ISRU-generated fuels.
- Electrolysis systems capable of electrolyzing CO<sub>2</sub> from the Mars atmosphere, and/or water from the Mars surface to generate oxygen, or to recover oxygen from CO<sub>2</sub> and water from crew respiration for life support.

Both component and system level technologies are of interest.

Technologies are sought that improve the durability, efficiency, and reliability of solid oxide fuel systems capable of internal reforming of hydrocarbon fuels. Hydrocarbon fuels of interest include methane and fuels generated by processing lunar and Mars soils. Primary solid oxide components and systems of interest are:

- Solid oxide cell, stack, materials and system development for operation on unreformed methane in designs scalable to 1 to 3 kW at maturity. There is a strong preference for high power density configurations, e.g., planar.
- Solid oxide cells and stacks must startup with a minimal amount of water and then be capable of sustained operation on pure methane.
- Development of hermetic sealing materials for ceramic to ceramic interconnect or ceramic to metal interconnect stacks capable of thermal cycling. Data for the proposed seals materials and sealing scheme/design should be included in the proposal.

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- Development of catalysts for direct internal reforming of methane. Provide single cell performance data on dry methane for the one or more of the proposed anode compositions.

Proposed technologies should demonstrate the following characteristics:

- Systems are expected to operate as specified after at least 20 thermal cycles during Phase I and the heat up rate must be stated in the proposal.
- The developed systems are expected to operate as specified after at least 500 hours of steady state operation on propellant-grade methane and oxygen with 2500 hours expected of a mature system. System should startup “dry” or with a minimal amount of water, but after reaching operating conditions an amount of water/H<sub>2</sub> consistent with what can be obtained from anode recycle can be used. Amounts must be justified in the proposal.
- Minimal cooling required for power applications. Cooling in the final application will be provided by means of conduction through the stack to a radiator exposed to space and/or by anode exhaust flow.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration. Emphasis should be on demonstrating technical feasibility, prototype hardware (2-4 cell stacks preferred), conceptual designs and implementation approaches.

## **H8.02 Space Nuclear Power Systems**

**Lead Center: GRC**

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

NASA is developing fission power system technology for future space exploration applications using a stepwise approach. Initial small fission systems are envisioned in the 1 to 10 kWe range that utilize cast uranium metal fuel and heat pipe cooling coupled to static or dynamic power conversion. Follow-on systems could produce 10s or 100s of kilowatts utilizing a pin-type uranium fueled reactor with pumped liquid metal cooling, dynamic power conversion, and high temperature radiators. The anticipated design life for these systems is 8 to 15 years with no maintenance. Candidate mission applications include power sources for robotic precursors, human outposts on the moon or Mars, and nuclear electric propulsion (NEP) vehicles. NASA is planning a variety of nuclear and non-nuclear system ground tests 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.

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 testing. Specific areas for development include:

- 800-1000 K heat transport technology for reactor cooling (liquid metal heat pipes, liquid metal pumps).
- 1-10 kWe-class power conversion technology (thermoelectric, Stirling, Brayton).
- 400-500 K heat rejection technology for waste heat removal (water heat pipes, composite radiators, water pumps).

The early systems are 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. Specific areas for development include:

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

Expected deliverables include monthly and final reports, analytical models, and experimental hardware. Phase I activities should focus on analytical validation of technical feasibility including conceptual designs and trade studies with supporting coupon/component level testing. Phase II activities should emphasize experimental testing using prototype hardware in a subsystem context under relevant operating conditions to demonstrate technology

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readiness.

### Space Communications and Navigation (SCaN) 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 asset's 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, reprogrammable communications systems and flight dynamics. 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: (<https://www.spacecomm.nasa.gov/spacecomm/> [8]).

Sub Topics:

#### **H9.01 SCaN Testbed (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 Space Communications and Navigation (SCaN) Testbed Project provides SBIR recipients 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 SCaN 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 NASA Space Network, White Sands Complex. Unique experimenter ground hardware equipment may also be used. For the flight system on-orbit, experiments will consist of software/firmware provided to NASA by the SBIR

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recipient. This call will not provide a means to develop nor fly any new hardware in space.

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:

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

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 SCaN Testbed system and STRS Architecture may be found at the following link:

<http://spaceflight systems.grc.nasa.gov/SpaceOps/CoNNeCT/> [9]).

These documents will provide an overview of the SCaN Testbed 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 control 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 SCaN Testbed ground-based SDR platforms and conduct their flight system experiment. Opportunities and plans should also be identified and summarized for potential

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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.
- 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).
- Plan and approach for Commercialization of the technology (part of final report).

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 SCaN Testbed breadboards and engineering models.
- Software/firmware application source and binary code (including test software) 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. Documentation of development tool chain and procedure to build files.
- Results of implementing the Commercialization Plan outlined in Phase I.

## H9.02 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

This subtopic seeks innovative technologies for long range Interplanetary Optical Telecommunications supporting the needs of space missions where robotic explorers will visit distant bodies within the solar system and beyond. Our goals are increased data-rate capability in both directions, in conjunction with significant reductions of mass, power-consumption, and volume at the spacecraft. 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 and spacecraft micro-vibration environment (TRL3 Phase I, and TRL4 Phase II).

- *Vibration Isolation and Rejection Platforms and Related Technologies* - Compact, lightweight, space qualifiable vibration isolation and rejection platforms for payloads with a mass between 3 and 20 kg that require less than 5 W of power and have a mass less than 3 kg that will attenuate an integrated spacecraft micro-vibration angular disturbance of 150 micro-radians to less than 0.5 micro-radians (1-sigma), from < 0.1 Hz to ~500 Hz (TRL3 Phase I, and TRL4 Phase II). Also, innovative low-noise, low mass, low power, DC-kHz inertial, angular, position, or rate sensors. Compact, ultra-low-power, low-mass, kHz bandwidth, tip-tilt mechanisms with sub-micro-radian pointing accuracies, angular ranges of  $\pm 5$  mrad and supporting up to 50 gram payloads.
- *Laser Transmitters* - Space-qualifiable, >25% DC-to-optical (wall-plug) efficiency, 0.2 to 16ns pulse width 1550-nm laser transmitter for pulse-position modulated (PPM) data with random pulses at duty cycles of 0.3% to 6.25%, <35ps pulse rise and fall times and jitter, <25% pulse-to pulse energy variation (at a given pulse width) near transform limited spectral width, single polarization output with at least 20 dB polarization extinction ratio, amplitude extinction ratio greater than 45dB, average power of 5 to 20W, massing less than 500 g/W. Laser transmitter to feature slot-serial PPM data input at CML or AC-coupled PCEL levels and an

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RS-422 or USB control port. All power consumed by control electronics will be considered as part of DC-to-optical efficiency. Also of interest for the laser transmitter is robust and compact packaging with >100krad radiation tolerant electronics inherent in the design. Detailed description of approaches to achieve the stated efficiency is a must (TRL3 Phase I, TRL4 Phase II).

- *Photon Counting Near-infrared Detectors Arrays for Ground Receivers* - Readout electronics and close packed (not lens-coupled) kilo-pixel arrays sensitive to 1520 to 1650 nm wavelength range with single photon detection efficiencies greater than 90%. Single photon detection jitters less than 40 picoseconds 1-sigma, active diameter greater than 500 microns, 1 dB saturation rates of at least 10 mega-photons (detected) per pixel, false count rates of less than 1 MHz/square-mm, all at an operational temperature > 1.2K.
- *Photon Counting Near-infrared Detectors Arrays for Flight Receivers* - 64x64 or larger array with integrated read-out integrated circuit for the 1030 to 1080 nm or 1520 to 1650 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation loss rates of at least 2 mega-photons/pixel and operational temperatures above 220K and dark count rates of <10 MHz/mm. Radiation doses of at least 5 Krad (unshielded) shall result in less than 10% drop in single photon detection efficiency and less than 2X increase in dark count rate.
- *Ground-based Telescope Assembly* - Ground station telescope/photon-bucket technologies for developing effective aperture diameter of e10 meter at modest cost. Operations wavelength is monochromatic at a wavelength in the range of 1000-1600nm. Key requirements: a maximum image spot size of <20 micro-radian; capable of operation while pointing to within 5° of the Sun; and field-of-view of >50 micro-radian. Telescope shall be positioned with a two-axis gimbal capable of <50 micro-radian pointing accuracy, with dynamic error <10 micro-radian RMS while tracking after tip-tilt correction.

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

References:

- (<http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/42091/1/11-1338.pdf> [10])
- ([http://ipnpr.jpl.nasa.gov/progress\\_report/42-183/183A.pdf](http://ipnpr.jpl.nasa.gov/progress_report/42-183/183A.pdf) [11])
- ([http://ipnpr.jpl.nasa.gov/progress\\_report/42-185/185D.pdf](http://ipnpr.jpl.nasa.gov/progress_report/42-185/185D.pdf) [12])
- ([http://ipnpr.jpl.nasa.gov/progress\\_report/42-182/182C.pdf](http://ipnpr.jpl.nasa.gov/progress_report/42-182/182C.pdf) [13])

### **H9.03 Long Range Space RF Telecommunications**

**Lead Center:** JPL

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

This subtopic is focused on development of innovative deep space long-range and near-Earth RF telecommunications technologies supporting the needs of space missions.

In the future, robotic and human exploration spacecraft with increasingly capable instruments producing large quantities of data will be visiting the moon and the planets. These spacecraft will also support long duration 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. Concurrently, the downlink data rate demands from Earth science spacecraft will be increasing. 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 deep 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%. Due to the applicability of communication components and subsystems with science instruments such as radar, technologies that can benefit both RF communication and advanced instruments are within the scope of this subtopic.



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Technologies of interest:

- Ultra-small, light-weight, low-cost, low-power, modular deep space and near-Earth transceivers, transponders, amplifiers, 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 CW medium output power (10-15 W) and CW high-output power (15-35 W), 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).
- Solid-state multi-function modules that can be commanded to toggle between amplifying conventional digital modulation format signals for communications to pulsed operation for synthetic aperture radar (SAR) with resolution on the order of few meters.
- Ultra low-noise amplifiers (MMICs or hybrid, uncooled) for RF front-ends (< 50 K noise temperature).
- 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.
- Innovative packaging techniques that can lead to small size, light weight compact SSPAs with integrated heat extraction for thermal stability and reliability.

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.

#### **H9.04 Flight Dynamics GNC Technologies and Software**

**Lead Center: GSFC**

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

NASA is investing in re-engineering its suite of tools and facilities that provide guidance, navigation, and control (GNC) services for the design, development, and operation of near-Earth and interplanetary missions. This solicitation seeks proposals that will develop ground system algorithms and software for flight dynamics GNC technologies to support engineering activities from concept development through operations and disposal. This subtopic does not target on-board algorithms or software.

This solicitation is primarily focused on NASA's needs in the following focused areas:

- Addition of advanced guidance, navigation, and control improvements to existing NASA software.
- Replacement of heritage GNC software systems that are nearing obsolescence or improvement of their maintainability.
- Interface improvements, tool modularization, APIs, workflow improvements, and cross platform interfaces to existing NASA software.
- Applications of optimal control theory to high and low thrust space flight guidance and control systems.
- Numerical methods and solvers for robust targeting, and non-linear, constrained optimization.
- Applications of cutting-edge estimation techniques to spaceflight navigation problems.

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- Applications of cutting-edge guidance and control techniques to space trajectories.
  - Applications of advanced dynamical theories to space mission design and analysis, in the context of unstable orbital trajectories in the vicinity of small bodies and libration points.

Proposals that could lead to the replacement of the Goddard Trajectory Determination System (GTDS), or leverage state-of-the-art capabilities already developed by NASA such as the General Mission Analysis Tool ([gmatcentral.org](http://gmatcentral.org) [14]), GPS-Inferred Positioning System and Orbit Analysis Simulation Software, (<http://gipsy.jpl.nasa.gov/orms/goa/> [15]), Optimal Trajectories by Implicit Simulation ([otis.grc.nasa.gov](http://otis.grc.nasa.gov) [16]) are especially encouraged. Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

Technologies and software should support a broad range of spaceflight customers. Those that are 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 here.

Phase I efforts shall demonstrate technical and cost feasibility at the TRL 3 level and provide a plan for completion of the effort in Phase II. Preliminary software, algorithms, and documentation shall be delivered to NASA for evaluation.

With the exception listed below for heritage software modifications, Phase II new technology development efforts shall deliver components at the TRL 5-6 level with mature algorithms and software components complete and preliminary integration and testing in an operational environment. For efforts that extend or improve existing NASA software tools, the TRL of the deliverable shall be consistent with the TRL of the heritage software. Note, for some existing software systems (see list above) this requires delivery at TRL 8. Final software, test plans, test results, and documentation shall be delivered to NASA.

## **H9.05 Advanced Celestial Navigation Techniques and Systems for Deep-Space Applications**

**Lead Center: GRC**

**Participating Center(s): GSFC**

NASA is seeking proposals to develop advanced celestial navigation techniques and system in support of deep-space missions. Advances in positioning, attitude estimation, orbit determination, time and frequency keeping and dissemination and orbit determination are sought. System and sub-system concepts should support significant advances of independence from Earth supervision including the ability to operate effectively in the absence of Earth-based transmissions or transmissions from planetary relay spacecraft while minimizing spacecraft burden by requiring low power and minimal mass and volume. While system concepts that operate in the complete absence of human intervention or Earth-based transmissions are preferred, testing and verification of proposed systems performance will, necessarily, include Earth-based systems.

Operation during all phases of mission operations, including cruise phase, orbit phase and circularization phases are of interest. An application of interest is to enable open-loop (i.e., beaconless) pointing of high rate optical communications terminals to earth terminals. Methods and systems should be sufficient accuracy to support this capability; however, concepts which are capable of supporting planetary missions of any type are of interest.

Subjects appropriate for this sub-topic include, but are not limited to:

- Advanced methods and sensors for optical/IR detection of star fields (i.e., star cameras).
- Advanced methods and sensors detecting RF and x-ray pulsars.
- Methods to process celestial observations to perform Orbit Determination (OD) and precision attitude estimation.

Proposals to develop Artificial Intelligence methods (e.g., supervisory control) should identify gaps in the knowledge base that are particular to the use of advanced celestial methods, unique to the deep space navigation problem. User spacecraft impact is of significant importance and proposed solutions include assessments of mass, power, thermal impact on targeted mission spacecraft. Current and past mission spacecraft may be used as paradigms.

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Proposals that include re-purposing/cross-purposing of advanced sensors contemplated for future deep-space missions such as x-ray telescopes are preferred.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware and software demonstration unit or software package for NASA testing at the completion of the Phase II contract. Deliverables must include a phased testing, verification and validation plan. Plans that include graduated flight testing are preferred.

#### Ground Processing & 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 (ISS); 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 astronauts. Activities include ground-based and in-flight processing and operations tasks, along with support that ensures these tasks are accomplished efficiently and accurately, and enable 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 ISS for both in-situ research and as a test bed for development of improved space exploration technologies. 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 test in at the completion of the Phase II contract and, if possible, demonstrate earth based uses or benefits.

Sub Topics:

#### **H10.01 Recycling/Reclamation of 3-D Printer Plastic for Reuse**

**Lead Center: MSFC**

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

The subtopic seeks to develop innovative concepts to support the development of recycling/reclaiming technologies for Acrylonitrile Butadiene Styrene (ABS) plastic parts in space, thus providing viable solutions for self-sustained additive manufacturing capability with plastic materials.

As the National Aeronautics and Space Administration (NASA) destinations push farther beyond the limits of low Earth orbit, the convenience of fabricating components and equipment on the ground to quickly resupply missions will no longer be a reasonable option. Resupply is difficult during deep space missions; it requires a paradigm shift in the way the Agency currently relies on an Earth-based supply chain for spares, maintenance, repair, and hardware design models, including those currently on the International Space Station (ISS). With the ISS program extension, there is a high likelihood of necessary replacement parts. This is a unique opportunity to begin changing the current model for resupply and repair to prepare and mature technology for deep space exploration missions.

3-D printing, formally known as "Additive Manufacturing", is the method of building parts layer-by-layer from data files such as Computer Aided Design models. Data files with tool and part schematics can be pre-loaded onto the device before a launch, or up-linked to the device while on-orbit. 3-D printers currently scheduled for on-board ISS use will employ extrusion-based additive manufacturing, which involves building an object out of plastic deposited by the melting of feedstock by an extruder head. The plastic extrusion additive manufacturing process is a low-energy, low-mass solution to many common needs on board the ISS.

The 3-D Printing in Zero-G "3-D Print" Technology Demonstration and the Additive Manufacturing Facility (AMF)

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plan to utilize the commercial 3-D printing standard 1.75mm ABS filament as feedstock on ISS. To truly develop a self-sustaining, closed-loop on-orbit manufacturing process that will result in less mass to launch and increased on-demand capability in space, a means of recycling and reclaiming the feedstock is required. This SBIR seeks technologies that can take ABS parts analogous to those which could be printed on ISS (maximum size of 6cm x 12 cm x 6 cm) and demonstrate recycling/reclamation capability of the part back into 1.75mm filament feedstock.

This subtopic seeks innovative technologies in the following areas:

- ABS part reclamation - decomposing a plastic part (maximum size of 6 cm x 12 cm x 6 cm) and reconstitution into 1.75mm ( $\pm 0.1$ mm) diameter wire spools, pellets, or other forms that can be fed into an extrusion device.
- Production of recycled plastic filament while maintaining repeatable, consistent filament diameter of 1.75mm with  $\pm 0.1$ mm tolerance.
- Methods to avoid bulging of feedstock as the filament is created.
- Gravity-independent filament spooling capability: drawing the filament onto a feedstock spool as it is being created without relying on gravity to guide the filament. Goal for spool dimension should be 156mm OD, 48mm ID, 43mm wide.
- Environmental containment for Foreign Object Debris (FOD) and material off-gassing.

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 for NASA testing at the completion of the Phase II contract. Demonstration of the Engineering Unit at the end of Phase II may lead to an opportunity for a Phase III contract for a Flight Unit.

Phase I Deliverables - Feasibility study with proposed path forward to develop Engineering Unit in Phase II; study should address how the design will meet flight certification, safety requirements, and operational constraints for spaceflight; and bench top proof-of-concept, including samples and test data, proving the proposed approach to develop a given product (TRL 3-5).

Phase II Deliverables - Functioning Engineering Unit of proposed product, along with full report of development and test data (TRL 5-6).

## **H10.02 International Space Station (ISS) Utilization**

**Lead Center:** JSC

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

NASA continues to invest in the near- and mid-term development of highly-desirable systems and technologies that provide innovative ways to leverage existing ISS facilities for new scientific payloads and to provide on orbit analysis to enhance capabilities. Utilization of the ISS is limited by available up-mass, down-mass, and crew time as well as by the capabilities of the interfaces and hardware already developed and in use. Innovative interfaces between existing hardware and systems, which are common to ground research, could facilitate both increased and faster payload development and subsequent utilization. Technologies that are portable and that can be matured rapidly for flight demonstration on the International Space Station are of particular interest.

Desired capabilities that will continue to enhance improvements to existing ISS research hardware include, but are not limited to, the below examples:

- Providing additional on-orbit analytical tools. Development of instruments for on-orbit analysis of plants, cells, small mammals and model organisms including *Drosophila*, *C. elegans*, and yeast. Instruments to support studies of bone and muscle loss, multi-generational species studies and cell and plant tissue are desired. Providing flight qualified hardware that is similar to commonly used tools in biological and material science laboratories could allow for an increased capacity of on-orbit analysis thereby reducing the number of samples which must be returned to Earth.
- Technologies that determine microbial content of the air and water environment of the crew habitat falls

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within acceptable limits and 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). Technologies that show improvements in miniaturization, reliability, life-time, self-calibration, and reduction of expendables are also of interest.

- Providing a Magnet Processing Module (MPM) for installation and operations in the Materials Science Research Rack (MSRR) would enable new and improved types of materials science investigations aboard the ISS. Essential components of the MPM include an electromagnet, which can provide field strength up to 0.2 Tesla and a high temperature insert, which can provide directional solidification processing capability at temperatures up to 1500 °C.
- Increased use of the Light Microscopy Module (LMM). Several additions to the module continue to be solicited, such as: laser tweezers, dynamic light scattering, stage stabilization (or sample position encoding) for reconstructing better 3-D confocal images.
- Instruments that can be used as infrared inspection tools for locating and diagnosing material defects, leaks of fluids and gases, and abnormal heating or electrical circuits. The technology should be suitable for hand-held portable use. Battery powered wireless operation is desirable. Specific issues to be addressed include: pitting from micrometeoroid impacts, stress fractures, leaking of cooling gases and liquids and detection of abnormal hot spots in power electronics and circuit boards.

For the above, research should be conducted to demonstrate technical feasibility and prototype hardware development during Phase I and show a path toward Phase II hardware and software demonstration and delivering an engineering development unit or software package for NASA testing at the completion of the Phase II contract that could be turned into a proof-of-concept system which can be demonstrated in flight.

Phase I Deliverables - Written report detailing evidence of demonstrated prototype technology in the laboratory or in a relevant environment and stating the future path toward hardware and software demonstration on orbit. 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 - Emphasis should be placed on developing and demonstrating hardware and/or software prototype that can be demonstrated on orbit (TRL 8), or in some cases 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 an engineering development 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. All space radiation environments in which humans may travel in the foreseeable future are considered, including geosynchronous orbit, Moon, Mars, and the Asteroids. Advances are needed in mitigation schema for the next generation of exploration vehicles inclusive of radiation shielding systems 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 clear that the ability to mitigate the risks posed to both crews and vehicle systems by the space weather environment is also of central importance. Advances in radiation shielding systems technologies are needed to protect humans from all threats of space radiation. All particulate radiations are considered, including electrons, protons, neutrons, alpha particles, light ions, and heavy ions. This topic is particularly interested in mid-TRL (technology readiness level) technologies. Lightweight radiation shielding materials are needed to shield humans in aerospace transportation vehicles, large space structures, space stations, orbiters, landers, rovers, habitats, and spacesuits. The materials emphasis should be on non-parasitic radiation shielding materials, or multifunctional materials, where two of the functions are structural and radiation shielding. Non-materials solutions, such as utilizing food, water, and waste already on board as radiation shielding are also sought. A challenge of particular interest is to contain and use human waste as radiation shielding. Advanced computer codes are needed to model and predict the transport of radiation through materials and subsystems, as well as to predict the effects of radiation on the physiological performance, health, and well-being of humans in space radiation environments. Laboratory and spaceflight data are needed to validate the accuracy of radiation transport codes, as well as to validate the effectiveness of multifunctional radiation shielding materials and subsystems. Also of interest are comprehensive radiation shielding databases and design tools to enable designers to incorporate and optimize radiation shielding into space systems during the initial design phases. Research under this topic should be conducted to demonstrate

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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.

Reference: Wilson, John W.; Townsend, Lawrence W.; Schimmerling, Walter; Khandelwal, Govind S.; Khan, Ferdous; Nealy, John E.; Cucinotta, Francis A.; Simonsen, Lisa C.; Shinn, Judy L.; and Norbury, John W.: Transport Methods and Interactions for Space Radiations. NASA Reference Publication (RP) 1257, December 1991.

Sub Topics:

### **H11.01 Radiation Shielding Systems**

**Lead Center:** LaRC

**Participating Center(s):** MSFC

Advances in radiation shielding systems technologies are needed to protect humans from the hazards of space radiation during NASA missions. All space radiation environments in which humans may travel in the foreseeable future are considered, including low Earth orbit (LEO), geosynchronous orbit, Moon, Mars, and the Asteroids. All particulate radiations are considered, including electrons, protons, neutrons, alpha particles, and light to heavy ions up to iron. Mid-TRL (3 to 5) technologies of specific interest include, but are not limited to, the following:

- Innovative lightweight radiation shielding materials are needed to shield humans in aerospace transportation vehicles, large space structures such as space stations, orbiters, landers, rovers, habitats, and spacesuits. The materials emphasis should be on non-parasitic radiation shielding materials, or multifunctional materials, where two of the functions are structural and radiation shielding. Phase I deliverables are materials coupons. Phase II deliverables are materials panels or standard materials test specimens, along with relevant materials test data.
- Non-materials solutions, such as utilizing food, water, and waste already on board as radiation shielding. A challenge of particular interest is to contain and use human waste as radiation shielding. Phase I deliverables are detailed conceptual designs. Phase II deliverables are working prototypes.
- Advanced computer codes are needed to model and predict the transport of radiation through materials and subsystems. Advanced computer codes are needed to model and predict the effects of radiation on the physiological performance, health, and well-being of humans in space radiation environments. Comprehensive radiation shielding design tools are needed to enable designers to incorporate and optimize radiation shielding into space systems during the initial design phases. Phase I deliverables are alpha-tested computer codes. Phase II deliverables are beta-tested computer codes.
- Laboratory and spaceflight data are needed to validate the accuracy of radiation transport codes. Laboratory and spaceflight data are needed to validate the effectiveness of multifunctional radiation shielding materials and subsystems. Comprehensive radiation shielding databases are needed to enable designers to incorporate and optimize radiation shielding into space systems during the initial design phases. Phase I deliverables are draft data compilations or databases. Phase II deliverables are formal, publishable, and archival data compilations or databases.

#### 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> [17]) 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:

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- 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 addresses a subset of the risks, with ISS Medical Projects responsible for the implementation of the research on various space and ground analog platforms. With the exception of Space Radiation, HRP subtopics are aligned with the Elements and solicit technologies identified in their respective research plans.

Sub Topics:

## **H12.01 Next Generation Oxygen Concentrator for Medical Scenarios**

**Lead Center: GRC**

**Participating Center(s): JSC**

For exploration missions, a contingency system which concentrates the oxygen within the cabin environment and provides the required concentration of oxygen to the crewmember for various medical scenarios will be necessary. Oxygen concentration technology is being pursued to concentrate oxygen from the ambient environment so that oxygen as a consumable resource and the fire hazard of an elevated cabin oxygen atmosphere can be reduced. The goal of this project is to develop an oxygen concentration module that minimizes the hardware mass, volume, and power footprint while still performing at the required clinical capabilities.

An Oxygen Concentrator Module (OCM) with an adjustable positive pressure output 2-15 lpm of O<sub>2</sub> at 50% to >90% oxygen concentrations by volume has been recommended by the flight medical team. The unit must be able to operate continuously in microgravity and partial gravity exploration atmospheres that include the atmospheres of 14.7 psia/21% oxygen, 10.2 psia/26.5% oxygen, and 8.2 psia/34% oxygen by volume. The unit must run continuously on available spacecraft power, and be switchable between 28 VDC and 120 VDC. It must have adequate heat rejection so as to not exceed a touch temperature of 45°C. It is also highly desirable to have a portable low output capability for use in EVA pre-breathing or patient transfer between vehicles. Usage scenarios for oxygen treatment of smoke inhalation or toxic spills also predicated the need for an inlet filter on the unit that removes (converts/absorbs/filters) toxic gases from the delivered gas stream to the patient.

The OCM system should be capable of regulating the oxygenation of the patient using a closed loop feedback system that senses the oxygenation level of the patient tissues and adjusts the oxygen flow rate and/or oxygen concentration according to treatment protocols for the illness being treated. The system shall also be able to operate open loop in the event of feedback signal failure. The control variable(s) are not specified (rate/concentration) here since the basic unit's topology may dictate how the regulation is best achieved. Because the system may be configured during times of duress, it shall be user friendly to the caretaker by adopting a "plug and play" philosophy.

This SBIR Phase I development is to determine the architecture of such a system exhibiting the characteristics (high capacity flow range, closed-loop tissue oxygen control, and operations in microgravity or partial gravity exploration atmospheres), a description of the basic unit as a sub-system component, method of optimizing power over the range of flows and oxygen levels, redundancy and sparing for a long duration missions, and the relationship of the OCM system to caretaker (what does the caretaker need to do to fulfill the medical need?).

Phase I Requirements - Phase I should concentrate on developing the scientific, technical, and commercial merit and feasibility of the proposed innovation resulting in a feasibility report and concept, complete with analyses that discuss functionality in microgravity and at the proposed exploration atmospheres, algorithms for closed-loop oxygenation protocols, and inlet filtering of smoke or toxic gases.

NASA Deliverables - A concept for a microgravity and partial gravity exploration atmospheres oxygen concentrator with a closed loop oxygenation flow rate system with inlet filtering of potential toxic ambient gases.

HRP IRP Risk - Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities.

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## **H12.02 Inflight Calcium Isotope Measurement Device**

**Lead Center:** JSC

Bone loss in crewmembers is a major concern for long duration space flight. The ability to rapidly detect changes in bone mineral balance (BMB) in crewmembers living on ISS would have great potential as a surveillance tool for future exploration missions. Calcium isotopes have been shown to detect changes in BMB on very short timescales (e.g., one week). In order to detect these important changes, a technological device could be used in-flight. Thus, we are seeking a device (portable to bench top size) with the same accuracy and precision as is currently available in the non-flyable Multiple Collector Inductively Coupled Plasma mass spectrophotometer.

**Phase I Requirements** - The sensitivity required to make the Calcium isotope measurements would need to be approximately  $10^{12}$ - $10^{16}$  (i.e., this is how sensitive the machine should be for finding the Calcium isotope; it should be able to pick up one "atom" or unit in a pool of  $10^{16}$  other things). Systems that measure elemental composition typically have sensitivities around  $10^6$ - $10^9$  for some elements. The absolute concentrations of the isotopes are not required. We are looking for an instrument that can measure the variations in the ratio of any two Calcium isotopes on the order of 0.1-0.5 parts per 10,000 ( $^{44}\text{Ca}/^{42}\text{Ca}$ ) but could vary depending on the isotopes used. A successful proposal will include the technologies being considered and detailed test plan for evaluating them during Phase I.

**Phase I deliverables** - Test results and plan for developing a low volume, low mass, easy-to-operate prototype. TRL of 3 desired.

**Phase II deliverables** - Prototype in year 1 with sample testing against industry standard in year 2.

**HRP IRP Risk** - Risk of Early Onset Osteoporosis Due to Spaceflight

Technology Readiness Levels (TRL) of 4 to 5 or higher are sought upon completion of the project.

## **H12.03 Objective Sleep Measures for Spaceflight Operations**

**Lead Center:** JSC

Currently in spaceflight, crewmembers report their sleep duration as requested by their crew surgeon. This approach has several limitations, including the burden it places on the crew and the tendency for subjective over-reporting of sleep (Lauderdale et al., 2008; Van Den Berg et al., 2008; Silva et al., 2007). Given evidence that demonstrates the relationship between sleep and circadian phase and performance, sleep-activity data should be collected as unobtrusively possible during long duration spaceflight. Wrist-worn actigraphy has been implemented as a successful, validated research tool in spaceflight but lacks features to render it a useful tool operationally, such as real-time feedback and minimal crew time requirements. Hence, there is a need for a minimally obtrusive or unobtrusive measure that evaluates sleep-wake activity plus light exposure; is acceptable for continuous wear; minimizes crew time by allowing for automatic downloads; provides immediate feedback to the user; incorporates the constraints of spaceflight hardware, such as extended battery life; and potentially incorporates other features, including other physiological sensors. The proposed technology should build on existing technologies with a focus on enhancing the product to ensure spaceflight readiness.

**Requirements** - Phase I should concentrate on the enhancement of a prototype device providing minimally obtrusive data collection that objectively measures sleep duration and other relevant characteristics in the spaceflight environment. Phase II should also yield a plan for continued development (if needed) and for validation of the device prior to spaceflight implementation.

**NASA Deliverables** - An objective, validated measure of sleep that is feasible and acceptable in the spaceflight environment.

**HRP IRP Risk** - Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness and Work Overload.

A TRL Start of 3-4 with a TRL End of 7-8 (at the end of Phase II) is desired for this project.



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## H12.04 Advanced Food 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 foods with a shelf life of five years will be required to support the crew. Concurrently, the food system requirements must efficiently balance with their use of vehicle resources such as mass, volume, water, air, waste, power, and crew time.

NASA provisions currently consist solely of shelf stable foods due to vehicle resource limitations preventing food refrigeration or freezing. Stability is achieved by thermal, irradiative processing, or drying to kill or prevent microorganism growth in the food. These methods coupled with environmental factors (such as moisture ingress and oxidation) impact the micronutrients within the food. Since the food system is the sole source of nutrition to the crew, a significant loss in nutrient availability could jeopardize the health and performance of the crew.

This subtopic requests methods or technologies that enable development of an acceptable and safe food system to deliver appropriate amounts of bioavailable nutrients to crewmembers throughout a five year mission with no resupply. Vitamin content in NASA foods, such as vitamin C, vitamin K, thiamin, and folic acid, are key nutrients degraded during processing and storage. NASA is seeking novel food ingredients, protective or stabilizing technologies (e.g., encapsulation), controlled-release systems, or novel processing technologies that allow the delivery of key nutrients at the time of consumption. Consideration must be given to food safety as well as acceptability, as under-consumption will similarly lead to nutritional deficiencies.

Deliverables - Feasibility demonstration of a novel food system approach with the potential to enable vitamin stability in an acceptable and safe food system for extended duration missions. Phase I should include a comprehensive report detailing the system feasibility, and show a clear path to Phase II development and analyses, with the expectation that Phase II will demonstrate that the food system will retain 70% of original content of vitamin C, vitamin K, thiamin, or folic acid over five years of ambient temperature storage. Phase II should deliver the innovation in a form that can be tested in NASA's food system.

HRP IRP Risk - Risk of Inadequate Food System.

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

### Non-Destructive Evaluation Topic H13

Future manned space missions will require technologies that enable detection and monitoring of the space flight vehicles during deep space missions. Development of these systems will also benefit the safety of current missions such as the International Space Station and Aerospace as a whole. Technologies sought under this SBIR Topic can be defined as advanced sensors, sensor systems, sensor techniques or software that enhance or expand NASA's Nondestructive Evaluation (NDE) and Structural Health Monitoring (SHM) capability beyond the current State of the Art. Sensors and Sensor systems sought under this topic can include but are not limited to techniques that include the development of quantum, meta- and nano sensor technologies for deployment. Technologies enabling the ability to perform inspections on large complex structures will be encouraged. Technologies should provide reliable assessments of the location and extent of damage. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who need to make important assessments quickly. Examples of structural components that will require sensor and sensor systems are multi-wall pressure vessels, batteries, thermal tile, thermal blankets, micrometeoroid shielding, International Space Station (ISS) Radiators or aerospace structural components. SHM technologies and integrated vehicle health management (IVHM) systems and analysis tools can include both active and passive SHM systems. Techniques sought include modular/low mass-volume systems, low power, low maintenance systems, and systems that reduce or eliminate wiring, as well as stand-alone smart-sensor systems that provide processed data as close to the sensor as practical and systems that are flexible in their applicability. Damage detection modes include leak detection, ammonia detection, micrometeoroid impact and others. Reduction in the complexity of standard wires and connectors and enabling

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sensing functions in locations not normally accessible with previous technologies is also desirable. Examples of space flight hardware will include light weight structural materials including composites and thin metals. Consideration will be given to the all system ability operate and survive in on-orbit and deep space.  
Sub Topics:

### **H13.01 Advanced NDE Techniques for Complex Built Up Structures**

**Lead Center:** LaRC

**Participating Center(s):** AFRC, GRC, GSFC, JSC, MSFC

Technologies sought under this SBIR program can be defined as advanced sensors, sensor systems, sensor techniques or software that enhance or expand NASA's current sensor capability. It is considered to be advantageous but not necessary to target structural components of space flight hardware. In a general sense space flight hardware will include light weight structural materials including composites and thin metals.

Technologies sought include modular smart advanced NDE sensors systems and associated capture and analysis software. It is advantageous for techniques to include the development on quantum, meta- and nano sensor technologies for deployment. Technologies enabling the ability to perform inspections on large complex structures will be encouraged. Technologies should provide reliable assessments of the location and extent of damage. Methods are desired to perform inspections in areas with difficult access in pressurized habitable compartments and external environments for flight hardware. Many applications require the ability to see through assembled conductive and/or thermal insulating materials without contacting the surface. Techniques that can dynamically and accurately determine position and orientation of the NDE sensor are needed to automatically register NDE results to precise locations on the structure. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who need make important assessments quickly. NDE inspection sensors are needed for potential use on free-flying inspection platforms. Integration of wireless systems with NDE may be of significant utility. It is strongly encouraged to provide explanation of how proposed techniques and sensors will be applied to a complex structure. Examples of structural components include but are not limited to multi-wall pressure vessels, batteries, tile, thermal blankets, micrometeoroid shielding, International Space Station (ISS) Radiators or other aerospace structural components.

Phase I Deliverables - Lab prototype, feasibility study or software package including applicable data or observation of a measurable phenomena on which the prototype will be built. Inclusion of a proposed approach to develop a given methodology to Technology Readiness Level (TRL) of 2-4. All Phase I's will include minimum of short description for Phase II prototype. It will be highly favorable to include description of how the Phase II prototype or methodology will be applied to structures.

Phase II Deliverables - Working prototype or software of proposed product, along with full report of development and test results. Prototype or software of proposed product should be of Technology Readiness Level (TRL 5-6). Proposal should include plan of how to apply prototype or software on applicable structure or material system. Opportunities and plans should also be identified and summarized for potential commercialization.

### **H13.02 Advanced Structural Health Monitoring**

**Lead Center:** LaRC

**Participating Center(s):** AFRC, ARC, GRC, GSFC, JSC, MSFC

Future manned space missions will require spacecraft and launch vehicles that are capable of monitoring the structural health of the vehicle and diagnosing and reporting any degradation in vehicle capability. This subtopic seeks new and innovative technologies in structural health monitoring (SHM) and integrated vehicle health management (IVHM) systems and analysis tools.

Techniques sought include modular/low mass-volume systems, low power, low maintenance systems, and systems that reduce or eliminate wiring, as well as stand-alone smart-sensor systems that provide processed data as close to the sensor as practical and systems that are flexible in their applicability. Examples of possible system are: Surface Acoustic Wave (SAW)-based sensors, passive wireless sensor-tags, flexible sensors for highly curved surfaces direct-write film sensors, and others. Damage detection modes include leak detection, ammonia detection, micrometeoroid impact and others. Reduction in the complexity of standard wires and connectors and enabling

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sensing functions in locations not normally accessible with previous technologies is also desirable. Proposed techniques should be capable of long term service with little or no intervention. Sensor systems should be capable of identifying material state awareness and distinguish aging related phenomena and damage related conditions. It is considered advantageous that these systems perform characterization of age-related degradation in complex composite and metallic materials. Measurement techniques and analysis methods related to quantifying material thermal properties, elastic properties, density, microcrack formation, fiber buckling and breakage, etc. in complex composite material systems, adhesively bonded/built-up and/or polymer-matrix composite sandwich structures are of particular interest. Some consideration will be given to the IVHM /SHM ability to survive in on-orbit and deep space conditions, allow for additions or changes in instrumentation late in the design/development process and enable relocation or upgrade on orbit. System should allow NASA to gain insight into performance and safety of NASA vehicles as well as commercial launchers, vehicles and payloads supporting NASA missions. Inclusion of a plan for detailed technical operation and deployment is highly favored.

Phase I Deliverables - Lab prototype or feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 2-4). Plan for Phase II including proposed verification methods.

Phase II Deliverables - Working engineering model or software of proposed product, along with full report of development and test results, including verification methods (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

#### In-Situ Resource Utilization - Mars Atmosphere/Gas Chemical Processing Topic H1.01

In-Situ Resource Utilization (ISRU) involves collecting and converting local resources into products that can reduce mission mass, cost, and/or risk of human exploration. ISRU products that provide significant mission benefits with minimal infrastructure required are propellants, fuel cell reactants, and life support consumable. Innovative technologies and approaches are sought related to ISRU processes associated with collecting, separating, pressurizing, and processing gases collected from in-situ resources including the Mars atmosphere, trash processing, and volatiles released from in-situ soil/regolith resources, into oxygen, methane, and water. State of the art (SOA) technologies for these ISRU processes either do not exist or are too complex, heavy, inefficient, or consume too much power. The innovative technologies and process sought must operate in low and micro-gravity environments, must be scalable from low demonstration processing and production flow rates of 0.045 kg/hr of carbon dioxide (CO<sub>2</sub>) and 0.015 kg/hr of oxygen (O<sub>2</sub>) to utilization flow rates of 2.25 kg/hr for CO<sub>2</sub> and 0.75 kg/hr for O<sub>2</sub>. Chemical processing technologies must operate between 15 to 75 psia.

Technologies of specific interest include:

- Regenerative dust filtration, especially Mars dust, that is: scalable, has minimum pressure drop, can operate at low inlet pressures, and provides 99% @ 0.3 um collection efficiency, with >95% regeneration capability for multiple cleaning cycles. SOA filters are replaced by the crew or sized for the complete mission. Since Mars ISRU operations will occur without a crew present and between 100 and 480 days in duration, cleaning and regeneration of filtration approaches is required.
- Dust/particle measurement device that allows for size and particle density measurements before and after filtration. Optional additional capabilities including electrostatic and or mineral characterization are also of interest. Dust measurement devices must integrate into limited volume areas and interface with atmosphere-inlets/trash processing outlet tubing.
- Lightweight, low-power device to deliver fresh Mars 'air' (0.1 psia) to the plant with small head pressure capability (10's torr). SOA blowers currently do not exist which can effectively move the low pressure Mars atmosphere efficiently (power and mass) for long-periods of time. Thermal management and/or use must be clearly defined for proposed devices.
- Lightweight, lower power device to collect and pressurize CO<sub>2</sub> from 0.1 psia to >15 psia; maximum 75 psia. SOA mechanical compressors are heavy, power intensive, and have limited life. Mars atmosphere CO<sub>2</sub> collection devices will need to operate for a minimum of 100 days and up to 480 days. Thermal management and/or use must be clearly defined for proposed devices.
- High throughput water separation from gas streams. SOA devices utilize water tanks and chillers which are potentially large, heavy, and power intensive. Highly efficient, low power, and compact membrane and adsorption based separation devices allowing for very low dew point exhaust are sought.

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- High throughput carbon monoxide/carbon dioxide separation and recycling concepts for processes with only partial conversion of CO<sub>2</sub> into usable products. Highly efficient, low power, and compact membrane and adsorption based separation devices are sought with minimum pressure drop.
  - Highly efficient chemical reactors and heat exchangers based on modular/stackable microchannel plate architectures. SOA catalyst bed type reactors are inefficient in mass and volume and are not easily scalable to higher processing rates without reactor bed redesigns and thermal management changes. Thermal management and/or use must be clearly defined for proposed devices.

Proposals must identify and provide clear benefits compared to state of the art technologies and processes in the areas of mass, volume, and/or power reduction as well as define the expected impact of changing gravity orientation and strength. SOA for most processing technologies are terrestrial applications or space life support systems. Phase I proposals for innovative technologies and processes must include the design and test of critical attributes or high risk areas associated with the proposed technology or process. Phase II proposals must further Phase I efforts leading to the design, build, test, and delivery of hardware (at rates specified above) that can be integrated into breadboard ISRU systems for testing with other technologies and processes (Technology Readiness Level 4 to 6).

Sub Topics:

#### High Power Electric Propulsion Topic H2.01

The goal of this subtopic is to develop innovative technologies that can lead to high-power (>50 kW to MW-class) electric propulsion systems. High-power (high-thrust) electric propulsion (>50kW per thruster) may enable dramatic mass and cost savings for lunar and Mars cargo missions, including Earth escape and near-Earth space maneuvers. At very high power levels, electric propulsion may enable piloted exploration missions.

Innovations and advancements leading to improvements in the end to end performance of high power electric propulsion systems are of interest. Technologies are sought that increase system efficiency; increase system and/or component life or durability; reduce system and/or component mass, complexity, or development issues; or provide other definable benefits. In general, thruster system efficiencies exceeding 60% and providing total impulse values greater than 10<sup>7</sup>. Desired specific impulses range from a value of 2000 s for Earth-orbit transfers to over 6000 s for planetary missions.

Specific technologies of interest in addressing these challenges include:

- Electric propulsion systems and components for alternate fuels such as the use of in-situ resources, condensable or metal propellants, and alternatives to Xenon.
- Novel methods for fabricating large refractory metal parts with complex shapes, with integrated heat pipes. Particular figures of merit include low cost, rapid turnaround, and ability to incorporate internal flow passages.
- Long life cathodes for high power electrostatic or electromagnetic thrusters capable of extended operation at required temperature and current levels for appropriate mission durations.
- Innovative plasma neutralization concepts.
- Highly accurate flow controllers and fast acting valves for pulsed thruster systems High current (MA), high repetition rate (up to 1-kHz), long life (greater than 10<sup>9</sup> pulses) solid state switches for high power inductive pulsed plasma thrusters.
- High-temperature permanent magnets and/or electromagnets; low-voltage, high-temperature wire for electromagnets; superconducting magnets.

Note to Proposer: Subtopic S3.02 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.02.

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

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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.

Sub Topics:

In-Space Chemical Propulsion Topic H2.02

This solicitation intends to examine a range of key technology options associated with non-toxic storable liquid propulsion systems for use in future exploration missions. Efficient propulsive performance and long duration storage attributes have made the use of hydrazine widespread across the aerospace community. However, hydrazine is highly corrosive and toxic, creating a need for non-toxic, high performance propellants for NASA, other government agencies, academia, and the commercial space industry.

Non-toxic engine liquid mono- and bi-propellants technologies are desired for use in lieu of the currently operational hydrazine based engine technologies. Handling and safety concerns with the current toxic chemical propellants can lead to more costly propulsion systems. The use of new non-toxic propellants has the potential to reduce the cost of access to space by lowering overall life cycle costs.

Demonstrations of a hydrazine alternative in a storable liquid mono- or bi-propellant chemical propulsion system implementation relevant to at least one of the following applications are desired: in-space reaction control propulsion, in-space primary propulsion, and launch vehicle reaction control propulsion. Non-toxic technologies could range from pump fed or pressure fed thruster systems from 1 to 1000 lbf.

Specific technologies of interest to meet proposed engine requirements include:

- Non-toxic mono- and bi-propellants 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.
- Alternate catalysts, ignition technologies to ignite advanced monopropellants.
- Advanced materials capable of withstanding hot and corrosive combustion environment of advanced mono- and bi-propellants.
- Techniques that lower the cost of manufacturing complex components such as injectors, catalysts, and combustion chambers. 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.

Note to Proposer: Subtopic S3.02 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.02.

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.

Sub Topics:

Nuclear Thermal Propulsion (NTP) Topic H2.03

This subtopic seeks to develop innovative NTP technologies supporting the needs of future space exploration.

Solid core NTP has been identified as an advanced propulsion concept which could provide the fastest trip times with fewer SLS launches than other propulsion concepts for human missions to Mars over a variety of mission years. The current NASA Strategic Space Technology Investment Plan states NTP is a high priority technology

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needed for future human exploration of Mars. NTP had major technical work done between 1955-1973 as part of the Rover and Nuclear Engine for Rocket Vehicle Application (NERVA) programs. A few other NTP programs followed including the Space Nuclear Thermal Propulsion (SNTP) program in the early 1990's. The NTP concept is similar to a liquid chemical propulsion system, except instead of combustion in the thrust chamber, a monopropellant is heated with a fission reactor (heat exchanger) in the thrust chamber. In addition, the engine components and surrounding structures are exposed to a radiation environment formed by the reactor during operation.

This solicitation will examine a range of modern technologies associated with NTP using solid core nuclear fission reactors. The engines are pump fed ~15,000-35,000 lbf with a specific impulse goal of 900 seconds (using hydrogen), and are used individually or in clusters for the spacecraft's primary propulsion system. The NTP can have multiple start-ups (>4) with cumulative run time >100 minutes in a single mission, which can last a few years.

Specific technologies of interest to meet the proposed requirements include:

- High temperature (> 2600K), low burn-up composite, carbide, and/or ceramic-metallic (cermet) based nuclear fuels with improved coatings and/or claddings to maximize hydrogen propellant heating and to reduce fission product gas release and particulates into the engine's hydrogen exhaust stream.
- Long life, lightweight, reliable turbopump modeling, designs and technologies including seals, bearing and fluid system components. Throttle ability is also considered. Zero net positive suction head (NPSH) hydrogen inducers have been demonstrated that can ingest 20-30% vapor by volume. The goal would be to develop inducers that can ingest 55% vapor by volume for up to 8 hours with less than 10 percent head fall off at the design point. Develop the capability to model (predict) turbopump cavitation dynamics. This includes first order rotating and alternating cavitation (1.1X 2X) and higher (6X-10X) order cavitation dynamics.
- Highly-reliable, long-life, fast-acting propellant valves with ultra-low hydrogen leakage that tolerate long duration space mission environments with reduced volume, mass, and power requirements are also desirable. Large propellant tank bottom valves can be expected to leak in the order of 1cc per minute of hydrogen measured at standard temperature and pressure (STP). For deep space missions valve leakage will need to be <.01 cc per minute at STP. Demonstrate a large tank bottom valve that can maintain a .01 cc per minute at STP. The valve should be able to cycle 10 times and maintain that leak rate. Valve cycle time can be on the order of one minute or more.
- 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. Robonaut type inspections for prototype flight test considered.
- Concepts to cool down the reactor decay heat after shutdown to minimize the amount of open cycle propellant used in each engine shutdown. Depending on the engine run time for a single burn, cool-down time can take many hours.
- Technology needed to store the NTP propellant for multiple years in-space as liquid hydrogen with almost zero boil-off for 900 days (includes time from first launch to final trans earth injection burn). Innovations are needed in thermal control materials and design, mechanical refrigeration systems, and vehicle design.

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 2-3). 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 component and/or breadboard validation measurements, including populated verification matrix from Phase I (TRL 4-5). Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:

Nuclear Thermal Propulsion (NTP) Ground Test Technologies Topic H2.04

A nuclear rocket engine uses a nuclear reactor to heat hydrogen to very high temperatures, which expands through

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a nozzle to generate thrust. This topic area seeks to develop advanced technology components and system level ground test systems that support Nuclear Thermal Propulsion (NTP) technology development and certification.

Solid core NTP has been identified as an advanced propulsion concept which could provide the fastest trip times with fewer SLS launches than other propulsion concepts for human missions to Mars over a variety of mission years. The current NASA Strategic Space Technology Investment Plan states NTP is a high priority technology needed for future human exploration of Mars. The NTP concept is similar to a liquid chemical propulsion system, except instead of combustion in the thrust chamber, a monopropellant is heated with a fission reactor (heat exchanger) in the thrust chamber. In addition, the engine components and surrounding structures are exposed to a radiation environment formed by the reactor during operation. The NTP had ground testing done between 1955-1973 as part of the Rover and Nuclear Engine for Rocket Vehicle Application (NERVA) programs. The Rover/NERVA ground tested a variety of engine sizes, for a variety of burn durations and start-ups. These ground tests were mostly exhausted in the open air. Information on the NERVA program can be found at (<http://history.nasa.gov/SP-4533/Plum%20Brook%20Complete.pdf> [1]).

Current regulations require exhaust filtering of any radioactive noble gases and particulates released to stay within the current environmental regulations. The NTP ground testing requires the development of robust materials, advanced instruments and monitoring systems capable of operating in extreme temperature, pressure and radiation environments. This topic area will investigate large scale engine exhaust scrubber technologies and options for integrating it to the NTP engine for ground tests. The NTP engines are pump fed ~15,000-35,000 lbf with a specific impulse goal of 900 seconds (using hydrogen). The NTP primary test requirements can have multiple start-ups (>8) with the longest single burn time ~50 minutes.

This subtopic seeks innovative technologies in the following areas to facilitate NTP ground testing:

- Advanced high-temperature and hydrogen embrittlement resistant materials for use in a hot hydrogen environment (<4400 °F).
- Efficient non-nuclear generation of high temperature, high flowrate hydrogen (<60 lb/sec).
- Devices for measurement of radiation, pressure, temperature and strain in a high temperature and radiation environment.
- Effluent scrubber technologies for efficient filtering and management of high temperature, high flow hydrogen exhausts.
- Innovative refractory materials which use nano-particle additives and/or unconventional non-cement based refractories that can withstand the extreme plume heating environments experienced during rocket propulsion testing.

Specific interests include:

- Filtering of radioactive particles and debris from exhaust stream having an efficiency rating greater than 99.9%.
- Removal of radioactive halogens, noble gases and vapor phase contaminants from a high flow exhaust stream with an efficiency rating greater than 99.5%.
- Applicable Integrated System Health Monitoring and autonomous test operations control systems.
- Modern robotics which can be used to inspect the ground test system exposed to a radiation environment.

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 2-3). 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 component and/or breadboard validation measurements, including populated verification matrix from Phase I (TRL 4-5). Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:

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### Thermal Control for Future Human Exploration Vehicles Topic H3.01

Future human spacecraft will require more sophisticated thermal control systems that can operate in severe environments ranging from full sun to deep space and can dissipate a wide range of heat loads. The systems must perform their function while using fewer spacecraft resources, including mass, volume and power. Advances are sought for microgravity thermal control in the following areas:

- Heat rejection systems and/or radiators that can operate at low fractions of their design heat load in the cold environments that are required for deep space missions. Systems that can maintain setpoint control and operate stably at 25% of their design heat load in a deep space (0 K) environment are sought. Innovative components, working fluids, and systems may be needed to achieve this goal.
- Lightweight non-venting phase change heat exchangers are sought to ameliorate the environmental transients that would be seen in planetary (or lunar) orbit. Heat exchangers that have minimal structural mass and good thermal performance are sought. The goal is a ratio exceeding 2/3 phase change material mass and 1/3 structural mass.
- Two-phase heat transfer components and system architectures that will allow the acquisition, transport, and rejection of waste heat loads in the range of 100 kW to 10 megawatts are sought.
- Nontoxic working fluids are needed that are compatible with aluminum components and combine low operating temperature limits (<250K) and favorable thermophysical properties - e.g., viscosity and specific heat.

Technologies are expected to be raised from TRL2 to TRL 3/4 during Phase I. Minimum deliverables at the end of Phase I are analysis/test reports, but delivery of development hardware for further testing is desirable. In addition, the necessity and usefulness of a follow-on Phase II should be demonstrated.

Technologies would be expected to be matured from TRL 3/4 to TRL 5 during a potential Phase II effort. Expected deliverables for a Phase II effort are analysis/test reports and prototypic hardware.

For more detailed relevant information:

([http://www.nasa.gov/pdf/501320main\\_TA14-Thermal-DRAFT-Nov2010-A.pdf](http://www.nasa.gov/pdf/501320main_TA14-Thermal-DRAFT-Nov2010-A.pdf) [2]).

Sub Topics:

#### Atmosphere Revitalization and Fire Recovery for Future Exploration Missions Topic H3.02

This topic seeks to develop targeted process technologies and equipment to advance the operability and reliability of atmosphere revitalization (AR) subsystems that enable crewed deep space exploration objectives.

Highly reliable AR subsystem equipment and process technologies, supplemented by atmosphere decontamination equipment and methods, are necessary components to crewed deep space exploration mission success. While the International Space Station (ISS) AR subsystem equipment approaches many of the functional goals necessary for deep space exploration mission success, flight operational experience has identified areas for improvement in resource recovery and rapid atmosphere decontamination capabilities. Technologies related to resource recovery include gas compression and management as well as gas separations. Rapid atmosphere decontamination capabilities are needed to remove the functional burden for recovering from a contamination event, such as a fire or chemical spill, from the primary AR subsystem equipment. Details in each functional area of interest are provided by the following:

- *Gas Compression and Management* - NASA is seeking safe, compact, quiet, long-lived, and efficient ways to compress, store, and deliver gaseous oxygen and carbon dioxide within an AR subsystem. Also, methods to store, condition, and deliver reactant gases, primarily carbon dioxide, to carbon dioxide reduction process equipment are sought. Present AR equipment aboard ISS consists of power-intensive, noisy compressors that have service lives less than 2 years. Significant acoustic treatment is necessary to achieve NC-40 criteria. Applications for deep space exploration missions include but are not limited to production of high pressure oxygen for EVA use, and compression and storage of carbon dioxide for use in carbon dioxide reduction systems. Improvements in service life, reliability, and mechanical compression for atmospheric gas recharge to pressures up to 3,600 psia, including long life and reliability, and novel methods to increase tank storage capacity at lower pressures are of particular interest.
- *Hydrogen Purification for Resource Recovery* - Resource recovery and recycling is an enabling functional area for the AR subsystems needed for long-duration missions. For this purpose, NASA is interested in a regenerative separation technology to enable maximum hydrogen recovery from a stream containing water



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vapor (saturated), carbon monoxide (CO), and hydrocarbons including methane, acetylene, ethane, and ethylene, among others. While a high quantity of methane in the hydrogen product stream is acceptable, and even desirable, the presence of CO, water, and other hydrocarbons is highly undesirable. Final gas composition must be >99% hydrogen with some allowable methane and the dewpoint must be less than -60 °C. System concepts must strive to minimize power, mass, and consumable requirements while maximizing efficiency, operational life, and reliability.

- *Post-Fire Cabin Atmosphere Cleanup* - A portable, self-contained fire and toxic atmosphere cleanup system is desired that can rapidly remove contaminants from a spacecraft volume, to quickly and effectively decontaminate cabin atmosphere after a fire. The capability to reduce starting concentrations by >80% within 15 minutes for a 100-m<sup>3</sup> volume is desired. Methods have involved either deploying a filter assembly to the commode after a fire and using the commode fan as the source of airflow or attaching a series of filters to a portable fan using an adapter kit. Both methods result in low atmospheric scrubbing flow rates and significant time for deployment as well as limited capacity and non-specific scrubbing. Russian-provided portable equipment aboard the ISS provides 65 m<sup>3</sup>/h flow through a replaceable cartridge. The equipment's mass is 17 kg and the power consumption is 150 W. Filter service life is 7.5 hours. The dimensions are approximately 33 cm diameter and 35 cm tall. Future equipment must provide the rapid contamination reduction within the characteristic size and performance envelope of the Russian-developed portable scrubbing device.

For each technical area, projects are sought to research and demonstrate technical feasibility during Phase I that will develop a clear technical maturation path towards Phase II hardware development and demonstration. Phase II products must include a demonstration unit suitable for testing by NASA.

Phase I Deliverables - Documentation, data, and feasibility assessment proving the proposed approach is suitable to develop the proposed product (at least TRL 3 at completion according to NPR 7123.1 TRL definition). A breadboard developmental unit is desirable.

Phase II Deliverables - Functional engineering development unit at a minimum high fidelity breadboard (brassboard fidelity preferred), defined by NPR 7120.8, and technical maturity level 4 (TRL 4 defined by NPR 7123.1) of the proposed product, along with a full report of developmental and performance results, including drawings, analyses, and models as applicable. Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:

Human Accommodations and Habitation Systems for Future Exploration Missions Topic H3.03

Habitation systems that are dispersed throughout a spacecraft volume need to be investigated as a system to improve future human accommodations. Current spacecraft interiors exceed acoustic limits from a wide range of equipment; have manual inventory tracking and no capability for assistance of lost items; and require substantial crew time and wipes for cleaning common crew surfaces (hand rails and panels) and water/solids hygiene surfaces. Future spacecraft interiors will need to be reconfigurable to meet changing crew needs as a mission moves from launch, transit, and exploration-destination phases. Adaptable distributed habitation technologies are needed in the following areas.

- *Quiet Crew Cabin Environments* - Smaller future vehicles will unlikely have dedicated quiet volumes for crew rest so maintaining a quiet cabin is required. Crew cabin acoustic noise mitigation needs to control noise levels to enable improved voice communication, alarm signal to noise ratio, and reduce crew fatigue from long duration noise exposure. There is need for non-wearable active and passive noise cancellation/reduction strategies for open crew cabin environment that do not impede voice or alarms. Need for adaptive broad coverage area to accommodate changing crew cabin layout and volume.
- *Crew Item Location Capability* - Significant crew time is lost in tracking or locating items at the piece part level in space habitat environment that serves both as living quarters and laboratory. Items are sometimes misplaced or simply float away in the microgravity environment. Innovative approaches are sought for automatic location and tracking of a large number of individual crew items as they move from their original launch configuration to any area in the crew cabin. Crew items range in size from pill size, hand tools, clothing, and spare equipment and vary in material composition from non-metallic, metallic, to fluid containing. There is a need for low-power, and miniature Radio Frequency Identification (RFID) readers for dense storage and sparse tag environments. Flexible reader deployment that allows individual item autonomous logistics management tracking and precise 3-D locating are desired. Solutions providing enhanced localization utilizing the EPCglobal UHF reader-tag protocols (Class 1 Gen2 or advanced

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classes) are of high interest. Similar types of reader-tag communication protocols at higher frequencies that enable more accurate spatial localization are also of interest. Innovative algorithmic solutions for finding lost items, based on RFID or similar sensory information, are also of interest. All solutions must accommodate a highly reflective and complex scattering environment such as a conductive habitat cylindrical volume of ~ 3.5 m diameter ~6 m in length.

- *Crew Cabin Surfaces* - Crew activity and surface contact of fabric and solid surfaces result in generation and accumulation of particulate, moisture, organic, and salt. Surface treatments for fabrics and solid surfaces to prevent this accumulation of contaminants are needed to reduce crew time and the large number of wipes used for cleaning. Innovative low out gassing, super hydrophobic, super hydrophilic, antistatic, and antimicrobial treatments are needed for crew hygiene areas and waste collection hardware is needed. Non-mechanical fastener/non-particle generating removable physical connections are needed for repeated reconfiguring of interior volumes on longer missions. Examples of the types of temporary and reversible physical connections include crew restraints (e.g., hand rails), close out panels, and the hook-and-loop type fasteners present on most crew items.

Phase I Deliverables - Detailed analysis, proof of concept test data, material test coupons, key algorithms/subroutines, and predicted performance comparison to industry state of the art.

Phase II Deliverables - Comparison of analysis to prototype test data in representative environment, sufficient material samples/components for independent evaluation, functional software, functional breadboard component hardware and/or system, and operations documentation.

Sub Topics:

Development of Treatment Technologies and Process Monitoring for Water Recovery Topic H3.04

The capability to recover potable water from wastewater is critical to enable space exploration missions beyond low Earth orbit. A major focus of technology development is to increase reliability of water recovery systems, so these systems require less crew intervention and a lower risk of failure with longer operational lifetimes. With these goals in mind, two areas of interest have been identified for further focus:

- *Water Recovery Post-Processing Systems* - Technologies are needed to increase the reliability of systems for polishing of partially-treated wastewater. The current state of the art uses catalytic oxidation to remove dissolved organic carbon contaminants. Technologies that operate below 100 °C or ambient pressure are desirable. Examples of these technologies include low-temperature catalytic oxidation, photolysis, or photocatalysis.
- *Monitoring Systems for Mineral Species in Water & Wastewater* - A capability is needed to measure dissolved mineral ions in water and wastewater, including polyatomic ions (could encompass organic ions) and the alkaline, alkaline-earth and transition metals. Multi-analyte capability is needed, such as that available from ion chromatography and plasma spectroscopy. Potential applications include measurement of typical ionic species in humidity condensate, potable water, wastewater, byproducts of water treatment such as brines, and biomedical and science samples. Desirable attributes should include minimal sample preparation, minimal consumables, in situ calibration, and operation in microgravity and partial gravity.

At the completion of Phase I, the technology should be TRL 3. The expected deliverable for Phase I is a detailed report describing experimental methods and results, with a clear feasibility demonstration of critical technology components. The equivalent system mass, including consumables, power, volume and mass, should be estimated for the technology and be included in the report. Phase II deliverables should have completed TRL 4 and be approaching TRL 5. The Phase II deliverable should include a prototype system suitable for additional testing at a NASA center as well as a detailed report of testing and development demonstrating TRL 4.

Sub Topics:

Space Suit Pressure Garment and Airlock Technologies Topic H4.01

Space suit pressure garment and airlock technology advancements are needed to accomplish future human space exploration missions and support ISS operations. EVA and crew survival pressure garments are addressed in this subtopic. Exploration destinations include deep-space microgravity objectives such as near-earth asteroids and Mars moons as well as lunar and Martian surface objectives involving gravitational forces and local environments. Innovative space suit technologies that improve performance and prevent injuries, extend service life and eliminate or reduce overhead, provide better environmental protection, and reduce suit system mass are required to enable a robust and flexible exploration capability. Innovative airlock technologies that protect habitable environments and reduce operational and logistical overhead are required to integrate with deep space and surface EVA-hosting systems to enable and operationally optimize achievement of exploration objectives. Key innovations sought

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include, in priority order:

- Reduction of suit mass, emphasizing light-weight structural components and bearings and the use of multi-function materials to reduce environmental protection layers.
- Improved mobility for enhanced task performance that also reduces injury risk.
- Improved material durability and extended service life (time and cycles).
- Improved accommodation of crew size variations for a suit system and an individual crew member.
- Reduction of crew time for maintenance and logistical support.
- Improved protection from natural and induced environments including vacuum/atmosphere, thermal, loads and dynamics, radiation, plasma and conventional shock hazards.
- Includes thin atmosphere thermal protection.
- Elimination/reduction of dust-caused failure or degradation and intrusion/contamination of habitable volumes.
- Innovative data collection techniques to define and improve methods for the human-to-suit interface.
- Improved occupant thermal comfort management.
- Improved ability to don and doff pressurized rear-entry suits.
- Self-diagnosing and repair technologies for suit wear and damage.
- Long-duration (week or longer) suited survival concepts, including nutrition delivery and hygiene maintenance.
- Low power, consumable, overhead and light-weight airlocks.
- Suitport designs reduce the impact to the pressure garment and crewmember (on-back mass during EVA).

#### Sub Topics:

##### Additive Manufacturing of Lightweight Metallic Structures Topic H5.01

The 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. Technologies developed under this subtopic are of interest to NASA programs such as Space Launch System (SLS), Multi-Purpose Crew Vehicle (MPCV), Orion, and commercial launch providers.

Metallic additive manufacturing (AM) technology builds near-net shape components one layer at a time using metal powder bed or wire fed processes and data from 3-D CAD models. Metallic AM technologies like Selective Laser Melting (SLM), Direct Metal Laser Sintering (DMLS), Electron Beam Freeform Fabrication (EBF3), and Laser Engineered Net Shaping (LENS) are of interest to NASA for fabrication of advanced metallic aerospace components and in-space fabrication and repair. These technologies enable the direct fabrication of net or near-net shape components without the need for tooling and with minimal or no machining thereby reducing component lead time, manufacturing cost, and material waste. Metallic AM also has the potential to enable novel product designs that could not be fabricated using conventional subtractive machining processes and extends the life of in-service parts through innovative repair methodologies. Currently, some metallic AM systems use sensors for process control but not for in-situ quality assurance (QA) or flaw detection.

The purpose of this subtopic is to invest in mid- and long-term research to establish rigorous, systematic, and scalable verification and validation methods for metallic AM. Beam tracking errors, part distortion, feedstock nozzle stand-off distance variability, excessive heat build-up in the deposit, stuck or unmelted feedstock, etc. can contribute to build deposit geometric anomalies and discontinuities. The objective would be to achieve a capability to have in-situ assessment during the deposition process to provide immediate feedback to the operator or a closed loop control system to enable real-time process correction or remedial actions to correct for defects. Although the technologies developed may be specific to one metallic AM system, it is desired that they have cross cutting capabilities to other metallic AM technologies. Proposals are invited that:

- Explore new and improved sensors and sensor systems for monitoring of the metallic AM build deposit.
- Offer technologies to use the signals generated by the energy beam (either electron beam or laser) or beam / substrate emissions for in-situ process monitoring and quality assurance.
- Propose additional devices to support real-time geometric part inspection and identification of flaws (voids, cracks, lack of fusion defects or other discontinuities).

Technologies should enable determination of the boundaries of the molten pool within 0.001" (in order to define the

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size and shape), measurement of temperature over the range from 700 °F to 3000 °F (representative of the molten pool and surrounding regions) to within 25 °F, measurement of geometric features to within +0.005", detect flaws in the range of 0.010 - 0.001", and determine chemical composition within 1 weight percent. Technologies should be compatible with standard high speed computer communication protocols and sensors should be able to update at frequencies on the order of 10 Hz. Highly desirable attributes are that technologies enable non-contact sensing and measurement, are vacuum compatible, and are relatively insensitive to contamination. Desirable attributes include that technologies are non-hazardous, do not require the use of additional consumables, and do not introduce contaminants into the process.

Research should be conducted to demonstrate technical feasibility in Phase I and show a path toward demonstration in Phase II of in-situ process monitoring and quality assurance. Phase II proposals should include delivery of a prototype system for test and evaluation in environments representative of NASA's metallic AM systems. Expected Technology Readiness Levels (TRL) at the completion of Phase I projects are 2-3 and 4-5 at the end of Phase II projects.

Links to information about NASA's additive manufacturing development projects can be found at:

- Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS).
  - (<http://www.nasa.gov/exploration/systems/sls/3dprinting.html> [3]).
- Electron Beam Freeform Fabrication (EBF3)
  - (<http://www.sciencedaily.com/releases/2009/11/091110071535.htm> [4]).
  - ([http://www.nmc.ctc.com/useruploads/file/events/PA\\_Karen\\_Taminger.pdf](http://www.nmc.ctc.com/useruploads/file/events/PA_Karen_Taminger.pdf) [5]).
- Laser Engineered Net Shaping (LENS).
  - (<http://www.sandia.gov/mst/pdf/LENS.pdf> [6]).

#### Sub Topics:

##### Deployable Structures Topic H5.02

Nearly all spacecraft flown to date are powered by deployable solar arrays, having up to 100 m<sup>2</sup> of solar cell area and 25 kW of electrical power. NASA has a vital interest in developing much larger arrays over the next 20 years with up to 4000 m<sup>2</sup> of deployed area (1 MW) for exploration missions using solar electric propulsion (SEP). Scaling up solar array deployed surface area by more than an order-of-magnitude will require game changing innovations. In particular, novel flexible-substrate designs are needed that minimize structural mass and packaging volume while maximizing deployment reliability, deployed stiffness, deployed strength, and longevity. Most of the mass savings in these very large future arrays will probably come from improvements to solar array supporting structures, not from improvements in the solar cells mounted on the arrays.

NASA is currently developing solar array systems for SEP in the 30-50 kW power range. This SBIR subtopic seeks innovative structures and materials technologies and capabilities for the next generation of lightweight solar arrays beyond 50 kW. Technologies are needed for the design and verification of large deployable solar arrays with:

- 200-400 m<sup>2</sup> of deployed area (50-100 kW) in 3-5 years.
- 400-1200 m<sup>2</sup> of deployed area (100-300 kW) in 5-10 years.
- 1200-4000 m<sup>2</sup> of deployed area (300-1000 kW) in 10-20 years.

These deployed areas are typically divided between two solar array wings, with each wing requiring half of the specified area.

This subtopic seeks innovations in the following areas for future large solar array structures:

- Novel design, packaging, deployment, and in-space manufacturing and assembly concepts.
- Lightweight, compact components including booms, ribs, substrates, and mechanisms.
- Validated modeling, analysis, and simulation techniques.
- Ground and in-space test methods.
- Load alleviation, damping, and stiffening techniques.
- High-fidelity, functioning laboratory models.

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Nominal solar array requirements for large-scale SEP applications are:

- Mass specific power > 120 W/kg at beginning of life (BOL).
- Stowed volume specific power > 40 kW/m<sup>3</sup> BOL.
- Deployment reliability > 0.999.
- Deployed stiffness > 0.1 Hz.
- Deployed strength > 0.2 g (all directions).
- Lifetime > 5 years.

Variations of NASA's in-house large solar array concept referred to as the Government Reference Array (GRA) could be used for design, analysis, and hardware studies. Improved packaging, joints, deployment methods, etc. to enable GRA-type solar arrays up to 4000 m<sup>2</sup> in size (1 MW) with up to 250 W/kg and 60 kW/m<sup>3</sup> BOL are of special interest. The GRA is described in Reference 2.

In Phase I, contractors should prove the feasibility of proposed innovations using suitable analyses and tests. In Phase II, significant hardware or software capabilities should be developed and demonstrated to advance their Technology Readiness Level (TRL). TRLs at the end of Phase II of 3-4 or higher are desired.

References:

- "Concept Design of High Power Solar Electric Propulsion Vehicles for Human Exploration"

([http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120000068\\_2011025608.pdf](http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120000068_2011025608.pdf) [7]).

- Pappa, R. S. et al., "Solar Array Structures for 300 kW-Class Spacecraft," Presented at the Space Power Workshop, April 24, 2013.

Sub Topics:

Advanced Fabrication and Manufacturing of Polymer Matrix Composite (PMC) Structures Topic H5.03  
The subtopic area for Polymer Matrix Composite (PMC) Materials and Manufacturing concentrates on developing lightweight structures, using advanced materials technologies and new manufacturing processes. The objective of the subtopic is to advance technology readiness levels of PMC materials and manufacturing for launch vehicles and in-space applications resulting in structures having affordable, reliable and predictable performance. The subtopic will address two areas, manufacturing of structures and highly damage-tolerant materials for use in cryogenic environments. Proposals to each area will be considered separately. Areas of interest include: advances in PMC materials for large-scale structures and for in-space applications; innovative automated manufacturing processes (e.g., fiber placement); advanced non-autoclave curing; damage-tolerant/repairable structures; low-cost, durable tooling; high temperature PMC materials for high performance composite structures (high temperature applications); and materials with high resistance to micro cracking at cryogenic temperatures. Reliable, affordable, and practical joining techniques for large segmented composite structures are desired.

Lightweight structures and PMC materials have been identified as a critical need for launch vehicles since the reduction of structural mass translates directly to vehicle additional performance, reduced cost, and increased payload mass capacity. Reliable large-scale (approximately 8 meters or greater in diameter) PMC structures will be critical to the "heavy lift" of America's next-generation space fleet. The capability to transfer and store for long-term propellant, particularly cryogenic propellants in orbit, can significantly increase the nation's ability to conduct complex and extended exploration missions beyond Earth's orbit. The use of PMC materials for cryotanks offers the potential of significant weight savings. Applications include storage of cryogenic propellants on an Earth Departure Stage, a lunar or asteroid descent vehicle, long-term cryogen storage on the Moon, and propellant tanks for a heavy lift launch vehicle. Consideration shall be made for manufacturability in the sense of either using out of autoclave cure or autoclave cure and, in made in sections, novel and reliable approaches to join sections of composite structures to take advantage of the high strength to weight properties so that the joining methods do not significantly increase the complexity or weight of the overall structure. Novel approaches from cradle to grave will be considered in the sense that these very large structures required robust and lightweight tooling and transportation methods for minimal modifications to existing facilities and use of existing transportation or minimal modifications to such infrastructures.

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Performance metrics for manufacturing structures include: achieving adequate structural and weight performance; manufacturing and life cycle affordability analysis; verifiable practices for scale-up; validation of confidence in design, materials performance, and manufacturing processes; low-cost, durable tooling; and quantitative risk reduction capability. Research should be conducted to demonstrate novel approaches, technical feasibility, and basic performance characterization for polymer matrix composite structures or low-cost, durable tooling during Phase I, and show a path toward a Phase II design allowables and prototype demonstration. Emphasis should be on demonstrable manufacturing technology that can be scaled up for very large structures.

Performance metrics for materials developed for cryotanks are: temperature-dependent material properties including strength, modulus, CTE, and fracture toughness; and demonstrated improved resistance over present SOA of multi-directional laminates to microcracking under cryogenic temperature cycling. Initial property characterization would be done at the coupon level in Phase I. Generation of design allowables, characterization of long-term material durability, and fabrication of larger panels would be part of follow-on efforts.

High temperature polymer matrices for high performance composite structures (high temperature applications) with ease of manufacturing using the current composite manufacturing techniques.

Sub Topics:

Hot Structures Topic H5.04

This subtopic seeks to develop innovative low cost, mass and structurally efficient high temperature materials for hot structures applications.

The National Aeronautics and Space Administration (NASA) has developed hot structure technology for several hypersonic vehicles. Significant reductions in vehicle weight can be achieved with the application of hot structures, which do not require parasitic thermal protection systems (TPS). The most significant technical issue that must be addressed in hot structure design is the development of cost effective, environmentally durable and manufacturable material systems capable of operating at temperatures from 1500 °C to 3000 °C, while maintaining structural integrity. The development of these durable and affordable material systems is critical to technology advances and to enabling future economical hypersonic vehicles. Atmospheric re-entry from cis-lunar space will push the boundaries of thermal structures system technical capabilities. Advanced hot structures are required to enable these future missions.

This subtopic seeks innovative technologies in the following areas:

- Light-weight, low-cost, composite material systems that include continuous fibers.
- Significant improvements of in-plane and thru the thickness mechanical properties, compared to current high temperature laminated composites.
- Decreased processing time and increased consistency for high temperature materials.
- Low conductivity, low thermal expansion, high impact resistance.
- High temperature performance improved with oxidation resistant coatings.

Overall looking for 20% or greater reduction in mass and an order of magnitude reduction in cost.

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

Phase I Deliverables – Test coupons and characterization samples for demonstrating the proposed approach to develop the hot structure material product (TRL 2-3). Matrix of verification/characterization testing to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables – Test coupons and manufacturing demonstration unit for proposed material product. A full report of the material development process will be provided along with the results of the conducted verification matrix from Phase I (TRL 3-4). Opportunities and plans should also be identified and summarized for potential commercialization.

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

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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.

Proposals will mature technology from TRL 4 to TRL 5 or 6 by the end of Phase II work. Phase I proposals must demonstrate the viability of the maturation.

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Proposal deliverables must include:

- Software (source code, build instructions, and dependencies are ideal, but binaries may be acceptable under some circumstances).
- Software interface description documents, software architecture descriptions, and other documentation.
- Demonstrations of software systems on relevant applications.
- Quantification of software performance on relevant problems, documented in a report.

Sub Topics:

Advanced Thermal Protection Systems Technologies 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 or integration techniques such as joining or attachment for such materials as follows:
  - Advancements in carbon felts including thickness (>1.0-in), density (>0.10 g/cm<sup>3</sup>), 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. If advances in integration techniques are proposed, NASA may provide materials GFE to use in the development effort.
  - Advances in ceramic felts including thickness (>1.0-in) and uniformity to use as reinforcement for flexible TPS in heating up to ~150 W/cm<sup>2</sup>.
  - 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. If advances in integration techniques are proposed, NASA may provide materials GFE to use in the development effort.
- TPS Materials advancements sought in felts or woven materials impregnated with polymers and/or additives to improve ablation and insulative 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/cm<sup>2</sup> (primarily convective) and integrated heat loads of up to 55 kJ/cm<sup>2</sup>, and the second at heat fluxes of 100-200 W/cm<sup>2</sup> and integrated heat loads of up to 25 kJ/cm<sup>2</sup>. 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/cm<sup>2</sup> and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 1.0 g/cm<sup>2</sup> 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/cm<sup>2</sup> (primarily convective) and integrated heat loads of 10 kJ/cm<sup>2</sup> and the second at heat fluxes of 30-50 W/cm<sup>2</sup> and heat loads of 5 kJ/cm<sup>2</sup>. 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/cm<sup>2</sup>, with radiation contributing up to 75% of that flux, and integrated heat loads from 75-150 kJ/cm<sup>2</sup>. 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/cm<sup>2</sup> and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 4.0 g/cm<sup>2</sup>, 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



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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 6 mm, and bondline defect detection requirements are on the order of 25.4 mm by 25.4 mm 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.

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

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). Small samples and initial test data may be provided to demonstrate feasibility. Development of the 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 4-5). Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:

Solid Oxide Fuel Cells and Electrolyzers Topic H8.01

Solid oxide technology for fuel cells and electrolyzers to enable:

- The operation of fuel cells using hydrocarbon reactants, including methane and ISRU-generated fuels.
- Electrolysis systems capable of electrolyzing CO<sub>2</sub> from the Mars atmosphere, and/or water from the Mars surface to generate oxygen, or to recover oxygen from CO<sub>2</sub> and water from crew respiration for life support.

Both component and system level technologies are of interest.

Technologies are sought that improve the durability, efficiency, and reliability of solid oxide fuel systems capable of internal reforming of hydrocarbon fuels. Hydrocarbon fuels of interest include methane and fuels generated by processing lunar and Mars soils. Primary solid oxide components and systems of interest are:

- Solid oxide cell, stack, materials and system development for operation on unreformed methane in designs scalable to 1 to 3 kW at maturity. There is a strong preference for high power density configurations, e.g., planar.
- Solid oxide cells and stacks must startup with a minimal amount of water and then be capable of sustained operation on pure methane.
- Development of hermetic sealing materials for ceramic to ceramic interconnect or ceramic to metal interconnect stacks capable of thermal cycling. Data for the proposed seals materials and sealing scheme/design should be included in the proposal.
- Development of catalysts for direct internal reforming of methane. Provide single cell performance data on dry methane for the one or more of the proposed anode compositions.

Proposed technologies should demonstrate the following characteristics:

- Systems are expected to operate as specified after at least 20 thermal cycles during Phase I and the heat

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up rate must be stated in the proposal.

- The developed systems are expected to operate as specified after at least 500 hours of steady state operation on propellant-grade methane and oxygen with 2500 hours expected of a mature system. System should startup “dry” or with a minimal amount of water, but after reaching operating conditions an amount of water/H<sub>2</sub> consistent with what can be obtained from anode recycle can be used. Amounts must be justified in the proposal.
- Minimal cooling required for power applications. Cooling in the final application will be provided by means of conduction through the stack to a radiator exposed to space and/or by anode exhaust flow.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration. Emphasis should be on demonstrating technical feasibility, prototype hardware (2-4 cell stacks preferred), conceptual designs and implementation approaches.

Sub Topics:

Space Nuclear Power Systems Topic H8.02

NASA is developing fission power system technology for future space exploration applications using a stepwise approach. Initial small fission systems are envisioned in the 1 to 10 kWe range that utilize cast uranium metal fuel and heat pipe cooling coupled to static or dynamic power conversion. Follow-on systems could produce 10s or 100s of kilowatts utilizing a pin-type uranium fueled reactor with pumped liquid metal cooling, dynamic power conversion, and high temperature radiators. The anticipated design life for these systems is 8 to 15 years with no maintenance. Candidate mission applications include power sources for robotic precursors, human outposts on the moon or Mars, and nuclear electric propulsion (NEP) vehicles. NASA is planning a variety of nuclear and non-nuclear system ground tests 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.

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 testing. Specific areas for development include:

- 800-1000 K heat transport technology for reactor cooling (liquid metal heat pipes, liquid metal pumps).
- 1-10 kWe-class power conversion technology (thermoelectric, Stirling, Brayton).
- 400-500 K heat rejection technology for waste heat removal (water heat pipes, composite radiators, water pumps).

The early systems are 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. Specific areas for development include:

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

Expected deliverables include monthly and final reports, analytical models, and experimental hardware. Phase I activities should focus on analytical validation of technical feasibility including conceptual designs and trade studies with supporting coupon/component level testing. Phase II activities should emphasize experimental testing using prototype hardware in a subsystem context under relevant operating conditions to demonstrate technology readiness.

Sub Topics:

SCaN Testbed (CoNNeCT) Experiments Topic H9.01

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 Space Communications and Navigation (SCaN) Testbed Project provides SBIR recipients 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.

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NASA seeks innovative software applications and experiments to run aboard the SCA<sub>N</sub> 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 NASA Space Network, White Sands Complex. Unique experimenter ground hardware equipment may also be used. For the flight system on-orbit, experiments will consist of software/firmware provided to NASA by the SBIR recipient. This call will not provide a means to develop nor fly any new hardware in space.

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:

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

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 SCA<sub>N</sub> Testbed system and STRS Architecture may be found at the following link:

[\(http://spaceflight systems.grc.nasa.gov/SpaceOps/CoNNeCT/ \[9\]\).](http://spaceflight systems.grc.nasa.gov/SpaceOps/CoNNeCT/)

These documents will provide an overview of the SCA<sub>N</sub> Testbed 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 control 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

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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 SCaN Testbed 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.
- 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).
- Plan and approach for Commercialization of the technology (part of final report).

#### 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 SCaN Testbed breadboards and engineering models.
- Software/firmware application source and binary code (including test software) 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. Documentation of development tool chain and procedure to build files.
- Results of implementing the Commercialization Plan outlined in Phase I.

#### Sub Topics:

##### Long Range Optical Telecommunications Topic H9.02

This subtopic seeks innovative technologies for long range Interplanetary Optical Telecommunications supporting the needs of space missions where robotic explorers will visit distant bodies within the solar system and beyond. Our goals are increased data-rate capability in both directions, in conjunction with significant reductions of mass, power-consumption, and volume at the spacecraft. 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 and spacecraft micro-vibration environment (TRL3 Phase I, and TRL4 Phase II).

- *Vibration Isolation and Rejection Platforms and Related Technologies* - Compact, lightweight, space qualifiable vibration isolation and rejection platforms for payloads with a mass between 3 and 20 kg that require less than 5 W of power and have a mass less than 3 kg that will attenuate an integrated spacecraft micro-vibration angular disturbance of 150 micro-radians to less than 0.5 micro-radians (1-sigma), from < 0.1 Hz to ~500 Hz (TRL3 Phase I, and TRL4 Phase II). Also, innovative low-noise, low mass, low power, DC-kHz inertial, angular, position, or rate sensors. Compact, ultra-low-power, low-mass, kHz bandwidth, tip-tilt mechanisms with sub-micro-radian pointing accuracies, angular ranges of  $\pm 5$  mrad and supporting up to 50 gram payloads.
- *Laser Transmitters* - Space-qualifiable, >25% DC-to-optical (wall-plug) efficiency, 0.2 to 16ns pulse width 1550-nm laser transmitter for pulse-position modulated (PPM) data with random pulses at duty cycles of 0.3% to 6.25%, <35ps pulse rise and fall times and jitter, <25% pulse-to pulse energy variation (at a given pulse width) near transform limited spectral width, single polarization output with at least 20 dB polarization extinction ratio, amplitude extinction ratio greater than 45dB, average power of 5 to 20W, massing less than 500 g/W. Laser transmitter to feature slot-serial PPM data input at CML or AC-coupled PCEL levels and an

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RS-422 or USB control port. All power consumed by control electronics will be considered as part of DC-to-optical efficiency. Also of interest for the laser transmitter is robust and compact packaging with >100krad radiation tolerant electronics inherent in the design. Detailed description of approaches to achieve the stated efficiency is a must (TRL3 Phase I, TRL4 Phase II).

- *Photon Counting Near-infrared Detectors Arrays for Ground Receivers* - Readout electronics and close packed (not lens-coupled) kilo-pixel arrays sensitive to 1520 to 1650 nm wavelength range with single photon detection efficiencies greater than 90%. Single photon detection jitters less than 40 picoseconds 1-sigma, active diameter greater than 500 microns, 1 dB saturation rates of at least 10 mega-photons (detected) per pixel, false count rates of less than 1 MHz/square-mm, all at an operational temperature > 1.2K.
- *Photon Counting Near-infrared Detectors Arrays for Flight Receivers* - 64x64 or larger array with integrated read-out integrated circuit for the 1030 to 1080 nm or 1520 to 1650 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation loss rates of at least 2 mega-photons/pixel and operational temperatures above 220K and dark count rates of <10 MHz/mm. Radiation doses of at least 5 Krad (unshielded) shall result in less than 10% drop in single photon detection efficiency and less than 2X increase in dark count rate.
- *Ground-based Telescope Assembly* - Ground station telescope/photon-bucket technologies for developing effective aperture diameter of e10 meter at modest cost. Operations wavelength is monochromatic at a wavelength in the range of 1000-1600nm. Key requirements: a maximum image spot size of <20 micro-radian; capable of operation while pointing to within 5° of the Sun; and field-of-view of >50 micro-radian. Telescope shall be positioned with a two-axis gimbal capable of <50 micro-radian pointing accuracy, with dynamic error <10 micro-radian RMS while tracking after tip-tilt correction.

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

#### References:

- (<http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/42091/1/11-1338.pdf> [10])
- ([http://ipnpr.jpl.nasa.gov/progress\\_report/42-183/183A.pdf](http://ipnpr.jpl.nasa.gov/progress_report/42-183/183A.pdf) [11])
- ([http://ipnpr.jpl.nasa.gov/progress\\_report/42-185/185D.pdf](http://ipnpr.jpl.nasa.gov/progress_report/42-185/185D.pdf) [12])
- ([http://ipnpr.jpl.nasa.gov/progress\\_report/42-182/182C.pdf](http://ipnpr.jpl.nasa.gov/progress_report/42-182/182C.pdf) [13])

#### Sub Topics:

Long Range Space RF Telecommunications Topic H9.03

This subtopic is focused on development of innovative deep space long-range and near-Earth RF telecommunications technologies supporting the needs of space missions.

In the future, robotic and human exploration spacecraft with increasingly capable instruments producing large quantities of data will be visiting the moon and the planets. These spacecraft will also support long duration 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. Concurrently, the downlink data rate demands from Earth science spacecraft will be increasing. 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 deep 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%. Due to the applicability of communication components and subsystems with science instruments such as radar, technologies that can benefit both RF communication and advanced instruments are within the scope of this subtopic.

#### Technologies of interest:

- Ultra-small, light-weight, low-cost, low-power, modular deep space and near-Earth transceivers, transponders, amplifiers, 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 CW medium output power (10-15 W) and CW high-output power (15-35 W), 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).
- Solid-state multi-function modules that can be commanded to toggle between amplifying conventional digital modulation format signals for communications to pulsed operation for synthetic aperture radar (SAR) with resolution on the order of few meters.
- Ultra low-noise amplifiers (MMICs or hybrid, uncooled) for RF front-ends (< 50 K noise temperature).
- 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.
- Innovative packaging techniques that can lead to small size, light weight compact SSPAs with integrated heat extraction for thermal stability and reliability.

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.

Sub Topics:

Flight Dynamics GNC Technologies and Software Topic H9.04

NASA is investing in re-engineering its suite of tools and facilities that provide guidance, navigation, and control (GNC) services for the design, development, and operation of near-Earth and interplanetary missions. This solicitation seeks proposals that will develop ground system algorithms and software for flight dynamics GNC technologies to support engineering activities from concept development through operations and disposal. This subtopic does not target on-board algorithms or software.

This solicitation is primarily focused on NASA's needs in the following focused areas:

- Addition of advanced guidance, navigation, and control improvements to existing NASA software.
- Replacement of heritage GNC software systems that are nearing obsolescence or improvement of their maintainability.
- Interface improvements, tool modularization, APIs, workflow improvements, and cross platform interfaces to existing NASA software.
- Applications of optimal control theory to high and low thrust space flight guidance and control systems.
- Numerical methods and solvers for robust targeting, and non-linear, constrained optimization.
- Applications of cutting-edge estimation techniques to spaceflight navigation problems.
- Applications of cutting-edge guidance and control techniques to space trajectories.
- Applications of advanced dynamical theories to space mission design and analysis, in the context of unstable orbital trajectories in the vicinity of small bodies and libration points.

Proposals that could lead to the replacement of the Goddard Trajectory Determination System (GTDS), or leverage state-of-the-art capabilities already developed by NASA such as the General Mission Analysis Tool ([gmatcentral.org](http://gmatcentral.org) [14]), GPS-Inferred Positioning System and Orbit Analysis Simulation Software, (<http://gipsy.jpl.nasa.gov/orms/goa/> [15]), Optimal Trajectories by Implicit Simulation ([otis.grc.nasa.gov](http://otis.grc.nasa.gov) [16]) are especially encouraged. Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

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Technologies and software should support a broad range of spaceflight customers. Those that are 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 here.

Phase I efforts shall demonstrate technical and cost feasibility at the TRL 3 level and provide a plan for completion of the effort in Phase II. Preliminary software, algorithms, and documentation shall be delivered to NASA for evaluation.

With the exception listed below for heritage software modifications, Phase II new technology development efforts shall deliver components at the TRL 5-6 level with mature algorithms and software components complete and preliminary integration and testing in an operational environment. For efforts that extend or improve existing NASA software tools, the TRL of the deliverable shall be consistent with the TRL of the heritage software. Note, for some existing software systems (see list above) this requires delivery at TRL 8. Final software, test plans, test results, and documentation shall be delivered to NASA.

Sub Topics:

Advanced Celestial Navigation Techniques and Systems for Deep-Space Applications Topic H9.05  
NASA is seeking proposals to develop advanced celestial navigation techniques and system in support of deep-space missions. Advances in positioning, attitude estimation, orbit determination, time and frequency keeping and dissemination and orbit determination are sought. System and sub-system concepts should support significant advances of independence from Earth supervision including the ability to operate effectively in the absence of Earth-based transmissions or transmissions from planetary relay spacecraft while minimizing spacecraft burden by requiring low power and minimal mass and volume. While system concepts that operate in the complete absence of human intervention or Earth-based transmissions are preferred, testing and verification of proposed systems performance will, necessarily, include Earth-based systems.

Operation during all phases of mission operations, including cruise phase, orbit phase and circularization phases are of interest. An application of interest is to enable open-loop (i.e., beaconless) pointing of high rate optical communications terminals to earth terminals. Methods and systems should be sufficient accuracy to support this capability; however, concepts which are capable of supporting planetary missions of any type are of interest.

Subjects appropriate for this sub-topic include, but are not limited to:

- Advanced methods and sensors for optical/IR detection of star fields (i.e., star cameras).
- Advanced methods and sensors detecting RF and x-ray pulsars.
- Methods to process celestial observations to perform Orbit Determination (OD) and precision attitude estimation.

Proposals to develop Artificial Intelligence methods (e.g., supervisory control) should identify gaps in the knowledge base that are particular to the use of advanced celestial methods, unique to the deep space navigation problem. User spacecraft impact is of significant importance and proposed solutions include assessments of mass, power, thermal impact on targeted mission spacecraft. Current and past mission spacecraft may be used as paradigms. Proposals that include re-purposing/cross-purposing of advanced sensors contemplated for future deep-space missions such as x-ray telescopes are preferred.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware and software demonstration unit or software package for NASA testing at the completion of the Phase II contract. Deliverables must include a phased testing, verification and validation plan. Plans that include graduated flight testing are preferred.

Sub Topics:

Recycling/Reclamation of 3-D Printer Plastic for Reuse Topic H10.01  
The subtopic seeks to develop innovative concepts to support the development of recycling/reclaiming technologies for Acrylonitrile Butadiene Styrene (ABS) plastic parts in space, thus providing viable solutions for self-sustained additive manufacturing capability with plastic materials.

As the National Aeronautics and Space Administration (NASA) destinations push farther beyond the limits of low Earth orbit, the convenience of fabricating components and equipment on the ground to quickly resupply missions will no longer be a reasonable option. Resupply is difficult during deep space missions; it requires a paradigm shift in the way the Agency currently relies on an Earth-based supply chain for spares, maintenance, repair, and

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hardware design models, including those currently on the International Space Station (ISS). With the ISS program extension, there is a high likelihood of necessary replacement parts. This is a unique opportunity to begin changing the current model for resupply and repair to prepare and mature technology for deep space exploration missions.

3-D printing, formally known as “Additive Manufacturing”, is the method of building parts layer-by-layer from data files such as Computer Aided Design models. Data files with tool and part schematics can be pre-loaded onto the device before a launch, or up-linked to the device while on-orbit. 3-D printers currently scheduled for on-board ISS use will employ extrusion-based additive manufacturing, which involves building an object out of plastic deposited by the melting of feedstock by an extruder head. The plastic extrusion additive manufacturing process is a low-energy, low-mass solution to many common needs on board the ISS.

The 3-D Printing in Zero-G “3-D Print” Technology Demonstration and the Additive Manufacturing Facility (AMF) plan to utilize the commercial 3-D printing standard 1.75mm ABS filament as feedstock on ISS. To truly develop a self-sustaining, closed-loop on-orbit manufacturing process that will result in less mass to launch and increased on-demand capability in space, a means of recycling and reclaiming the feedstock is required. This SBIR seeks technologies that can take ABS parts analogous to those which could be printed on ISS (maximum size of 6cm x 12 cm x 6 cm) and demonstrate recycling/reclamation capability of the part back into 1.75mm filament feedstock.

This subtopic seeks innovative technologies in the following areas:

- ABS part reclamation - decomposing a plastic part (maximum size of 6 cm x 12 cm x 6 cm) and reconstitution into 1.75mm ( $\pm 0.1$ mm) diameter wire spools, pellets, or other forms that can be fed into an extrusion device.
- Production of recycled plastic filament while maintaining repeatable, consistent filament diameter of 1.75mm with  $\pm 0.1$ mm tolerance.
- Methods to avoid bulging of feedstock as the filament is created.
- Gravity-independent filament spooling capability: drawing the filament onto a feedstock spool as it is being created without relying on gravity to guide the filament. Goal for spool dimension should be 156mm OD, 48mm ID, 43mm wide.
- Environmental containment for Foreign Object Debris (FOD) and material off-gassing.

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 for NASA testing at the completion of the Phase II contract. Demonstration of the Engineering Unit at the end of Phase II may lead to an opportunity for a Phase III contract for a Flight Unit.

Phase I Deliverables - Feasibility study with proposed path forward to develop Engineering Unit in Phase II; study should address how the design will meet flight certification, safety requirements, and operational constraints for spaceflight; and bench top proof-of-concept, including samples and test data, proving the proposed approach to develop a given product (TRL 3-5).

Phase II Deliverables - Functioning Engineering Unit of proposed product, along with full report of development and test data (TRL 5-6).

Sub Topics:

International Space Station (ISS) Utilization Topic H10.02

NASA continues to invest in the near- and mid-term development of highly-desirable systems and technologies that provide innovative ways to leverage existing ISS facilities for new scientific payloads and to provide on orbit analysis to enhance capabilities. Utilization of the ISS is limited by available up-mass, down-mass, and crew time as well as by the capabilities of the interfaces and hardware already developed and in use. Innovative interfaces between existing hardware and systems, which are common to ground research, could facilitate both increased and faster payload development and subsequent utilization. Technologies that are portable and that can be matured rapidly for flight demonstration on the International Space Station are of particular interest.

Desired capabilities that will continue to enhance improvements to existing ISS research hardware include, but are not limited to, the below examples:

- Providing additional on-orbit analytical tools. Development of instruments for on-orbit analysis of plants,



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cells, small mammals and model organisms including *Drosophila*, *C. elegans*, and yeast. Instruments to support studies of bone and muscle loss, multi-generational species studies and cell and plant tissue are desired. Providing flight qualified hardware that is similar to commonly used tools in biological and material science laboratories could allow for an increased capacity of on-orbit analysis thereby reducing the number of samples which must be returned to Earth.

- Technologies that determine microbial content of the air and water environment of the crew habitat falls within acceptable limits and 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). Technologies that show improvements in miniaturization, reliability, life-time, self-calibration, and reduction of expendables are also of interest.
- Providing a Magnet Processing Module (MPM) for installation and operations in the Materials Science Research Rack (MSRR) would enable new and improved types of materials science investigations aboard the ISS. Essential components of the MPM include an electromagnet, which can provide field strength up to 0.2 Tesla and a high temperature insert, which can provide directional solidification processing capability at temperatures up to 1500 °C.
- Increased use of the Light Microscopy Module (LMM). Several additions to the module continue to be solicited, such as: laser tweezers, dynamic light scattering, stage stabilization (or sample position encoding) for reconstructing better 3-D confocal images.
- Instruments that can be used as infrared inspection tools for locating and diagnosing material defects, leaks of fluids and gases, and abnormal heating or electrical circuits. The technology should be suitable for hand-held portable use. Battery powered wireless operation is desirable. Specific issues to be addressed include: pitting from micrometeoroid impacts, stress fractures, leaking of cooling gases and liquids and detection of abnormal hot spots in power electronics and circuit boards.

For the above, research should be conducted to demonstrate technical feasibility and prototype hardware development during Phase I and show a path toward Phase II hardware and software demonstration and delivering an engineering development unit or software package for NASA testing at the completion of the Phase II contract that could be turned into a proof-of-concept system which can be demonstrated in flight.

Phase I Deliverables - Written report detailing evidence of demonstrated prototype technology in the laboratory or in a relevant environment and stating the future path toward hardware and software demonstration on orbit. 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 - Emphasis should be placed on developing and demonstrating hardware and/or software prototype that can be demonstrated on orbit (TRL 8), or in some cases 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 an engineering development 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 Shielding Systems Topic H11.01

Advances in radiation shielding systems technologies are needed to protect humans from the hazards of space radiation during NASA missions. All space radiation environments in which humans may travel in the foreseeable future are considered, including low Earth orbit (LEO), geosynchronous orbit, Moon, Mars, and the Asteroids. All particulate radiations are considered, including electrons, protons, neutrons, alpha particles, and light to heavy ions up to iron. Mid-TRL (3 to 5) technologies of specific interest include, but are not limited to, the following:

- Innovative lightweight radiation shielding materials are needed to shield humans in aerospace transportation vehicles, large space structures such as space stations, orbiters, landers, rovers, habitats, and spacesuits. The materials emphasis should be on non-parasitic radiation shielding materials, or multifunctional materials, where two of the functions are structural and radiation shielding. Phase I deliverables are materials coupons. Phase II deliverables are materials panels or standard materials test specimens, along with relevant materials test data.
- Non-materials solutions, such as utilizing food, water, and waste already on board as radiation shielding. A challenge of particular interest is to contain and use human waste as radiation shielding. Phase I deliverables are detailed conceptual designs. Phase II deliverables are working prototypes.
- Advanced computer codes are needed to model and predict the transport of radiation through materials and subsystems. Advanced computer codes are needed to model and predict the effects of radiation on the physiological performance, health, and well-being of humans in space radiation environments.

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Comprehensive radiation shielding design tools are needed to enable designers to incorporate and optimize radiation shielding into space systems during the initial design phases. Phase I deliverables are alpha-tested computer codes. Phase II deliverables are beta-tested computer codes.

- Laboratory and spaceflight data are needed to validate the accuracy of radiation transport codes. Laboratory and spaceflight data are needed to validate the effectiveness of multifunctional radiation shielding materials and subsystems. Comprehensive radiation shielding databases are needed to enable designers to incorporate and optimize radiation shielding into space systems during the initial design phases. Phase I deliverables are draft data compilations or databases. Phase II deliverables are formal, publishable, and archival data compilations or databases.

#### Sub Topics:

##### Next Generation Oxygen Concentrator for Medical Scenarios Topic H12.01

For exploration missions, a contingency system which concentrates the oxygen within the cabin environment and provides the required concentration of oxygen to the crewmember for various medical scenarios will be necessary. Oxygen concentration technology is being pursued to concentrate oxygen from the ambient environment so that oxygen as a consumable resource and the fire hazard of an elevated cabin oxygen atmosphere can be reduced. The goal of this project is to develop an oxygen concentration module that minimizes the hardware mass, volume, and power footprint while still performing at the required clinical capabilities.

An Oxygen Concentrator Module (OCM) with an adjustable positive pressure output 2-15 lpm of O<sub>2</sub> at 50% to >90% oxygen concentrations by volume has been recommended by the flight medical team. The unit must be able to operate continuously in microgravity and partial gravity exploration atmospheres that include the atmospheres of 14.7 psia/21% oxygen, 10.2 psia/26.5% oxygen, and 8.2 psia/34% oxygen by volume. The unit must run continuously on available spacecraft power, and be switchable between 28 VDC and 120 VDC. It must have adequate heat rejection so as to not exceed a touch temperature of 45°C. It is also highly desirable to have a portable low output capability for use in EVA pre-breathing or patient transfer between vehicles. Usage scenarios for oxygen treatment of smoke inhalation or toxic spills also predicated the need for an inlet filter on the unit that removes (converts/absorbs/filters) toxic gases from the delivered gas stream to the patient.

The OCM system should be capable of regulating the oxygenation of the patient using a closed loop feedback system that senses the oxygenation level of the patient tissues and adjusts the oxygen flow rate and/or oxygen concentration according to treatment protocols for the illness being treated. The system shall also be able to operate open loop in the event of feedback signal failure. The control variable(s) are not specified (rate/concentration) here since the basic unit's topology may dictate how the regulation is best achieved. Because the system may be configured during times of duress, it shall be user friendly to the caretaker by adopting a "plug and play" philosophy.

This SBIR Phase I development is to determine the architecture of such a system exhibiting the characteristics (high capacity flow range, closed-loop tissue oxygen control, and operations in microgravity or partial gravity exploration atmospheres), a description of the basic unit as a sub-system component, method of optimizing power over the range of flows and oxygen levels, redundancy and sparing for a long duration missions, and the relationship of the OCM system to caretaker (what does the caretaker need to do to fulfill the medical need?).

Phase I Requirements - Phase I should concentrate on developing the scientific, technical, and commercial merit and feasibility of the proposed innovation resulting in a feasibility report and concept, complete with analyses that discuss functionality in microgravity and at the proposed exploration atmospheres, algorithms for closed-loop oxygenation protocols, and inlet filtering of smoke or toxic gases.

NASA Deliverables - A concept for a microgravity and partial gravity exploration atmospheres oxygen concentrator with a closed loop oxygenation flow rate system with inlet filtering of potential toxic ambient gases.

HRP IRP Risk - Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities.

#### Sub Topics:

##### Inflight Calcium Isotope Measurement Device Topic H12.02

Bone loss in crewmembers is a major concern for long duration space flight. The ability to rapidly detect changes in bone mineral balance (BMB) in crewmembers living on ISS would have great potential as a surveillance tool for future exploration missions. Calcium isotopes have been shown to detect changes in BMB on very short timescales (e.g., one week). In order to detect these important changes, a technological device could be used in-flight. Thus,

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we are seeking a device (portable to bench top size) with the same accuracy and precision as is currently available in the non-flyable Multiple Collector Inductively Coupled Plasma mass spectrophotometer.

Phase I Requirements - The sensitivity required to make the Calcium isotope measurements would need to be approximately  $10^{12}$ - $10^{16}$  (i.e., this is how sensitive the machine should be for finding the Calcium isotope; it should be able to pick up one "atom" or unit in a pool of  $10^{16}$  other things). Systems that measure elemental composition typically have sensitivities around  $10^6$ - $10^9$  for some elements. The absolute concentrations of the isotopes are not required. We are looking for an instrument that can measure the variations in the ratio of any two Calcium isotopes on the order of 0.1-0.5 parts per 10,000 ( $^{44}\text{Ca}/^{42}\text{Ca}$ ) but could vary depending on the isotopes used. A successful proposal will include the technologies being considered and detailed test plan for evaluating them during Phase I.

Phase I deliverables - Test results and plan for developing a low volume, low mass, easy-to-operate prototype. TRL of 3 desired.

Phase II deliverables - Prototype in year 1 with sample testing against industry standard in year 2.

HRP IRP Risk - Risk of Early Onset Osteoporosis Due to Spaceflight

Technology Readiness Levels (TRL) of 4 to 5 or higher are sought upon completion of the project.

Sub Topics:

Objective Sleep Measures for Spaceflight Operations Topic H12.03

Currently in spaceflight, crewmembers report their sleep duration as requested by their crew surgeon. This approach has several limitations, including the burden it places on the crew and the tendency for subjective over-reporting of sleep (Lauderdale et al., 2008; Van Den Berg et al., 2008; Silva et al., 2007). Given evidence that demonstrates the relationship between sleep and circadian phase and performance, sleep-activity data should be collected as unobtrusively possible during long duration spaceflight. Wrist-worn actigraphy has been implemented as a successful, validated research tool in spaceflight but lacks features to render it a useful tool operationally, such as real-time feedback and minimal crew time requirements. Hence, there is a need for a minimally obtrusive or unobtrusive measure that evaluates sleep-wake activity plus light exposure; is acceptable for continuous wear; minimizes crew time by allowing for automatic downloads; provides immediate feedback to the user; incorporates the constraints of spaceflight hardware, such as extended battery life; and potentially incorporates other features, including other physiological sensors. The proposed technology should build on existing technologies with a focus on enhancing the product to ensure spaceflight readiness.

Requirements - Phase I should concentrate on the enhancement of a prototype device providing minimally obtrusive data collection that objectively measures sleep duration and other relevant characteristics in the spaceflight environment. Phase II should also yield a plan for continued development (if needed) and for validation of the device prior to spaceflight implementation.

NASA Deliverables - An objective, validated measure of sleep that is feasible and acceptable in the spaceflight environment.

HRP IRP Risk - Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness and Work Overload.

A TRL Start of 3-4 with a TRL End of 7-8 (at the end of Phase II) is desired for this project.

Sub Topics:

Advanced Food Technology Project Topic H12.04

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 foods with a shelf life of five years will be required to support the crew. Concurrently, the food system requirements must efficiently balance with their use of vehicle resources such as mass, volume, water, air, waste, power, and crew time.

NASA provisions currently consist solely of shelf stable foods due to vehicle resource limitations preventing food refrigeration or freezing. Stability is achieved by thermal, irradiative processing, or drying to kill or prevent microorganism growth in the food. These methods coupled with environmental factors (such as moisture ingress and oxidation) impact the micronutrients within the food. Since the food system is the sole source of nutrition to the crew, a significant loss in nutrient availability could jeopardize the health and performance of the crew.

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This subtopic requests methods or technologies that enable development of an acceptable and safe food system to deliver appropriate amounts of bioavailable nutrients to crewmembers throughout a five year mission with no resupply. Vitamin content in NASA foods, such as vitamin C, vitamin K, thiamin, and folic acid, are key nutrients degraded during processing and storage. NASA is seeking novel food ingredients, protective or stabilizing technologies (e.g., encapsulation), controlled-release systems, or novel processing technologies that allow the delivery of key nutrients at the time of consumption. Consideration must be given to food safety as well as acceptability, as under-consumption will similarly lead to nutritional deficiencies.

Deliverables - Feasibility demonstration of a novel food system approach with the potential to enable vitamin stability in an acceptable and safe food system for extended duration missions. Phase I should include a comprehensive report detailing the system feasibility, and show a clear path to Phase II development and analyses, with the expectation that Phase II will demonstrate that the food system will retain 70% of original content of vitamin C, vitamin K, thiamin, or folic acid over five years of ambient temperature storage. Phase II should deliver the innovation in a form that can be tested in NASA's food system.

HRP IRP Risk - Risk of Inadequate Food System.

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

Sub Topics:

Advanced NDE Techniques for Complex Built Up Structures Topic H13.01

Technologies sought under this SBIR program can be defined as advanced sensors, sensor systems, sensor techniques or software that enhance or expand NASA's current sensor capability. It is considered to be advantageous but not necessary to target structural components of space flight hardware. In a general sense space flight hardware will include light weight structural materials including composites and thin metals.

Technologies sought include modular smart advanced NDE sensors systems and associated capture and analysis software. It is advantageous for techniques to include the development on quantum, meta- and nano sensor technologies for deployment. Technologies enabling the ability to perform inspections on large complex structures will be encouraged. Technologies should provide reliable assessments of the location and extent of damage. Methods are desired to perform inspections in areas with difficult access in pressurized habitable compartments and external environments for flight hardware. Many applications require the ability to see through assembled conductive and/or thermal insulating materials without contacting the surface. Techniques that can dynamically and accurately determine position and orientation of the NDE sensor are needed to automatically register NDE results to precise locations on the structure. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who need make important assessments quickly. NDE inspection sensors are needed for potential use on free-flying inspection platforms. Integration of wireless systems with NDE may be of significant utility. It is strongly encouraged to provide explanation of how proposed techniques and sensors will be applied to a complex structure. Examples of structural components include but are not limited to multi-wall pressure vessels, batteries, tile, thermal blankets, micrometeoroid shielding, International Space Station (ISS) Radiators or other aerospace structural components.

Phase I Deliverables - Lab prototype, feasibility study or software package including applicable data or observation of a measurable phenomena on which the prototype will be built. Inclusion of a proposed approach to develop a given methodology to Technology Readiness Level (TRL) of 2-4. All Phase I's will include minimum of short description for Phase II prototype. It will be highly favorable to include description of how the Phase II prototype or methodology will be applied to structures.

Phase II Deliverables - Working prototype or software of proposed product, along with full report of development and test results. Prototype or software of proposed product should be of Technology Readiness Level (TRL 5-6). Proposal should include plan of how to apply prototype or software on applicable structure or material system. Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:

Advanced Structural Health Monitoring Topic H13.02

Future manned space missions will require spacecraft and launch vehicles that are capable of monitoring the structural health of the vehicle and diagnosing and reporting any degradation in vehicle capability. This subtopic seeks new and innovative technologies in structural health monitoring (SHM) and integrated vehicle health management (IVHM) systems and analysis tools.

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Techniques sought include modular/low mass-volume systems, low power, low maintenance systems, and systems that reduce or eliminate wiring, as well as stand-alone smart-sensor systems that provide processed data as close to the sensor as practical and systems that are flexible in their applicability. Examples of possible system are: Surface Acoustic Wave (SAW)-based sensors, passive wireless sensor-tags, flexible sensors for highly curved surfaces direct-write film sensors, and others. Damage detection modes include leak detection, ammonia detection, micrometeoroid impact and others. Reduction in the complexity of standard wires and connectors and enabling sensing functions in locations not normally accessible with previous technologies is also desirable. Proposed techniques should be capable of long term service with little or no intervention. Sensor systems should be capable of identifying material state awareness and distinguish aging related phenomena and damage related conditions. It is considered advantageous that these systems perform characterization of age-related degradation in complex composite and metallic materials. Measurement techniques and analysis methods related to quantifying material thermal properties, elastic properties, density, microcrack formation, fiber buckling and breakage, etc. in complex composite material systems, adhesively bonded/built-up and/or polymer-matrix composite sandwich structures are of particular interest. Some consideration will be given to the IVHM /SHM ability to survive in on-orbit and deep space conditions, allow for additions or changes in instrumentation late in the design/development process and enable relocation or upgrade on orbit. System should allow NASA to gain insight into performance and safety of NASA vehicles as well as commercial launchers, vehicles and payloads supporting NASA missions. Inclusion of a plan for detailed technical operation and deployment is highly favored.

Phase I Deliverables - Lab prototype or feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 2-4). Plan for Phase II including proposed verification methods.

Phase II Deliverables - Working engineering model or software of proposed product, along with full report of development and test results, including verification methods (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics: