NASA SBIR 2008 Phase I Solicitation

Exploration Systems

Avionics and Software Topic X1
Exploration Technology Development Program (ETDP) leads the Agency in the development of advanced avionics, software and information technology capabilities and research for Exploration Systems. The Avionics and Software elements perform mission-driven research and development to enable new system functionality, reduce risk, and enhance the capability for NASA's exploration missions. NASA’s focus has clarified around Exploration, and the agency's expertise and capabilities are being called upon to support these missions. The Ares Launch Vehicle, the Orion Crew Exploration Vehicle (CEV), the Altair Lunar Lander, and future lunar surface systems will each require unique advances in avionic and software technologies such as integrated systems health management, autonomous systems for the crew and mission operations, radiation hardened processing, and reliable, dependable software. Exploration requires the best of the nation's technical community to step up to providing the technologies, engineering, and systems to regain the frontiers of the Moon, to extend our reach to Mars, and to explore the beyond.
Sub Topics:

X1.01 Automation for Vehicle and Habitat Operations

Lead Center: ARC

Participating Center(s): JPL

Automation will be instrumental for decreasing workload, reducing dependence on Earth-based support staff, enhancing response time, and releasing crew and operators from routine tasks to focus on those requiring human judgment, leading to increased efficiency and reduced mission risk. To enable the application of intelligent automation and autonomy techniques, the technologies need to address two significant challenges: adaptability and software validation. Reusable automation software must be adaptable to new applications without undue difficulty, and easily adjusted as the application operations change. The software and the adaptation to a given application must also be trusted before it can be accepted. Proposals are solicited in the areas of:

Automation Support Tools

Support tools are needed to facilitate the authoring and validation of plans and execution scripts. Tools that are not tied specifically to one executive would provide NASA the most flexibility in applying such tools across projects. Examples of needed capabilities include:

- Graphical tool for monitoring and debugging plan execution;
- Graphical tool for creating and editing execution scripts;
- Tools for authoring and validating execution plans;
- User friendly abstraction of low-level execution languages by adding syntactic enhancements.

Decision Support Systems

Decision support systems amplify the efficiency of operators by providing the information they need when and where they need it. Decision support tools are needed that:

- Command and supervise complex tasks while projecting the outcome of actions and identify potential problems;

- Understand system state, including visualization and summarization;
- Allow the system to interact with a user when generating the plan and allow evaluation of alternate courses of action;
- Integrate a planning and scheduling system as part of an on-board, closed loop controller;
- Scale up existing techniques to larger problem applications.

Trustable Systems

Systems that support or interact with crew require a very high level of reliability. Tools are needed that improve the reliability and trustworthiness of autonomous systems. These include:

- Ability to predict what the system will do;
- Guarantees of behavioral properties;
- Other properties that increase the operator's trust;
- Verifiability (e.g., restricted executive languages that facilitate model-based verification).

X1.02 Reliable Software for Exploration Systems

Lead Center: ARC

Participating Center(s): JPL, JSC, LaRC

The objective of this subtopic is to develop software engineering technologies that enable engineers to cost-effectively develop and maintain NASA mission-critical software systems. Particular emphasis will be on software engineering technologies applicable to the high levels of reliability needed for human-rated space vehicles. A key requirement is that proposals address the usability of software engineering technologies by NASA engineers, and not only specialists in the technology.

Many of the capabilities needed for successful human exploration of space will rely on software. In addition to traditional capabilities, such as GNC (guidance, navigation, and control) or C&DH (command and data handling), new capabilities are under development: integrated vehicle health management, autonomous vehicle-centered operations, automated mission operations, and, further out, mixed human-robotic teams to accomplish mission objectives. It will be challenging, but critical to NASA's exploration objectives to ensure that these capabilities are reliable and can be developed and maintained affordably. Mission phases that can be addressed include not only the software life-cycle (requirement engineering through verification and validation) but also upstream activities (e.g., mission planning that incorporates trade-space for software-based capabilities) and post-deployment (e.g., new approaches for computing fault tolerance, rapid reconfiguration, and certification of mission-critical software systems).

Software engineering tools and methods that address reliability for exploration missions are sought, including:

- Automated software generation methods from engineering models that ensure integrity; for example, methods ensuring semantic equivalence between UML models and generated code, generated code optimizations that preserve semantics, and tools that provide navigable two-way traceability from models to code.
- Methods for ensuring safe modification and updates to existing code.
- Scalable verification technologies for complex mission software.
- Automated testing technology that ensures coverage targeted both at the system level and software level.
- Technology for calibrating software-based simulators and testbeds against high-fidelity hardware-in-the-loop testbeds in order to achieve dependable test coverage.
- Cost-effective architectures and methods for software fault tolerance for real-time mission-critical applications.

This subtopic also collaborates with the Small Spacecraft Build effort highlighted in Topic S4 (Low-Cost Small Spacecraft and Technologies). Respondents are encouraged to consider a possible flight opportunity for their proposed work under small spacecraft in addition to considering Exploration customers.

X1.03 Radiation Hardened/Tolerant and Low Temperature Electronics and Processors

Lead Center: LaRC

Participating Center(s): GSFC, MSFC

The goal of leaving low Earth orbit for the purpose of human and robotic exploration will require avionic systems and components that are capable of operating in the extreme temperature and radiation environments of deep space, the lunar surface, and eventually the Martian surface. Spacecraft vehicle electronics will be required to operate across a wide temperature range and must be capable of enduring frequent (and often rapid) thermal-cycling. Packaging for these electronics must be able to accommodate the mechanical stress and fatigue associated with the thermal cycling. Spacecraft vehicle electronics must be radiation hardened for the target environment. They must be capable of operating through a total ionizing dose (TID) of 100 krads (Si) or more and providing single-event latchup immunity (SEL) of 100 MeV cm^2/mg or more.

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

- Low power, high efficiency, radiation-hardened processor technologies optimized for numerically intensive algorithms and applications, capable of a sustained processor throughput of 5 GMACS for 16-bit operations and a sustained processor efficiency of 5 GMACS/W.
- Field Programmable Gate Array technologies providing reliable reprogrammable capabilities that are radiation hardened by design and/or radiation hardened by process.
- Innovative radiation hardened volatile and nonvolatile memory technologies.
- Packaging capable of surviving numerous thermal cycles and tolerant of the extreme temperatures on the Moon and Mars. This includes the use of appropriate materials including substrates, die-attach, encapsulants, thermal compounds, etc.

X1.04 Integrated System Health Management for Ground Operations

Lead Center: ARC

Participating Center(s): JPL, KSC, MSFC, SSC

Innovative health management technologies are needed throughout NASA’s Constellation architecture in order to increase the safety and mission-effectiveness of future spacecraft and launch vehicles. In human space flight, a significant concern for NASA is the safety of ground and flight crews under off-nominal or failure conditions. The stringent launch availability requirements of the Constellation Program challenge traditional vehicle processing and launch operations. Some of the challenges for the new architecture include optimization of sensors (placement, physical and functional redundancy, weight and cost), validation of inherently unreliable sensors, increasing the effective capability for state determination using innovative analysis algorithms, and integration of sensor information distributed across ground support equipment and the vehicles in multiple processing locations and phases. Diagnostic and prognostic analyses which provide an accurate assessment of system and component health will ensure the completion of complex launch processing flows on schedule. Projects may focus on one or more relevant subsystems such as solid rocket motors, liquid propulsion systems, structures and mechanisms, thermal protection systems, power, avionics, life support, and communications. Proposals that involve the use of existing testbeds or facilities at one of the participating NASA centers (ARC, MSFC, KSC, or JPL) for technology validation and maturation are strongly encouraged. Specific technical areas of interest related to integrated systems health management include the following:

- Innovative methods for sensor validation and robust state estimation in the presence of inherently unreliable sensors. Proposals should focus on data analysis and interpretation during pre-flight checkout using legacy sensors rather than development of new sensors or sensor systems.
- Model-based methods for fault detection and isolation in rocket propulsion systems based on existing sensor suites during pre-launch propellant loading and during mission operations.
- Concepts for advanced built-in-tests for spacecraft avionics that reduce or eliminate the need for extensive functional verification and to predict remaining life of avionics systems based on usage history.
- Prognostic techniques able to anticipate system degradation and enable further improvements in mission success probability, operational effectiveness, and automated recovery of function. Proposals in this area should focus on systems and components commonly found in spacecraft.
- Innovative human-system integration methods that can convey a wealth of health and status information to pre-flight check-out crews, ground operations and mission support staff quickly and effectively, especially under off-nominal and emergency conditions.
- Innovative approaches to effective utilization of health information from NASA spacecraft and launch vehicles with seamless integration to ground based systems using commercial health information from programmable logic controller systems and commercial Reliability, Availability and Serviceability (RAS) systems.

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Environmental Control and Life Support Topic X2

Environmental Control and Life Support (ECLS) encompasses the process technologies and equipment necessary to provide and maintain a livable environment within the pressurized cabin of crewed spacecraft and to support associated human systems, such as EVA (Extra Vehicular Activity). Functional areas of interest to this solicitation include thermal control and ventilation, atmosphere resource management and particulate control, waste management and habitation systems, environmental monitoring and fire protection systems. Technologies must be directed at lunar transit and surface missions, including such vehicles as lunar landers, surface habitats and pressurized rovers. Requirements include operation in micro- and partial- (1/6th) gravity and compatibility with cabin atmospheres of up to 34% O_2 by volume and pressures as low as 7.6 psia. Special emphasis is placed on developing technologies that will fill existing gaps; have a significant impact on reduction of mass, power, volume and crew time; and increased safety and reliability. Results of a Phase 1 contract should show feasibility of the technology and approach. A resulting Phase 2 contract should lead to development and evaluation of prototype hardware. Specific technologies of interest to this specific solicitation are addressed in each subtopic.

Sub Topics:

X2.01 Spacecraft Cabin Ventilation and Thermal Control

Lead Center: JSC

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

Advanced technologies are sought for cabin ventilation and thermal management for next generation human spacecraft including lunar lander, lunar habitat, and pressurized rovers.

Spacecraft Ventilation

Controlling acoustic noise levels within spaceflight vehicles is needed to provide for adequate voice and ground communications, habitability, and alarm audibility. This will become very important with longer duration missions such as Lunar Habitat and Mars missions. Past experience has shown that controlling acoustic noise levels inside the spacecraft depend upon development of quiet ventilation system and environmental control system fans and pumps, as well as inclusion of effective noise controls to reduce the noise that is created (i.e., source and path technologies).

Advances are sought in the general areas of source noise-level reduction, vibration isolation, acoustic absorption, and sound blocking and sealing (i.e., source and packaging). Noise reduction technology should achieve significant noise reductions (> 5dB) with minimal impacts to performance characteristics (pressure rise and flow rate). Noise reductions and performance capabilities should be demonstrated. Materials should meet flight requirements for flammability, frangibility, and off-gassing. Ventilation fans and fluid pumps are the major source of interior spacecraft noise. Fan and pump technologies that prevent the generation of acoustic noise or limit its transmission to mounting structure or surrounding air are desired. Technologies achieving 5 dB or greater attenuation and accommodating variable equipment speeds, variable acoustic spectrums, and atmospheric pressures from 8 to 15 psia are required.

Thermal Control Systems

Future spacecraft will require more sophisticated thermal control systems that can dissipate or reject greater heat loads at higher input heat fluxes while using fewer of the limited spacecraft mass, volume and power resources. The thermal control designs also must accommodate the harsh environments associated with these missions including dust and high sink temperatures. Modular, reconfigurable designs could limit the number of required spares.

The lunar environment presents several challenges to the design and operation of active thermal control systems. During the Apollo program, landings were located and timed to occur early in the lunar day, resulting in a benign thermal environment. The long duration polar lunar bases that are foreseen in 15 years will see extremely cold thermal environments, as will the radiators for Martian transit spacecraft. Long sojourns remote from low-Earth orbit will require lightweight, but robust and reliable systems.

Innovative thermal management components and systems are needed to accomplish the rejection of heat from lunar bases. Advances are sought in the general areas of radiators, thermal control loops and equipment. Variable emissivity coatings, clever working fluid selection, or robust design could be used to prevent radiator damage from freezing at times of low heat load. Also, the dusty environment of an active lunar base may require dust mitigation and removal techniques to maintain radiator performance over the long term.

The lunar base may include high efficiency, long life mechanical pumps. Part of the thermal control system in the lunar base is likely to be a condensing heat exchanger, which should be designed to preclude microbial growth. Small heat pumps could be used to provide cold fluid to the heat exchanger, increasing the average heat rejection temperature and reducing the size of the radiators.

Thermal management of the lunar habitat, landers, and rovers may require mechanically pumped two-phase fluid loops. Innovative design of the loops and components is needed.

Future space systems may generate large amounts of waste heat which could either be rejected or redirected to areas which require it. Novel thermal bus systems which can obtain, transport, and reject heat between various components are sought. The system should be highly configurable and adaptable to changes in equipment locations. Large diurnal temperature changes in the environment are expected. Possible systems include single and two-phase pumped fluid loops, capillary-based loops, and heat pumps.

A scaling methodology is needed to allow long term 1-g testing of two-phase systems (including pumped two-phase loops, heat pumps, and condensing heat exchangers) representative of the 1/6th Earth-normal gravity of the Moon.

X2.02 Spacecraft Cabin Atmospheric Resource Management and Particulate Matter Removal

Lead Center: MSFC

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

Particulate Matter Removal and Disposal

Particulate matter suspended in the habitable cabin atmosphere is a challenge for all phases of exploration missions. Removing and disposing of particulate matter originating from sources internal to the habitable cabin and from surface dust intrusion is of interest. Process technologies and equipment that efficiently remove the range of particulate matter sizes and morphologies encountered in a crewed spacecraft cabin from the atmosphere and surfaces are sought. Candidate technology solutions should provide high efficiency and long-lived removal capacity. Successful process technologies must be tolerant of the abrasive properties of lunar surface dust. Performance should be demonstrated with appropriate lunar dust analogs or simulants. Process technologies sought must be highly efficient and promote safe disposal of accumulated particulate matter. Areas of emphasis include:

- Removal and Disposal of Fine Particulate Matter Suspended in a Cabin Atmosphere: It is hypothesized that fine particulate matter introduced into the cabin will be detrimental to crew health. Filtration technologies are sought that will limit the levels of lunar dust contaminants of less than 10 micron size in the cabin atmosphere below 0.05 mg/m^3 while providing significantly improved capture efficiency with minimal pressure drop. These may include but are not limited to mechanical filtration, inertial separation and impingement, and electrostatic and/or electrically enhanced separation solid-gas processes that are light-weight, low power and operate at reduced atmospheric pressures. Process technologies that offer both improved efficiency and are suitable for in situ regeneration as described below are preferred. Novel techniques and materials are of interest.

- Regenerative Processes and Filters: Regenerable solid-gas separations techniques and process technologies are sought that effectively handle a broad size range from >100 microns in aerodynamic diameter to
- Vacuum Cleaner for Planetary Surface Vehicles and Habitats: Portable crew-operated devices for removing particulate matter from a wide range of surfaces (polymer, metallic, and fabric), operating at cabin atmospheric pressures ranging from 8 to 15 psia, and minimizing electrical power and acoustic noise generation are of interest. Successful devices may employ several of the above mentioned processes or filtration systems to remove a wide range of particulate matter sizes up to 2 mm in aerodynamic diameter without contaminating the air with ultrafine particulates. The ability for the portable device to be operated as a supplemental, portable cabin air filtration unit is a plus.

Atmospheric Resource Management

Atmospheric resource management encompasses process technologies and equipment to supply, store, and condition atmospheric gases; provide gaseous oxygen at pressures at or above 3,600 psia; and achieve mass closure by recycling resources and using in situ resources. Areas of emphasis include:

- Carbon Dioxide Reduction for Recovery of Oxygen: Process technologies for reducing carbon dioxide to a carbon product via high single-pass reaction efficiency with a product yield >90% are of interest. Successful process technologies and/or process technology unit operations combinations must demonstrate efficient power use and address safety issues associated with traditional reduction processes.

- High Pressure Oxygen Gas Supply: Process technologies leading to an on-demand, in-flight renewable source of oxygen at or above 3,600-psia are of interest. Process technologies employed for achieving these needs may include mechanical compressors, temperature or pressure-swing adsorption compressors, high pressure electrolytic oxygen production or other novel means.

X2.03 Spacecraft Habitation and Waste Management Systems

Lead Center: ARC

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

Waste management and habitation systems supporting critical needs for lunar mission architectures are requested. Improved technologies for recovery of water and other resources as well as safe long term stabilization and storage of residuals inside and outside the habitat are needed. Waste processes collect, process, recover resources, stabilize, and store residuals. Proposals should explicitly describe the weight, power, and volume advantages of the proposed technology.

Clothing/Laundry Systems

Clothing is a major consumable and trash source. Low mass reusable or long usage clothing options that meet flammability, out gassing, and crew comfort requirements are desired. Techniques, equipment, and clothing material that extend clothing life, facilitate clothing washing/drying, low consumable mass/volumes, low acoustic generation, and low water usage are desirable. Technologies must minimize crew time, be compatible with lunar gravity, atmospheric pressures from 8 to 15 psia, minimize electrical power, minimize acoustic noise generation, be flame resistant in 32% oxygen environments, have low outgassing, and have non-toxic cleaning agents waste products compatible with biological water processing and atmospheric trace contaminant control.

Waste Management

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

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

X2.04 Spacecraft Environmental Monitoring and Control

Lead Center: JPL

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

X2.05 Spacecraft Fire Protection

Lead Center: GRC

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

NASA's fire protection strategy includes: strict control of ignition sources and flammable material, early detection and annunciation of fire signatures, and effective fire suppression and response procedures. While proposals in all of these areas are applicable, they are particularly sought in the areas of nonflammable crew clothing and fire suppression technology.

The requirements for crew clothing are balanced between comfort, durability, and flammability. Non-flammable alternatives are requested for shirts, shorts, sweaters, jackets, etc. and, ideally, would be available in a variety of colors and weights. For exploration missions, clothing should be nonflammable up to 34% O_2 by volume without being stiff and uncomfortable. The flammability characteristics of the clothing must be maintained through the recommended cleaning process.

Fire suppression technologies for exploration spacecraft and habitats must:

- Be applicable for use in a confined habitable volume having an atmosphere of up to 34% O_2 by volume and pressures as low as 7.6 psia;
- Be suitable for use in a portable fire extinguisher against fires behind panels and close-outs or the cabin open volume;
- Have minimal mass and volume requirements including consumables required for post-fire clean-up; and
- Be compatible with the spacecraft environmental control and life support system.

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

Lunar In Situ Resource Utilization Topic X3

The purpose of In Situ Resource Utilization (ISRU) is to harness and utilize resources at the site of exploration to create products and services which can enable and significantly reduce the mass, cost, and risk of near-term and long-term space exploration. In particular, the ability to make propellants, life support consumables, fuel cell reagents, and radiation shielding can significantly reduce the cost, mass, and risk of sustained human activities beyond Earth. The ability to modify the lunar landscape for safer landing, transfer of payloads from the lander to an outpost, dust generation mitigation, and infrastructure emplacement and buildup are also extremely important for long-term lunar operations. To perform these tasks on the lunar surface, detailed knowledge of the terrain, local minerals and potential resources, and subsurface futures is important for planning and operations at the start of establishing long-term human presence on the lunar surface. Lastly, since ISRU systems and operations have never been demonstrated before in missions, it is important that ISRU concepts and technologies be evaluated under relevant conditions (1/6 g and vacuum) as well as anchored through modeling to lunar soil and environmental conditions. With this in mind, the ISRU Project within the Exploration Technology Development Program (ETDP) has initiated development and testing of hardware and systems in three main focus areas: (1) Regolith Excavation, Handling and Material Transportation; (2) Oxygen Extraction from Regolith; and (3) ISRU Development & Precursor Activities. The purpose of the following subtopics is to develop and demonstrate hardware and software technologies that can be added to on-going analysis and ISRU capability development and demonstration activities in ETDP to meet Outpost architecture and surface manipulation objectives for near and long term human exploration of the Moon.
Sub Topics:

X3.01 Lunar Regolith Excavation and Material Handling

Lead Center: JSC

Participating Center(s): GRC, KSC

The lunar regolith excavation, handling, and material transportation subtopic includes all aspects of lunar regolith handling for oxygen and other resource collection and site preparation and Outpost infrastructure emplacement, including tasks such as clearing/leveling landing areas and pathways, buildup of berms and burying of reactors or habitats for radiation protection. Excavation capabilities may involve excavation and collection of both unconsolidated and consolidated surface regolith. Hardware must be able to operable over broad temperature ranges (generally 110K to 400K) and in the presence of abrasive lunar regolith and partial-gravity environments. Expectations for maintenance by crew must be minimal and affordable. Therefore, general attributes desired for all proposed hardware include the following: lightweight, abrasion resistant, vacuum and large temperature variation compatible materials, low power, robust/low maintenance, and minimize dust generation/saltation during operation. Specific software and hardware for insertion into on-going ISRU Project development and demonstration activities include:

- Excavation hardware for oxygen production: Unconsolidated material, 17 kg/hr based on hydrogen reduction, <10 cm deep; avoid or mitigate rocks >5 cm diameter (See note on mobility platform below).
- Excavation hardware for deep digging: Consolidated material, 3 m deep and 1 meter in diameter at a minimum; (See mobility platform note below).
- Granular materials mixing and separation for reactor feedstock conditioning: remove material > 0.5 cm diameter before dumping into storage bin during excavation operation for oxygen extraction from regolith.
- Dust tolerant, lightweight mechanisms and actuators for excavation and material transport operations.
- Site preparation hardware, automation, and control for surface contouring and area clearing and leveling.
- Site preparation hardware, automation, and control for berm building; 3 meters tall; 45 degree slope minimum based on landing plume mitigation.

Phase 1 proposals should demonstrate technical feasibility of the technology and/or subsystem through laboratory validation of critical aspects of the innovation proposed, as well as the design and path toward delivering hardware/subsystems in Phase 2 for incorporation into existing development activities.

Proposers are encouraged to use the Lunar Sourcebook at a minimum for understanding lunar regolith material parameters in the design and testing of hardware proposed. To determine implement size and time required to complete tasks, proposers have three options for surface mobility: 1) part time use of NASA's large crew rover currently under development (2000 kg mass, 1.33 m wide, 4.5 m long, and 0.2 m high chasse frame, 0 to 0.67 m frame height variation capability from surface), 2) operation on a smaller dedicated ISRU rover yet to be developed, 3) optimize vehicle size to minimize total system mass and power. For option 2, interface requirements for on-going development efforts will be provided after selection. For option 3, proposers may evaluate surface mobility aspects in their proposal but cannot exceed 35% of the budget for the proposed effort.

X3.02 Oxygen Production from Lunar Regolith

Lead Center: JSC

Participating Center(s): GRC, KSC, MSFC

Oxygen (O_2) production from lunar regolith processing consists of receiving regolith from the excavation subsystem into a hopper, transferring that regolith into a chemical or an electrochemical reactor, intermediate reactions to produce O_2 and regenerate reactants if required, purification and transfer of the O_2 produced, and removal of processed regolith from the reactor to an outlet hopper. Three O_2 production from lunar regolith reaction concepts are currently under development: Hydrogen reduction, Carbothermal reduction, and Molten Oxide Electrolysis at initial lunar Outpost production scale of 1 to 2 MT per year. The production plant will utilize solar power, and two operation options are: 1) operate at polar location with solar energy available for processing to occur 70% of the year with highlands soil feedstock, and 2) operation at an equatorial location with solar energy available for processing to occur 45% of the year with mare soil feedstock. To maximize the benefits of ISRU for lunar missions, O_2 production systems must be able to produce many times their own mass in O_2 and other products, must be able to autonomously operate in a harsh environment that can have wide temperature swings, and must operate with little or no maintenance and little or no loss of reactants and O_2 while handling and processing highly abrasive lunar regolith. Systems must also be able to sustain numerous startup and shutdown sequences when solar power is not available. Shutdown periods can vary from twenty hours to 14 days.

This subtopic is seeking hardware, subsystem, and system components and technologies for insertion and integration into on-going oxygen extraction from regolith development and demonstration efforts. Component and technology areas of particular interest are:

- Move feedstock material from hopper on ground to 2 m height for reactor inlet hopper; 40 kg/hr; material size
- Inlet/outlet regolith hopper design and valve/seal concepts with no gas leakage, 1000's of operating cycles with abrasive lunar material, and minimum heat loss.
- Methods and hardware for recovering heat energy from spent regolith to pre-heat inlet regolith; 1050°C spent regolith temp, 750°C inlet regolith starting temp; 20 kg/batch.
- Molten material removal from molten electrolysis; 5 to 10 kg per batch size.
- Non-eroding cathode/anode concepts for molten oxide electrolysis; 5 to 10 kg batch size.
- Water condensers that use the space environment for water condensation/separation with minimal energy usage.
- Gas Separators that provide low pressure drop separation of the system and product gas streams from impurities (e.g. HCl, HF, H_2S, SO_2); impurities in ppm quantities.
- Microchannel methanation reactors that convert a mixture of carbon monoxide, carbon dioxide, and hydrogen to methane and water vapor with carbon monoxide and carbon dioxide consumed to the maximum extent possible.
- Advanced reactor concepts for carbothermal reduction or molten oxide electrolysis.

Phase 1 proposals should demonstrate technical feasibility of the technology or hardware concept through laboratory validation of critical aspects of the innovation proposed, as well as the design and path toward delivering hardware/subsystems in Phase 2 for incorporation into existing development activities. Interface requirements for on-going development efforts will be provided after selection. Proposers are encouraged to use the Lunar Sourcebook at a minimum for understanding lunar regolith material parameters in the design and testing of hardware proposed. It is also recommended that JSC-1a simulants be used during testing unless a more appropriate simulant can be obtained or manufactured.

X3.03 Lunar ISRU Development and Precursor Activities

Lead Center: JSC

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

The ISRU Project has initiated development and testing of hardware and systems that can achieve early lunar

Outpost needs with respect to oxygen (O_2) production from regolith and site preparation and outpost infrastructure emplacement. However, before ISRU hardware will be built and deployed on the lunar surface for Outpost operations, ISRU concepts and operations will need to be anchored through computer modeling, evaluated under simulated lunar environmental conditions (1/6 g and vacuum), and possibly on precursor flight missions. Secondly, before outpost emplacement occurs and O_2 production from lunar regolith begins, detailed knowledge of the terrain, local minerals, and potential resources is important for planning and operations at the start of establishing long-term Outpost capabilities. Lastly, while the other two ISRU subtopics are specifically aimed at increasing the fidelity and performance of on-going development activities at a scale appropriate for early lunar Outpost needs, it is recognized that evaluating the feasibility and benefits of other technologies and concepts not ready for insertion into these efforts should be pursued. With these objectives in mind, this subtopic is aimed at providing development support capabilities, sub-scale or precursor hardware that can be evaluated under simulated lunar environmental conditions (1/6 g and/or vacuum), and advanced ISRU concepts not ready for incorporation into current ISRU system laboratory and field test activities. Proposals aimed at the following are of particular interest:

- Computer models to predict excavation-tool soil interaction and flow behavior of lunar regolith under vacuum conditions and 1/6 g for hardware design and performance prediction.
- Vacuum compatible geotechnical instruments to verify soil bin characteristics; instruments that can be mounted and operated from rovers for field testing are also of interest.
- Mineral beneficiation concepts to separate iron oxide-bearing material from bulk regolith; up to 20 kg/hr based on hydrogen reduction. Hardware/concepts need to be designed for compatibility with both 1/6 g flight experiments and ground vacuum experiments.
- Lunar regolith storage and granular flow devices and instruments to evaluate and characterize regolith behavior under 1/6 g flight and ground vacuum experimental conditions.
- Advanced excavation implement concepts and hardware that can utilized to evaluate implement/soil interaction characteristics under 1/6 g flight and ground vacuum conditions.
- Development of specialty lunar simulants for beneficiation and microwave processing of lunar regolith; proposals must estimate production costs per kilogram by end of Phase 1.
- Lunar surface stabilization and regolith binding methods (including but not limited to sintering and melting) for level areas and trench/berm walls; bearing strength and smoothness requirements are not currently established but should be considered in the proposal.
- Processing concepts for production of carbon monoxide, carbon dioxide, and/or water from plastic trash and dried crew solid waste using solar thermal energy; in situ produced oxygen or other reagents/consumables must be identified and quantified; recycling schemes for reagents to minimize consumables should be evaluated.

Phase 1 proposals should demonstrate technical feasibility of the technology and/or subsystem through laboratory validation of critical aspects of the innovation proposed, as well as the design and path toward delivering hardware/subsystems in Phase 2. Hardware/concepts need to be designed for compatibility with both 1/6 g flight experiments and ground vacuum experiments.

Structures, Materials and Mechanisms Topic X4

The SBIR topic area of Structures, Materials and Mechanisms centers on developing lightweight structures, advance materials technologies, and low-temperature mechanisms for enabling Exploration Vehicles and Lunar Surface Systems.

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 that would facilitate additional logistics capacity and increased science return for all mission phases. The major technology drivers of the lightweight structure technology development are to significantly enhance structural systems by 1) lowering mass and/or improving efficient volume for reduced launch costs, 2) improving performance to reduce risk and extend life, and 3) improving manufacturing and processing to reduce costs.   The targeted application of the technology is the Ares V launch vehicle, Lunar Lander, and Lunar Surface Systems such as the crew habitats.

Low-temperature mechanism technology is being developed for reliable and efficient operation of mechanisms in lunar temperatures including operations in lunar shadows at -230°C and sustained surface operations thru varying lunar temperatures of -230°C to +120°C for lunar surface rovers, robotics, and mechanized operations. The technology drivers of the low temperature mechanism technology development are to significantly enhance operation of mechanized parts by 1) lowering the operating temperature for life of the component and 2) improving mechanism performance (torque output, actuation performance, lubrication state) at the lunar environment conditions of cold and vacuum over the required life of the mechanism. The targeted application of the technology is to provide for operation of motors and drive systems, lubricated mechanisms, and actuators of lunar rovers and mobility systems, ISRU machinery, robotic systems mechanisms, and surface operations machinery (i.e., cranes, deployment systems, airlocks) for lunar surface operations.

This topic area is to enhance and fill gaps in technology development programs in the Exploration Technology Exploration Program Structures, Materials, and Mechanisms Project. Areas of development included in the SMM project include: low temperature drive system, motor, and gearbox system, personal kit radiation shielding materials, low density parachute material systems, expandable structural systems, Friction stir welded spun-domes, and advance composite structures. This topic area is responsible for mid-level technology research, development, and testing through experimental and/or analytical validation.

Sub Topics:

X4.01 Low Temperature Mechanisms

Lead Center: GSFC

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

This subtopic focuses on the development of selected hardware and lubricants to support technologies for motors and drive systems (e.g., gear boxes) that will operate in cryogenic temperature environments such as permanently shaded craters on the Moon, and/or on the lunar surface exposed to the day/night cycle. In the former situation such mechanisms may be exposed to, and will need to operate in, sink temperatures as low as approximately 25K. In the latter situation they will need to operate over a temperature sink range of approximately 83K to 403K (-190°C to +130°C). A five year lifetime is desired. The component technologies developed in this effort will be utilized for rovers, cranes, instruments, drills, crushers, and other such facilities. The nearer term focus for this effort is for lunar missions, but these technologies should ideally be translatable to applications on Mars. These components must operate in a hard vacuum and/or planetary environment, with partial gravity, abrasive dust, and full solar and cosmic radiation exposure. Additional requirements include high reliability, ease of maintenance, low-system volume, low mass, and minimal power requirements. Low out-gassing is desirable, as are modular design characteristics, fail-safe operation, and reliability for handling fluids, slurries, biomass, particulates, and solids. While dust mitigation is not specifically included in this subtopic, proposed concepts should be cognizant of the need for such technologies. Specific areas of interest include innovative long life, light weight wide low temperature motors (in the range of 100W to 5 kWatts), gear boxes, lubricants, and closely related components that are suitable for the environments discussed above. One lubrication technology of specific interest is ionic fluids. Proposals for ionic fluid lubricant improvement should identify and/or formulate low volatility, non-corrosive extreme pressure

(EP) and anti-wear additives for ionic fluid space lubricant candidate materials. Lubricant proposals should also include a sufficient quantity of the formulated end product so as to allow standard STLE 4-ball evaluation testing, comparing neat (unformulated) base ionic fluid performance to formulated ionic fluid performance.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

X4.02 Advanced Radiation Shielding Materials and Structures

Lead Center: LaRC

Participating Center(s): ARC, GSFC, MSFC

Advances in radiation shielding materials and structures technologies are needed to protect humans from the hazards of space radiation during NASA missions. The primary area of interest for this 2008 solicitation is radiation shielding materials and structures for protection from long-duration lunar surface galactic cosmic radiation (GCR). The particular radiation species of greatest concern are protons, light ions, heavy ions, and neutrons. Research should be conducted to demonstrate technical feasibility during Phase 1 and to show a path toward a Phase 2 technology demonstration. Specific areas in which SBIR-developed technologies can contribute to NASA's overall mission requirements for advanced radiation shielding materials and structures include the following:

- Innovative lightweight radiation shielding materials and structures to shield humans in crew exploration vehicles, landers, rovers, and habitats and during lunar surface operations.
- Physical, mechanical, structural, and other relevant characterization data to validate and qualify multifunctional radiation shielding materials and structures.
- Innovative processing methods to produce quality-controlled advanced radiation shielding materials of all forms - resins, fibers, fabrics, foams, composites, light alloys, and hybrid materials.
- Innovative concepts to reuse, recycle, and reprocess materials and structures in space for use as radiation shielding materials and structures.

X4.03 Expandable Structures

Lead Center: LaRC

Participating Center(s): JPL, JSC, MSFC

X4.04 Composite Structures - NDE/Structures Health Monitoring

Lead Center: JSC

Participating Center(s): ARC, JSC, LaRC

Monitoring systems for advanced composite structures on the Exploration Program vehicles and systems lack sensors that are practically deployable. Monitoring is needed for improved robustness and reliability of composite structures or the mass advantage and performance of composites may not be realized. Adding sensors efficiently at any point in the vehicle lifetime is a necessity since some monitoring is needed for troubleshooting, validation of the loads, strain and thermal environment.

Sensors and their acquisition systems are needed that require a reduced wire infrastructure. Acoustic Emissions (AE) sensors have been shown to receive indications well out ahead of failure. Since propagation distance varies with each configuration and expected fault, many sensors will be needed to ensure composite health. The amount of wiring needed with standard approaches can offset much of the weight savings from composites and increase costs.

New AE sensor mounting methods and flexible sensors are needed that accommodate sometimes highly curved surfaces, don't fail or unbond at cryogenic tank temperatures and withstand high G loading. Very small sensors will need to be embedded at times to accommodate cases where attaching is impractical or the phenomenon can best be measured from within the composite structure.

Wireless sensors and wireless data acquisition systems with local processing of the composite structures events are needed to reduce the wiring and total data handling needs. Totally passive wireless sensor-tags can have advantages in certain applications.

Applications include: Advanced composite structures such as cryotanks, large area composites such as launch vehicle fairings, hard to access/inspect composite members, as well as metallic pressurized structures of all kinds. Interior as well as exterior measurements of the pressure vessel are needed.

Technologies: Flexible, highly efficient piezo materials for sensors, passive sensor-tags for communication, compact sensor data systems for modularity. Versions may be adaptable for acceleration, displacement/strain monitoring CEV parachutes as well for inflatable habitats.

TRL-3 should be achievable by the end of Phase 1.

TRL-6 should be achievable by the end of Phase 2.

X4.05 Composite Structures - Cryotanks

Lead Center: LaRC

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

While Aluminum-lithium may be adequate for cryotanks (for immediate use and long-term storage) the use of composite materials offers the potential of significant weight savings. Composite cryotank technology would be applicable to EDS propellant tanks, Altair propellant tanks, lunar cryogenic storage tanks and Ares V tanks.

A material system (resin + fiber) which displays high resistance to microcracking at cryogenic temperatures is necessary for linerless cryotanks which provide the most weight-saving potential. This SBIR will focus on development of toughened, high strength composite materials because the literature indicates that they have the highest microcrack resistance at cryogenic temperatures.

Greatest interest is in novel approaches to increase resin strength and/or reduce resin CTE, thereby increasing resistance to microcracking at cryogenic temperature. Possible topics could include use of toughening agents, novel surface treatments for carbon fibers, reduced-temperature curing methods that reduce residual thermal stresses, etc.

Performance enhancements would be evaluated by a characterization program, which would ideally generate temperature-dependent material properties including strength, modulus, and CTE as functions of temperature. Additionally, notch sensitivity, plain strain fracture toughness, and microcracking fracture toughness as functions of temperature are desirable.

Tests will need to be performed at temperatures between -273°C and 23°C to fully characterize any nonlinearity in material properties with changes in temperature.

Initial property characterization would be done at the coupon level in Phase 1. Generation of design allowables, characterization of long-term material durability, and fabrication of larger panels would be part of follow-on efforts.

X4.06 Composite Structures - Manufacturing

Lead Center: MSFC

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

This subtopic solicits innovative research for advanced composite materials processing and characterization concepts that support the development of lightweight structures technologies that should be applicable for space transportation vehicle systems. Interests are in advanced composite structures, which can be tailored for strength, stiffness, weight and temperature capabilities with high performance at a lower cost. Reduction in structural mass translates directly to additional up-and-down mass capability that would facilitate logistics and increase science return for future missions. Advanced composites are targeted that could be implemented into launch vehicles, lunar landers, and habitats. Innovations in technology are needed for manufacturing, processing and bonded joints for structural and cryogenic applications. Manufacturing processes of interest are automated composite fiber/tape placement, non-autoclave curing, and bonding of composite joints. Development of concepts can include material system characterization, proof-of-concept demonstrations for lightweight structures, enabling performance, and affordability (including life cycle costs) enhancement.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Demonstrate manufacturing technology that can be scaled up for very large structures.

Lunar Operations Topic X5

This call for technology development is in direct support of the Exploration Systems Mission Directorate (ESMD) Technology Development Program. The purpose of this research is to develop component level technologies to support the Constellation Program’s human lunar return missions. These initial missions will be heavily engaged in construction methods, establishing self-sustaining power generation, and producing life support consumables in situ in order to establish continuous operational capability via Earth based and lunar based assets.

The objective is to produce new technology that will reduce lunar operations workloads associated with crew extra-vehicular activities (EVA) and intra-vehicular activities (IVA), and reduce the total mass-volume-power of equipment and materials required to support both short and long duration Lunar stays. The proposals must focus on component technologies to maximize the operations of exploration hardware allowing for less expensive, more productive and less risky missions.

Lunar operations are a stepping stone toward higher exploration goals. This research focuses on technology development for the critical functions that will secure an extended human presence on the Lunar surface and ultimately enable surface exploration for the advancement of scientific achievements. Surface exploration begins with short duration missions to establish extensible functional capabilities. Successive buildup missions establish a continuous operational platform from which to conduct scientific research while on the lunar surface. Reducing risk and ensuring mission success depends on the coordinated interaction of many functional systems including life support, power, communication infrastructure, and transportation. This topic addresses technology needs associated with Lunar surface systems, interaction of humans and machines, and extended operational life-cycles of resources by way of eliminating environmental contamination of mechanisms.

Sub Topics:

X5.01 Lunar Surface Systems

Lead Center: JSC

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

The objective of this subtopic is to address projected technology needs for surface system elements supporting lunar operations. Communication integrity between lunar assets is essential during crewed translation across the lunar surface as well as during uncrewed autonomous translation of mobile assets. Navigation is essential to performing many lunar surface tasks, including exploration traverses, site surveys, material/payload transport, etc. The current lunar architecture plan for lunar surface navigation focuses on a deployed infrastructure-based solution (fixed radiometric towers, comm/nav orbiters, etc.) Although this approach is appropriate for outpost-centric operations, it is insufficient for operations in rough and steep terrain (e.g., inside deep craters) or when activity is temporarily required in regions without coverage. Commodities distribution systems (including umbilicals/connectors) will be employed to route communication and power lines to remote equipment and surface assets. These new capabilities are required to make planetary surface missions more reliable, safer, and affordable.

Maximizing the useful life of surface assets is essential to a successful lunar program. Material components must be robust and tolerate extreme temperature fluctuations and endure harsh environmental effects due to solar events, micrometeorite bombardment, and abrasive lunar dust.

Proposals are sought which address the following technology needs:

- Electrical connectors that can be repeatedly mated and de-mated (5000+ cycles) without failure in a contaminating environment consisting of regolith grain size ranging from 100um down to 10um. Capable of carrying 10kw of power transmission. Automated mating and de-mating is required.
- Lunar wireless network. Must support 15 simultaneous users with aggregate bandwidth of 80mbs at extended ranges to at least 5.6km. Must support minimum data rates of 16kbs and maximum data rates of 20mbs. Must be able to convert conventional IP stacks to SN stacks.
- Navigation and communication infrastructure technologies for use on the Lunar surface to support surface mobility and communication between lunar base, EVA astronaut and mobile rover/robotic assistant. Communication infrastructure not limited to surface-based assets but could include orbiting communication assets as well. Line of site communication must be maintained at all times. Redundant communication

paths assure constant communication link and reduce the possibility of loss of communication. Data rates in excess of 200 Mbps for comm network. Less than 100W system power. Coverage area on the order of 100 km radius from a central point.

- Passive navigation sensors to improve surface vehicle operation: collision avoidance, hazard detection, relative positioning (to artificial and natural objects). Emphasis is placed on sensors that can function in a wide range of lunar conditions (illumination, temperature, etc.)

- Flight vehicle sensors repurposed for surface use. Numerous flight sensors (low light imager, star tracker, 3D flash & scanned lidar) may be suitable for lunar surface operations if modified appropriately.

X5.02 Surface System Dust Mitigation

Lead Center: GRC

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

Lunar lander and surface systems will likely employ common hatch and airlock systems for docking, mating, and integration of spacecraft, habitat, EVA, and mobility elements. The large number of EVAs will require hatches that are safe if non-pressure assisted, and do not have to be serviced or replaced regularly.

Lunar lander will require materials and mechanisms that do not collect dust and do not abrade when in contact with lunar regolith. Technologies are also needed to remove lunar regolith, including dust, from materials and mechanisms.

Lunar Surface systems will require EVA compatible connectors for fluid, power, and other umbilicals for transfer of consumables, power, data, etc. between architecture elements that will maintain functionality in the presence of lunar regolith, including dust.

Lunar surface systems (power, mobility, etc.) will require gimbals, drives, actuators, motors, and other mechanisms with required operational life when exposed to lunar regolith, including dust.

Radiators and other thermal control surfaces for lander and surface systems must maintain performance and/or mitigate the effects of contamination from lunar regolith, including dust.

X5.03 Extravehicular Activity (EVA)

Lead Center: JSC

Participating Center(s): GRC

Proposals are sought which address the following technology needs of the advanced extravehicular activity (EVA) system:

Space suit pressure garment radiation and puncture protection technologies, dust and abrasion protection materials, flexible thermal insulation suitable for use in vacuum and low ambient pressure, and space suit low profile bearings. Technology development is needed for minimum gas loss airlocks providing quick exit and entry, suit port/suit lock systems for docking a space suit to a dust mitigating entry/hatch, and active and passive space suit and equipment dust removal technologies.

Portable life support system (PLSS) technologies that are robust, lightweight, and maintainable. PLSS technologies require a minimum of 100 EVAs x 4 life cycles (3200 hrs). High-capacity chemical oxygen storage systems for an emergency supply of oxygen, low-venting or non-venting regenerable individual life support subsystem concepts for crew member cooling, heat rejection, and removal of expired water vapor and CO_2; lightweight convection and freezable radiators for thermal control with a mass usage of water not to exceed 1.9 kg; innovative garments that provide direct thermal control to crew member.

Space suit displays, cameras, controls, and integrated systems technologies for gathering, processing, and displaying various types of information to the suited crew member, using low mass, low volume, low power, radiation hardened or tolerant equipment. Technology development is needed in the area of suit health and crew health sensors; cameras; and displays, mounted both inside and outside the space suit. Research is also needed for lightweight, low power general purpose computing platforms, such as processors or FPGAs to allow the use of on-suit software applications such as biomedical advisory algorithms, procedure displays, navigation displays, and voice recognition applications. Low computational overhead voice recognition processing systems capable of performing on lightweight radiation tolerant embedded computing platforms are also desired.

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Energy Generation and Storage Topic X6

This topic includes technology development for batteries, fuel cells, regenerative fuel cells, and fission and isotopic power systems for the Altair lunar lander and surface operations on the Moon and Mars. Technologies developed must be infused into these Constellation program elements: primary fuel cells for the Altair lunar lander descent stage, secondary batteries for the Altair ascent stage, secondary batteries for extravehicular activities (EVA) suits, and regenerative fuel cells, fission and isotopic power systems on the Moon and Mars to power habitats, in situ resource production, and mobility systems. Specific technology goals and component needs are given in the sub-topics. General mission priorities for energy storage and generation include:

- EVA suits require secondary batteries sufficient to power all portable life support, communications, and electronics for an 8-hour mission with minimal volume. Battery operation required for six months and 100 recharge cycles with a shelf life of at least two years. Mission priorities include human-safe operation; 8-hr duration; high specific energy; and high energy-density.
- Secondary batteries for the Altair ascent stage require nominally 10 recharge cycles with 1.7 kW nominal power and 2 kW peak power, operating for 7 hours continuously. Mission priorities include human-safe, reliable operation and high energy-density in a 0 – 30°C and 0 – 1/6 gravity environment.
- The Altair descent stage requires a fuel cell with a nominal power level of 3 kW with 5.5 kW peak, operating for 220 hours continuously. Mission priorities include human-safe reliable operation; the ability to scavenge available fuel; and high energy-density.
- Regenerative fuel cells, which combine a fuel cell with a water electrolyzer, have been baselined for lunar surface system operations. Mission priorities include reliable, long-duration maintenance-free operation; human-safe operation; high specific-energy; and high system efficiency in a 0 - 100°C, 1/6 gravity environment.
- Architecture studies have identified nuclear power technology to effectively satisfy high power requirements for extended duration lunar surface missions. Nuclear power generation is especially attractive for missions with significant solar eclipse periods, including non-polar locations and inside lunar craters, as well as Mars outposts.
- Power systems for lunar rovers require human-safe operation; reliable, maintenance-free operation; and high specific-energy.

Sub Topics:

X6.01 Fuel Cells for Surface Systems

Lead Center: GRC

Participating Center(s): JPL, JSC

Energy storage devices are required to enable future robotic and human exploration missions. Advanced primary fuel cell and regenerative fuel cell (RFC) energy storage systems are sought for Exploration mission applications, specifically descent for power for the Altair lander and stationary power for lunar surface bases. Technology advances that reduce the weight and volume, improve the efficiency, life, safety, system simplicity and reliability of fuel cell, electrolysis, and RFC systems are desired. The specific advancements of interest are outlined below:

Regenerative Fuel Cell (RFC) Systems: Primary fuel cells, water electrolyzers, and associated balance-of-plant hardware constitute a RFC system. Performance of fuel cell and electrolysis system functions through passive means and the elimination of as many ancillary components as possible have been identified as the most direct approach to achieving mission efficiency, life, and reliability goals. Specifically, technological advances are sought in the following areas:

- Static Cathode Water Vapor Feed Electrolysis Cell: Preliminary system studies have shown that static cathode feed electrolyzers have the most potential for system simplicity and the fewest number of ancillary components. Proton-exchange-membrane (PEM) electrolysis technology is sought that electrolyzes water vapor supplied to the hydrogen evolving electrode. The electrolysis cell should operate at balanced pressures up to 2000 psi and must not require circulation of hydrogen to transport the water to the electrolysis cell cathode. The exiting hydrogen and oxygen must not contain liquid water droplets, but may contain water vapor.
- Passive Fuel Cell or Electrolysis Cell Heat Removal/ Thermal Control: Passive thermal control of individual cells within a fuel cell or electrolysis stack has the potential to eliminate actively pumped liquid coolant loops. A highly thermally conductive heat pipe plate that is also electrically conductive is sought to passively remove the heat from the individual fuel cells or electrolysis cells within a cell stack. The flat plates that are sought should have a thermal conductivity exceeding 2000 W/m/K, a thickness of <= 0.050 inches, a resistivity of <= 0.2 ohm-cm, and a bulk density of <= 3 grams/cm^3.

- Fuel Cell/ Electrolysis Cell Voltage Monitor Application Specific Integrated Circuit (ASIC): A cell voltage monitoring ASIC has the potential to eliminate a number of discreet electrical components within a fuel cell, electrolysis, or RFC electrical control system. An ASIC is sought that monitors up to 48 differential cell voltages (0-2 VDC) with

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

X6.02 Advanced Space-Rated Batteries

Lead Center: GRC

Participating Center(s): JPL, JSC

Advanced human-rated energy rechargeable batteries are required for future robotic and human exploration missions. Advanced Li-based battery systems are sought for use on Exploration mission applications including power for landers, rovers, and Extravehicular activities (EVA). Areas of emphasis include advanced component materials with the potential to achieve weight and volume performance improvements and safety advancements in human-rated systems.

Rechargeable lithium-based batteries with advanced non-toxic anode and cathode materials and nonflammable electrolytes are of particular interest. The focus of this solicitation is on advanced cell components and materials to provide weight and volume improvements and safety advancements that contribute to the following cell level metrics:

- Specific energy of 300 Wh/kg @ C/2 discharge rate and 0°C;
- Energy density greater than 500 Wh/l;
- Calendar life of 5 years.

The cycle life requirements for these missions are relatively benign; the cycle life required at 100% Depth of Discharge (DOD) is in the range of 250 cycles.

Systems that combine all of the above characteristics and demonstrate a high degree of safety and reliability are desired. Innovative solutions that offer the cell level characteristics described above are of particular interest. Proposals are sought which address:

- Advanced cathodes with specific capacities >= 300 mAh/g at C/2 rate discharge and 0°C, and/or
- Advanced anodes with specific capacities >= 600 mAh/g at C/2 and 0°C with minimal irreversible capacity loss,
- Nonflammable electrolytes, and/or
- Electrolytes that are stable up to 5 volts.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

Cryogenic Systems Topic X7

The Exploration Systems architecture presents cryogenic storage, distribution, and fluid handling challenges that require new technologies to be developed. Reliable knowledge of low-gravity cryogenic fluid management behavior is lacking and yet is critical for Altair and Ares in the areas of storage, distribution, and low-gravity propellant management. Additionally, Earth-based and lunar surface missions will require success in storing and transferring liquid and gas commodities. Some of the technology challenges are for long-term cryogenic propellant storage and distribution; cryogenic fluid ground processing and fluid conditioning; liquid hydrogen and liquid oxygen liquefaction processes on the lunar surface. Furthermore, specific technologies are required in valves, regulators, instrumentation, modeling, mass gauging, cryocoolers, and passive and active thermal control techniques. The

technical focus for component technologies are for accuracy, reduced mass, minimal heat leak, minimal leakage, and minimal power consumption. The anticipated technologies proposed are expected to increase reliability, increase cryogenic system performance, and are capable of being made flight qualified and/or certified for the flight systems and dates to meet Exploration Systems mission requirements.
Sub Topics:

X7.01 Cryogenic Storage for Space Exploration Applications

Lead Center: ARC

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

This subtopic includes technologies for long-term cryogenic propellant storage applications in-space, on the lunar surface, and on the Earth. These technologies will impact cryogenic systems for space transportation orbit transfer vehicles, space power systems, spaceports, spacesuits, lunar habitation systems, robotics, in situ propellant systems, and launch site ground operations. Each of these applications has unique performance requirements that need to be met. Innovative concepts are requested for cryogenic insulation systems, fluid system components, and cryogenic conditioning systems.

Long term storage (14 days) of LO_2/ LH_2 cryogenic propellants in low-gravity with minimal propellant loss is required to support space transportation orbit transfer vehicles. The Earth Departure Stage (EDS) and the Altair (Lunar Lander) descent stage require LH_2 and LO_2 storage durations of 14 days in Low Earth Orbit (LEO). Long-term storage (224 days) of LO_2/ LCH_4 cryogenic propellants in low-gravity and reduced gravity with minimal propellant loss is required to support space transportation orbit transfer vehicles. The Altair (Lunar Lander) ascent stage requires LO_2 and LCH_4 storage durations of up to 14 days in LEO and up to an additional 210 days on the lunar surface. Long term storage (224 days) of LO_2 cryogenic propellant on the lunar surface and liquefaction of resource with minimal propellant loss is required to support space power systems, spaceports, spacesuits, lunar habitation systems, robotics, in situ propellant systems. Long term storage (6 months) of LO_2/ LH_2/ LCH_4 cryogenic propellants in 1-g on the surface of the Earth with minimal propellant loss is required to support launch site ground operations. Passive and active thermal control, and pressure control/ thermodynamic venting technologies are sought after.

In-space Storage and Lunar Surface Storage

Passive thermal control serves to limit the heat leak into the cryogenic storage system (LH_2 loss 2 loss 4 loss

Active thermal control combines the passive thermal control technology element with active refrigeration (cryocoolers) to allow storage periods from a few months to years with reduced boil-off losses (LH_2 loss 2 loss 2) cryocoolers of sufficient cooling capacity (20 watts) to eliminate LH_2 boil-off do not exist, and thus the development of 20K cryocoolers is a long-lead technology item. State-of-the-art cryocoolers in the 80K range (LO_2/LCH_4 temperatures) have been developed for cooling sensors and have flown on numerous satellites. However, the integration of these cryocoolers into an active thermal control system for propellant storage of LO_2 and LH_2 is a technology issue. Active thermal control development needs include: flight-type 20K, 20 watt capacity cryocoolers designed for integration into space-based LH_2 storage systems, integrated refrigeration and storage systems, innovative heat exchanger concepts, flight cryocooler to propellant tank integration techniques for large space-based storage systems, distributed cooling shields integrated with MLI, circulator development, development and testing of active cooling techniques for tank penetrations and supports is required.

Pressure control utilizes thermodynamic venting in low-gravity or direct venting in partial gravity to enable selective venting of vapor if necessary (ratio of kilograms of TVS mass per watt of heat removal from $LH_2$2 4 2, LO_2 and LCH_4 to determine the effect of internal tank hardware configuration on fluid mixing.

Earth-based Storage

Passive and active thermal control serves to limit the heat leak into the cryogenic storage system and eliminate cryogen boil-off, but not limited by mass or reliability typically associated with flight systems (LH_2 loss 2 loss 4 loss

X7.02 Cryogenic Fluid Transfer and Handling

Lead Center: KSC

Participating Center(s): GRC, GSFC, JSC

Cryogenic fluid transfer and handling for spacecraft propulsion systems, launch facility ground processing, and Lunar surface systems are critical to the advancement of NASA's exploration goals. Technology development in cryogenic fluid transfer and handling directly supports the Lunar Lander, Ground Operations, Ares, and Lunar Surface Systems programs. Specifically, for Earth-based applications, propellant conditioning and cryogenic densification technologies are required. Propellant conditioning systems are needed to help control the state of the propellant that is loaded into the flight tank at the launch pad. Other technologies are primarily for active control of cryogenic propellants for densification or subcooling on the launch pad as well as liquefaction on the lunar surface.

Component technologies for cryogenic fluid transfer include regulators, valves, umbilicals, quick disconnects, pumps, distribution line insulation materials and techniques, and thermal standoffs for LH_2, LO_2, LCH_4 and cold GHe (~90K). Cryogenic components using advanced actuation technologies such as piezoelectric ceramics which demonstrates reduced heat flux into the cryogenic fluids as compared to conventional electromechanical actuators is highly desirable. Operating ranges for these components should include but are not limited to normal boiling point (NBP) LH_2 and NBP LO_2 components rated for 50 - 100 psia, NBP LO_2 and below NBP LCH_4 components rated for 100 - 400 psia, and cold GHe (~90K) components rated for 400 to 4,500 psia. The technical focus for these components are for reduced thermal mass, minimal heat leak, minimal leakage, and minimal power consumption. Analytical tools for the design and/or analysis of cryogenic fluid transfer components are also needed. These tools should focus on providing analytical capabilities, which directly correspond to cryogenic fluid component design or thermal analysis.

Advanced transfer systems capable of delivering high quality of liquid over a wide flow range between 100 GPM and 1000 GPM are sought. Liquid oxygen pumps that minimize fluid heating while allowing for a range of flowrates are also needed. Propellant subcooling or densification systems for LOX, LH_2 and LCH_4 are required, to provide for extended storage duration on orbit prior to boil off. These systems should be sized to accommodate the Altair propulsion system. Densification systems should offer reliability and efficiency benefits over past systems. Anti-stratification concepts to ensure homogeneous fluid conditions in the flight tank are needed, and better transfer line insulation to minimize heat leak are required. Connections and recirculation systems to maintain propellant state in the flight tank are also desired.

On the lunar surface, oxygen may be produced via an in situ resource utilization reactor. Efficient liquefaction of this oxygen will depend on integration of the liquefier with the gas production stream. Open cycle liquefaction systems must interface with the high-pressure electrolysis systems at the output of the reactor. Compact, low temperature radiators capable of rejecting 50-100W of heat at 140K to deep space are needed for passive cooling prior to the final liquefaction steps. High efficiency, low mass recuperative heat exchangers are needed for effective heat transfer between gas streams. Innovative heat rejection systems designed for the lunar thermal environment are needed. Heat pumps to increase the high temperature heat rejection point of the cycle can also be proposed.

Next, hydrogen cooling and/or liquefaction are required for lunar surface applications involving regenerative fuel cell systems. Efficient 20K cryocooler technology is needed. Reliquefaction systems should be capable of meeting hydrogen flowrates around 1 gram/second. Open cycle hydrogen cooling systems with low temperature isentropic expansion from 3000 psi to the desired storage pressure are needed. Heat switch technology to control energy flow during the lunar day/night cycle will also be considered.

X7.03 Cryogenic Instrumentation for Ground and Flight Systems

Lead Center: GRC

Participating Center(s): JSC, KSC, MSFC

This subtopic includes technologies for reliable, accurate cryogenic propellant instrumentation needs in-space, on the lunar surface, and on the Earth. These technologies will impact cryogenic systems for space transportation orbit transfer vehicles, space power systems, spaceports, lunar habitation systems, in situ propellant systems, and launch site ground operations. Innovative concepts are requested to enable accurate measurement of cryogenic liquid mass in low-gravity storage tanks with and without propellant settling, to enable the ability to detect in-space and on-pad leaks from the storage system, and address other cryogenic instrumentation needs. Cryogenic propellants such as hydrogen, methane, and oxygen are required for many current and future space missions. Operating efficiency and reliability of these cryogenic systems must be improved considering the launch environment, operations in a space environment, and system life, cost, and safety. Proposed technologies should offer enhanced safety, reliability, or economic efficiency over current state-of-the-art, or should feature enabling technologies to allow NASA to meet future space exploration goals.

Mass Gauging technologies will principally impact cryogenic systems for space transportation orbit transfer vehicles. Mass gauging provides accurate measurement of cryogenic liquid mass (LH_2, LO_2, and LCH_4) in low gravity storage tanks, and is critical to allowance of smaller propellant tank residuals in assuring mission success. Both low-gravity mass-gauging (measurement uncertainty

Leak detection technologies impact cryogenic systems for space transportation orbit transfer vehicles, lunar surface, and launch site ground operations. These systems will be operational both in atmospheric conditions and in vacuum with multiple sensor systems distributed across the vehicle or a region of interest to isolate leak location. Methane and hydrogen leak detection sensors with milli-second response times and 1 ppm detection sensitivity in air are desired for ground and launch operations.

Other cryogenic instrumentation needs include minimally invasive cryogenic liquid flow measurement sensors for rocket engine feed lines, and sensors to detect and quantify two-phase flow (bubbles) within the feed lines.

Protection Systems Topic X8

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

Sub Topics:

X8.01 Detachable, Human-Rated, Ablative Environmentally Compliant TPS

Lead Center: ARC

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

The technologies described below support the goal of developing higher performance TPS materials and integrated entry systems architectures for higher performance CEV as well as future Exploration missions.

Development of TPS materials for maximum reliability and survivability with minimized mass requirements, under severe combined convective and radiative heating, including development of acreage materials, adhesives, joints, penetrations, deployables, inflatables and seals.

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. This leads to higher fidelity design tools, risk reduction, decreased heat shield mass and a direct payload increase.

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 themselves have the proper integrity and are free of voids or defects.

Advances are sought in ablation modeling, including radiation, convection, gas surface interactions, pyrolysis, coking, and charring. There is a specific need for improved models for low density charring ablators.

Advances in Multidisciplinary Design Optimization (MDO) are sought specifically in application to address combined aerothermal environments, material response, vehicle shape, vehicle size, aerodynamic stability, mass, and cross-range, characterizing the entry vehicle design problem.

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

Exploration Crew Health Capabilities Topic X9

Human space flight is associated with losses in muscle strength, bone mineral density and aerobic capacity. Crewmembers returning from the International Space Station (ISS) can lose as much as 10-20% of their strength in weight bearing and postural muscles. Likewise; bone mineral density is decreased at a rate of ~1% per month. Although aerobic capacity has not been formally measured in returning ISS crew, short duration Space Shuttle crewmembers have been shown to undergo a 22% reduction in VO2max in response to space flight. During future exploration missions such physiological decrements represent the potential for a significant loss of human performance which could lead to mission failure and/or a threat to crewmember health and safety. The ability to estimate the physical cost of exploration tasks, monitor crew health and fitness, and to provide effective hardware for exercise countermeasures use will be valuable in supporting safe and successful space exploration. Exercise systems is seeking technologies or devices to provide resistive and aerobic exercise in flight, monitor a crewmember inflight fitness state or simulate an Extra Vehicular Activity (EVA) suit on the ground.
Sub Topics:

X9.01 Crew Exercise System

Lead Center: GRC

Participating Center(s): JSC

Compact, reliable, multi-function exercise devices/systems are required to protect bone, muscle, and cardiovascular health during lunar outpost missions (missions with total duration less than 6 months). This device should be easily configured and stowed, require minimal power to operate, include instrumentation to document exercise session parameters including portable electronic media, and require minimum periodic calibration (no more than 2 times per year). The device must be capable of providing whole body axial loading and individual joint resistive loading that ideally simulates free weights. If unable to match the inertial properties of free weights, then the device must provide near constant loading at any given load setting and achieve an eccentric to concentric load ratio greater than 90%. The load must be adjustable in increments no greater than 2.5 kgs and provide adequate loading to protect muscle strength and bone health such that post-mission muscle strength is maintained at or above 80% of baseline values; bone mass DEXA T score must not exceed – 2.0 S.D. below the mean bone mineral density at mission’s end. The same device must be capable of providing whole-body aerobic exercise levels necessary to maintain aerobic capacity at or above 75% of baseline VO2max. Finally, the ideal device should also stimulate the sensory-motor system which controls balance and coordination.

A small, lightweight, sensor-based fitness monitoring system that can be used to assess periodic fitness during lunar outpost missions and transit to Mars is also desired. Devices should be small, employ re-usable elements (versus requiring consumables), and be minimally invasive to measure heart rate and rhythm, oxygen consumption and lactic acid threshold. The ideal system would also include other medical monitoring capabilities such that it could be utilized to assess other crew health variables (e.g., imaging capabilities, respiration rate, blood parameters, etc.).

The Exercise Systems subtopic is also seeking a wearable suit or system that simulates the mechanical properties of the current extravehicular space suit. System should be lightweight (less than 30 pounds), easy to don/doff (especially in the supine position), replicate the mechanical properties of a space suit (in terms of resistance to motion and mass and inertia), and able to be worn during conduct of simulated lunar tasks that last up to 4 hours. Suit system must be adjustable to accommodate individuals of different height and weight. Joints of primary interest to simulate in this system are the shoulder, elbow, trunk, hip, and knee.

Phase 1 Requirements: Phase 1 expectations would be a fully developed concept, complete with feasibility analyses and top-level drawings. A breadboard or prototype is highly desired.

Exploration Medical Capability Topic X10

The Exploration Medical Capability Topic is soliciting research and technology development for key areas of crew health maintenance, including injury/illness treatment scenarios. The Vision for Space Exploration presents significant new challenges to crew health care capabilities. These challenges include the hazards created by the terrain of lunar or planetary surfaces that may be difficult to traverse during exploration, the effects of gravity transitions, low gravity environments, and limited communications with ground-based personnel for diagnosis and consultation. Each challenge has associated medical implications and medical requirements and technologies to ensure safety and success. The areas of concern for the ExMC that are targeted in this solicitation include: Non-toxic In-flight Sprain/Strain Therapeutic Treatment; Through-suit Medication Delivery in a Reduced Pressure Environment; Reusable Diagnostic Lab Analysis Technology; Biosensors for Lunar EVA Suits; and a Lightweight/compact Oxygen Concentrator. Proposals may respond to one or more of these areas.

Sub Topics:

X10.01 In Flight Diagnosis and Treatment

Lead Center: JSC

Participating Center(s): ARC, GRC

Proposals may respond to one or more of the following areas:

Non-Toxic Sprain/Strain Treatment

With longer missions and more labor intensive tasks expected in the Constellation Program, the likelihood of musculoskeletal injuries such as sprains and strains are expected to increase. Standard terrestrial therapeutic response to treating sprains and strains is to provide cold compress or heat treatment to the affected area. The focus of this subtopic is to develop a reusable cold compress and/or heat treatment that can be stowed in its inactive state in the vehicle’s ambient environment, activated to provide the desired therapeutic relief, recharged using available vehicle resources, and restowed in its inactive state for future use. This capability is desired on the International Space Station and all Constellation Program vehicles that support missions involving labor intensive tasks or exercise countermeasures. Efforts should be made to minimize the volume and mass footprint of the deployed system so that when activated and treating the patient, the patient will have mobility and free movement to continue with mission tasks and objectives. The cold compress and heat treatment capability can be provided through separate systems and does not necessarily have to be the same piece of hardware. The materials used shall be non-toxic in the quantities provided. Current terrestrial solutions are undesirable due to the chemicals involved, onetime use designs or requirement for pre-cooling (e.g., freezer) or pre-heating (e.g., microwave) devices.

Phase 1 Requirements: Phase 1 would include trade studies with reports and down select recommendation. A prototype is preferable.

Phase 2 Requirements: Phase 2 would deliver a working prototype and documentation packages for NASA safety and design reviews.

Reusable Diagnostic Lab Technology

On-board clinical diagnostics to monitor crew member physiology must be available for both mid-term lunar and long-term Mars exploration missions. As in terrestrial medicine, devices with which to measure multiple constituents of small volume samples of bodily fluids are crucial components in assessing astronaut health. Nevertheless, mass, space, and power requirements of such devices are an obvious concern in an environment with scarce resources. Miniaturized laboratory analysis sensors represent a potential solution, given that these devices and supporting hardware are designed to be small, lightweight, and require little power. However, current sensor cartridges are typically single-use with limited shelf life. In order to satisfy the needs of longer duration exploration missions, reusable laboratory analysis sensors with increased shelf life must be designed without compromising accuracy or sensitivity. NASA seeks proposals for developing such reusable laboratory analysis sensors for analysis of bodily fluids, including blood, urine and saliva. The ability to analyze whole blood for a complete blood count with differential and hemoglobin is essential. Priority will be given to designs which also incorporate onboard detection capabilities for other analytes, such as electrolytes, lipids, proteins and hormones. Multiplexed systems providing runtime selection of the assay suite are also desirable. The detection system should minimize the use of electrical power, external optics or other infrastructure, and the use of reagents and additives. The device can rely on a PC or PDA for signal processing and display if desired, but the footprint of all other components should be tightly controlled. The best design will require minimal user interaction for processing or maintenance.

Phase 1 Requirements: During Phase 1, research should be conducted to demonstrate technical feasibility with a draft end item functional requirements document. Phase 1 will also produce documentation showing a viable path to a Phase 2 breadboard demonstration.

Lightweight/Compact Oxygen Concentrator

Concentrated oxygen for medical use is a consumable that when used cannot be replenished. Due to relatively low metabolic consumption, a large percentage of the concentrated oxygen is not consumed but is instead released into the vehicle’s cabin where it offers minimal medical use and is essentially wasted. This release of concentrated oxygen leads to increased ambient oxygen levels to the point where the vehicle oxygen fire limit will be exceeded. An effective solution to both these issues involves use of an oxygen concentrator that can take ambient air and re-concentrate the oxygen providing medical grade oxygen and removing excess oxygen from the vehicle cabin. However, oxygen concentrator technology to date is mostly large, massive, and power intensive. The focus of this subtopic is to develop a small, lightweight, portable oxygen concentrator that can produce concentrated medical oxygen using ambient vehicle cabin air. Of particular interest is oxygen concentration technology that can produce at minimum 60% oxygen at 4-6 liters per minute. Efforts should be made to minimize the volume, mass, and power draw of the system. The oxygen concentrator will use vehicle power as its primary source of power; however there is a brief need for battery power for when the patient is transported between vehicles. This technology is desired on ISS and future exploration vehicles supporting long duration missions.

Phase 1 Requirements: Phase 1 deliverables should include trade studies with down select criteria and recommendations for which technology will best meet the O_2 concentrator figures of merit. A requirements document for a Phase 2 prototyping effort should also be included.

X10.02 EVA Suit Monitoring and Treatment

Lead Center: JSC

Participating Center(s): ARC, GRC

Proposals may respond to one or more of the following areas:

Through-Suit Medication Delivery

NASA operations concepts envision contingencies where astronauts may be required to wear Extra Vehicular Activity (EVA) suits for up to 120 hours. If a crewmember requires medication while in a suit, a method of administration must be developed that does not compromise the integrity of the suit, nor the environment it provides. Current concepts for the EVA suit include a self-sealing diaphragm through which injections could be given. However, fluid management in microgravity presents problems with filling a syringe and delivering medication in such an environment. The three main concerns are preventing bubbles from being injected, appropriate fluid management, and excessive volume requirements for pre-loaded syringes. Due to uncertainties about when such an event might occur, the system would have to function in the range of gravity levels between 0 to 1G, as well as pressure levels from vacuum to 1 atmosphere, and require very little volume and no power. Accordingly, NASA seeks proposals detailing concepts for such a system.

Phase 1 Requirements: Phase 1 would include appropriate trade studies, design concepts, and any limited laboratory proof-of-concept testing required to support Phase 2 development.

Phase 2 Requirements: Phase 2 would include fabrication, testing, and validation of breadboard hardware that could be delivered to NASA for evaluation at the conclusion of Phase 2. Phase 2 would be a commercial system that NASA or a prime contractor could integrate within the Exploration Medical Kit.

Biosensors for Lunar EVA Suits

During surface Extravehicular Activities (EVAs), it is anticipated that the flight surgeons will need the ability to monitor heart rate, heart rhythm (ECG), derived core body temperature, and calculated metabolic rate to ensure the health and safety of the crewmember. Of particular interest are technologies that would allow data to be collected, with minimal crew time or effort required to don/doff the measurement hardware, while also maintaining crew comfort (i.e., sensors NOT involving skin preparation, gels, or taping). Also of interest are technologies/systems that would allow the collection of robust, diagnostic quality signals even during periods of strenuous lunar surface operations (lifting, climbing ladders, recovering from falls, and assembling structures).

Phase 1 Requirements: Phase 1 should deliver prototype functioning sensors, but not necessarily in their final form. A report showing prototype function versus a benchmark system’s function will be provided. Also a roadmap to getting to the final sensor will be provided.

Phase 2 Requirements: Phase 2 should deliver sensors in their spaceflight-friendly, miniaturized form. Data from spaceflight analog testing using protocols delivered from NASA will also be expected.

Behavioral Health and Performance Topic X11

The Behavioral Health and Performance topic is interested in developing strategies, tools, and technologies to mitigate Behavioral Health and Performance risks. The Behavioral Health and Performance topic is seeking tools and technologies to prevent performance degradation, human errors, or failures during critical operations resulting from: fatigue or work overload; deterioration of morale and motivation; interpersonal conflicts or lack of team

cohesion, coordination, and communication; team and individual decision-making; performance readiness factors (fatigue, cognition, and emotional readiness); and behavioral health disorders. For 2008, the Behavioral Health and Performance topic is interested in the following technologies: Crew Cohesion Monitoring Technologies; Behavioral Assessment Tools; and an Individualized Fatigue Meter. Proposals may respond to one or more of these areas.
Sub Topics:

X11.01 Behavioral Assessment Tools

Lead Center: JSC

During Exploration Missions, and especially during a Mars Mission, real time communication between the crew and flight surgeons and crew and mission control will not be available as it is now on ISS and the Shuttle. Flight surgeons have stated the need for unobtrusive monitoring tools that are transparent to crews, require minimal crew time or effort, and that help detect if crews are having difficulties with coping with the spaceflight environment. The aim of this subtask is to provide tools that will automatically generate feedback for astronauts and flight surgeons, regarding team cohesion and behavioral health status of crews in-flight.

Requirements for Behavioral Assessment Tools:

- Be unobtrusive;
- Be transparent to crews;
- Require minimal crew time or effort.

Proposals may respond to one or more of the following areas:

Crew Cohesion Monitoring Technology

Detect if crews are having difficulty with team cohesion within the spaceflight environment.

Phase 1 Requirements: Phase 1 will involve an assessment of current methods through which to monitor/measure cohesion within the military and other agencies will be provided. Recommendations regarding enhancements to current technology or the development of a new technology will be presented. The spaceflight environment (current and future) and models related to team cohesion will be assessed in order to determine the optimal requirements for developing a Crew Cohesion Technology suitable for NASA human space exploration. The resulting deliverable will be requirements for a Crew Cohesion Monitoring Technology.

Phase 2 Requirements: Phase 2 requires the development of a prototype Crew Cohesion Monitoring Technology based on accurate models and Phase 1 findings. The prototype will include the hardware, manual and trouble-shooting guide, and results from evaluation and testing the functionality of the prototype device.

Behavioral Health Assessment Tool

Detect if crews are facing increased risk related to interpersonal and psychosocial issues, or other behavioral health problems, and provide feedback to the crewmember and flight surgeon.

Phase 1 Requirements: During Phase 1, the current and future spaceflight environment will be assessed in order to determine the optimal requirements for providing Behavioral Health Assessment tools suitable for NASA human space exploration. An analysis of current methods through which to assess behavioral health status will be provided. Recommendations regarding enhancements to current technology (and how these enhancements will be implemented), or the development of a new technology will be presented. These recommendations will be documented along with a plan to take to Phase 2.

Phase 2 Requirements: Phase 2 requires the development of a prototype Behavioral Health Assessment Technology based on accurate models and Phase 1 findings. The prototype will include the hardware, manual and trouble-shooting guide, and results from evaluation and testing the functionality of the prototype device.

Individualized Fatigue Meter

Design and/or enhance a fatigue meter that would provide immediate feedback to the individual regarding their specific alertness or fatigue levels. Specifically, the feedback from the Fatigue Meter shall be based at a minimum, on the following factors, but other relevant factors can be included:

- A clear, concise method for indicating alertness or fatigue state to the user;
- Length and restfulness of sleep;
- Quantity and quality of physical activity;
- Wavelength and timing of light exposure;
- Heart rate;
- Body temperature.

Phase 1 Requirements: Fatigue Meter Evaluation – A market analysis and a literature review of the state of the art current tools will be conducted. Recommendations regarding enhancements to current technology (and how those enhancements will be implemented), or the development of a new technology will be presented. The spaceflight environment (current and future) and mathematical models related to sleep and performance will be assessed in order to determine the optimal requirements for developing a Fatigue Meter suitable for human space exploration. These recommendations will be documented along with a plan to take to Phase 2.

Phase 2 Requirements: Fatigue Meter Prototype developed based on accurate models and Phase 1 findings. Develop prototype hardware. Develop manual and trouble-shooting guide. Evaluate and test the functionality of the prototype device.

Space Human Factors and Food Systems Topic X12

The new Vision for Space Exploration encompasses needs for innovative technologies in the areas of Space Human Factors and Food Systems. Operations in confined, isolated, and foreign environments can lead to impairments of human performance. Research and development activities in the Space Human Factors and Food Systems topic address challenges that are fundamental to design and development of the next generation crewed space vehicles. These challenges include: 1) understanding the requirements for information feedback to the crew and developing technologies to ensure these requirements are met, 2) building tasks and tools that are compatible with humans and that enable human performance consistent with mission success, and 3) providing extended shelf life foods with improved nutritional content, quality and reduced packaging mass. This Topic seeks methods for monitoring, modeling, and predicting human performance in the spaceflight environment. The Space Human Factors and Food Systems is seeking new Space Human Factors Assessment Tools and Advanced Food Technologies that utilize non-foil barriers and allow food processing or preparation in a reduced gravity and pressure environment.

Sub Topics:

X12.01 Space Human Factors Assessment Tools

Lead Center: JSC

Operations in confined, isolated, and foreign environments can lead to impairments of human performance. This subtopic seeks methods for monitoring, modeling, and predicting human performance in the spaceflight environment for accurate and valid human system integration into vehicle design and operations. In particular, the Space Human Factors Engineering Project within the Human Research Program is interested in obtaining timely and context-specific Human Factors (HF) incident data. Currently, space HF data come from crew debriefs. Such debriefs rely on retrospective recall, which could suffer delays of up to six months. Furthermore, opportunities to discuss HF issues in detail during these debriefs are limited. Consequently, the HRP sees the need to develop an automated human factors incident reporting tool.

Objective: Development of tool that assists the gathering and reporting HF incidents for long-duration space missions.

Requirements: In general, the tool will be used to help detect areas where HF can contribute to mission success, assess the effects of operational and hardware changes, and complement existing HF data sources for operations. Specifically, the tool shall meet the following requirements:

1. The crew shall have easy access to the tool at any time to eliminate the need for the crew to recall information retrospectively.
2. An easy-to-use data gathering protocol with the following functionalities: Allow data to be entered either as text, audio, and/or video inputs,
3. It is desirable for tool to detect a system anomaly automatically and immediately record system status. At a minimum, however, the tool should provide an easily accessible event marker for the crew to mark the context and take a snapshot of the system and operator system status.
4. Provide a user-friendly automated data search engine for extracting meaningful incident information from the raw data. Examples of desirable search schemes include natural language, spatial, temporal searches, etc.

Phase 1 Requirements: The technical merit of the tool will be explored to evaluate feasibility. The Phase 1 report will include results of the evaluation/research/ or development of automated data mining technologies, definition of optimal data gathering protocol(s), and recommendations for optimal hardware/software design. Development of hardware and software algorithms is highly desirable.

Phase 2 Requirements: Development of a working tool prototype, with documentation of functionality and usability evaluation and testing.

X12.02 Advanced Food Technologies

Lead Center: JSC

The purpose of the Advanced Food Technology Project is to develop, evaluate and deliver food technologies for human centered spacecraft that will support crews on missions to the Moon, Mars, and beyond. Safe, nutritious, acceptable, and varied shelf-stable foods with a shelf life of 3 - 5 years will be required to support the crew during future exploration missions to the Moon or Mars. Concurrently, the food system must efficiently balance appropriate vehicle resources such as mass, volume, water, air, waste, power, and crew time. One of the objectives during the lunar outpost missions is to test technologies that can be used during the Mars missions. This subtopic will concentrate on two specific areas; food packaging and lunar outpost food preparation and food processing.

Non-Foil High Barrier Materials

Development of shelf-stable food items that use high-quality ingredients is important to maintaining a healthy diet and the psychosocial well being of the crew. Shelf-life extension may be attained through new food preservation methods and/or packaging. New food packaging technologies are needed that have adequate oxygen and water barrier properties to maintain the foods' quality over a 3 - 5 year shelf life. The packaging must also minimize waste by using high barrier packaging with less mass and volume. The current flexible pouch packaging used for the thermostabilized and irradiated food items contains a layer of foil. Although the foil provides excellent oxygen and water barrier properties, it also contributes to added waste. Food packaging will be a major contributor to the trash on the lunar or Mars surface. One of the proposed methods to dispose of trash on the lunar or Mars surface is incineration. However, the foil layer will not incinerate completely and there will be ash formed. Two emerging food preservation technologies, high pressure processing and microwave processing, are being considered for future NASA missions. However, the current high barrier packaging material cannot be used for these processes. The material delaminates during high pressure processing and cannot be used in microwave processing. Hence, any food packaging material developed in response to this subtopic should be compatible with one or more of the following food preservation technologies: retort processing, microwave processing, and/or high pressure processing. In addition, the material should have an oxygen transmission rate that shall not exceed 0.06 cc/m^2/24 hrs/atm and a water vapor transmission rate that shall not exceed 0.01 gm/m^2/24 hrs as stated in the MIL-PRF 33073F specification.

Effect of Partial Gravity and Reduced Atmospheric Pressure

It will require approximately 10,000 kg of packaged food for a 6-crew, 1000 day mission to Mars. For that reason, it has been proposed to use a food system which incorporates processing of raw ingredients into edible ingredients and uses these edible ingredients in recipes in the galley to produce meals. This type of food system will require food processing and food preparation equipment. The equipment should be miniaturized, multipurpose and efficiently use vehicle resources such as mass, volume, water, and power. Food preparation may include gourmet kitchen appliances such as food processors or bread makers in addition to the standard stove and oven. Proposed food processing equipment may include a mill to produce wheat and soy flour, a soy milk/tofu processor, and a concentrator. The Moon's gravity is 1/6 of Earth's gravity. In addition, it is being proposed that the habitat will have a reduced atmospheric pressure of 8 psia which is equivalent to a 16,000 foot mountain top. These two factors will affect the heat and mass transfer during food processing and food preparation of the food. Heat transfer is required for proper microbial kill and to produce the desired texture and appearance of the food prior to consumption. At this pressure, the boiling temperature of water will be 181°F which has significant implications for preventing microbial contamination and to acceptable food quality. Prior to any design of food processing or preparation equipment, the effects of partial gravity and partial atmospheric pressure as it relates to fluid management, heat and mass transfer and chemical reactions must be determined. Once the effects are determined, methods to overcome these effects must be developed. All of this needs to happen prior to any fabrication of actual food processing or food preparation equipment that can be used in the Lunar Habitat.

The response to this subtopic should include a plan to either (1) develop food packaging technologies that respond the above requirements, or (2) develop a technology which will aid in determining the effects of reduced cabin pressure and reduced gravity and/or (3) develop a technology that will enable safe and timely food processing and food preparation in reduced cabin pressure and reduced gravity.

Phase 1 Requirements: Phase 1 should concentrate on the scientific, technical, and commercial merit and feasibility of the proposed innovation resulting in a feasibility report and concept, complete with analyses and top-level drawings.

Space Radiation Topic X13

The goal of the NASA Space Radiation Research Program is to assure that we can safely live and work in the space radiation environment, anywhere, any time. Space radiation is different from forms of radiation encountered on Earth. Radiation in space consists of high-energy protons, heavy ions and secondary products created when the protons and heavy ions pass through spacecraft shielding and human tissue. The Space Radiation Program Element, within the Human Research Program uses the NASA Research Announcement as a primary means of soliciting research to understand the health risks and reduce the uncertainties in risk projection; however, there are areas where the SBIR program contributes. Specific areas where SBIR technologies can contribute to NASA's overall goal include: reliable radiation monitoring for manned and unmanned spaceflight; and radiation damage imaging.

Sub Topics:

X13.01 Active Charged Particle and Neutron Radiation Measurement Technologies

Lead Center: ARC

Participating Center(s): JSC

The goal of the NASA Space Radiation Research Program is to assure that we can safely live and work in the space radiation environment, anywhere, any time. Space radiation is different from forms of radiation encountered on Earth. Radiation in space consists of high-energy protons, heavy ions and secondary particles created when the protons and heavy ions pass through spacecraft and human tissue.

Areas of Interest: Charged particles (protons and heavy ions) and secondary radiations, such as neutrons, contribute the most significant fraction to the total dose-equivalent received by astronauts. At present, NASA has active detectors on International Space Station (ISS) that measure the microdosimetric quantities and the charge and energy spectra of the space radiation field. Neutron specific data are included as part of the microdosimetric measurements. For Exploration class missions, however, more compact and reliable active detection systems will be needed to make microdosimetric, charge, and energy measurements of the total space radiation environment. Advanced technologies (up to technology readiness level 4) are requested.

Subtopic Requirements/Needs:

Tissue Equivalent Microdosimeter

NASA has a need for small/low-mass/low-power microdosimeter to support Exploration class missions. The microdosimeter should be capable of performing single event microdosimetric measurements of tissue equivalent volumes with simulated diameters of 1-2 micrometers. The microdosimeter should be sensitive to lineal energies of 0.2 - 1000 keV/micron. Design goals for mass and volume should be 2 kg and 2000 cm^3, respectively. The microdosimeter should be able to measure charged particles and neutrons in ambient conditions in space (0.01 mGy/hr) and during a large solar particle event (100 mGy/hr). The time resolution of the lineal energy measurements should be less than or equal to 1 minute.

Charged Particle Spectrometer

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

Neutron Spectrometer

Systems are needed specifically to measure the neutron component of the dose and provide the neutron dose-equivalent in real time. Of interest would be compact active monitoring devices that could measure neutron energy spectra. The principal energies of interest are neutrons from 0.5 MeV to 150 MeV. The spectrometer should be able to measure neutrons at ambient conditions such that proton/ion veto capability should be approaching 100% at solar minimum galactic cosmic radiation (GCR) rates. The spectrometer should be able to measure ambient dose equivalent of 0.02 mSv in a 1 hour measurement period, using ICRP 74 (1997) conversion factors. Design goals for mass and volume should be 5 kg and 6000 cm^3, respectively. The spectrometer shall store all necessary science data and unfolding/processing algorithms shall be determined and provided for post measurement data evaluation.

Phase 1 Requirements: Expected deliverable for Phase 1 is a detailed report that (1) establishes proof of concept; (2) addresses the scientific, technical and commercial merit and feasibility of the proposed technology and its relevance and significance to one or more NASA needs within the Solicitation; and (3) provides a preliminary strategy that addresses key technical, market, business factors, demonstration of the proposed innovation, and its transition into products for NASA mission programs and other potential customers.

X13.02 Technology/Technique for Imaging Radiation Damage at the Cellular Level

Lead Center: JSC

New quantitative techniques need to be developed in order to assess astronauts’ exposure to space radiation. Charged particles (protons and heavy ions) are of major concern for health risks because they cause chromosome damage. Current methods for measuring space radiation chromosome damage are time consuming and have limitations in sensitivity and accuracy. The Space Radiation Element within the Human Research Program seeks a sensitive, accurate method for assessing chromosome damage, while at the same time being less time consuming than current mFISH and mBand techniques.

Subtopic Requirements/Needs: Of particular interest are ground laboratory techniques using fluorescence in situ hybridization to detect various types of chromosome damage. The technique should be able to measure charged particle exposure at both ambient conditions in space (0.005 mGy/hr) and during a large solar particle event (1000 mGy/hr). The technique should be able to detect various types of chromosome damage such as inversions and deletions in various regions of chromosomes. The technique must be able to quantify chromosome abnormalities that persist after space flight.

Phase 1 Requirements: Phase 1 expectations include a report describing the fully developed concept with feasibility analyses and comparisons to existing methods.

Inflight Biological Sample Preservation and Analysis Topic X14

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

Sub Topics:

X14.01 On Orbit Ambient Biological Sample Preservation Techniques

Lead Center: JSC

Measurement of blood and urine analytes is a common clinical medicine practice used for differential disease diagnosis and determination of the therapeutic response to treatment. Accurate biochemical results depend on maintaining the integrity of blood and urine samples until analyses can be completed. Improper sample collection, handling, or preservation may lead to critical errors in diagnostic interpretation of analytical results. Traditional methods have been developed that include the use of sample component separation by means of centrifugation, refrigeration, freezing or the addition of preservatives to maintain the integrity of biological samples. While such techniques are easily achieved in a routine clinical setting, the spaceflight environment presents unique challenges to sample processing and stowage. Diagnosis, treatment and research of health-related issues in human crewmembers during their confinement in the remote spaceflight environment depend on the ability to maintain the analytical integrity of biological samples. Thus, novel on-orbit methods for the ambient preservation of biological samples are critical for scientific research, monitoring of crew health and evaluation of countermeasure efficacy. The Dried Chemistry Technology developed at NASA/JSC represents one approach to the collection and preservation of in-flight blood and urine samples. Briefly, whole blood collected by venipuncture into flight-certified tubes is applied either directly to special filter cards, or alternatively, serum or plasma separated from the red cells by means of the ISS refrigerated centrifuge is applied to the filter cards. Urine samples can also be applied directly to the filter cards. The whole blood, plasma, serum, or urine filter cards are then dried and stored at ambient temperature pending analyses which may require that they be returned to Earth. Many analytes in blood and urine samples prepared and stored by means of the NASA/JSC Dried Chemistry Technology are stable for several months. The development of alternative innovative techniques with advantages over currently used methods for processing and preserving biological samples at ambient temperatures during spaceflight that provide a high level of reliability in maintaining a wide array of both blood and urine analytes over a long period of ambient stowage is highly desirable.

Phase 1 Requirements: Phase 1 expectations include at a minimum a fully developed concept with feasibility analyses and top-level drawings. A breadboard or prototype is highly desirable.

X14.02 On Orbit Cell Counting and Analysis Capability

Lead Center: JSC

Cell counting and analysis within the clinical hematology/immunology area generally refers to identification and enumeration of various populations of white blood cells in the peripheral blood. This capability has direct clinical relevance, as peripheral cell populations may expand (proliferation in response to pathogen, hematological malignancy) or contract (sequestered at localized site of inflammation) related to specific disease states. In medicine, the complete blood count, white blood count and CD4+ T cell counts are examples of routinely used cell counting assays. Instrumentation typically used for automated analysis includes hematology analyzers and flow cytometers. Hematology instruments generally accept unstained cells for analysis and differentiate the subpopulations based on scatter properties alone. Flow cytometers require pre-staining of specific cell surface proteins with fluorescent dyes, the emission of which will be optically detected by the cytometer upon excitation with an onboard laser. Flow cytometers may range from large, multi-laser/multi-color instruments with sorting capability, to miniaturized bench top instruments with diode lasers and less capability. NASA is interested in developing a microgravity-compatible instrument capable of on-orbit cell counting. This instrument could support medical testing of crewmembers as well as various research activities. The instrument technology is not constrained, and might range from typical cytometer fluidics, a micro fluidics approach, or some other novel method for resolving and counting cells. It is generally believed that typical sheath-fluid based cell focusing, used in standard flow cytometers, is not desirable due to microgravity incompatibility and operational constraints (fluid volume, mass and waste constraints). Extremely miniaturized and lightweight instrumentation, without high-energy lasers, and requiring minimal sample volume or exogenous (sheath) fluid to operate, and generating minimal biohazardous waste would have the greatest chance for success. An associated sample processing system may be required, that would stain, lyse or otherwise process the whole blood or cell sample is anticipated. The instrument should be capable of deriving absolute counts, in addition to the relevant percentage of various cell subpopulations.

Phase 1 Requirements: Phase 1 expectations would be at a minimum a fully developed concept, complete with feasibility analyses and top-level drawings. A breadboard or prototype is highly desired.

Automation for Vehicle and Habitat Operations Topic X1.01

Automation will be instrumental for decreasing workload, reducing dependence on Earth-based support staff, enhancing response time, and releasing crew and operators from routine tasks to focus on those requiring human judgment, leading to increased efficiency and reduced mission risk. To enable the application of intelligent automation and autonomy techniques, the technologies need to address two significant challenges: adaptability and software validation. Reusable automation software must be adaptable to new applications without undue difficulty, and easily adjusted as the application operations change. The software and the adaptation to a given application must also be trusted before it can be accepted. Proposals are solicited in the areas of:

Automation Support Tools

Support tools are needed to facilitate the authoring and validation of plans and execution scripts. Tools that are not tied specifically to one executive would provide NASA the most flexibility in applying such tools across projects. Examples of needed capabilities include:

- Graphical tool for monitoring and debugging plan execution;
- Graphical tool for creating and editing execution scripts;
- Tools for authoring and validating execution plans;
- User friendly abstraction of low-level execution languages by adding syntactic enhancements.

Decision Support Systems

Decision support systems amplify the efficiency of operators by providing the information they need when and where they need it. Decision support tools are needed that:

- Command and supervise complex tasks while projecting the outcome of actions and identify potential problems;
- Understand system state, including visualization and summarization;
- Allow the system to interact with a user when generating the plan and allow evaluation of alternate courses of action;
- Integrate a planning and scheduling system as part of an on-board, closed loop controller;
- Scale up existing techniques to larger problem applications.

Trustable Systems

Systems that support or interact with crew require a very high level of reliability. Tools are needed that improve the reliability and trustworthiness of autonomous systems. These include:

- Ability to predict what the system will do;
- Guarantees of behavioral properties;
- Other properties that increase the operator's trust;
- Verifiability (e.g., restricted executive languages that facilitate model-based verification).

Sub Topics:

Radiation Hardened/Tolerant and Low Temperature Electronics and Processors Topic X1.03

The goal of leaving low Earth orbit for the purpose of human and robotic exploration will require avionic systems and components that are capable of operating in the extreme temperature and radiation environments of deep space, the lunar surface, and eventually the Martian surface. Spacecraft vehicle electronics will be required to operate across a wide temperature range and must be capable of enduring frequent (and often rapid) thermal-cycling. Packaging for these electronics must be able to accommodate the mechanical stress and fatigue associated with the thermal cycling. Spacecraft vehicle electronics must be radiation hardened for the target environment. They must be capable of operating through a total ionizing dose (TID) of 100 krads (Si) or more and providing single-event latchup immunity (SEL) of 100 MeV cm^2/mg or more.

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

- Low power, high efficiency, radiation-hardened processor technologies optimized for numerically intensive algorithms and applications, capable of a sustained processor throughput of 5 GMACS for 16-bit operations and a sustained processor efficiency of 5 GMACS/W.
- Field Programmable Gate Array technologies providing reliable reprogrammable capabilities that are radiation hardened by design and/or radiation hardened by process.
- Innovative radiation hardened volatile and nonvolatile memory technologies.

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

Sub Topics:
Spacecraft Cabin Ventilation and Thermal Control Topic X2.01

Advanced technologies are sought for cabin ventilation and thermal management for next generation human spacecraft including lunar lander, lunar habitat, and pressurized rovers.

Spacecraft Ventilation

Controlling acoustic noise levels within spaceflight vehicles is needed to provide for adequate voice and ground communications, habitability, and alarm audibility. This will become very important with longer duration missions such as Lunar Habitat and Mars missions. Past experience has shown that controlling acoustic noise levels inside the spacecraft depend upon development of quiet ventilation system and environmental control system fans and pumps, as well as inclusion of effective noise controls to reduce the noise that is created (i.e., source and path technologies).

Advances are sought in the general areas of source noise-level reduction, vibration isolation, acoustic absorption, and sound blocking and sealing (i.e., source and packaging). Noise reduction technology should achieve significant noise reductions (> 5dB) with minimal impacts to performance characteristics (pressure rise and flow rate). Noise reductions and performance capabilities should be demonstrated. Materials should meet flight requirements for flammability, frangibility, and off-gassing. Ventilation fans and fluid pumps are the major source of interior spacecraft noise. Fan and pump technologies that prevent the generation of acoustic noise or limit its transmission to mounting structure or surrounding air are desired. Technologies achieving 5 dB or greater attenuation and accommodating variable equipment speeds, variable acoustic spectrums, and atmospheric pressures from 8 to 15 psia are required.

Thermal Control Systems

Future spacecraft will require more sophisticated thermal control systems that can dissipate or reject greater heat loads at higher input heat fluxes while using fewer of the limited spacecraft mass, volume and power resources. The thermal control designs also must accommodate the harsh environments associated with these missions including dust and high sink temperatures. Modular, reconfigurable designs could limit the number of required spares.

The lunar environment presents several challenges to the design and operation of active thermal control systems. During the Apollo program, landings were located and timed to occur early in the lunar day, resulting in a benign thermal environment. The long duration polar lunar bases that are foreseen in 15 years will see extremely cold thermal environments, as will the radiators for Martian transit spacecraft. Long sojourns remote from low-Earth orbit will require lightweight, but robust and reliable systems.

Innovative thermal management components and systems are needed to accomplish the rejection of heat from lunar bases. Advances are sought in the general areas of radiators, thermal control loops and equipment. Variable emissivity coatings, clever working fluid selection, or robust design could be used to prevent radiator damage from freezing at times of low heat load. Also, the dusty environment of an active lunar base may require dust mitigation and removal techniques to maintain radiator performance over the long term.

The lunar base may include high efficiency, long life mechanical pumps. Part of the thermal control system in the lunar base is likely to be a condensing heat exchanger, which should be designed to preclude microbial growth. Small heat pumps could be used to provide cold fluid to the heat exchanger, increasing the average heat rejection temperature and reducing the size of the radiators.

Thermal management of the lunar habitat, landers, and rovers may require mechanically pumped two-phase fluid loops. Innovative design of the loops and components is needed.

Future space systems may generate large amounts of waste heat which could either be rejected or redirected to areas which require it. Novel thermal bus systems which can obtain, transport, and reject heat between various components are sought. The system should be highly configurable and adaptable to changes in equipment locations. Large diurnal temperature changes in the environment are expected. Possible systems include single and two-phase pumped fluid loops, capillary-based loops, and heat pumps.

A scaling methodology is needed to allow long term 1-g testing of two-phase systems (including pumped two-phase loops, heat pumps, and condensing heat exchangers) representative of the 1/6th Earth-normal gravity of the Moon.

Sub Topics:
Spacecraft Cabin Atmospheric Resource Management and Particulate Matter Removal Topic X2.02
Particulate Matter Removal and Disposal

Particulate matter suspended in the habitable cabin atmosphere is a challenge for all phases of exploration missions. Removing and disposing of particulate matter originating from sources internal to the habitable cabin and from surface dust intrusion is of interest. Process technologies and equipment that efficiently remove the range of particulate matter sizes and morphologies encountered in a crewed spacecraft cabin from the atmosphere and surfaces are sought. Candidate technology solutions should provide high efficiency and long-lived removal capacity. Successful process technologies must be tolerant of the abrasive properties of lunar surface dust. Performance should be demonstrated with appropriate lunar dust analogs or simulants. Process technologies sought must be highly efficient and promote safe disposal of accumulated particulate matter. Areas of emphasis include:

- Removal and Disposal of Fine Particulate Matter Suspended in a Cabin Atmosphere: It is hypothesized that fine particulate matter introduced into the cabin will be detrimental to crew health. Filtration technologies are sought that will limit the levels of lunar dust contaminants of less than 10 micron size in the cabin atmosphere below 0.05 mg/m^3 while providing significantly improved capture efficiency with minimal pressure drop. These may include but are not limited to mechanical filtration, inertial separation and impingement, and electrostatic and/or electrically enhanced separation solid-gas processes that are light-weight, low power and operate at reduced atmospheric pressures. Process technologies that offer both improved efficiency and are suitable for in situ regeneration as described below are preferred. Novel techniques and materials are of interest.

- Regenerative Processes and Filters: Regenerable solid-gas separations techniques and process technologies are sought that effectively handle a broad size range from >100 microns in aerodynamic diameter to
- Vacuum Cleaner for Planetary Surface Vehicles and Habitats: Portable crew-operated devices for removing particulate matter from a wide range of surfaces (polymer, metallic, and fabric), operating at cabin atmospheric pressures ranging from 8 to 15 psia, and minimizing electrical power and acoustic noise generation are of interest. Successful devices may employ several of the above mentioned processes or filtration systems to remove a wide range of particulate matter sizes up to 2 mm in aerodynamic diameter without contaminating the air with ultrafine particulates. The ability for the portable device to be operated as a supplemental, portable cabin air filtration unit is a plus.

Atmospheric Resource Management

Atmospheric resource management encompasses process technologies and equipment to supply, store, and condition atmospheric gases; provide gaseous oxygen at pressures at or above 3,600 psia; and achieve mass closure by recycling resources and using in situ resources. Areas of emphasis include:

- Carbon Dioxide Reduction for Recovery of Oxygen: Process technologies for reducing carbon dioxide to a carbon product via high single-pass reaction efficiency with a product yield >90% are of interest. Successful process technologies and/or process technology unit operations combinations must demonstrate efficient power use and address safety issues associated with traditional reduction processes.

- High Pressure Oxygen Gas Supply: Process technologies leading to an on-demand, in-flight renewable source of oxygen at or above 3,600-psia are of interest. Process technologies employed for achieving these needs may include mechanical compressors, temperature or pressure-swing adsorption compressors, high pressure electrolytic oxygen production or other novel means.

Sub Topics:
Spacecraft Environmental Monitoring and Control Topic X2.04

Sub Topics:
Spacecraft Fire Protection Topic X2.05
NASA's fire protection strategy includes: strict control of ignition sources and flammable material, early detection and annunciation of fire signatures, and effective fire suppression and response procedures. While proposals in all of these areas are applicable, they are particularly sought in the areas of nonflammable crew clothing and fire suppression technology.

The requirements for crew clothing are balanced between comfort, durability, and flammability. Non-flammable alternatives are requested for shirts, shorts, sweaters, jackets, etc. and, ideally, would be available in a variety of colors and weights. For exploration missions, clothing should be nonflammable up to 34% O_2 by volume without being stiff and uncomfortable. The flammability characteristics of the clothing must be maintained through the recommended cleaning process.

Fire suppression technologies for exploration spacecraft and habitats must:

- Be applicable for use in a confined habitable volume having an atmosphere of up to 34% O_2 by volume and pressures as low as 7.6 psia;

- Be suitable for use in a portable fire extinguisher against fires behind panels and close-outs or the cabin open volume;
- Have minimal mass and volume requirements including consumables required for post-fire clean-up; and
- Be compatible with the spacecraft environmental control and life support system.

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

Sub Topics:

Lunar Regolith Excavation and Material Handling Topic X3.01

The lunar regolith excavation, handling, and material transportation subtopic includes all aspects of lunar regolith handling for oxygen and other resource collection and site preparation and Outpost infrastructure emplacement, including tasks such as clearing/leveling landing areas and pathways, buildup of berms and burying of reactors or habitats for radiation protection. Excavation capabilities may involve excavation and collection of both unconsolidated and consolidated surface regolith. Hardware must be able to operable over broad temperature ranges (generally 110K to 400K) and in the presence of abrasive lunar regolith and partial-gravity environments. Expectations for maintenance by crew must be minimal and affordable. Therefore, general attributes desired for all proposed hardware include the following: lightweight, abrasion resistant, vacuum and large temperature variation compatible materials, low power, robust/low maintenance, and minimize dust generation/saltation during operation. Specific software and hardware for insertion into on-going ISRU Project development and demonstration activities include:

- Excavation hardware for oxygen production: Unconsolidated material, 17 kg/hr based on hydrogen reduction, <10 cm deep; avoid or mitigate rocks >5 cm diameter (See note on mobility platform below).
- Excavation hardware for deep digging: Consolidated material, 3 m deep and 1 meter in diameter at a minimum; (See mobility platform note below).
- Granular materials mixing and separation for reactor feedstock conditioning: remove material > 0.5 cm diameter before dumping into storage bin during excavation operation for oxygen extraction from regolith.
- Dust tolerant, lightweight mechanisms and actuators for excavation and material transport operations.
- Site preparation hardware, automation, and control for surface contouring and area clearing and leveling.
- Site preparation hardware, automation, and control for berm building; 3 meters tall; 45 degree slope minimum based on landing plume mitigation.

Phase 1 proposals should demonstrate technical feasibility of the technology and/or subsystem through laboratory validation of critical aspects of the innovation proposed, as well as the design and path toward delivering hardware/subsystems in Phase 2 for incorporation into existing development activities.

Proposers are encouraged to use the Lunar Sourcebook at a minimum for understanding lunar regolith material parameters in the design and testing of hardware proposed. To determine implement size and time required to complete tasks, proposers have three options for surface mobility: 1) part time use of NASA’s large crew rover currently under development (2000 kg mass, 1.33 m wide, 4.5 m long, and 0.2 m high chasse frame, 0 to 0.67 m frame height variation capability from surface), 2) operation on a smaller dedicated ISRU rover yet to be developed, 3) optimize vehicle size to minimize total system mass and power. For option 2, interface requirements for on-going development efforts will be provided after selection. For option 3, proposers may evaluate surface mobility aspects in their proposal but cannot exceed 35% of the budget for the proposed effort.

Sub Topics:

Oxygen Production from Lunar Regolith Topic X3.02

Oxygen (O_2) production from lunar regolith processing consists of receiving regolith from the excavation subsystem into a hopper, transferring that regolith into a chemical or an electrochemical reactor, intermediate reactions to produce O_2 and regenerate reactants if required, purification and transfer of the O_2 produced, and removal of processed regolith from the reactor to an outlet hopper. Three O_2 production from lunar regolith reaction concepts are currently under development: Hydrogen reduction, Carbothermal reduction, and Molten Oxide Electrolysis at initial lunar Outpost production scale of 1 to 2 MT per year. The production plant will utilize solar power, and two operation options are: 1) operate at polar location with solar energy available for processing to occur 70% of the year with highlands soil feedstock, and 2) operation at an equatorial location with solar energy available for processing to occur 45% of the year with mare soil feedstock. To maximize the benefits of ISRU for lunar missions, O_2 production systems must be able to produce many times their own mass in O_2 and other products, must be able to autonomously operate in a harsh environment that can have wide temperature swings, and must operate with little or no maintenance and little or no loss of reactants and O_2 while handling and processing highly abrasive lunar regolith. Systems must also be able to sustain numerous startup and shutdown sequences when solar power is not available. Shutdown periods can vary from twenty hours to 14 days.

This subtopic is seeking hardware, subsystem, and system components and technologies for insertion and integration into on-going oxygen extraction from regolith development and demonstration efforts. Component and technology areas of particular interest are:

- Move feedstock material from hopper on ground to 2 m height for reactor inlet hopper; 40 kg/hr; material size
- Inlet/outlet regolith hopper design and valve/seal concepts with no gas leakage, 1000's of operating cycles with abrasive lunar material, and minimum heat loss.
- Methods and hardware for recovering heat energy from spent regolith to pre-heat inlet regolith; 1050°C spent regolith temp, 750°C inlet regolith starting temp; 20 kg/batch.
- Molten material removal from molten electrolysis; 5 to 10 kg per batch size.
- Non-eroding cathode/anode concepts for molten oxide electrolysis; 5 to 10 kg batch size.
- Water condensers that use the space environment for water condensation/separation with minimal energy usage.
- Gas Separators that provide low pressure drop separation of the system and product gas streams from impurities (e.g. HCl, HF, H_2S, SO_2); impurities in ppm quantities.
- Microchannel methanation reactors that convert a mixture of carbon monoxide, carbon dioxide, and hydrogen to methane and water vapor with carbon monoxide and carbon dioxide consumed to the maximum extent possible.
- Advanced reactor concepts for carbothermal reduction or molten oxide electrolysis.

Phase 1 proposals should demonstrate technical feasibility of the technology or hardware concept through laboratory validation of critical aspects of the innovation proposed, as well as the design and path toward delivering hardware/subsystems in Phase 2 for incorporation into existing development activities. Interface requirements for on-going development efforts will be provided after selection. Proposers are encouraged to use the Lunar Sourcebook at a minimum for understanding lunar regolith material parameters in the design and testing of hardware proposed. It is also recommended that JSC-1a simulants be used during testing unless a more appropriate simulant can be obtained or manufactured.

Sub Topics:

Lunar ISRU Development and Precursor Activities Topic X3.03

The ISRU Project has initiated development and testing of hardware and systems that can achieve early lunar Outpost needs with respect to oxygen (O_2) production from regolith and site preparation and outpost infrastructure emplacement. However, before ISRU hardware will be built and deployed on the lunar surface for Outpost operations, ISRU concepts and operations will need to be anchored through computer modeling, evaluated under simulated lunar environmental conditions (1/6 g and vacuum), and possibly on precursor flight missions. Secondly, before outpost emplacement occurs and O_2 production from lunar regolith begins, detailed knowledge of the terrain, local minerals, and potential resources is important for planning and operations at the start of establishing long-term Outpost capabilities. Lastly, while the other two ISRU subtopics are specifically aimed at increasing the fidelity and performance of on-going development activities at a scale appropriate for early lunar Outpost needs, it is recognized that evaluating the feasibility and benefits of other technologies and concepts not ready for insertion into these efforts should be pursued. With these objectives in mind, this subtopic is aimed at providing development support capabilities, sub-scale or precursor hardware that can be evaluated under simulated lunar environmental conditions (1/6 g and/or vacuum), and advanced ISRU concepts not ready for incorporation into current ISRU system laboratory and field test activities. Proposals aimed at the following are of particular interest:

- Computer models to predict excavation-tool soil interaction and flow behavior of lunar regolith under vacuum conditions and 1/6 g for hardware design and performance prediction.
- Vacuum compatible geotechnical instruments to verify soil bin characteristics; instruments that can be mounted and operated from rovers for field testing are also of interest.
- Mineral beneficiation concepts to separate iron oxide-bearing material from bulk regolith; up to 20 kg/hr based on hydrogen reduction. Hardware/concepts need to be designed for compatibility with both 1/6 g flight experiments and ground vacuum experiments.
- Lunar regolith storage and granular flow devices and instruments to evaluate and characterize regolith behavior under 1/6 g flight and ground vacuum experimental conditions.
- Advanced excavation implement concepts and hardware that can utilized to evaluate implement/soil interaction characteristics under 1/6 g flight and ground vacuum conditions.
- Development of specialty lunar simulants for beneficiation and microwave processing of lunar regolith; proposals must estimate production costs per kilogram by end of Phase 1.
- Lunar surface stabilization and regolith binding methods (including but not limited to sintering and melting) for level areas and trench/berm walls; bearing strength and smoothness requirements are not currently established but should be considered in the proposal.
- Processing concepts for production of carbon monoxide, carbon dioxide, and/or water from plastic trash and dried crew solid waste using solar thermal energy; in situ produced oxygen or other reagents/consumables must be identified and quantified; recycling schemes for reagents to minimize consumables should be evaluated.

Phase 1 proposals should demonstrate technical feasibility of the technology and/or subsystem through laboratory validation of critical aspects of the innovation proposed, as well as the design and path toward delivering hardware/subsystems in Phase 2. Hardware/concepts need to be designed for compatibility with both 1/6 g flight experiments and ground vacuum experiments.

Sub Topics:

Low Temperature Mechanisms Topic X4.01

This subtopic focuses on the development of selected hardware and lubricants to support technologies for motors and drive systems (e.g., gear boxes) that will operate in cryogenic temperature environments such as permanently shaded craters on the Moon, and/or on the lunar surface exposed to the day/night cycle. In the former situation such mechanisms may be exposed to, and will need to operate in, sink temperatures as low as approximately 25K. In the latter situation they will need to operate over a temperature sink range of approximately 83K to 403K (-190°C to +130°C). A five year lifetime is desired. The component technologies developed in this effort will be utilized for rovers, cranes, instruments, drills, crushers, and other such facilities. The nearer term focus for this effort is for lunar missions, but these technologies should ideally be translatable to applications on Mars. These components must operate in a hard vacuum and/or planetary environment, with partial gravity, abrasive dust, and full solar and cosmic radiation exposure. Additional requirements include high reliability, ease of maintenance, low-system volume, low mass, and minimal power requirements. Low out-gassing is desirable, as are modular design characteristics, fail-safe operation, and reliability for handling fluids, slurries, biomass, particulates, and solids. While dust mitigation is not specifically included in this subtopic, proposed concepts should be cognizant of the need for such technologies. Specific areas of interest include innovative long life, light weight wide low temperature motors (in the range of 100W to 5 kWatts), gear boxes, lubricants, and closely related components that are suitable for the environments discussed above. One lubrication technology of specific interest is ionic fluids. Proposals for ionic fluid lubricant improvement should identify and/or formulate low volatility, non-corrosive extreme pressure (EP) and anti-wear additives for ionic fluid space lubricant candidate materials. Lubricant proposals should also include a sufficient quantity of the formulated end product so as to allow standard STLE 4-ball evaluation testing, comparing neat (unformulated) base ionic fluid performance to formulated ionic fluid performance.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

Sub Topics:

Advanced Radiation Shielding Materials and Structures Topic X4.02

Advances in radiation shielding materials and structures technologies are needed to protect humans from the hazards of space radiation during NASA missions. The primary area of interest for this 2008 solicitation is radiation shielding materials and structures for protection from long-duration lunar surface galactic cosmic radiation (GCR). The particular radiation species of greatest concern are protons, light ions, heavy ions, and neutrons. Research should be conducted to demonstrate technical feasibility during Phase 1 and to show a path toward a Phase 2 technology demonstration. Specific areas in which SBIR-developed technologies can contribute to NASA's overall mission requirements for advanced radiation shielding materials and structures include the following:

- Innovative lightweight radiation shielding materials and structures to shield humans in crew exploration vehicles, landers, rovers, and habitats and during lunar surface operations.
- Physical, mechanical, structural, and other relevant characterization data to validate and qualify multifunctional radiation shielding materials and structures.
- Innovative processing methods to produce quality-controlled advanced radiation shielding materials of all forms - resins, fibers, fabrics, foams, composites, light alloys, and hybrid materials.

- Innovative concepts to reuse, recycle, and reprocess materials and structures in space for use as radiation shielding materials and structures.

Sub Topics:
Expandable Structures Topic X4.03

Sub Topics:
Composite Structures - NDE/Structures Health Monitoring Topic X4.04
Monitoring systems for advanced composite structures on the Exploration Program vehicles and systems lack sensors that are practically deployable. Monitoring is needed for improved robustness and reliability of composite structures or the mass advantage and performance of composites may not be realized. Adding sensors efficiently at any point in the vehicle lifetime is a necessity since some monitoring is needed for troubleshooting, validation of the loads, strain and thermal environment.

Sensors and their acquisition systems are needed that require a reduced wire infrastructure. Acoustic Emissions (AE) sensors have been shown to receive indications well out ahead of failure. Since propagation distance varies with each configuration and expected fault, many sensors will be needed to ensure composite health. The amount of wiring needed with standard approaches can offset much of the weight savings from composites and increase costs.

New AE sensor mounting methods and flexible sensors are needed that accommodate sometimes highly curved surfaces, don't fail or unbond at cryogenic tank temperatures and withstand high G loading. Very small sensors will need to be embedded at times to accommodate cases where attaching is impractical or the phenomenon can best be measured from within the composite structure.

Wireless sensors and wireless data acquisition systems with local processing of the composite structures events are needed to reduce the wiring and total data handling needs. Totally passive wireless sensor-tags can have advantages in certain applications.

Applications include: Advanced composite structures such as cryotanks, large area composites such as launch vehicle fairings, hard to access/inspect composite members, as well as metallic pressurized structures of all kinds. Interior as well as exterior measurements of the pressure vessel are needed.

Technologies: Flexible, highly efficient piezo materials for sensors, passive sensor-tags for communication, compact sensor data systems for modularity. Versions may be adaptable for acceleration, displacement/strain monitoring CEV parachutes as well for inflatable habitats.

TRL-3 should be achievable by the end of Phase 1.

TRL-6 should be achievable by the end of Phase 2.

Sub Topics:
Composite Structures - Cryotanks Topic X4.05
While Aluminum-lithium may be adequate for cryotanks (for immediate use and long-term storage) the use of composite materials offers the potential of significant weight savings. Composite cryotank technology would be applicable to EDS propellant tanks, Altair propellant tanks, lunar cryogenic storage tanks and Ares V tanks.

A material system (resin + fiber) which displays high resistance to microcracking at cryogenic temperatures is necessary for linerless cryotanks which provide the most weight-saving potential. This SBIR will focus on development of toughened, high strength composite materials because the literature indicates that they have the highest microcrack resistance at cryogenic temperatures.

Greatest interest is in novel approaches to increase resin strength and/or reduce resin CTE, thereby increasing resistance to microcracking at cryogenic temperature. Possible topics could include use of toughening agents, novel surface treatments for carbon fibers, reduced-temperature curing methods that reduce residual thermal stresses, etc.

Performance enhancements would be evaluated by a characterization program, which would ideally generate temperature-dependent material properties including strength, modulus, and CTE as functions of temperature. Additionally, notch sensitivity, plain strain fracture toughness, and microcracking fracture toughness as functions of temperature are desirable.

Tests will need to be performed at temperatures between -273°C and 23°C to fully characterize any nonlinearity in material properties with changes in temperature.

Initial property characterization would be done at the coupon level in Phase 1. Generation of design allowables, characterization of long-term material durability, and fabrication of larger panels would be part of follow-on efforts.

Sub Topics:

Composite Structures - Manufacturing Topic X4.06

This subtopic solicits innovative research for advanced composite materials processing and characterization concepts that support the development of lightweight structures technologies that should be applicable for space transportation vehicle systems. Interests are in advanced composite structures, which can be tailored for strength, stiffness, weight and temperature capabilities with high performance at a lower cost. Reduction in structural mass translates directly to additional up-and-down mass capability that would facilitate logistics and increase science return for future missions. Advanced composites are targeted that could be implemented into launch vehicles, lunar landers, and habitats. Innovations in technology are needed for manufacturing, processing and bonded joints for structural and cryogenic applications. Manufacturing processes of interest are automated composite fiber/tape placement, non-autoclave curing, and bonding of composite joints. Development of concepts can include material system characterization, proof-of-concept demonstrations for lightweight structures, enabling performance, and affordability (including life cycle costs) enhancement.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Demonstrate manufacturing technology that can be scaled up for very large structures.

Sub Topics:

Lunar Surface Systems Topic X5.01

The objective of this subtopic is to address projected technology needs for surface system elements supporting lunar operations. Communication integrity between lunar assets is essential during crewed translation across the lunar surface as well as during uncrewed autonomous translation of mobile assets. Navigation is essential to performing many lunar surface tasks, including exploration traverses, site surveys, material/payload transport, etc. The current lunar architecture plan for lunar surface navigation focuses on a deployed infrastructure-based solution (fixed radiometric towers, comm/nav orbiters, etc.) Although this approach is appropriate for outpost-centric operations, it is insufficient for operations in rough and steep terrain (e.g., inside deep craters) or when activity is temporarily required in regions without coverage. Commodities distribution systems (including umbilicals/connectors) will be employed to route communication and power lines to remote equipment and surface assets. These new capabilities are required to make planetary surface missions more reliable, safer, and affordable.

Maximizing the useful life of surface assets is essential to a successful lunar program. Material components must be robust and tolerate extreme temperature fluctuations and endure harsh environmental effects due to solar events, micrometeorite bombardment, and abrasive lunar dust.

Proposals are sought which address the following technology needs:

- Electrical connectors that can be repeatedly mated and de-mated (5000+ cycles) without failure in a contaminating environment consisting of regolith grain size ranging from 100um down to 10um. Capable of carrying 10kw of power transmission. Automated mating and de-mating is required.
- Lunar wireless network. Must support 15 simultaneous users with aggregate bandwidth of 80mbs at extended ranges to at least 5.6km. Must support minimum data rates of 16kbs and maximum data rates of 20mbs. Must be able to convert conventional IP stacks to SN stacks.
- Navigation and communication infrastructure technologies for use on the Lunar surface to support surface mobility and communication between lunar base, EVA astronaut and mobile rover/robotic assistant. Communication infrastructure not limited to surface-based assets but could include orbiting communication assets as well. Line of site communication must be maintained at all times. Redundant communication paths assure constant communication link and reduce the possibility of loss of communication. Data rates in excess of 200 Mbps for comm network. Less than 100W system power. Coverage area on the order of 100 km radius from a central point.
- Passive navigation sensors to improve surface vehicle operation: collision avoidance, hazard detection, relative positioning (to artificial and natural objects). Emphasis is placed on sensors that can function in a wide range of lunar conditions (illumination, temperature, etc.)
- Flight vehicle sensors repurposed for surface use. Numerous flight sensors (low light imager, star tracker, 3D flash & scanned lidar) may be suitable for lunar surface operations if modified appropriately.

Sub Topics:
Fuel Cells for Surface Systems Topic X6.01
Energy storage devices are required to enable future robotic and human exploration missions. Advanced primary fuel cell and regenerative fuel cell (RFC) energy storage systems are sought for Exploration mission applications, specifically descent for power for the Altair lander and stationary power for lunar surface bases. Technology advances that reduce the weight and volume, improve the efficiency, life, safety, system simplicity and reliability of fuel cell, electrolysis, and RFC systems are desired. The specific advancements of interest are outlined below:

Regenerative Fuel Cell (RFC) Systems: Primary fuel cells, water electrolyzers, and associated balance-of-plant hardware constitute a RFC system. Performance of fuel cell and electrolysis system functions through passive means and the elimination of as many ancillary components as possible have been identified as the most direct approach to achieving mission efficiency, life, and reliability goals. Specifically, technological advances are sought in the following areas:

- Static Cathode Water Vapor Feed Electrolysis Cell: Preliminary system studies have shown that static cathode feed electrolyzers have the most potential for system simplicity and the fewest number of ancillary components. Proton-exchange-membrane (PEM) electrolysis technology is sought that electrolyzes water vapor supplied to the hydrogen evolving electrode. The electrolysis cell should operate at balanced pressures up to 2000 psi and must not require circulation of hydrogen to transport the water to the electrolysis cell cathode. The exiting hydrogen and oxygen must not contain liquid water droplets, but may contain water vapor.

- Passive Fuel Cell or Electrolysis Cell Heat Removal/ Thermal Control: Passive thermal control of individual cells within a fuel cell or electrolysis stack has the potential to eliminate actively pumped liquid coolant loops. A highly thermally conductive heat pipe plate that is also electrically conductive is sought to passively remove the heat from the individual fuel cells or electrolysis cells within a cell stack. The flat plates that are sought should have a thermal conductivity exceeding 2000 W/m/K, a thickness of <= 0.050 inches, a resistivity of <= 0.2 ohm-cm, and a bulk density of <= 3 grams/cm^3.

- Fuel Cell/ Electrolysis Cell Voltage Monitor Application Specific Integrated Circuit (ASIC): A cell voltage monitoring ASIC has the potential to eliminate a number of discreet electrical components within a fuel cell, electrolysis, or RFC electrical control system. An ASIC is sought that monitors up to 48 differential cell voltages (0-2 VDC) with

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

Sub Topics:
Advanced Space-Rated Batteries Topic X6.02
Advanced human-rated energy rechargeable batteries are required for future robotic and human exploration missions. Advanced Li-based battery systems are sought for use on Exploration mission applications including power for landers, rovers, and Extravehicular activities (EVA). Areas of emphasis include advanced component materials with the potential to achieve weight and volume performance improvements and safety advancements in human-rated systems.

Rechargeable lithium-based batteries with advanced non-toxic anode and cathode materials and nonflammable electrolytes are of particular interest. The focus of this solicitation is on advanced cell components and materials to provide weight and volume improvements and safety advancements that contribute to the following cell level metrics:

- Specific energy of 300 Wh/kg @ C/2 discharge rate and 0°C;
- Energy density greater than 500 Wh/l;
- Calendar life of 5 years.

The cycle life requirements for these missions are relatively benign; the cycle life required at 100% Depth of Discharge (DOD) is in the range of 250 cycles.

Systems that combine all of the above characteristics and demonstrate a high degree of safety and reliability are desired. Innovative solutions that offer the cell level characteristics described above are of particular interest. Proposals are sought which address:

- Advanced cathodes with specific capacities >= 300 mAh/g at C/2 rate discharge and 0°C, and/or
- Advanced anodes with specific capacities >= 600 mAh/g at C/2 and 0°C with minimal irreversible capacity loss,
- Nonflammable electrolytes, and/or
- Electrolytes that are stable up to 5 volts.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

Sub Topics:
Cryogenic Storage for Space Exploration Applications Topic X7.01
This subtopic includes technologies for long-term cryogenic propellant storage applications in-space, on the lunar surface, and on the Earth. These technologies will impact cryogenic systems for space transportation orbit transfer vehicles, space power systems, spaceports, spacesuits, lunar habitation systems, robotics, in situ propellant systems, and launch site ground operations. Each of these applications has unique performance requirements that need to be met. Innovative concepts are requested for cryogenic insulation systems, fluid system components, and cryogenic conditioning systems.

Long term storage (14 days) of LO_2/ LH_2 cryogenic propellants in low-gravity with minimal propellant loss is required to support space transportation orbit transfer vehicles. The Earth Departure Stage (EDS) and the Altair (Lunar Lander) descent stage require LH_2 and LO_2 storage durations of 14 days in Low Earth Orbit (LEO). Long-term storage (224 days) of LO_2/ LCH_4 cryogenic propellants in low-gravity and reduced gravity with minimal propellant loss is required to support space transportation orbit transfer vehicles. The Altair (Lunar Lander) ascent stage requires LO_2 and LCH_4 storage durations of up to 14 days in LEO and up to an additional 210 days on the lunar surface. Long term storage (224 days) of LO_2 cryogenic propellant on the lunar surface and liquefaction of resource with minimal propellant loss is required to support space power systems, spaceports, spacesuits, lunar habitation systems, robotics, in situ propellant systems. Long term storage (6 months) of LO_2/ LH_2/ LCH_4 cryogenic propellants in 1-g on the surface of the Earth with minimal propellant loss is required to support launch site ground operations. Passive and active thermal control, and pressure control/ thermodynamic venting technologies are sought after.

In-space Storage and Lunar Surface Storage

Passive thermal control serves to limit the heat leak into the cryogenic storage system (LH_2 loss 2 loss 4 loss

Active thermal control combines the passive thermal control technology element with active refrigeration (cryocoolers) to allow storage periods from a few months to years with reduced boil-off losses (LH_2 loss 2 loss 2) cryocoolers of sufficient cooling capacity (20 watts) to eliminate LH_2 boil-off do not exist, and thus the development of 20K cryocoolers is a long-lead technology item. State-of-the-art cryocoolers in the 80K range (LO_2/LCH_4 temperatures) have been developed for cooling sensors and have flown on numerous satellites. However, the integration of these cryocoolers into an active thermal control system for propellant storage of LO_2 and LH_2 is a technology issue. Active thermal control development needs include: flight-type 20K, 20 watt capacity cryocoolers designed for integration into space-based LH_2 storage systems, integrated refrigeration and storage systems, innovative heat exchanger concepts, flight cryocooler to propellant tank integration techniques for large space-based storage systems, distributed cooling shields integrated with MLI, circulator development, development and testing of active cooling techniques for tank penetrations and supports is required.

Pressure control utilizes thermodynamic venting in low-gravity or direct venting in partial gravity to enable selective venting of vapor if necessary (ratio of kilograms of TVS mass per watt of heat removal from $LH_2$2 4 2, LO_2 and LCH_4 to determine the effect of internal tank hardware configuration on fluid mixing.

Earth-based Storage

Passive and active thermal control serves to limit the heat leak into the cryogenic storage system and eliminate cryogen boil-off, but not limited by mass or reliability typically associated with flight systems (LH_2 loss 2 loss 4 loss

Sub Topics:

Cryogenic Fluid Transfer and Handling Topic X7.02

Cryogenic fluid transfer and handling for spacecraft propulsion systems, launch facility ground processing, and Lunar surface systems are critical to the advancement of NASA’s exploration goals. Technology development in cryogenic fluid transfer and handling directly supports the Lunar Lander, Ground Operations, Ares, and Lunar Surface Systems programs. Specifically, for Earth-based applications, propellant conditioning and cryogenic densification technologies are required. Propellant conditioning systems are needed to help control the state of the propellant that is loaded into the flight tank at the launch pad. Other technologies are primarily for active control of cryogenic propellants for densification or subcooling on the launch pad as well as liquefaction on the lunar surface.

Component technologies for cryogenic fluid transfer include regulators, valves, umbilicals, quick disconnects, pumps, distribution line insulation materials and techniques, and thermal standoffs for LH_2, LO_2, LCH_4 and cold GHe (~90K). Cryogenic components using advanced actuation technologies such as piezoelectric ceramics which demonstrates reduced heat flux into the cryogenic fluids as compared to conventional electromechanical actuators is highly desirable. Operating ranges for these components should include but are not limited to normal boiling point (NBP) LH_2 and NBP LO_2 components rated for 50 - 100 psia, NBP LO_2 and below NBP LCH_4 components rated for 100 - 400 psia, and cold GHe (~90K) components rated for 400 to 4,500 psia. The technical focus for these components are for reduced thermal mass, minimal heat leak, minimal leakage, and minimal power consumption. Analytical tools for the design and/or analysis of cryogenic fluid transfer components are also needed. These tools should focus on providing analytical capabilities, which directly correspond to cryogenic fluid component design or thermal analysis.

Advanced transfer systems capable of delivering high quality of liquid over a wide flow range between 100 GPM and 1000 GPM are sought. Liquid oxygen pumps that minimize fluid heating while allowing for a range of flowrates are also needed. Propellant subcooling or densification systems for LOX, LH_2 and LCH_4 are required, to provide for extended storage duration on orbit prior to boil off. These systems should be sized to accommodate the Altair propulsion system. Densification systems should offer reliability and efficiency benefits over past systems. Anti-stratification concepts to ensure homogeneous fluid conditions in the flight tank are needed, and better transfer line insulation to minimize heat leak are required. Connections and recirculation systems to maintain propellant state in the flight tank are also desired.

On the lunar surface, oxygen may be produced via an in situ resource utilization reactor. Efficient liquefaction of this oxygen will depend on integration of the liquefier with the gas production stream. Open cycle liquefaction systems must interface with the high-pressure electrolysis systems at the output of the reactor. Compact, low temperature radiators capable of rejecting 50-100W of heat at 140K to deep space are needed for passive cooling prior to the final liquefaction steps. High efficiency, low mass recuperative heat exchangers are needed for effective heat transfer between gas streams. Innovative heat rejection systems designed for the lunar thermal environment are needed. Heat pumps to increase the high temperature heat rejection point of the cycle can also be proposed.

Next, hydrogen cooling and/or liquefaction are required for lunar surface applications involving regenerative fuel cell systems. Efficient 20K cryocooler technology is needed. Reliquefaction systems should be capable of meeting hydrogen flowrates around 1 gram/second. Open cycle hydrogen cooling systems with low temperature isentropic expansion from 3000 psi to the desired storage pressure are needed. Heat switch technology to control energy flow during the lunar day/night cycle will also be considered.

Sub Topics:

Cryogenic Instrumentation for Ground and Flight Systems Topic X7.03

This subtopic includes technologies for reliable, accurate cryogenic propellant instrumentation needs in-space, on the lunar surface, and on the Earth. These technologies will impact cryogenic systems for space transportation orbit transfer vehicles, space power systems, spaceports, lunar habitation systems, in situ propellant systems, and launch site ground operations. Innovative concepts are requested to enable accurate measurement of cryogenic liquid mass in low-gravity storage tanks with and without propellant settling, to enable the ability to detect in-space and on-pad leaks from the storage system, and address other cryogenic instrumentation needs. Cryogenic propellants such as hydrogen, methane, and oxygen are required for many current and future space missions. Operating efficiency and reliability of these cryogenic systems must be improved considering the launch environment, operations in a space environment, and system life, cost, and safety. Proposed technologies should offer enhanced safety, reliability, or economic efficiency over current state-of-the-art, or should feature enabling technologies to allow NASA to meet future space exploration goals.

Mass Gauging technologies will principally impact cryogenic systems for space transportation orbit transfer vehicles. Mass gauging provides accurate measurement of cryogenic liquid mass (LH_2, LO_2, and LCH_4) in low gravity storage tanks, and is critical to allowance of smaller propellant tank residuals in assuring mission success. Both low-gravity mass-gauging (measurement uncertainty

Leak detection technologies impact cryogenic systems for space transportation orbit transfer vehicles, lunar surface, and launch site ground operations. These systems will be operational both in atmospheric conditions and in vacuum with multiple sensor systems distributed across the vehicle or a region of interest to isolate leak location. Methane and hydrogen leak detection sensors with milli-second response times and 1 ppm detection sensitivity in air are desired for ground and launch operations.

Other cryogenic instrumentation needs include minimally invasive cryogenic liquid flow measurement sensors for rocket engine feed lines, and sensors to detect and quantify two-phase flow (bubbles) within the feed lines.

Sub Topics:
Detachable, Human-Rated, Ablative Environmentally Compliant TPS Topic X8.01
The technologies described below support the goal of developing higher performance TPS materials and integrated entry systems architectures for higher performance CEV as well as future Exploration missions.

Development of TPS materials for maximum reliability and survivability with minimized mass requirements, under severe combined convective and radiative heating, including development of acreage materials, adhesives, joints, penetrations, deployables, inflatables and seals.

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. This leads to higher fidelity design tools, risk reduction, decreased heat shield mass and a direct payload increase.

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 themselves have the proper integrity and are free of voids or defects.

Advances are sought in ablation modeling, including radiation, convection, gas surface interactions, pyrolysis, coking, and charring. There is a specific need for improved models for low density charring ablators.

Advances in Multidisciplinary Design Optimization (MDO) are sought specifically in application to address combined aerothermal environments, material response, vehicle shape, vehicle size, aerodynamic stability, mass, and cross-range, characterizing the entry vehicle design problem.

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

Sub Topics:
Crew Exercise System Topic X9.01

Compact, reliable, multi-function exercise devices/systems are required to protect bone, muscle, and cardiovascular health during lunar outpost missions (missions with total duration less than 6 months). This device should be easily configured and stowed, require minimal power to operate, include instrumentation to document exercise session parameters including portable electronic media, and require minimum periodic calibration (no more than 2 times per year). The device must be capable of providing whole body axial loading and individual joint resistive loading that ideally simulates free weights. If unable to match the inertial properties of free weights, then the device must provide near constant loading at any given load setting and achieve an eccentric to concentric load ratio greater than 90%. The load must be adjustable in increments no greater than 2.5 kgs and provide adequate loading to protect muscle strength and bone health such that post-mission muscle strength is maintained at or above 80% of baseline values; bone mass DEXA T score must not exceed – 2.0 S.D. below the mean bone mineral density at mission's end. The same device must be capable of providing whole-body aerobic exercise levels necessary to maintain aerobic capacity at or above 75% of baseline VO2max. Finally, the ideal device should also stimulate the sensory-motor system which controls balance and coordination.

A small, lightweight, sensor-based fitness monitoring system that can be used to assess periodic fitness during lunar outpost missions and transit to Mars is also desired. Devices should be small, employ re-usable elements (versus requiring consumables), and be minimally invasive to measure heart rate and rhythm, oxygen consumption and lactic acid threshold. The ideal system would also include other medical monitoring capabilities such that it could be utilized to assess other crew health variables (e.g., imaging capabilities, respiration rate, blood parameters, etc.).

The Exercise Systems subtopic is also seeking a wearable suit or system that simulates the mechanical properties of the current extravehicular space suit. System should be lightweight (less than 30 pounds), easy to don/doff (especially in the supine position), replicate the mechanical properties of a space suit (in terms of resistance to motion and mass and inertia), and able to be worn during conduct of simulated lunar tasks that last up to 4 hours. Suit system must be adjustable to accommodate individuals of different height and weight. Joints of primary interest to simulate in this system are the shoulder, elbow, trunk, hip, and knee.

Phase 1 Requirements: Phase 1 expectations would be a fully developed concept, complete with feasibility analyses and top-level drawings. A breadboard or prototype is highly desired.

Sub Topics:
In Flight Diagnosis and Treatment Topic X10.01
Proposals may respond to one or more of the following areas:

Non-Toxic Sprain/Strain Treatment

With longer missions and more labor intensive tasks expected in the Constellation Program, the likelihood of musculoskeletal injuries such as sprains and strains are expected to increase. Standard terrestrial therapeutic response to treating sprains and strains is to provide cold compress or heat treatment to the affected area. The focus of this subtopic is to develop a reusable cold compress and/or heat treatment that can be stowed in its inactive state in the vehicle's ambient environment, activated to provide the desired therapeutic relief, recharged using available vehicle resources, and restowed in its inactive state for future use. This capability is desired on the International Space Station and all Constellation Program vehicles that support missions involving labor intensive tasks or exercise countermeasures. Efforts should be made to minimize the volume and mass footprint of the deployed system so that when activated and treating the patient, the patient will have mobility and free movement to continue with mission tasks and objectives. The cold compress and heat treatment capability can be provided through separate systems and does not necessarily have to be the same piece of hardware. The materials used shall be non-toxic in the quantities provided. Current terrestrial solutions are undesirable due to the chemicals involved, onetime use designs or requirement for pre-cooling (e.g., freezer) or pre-heating (e.g., microwave) devices.

Phase 1 Requirements: Phase 1 would include trade studies with reports and down select recommendation. A prototype is preferable.

Phase 2 Requirements: Phase 2 would deliver a working prototype and documentation packages for NASA safety and design reviews.

Reusable Diagnostic Lab Technology

On-board clinical diagnostics to monitor crew member physiology must be available for both mid-term lunar and long-term Mars exploration missions. As in terrestrial medicine, devices with which to measure multiple constituents of small volume samples of bodily fluids are crucial components in assessing astronaut health. Nevertheless, mass, space, and power requirements of such devices are an obvious concern in an environment with scarce resources. Miniaturized laboratory analysis sensors represent a potential solution, given that these devices and supporting hardware are designed to be small, lightweight, and require little power. However, current sensor cartridges are typically single-use with limited shelf life. In order to satisfy the needs of longer duration exploration missions, reusable laboratory analysis sensors with increased shelf life must be designed without compromising accuracy or sensitivity. NASA seeks proposals for developing such reusable laboratory analysis sensors for analysis of bodily fluids, including blood, urine and saliva. The ability to analyze whole blood for a complete blood count with differential and hemoglobin is essential. Priority will be given to designs which also incorporate onboard detection capabilities for other analytes, such as electrolytes, lipids, proteins and hormones. Multiplexed systems providing runtime selection of the assay suite are also desirable. The detection system should minimize the use of electrical power, external optics or other infrastructure, and the use of reagents and additives. The device can rely on a PC or PDA for signal processing and display if desired, but the footprint of all other components should be tightly controlled. The best design will require minimal user interaction for processing or maintenance.

Phase 1 Requirements: During Phase 1, research should be conducted to demonstrate technical feasibility with a draft end item functional requirements document. Phase 1 will also produce documentation showing a viable path to a Phase 2 breadboard demonstration.

Lightweight/Compact Oxygen Concentrator

Concentrated oxygen for medical use is a consumable that when used cannot be replenished. Due to relatively low metabolic consumption, a large percentage of the concentrated oxygen is not consumed but is instead released into the vehicle’s cabin where it offers minimal medical use and is essentially wasted. This release of concentrated oxygen leads to increased ambient oxygen levels to the point where the vehicle oxygen fire limit will be exceeded. An effective solution to both these issues involves use of an oxygen concentrator that can take ambient air and re-concentrate the oxygen providing medical grade oxygen and removing excess oxygen from the vehicle cabin. However, oxygen concentrator technology to date is mostly large, massive, and power intensive. The focus of this subtopic is to develop a small, lightweight, portable oxygen concentrator that can produce concentrated medical oxygen using ambient vehicle cabin air. Of particular interest is oxygen concentration technology that can produce at minimum 60% oxygen at 4-6 liters per minute. Efforts should be made to minimize the volume, mass, and power draw of the system. The oxygen concentrator will use vehicle power as its primary source of power; however there is a brief need for battery power for when the patient is transported between vehicles. This technology is desired on ISS and future exploration vehicles supporting long duration missions.

Phase 1 Requirements: Phase 1 deliverables should include trade studies with down select criteria and recommendations for which technology will best meet the O_2 concentrator figures of merit. A requirements document for a Phase 2 prototyping effort should also be included.

Sub Topics:
EVA Suit Monitoring and Treatment Topic X10.02
Proposals may respond to one or more of the following areas:

Through-Suit Medication Delivery

NASA operations concepts envision contingencies where astronauts may be required to wear Extra Vehicular Activity (EVA) suits for up to 120 hours. If a crewmember requires medication while in a suit, a method of administration must be developed that does not compromise the integrity of the suit, nor the environment it provides. Current concepts for the EVA suit include a self-sealing diaphragm through which injections could be given. However, fluid management in microgravity presents problems with filling a syringe and delivering medication in such an environment. The three main concerns are preventing bubbles from being injected, appropriate fluid management, and excessive volume requirements for pre-loaded syringes. Due to uncertainties about when such an event might occur, the system would have to function in the range of gravity levels between 0 to 1G, as well as pressure levels from vacuum to 1 atmosphere, and require very little volume and no power. Accordingly, NASA seeks proposals detailing concepts for such a system.

Phase 1 Requirements: Phase 1 would include appropriate trade studies, design concepts, and any limited laboratory proof-of-concept testing required to support Phase 2 development.

Phase 2 Requirements: Phase 2 would include fabrication, testing, and validation of breadboard hardware that could be delivered to NASA for evaluation at the conclusion of Phase 2. Phase 2 would be a commercial system that NASA or a prime contractor could integrate within the Exploration Medical Kit.

Biosensors for Lunar EVA Suits

During surface Extravehicular Activities (EVAs), it is anticipated that the flight surgeons will need the ability to monitor heart rate, heart rhythm (ECG), derived core body temperature, and calculated metabolic rate to ensure the health and safety of the crewmember. Of particular interest are technologies that would allow data to be collected, with minimal crew time or effort required to don/doff the measurement hardware, while also maintaining crew comfort (i.e., sensors NOT involving skin preparation, gels, or taping). Also of interest are technologies/systems that would allow the collection of robust, diagnostic quality signals even during periods of strenuous lunar surface operations (lifting, climbing ladders, recovering from falls, and assembling structures).

Phase 1 Requirements: Phase 1 should deliver prototype functioning sensors, but not necessarily in their final form. A report showing prototype function versus a benchmark system's function will be provided. Also a roadmap to getting to the final sensor will be provided.

Phase 2 Requirements: Phase 2 should deliver sensors in their spaceflight-friendly, miniaturized form. Data from spaceflight analog testing using protocols delivered from NASA will also be expected.

Sub Topics:

Behavioral Assessment Tools Topic X11.01

During Exploration Missions, and especially during a Mars Mission, real time communication between the crew and flight surgeons and crew and mission control will not be available as it is now on ISS and the Shuttle. Flight surgeons have stated the need for unobtrusive monitoring tools that are transparent to crews, require minimal crew time or effort, and that help detect if crews are having difficulties with coping with the spaceflight environment. The aim of this subtask is to provide tools that will automatically generate feedback for astronauts and flight surgeons, regarding team cohesion and behavioral health status of crews in-flight.

Requirements for Behavioral Assessment Tools:

- Be unobtrusive;
- Be transparent to crews;
- Require minimal crew time or effort.

Proposals may respond to one or more of the following areas:

Crew Cohesion Monitoring Technology

Detect if crews are having difficulty with team cohesion within the spaceflight environment.

Phase 1 Requirements: Phase 1 will involve an assessment of current methods through which to monitor/measure cohesion within the military and other agencies will be provided. Recommendations regarding enhancements to current technology or the development of a new technology will be presented. The spaceflight environment (current and future) and models related to team cohesion will be assessed in order to determine the optimal requirements for developing a Crew Cohesion Technology suitable for NASA human space exploration. The resulting deliverable will be requirements for a Crew Cohesion Monitoring Technology.

Phase 2 Requirements: Phase 2 requires the development of a prototype Crew Cohesion Monitoring Technology based on accurate models and Phase 1 findings. The prototype will include the hardware, manual and trouble-shooting guide, and results from evaluation and testing the functionality of the prototype device.

Behavioral Health Assessment Tool

Detect if crews are facing increased risk related to interpersonal and psychosocial issues, or other behavioral health problems, and provide feedback to the crewmember and flight surgeon.

Phase 1 Requirements: During Phase 1, the current and future spaceflight environment will be assessed in order to determine the optimal requirements for providing Behavioral Health Assessment tools suitable for NASA human space exploration. An analysis of current methods through which to assess behavioral health status will be provided. Recommendations regarding enhancements to current technology (and how these enhancements will be implemented), or the development of a new technology will be presented. These recommendations will be documented along with a plan to take to Phase 2.

Phase 2 Requirements: Phase 2 requires the development of a prototype Behavioral Health Assessment Technology based on accurate models and Phase 1 findings. The prototype will include the hardware, manual and trouble-shooting guide, and results from evaluation and testing the functionality of the prototype device.

Individualized Fatigue Meter

Design and/or enhance a fatigue meter that would provide immediate feedback to the individual regarding their specific alertness or fatigue levels. Specifically, the feedback from the Fatigue Meter shall be based at a minimum, on the following factors, but other relevant factors can be included:

- A clear, concise method for indicating alertness or fatigue state to the user;
- Length and restfulness of sleep;
- Quantity and quality of physical activity;
- Wavelength and timing of light exposure;
- Heart rate;
- Body temperature.

Phase 1 Requirements: Fatigue Meter Evaluation – A market analysis and a literature review of the state of the art current tools will be conducted. Recommendations regarding enhancements to current technology (and how those enhancements will be implemented), or the development of a new technology will be presented. The spaceflight environment (current and future) and mathematical models related to sleep and performance will be assessed in order to determine the optimal requirements for developing a Fatigue Meter suitable for human space exploration. These recommendations will be documented along with a plan to take to Phase 2.

Phase 2 Requirements: Fatigue Meter Prototype developed based on accurate models and Phase 1 findings. Develop prototype hardware. Develop manual and trouble-shooting guide. Evaluate and test the functionality of the prototype device.

Sub Topics:

Space Human Factors Assessment Tools Topic X12.01

Operations in confined, isolated, and foreign environments can lead to impairments of human performance. This subtopic seeks methods for monitoring, modeling, and predicting human performance in the spaceflight environment for accurate and valid human system integration into vehicle design and operations. In particular, the Space Human Factors Engineering Project within the Human Research Program is interested in obtaining timely and context-specific Human Factors (HF) incident data. Currently, space HF data come from crew debriefs. Such debriefs rely on retrospective recall, which could suffer delays of up to six months. Furthermore, opportunities to discuss HF issues in detail during these debriefs are limited. Consequently, the HRP sees the need to develop an automated human factors incident reporting tool.

Objective: Development of tool that assists the gathering and reporting HF incidents for long-duration space missions.

Requirements: In general, the tool will be used to help detect areas where HF can contribute to mission success, assess the effects of operational and hardware changes, and complement existing HF data sources for operations. Specifically, the tool shall meet the following requirements:

1. The crew shall have easy access to the tool at any time to eliminate the need for the crew to recall information retrospectively.
2. An easy-to-use data gathering protocol with the following functionalities: Allow data to be entered either as text, audio, and/or video inputs,
3. It is desirable for tool to detect a system anomaly automatically and immediately record system status. At a minimum, however, the tool should provide an easily accessible event marker for the crew to mark the context and take a snapshot of the system and operator system status.
4. Provide a user-friendly automated data search engine for extracting meaningful incident information from the raw data. Examples of desirable search schemes include natural language, spatial, temporal searches, etc.

Phase 1 Requirements: The technical merit of the tool will be explored to evaluate feasibility. The Phase 1 report will include results of the evaluation/research/ or development of automated data mining technologies, definition of optimal data gathering protocol(s), and recommendations for optimal hardware/software design. Development of hardware and software algorithms is highly desirable.

Phase 2 Requirements: Development of a working tool prototype, with documentation of functionality and usability evaluation and testing.

Sub Topics:

Advanced Food Technologies Topic X12.02

The purpose of the Advanced Food Technology Project is to develop, evaluate and deliver food technologies for human centered spacecraft that will support crews on missions to the Moon, Mars, and beyond. Safe, nutritious, acceptable, and varied shelf-stable foods with a shelf life of 3 - 5 years will be required to support the crew during future exploration missions to the Moon or Mars. Concurrently, the food system must efficiently balance appropriate vehicle resources such as mass, volume, water, air, waste, power, and crew time. One of the objectives during the lunar outpost missions is to test technologies that can be used during the Mars missions. This subtopic will concentrate on two specific areas; food packaging and lunar outpost food preparation and food processing.

Non-Foil High Barrier Materials

Development of shelf-stable food items that use high-quality ingredients is important to maintaining a healthy diet and the psychosocial well being of the crew. Shelf-life extension may be attained through new food preservation methods and/or packaging. New food packaging technologies are needed that have adequate oxygen and water barrier properties to maintain the foods' quality over a 3 - 5 year shelf life. The packaging must also minimize waste by using high barrier packaging with less mass and volume. The current flexible pouch packaging used for the thermostabilized and irradiated food items contains a layer of foil. Although the foil provides excellent oxygen and water barrier properties, it also contributes to added waste. Food packaging will be a major contributor to the trash on the lunar or Mars surface. One of the proposed methods to dispose of trash on the lunar or Mars surface is incineration. However, the foil layer will not incinerate completely and there will be ash formed. Two emerging food preservation technologies, high pressure processing and microwave processing, are being considered for future NASA missions. However, the current high barrier packaging material cannot be used for these processes. The material delaminates during high pressure processing and cannot be used in microwave processing. Hence, any food packaging material developed in response to this subtopic should be compatible with one or more of the following food preservation technologies: retort processing, microwave processing, and/or high pressure processing. In addition, the material should have an oxygen transmission rate that shall not exceed 0.06 cc/m^2/24 hrs/atm and a water vapor transmission rate that shall not exceed 0.01 gm/m^2/24 hrs as stated in the MIL-PRF 33073F specification.

Effect of Partial Gravity and Reduced Atmospheric Pressure

It will require approximately 10,000 kg of packaged food for a 6-crew, 1000 day mission to Mars. For that reason, it has been proposed to use a food system which incorporates processing of raw ingredients into edible ingredients and uses these edible ingredients in recipes in the galley to produce meals. This type of food system will require food processing and food preparation equipment. The equipment should be miniaturized, multipurpose and efficiently use vehicle resources such as mass, volume, water, and power. Food preparation may include gourmet kitchen appliances such as food processors or bread makers in addition to the standard stove and oven. Proposed food processing equipment may include a mill to produce wheat and soy flour, a soy milk/tofu processor, and a concentrator. The Moon's gravity is 1/6 of Earth's gravity. In addition, it is being proposed that the habitat will have a reduced atmospheric pressure of 8 psia which is equivalent to a 16,000 foot mountain top. These two factors will affect the heat and mass transfer during food processing and food preparation of the food. Heat transfer is required for proper microbial kill and to produce the desired texture and appearance of the food prior to consumption. At this pressure, the boiling temperature of water will be 181°F which has significant implications for preventing microbial contamination and to acceptable food quality. Prior to any design of food processing or preparation equipment, the effects of partial gravity and partial atmospheric pressure as it relates to fluid management, heat and mass transfer and chemical reactions must be determined. Once the effects are determined, methods to overcome these effects must be developed. All of this needs to happen prior to any fabrication of actual food processing or food preparation equipment that can be used in the Lunar Habitat.

The response to this subtopic should include a plan to either (1) develop food packaging technologies that respond the above requirements, or (2) develop a technology which will aid in determining the effects of reduced cabin pressure and reduced gravity and/or (3) develop a technology that will enable safe and timely food processing and food preparation in reduced cabin pressure and reduced gravity.

Phase 1 Requirements: Phase 1 should concentrate on the scientific, technical, and commercial merit and feasibility of the proposed innovation resulting in a feasibility report and concept, complete with analyses and top-level drawings.

Sub Topics:

Active Charged Particle and Neutron Radiation Measurement Technologies Topic X13.01

The goal of the NASA Space Radiation Research Program is to assure that we can safely live and work in the space radiation environment, anywhere, any time. Space radiation is different from forms of radiation encountered on Earth. Radiation in space consists of high-energy protons, heavy ions and secondary particles created when the protons and heavy ions pass through spacecraft and human tissue.

Areas of Interest: Charged particles (protons and heavy ions) and secondary radiations, such as neutrons, contribute the most significant fraction to the total dose-equivalent received by astronauts. At present, NASA has active detectors on International Space Station (ISS) that measure the microdosimetric quantities and the charge and energy spectra of the space radiation field. Neutron specific data are included as part of the microdosimetric measurements. For Exploration class missions, however, more compact and reliable active detection systems will be needed to make microdosimetric, charge, and energy measurements of the total space radiation environment. Advanced technologies (up to technology readiness level 4) are requested.

Subtopic Requirements/Needs:

Tissue Equivalent Microdosimeter

NASA has a need for small/low-mass/low-power microdosimeter to support Exploration class missions. The microdosimeter should be capable of performing single event microdosimetric measurements of tissue equivalent volumes with simulated diameters of 1-2 micrometers. The microdosimeter should be sensitive to lineal energies of 0.2 - 1000 keV/micron. Design goals for mass and volume should be 2 kg and 2000 cm^3, respectively. The microdosimeter should be able to measure charged particles and neutrons in ambient conditions in space (0.01 mGy/hr) and during a large solar particle event (100 mGy/hr). The time resolution of the lineal energy measurements should be less than or equal to 1 minute.

Charged Particle Spectrometer

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

Neutron Spectrometer

Systems are needed specifically to measure the neutron component of the dose and provide the neutron dose-equivalent in real time. Of interest would be compact active monitoring devices that could measure neutron energy spectra. The principal energies of interest are neutrons from 0.5 MeV to 150 MeV. The spectrometer should be able to measure neutrons at ambient conditions such that proton/ion veto capability should be approaching 100% at solar minimum galactic cosmic radiation (GCR) rates. The spectrometer should be able to measure ambient dose equivalent of 0.02 mSv in a 1 hour measurement period, using ICRP 74 (1997) conversion factors. Design goals for mass and volume should be 5 kg and 6000 cm^3, respectively. The spectrometer shall store all necessary science data and unfolding/processing algorithms shall be determined and provided for post measurement data evaluation.

Phase 1 Requirements: Expected deliverable for Phase 1 is a detailed report that (1) establishes proof of concept; (2) addresses the scientific, technical and commercial merit and feasibility of the proposed technology and its relevance and significance to one or more NASA needs within the Solicitation; and (3) provides a preliminary strategy that addresses key technical, market, business factors, demonstration of the proposed innovation, and its transition into products for NASA mission programs and other potential customers.

Sub Topics:
Technology/Technique for Imaging Radiation Damage at the Cellular Level Topic X13.02
New quantitative techniques need to be developed in order to assess astronauts' exposure to space radiation. Charged particles (protons and heavy ions) are of major concern for health risks because they cause chromosome damage. Current methods for measuring space radiation chromosome damage are time consuming and have limitations in sensitivity and accuracy. The Space Radiation Element within the Human Research Program seeks a sensitive, accurate method for assessing chromosome damage, while at the same time being less time consuming than current mFISH and mBand techniques.

Subtopic Requirements/Needs: Of particular interest are ground laboratory techniques using fluorescence in situ hybridization to detect various types of chromosome damage. The technique should be able to measure charged particle exposure at both ambient conditions in space (0.005 mGy/hr) and during a large solar particle event (1000 mGy/hr). The technique should be able to detect various types of chromosome damage such as inversions and deletions in various regions of chromosomes. The technique must be able to quantify chromosome abnormalities that persist after space flight.

Phase 1 Requirements: Phase 1 expectations include a report describing the fully developed concept with feasibility analyses and comparisons to existing methods.

Sub Topics:

On Orbit Ambient Biological Sample Preservation Techniques Topic X14.01

Measurement of blood and urine analytes is a common clinical medicine practice used for differential disease diagnosis and determination of the therapeutic response to treatment. Accurate biochemical results depend on maintaining the integrity of blood and urine samples until analyses can be completed. Improper sample collection, handling, or preservation may lead to critical errors in diagnostic interpretation of analytical results. Traditional methods have been developed that include the use of sample component separation by means of centrifugation, refrigeration, freezing or the addition of preservatives to maintain the integrity of biological samples. While such techniques are easily achieved in a routine clinical setting, the spaceflight environment presents unique challenges to sample processing and stowage. Diagnosis, treatment and research of health-related issues in human crewmembers during their confinement in the remote spaceflight environment depend on the ability to maintain the analytical integrity of biological samples. Thus, novel on-orbit methods for the ambient preservation of biological samples are critical for scientific research, monitoring of crew health and evaluation of countermeasure efficacy. The Dried Chemistry Technology developed at NASA/JSC represents one approach to the collection and preservation of in-flight blood and urine samples. Briefly, whole blood collected by venipuncture into flight-certified tubes is applied either directly to special filter cards, or alternatively, serum or plasma separated from the red cells by means of the ISS refrigerated centrifuge is applied to the filter cards. Urine samples can also be applied directly to the filter cards. The whole blood, plasma, serum, or urine filter cards are then dried and stored at ambient temperature pending analyses which may require that they be returned to Earth. Many analytes in blood and urine samples prepared and stored by means of the NASA/JSC Dried Chemistry Technology are stable for several months. The development of alternative innovative techniques with advantages over currently used methods for processing and preserving biological samples at ambient temperatures during spaceflight that provide a high level of reliability in maintaining a wide array of both blood and urine analytes over a long period of ambient stowage is highly desirable.

Phase 1 Requirements: Phase 1 expectations include at a minimum a fully developed concept with feasibility analyses and top-level drawings. A breadboard or prototype is highly desirable.

Sub Topics:

On Orbit Cell Counting and Analysis Capability Topic X14.02

Cell counting and analysis within the clinical hematology/immunology area generally refers to identification and enumeration of various populations of white blood cells in the peripheral blood. This capability has direct clinical relevance, as peripheral cell populations may expand (proliferation in response to pathogen, hematological malignancy) or contract (sequestered at localized site of inflammation) related to specific disease states. In medicine, the complete blood count, white blood count and CD4+ T cell counts are examples of routinely used cell counting assays. Instrumentation typically used for automated analysis includes hematology analyzers and flow cytometers. Hematology instruments generally accept unstained cells for analysis and differentiate the subpopulations based on scatter properties alone. Flow cytometers require pre-staining of specific cell surface proteins with fluorescent dyes, the emission of which will be optically detected by the cytometer upon excitation with an onboard laser. Flow cytometers may range from large, multi-laser/multi-color instruments with sorting capability, to miniaturized bench top instruments with diode lasers and less capability. NASA is interested in developing a microgravity-compatible instrument capable of on-orbit cell counting. This instrument could support medical testing of crewmembers as well as various research activities. The instrument technology is not constrained, and might range from typical cytometer fluidics, a micro fluidics approach, or some other novel method for resolving and counting cells. It is generally believed that typical sheath-fluid based cell focusing, used in standard flow cytometers, is not desirable due to microgravity incompatibility and operational constraints (fluid volume, mass and waste constraints). Extremely miniaturized and lightweight instrumentation, without high-energy lasers, and requiring minimal sample volume or exogenous (sheath) fluid to operate, and generating minimal biohazardous waste would have the greatest chance for success. An associated sample processing system may be required, that would stain, lyse or otherwise process the whole blood or cell sample is anticipated. The instrument should be capable of deriving absolute counts, in addition to the relevant percentage of various cell subpopulations.

Phase 1 Requirements: Phase 1 expectations would be at a minimum a fully developed concept, complete with feasibility analyses and top-level drawings. A breadboard or prototype is highly desired.

Sub Topics: