The crews that leave the Earth for exploration destinations must keep healthy to perform their mission and to return safely back to Earth. The subtopics seek innovative technologies that will enable crew health and performance, and that will assure there will be no unacceptably long-term consequences after returning while supporting healthy and productive sustained human presence. Proposals for technologies that will enable human space exploration are sought in the areas of Radiation Health and Radiation Shielding; Human Health Countermeasures including artificial gravity, exercise, pharmacology and nutrition, cell and tissue-based analog systems, and physiological countermeasures; Exploration Biology, including the science, spaceflight systems, and technologies that support human exploration; Autonomous Medical Care including technologies of prevention, monitoring, diagnosis, and treatment of human medical problems. Research should be conducted to demonstrate technical feasibility during the Phase 1 contract and show a path toward a Phase 2 specific deliverable. The contractor will then, when appropriate, deliver a demonstration unit of the instrumentation for NASA testing before the completion of the Phase 2 contract.

Subtopics

X11.01 Radiation Health

Lead Center: JSC

Participating Center(s): ARC, LaRC, MSFC

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 distinct from terrestrial forms of radiation, being comprised of high-energy protons and heavy ions and their secondaries produced in shielding and tissue. The Radiation Program Element uses the NASA Research Announcement as a primary means of soliciting research to reduce the uncertainties in risk projections; however, there are specific areas where the SBIR technologies can potentially contribute to NASA's overall goal:

**Ground-Based Heavy Ion Accelerator Research Support Equipment**

NASA utilizes facilities at Brookhaven National Laboratory (BNL) to conduct fundamental radiobiology and shielding experiments. However, the facilities at BNL were not developed with NASA's high number of investigators in mind, thus there are areas where technology developments can improve efficiency and throughput. Technologies of specific interest include, but are not limited to, the following:
• Advanced animal support equipment, sample holders, live imaging of samples on the beam line during heavy ion irradiation, or specimen transport systems that allow remote transport into and out of the target areas, and precise positioning of specimens in the beam line with minimal human interaction in the target areas;

• Environmental control for cell studies while in the beam line and automated fixation capabilities to perfuse small cell and tissue samples directly after exposure to the ion beam;

• Controlled beam line access that provides safe, but rapid and reliable human access to the beam target areas and lockout during specimen exposure; and

• Advanced detector systems to provide rapid assessments of elemental fluence spectra and neutron fluence spectra following heavy ion irradiation of biological or shielding samples.

High Throughput Genomic Analysis Techniques

Following low-dose irradiation of cells by protons and heavy ions, damage is localized to only a very few cells. The ability to separate cells with or without genetic changes in an automated manner is of interest. Current technologies are inefficient in identifying small-scale genetic changes (less than several thousand base-pairs (Mbp)) under these conditions. Technologies of interest are:

• Complementary technologies to the fluorescence in situ hybridization (FISH) method used to score large scale (>1 Mbp) genetic changes to chromosomes following low dose irradiation in order to rapidly score small-scale genetic changes (Imaging techniques to rapidly identify with high accuracy undamaged cells from a cell population irradiated at low doses.

Radiation Shielding and Fabrication

The NASA Space Radiation Research Program uses the NASA Research Announcement (NRA) as the primary means of soliciting research to conceive and radiation-test new radiation shielding materials concepts. The materials concepts include new and innovative lightweight radiation shielding materials to shield humans in crew exploration vehicles, large space structures such as space stations, orbiters, landers, rovers, habitats, and spacesuits. The materials emphasis is on non-parasitic radiation shielding materials, or multifunctional materials, where one of the functions is the radiation shielding, but also serves as structural and other functional components of flight and/or habitat systems. The specific areas in which SBIR-developed technologies can contribute to NASA’s overall mission requirements for advanced radiation shielding materials technologies are:

• Characterization of the physical, chemical and relevant functional properties and the validation and qualification of such multi-functional radiation shielding materials;

• New and innovative manufacturing techniques for producing quality-controlled advanced radiation shielding products and structural components, including innovative scale-up methods for producing quality-controlled viable quantities of advanced radiation shielding materials;
• New and innovative processing methods for producing quality-controlled advanced radiation shielding materials of all forms - resins, fibers, fabrics, composites and fiber-reinforced composite materials;

• New and innovative fabrication techniques for fabricating advanced radiation shielding materials into useful products and structural components; and

• New and innovative commercialization strategies to introduce advanced radiation shielding materials technologies into the marketplace to enable availability of the technologies for use by NASA and the space exploration community.

Reliable Radiation Dosimeters for Manned and Unmanned Spaceflight

Current environment dosimeters have exceeded their designed lifetimes and should be replaced. These include small, active dosimeters to monitor individual astronauts’ exposure, Tissue Equivalent Proportional Counters (TEPC), Charged Particle Directional Spectrometer (CPDS) capable of internal and external deployment, and externally deployed electron and neutron detectors. New software needs to be fault tolerant and updated to current operating systems; new hardware and software must be fully documented (schematics, etc.). Areas of interest are:

• Advanced spaceflight detector systems to provide reliable environment data for a specific spectrum of energies, including: real time dosimetry providing dose and particle types and energies and cumulative dosimeters for characterizing space environments for use onboard spacecraft and planetary surfaces as well as alarm systems for Solar Particle Events; and

• Microdosimetry for operational and research applications, including implantable dosimeters for biological studies, that translate particle counts into biologically relevant dose or damage.

X11.02 Human Health Countermeasures

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

In order for humans to live and function safely and efficiently in space or in the hypogravity of the Moon (1/6g) or Mars (3/8g), a good understanding of the effects of micro- and hypogravity and other factors associated with the space environment on human physiology and human responses to the space and extra planetary environments is required. A variety of countermeasures must be developed to oppose the deleterious changes that occur in space and upon subsequent exposure to other gravitational fields. The ability to monitor the effectiveness of countermeasures and alterations in human physiology during space exploration missions, particularly when several countermeasures are used concurrently, is equally important. This subtopic seeks innovative technologies in several very specific key areas. Since launch costs relate directly to mass and volume, instruments and sensors must be small and lightweight with an emphasis on multi-functional capabilities. Low power consumption is a major factor, as are design enhancements to improve the operation, design reliability, and maintainability of these instruments in the environment of space and on planetary surfaces. As the efficient use of time is extremely important, innovative instrumentation setup, ease of usage, improved astronaut (patient) comfort, noninvasive sensors, and easy-to-read information displays are also very important considerations. Extended shelf life and ambient storage conditions of consumables are also key necessities. Ability to operate in 0g, 1/6g, and 3/8g becomes more important as we march towards human Moon and Mars missions.
**Exercise and Related Hardware**

Development of an immersive visual display system is required to be interfaced with treadmill exercise devices. This system may not be head-mounted but could be free standing and provide at least a 180° field of view. This visual display would allow visual flow patterns to be displayed to a non-encumbered subject during in-flight or on-surface treadmill exercise. In addition, miniaturized exercise hardware (treadmill or resistance exercise); physiological monitoring devices; and metabolic gas (carbon dioxide and oxygen) analysis systems for use with exercise and miniaturized interactive feedback and entertainment systems.

A tool or toolkit should simulate and visualize the exercise device design and performance. A comprehensive, scaled 3D/virtual human model interface would be valuable to show biomechanical and kinetic effects of the exercise device. Relative physiological data from anthropometry to stress/fatigue to trauma/insult onset should be targeted. If in-flight/on-orbit micro gravitational and planetary surface gravitational forces can be simulated, this could help produce germane simulations with which to implement new designs and products. A time-delay algorithm would be advantageous in helping provide for latency-moderated haptics (force-feedback) and long-distance teleoperative control. This will allow remote teleoperation with force-feedback despite the high latencies involved.

**Noninvasive Pharmacotherapy and Monitoring**

Development of innovative technologies resulting in noninvasive methods for diagnosis, treatment, and therapeutic drug monitoring is needed to facilitate effective pharmacotherapy of humans in space. Many questions remain about the effectiveness of pharmaceuticals in micro- and hypo-gravity environments, which may interfere with their activity by sensitizing or desensitizing the crewmember or interfering in other ways with the desired physiological effect. Micro-encapsulation of drugs, radio contrast agents, crystals, and development of novel drug delivery systems wherein immiscible liquid interactions, electrostatic coating methods, and drug release kinetics from microcapsules or liposomes can be altered under microgravity. Devices for continual monitoring of physiology during pharmacotherapy would also be advantageous to ensure that on-orbit expression of therapies relates to on-Earth histories.

**Device for Providing Increased Neuromuscular Activation during Spaceflight**

Astronauts returning from spaceflight exhibit post-flight postural and gait instabilities that are a result of neural adaptation to microgravity. A small, lightweight countermeasure device is required to stimulate somatosensory receptors on the plantar surface of the feet during in-flight exercise with the goal of increasing neuromuscular activation and enhancing sensorimotor integration. This system would integrate with in-flight exercise hardware and coupled with visual stimulation systems would allow a more complete sense of immersion to enhance in-flight postural and locomotor training.

**Device for Measuring Body Fluid Shift**

A body impedance device to measure fluid shifts in four segments of the body associated with a short-radius centrifuge. The device should measure the following parameters, namely, resistance, change in resistance and rate of change of resistance and reactance. The device should withstand g forces (5g) produced by centrifugation and meet safety standards such as subject isolation.
MEMS-Based Human Blood Cell Analyzer

Development of a small, automated and micro- and hypo-gravity capable instrument that will analyze micro liter quantity of human whole blood and provide a complete blood cell count (RBC, WBC, platelet, hemoglobin concentration, hematocrit, WBC differential, and calculated RBC indices) that correlates with traditional ground-based impedance or light-scattering technologies is needed. Likely devices based on MEMS will employ a biocompatible combination of micro fluidics, micromechanics, micro-optics, microelectronics, and data telemetry capabilities in an integrated handheld package with a user-friendly operator interface.

Cell/Tissue Analog Studies

Cell/Tissue analog studies in ground-based, microgravity-analog bioreactors allow us to understand the ill-effects of microgravity and radiation on human tissues-especially, bone, muscle, and cardiac and immune response. Technologies that allow automated biosampling, lyophilization of mammalian cells, miniaturized protein microarray analyzer, tools derived from Bionanotechnology relevant to the understanding are of interest.

X11.03 Autonomous Medical Care

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

Exploration missions require a healthy, well-performing crew supported by a robust infrastructure for the monitoring, diagnosis, and treatment of medical conditions. Since return time to Earth and communications delays during such missions will greatly reduce the effectiveness of Earth-involvement, the crew must be capable of performing the majority of medical activities independently. Therefore, this system of autonomous medical care must provide the capability for patient care as well as measure and assess fitness levels for duty during a mission with little or no real-time support from Earth. The objective of this subtopic is to sponsor applied research leading to the development of such an infrastructure with the associated medical devices and procedures that will mitigate crew health, safety, and performance risks during future flight missions to the Moon and Mars. Medical diagnostic, treatment, and monitoring devices are critical for providing health care and medical intervention during missions, particularly extended-duration spaceflight to the Moon and Mars. Of particular interest are devices with minimized mass, volume, consumables, and power consumption that are capable of multiple functions in both micro-g and sub-g environments. Design enhancements that improve the operation, reliability, flexibility, and maintainability of medical devices in the space environment are also sought. Additional considerations include innovative approaches to human-device interactivity and interface, automation of device functions, improved ease of use, and astronaut comfort.

Device for Body Chemistry Assessment

Development of an integrated, adaptable laboratory analysis system/sensor system for in-flight assessment of body fluids (including blood) and solids is desired. This system would be used to obtain quantitative measurement of dissolved gases, calcium ions, and other electrolytes, proteins, lipids, hormones, carbohydrates, vitamins, minerals and clinical drug levels with minimal or no consumables usage or specimen preparation skill. Likely candidates will be based on MEMS technology and will employ a biocompatible combination of micro fluidics, micromechanics, micro-optics, microelectronics, and data telemetry capabilities in an integrated handheld package with a user-friendly operator interface.
Voice- and Gesture-Actuated Interactive Procedures

Astronauts working in space or on the lunar or Martian surface will require a hands-free, interactive, step-by-step environment for performing flight medical procedures. This system should have the capability to utilize links, prepare textual or graphical indication of progress through a procedure, return to previous steps, page forward/page backward, and automatically annotate verbal input relative to subject response during procedure or treatment. An inventory capability must exist for obtaining and stowing required items (including medications) as well as a mechanism to assess the resulting consumables status after a procedure has been completed. Ground-monitoring capability is also required, at least in the early stages.

Closed Loop Medical Respirator

A closed loop flight and human certified medical respirator with real-time remote monitoring and remote control capability is required. This respirator must incorporate a function to limit the amount of \( \text{O}_2 \) leaking into the space vehicle or surface habitat. Current \( \text{O}_2 \) limits range from \( \sim 20/21\% \) at sea level with maximum levels of 30\% in a 10.2 psi environment. (This upper limit mitigates flammability concerns and is dictated by ambient pressure.) The system should incorporate real-time remote monitoring and control capabilities.

Medical Grade Water Generation

Methods and technologies for in-flight creation of medical grade water from any available water source are required. Because some pharmacological preparations appear to degrade in the space environment, it is highly desirable, from both a consumables perspective as well as from the standpoint of mass, to fly desiccated pharmacological substrates whenever possible and to reconstitute them only when needed. For this reason, medical grade water is required along with a low-g (e.g., 0 g, 1/3 g, and 1/6 g) system to deliver generated water to the substrate and mix as necessary. The general requirements of low mass, user-friendly interface, reliability, and automation are critical to this system. There should be a mechanism included to verify that the water produced meets standard requirements for the medical grade designator.

Diagnostic Imaging Capability

During long duration flights, it will be important to have medical imaging capability available to assist in diagnosis, treatment, and monitoring during and after medical events. This capability is likely to be an ultrasonic, low power, portable device that provides for diagnostic assistance via data processing algorithms. These algorithms would be expected to provide guidance for the crewmember administering the exam as well as identifying probable diagnoses options and possible treatments for each. The system should be flexible enough to provide fracture analysis, bone density levels, and body cavity status.

In-Flight Suction

Long duration missions must have the capability to provide medical suction for patients in the event of injury or serious illness. This system must be capable of providing suction for a variety of body orientations in multiple reduced gravity environments. It should be a stand-alone system that does not require oversight by another crewmember. In the event of malfunction, it should provide an audio alert, a display of the malfunction type, plus a safing algorithm. The contents of the suction system must be easily disposed of safely and without release of contents into the environment.
Biomedical Signal Processing

Assessment of an ill or injured crewmember may sometimes be accomplished in large part by the status of the biomedical signal, or EKG. This will have to be a "smart" system, which analyzes sensor placement, sensor health, signal monitoring, signal normalcy, and signal analysis. It is required that the biomedical signal be capable of monitoring cardiac health and physiological state. The processor must be fail-safe and must annunciate an audible alarm when a malfunction occurs. A display should provide a readout of the anomaly type and the system must safe itself when malfunctions occur. (NOTE: There may be a subset of malfunctions {e.g., loose lead} that will not require a shut-off or self-safing function.) The system must be volumetrically small with minimal mass.

Intelligent Software Modules

Software modules with the capability to review medical data in a SQL compliant database, assign or suggest appropriate SNOMED CT codes, and store the suggested codes in electronic format with discrete elements is highly desirable to avoid having to train hierarchical nomenclature to crewmembers. The hierarchical relationships between SNOMED codes should be maintained and stored in the output.