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Funding and Strategic Alignment Guidance for Infusing Small Business Innovation Research Technology Into NASA Programs Associated With the Human Exploration and Operations Mission Directorate

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September 2015

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Abstract

This report is intended to help NASA program and project managers incorporate Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) technologies that have gone through Phase II of the SBIR program into NASA Human Exploration and Operations Mission Directorate (HEOMD) programs. Other Government and commercial project managers can also find this information useful.

Introduction

Incorporating Small Business Innovation Research (SBIR)-developed technology into NASA programs is important, especially given the Agency's limited resources for technology development. The SBIR program's original intention was for technologies that completed Phase II to be ready for integration into NASA programs, however, in many cases there is a gap between Technology Readiness Levels (TRLs) 5 and 6 that needs to be closed.

After Phase II projects are completed, the technology is evaluated against various parameters and a TRL rating is assigned. Most programs tend to adopt more mature technologies—at least TRL 6 to reduce the risk to the mission rather than adopt TRLs between 3 and 5 because those technologies perceived as too risky. The gap between TRLs 5 and 6 is often called the "Valley of Death" (Fig. 1) and historically it has been difficult to close because of a lack of funding support from programs. Several papers already have suggested remedies on how to close the gaps (Refs. 1 to 4).

To address the TRL gap, NASA's SBIR program has made a considerable effort to strengthen the critical connection between SBIR and NASA programs through post-Phase II initiatives. As a result NASA SBIR now supports its small business partners with three post-Phase II options that focus on creating opportunities for technology infusion and commercialization. The Phase II Enhancement (Phase II-E), Phase II Expanded (Phase II-X), and the Commercialization Readiness Program (CRP) options provide opportunities for Phase II technologies to be integrated and tested in the NASA system platform or in the space environment.

		TRL	Description
SBIR Phases I and II	Basic research	1	Basic scientific/engineering principles observed and reported
	Feasibility research	2	Technology concept, application, and potential benefits formulated (candidate system selected)
	Feasibility research	3	Analytic and/or experimental proof-of-concept completed (breadboard test)
	Technology development	4	System concept observed in laboratory environment (candidate system selected)
Technology demonstration "Valley of Death"	Technology development	5	System concept tested and potential benefits substantiated in a controlled relevant environment
	System development	6	Prototype of system concept is demonstrated in a relevant environment
System development	System development	7	System prototype is tested and potential benefits substantiated more broadly in a relevant environment
	Operational verification	8	Actual system constructed and demonstrated with benefits substantiated in a relevant environment
	Operational verification	9	Operational use of actual system tested with benefits proven

Figure 1.—Technology Readiness Levels (TRLs).

Aligning SBIR Technologies Into HEOMD Operations and Programs

This section discusses how NASA program managers can incorporate SBIR technologies into Human Exploration and Operations Mission Directorate (HEOMD) programs by showing where there is relevant alignment. This information also will be helpful for other Government agencies or commercial entities that pursue related fields.

HEOMD research focuses on leadership and management of space operations related to human exploration in and beyond low Earth orbit. HEOMD is structured into the following two operations:

(1) Exploration: Manages commercial space transportation, exploration systems development, human space flight capabilities, advanced exploration systems, and space life sciences research and applications.
(2) Space: Supports space and ground infrastructure, capabilities that enable rocket propulsion testing; ensure safe, reliable, and affordable access to space; and maintain secure and dependable communications between ground stations and platforms across the solar system.

Figure 2 shows the HEOMD structure of Exploration and Space Operations that focus on enhanced research and technological capabilities to travel beyond low Earth orbit. Table 1 shows NASA's funding request from fiscal years (FYs) 2015 to 2019 for HEOMD programs.

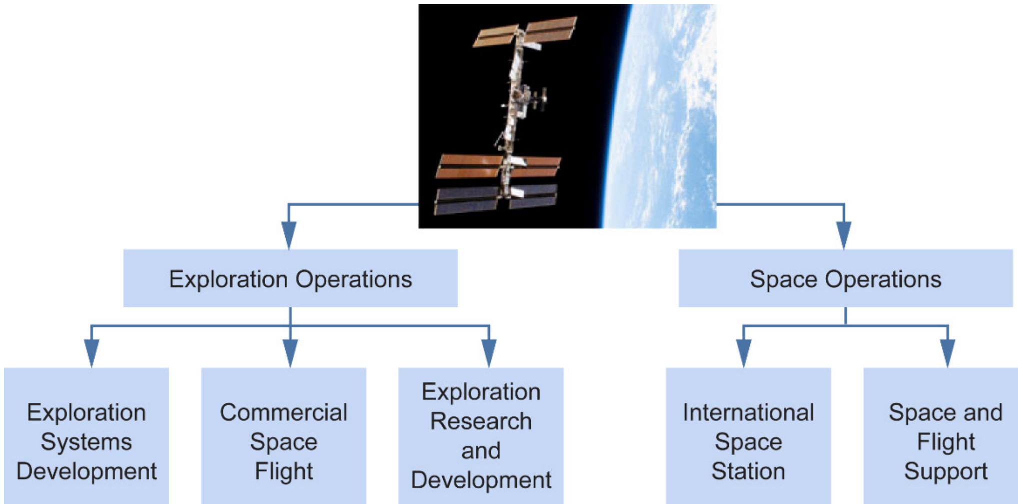

Figure 2.—Human Exploration Operations Mission Directorate (HEOMD) programs.

TABLE 1.—FISCAL YEAR (FY) BUDGET REQUEST SUMMARIES FOR HEOMD PROGRAMS (IN MILLIONS OF DOLLARS) (REF. 5)

Program	Actual	Projected			
	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
Exploration Operations					
Orion Multi-Purpose Crew Vehicle	1,052	1,096	1,119	1,122	1,126
Space Launch System	1,380	1,356	1,353	1,418	1,526
Exploration Ground Systems	351	410	432	441	453
Commercial Crew	848	872	791	730	172
Human Research	160	167	173	178	178
Advanced Exploration Systems	182	176	178	216	216
Space Operations					
ISS Systems Operations and Maintenance	1,207	1,211	1,337	1,347	1,347
ISS Research	312	312	312	312	312
ISS Crew and Cargo Transportation	1,530	1,602	1,617	1,630	2,159
21st Century Space Launch Complex	25	11	11	11	---
Space Communications and Navigation	591	553	553	534	534
Human Space Flight Support	108	112	112	112	112
Launch Service	83	89	89	89	89
Rocket Propulsion Test	45	47	47	47	47

- Orion Multi-Purpose Crew Vehicle Program
- Space Launch System Program
- Exploration Ground Systems Program
- Commercial Crew Program
- Human Research Program
- Advanced Exploration Systems Program

- ISS Systems Operations and Maintenance Program
- ISS Research Program
- ISS Crew and Cargo Transportation Program
- 21st Century Space Launch Complex Program
- Space Communications and Navigation Program
- Human Space Flight Support Program
- Launch Service Program
- Rocket Propulsion Test Program

Figure 3.—HEOMD operations and programs.

HEOMD Operations and Programs Summaries

Figure 3 shows each HEOMD operation and its associated programs.

Exploration Operations

- Orion Multi-Purpose Crew Vehicle Program: Develops the vehicle that will carry the crew to orbit, provide emergency abort capability, sustain the crew while in space, and provide safe reentry from deep space return speeds.
- Space Launch System (SLS) Program: Develops the heavy lift vehicle that will launch the crew vehicle, other modules, and cargo for deep space missions.
- Exploration Ground Systems Program: Develop the necessary launch site infrastructure to prepare, assemble, test, launch, and recover the SLS and Orion flight systems.
- Commercial Crew Program: Focuses on how to partner with the U.S. private sector to develop and operate safe, reliable, and affordable crew transportation to low Earth orbit. During the development phase of their crew transportation systems, NASA provides technical and financial assistance to industry partners.
- Human Research Program: Researches the effects of space flight on humans and develops countermeasures to lessen the effects of the hostile space environment on human health and performance. HRP utilizes ground research facilities, the ISS, and analog environments to research issues and develop countermeasures for future missions to deep space destinations, including Mars.
- Advanced Exploration Systems Program: Develops exploration technologies applicable to multiple missions and destinations to reduce risk, lower lifecycle cost, and validate operational concepts for future human missions to deep space. Several of these technologies are applicable to NASA's planned Asteroid Redirect Mission.

Space Operations

- ISS System Operations and Maintenance Program: Ensures that the Station is operational and available to perform its research mission at all times. A critical component of the Systems

Operations and Maintenance is immediate, emergency services and analyses conducted by mission control teams on Earth.

- ISS Research Program: Provides an unparalleled capability for space-based research and a unique venue for developing technologies for future human space exploration. Enables scientific investigation of physical processes in an environment very different from that of Earth.
- ISS Crew and Cargo Transportation Program: Provides cargo delivery to ISS under the Commercial Resupply Services (CRS) contracts with Orbital Sciences Corporation (Orbital) and Space Exploration Technologies (SpaceX). The FY 2015 budget supports these contracted flights, as well as future flights to provide for cargo transportation, including National Laboratory research payloads.
- 21st Century Space Launch Complex Program: Assures reliable access to space by providing leadership, expertise, and cost-effective expendable launch vehicle services for NASA missions. Focus on Modernizes and transforms the Florida launch and range complex into a more robust launch capability at Kennedy Space Center (KSC) that can support multiple users.
- Space Communications and Navigation Program: Provides mission-critical communications and navigation services required by all NASA space missions. SCaN retrieves science and spacecraft health data, uploads commands, and sends data to individual mission control centers. Navigation services accurately determine where a satellite is and where it is going to enable plans for course changes, interpret science data, and position the spacecraft for communication opportunities.
- Human Space Flight Support Program: Supports the training, readiness, and health of the crewmembers prior to, during, and after a spaceflight mission. Prepares the human system for living and working in the hostile space environment extended periods.
- Launch Service Program: Acts as a broker, matching spacecraft with launch vehicles through competitive processes with commercial providers. Acquires and manages launch services, and ensures that pricing is consistent and fair. Certifies the readiness of new commercial launch vehicles for NASA and other civil sector agencies' high value spacecraft. Conducts engineering analyses and other technical tasks that maximize launch success for every NASA robotic payload.
- Rocket Propulsion Test Program: Maintains and manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions. Retains a skilled workforce, capable of performing tests on all modern day rockets including supporting complex rocket engine developments. Evaluates customer test requirements and desired outcomes, minimizing test time and costs. Manages facility usage and eliminates redundant capability by closing, consolidating, modernizing, and streamlining NASA's rocket test facilities.

Fiscal Year 2015 Solicitation Topics and Subtopics Related to HEOMD

The annual NASA-wide SBIR solicitation contains several topics and subtopics that are developed to strategically align with HEOMD programs, thereby supporting the directorate's current needs and objectives. To help the small business principal investigators (PIs) and HEOMD program managers, it is important to understand how the SBIR topics and subtopics are mapped to HEOMD programs. Figure 4 shows the FY 2015 solicitation topics and subtopics for HEOMD programs and Figure 5 maps the FY 2015 solicitation subtopics to HEOMD programs.

H1 In-Situ Resource Utilization

- H1.01 Regolith ISRU for Mission Consumable Production

H2 Space Transportation

- H2.01 In-Space Chemical Propulsion
- H2.02 Nuclear Thermal Propulsion (NTP)
- H2.03 High Power Electric Propulsion
- H2.04 Cryogenic Fluid Management for In-Space Transportation

H3 Life Support and Habitation Systems

- H3.01 Environmental Monitoring for Spacecraft Cabins
- H3.02 Bioregenerative Technologies for Life Support

H4 Extra-Vehicular Activity and Crew Survival Systems Technology

- H4.01 Crew Survival Systems for Launch, Entry, Abort
- H4.02 EVA Space Suit Pressure Garment Systems
- H4.03 EVA Space Suit Power, Avionics, and Software Systems

H5 Lightweight Spacecraft Materials and Structures

- H5.01 Deployable Structures
- H5.02 Extreme Temperature Structures
- H5.03 Multifunctional Materials and Structures

H6 Autonomous & Robotic Systems

- H6.01 Mobility Subsystem, Manipulation Subsystem, and Human System Interaction

H7 Entry, Descent, and Landing Technologies

- H7.01 Ablative Thermal Protection Systems Technologies,Sensors, and NDE Methods
- H7.02 Diagnostic Tools for High Velocity Testing and Analysis

H8 High Efficiency Space Power Systems

- H8.01 Space Nuclear Power Systems
- H8.02 Solid Oxide Fuel Cells and Electrolyzers
- H8.03 Advanced Photovoltaic Systems

H9 Space Communications and Navigation (SCaN)

- H9.01 Long Range Optical Telecommunications
- H9.02 Intelligent Communication Systems
- H9.03 Flight Dynamics and Navigation Technology

H10 Ground Processing

- H10.01 Cryogenic Purge Gas Recovery and Reclamation

H11 Radiation Protection

- H11.01 Radiation Shielding Technologies

H12 Human Research and Health Maintenance

- H12.01 Measurements of Net Ocular Blood Flow
- H12.02 Unobtrusive Workload Measurement
- H12.03 Technology for Monitoring Muscle Protein Synthesis and Breakdown in Spaceflight

H13 Non-Destructive Evaluation

- H13.01 Advanced NDE Modeling and Analysis

H14 International Space Station (ISS) Demonstration & Development of Improved Exploration Technologies and Increased ISS Utilization

- H14.01 International Space Station (ISS) Utilization
- H14.02 International Space Station (ISS) Demonstration of Improved Exploration Technologies
- H14.03 Recycling/Reclamation of 3-D Printer Plastic Including Transformation of Launch Package Solutions into 3-D Printed Parts
- H14.04 Optical components, sensors, and systems for ISS utilization

Figure 4.—Fiscal year 2015 SBIR HEOMD topics and subtopics.

Topics and Subtopics	HEOMD programs
H1 In-Situ Resource Utilization H1.01 Regolith ISRU for Mission Consumable Production	• Orion Multi-Purpose Crew Vehicle Program
H2 Space Transportation H2.01 In-Space Chemical Propulsion H2.02 Nuclear Thermal Propulsion (NTP) H2.03 High Power Electric Propulsion H2.04 Cryogenic Fluid Management for In-Space Transportation	• Orion Multi-Purpose Crew Vehicle Program • Space Launch System Program • Advanced Exploration Systems Program • ISS Research Program • Rocket Propulsion Test Program
H3 Life Support and Habitation Systems H3.01 Environmental Monitoring for Spacecraft Cabins H3.02 Bioregenerative Technologies for Life Support	• Advanced Exploration Systems Program • ISS Systems Operations and Maintenance Program • ISS Research Program • ISS Crew and Cargo Transportation Program
H4 Extra-Vehicular Activity and Crew Survival Systems Technology H4.01 Crew Survival Systems for Launch, Entry, Abort H4.02 EVA Space Suit Pressure Garment Systems H4.03 EVA Space Suit Power, Avionics, and Software Systems	• Orion Multi-Purpose Crew Vehicle Program • Commercial Crew Program • Advanced Exploration Systems Program • ISS Systems Operations and Maintenance Program
H5 Lightweight Spacecraft Materials and Structures H5.01 Deployable Structures H5.02 Extreme Temperature Structures H5.03 Multifunctional Materials and Structures	• Orion Multi-Purpose Crew Vehicle Program • ISS Systems Operations and Maintenance Program • ISS Research Program
H6 Autonomous & Robotic Systems H6.01 Mobility Subsystem, Manipulation Subsystem, and Human System Interaction	• Space Launch System Program • Advanced Exploration Systems Program • ISS Systems Operations and Maintenance Program • ISS Research Program
H7 Entry, Descent, and Landing Technologies H7.01 Ablative Thermal Protection Systems Technologies, Sensors, and NDE Methods H7.02 Diagnostic Tools for High Velocity Testing and Analysis	• Advanced Exploration Systems Program • ISS Crew and Cargo Transportation Program

Figure 5.— Fiscal year 2015 SBIR subtopics mapped to HEOMD programs.

Topics and Subtopics	HEOMD programs
H8 High Efficiency Space Power Systems H8.01 Space Nuclear Power Systems H8.02 Solid Oxide Fuel Cells and Electrolyzers H8.03 Advanced Photovoltaic Systems	• Space Launch System Program • Advanced Exploration Systems Program • ISS Systems Operations and Maintenance Program • ISS Crew and Cargo Transportation Program
H9 Space Communications and Navigation (SCaN) H9.01 Long Range Optical Telecommunications H9.02 Intelligent Communication Systems H9.03 Flight Dynamics and Navigation Technology	• Advanced Exploration Systems Program • ISS Research Program • Space Comunications and Navigation Program
H10 Ground Processing H10.01 Cryogenic Purge Gas Recovery and Reclamation	• Space Launch System Program • Launch Services Program • Rocket Propulsion Test Program
H11 Radiation Protection H11.01 Radiation Shielding Technologies	• Orion Multi-Purpose Crew Vehicle Program • Human Research Program • Advanced Exploration Systems Program • ISS Crew and Cargo Transportation Program
H12 Human Research and Health Maintenance H12.01 Measurements of Net Ocular Blood Flow H12.02 Unobtrusive Workload Measurement H12.03 Technology for Monitoring Muscle Protein Synthesis and Breakdown in Spaceflight	• Human Research Program • ISS Systems Operations and Maintenance Program • ISS Research Program • Human Space Flight Support Program
H13 Non-Destructive Evaluation H13.01 Advanced NDE Modeling and Analysis	• Advanced Exploration Systems Program • ISS Research Program
H14 International Space Station (ISS) Demonstration & Development of Improved Exploration Technologies and Increased ISS Utilization H14.01 International Space Station (ISS) Utilization H14.02 International Space Station (ISS) Demonstration of Improved Exploration Technologies H14.03 Recycling/Reclamation of 3-D Printer Plastic Including Transformation of Launch Package Solutions into 3-D Printed Parts H14.04 Optical Components, Sensors, and Systems for ISS Utilization	• ISS Systems Operations and Maintenance Program • ISS Research Program • ISS Crew and Cargo Transportation Program

Figure 5.—Concluded.

SBIR Solicitation Process

Understanding how the SBIR solicitation process works should help small businesses and HEOMD project managers form partnerships to incorporate SBIR technologies into NASA programs and projects. For example, when HEOMD program managers identify specific SBIR subtopics that are likely to generate technologies that could apply to their programs or projects, the SBIR office would provide information about previously developed technologies that could be incorporated into their work. Small business PIs would also benefit from understanding NASA program and project needs, thus increasing the likelihood that the technologies they developed will be infused into HEOMD projects. FY 2015 solicitations are posted at http://sbir.gsfc.nasa.gov/solicitations.

Fiscal Year 2015 ARMD SBIR Topic and Subtopic Summaries

Topics and subtopics for all directorates are listed in Chapter 9 of the FY 2015 SBIR solicitation. Topics and subtopics related to the HEOMD directorate follow.

Topic H1 In-Situ Resource Utilization

H1.01 Regolith ISRU for Mission Consumable Production

Involves collecting and converting local resources into products that can reduce mission mass, cost, and/or risk of human exploration. The primary destinations of interest for human exploration, the Moon, Mars and it's moons, and Near Earth Asteroids, all contain regolith/soil that contain resources that can be harvested into products. The resources of primary interest are water and other components that can be released from the regolith/soil by heating, and oxygen found in the minerals to make consumables for life support, power, and propulsion system applications.

Topic H2 Space Transportation

H2.01 In-Space Chemical Propulsion

Examines a range of key technology options associated with space engines that use methane as the propellant. Key operational and performance parameters include - Reaction control thruster development in the 5 to 100 lbf thrust class with a target vacuum specific impulse of 325-sec. The reaction control engines would operate cryogenic liquid-liquid for applications requiring integration with main engine propellants.

H2.02 Nuclear Thermal Propulsion

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

H2.03 High Power Electric Propulsion

Develops innovative technologies that can lead to high-power (100-kW to MW-class) electric propulsion systems. Advanced concepts for high power plasma thruster systems that provide quantifiable benefits over state of the art high power electric propulsion systems. Electric propulsion systems and components that enable the use of alternative space storable propellants, such as condensable or metal propellants and potential in-situ resource derived propellants.

H2.04 Cryogenic Fluid Management for In-Space Transportation

Focuses on to cryogenic propellant (such as hydrogen, oxygen, and methane) storage, transfer, and instrumentation to support NASA's exploration goals. Cryogenic pressure transducers (0 to 50 psia typical range, 1 percent full scale accuracy, 0.5 Hz response) at 20 K. Low power (<15 W goal) video camera systems for viewing fluid dynamics within a propellant tank (3 to 5 m diameter). Lightweight, multifunctional cryogenic insulation systems (including attachment methods) that can survive exposure to the free stream during the launch/ascent environment in addition to high performance (less than 0.5 W/m^2 with a warm boundary of 220 K) on orbit or <5 W/m^2 on Mars surface.

Topic H3 Life Support and Habitation Systems

H3.01 Environmental Monitoring for Spacecraft Cabins

Focuses on measurement of inorganic species in water, particulate monitor for air, and microbial monitor. Monitoring capability is of interest for identification and quantification of inorganic species in potable water, thermal control system cooling water, and human wastewater. Real-time measurement instruments must be compact and low power, without volatile working fluids, intuitive for crew to operate, requiring minimal maintenance, and able to maintain calibration for years. A large measurement range is necessary in low gravity due to the absence of gravitational settling, and it is expected that more than one instrument, or a multisensor unit, will be required to cover the desired range from nanometer (ultrafine) to 50 µm in diameter).

H3.02 Bioregenerative Technologies for Life Support

Focuses on food production and related food safety technologies for ISS, transit missions, and eventual surface missions (fractional gravity). Of special interest is the use of photosynthetic organisms such as plants to produce food, and contribute to cabin O_2 production and CO_2 removal. Food production technologies should address how light use efficiency will be improved to reduce energy costs, including advanced electric and solar lighting concepts. Focus on efficient biological or biochemical approaches to assist in purifying and recycling wastewater in confined spaces such as crewed spacecraft or space habitats. Of special interest are biological approaches and bioreactors for removing carbon, nitrogen and phosphorus, and reduction of biosolids.

Topic H4 Extra-Vehicle Activity and Crew Survival Systems Technology

H4.01 Crew Survival Systems for Launch, Entry, Abort

Support the launch, entry, and abort (LEA) crew survival equipment needs for future human exploration beyond low Earth orbit. Primary goals include development of technologies enhancing crew survival in the launch, entry, and abort phases of flight as well as the post-landing environment, significant mass reduction of hardware, and development of space-qualified survival hardware technologies designed to operate after exposure to space vacuum and thermal effects. LEA crew survival equipment development is a critical need tied to any future manned Design Reference Mission (DRM) laid out by the agency, as well as providing benefit to both Orion/MPCV and Commercial Crew Program engineering efforts.

H4.02 EVA Space Suit Pressure Garment Systems

Focused on providing enabling technologies for long-duration missions inclusive of extensive extra-vehicular activity (EVA). To that end, priority technologies address mass reductions, durability and reliability. Mass reduction for exploration pressure garments is driven, in addition to launch mass considerations, by the human factor of on-back weight for a planetary walking suit configuration following a long-duration micro-gravity transit, which may reduce astronaut load bearing capability. Driving reference missions such as a 1.5-year Mars surface stay include on the order of 700 hr of EVA.

Therefore, long-duration exploration missions require, in some cases orders of magnitude, increases in suit durability or new approaches to providing long duration mission EVA capability or logistics.

H4.03 EVA Space Suit Power, Avionics, and Software Systems

Seek flight rated electronic devices needed to complement the existing inventory of flight rated parts so as to enable the creation of an advanced avionics suite for spacesuits. The suit and its corresponding avionics should be capable of being stowed inside a spacecraft outside the low Earth orbit (LEO) environment for periods of up to 5 years (TBR). Devices should also be capable of supporting EVA sorties of at least 8 hr and total lifetime operational durations of at least 2300 hr (TBR) for a Mars surface mission. Devices should be immune to single event latch-up (SEL) for particles with Linear Energy Transfer (LET) values of at least 75 Mev-cm^2/mg. and maintain full functionality for total ionizing doses of at least 20 Krad (Si). Criticality 1 devices (life support) must be fully mitigated against single event errors (SEE) for all potential mission radiation environments, including solar flares. Lower criticality devices can be less tolerant of SEEs, but must still operate with acceptable error rates in all potential radiation environments. Power consumption should be no more than 2X similar COTS or mil-spec devices.

Topic H5 Lightweight Spacecraft Materials and Structures

H5.01 Deployable Structures

Focus on structures that are folded or retracted for launch and then expand to a larger size once in their operational environment. Deployable structures include but are not limited to mechanically deployed structures, strain energy deployed structures, and inflated structures. These systems require innovative packaging and deployment approaches to maximize the ratio of the deployed dimensions to launch volume. The successful design and operation of structurally efficient deployable structures for spacecraft is always one of the highest concerns for mission success especially as their size increases or human life is at risk. Seeks deployable structures innovations this year in two areas of special interest for proposed deep-space space exploration missions: (1) large deployable solar arrays for 50+ kW solar electric propulsion (SEP) missions, and (2) lightweight deployable hatches for manned inflatable structures. Design solutions must minimize mass and launch volume while meeting all other mission requirements including deployed strength, stiffness, and durability.

H5.02 Extreme Temperature Structures

Focus on developing innovative low cost and lightweight structures for cryogenic and elevated temperature environments. The storage of cryogenic propellants and the high temperature environment during atmospheric entry require advanced materials to provide low mass, affordable, and reliable solutions. The development of durable and affordable material systems is critical to technology advances and to enabling future launch and atmospheric entry vehicles. The subtopic focuses on two main areas: highly damage-tolerant composite materials for use in cryogenic storage applications and high temperature composite materials for hot structures applications.

H5.03 Multifunctional Materials and Structures

Focus on integration of acoustic meta-material concepts into the primary structure to reduce interior acoustic and vibration environments. Specifically, innovations are solicited which maintain the load bearing capability of the primary structure while simultaneously reducing interior noise and vibration levels below 400 Hz. Successful innovations are anticipated to enable the design of lighter and cheaper spacecraft and launch vehicle structures, as well as lower costs associated with ruggedizing and qualifying spacecraft and launch vehicle secondary structures. Focus on sensory materials incorporated into a primary structure to provide health monitoring data, and low-mass/wireless methods of transmitting localized structural responses to diagnostic models for material and structural state. Manufacturing technologies capable of producing structural components with embedded capability for sensing strain, damage initiation and propagation, and temperature are of particular interest. Ideally, the sensing technology should also augment the load carrying capability or some other structural design requirement. Technologies should enable weight reduction with similar or better structural performance when compared to traditional approaches.

Topic H6 Autonomous and Robotic Systems

H6.01 Mobility Subsystem, Manipulation Subsystem, and Human System Interaction

Create human-robotic technologies (hardware and software) to improve the exploration of space. Robots can perform tasks to assist and off-load work from astronauts. Robots may perform this work before, in support of, or after humans. Ground controllers and astronauts will remotely operate robots using a range of control modes (tele-operation to supervised autonomy), over multiple spatial ranges (shared-space, line-of-sight, in orbit, and interplanetary), and with a range of time-delay and communications bandwidth.

Topic H7 Entry, Descent, and Landing Technologies

H7.01 Ablative Thermal Protection Systems Technologies, Sensors, and NDE Methods

Develop in-situ sensor systems including pressure sensors, heat flux sensors, surface recession diagnostics, and in-depth or structural interface thermal response measurement devices, for use on rigid and/or flexible ablative materials. Individual sensors can be proposed; however, instrumentation systems that include power, signal conditioning and data collection electronics are of particular interest.
In-situ heat flux sensors and surface recession diagnostics tools are needed for flight systems to provide better traceability from the modeling and design tools to actual performance. Focus on non Destructive Evaluation (NDE) tools for evaluation of bondline and in-depth integrity for light- weight rigid and/or flexible ablative materials. Non Destructive Evaluation (NDE) tools are sought to verify design requirements are met during manufacturing and assembly of the heat shield, e.g., verifying that anisotropic materials have been installed in their proper orientation, and that the bondline as well as the TPS materials have the proper integrity and are free of voids or defects.

H7.02 Diagnostic Tools for High Velocity Testing and Analysis

Develop diagnostics for analyzing ground tests in high enthalpy, high velocity flows used to replicate vehicle entry, descent and landing conditions. Diagnostics developed will be tested in NASA's high enthalpy facilities, which include the Electric Arc Shock Tube (EAST), Arc Jets, Ballistic Range, Hypersonic Materials Environmental Test System (HyMETS), and 8 ft High Temperature Tunnel (HTT). Focus on development of improved diagnostics for hypervelocity flows allows us to better understand the composition and thermochemistry of our ground test facilities and are important for building ground-to-flight traceability. Characterizations in facilities may be used to validate and/or calibrate predictive modeling tools which are used to design and margin EDL requirements.

Topic H8 High Efficiency Space Power Systems

H8.01 Space Nuclear Power Systems

Develop fission power system technology for future space exploration applications using a stepwise approach. Initial small fission systems are envisioned in the 1 to 10 kWe range that utilize cast uranium-metal fuel and heat pipe cooling coupled to static or dynamic power conversion. Follow-on systems could produce 10 or 100 s of kilowatts utilizing a pin-type uranium fueled reactor with pumped liquid metal cooling, dynamic power conversion, and high temperature radiators. The anticipated design life for these systems is 8 to 15 years with no maintenance.

H8.02 Solid Oxide Fuel Cells and Electrolyzers

Address challenges common to both fuel cells fed by oxygen and hydrocarbon fuels, and electrolyzers fed by carbon dioxide and/or water. Hydrocarbon fuels of interest include methane and fuels generated by processing lunar and Mars soils. Primary solid oxide components and systems of interest are including solid oxide cell, stack, materials and system development for operation on direct methane in designs scalable to 1 to 3 kW at maturity. Strong preference for high power density configurations. Cell and stack development capable of Mars atmosphere electrolysis should consider feasibility at 0.4 to 0.8 kg/hr O_2; scalable to 2 to 3.5 kg/hr O_2 at maturity.

H8.03 Advanced Photovoltaic Systems

Focuses on advanced photovoltaic (PV) blanket and component technology/designs that support very high power and high voltage (> 200 V) applications PV power generation (cell, interconnect, and small self-deployable arrays) for CubeSat/ small satellite applications PV module/ component technologies that emphasize low mass and cost reduction (in materials, fabrication and testing). Improvements to solar cell efficiency that are consistent with low cost, high volume fabrication techniques. Automated/modular fabrication methods for PV panels/modules on flexible blankets (includes cell laydown, interconnects, shielding and high voltage operation mitigation techniques). Integrated PV system including cells, blanket, array, inverters, interconnect technologies, storage, structures, etc. with a balance-of-components while matching specifications of various systems.

Topic H9 Space Communications and Navigation (SCaN)

H9.01 Long Range Optical Telecommunications

Focus on PPM Space Laser Transmitters including (1) Space-qualifiable, 1520 to 1630 nm laser transmitter for pulse-position modulated (PPM) with >25 percent DC-to-optical (wall-plug) efficiency. (2) PPM Ground Laser Transmitters – >2000W average power PPM laser transmitters for nested modulation forward links to support simultaneous data rates of ~10 b/s (outer code) and at least 10 Mb/s (inner code) with an outer rate inter-symbol guard time of 50 percent. Operational wavelength in either 1030 to 1080 nm or 1480 to 1570 nm bands. (3) Photon Counting Near-infrared Detectors Arrays for Ground Receivers – Close packed (not lens-coupled) kilo-pixel arrays sensitive to 1520 to 1630 nm wavelength range with single photon detection efficiencies greater than 90 percent, single photon detection jitters less than 40 ps

FWHM, (4) Photon Counting PPM Digital Ground Receivers – Digital receiver and decoder assemblies for processing photon counting detector array outputs of PPM encoded data, and (5) Photon Counting Near-infrared Detectors Arrays for Flight Receivers – 128×128 or larger array with integrated read-out integrated circuit and thermo-electric cooling for the 1030 to 1080 nm or 1520 to 1650 nm wavelength range with single photon detection efficiencies greater than 40 percent.

H9.02 Intelligent Communication Systems

Focus on system wide distributed intelligence of cognitive and intelligent applications – while much of the current research often describes negotiations and improvements between two radio nodes, the subtopic seeks solutions to understand system wide aspects and impacts of this new technology. Areas of interest include (but not limited to) system wide effects (e.g., protocols) to decisions made by one or more communication/navigation elements e.g., how changing data rate, modulation, or frequency between nodes effects data distribution through relay satellites, and throughout space and ground network and multiple access techniques that optimize connectivity and throughput while minimizing onboard data storage and interference. Seek (1) cognitive engine (algorithm) and component development - to demonstrate new capability in sensing and adapting to the radio/mission environment, (2) Flexible and adaptive hardware systems (e.g., signal processing platforms, adaptive front ends for RF or optical communications, and other intelligent electronics) which directly implements or demonstrates cognitive or intelligent applications as an alternative to more general software-based intelligent systems, and (3) Autonomous Ka-band and/or optical communications antenna pointing on mission spacecraft within intelligent multiple access systems.

H9.03 Flight Dynamics and Navigation Technology

Focus on (1) software that fuses and analyzes spacecraft sensor data and other spacecraft tracking data available at ground/mission operations centers (i.e., facility software), and (2) Advanced celestial navigation techniques including devices and systems, especially those that support of deep-space, planetary missions. System concepts should support significant advances of independence from Earth supervision including the ability to operate effectively in the absence of Earth-based transmissions or transmissions from planetary relay spacecraft with those that operate in the complete absence of human intervention or Earth-based transmissions are preferred. Of particular interest are concepts that support pointing of high rate optical communications terminals to earth terminals that do not rely on the use of optical uplinks or beacons for achieving proper pointing of the communication beam. However, concepts which are capable of supporting planetary missions of any type are of interest. Proposals that include re-purposing/cross-purposing of advanced sensors contemplated for future deep-space missions such as x-ray telescopes are preferred.

Topic H10 Ground Processing

H10.01 Cryogenic Purge Gas Recovery and Reclamation

Address the following technologies (1) Enhanced membrane technologies including Proton Exchange Membrane (PEM) fuel cells that increase the efficiency, recovery production rate or life span of fuel cell based separation technologies, (2) Development of alternative cryogenic gas separation technologies,
(3) Technologies for the rapid capture and storage of high volumes of mixed cryogenic gases,
(4) Development of zero trapped gas system technologies to improve purge effectiveness, and
(5) Development of real-time, solid state sensor technologies for monitoring the current state of the

system concentration levels and helium/nitrogen purge process effectively (e.g., hydrogen, oxygen, water vapor content, etc.).

Topic H11 Radiation Protection

H11.01 Radiation Shielding Technologies

Address lightweight innovative radiation shielding materials to shield humans in aerospace transportation vehicles, large space structures such as space stations, orbiters, landers, rovers, habitats, and spacesuits. The materials emphasis should be on nonparasitic radiation shielding materials, or multifunctional materials, where two of the functions are structural and radiation shielding. Materials of interest include, but are not limited to, polymers, polymer matrix composites, nanomaterials, and regolith derived materials. The objective is to replace primary, secondary, and interior structures, including equipment and components, with radiation protective materials. There is particular interest in the development of high hydrogen content materials and materials systems to replace traditional materials.

Topic H12 Human Research and Health Maintenance

H12.01 Measurements of Net Ocular Blood Flow

Focus on development of rapid and accurate techniques to characterize the net blood flow to and from the eye. Measurements of interest include the temporal history of the following (1) Maps of choroidal and retinal thickness, which include near- and far-field contributions, (2) Net volume of the choroid and retina, (3) Net volumetric blood flow to and from the choroid and retina and, (4) Pressures and net luminal areas at the entrance and exit of the choroid and retina. Measurements must be presented in physical units, such as blood flow in milliliters per minute. The measurement system must also process the raw data, either in a real-time or post-processing mode. Data analysis capabilities should include the calculation of the overall time-averaged mean values, as well as the mean waveform over a cardiac cycle. It would be of significant interest if comparable measurements were made simultaneously of intraocular pressure, reference arterial pressure (systemic, brachial and/or ophthalmic artery), fundus pulsation amplitude, and/or heart rate.

H12.02 Unobtrusive Workload Measurement

Addresses technologies and methods to measure, assess, and predict astronaut workload unobtrusively, and to extend these technologies to measuring and predicting astronaut workload during long duration operations. Unobtrusive measures would be ones that do not require operators to specifically interact with a technology or provide inputs, and would not interrupt an operator’s work. Unobtrusive objective measures such as video, voice, thermal infrared imaging or eye tracking methods may be more appropriate when measuring long duration workload, so long as the technology’s credibility is ensured.

H12.03 Technology for Monitoring Muscle Protein Synthesis and Breakdown in Spaceflight

Focus on novel, non- or minimally-invasive technologies to measure muscle protein turnover for use in subsequent research studies. The most important measurement would be a synthesis breakdown ratio indicative of the state of muscle balance (formation, breakdown or stability) as opposed to exact protein synthetic rates. However, absolute protein synthesis and breakdown rates are highly desirable. Addresses the following Human Research Program requirements: Risk of Impaired Performance Due to Reduced

Muscle Mass, Strength and Endurance; and Characterize the time course of changes in muscle protein turnover, muscle mass and function during long duration space flight.

Topic H13 Nondestructive Evaluation

H13.01 Advanced NDE Modeling and Analysis

Addresses real-time large scale nondestructive evaluation (NDE) and structural health monitoring (SHM) simulations and automated data reduction/analysis methods for large data sets. Simulation techniques will seek to expand NASA's use of physics based models to predict inspection coverage for complex aerospace components and structures. Analysis techniques should include optimized automated reduction of NDE/SHM data for enhanced interpretation appropriate for detection/characterization of critical flaws in space flight structures and components. Space flight structures will include light weight structural materials such as composites and thin metals. Techniques sought include advanced material-energy interaction simulation in high-strength lightweight material systems and include energy interaction with realistic damage types in complex 3–D component geometries (such as bonded/built-up structures).

Topic H14 International Space Station (ISS) Demonstration and Development of Improved Exploration Technologies and Increased ISS Utilization

H14.01 International Space Station (ISS) Utilization

Focuses on providing additional on-orbit analytical tools. Development of instruments for on-orbit analysis of plants, cells, small mammals and model organisms including Drosophila, C. elegans, and yeast. Instruments to support studies of bone and muscle loss, multigenerational species studies and cell and plant tissue are desired. Providing flight qualified hardware that is similar to commonly used tools in biological and material science laboratories could allow for an increased capacity of on-orbit analysis thereby reducing the number of samples which must be returned to Earth. Development of instruments and software for reconstructing 3–D tomographic images that provides a nonintrusive measurement of the spatial phase distribution in gas-liquid flows. Instruments must be capable of a high temporal acquisition (200 Hz or greater) with resolution between phase boundaries within the measured region on the order of 2 to 3 mm or better. The fluids are typically air-water systems.

H14.02 International Space Station (ISS) Demonstration of Improved Exploration Technologies

Focus on ambient temperature catalyst replacement for the ISS Water Processing Assembly, high pressure oxygen generation applicable to both ISS and future human space flight vehicles, demonstrated on ISS. Emphasis should be placed on developing and demonstrating hardware and/or software prototypes that can be demonstrated on orbit (TRL 8). The contract should deliver unit for functional and environmental testing at the completion of the Phase II contract. The technology at the end of Phase II should be at a TRL of 6-7.

H14.03 Recycling/Reclamation of 3–D Printer Plastic Including Transformation of Launch Package Solutions into 3–D Printed Parts

Focus on launch packing solutions that can be composed of materials suitable for recyclable processing into 1.75 mm filament and subsequently 3–D printed parts. This capability will significantly decrease current waste and substantially increase sustainability. The solution maybe obtained using a variety of approaches, such as (1) Converting commonly used 3–D printing feedstocks into packing solutions, including but not limited foam or bags, (2) Transforming traditional packing materials into 3–D Printing feedstock, and (3) Developing a technology that utilizes a novel approach to identify compatible materials for both packing solutions and 3–D Printing. For example, this could include such materials as netting, fabrics, structures, containers, etc.

H14.04 Optical Components, Sensors, and Systems for ISS Utilization

Focus on development of sensors and systems using innovative sources, detectors, materials, components and configurations for accomplishing new and/or improved performance, increased reliability and ruggedness, reduction in size, weight and power consumption (SWaP), and cost would advance HEOMD missions. Topics of interest include but not limited to optical materials, optical components such high temperature and broadband windows and elements, active and passive sensing architectures, smart sensors and sensor suites including multifunctional aspects, monolithic or hybrid high operating temperature detectors and focal plane arrays, ISS compatible miniature remote sensing systems for characterization of hard targets, terrain mapping, deep space imaging (3–D and hyper spectral) sensors and systems, and precision, navigation, and timing systems.

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