

Extravehicular Activity Framework for Exploration - 2019

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The Extravehicular Activity (EVA) Framework for Exploration describes NASA’s EVA System Goals in the broader context of ongoing human spaceflight efforts. The purpose of this document is to drive integration, coordination and communication of the EVA community’s exploration development plans as crafted to meet long-term EVA needs. Inclusive in the EVA community are NASA partners in academia and industry. The 2019 EVA Framework outlines the office’s current method to answer the following questions: What product does NASA use to compare, contrast and integrate across the elements of the EVA community’s perceived gaps, risks, and unfunded work, particularly for future systems intended for use beyond Low Earth Orbit (LEO)? What product does NASA use to proactively coordinate support across the EVA community’s wide spectrum of exploration development work? Where can one go to obtain awareness of ongoing efforts, particularly during consideration of new-start activities and proposals? These questions lead to the need for a product that speaks to the distributed nature of the EVA System across human spaceflight programs, concept studies and flight vehicle architectural elements. This framework can be used and evaluated by the EVA community to assess the full spectrum of needs and answer the question of “what are we missing” or “are we doing things that just do not make sense”. In the end is the EVA community effectively pursuing the future needs of EVA? If answers to those questions reveal the need for change or re-prioritization then actions can be taken through existing project control processes as well as revision to this document and supporting project plans.

Nomenclature

ACSC	=	Advanced Cislunar Surface Capability
AEA	=	Assured EVA Availability
ARGOS	=	Active Response Gravity Offload System
BAA	=	Broad Agency Announcement
CO ₂	=	Carbon Dioxide
DCS	=	Decompression Sickness
DRM	=	Design Reference Mission
ECLSS	=	Environmental Control and Life Support Systems
EEWG	=	EVA Exploration Working Group
EMU	=	Extravehicular Mobility Unit
EVA	=	Extravehicular Activity
FMEA	=	Failure Modes and Effects Analysis
GER	=	Global Exploration Roadmap
HEOMD	=	Human Exploration and Operations Mission Directorate
HLS	=	Human Landing System
HQ	=	Headquarters
HRP	=	Human Research Program
ISS	=	International Space Station
JSC	=	Johnson Space Center
LEO	=	Low Earth Orbit
MIG	=	Mars Integration Group
NASA	=	National Aeronautics and Space Administration

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- NBL = Neutral Buoyancy Laboratory
- NRHO = Near Rectilinear Halo Orbit
- PDR = Preliminary Design Review
- PGS = Pressure Garment System
- PLSS = Portable Life Support System
- PRA = Probabilistic Risk Assessment
- S&MA = Safety and Mission Assurance
- SAFER = Simplified Aid for EVA Rescue
- SBIR = Small Business Innovative Research
- SE&I = Systems Engineering and Integration
- SMT = System Maturation Team
- STTR = Small Business Technology Transfer
- USOS = US Orbital Segment
- xEMU = Exploration Extravehicular Mobility Unit

I. Introduction

THE following subsections provide a comprehensive overview of NASA’s Exploration EVA framework for exploration and the rationale that has led to its current form. In particular, the purpose of the document places NASA’s EVA System Goals in the broader context of ongoing human spaceflight efforts. A methodology and context section defines the overarching approach and conventions or summarizes from other Exploration EVA Products. The 2019 Exploration EVA system technology development tasks are documented with relevant background explanations and the detailed task descriptions. Brief explanations of cost management and governance philosophies are provided, followed by a section with closing remarks on the long-term EVA development strategy. Appendices capture reference information such as a snapshot in time of the EVA System Maturation Team (SMT) Gap List that is maintained in the EVA Gap Tool and notional agendas for the EVA Exploration Working Group (EEWG). This is typically done where the material is available but is more “out year” in nature and will eventually be pulled forward into the primary section as time goes by and the content is more definitive and tactical in nature.

A. Purpose

The purpose of this document is to drive integration, coordination, standardization, and communication of NASA’s EVA community exploration strategic plans as crafted to meet long-term EVA needs. An example of this would be the goal of NASA’s Exploration EVA Systems Engineering & Integration (SE&I) team to develop and publicize a library of products that succinctly take into account years of lessons learned for EVA operations, design, compatibility and safety. NASA’s Exploration EVA System development strategy is currently supported by several separate programs and/or distinct programmatic efforts:

Table 1. NASA Exploration Strategic and Supporting Programmatic Efforts.

Program	Supporting Efforts
The International Space Station (ISS) Program	US Orbital Segment (USOS) EVA flight operations and Technology Development/Risk Reduction
The Gateway Program (Gateway)	Deep space EVA exploration demonstration and contingency capabilities
The Advanced Cislunar Surface Capabilities (ACSC) Team	Lunar Surface EVA exploration missions, such as the Human Landing System and Surface Capabilities
The Human Research Program (HRP)	Researches fundamental human physiology, mitigates physiological risks related to or induced by EVA

In addition to these, many other smaller programs/projects/tasks with EVA relevancy exist within NASA's Human Exploration and Operations Mission Directorate (HEOMD) and other NASA Divisions such as Space Technology Mission Directorate. These may include Small Business Innovative Research (SBIR's), Small Business Technology Transfer (STTRs'), Institutional Research and Development funded projects, cislunar, lunar surface, Mars capability studies, and analog teams. An example of this is the JSC Exploration Mission Planning Office's Mars Integration Group (MIG). While the existence of such a wide variety of effort is certainly preferred over the alternative (i.e. a situation wherein there is little to no ongoing work in the field) it does raise a non-trivial set of questions:

- 1) What product does NASA use to compare, contrast and integrate across the elements of the EVA community's gaps, risks, and unfunded work, particularly for future systems intended for use beyond LEO?
- 2) What product does NASA use to proactively coordinate support across the EVA community's wide spectrum of exploration development work?
- 3) Where can one go to obtain awareness of ongoing efforts, particularly during consideration of new-start activities and proposals?
- 4) Where can one go to obtain a view of the rate of progress being made towards future EVA systems?

These questions lead to the need for a product that speaks to the distributed nature of the EVA system across Human Spaceflight programs, from concept studies to flight elements. This document is intended to address that need. Since documents themselves are inanimate things, just exactly how the authorship of this product is envisioned to do so likely bears explanation. To begin, it should be clearly stated that most activities described herein existed or were individually funded/approved before the 2017 revision, when the first attempt to speak to the entire spectrum of Exploration EVA System Development Plan was released.

The first revision of this document, entitled "2017 Exploration EVA System Development Plan" was intended to serve as a place to present, describe and knit together all the different activities that are ongoing. This clearly described or pointed to adequate references documenting all tasks ongoing "in the name of EVA." The intent for this document, the "2019 EVA Framework for Exploration," is to provide the EVA community a publically accessible document for assessing the full spectrum of needs and tasks and answer the question of "what are we missing" or "are we doing things that just do not make sense". If answers to those questions reveal the need for change or re-prioritization then actions can be taken through existing project control processes as well as revision to this document and supporting project plans. Thus, the Framework itself doesn't "do" the work – the community of people creating, reviewing, commenting and using the document do. The document is merely an object that creates a focus for a process and conversations. Contradictory or inconsistent statements, missing task descriptions or glaring errors will not survive long as the team members will strive to improve the product. The conversations leading to eliminating those errors in this written document will address the real-world issues that may exist. It's not the document itself but rather the journey of perfecting the EVA Exploration Framework for Exploration that enables the desired outcome.

B. Scope

The plan includes the tactical content of Fiscal Year 2019 and strategic out-year EVA development activities that support ISS and future EVA needs for destinations beyond LEO. The 2019 Framework provides updates to the previous plan in several key ways:

- 1) Articulate tasks and efforts as aligned with 2019 resources and priorities.
- 2) Include content addressing the broader EVA community beyond the Space Suit-centric portion of the previous plan.

The 2019 Framework provides a linkage between longer-term strategy and nearer term tactical planning products. Furthermore, it identifies the products and actions the EVA Office must create or execute in order to facilitate the performing organizations' detailed work plans.

Because of the widely varying scope, differing levels of maturity and different levels of resources across the projects that constitute Exploration EVA Framework, there are and must be differing levels of detail captured in this document. For example, the detailed content development and negotiation of a given year's scope for large, mature projects which have multi-year histories is generally worked for many months and leads to that project's Work Plan which is then cited by this document. In contrast, "new start", short term or small scale efforts are described in more detail here in order to encourage infusion across the ongoing portfolio of work without driving creation of a disproportionate amount of stand-alone documentation that may take longer to finish than the task itself. This model is followed regardless of whether the new start task emerges as an independent function or is merely a change in priorities/content in an ongoing project.

Throughout the year, content from this plan is worked across the EVA community through many project teams meetings, working groups and control boards. The primary method for general status and insight into progress toward

plan content is through community membership and representative participation at the Johnson Space Center (JSC) EEWG.

Though not every topic is discussed at every EEWG, a rotating cycle of informational presentations is designed to ensure community awareness and as necessary guide plan revisions to each element of this document, with all elements receiving dedicated time at least once per quarter (and therefore a minimum of four times per fiscal year). Additionally, each instance of the EEWG also provides an opportunity for round-table conversation and emergence of novel/unplanned topics as they arise. From the EEWG, topics may be forward to other venues such as the EVA Configuration Control Board or elsewhere as appropriate. A summary of venues and opportunities for communication and collaboration include but are not limited to the following:

Table 2. EVA Community Coordination Venues.

Venue	Host Organization
EVA Exploration Working Group (EEWG)	EVA Office (XX)
Human Health and Performance EVA Research and Integration Working Group	Biomedical Research and Environmental Sciences Division (SK)
xEVA Systems Panel	EVA Office (XX)
xEMU Systems Engineering and Integration Forum	Crew and Thermal Systems Engineering Division (EC)
EVA Annual Workshop and Virtual Meetings	EVA Office (XX)

II. EVA Strategic Planning Goals

“Achieve safe, affordable, and effective EVA capabilities that enhance the human experience as we explore beyond Earth”

In 2016, the EVA community worked to develop the Mission Statement shown above. Perhaps the highest level “goal” in and of itself, the EVA Mission Statement ties together the work being done to improve EVA operations on ISS today with near term and long term strategic goals for EVA capability:

- 1) Reduce current EMU risk posture for ISS USOS EVAs through 2024.
- 2) Ensure ISS USOS EVA capability through at least 2028
- 3) Posture NASA and commercial entities for longer term EVA capabilities

Upon initial inspection, some elements of the first two nearer-term goals may not readily seem to fit within an “exploration” context. However, closer examination connects them: Hardware changes and other risk reduction efforts being incorporated into the contemporary ISS EVA System are each at least partially considered for applicability/appropriateness for operations beyond ISS. A ready example of this is the ongoing Carbon Dioxide (CO₂) Sensor Replacement/Upgrade project that supports strategy 2 and 3 above, wherein the technologies being pursued are also chosen for their future compatibility with the NASA Exploration EVA System Reference Architecture (detailed in section III.B). In this way, much as the modern day EMU used on ISS was “inherited” from the Space Shuttle Program, so too it is expected that much of the ISS EVA System will live into the next Program.

HEOMD’s longer term EVA capability goals are represented in the recently baselined “Human Exploration and Operations – Exploration Objectives” document, HEOMD-001¹. HEOMD-001 divides exploration into Phases with definitions as excerpted from the text:

A. Phase 0: Exploration Systems Testing on ISS

This phase encompasses NASA’s current human exploration activities aboard the International Space Station (ISS) that enable exploration objectives in cislunar and deep space...

B. Phase 1: Cislunar Demonstration of Exploration Systems

This phase covers demonstration of the integrated Space Launch System and Orion spacecraft and other exploration activities primarily occurring in cislunar space to support short-duration objectives as well as closure of key strategic knowledge gaps. Phase 1 culminates in the initial operations capability of the... Gateway... in the mid-2020s as well as demonstration of advanced EVA capabilities.

C. Phase 2: Cislunar Validation of Exploration Systems

This phase covers validation of integrated Space Launch System, Orion, habitation, crew, and in-space transportation systems in cislunar space in preparation for Mars-class missions, as well as closure of key strategic knowledge gaps. Phase 2 culminates in the demonstration of a one year, Mars-class crewed “shakedown cruise” of the Deep Space Transport in the 2030 timeframe.

D. Phase 3+: Beyond Earth-Moon System

This phase covers beyond cislunar space activities building on what is learned in Phases 0 – 2 to enable human missions to the Mars vicinity, including the Martian moons, and eventually the Martian surface.

The EVA-specific objectives in HEOMD-001 are broken out by phases and include:

- P0-04: Demonstrate in-space exploration class EVA technologies
- P1-11: Validate ability to conduct EVA in deep space
- P2-05: Validate capability and reliability of Environmental Control and Life Support Systems (ECLSS) to support a Mars class mission including dormancy periods.

Additionally, several other HEOMD-001 objectives are significantly enabled by EVA or have a strong EVA component:

- P1-18: Enable science community objectives in deep space
- P2-10: Validate maintenance and repair capabilities in deep space with limited or no resupply
- P2-12 Enable science community objectives in deep space

Note that there are no Phase 3 definitions for EVA or any other human spaceflight system defined in the baseline of HEOMD-001. However, for the purposes of EVA’s strategic planning, the EVA community’s products also articulate EVA System gaps, risks and architectural intent all the way to Mars Surface. This is done to ensure that, NASA’s Exploration EVA System Reference Architecture in EVA-EXP-0041 and other products are not developed without Mars surface in mind or without at least consideration of the challenges of being Mars-surface compatible. In some cases there may be known limits to available and emerging technologies that make them incompatible with Mars Surface, but in those cases they are identified early and the community works to place “scars” around them to limit the impact of “fixes”. As such issues emerge and are better characterized, work to reduce/eliminate the gaps and risks is prioritized.

III. Methodology and Context

The subsections that follow, bind together the supporting, explanatory information necessary to understand the perspective and philosophy from which the rest of the document is written. After review of this section if any “leap of logic” or contradiction is found to remain it is either a shortcoming of the following explanation or an actual disconnect in the activities the EVA community is pursuing. Either case is important and should be referred to the document authors for correction. This feedback is vital to ensuring the Framework continues to evolve and provide a worthwhile resource to the EVA community.

A. Approach and Conventions

The following figure provides a reference for “who” the NASA EVA community includes:



Figure 1. NASA EVA Community Coordination Venues.

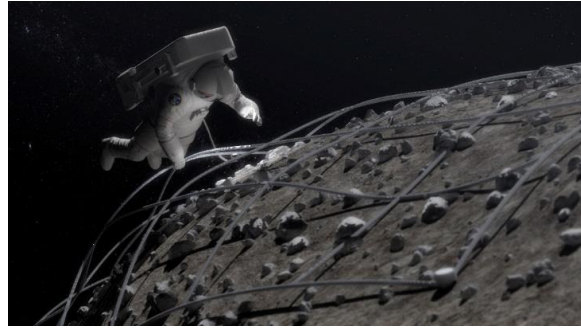
The full breadth of the EVA community is involved in the pursuit of the goals and tasks discussed in this document. Though small in numbers, the EVA community is broad and diverse in membership. Experts and leaders from all aspects of NASA, including NASA Headquarters (HQ), S&MA, Science and Technology Development, Engineering, Programmatic, Procurement, Academia and Industry work together with International Partners to make EVA successful. In doing so, the EVA community members pursue many parallel paths:

- 1) Continual support of the existing operating EVA System on ISS, including a robust AEA Program supported by ISS, which works to extend the life and availability of the existing EMU fleet.
- 2) Infusion of new technologies (such as alternative CO₂ Sensor designs) into the EMU fleet.
- 3) Coordination of flight operations, training activities and hardware exchanges with International Partners through the ISS Program.
- 4) Pursuit of a NASA Exploration EVA Suit Reference Design through the agency's xEMU project.
- 5) Creation and maintenance of Exploration EVA SE&I products including Exploration EVA System Compatibility requirements for robotic spacecraft and other supporting documentation for payload and future spacecraft development.
- 6) Support of an active and effective EVA SMT.
- 7) Yearly review of the Exploration EVA SMT Gaps housed in the EVA Gap Tool.
- 8) Engagement of all HEOMD Exploration Design Reference Missions (DRM's) and concept or feasibility study teams including regular (often daily or weekly) interaction with:
 - a. The NextSTEP Habitat Broad Agency Announcements (BAA's)
 - b. The Mars Integration Group (MIG)
 - c. Advanced Cislunar Surface Capabilities (ACSC)

However, circumstances across the portfolio of DRMs often change as the broader landscape of Agency policy evolves. In order to provide flexible and responsive support to shifts in Agency Policy, HEOMD priorities, Program constraints and DRM assumptions and goals, EVA has sought and created a methodology for organizing the EVA System's exploration strategic planning efforts in a more general manner. This has been dubbed "EVA Destination Classes" and can be briefly summarized in Figure 2 as follows:



a) Microgravity, engineered surface, thermal vacuum. *Gemini, Apollo deep-space, Skylab, Mir, Shuttle, ISS, and Gateway.*



b) Microgravity, natural surface, thermal vacuum. *Near-Earth asteroids, Phobos, and Deimos*



c) Partial-gravity, natural surface, thermal vacuum. *Earth's Moon.*



d) Partial-gravity, natural surface, partial atmosphere. *Mars surface.*

Figure 2. EVA Destination Classes.

All of EVA's SE&I products as well as NASA's Exploration EVA System Reference Architecture are organized to align with the Destination Classes. For instance, instead of labelling past content exclusively under "Gateway" or "Moons of Mars Study", micro-gravity natural surface, thermal vacuum will show a corresponding ops con that is generally true regardless of whatever the study is named. This allows the system to be responsive to any portfolio of DRM studies while making progress within the EVA community in parallel with DRM change, quickly shifting to the specifics of new DRMs as required.

2019 efforts will continue to address and reduce cost, technical and schedule risk associated with future implementation phases of flight development. Independent of specific procurement strategies, the Agency must perform the tasks outlined in this plan to meet the objectives of maturing a reference suit system architecture and the broader EVA System. Therefore, this plan considers a wide portfolio of technology development and knowledge capture tasks that best support EVA's needs beyond LEO, reducing the gaps and risks identified in the EVA Gap Tool and the HRP EVA Physiology Risk List.

The approach in the 2019 timeframe will be to focus on the following, in parallel:

- 1) Integrate and document the requirements necessary to support future development of Exploration EVA flight systems. The goal is to be prepared to support the ISS xEMU Demonstration, as well as flight acquisition of full suit or EVA subsystems at any time.
- 2) SE&I Products. This set will include an approach for use of industry standards and expectations for integration with ISS with decomposition and traceability to specific standards used in the NASA Exploration EVA Suit Reference Design.
- 3) Acquire, organize, and disseminate 8+ years of EVA technology development information to improve industry involvement in technology development and future acquisitions.
- 4) Support the maturation of all products associated with the Exploration EVA Portable Life Support System (PLSS) to Preliminary Design Review (PDR) level by mid-2019. Continue to mature system level technology readiness.

- 5) Conduct micro-gravity evaluation of the Exploration Pressure Garment System (PGS) within the Neutral Buoyancy Laboratory (NBL) with a range of lower torso mobility and operating pressure conditions.
- 6) Perform system-level analyses to address major architectural risks associated with supporting ISS operations and future exploration needs. An example would be that ISS requires two-fault tolerance, whereas a lunar landing program might trade mass-savings for more risk – the xEVA program will need to address these types of discrepancies between programs.
- 7) Perform component-level development and evaluations of alternatives.
- 8) Plan and initiate pressure garment benchmark testing and evaluation to support EVA SMT and HRP gap/risk closures.

The Government-led EVA suit development efforts will continue to maintain and attempt to acquire intellectual property rights in a way that facilitates data dissemination to the broader EVA community. This is prioritized in conjunction with efforts that maintain a healthy EVA contractor base and critical skills necessary to support safe EVA operations and development.

Finally, the approach assumes there will continue to be a healthy EVA technology development capability in parallel to any flight system acquisition. This capability would be responsible for continuing to support high risk areas associated with the flight development as well as moving on to lower Technology Readiness Level technologies associated with the unique EVA needs for exploration beyond LEO, particularly the two Partial Gravity Destination Classes.

B. Exploration EVA System Reference Architecture Definition

Viewed through the lens of EVA Destination Classes and the corresponding organization of HEOMD’s Exploration DRM’s, the EVA community has settled upon a convention for NASA’s Exploration EVA System Reference Architecture, as seen in Figure 3.



Figure 3. Exploration EVA System Reference Architecture.

Given these definitions and the current state of technologies, the PLSS and PGS are within reach. Used together or separately in some cases, these items will meet the demands of missions on the Global Exploration Roadmap (GER)

from ISS to cislunar space, lunar surface, and the moons of Mars. For Mars Surface, the PLSS and PGS needed will require further technology development efforts.

The combination of the PLSS with the PGS that creates the xEMU addresses all currently understood EVA needs for HEOMD-001's Phase 1 and Phase 2 Objectives². For HEOMD-001 Phase 0 demonstrations on ISS, the primary EVA objective would be to gain confidence in PLSS performance. Focusing on the PLSS during ISS Demonstrations could be enabled by reuse of contemporary ISS EMU Softgoods. Such an incremental step would defer the development of the complete PGS, among other features. This configuration and approach is called "ISS xEMU Demo."

It should be noted that the xEMU PLSS and PGS as envisioned are not "Suitport Compatible". Though they do not preclude the future development of the Suitport concept, the NASA Reference Design of the PLSS and xEMU assume EVA access is achieved through a more conventional airlock volume.

IV. 2019 Exploration EVA Systems Development Tasks

The work elements of the Framework are captured in this section. The default convention is to provide a "Background" explanation followed by the "Detailed Task Description." Where appropriate, as in the case of large projects, pointers to dedicated Project Plans, Internal Task Agreements and supporting materials are provided in lieu of duplication of information.

A. Exploration EVA Suit Demonstration and Technology Development Project

The development of NASA's Exploration EVA System Reference Design is a continuation of the efforts conducted under the Advanced Exploration Systems Advanced Space Suit Project, and is now supported by the ISS Program via the EVA Office. The project goal is to mature a reference concept and perform a flight demonstration on ISS in the mid 2020's.

The xEMU Project Manager is responsible for production of a Project Plan, which includes the project organizational structure and lists the core members of the project as well as project Work Breakdown Structure. This includes tracking and management of component development efforts performed by other projects that are key to the overall EVA system development effort. The xEMU Project manager is furthermore responsible for creating and implementing any work agreements necessary to coordinate supporting organizations working under the Project and communicating with the EVA Office for any additional needs that are beyond the ability of the project to acquire on its own. Such examples may include utilization of EMU flight hardware or ISS Program test facilities.

1. PLSS Development

The majority of PLSS development tasks are recorded in the Project Plan, which include

- 1) Procurement of specific components to support component level technology maturation and buildup of a high fidelity PLSS.
- 2) Testing and performance evaluation of the latest components.
- 3) Systems analysis (structural and stress, for example) and model development to support a PDR review in mid-2019.
- 4) Requirements and specifications development and the subsystem and component level for the engineering reference design.

2. PGS Development

The PGS development tasks are also recorded in the Project Plan. These include tests with the following goals:

- 1) Validating volumetric performance in the NBL for use on ISS.
- 2) Evaluating performance in the NBL of an advanced Hard Upper Torso with an EMU Lower Torso Assembly, including use of ISS EVA tools, with test subjects across size ranges.
- 3) Supporting HRP benchmark testing³, including testing of planetary prototypes in the Active Response Gravity Offload System (ARGOS) facility.⁴
- 4) Requirements and specifications development and the subsystem and component level for the engineering reference design.

B. Exploration EVA Tools Technology Demonstration Project

The goal in EVA Tools development over the next year is to better define a common EVA tool suite for microgravity space exploration, as well as define a baseline set of surface EVA tools, including geology tools.

C. Exploration EVA Flight Operations Development

Exploration EVA has a significant need to incorporate the expertise and insight earned through the first 54 years of USOS EVA operations by the JSC Flight Operations Directorate. There is a wide spectrum of needs that vary in both desired timing and likely level of effort necessary to address. Additionally, some needs may be more appropriately addressed by Civil Servants (such as procurement-sensitive requirements development). The following tasks are grouped into different themes/types of content.

1. *Requirements Development: Provide formal EVA Operations expertise support/staffing to the EVA RWG.*
2. *EVA Exploration Working Group Participation: Provide formal EVA Operations expertise/staffing to the EEWG.*
3. *General Exploration EVA Operational Concept Development: Continues work on the top level Exploration EVA ConOps through maintenance and update of revision A of the product built in 2018.*
 - 1) Includes synchronization with EVA SMT Gap List
 - 2) Includes updates as driven by results of Integrated EVA Testing
 - 3) Includes updates as driven by evolving Exploration DRM's
4. *ISS Transition ConOps Development: Provides a specific OpsCon for a possible scenario of fleet transition from the existing ISS EMU to a major EMU Upgrade or Replacement during operations on ISS.*
 - 1) Maintenance and update once baseline is established
5. *EVA Flight Experience Evaluation of Exploration EVA Trade Studies: Provides direct access to EVA console records for flight data mining. Example includes research and compilation of ISS EMU consumables actuals from EVA console records*

Support EVA Office Coordination of Integrated Exploration EVA Testing Operations:: Provides inputs and updates to EVA Con Ops and Architectures through use of test facilities and analogs such as the NBL, ARGOS, NASA Extreme Environment Mission Operations, etc.

- 1) Includes coordination of Test Objectives and correlation with EVA SMT Gaps
- 2) Provides coordination across Exploration DRM study leaders, EVA Tools Developers and Facility/Analog mission leadership

D. Systems Engineering and Integration

To support the buildout of the NASA Exploration EVA System Reference Design, a number of SE&I products must be developed. These are categorized as programmatic documents, reference architecture documents, vehicle interface evaluations, and the following products:

1. Development Data Compilation and Organization

Data accumulated from analysis, testing, and design efforts in this plan will be organized by the EVA community as a critical part of the plan. A goal for 2019 is to capture, organize and disseminate all significant data resulting from technology development and system analyses currently available. This effort will be continued to eventually capture a PDR-level design reference to be used by NASA, technologists and all potential future bidders for EVA development as reference material.

2. Study of Post-Launch Life Pressurized Hours Philosophy

It is likely unrealistic to expect to bring PLSS elements back from Mars Surface missions. In fact, general EVA operational concepts postulate that we intentionally will not return surface EVA suits from Mars. This is done to meet the constraints of planetary protection and Mars ascent launch vehicle mass limitations. Furthermore, it is probably unreasonable to expect or constrain each Mars surface crew to re-use the previous mission's PGS or PLSS. This intones that there is little value in Mars surface suits having any life capability beyond what will be used on the surface for a given mission.

In 2019, the EVA community is continuing to revise general EVA operational concepts to better flesh out Mars surface operations details. Specifically, this effort should seek to address the following:

- 1) Construct the minimum and maximum surface stay durations per the GER
 - 2) Articulate a philosophy of how many EVA hours per crew member per week are assumed
 - 3) Calculate the implied cycles experienced per crew member in the minimum and maximum cases
 - 4) Apply current state of the art cycle life capabilities to discern that the implications are to logistics versus potential technology gaps
- #### *3. NASA@WORK Coordination*

NASA's Innocentive Challenge NASA@WORK provides a crowd sourcing opportunity to reach out to the community to assist in finding a hidden EVA System gaps. This can be a yearly contribution to the EVA SMT gaps revision.

4. NextSTEP Habitat BAA

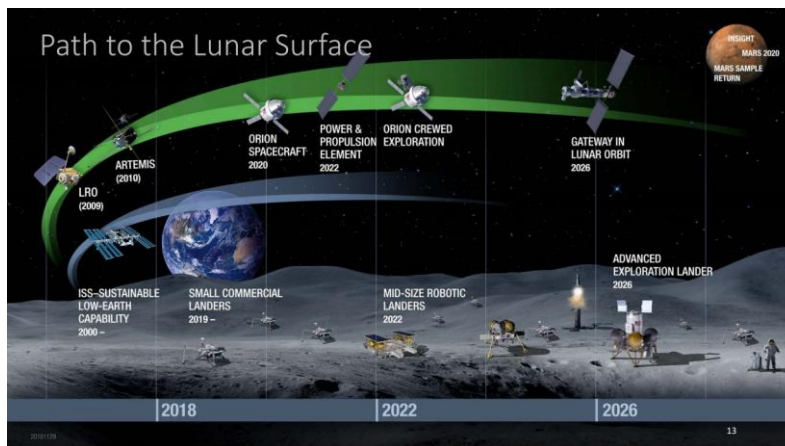
The BAA is focused on developing deep space habitation concepts, engineering design and development, and risk reduction efforts leading to a habitation capability in cislunar space that can support more extensive human space flight missions in the proving ground around and beyond cislunar space while encouraging application to commercial LEO habitation capabilities.⁵ EVA community participation and support to validate operational concepts ensure that EVA is not an afterthought for future programs.

5. Advanced Cislunar Surface Capabilities

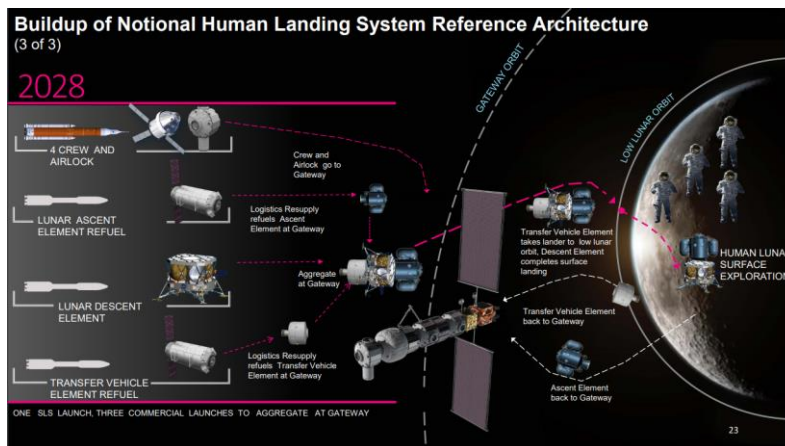
The Human Landing System (HLS) portion of the Advanced Cislunar Surface Capabilities (ACSC) study team is formulated to focus on transportation and interface to Gateway, as well as perform a surface system capability and evolution plan. The formulation team within HLS comprises of the following element teams:

- 1) Descent Element
- 2) Ascent Element (consisting of a Crew Cabin and a Propulsion Module)
- 3) Transfer Vehicle Element
- 4) Refueling Element
- 5) Surface Suits Element

The Surface Suits Element and Crew Cabin team within the Ascent Element group have kicked off an EVA Access Trade Study to evaluate and score various suit, airlock, and cabin architectures as they would apply to the overall HLS system reference architecture, as seen in Figure 4.



a) ACSC Lunar Surface Architecture. Concept leading to humans back on the surface of the moon.



b) Notional Architecture for Lunar Surface. Concept leading to humans back on the surface of the moon.

Figure 4. Advanced Cislunar Surface Capabilities Architecture.⁶

6. Mars Integration Group

The MIG replaces the Mars Study Capability Team, which replaces the Evolvable Mars Campaign to provide trades studies, decision analysis packages and data to NASA HQ decision makers. They are currently funded as part of the ACSC team. They are gathering knowledge from Evolvable Mars Campaign and past studies into a searchable library and developing a reference Mars architecture to use as a basis of comparative analysis of options for future studies. The following is a subset of MIG tasks that EVA is expected to participate in to varying degrees:

- 1) Habitats Strategy, Proving Ground to Mars
- 2) ECLSS and Critical Resource Assessment
- 3) Updated “Basis of Comparison” Architecture
- 4) Human Mars Landing Site Workshops
- 5) SBIR/STTR Subtopic Descriptions and Context

E. Safety and Mission Assurance

NASA’s safety community is closely integrated with all phases of EVA work, including policy definition, trade studies, and risk assessments.

1. 8705.2B Compliance Philosophy Evaluation

NASA has documented the highest level of agency policy regarding Human Rating via NPR 8705.2C “Human-Rating Requirements for Space Systems.”⁷⁷ Broad in scope, this document casts the general policies associated with formulating the processes and expectations unique to each individual Human Spaceflight Program or element and is a must-read for any member of the spaceflight community involved in such activities or interested in understanding the foundations of the philosophy.

By examining those programs that the NPR is applied to or exempted from within the Applicability section, one can discern the context of 8705.2B’s entrance into the documentation hierarchy of Human Spaceflight. In particular, the following statement is relevant to EVA:

P.2.1 The human-rating requirements in this NPR apply to the development and operation of crewed space systems developed by NASA used to conduct NASA human spaceflight missions. This NPR may apply to other crewed space systems when documented in separate requirements or agreements... The types of crewed space systems that require a Human-Rating Certification (per this NPR) include, but are not limited to, spacecraft and their launch vehicles, planetary bases and other planetary surface mobility systems that provide life support functions, and Extravehicular Activity (EVA) suits.

P.2.2 The Space Shuttle, the International Space Station (ISS), and Soyuz spacecraft are not required to obtain a Human-Rating Certification in accordance with this NPR. These programs utilize existing policies, procedures, and requirements to certify their systems for NASA missions.

It should be clear from this excerpt alone that NASA generally intends to apply 8705.2 to future EVA suits. The Extravehicular Mobility Unit used on ISS as of 2019 was “inherited” from the Shuttle Program. Though many changes have been implemented over the life of the ISS and EMU, this should be evidence that any significant investment in EVA under the auspices of ISS may very well outlive ISS.

In 2019 the EVA community (and in particular the EVA Office and EVA S&MA) should work to develop and document a general philosophy that records expectations on the following:

- 1) What would the “best” approach be for building an 8705.2 compliance package on the next EVA System/EVA Suit flight development effort?
- 2) What can and should be done to document and explain NASA’s intent on 8705.2 compliance? What might a contractor’s role be, and what is NASA’s role?
- 3) How do these ideas need to be instilled in NASA’s reference products, particularly any Safety or SE&I materials that are developed to complete the reference package?

This effort is intended to be a planning exercise and one that is primarily a NASA/government responsibility for developing the philosophical framework. It is not intended to demand any significant resources in 2019, though it is intended to produce a written record that can be shelved until required for future activities.

2. Probabilistic Risk Assessment of Exploration EVA System

Classic Failure Modes and Effects Analysis (FMEA) focus on the severity of a failure’s consequence by presuming the failure has occurred. Probabilistic Risk Assessment (PRA) is a technique providing increased insight into the likelihood of risks manifesting by considering the probability that a failure will occur. Recent events in flight EVA activities have led to creation/update of a PRA for the contemporary ISS EMU system as a quantification of what the existing EMU design’s risk exposure may be.

This methodology could be extended to EVA Development work, particularly NASA’s Exploration EVA Suit Reference Design. Done appropriately, this could allow for comparison of both the likelihood (PRA) and severity (FMEA) of failures between the heritage EMU design and the NASA Exploration EVA Suit Reference.

In 2019, the EVA Office and EVA Safety will investigate options on pursuing a PRA for the NASA Exploration EVA Suit Reference Design. To be clear, this is not a commitment to do the PRA yet, but rather a commitment to figure out what it will take to do one and what the most appropriate path forward is for the Reference Architecture in this particular arena. This task will include consideration of:

- 1) What mechanisms are viable options for conducting the PRA? Is it possible to utilize the same team that conducted the recent EMU PRA?
- 2) How would a PRA effort be conducted given that the NASA Reference Design is still “in work” and may evolve during the time of the PRA?
- 3) How might the team members conducting the PRA do so with minimal impact to the ongoing efforts of the Exploration EVA Suit hardware team?
- 4) If completed, what would the final form of the PRA be, and what would the expectations of NASA be for its utilization/incorporation into NASA’s Reference Design?

F. Engineering Analysis and Analytical Capability Development

This section collects those tasks that are engineering discipline-specific focus in nature. The typical engineering disciplines encountered in the EVA System are individually addressed, including acknowledgement that a given discipline has no known ongoing work towards Exploration EVA.

1. Environmental Analysis

The EVA community is regularly studying various environmental impacts on space systems to understand the nature of these environments, how to design a system to withstand them, and develop requirements to protect for them. Some examples of these environments are radiation, thermal, meteorite, and dust protection. In the interest of brevity, only thermal environments are discussed below, however the community is involved in studies of all those listed.

In 2019, the Deep Space EVA Thermal Analysis Task will extend initial evaluations conducted for Orion, Asteroid Redirect Crewed Mission (closed out in 2017), and now Gateway, by establishing a more robust, comprehensive thermal model and documenting the impact of performance improvements and limitations given currently known spacecraft parameters. The task will be abstracted from any one program/stack and take an approach that is focused on educating the EVA community through definition, analysis and detailed documentation of bounding scenarios. It is the intention of the EVA Office that this effort would also facilitate improvement/extension in certain requirements language statements about EVA environments and touch temperature limitations. In particular, the plan is to develop an overarching min/max heat flux value (or functional equivalent) that can be delivered to spacecraft builders as part of a “shall create/manage the combined natural and spacecraft induced thermal environment to limit heat transfer into/out of the independent (i.e. not thermally conductively attached to the spacecraft) EVA crew member to a given value.”

The full breadth and scope of this effort will not be completed in 2019. Instead, it is intended to provide a firm foundation that can be further built upon in subsequent years while still yielding preliminary results for limited cases this year. Ideally, the 2019 resources will provide for an update of the thermal environments analysis will be performed to reflect the current Gateway stack architecture and alternate configurations (depending on available funding) under evaluation by the Gateway Program (details to be provided by the EVA Office). This evaluation will perform a preliminary assessment of the impacts of cislunar Near Rectilinear Halo Orbit (NRHO) orbits on Gateway thermal environments. The Gateway geometry, external vehicle characteristics, and tail-to-sun constraint definition (range of allowable angles) are to be provided in order to perform this assessment.

2. Stress

NASA’s Exploration EVA System is not pursuing any tasks changing the methodology or analytical capability within the classical discipline of Stress Analysis at this time. Current methods appear adequate for known needs.

3. Materials Engineering/Materials Science

Fundamental Materials Science and Materials Engineering work relevant to Exploration EVA is ongoing. There are two particular tasks that are being pursued, the results of which may address EVA SMT Gaps. These include:

- 1) Space Suit Materials Sample deployment to Mars (Mars 2020 Program with the Jet Propulsion Laboratory)
- 2) Spectra replacement evaluation (ISS AEA Program)

4. *Electrical Engineering, Computer Science, Computer Engineering, Software Engineering, and Computational Fluid Dynamics*

NASA's Exploration EVA System is not pursuing any tasks changing the methodology or analytical capability within the disciplines listed in the heading of this sub-section at this time. Current methods appear adequate for known needs.

G. Human Health and Performance

NASA Johnson Space Center's Human Health and Performance Directorate conducted significant work towards characterizing the risks to human health and performance from EVA operations, decompression sickness (DCS) and mild hypobaric hypoxia due to the Exploration Atmosphere. This work is formally documented in the Integrated EVA Human Research Plan.⁸

1. *Exploration Atmospheres Clinical Trials and EVA Prebreathe Development*

Significant debate has occurred around options for EVA Prebreathe in exploration architectures. Historically, trends in actual Prebreathe protocols utilized in flight have been towards:

- 1) Reducing the amount of time the EVA Crew spends physically isolated from the rest of the host spacecraft for prebreathe processes
- 2) Reducing the amount time the EVA Crew spends sealed inside their suit (prior to EVA) exclusively for prebreathe purposes
- 3) Reducing the overall amount of Crew time and consumables dedicated to supporting/executing the Prebreathe process

These trends reflect the interests of the EVA Crew's comfort and the need to reduce the impact or "schedule footprint" that conducting an EVA imposes upon the rest of Crew's other duties while in flight. In 2019, there will be testing of Exploration Atmospheres at JSC. More details can be found in the Integrated EVA Human Research Plan.

Through the use of a Variable Setpoint O₂ Regulator in the PLSS and the natural reduction of suit pressure that can be created if suit leakage and CO₂ removal is allowed to proceed without 100% backfill, the pressure is gradually reduced during the beginning of the EVA to control DCS risk while allowing the EVA to begin earlier than if the full prebreathe had been conducted prior to hatch opening.

- 1) The EVA Office will coordinate supporting information from the Crew and Thermal Systems Division that highlights what the "pressure decrease rate" of the NASA Exploration EVA Design Reference Suit will likely be given anticipated suit leaks and CO₂ removal technologies. This will support timeline generation and identification of lead/lag on the DCS curve vs. suit depressurization curve.
- 2) The intent is to identify potential savings in prebreathe-related crew time and consumables that may be enabled by performing one or more periods of an EVA at higher suit operating pressures.

Neither the prebreathe modeling analysis nor any other planned 2019 work will address the other potentially significant human health and performance implications of requiring crewmembers to operate in suits at increased pressures. Additional human research studies will be defined and proposed if further assessment of higher suit operating pressures is pursued beyond 2019.

2. *Update and comparison of HRP EVA Risks with EVA SMT Gaps*

HRP has a mature process for identification, mitigation and documentation of human spaceflight risks. Continued, regular communication of the HRP EVA Risks, including their status and planned mitigation strategies, is necessary in order to sustain awareness. Furthermore, progress in HRP EVA Risks may lead to or compliment progress on EVA SMT Gaps and vice-versa. Thus, an annual review (at a minimum) should be conducted within the EVA community to compare, contrast and update the HRP EVA Risk and EVA SMT Gaps to ensure consistency and progress. This process can also be synchronized to compliment the Annual HRP Investigator's Workshop⁹, the Annual EVA Technology Development Workshop as well as the update schedule for the HRP Evidence Book. For 2019, the following activities and questions should be addressed:

- 1) What is the best/most appropriate "operating rhythm or schedule" for updating/comparing/contrasting the HRP EVA Risks and the EVA SMT Gaps?
- 2) Conduct the 2019 HRP EVA Risk and EVA SMT comparison activity.

3. *EVA Suit Occupational Surveillance*

A critical element in future EVA risk and injury mitigation efforts is the systematic collection and archiving of suit occupational surveillance data. Specifically, data regarding the suit used, how it was sized, assessment of suit fit, tasks performed, the person using the suit, any existing health conditions, and any discomfort, trauma, or injuries that result from suit exposure. This data has been collected with varying levels of consistency in prior years. Previous data mining efforts have provided valuable insights, but have been limited by inconsistent and incomplete datasets. A task

is currently underway to implement a standard tracking questionnaire, database, and process for the systematic collection of this data for all EVA suit exposures including testing, training, and flight EVAs.¹⁰

The data collected will be continually analyzed and used to identify potential injury mechanisms and predictors of negative health consequences. Over time, the data will also be used to assess the efficacy of countermeasures as they are implemented in the form of modifications to hardware, training, and/or operations.

V. Conclusion

The EVA Framework for Exploration is structured to support the critical needs of the ISS Program and achieve near term progress that is relevant to NASA's long term Human Space Flight goals. This plan is intended to create a coherent reference package that supports the development of the future Exploration EVA System with thorough and clear communication of all details available from the government. As such, it draws upon the needs highlighted in the ISS Risk Database through ongoing EVA flight operations as well as NASA's Global Exploration Roadmap (GER), the Gateway Program, and Exploration DRMs and studies such as ACSC, MSC and the System Maturation Teams. The plan is structured such that any content that cannot be immediately invested in is clearly identified as such and tracked for future opportunities such as SBIR/STTR calls. This mechanism can also be used to highlight such gaps as potential risks during adoption of the Reference Architecture by projects, programs or acquisitions, communicating "where the government left off".

Regardless of what style or mechanism might be used for future flight hardware procurements, or what exactly the details of the parallel flight and technology development efforts look like, it is fully anticipated that whatever "flies next" in EVA will not be "the last EVA Suit humans will ever need". For instance, the state-of-the-art in materials and design for Pressure Garments are expected to provide adequate performance in all environmental parameters relevant to EVA through cis-lunar space and all the way to Mars orbit (including the moons of Mars) but are not appropriate for operations on Mars surface proper. Alternatively, the current state of the art in CO₂ removal methods will need augmentation to extend operation from a vacuum environment (which all destinations short of Mars surface present) to the very low pressure atmosphere of Mars surface. As a third example, efforts focusing on increasing EVA Autonomy (solutions that facilitate EVA operations at destinations with extended communication delays or increased amounts of EVA) clearly require investment to prepare for long term planetary surface operations.

The Framework describes a path from where EVA and Human Spaceflight are today, as operating on ISS, to Mars surface and vicinity operations with additional successes along the way. This can be summarized as follows:

- 1) Operation of the ISS EMU through 2024 with demonstration of Exploration EVA capability per HEOMD-001's Phase 0 objectives. Note that the community would be wise to plan for continued use through 2028 and onward.¹¹
- 2) HEOMD-001 Phase 1 and Phase 2 cislunar space demonstration and validation, utilizing the EVA technology and capability as demonstrated on ISS in HEOMD-001's Phase 0.¹²
- 3) Planetary Surface EVA Tech Dev efforts increase as cislunar space flight operations mature through Phase 2 and parallel Technology Development efforts for partial gravity (such as Mars Surface) increase the Technology Readiness Level.
- 4) Deep space transit capability supported by EVA for Phase 3 operations "Beyond Earth-Moon System".
- 5) Extended operations in Phase 3 including the Mars operations with on-ramping of technology development products into Mars Surface Suit in 2030's.

By providing a Reference Architecture that is modular in nature and supports an incremental development approach, the roadmap above allows for incorporation of disruptive technologies that emerge over the course of the 2020's and 2030's while ensuring the minimum amount of steady progress is being made towards Mars surface operations. Thus, the content within the Framework for the near term (2019) orients NASA and EVA towards the Martian surface such that each step along the journey simultaneously facilitates success of flight operations while reducing future risk and uncertainty, culminating in an EVA System that can successfully conduct EVA's across all destinations humans may spacewalk in within the inner Solar System.

Appendix A – EVA System Maturation Team Gap List

Gateway Program				
T/D/K	Enabling/ Enhancing	Gap Name	Description	Status
K	Enabling	Inspired CO2 requirement	Need validated inspired CO2 limits that are relevant to suited operations. The current requirement set is based on wall-mounted sensors with no correlation to inspired vales.	10/24/2016: SA is aware of this disconnect and is tracking it on list of NASA-STD-3000 forward work. Some funding had been provided by HRP for this work. 9/11/18 No census exists on the requirement, but research is ongoing.
K	Enabling	Gateway Contingency EVA Requirements	What is needed to use a LEA suit for EVA, as is being discussed for Lunar Architecture or Gateway Internal EVA? Given standard hatch diameters, assuming an xEMU does not fit, what LEA capabilities are needed to perform these EVAs? Determination of the hardware solution requires expected EVA duration, CO2 washout, task performance etc. Capsule-based EVA on a limited-duration or contingency basis is more readily achievable. There would be significant challenges in meeting ISS-style EVA requirements with an OCSS-style system.	EC5 performed significant initial work toward LEA EVA capability in support of the ARCM concept in 2013 and 2014 use. Crew consensus memo indicates the MACES architecture is acceptable for use in contingency scenarios with some modification. These comments are largely applicable to the OCSS system as well. The OCSS team believes that for contingency EVAs under 4 hours with no liquid cooling requirements, the system design could be very simple and potentially similar to the Gemini configuration. There are no open technology gaps required to meet properly constrained contingency EVA requirements.
D	Enabling	5th Percentile Crewmember Fit	Need a suit that accomodates fifth percentile crewmember dimensions (minimum) and still accomodates all system required services (purge valve, umbilical services, display/control unit, positive pressure relief valve, etc).	10/24/2016: A reduced profile display and control unit (DCU) prototype was developed to fit within the chest area of Z-2 (1%-ile female shoulder breadth) that accomodates listed features. A high fidelity version with functional SCU QD will be tested summer 2017 with Z-2. 7/18/17: HUT is being redesigned in-house to better accommodate Z-2 size range (5%-ile shoulder breadth) and be inclusive of fluid line routings. Anticipate next prototype in FY18. 9/12/2018 A limited fleet sizing study is underway for xEMU, but significant further work is required.
D	Enhancing	Helmet Anti-fog	Need helmet anti-fog with life greater than or equal to the Earth based maintenance interval of the helmet, with elongation properties similar to polycarbonate helmet material. Needs to be O2 compatible, non-irritant, non-toxic, and stable at 3.0 psia. If life cycle is less than ground maintenance interval, then anti-fog will need to be reapplied in-flight without damaging the helmet (including unintentional scratches).	11/15/16: . Unfunded. Past efforts have failed either because the material was not durable enough to withstand multiple EVAs with associated cleaning, or cracked/crazed when the helmet was pressurized. May need to update with Dec2016 SSCN data 9/11/2018: EMU program intends to procure helmets with updated antifog. xPGS will incorporate an updated material into the xPGS helmet bubble design. Current plan is to certify this anti-fog system as part of the xEMU demo effort. Z-2.5 helmet delivered with anti-fog coating, but is highly sensitive to cleaning agents other than water. Closure duration 1-3 years.

T	Enhancing	Plasma Protection	Need an integrated suit design that can withstand the plasma environment and protect the crewmember at each destination. System plasma shock dissipation and protection is used in conjunction with operational constraints. While the EMU is capable of operating in some cis-lunar plasma environments, enhanced capability is required for operational flexibility in more environments.	<p>5/30/16: Phase II SBIR to address anti-shock coatings on suit hardgoods. CxP DSNE describes lunar environment with some limited maturity; document not finalized. Both AES EVA and CSSS have draft environment spec books that have been compiled from agency resources. Neither book is complete, nor endorsed. Neither project has significant resources available to finalize the books. We have had initial discussions with SERVI to address the knowledge gap/requirements definition. At this point we do not know how/if they will be able to help though.</p> <p>8/8/17: SBIR Phase II completed and hardware is at JSC ready for testing. There is potential collaboration w/ EMU for testing and early demo/cert on ISS. TRL 3</p> <p>9/11/18: Self-healing anti-shock coating for bearings developed on SBIR is part of the xEMU demo effort at this time. The gateway environment passes into the solar wake behind the moon and the plasma charging environment may become more pronounced. SSERVI DREAM 2 team recommended making the space suit exterior conductive, though this poses potential problems. IRD Funding awarded for partially conductive fabric coating in FY19 for potential use in plasma charge dissipation. Knowledge gaps exist in this area as well.</p>
T	Enhancing	Trace Contaminant Removal	Need a continuous trace contaminant removal capability that is regenerative (not a routinely consumable item). Activated charcoal is the state of the art and provides a logistics hit to all exploration reference missions to remove NH ₃ , CO, CH ₂ O, CH ₃ SH, etc. The minimum objective would be to remove all of the significant compounds that threaten to exceed the 7-day SMAC during an EVA with the optimal objective to enable removal of less significant compounds. Ideally, this is either a passive membrane or actively switched regenerating beds that can be paired with the CO ₂ /RH removal approach.	12/2018 Work on regenerable TCCs is currently underway on SBIR contracts, 80NSSC18P1961 (Advanced Fuel Research, Inc. Phase 1), NNX17CJ09C (Serionix Phase II), and NNX17CJ10C (Precision Combustion Phase-II). A phase one SBIR (NNX16CJ53P with TDA Research Inc) was completed but a Phase-II was not awarded. Estimated closure duration 3-5 years.
D	Enhancing	Radiation hardened DC/DC Converters	<p>Need radiation-hardened, isolated DC/DC converters with an efficiency of >80%. This efficiency gain would enhance the performance of the PLSS by reducing the power consumption of the system as a whole.</p> <p>For spacesuit life support systems, there are a number of small point of load applications such as smart instruments, controllers, etc. that require small, low power output, isolated DC/DC converters. With derating and the limited offering available from existing catalog parts, the available efficiency is often much lower than the rated efficiencies advertised for the part of 70-80% as the converter losses become a larger part of the overall output dropping the realized efficiencies below 65%. Current state of the art is ~70% for 28V to 5V DC/DC with MS Kennedy P/N BBF2805S as an example.</p>	<p>7/18/17: Initial round of testing on singular COTS components were promising (ref. PLSS tech memo)</p> <p>9/12/18: Submitted as a 2019 SBIR Phase I topic on H212, proposal call attached. Estimated closure 2-3 year duration.</p>

T	Enhancing	PLSS Batteries	Need safe, high-energy density power sources that are rechargeable post-EVA. The current state of the art is Li-Ion batteries with cell level energy densities of ~200 Wh/kg but packaged energy densities of ~130Wh/kg after addressing mitigation for thermal runaway. Enhancing battery performance can reduce PLSS mass and volume, or allow for additional power capability.	7/18/17: Testing with COTS (same cells as LLB but different packaging) with EP; effort is collaborative with SAFER team. Have alternate battery designs from ER and AMPS. 12/18: 2018 Phase I SBIR awarded to NOHMs Technologies (80NSSC18P1959) for safe, high energy space suit batteries. The proposed system is an ionic liquid-based hybrid electrolyte system. Estimated Closure 3-5 year duration.
T	Enhancing	Multi-gas Monitoring	Need a system to measure/monitor O2, CO2, H2O, NH3, CO, CH2O, CH3SH, etc. Measuring trace contaminants becomes more necessary if a pressure or temperature swing adsorption continuous removal approach for trace contaminants is implemented in an EVA system. This system would replace the traditional activated charcoal cartridge from the list of logistics items but would require measurement of system performance beyond user detection of odor.	7/18/17: JPL and Vista Photonics are doing a combustion products monitoring project for Orion and it could potentially be tuned to other compounds but it has not been expressly investigated for our applications. 12/18: Serinus Labs was awarded a 2018 Phase I SBIR for multi-gas monitoring using chemical sensitive field effect transistors. Intelligent Optical systems has a Phase III (80NSSC18P0776) for luminescence sensors for pO2, pCO2, relative humidity, temperature, and pressure in a compact package.
T	Enhancing	Oxygen Pressure Sensor	Need a pressure sensor which is small form factor, high reliability, radiation hardened, and low power consumption.	7/18/17: Have GP50 sensors that can meet minimal requirements but improved performance for future missions is desired. 12/18: No current developmental work.
D	Enhancing	CO2 Sensor	Need CO2/O2 sensor which is sized appropriately for inclusion in a PLSS, not susceptible to humidity, has accurate readings in 3 psia to 23 psia range, has low time between each sample collection and its associated reporting. The sensor should be a common sensor & avionics package used by EVA, ECLSS and others and capable of sensing a variety of gas (eg. ammonia, CO2, water vapor, O2, etc).	11/15/2016: Three different CO2 sensor designs are being developed via AES efforts. Two are susceptible to humidity; one is not, but it has a low TRL. The ISS Program has also initiated an effort to develop a drop-in replacement for the EMU sensor using AES technology. Design downselect is scheduled for end FY2017. Modified EMU CO2 Sensor - high TRL, can be adapted to Advanced PLSS, susceptible to humidity, can be adapted to sense O2, small form factor Vista Photonics - moderate TRL, susceptible to humidity, need separate detector to sense O2 and humidity, form factor not small Intelligent Optical Systems - low TRL, impervious to humidity, can sense multiple gases with one detector, largest form factor of three detectors 7/18/17: ISS DTO project for CO2 sensor downselected requirements to only measure CO2 and water vapor. For these two aspects, there are two sensors at mid-TRL capability. There are no sensors today that meet PLSS requirements and provide measures of all listed chemicals. 9/12/18 The UTAS Non-dispersive Infrared (NDIR) CO2-only sensor was selected over Tunable Diode Laser (TDL) designs for both the EMU CO2 sensor replacement and the xEMU Demo sensor. The system uses a COTS IR source and detector with improvements to condensation mitigation, simplified temperature compensation, power, and latch up recovery. Multigas capability with smaller form factor is still desired for the future.

T	Enhancing	Alternate Suit Ventilation Circulation	Need a vent loop system with an increased head rise over traditional centrifugal fans. The system would ideally need to yield 7-10 inches of H2O of headrise at 4.3 psia suit and provide flowrates in the vicinity of 4.5-6 ACFM. There is interest in developing ventilation techniques that would move the PLSS away from the current high-speed turbomachinery approach.	7/18/17: Increased vent loop fan performance as described is an enhancing feature desired for Mars surface missions. The PLSS can meet requirements for xEMU with the planned ventilation loop implementation, as tested in PLSS 2.0 and planned for PLSS 2.5 testing. 12/18: No current development other than the primary path xPLSS for the Demo development. Fan 3.0 is expected to provide 4.9 in H2O headrise with a single-stage centrifugal fan optimized for 35,000 rpm and a power draw of 10.2 Watts at 5.3 ACFM and 4.3 psia.
D	Enhancing	EVA Radio	Need a radiation hardened, radio programmable to support high-criticality UHF communication (voice & limited data) while simultaneously transmitting on a second frequency with high data throughput.	7/18/17: Collaborating with EV and Innoflight Systems on radio (Phase II SBIR ends in FY18) 12/18: Innoflight Phase III was awarded, and is on contract to deliver a DVT version of the system in FY19. The system is planned to be integrated to the xEMU Demo system.
D	Enhancing	Low-mass Bearings	Need high strength to weight ratio pressurized bearings. Improvements made over the stainless-steel bearings on the EMU can significantly reduce the weight. Most promising current candidates are titanium-alloy bearings in combination with coatings to control surface wear.	5/31/2016: Ti bearings were included in the Z-2 construction and will be evaluated, for mobility and wear, through FY17. The scope of weight reduction includes things such as optimization of stress analysis to lean out the designs of composite components and bearing profiles to just meet 2.0 FOS, for example. Obtaining softgoods that have best available function to mass ratio is another aspect of this. From past experience, this usually does not become a funding priority until a program has a launch mass problem. It will happen, so we really like to get out ahead of it and in the process be able to realize the best possible system level design in parallel. 8/8/17: SBIR Phase II with titanium looks promising; concludes in FY18 9/12/2018: Phase II SBIR titanium bearing development completed, and Phase-III awarded to build DVT-quality hardware prototypes for the shoulder scye and upper arm bearing. Planned infusion to xEMU following completion of Phase III. Advancements should be applicable to the other bearing locations.
T	Enhancing	Smart Thermal Control	Need system heat rejection method which eliminates the need for a separate TCV (autocooling). An ideal cooling system would not require user input or active control to maintain the appropriate thermal balance of the system.	7/18/17: Enhancing capability. The current PLSS design incorporates an autocooling control mode that is algorithm driven. The algorithm is analytically derived and should be further refined/validated with HitL testing. 12/18: No new status or development in this technology area. Algorithmic autocooling based on metabolic rate and environmental heat leakage is implemented on the xEMU Demo system. Innovations in this area may be coupled with advances to the liquid cooling garment.
D	Enhancing	Thermostat Glove Heater Control	Need a glove heater system that can automatically maintain safe operating temperatures in the suit glove. An automatic thermostat controlled system could optimize power draw and eliminate the bulky user control in the suit gauntlet area.	12/18: No work initiated. Current EMU system uses an on-off pull tab actuated switch in the glove gauntlet to active the fingertip heater elements.
T	Enhancing	Anti-microbial/anti-fungal bladder materials	Need material for use within the TCU, bladder, and LCVG that is antimicrobial, antifungal, non-toxic, and O2 compatible. (NASA-STD-3001v2: 4.5.2-4	5/31/2016: CSSS began to address this gap as part of their LCVG development effort but the status of that effort is unknown. Internal testing was conducted in 2010 and is documented in CTSD-CX-0120.

T	Enhancing	EVA Glove Mobility and Durability	Current gloves result in approx 75% loss of functional performance (combined strength and mobility) upon donning and pressurizing. Gloves have the shortest effective use life of all EVA pressure garment components, mostly due to the severity of sharp and abrasive hazards found on EVA external interfaces. Glove Thermal Micrometeoroid Garments (TMG) are the first pressure garment components to wear out and must be frequently replaced on the ISS.	11/15/2016: Two new gas pressurized glove prototypes were delivered under the HPEG project in FY16. The gloves are being evaluated in the glovebox at for mobility at 0, 4.3, and 8.0 psid using the HPEG Glove Mobility Protocol. Test results expected to be published Sept, 2017. 9/12/2018: HPEG results published, EMU phase VI is planning an upgrade that incorporates some of the recommended changes.
T	Enhancing	Reuseable Drink Bag	Need a reusable drink bag that is not susceptible to biological build-up and that requires limited maintenance between EVA uses, to decrease the amount of logistics during long duration missions. Solutions could include multi-use, cleanable, or extremely light/cheap disposable options.	ISS DIDB is disposable, not infinitely reusable. Prior to implementation of the DIDB, the EMU utilized a reusable drink bag. This system worked well for Shuttle missions with short durations between EVAs. However, due to drying and cleaning issues, this was not a practical solution for space station. However trade space could be reopened to meet needs without new tech (just fly more DIDBs). 12/18: There has been no new work or updates in this technology area.
D	Enhancing	Cooling Garment	Need cooling garment with improved UA over Shuttle version (SotA). Improve the UA such that warmer water can be used to sink the waste heat from the human and hence reduce the evaporator size or potential need for boost compressor/radiator. Drastically alter the human to cooling loop interfaces such as a fluid filled suit with pumped directly cooled water.	11/15/2016: CSSS RL-LCVG was tested as part of PLSS 2.0 HitL testing but did not show improvement in cooling efficiency over the EMU LCVG. 7/18/17: For primary cooling, the current LCVG is sufficient. Improved UA would be enhancing from PLSS thermal loop power and reliability perspective, but is not required. A secondary LCG cooling loop is required to meet xEMU-Lite design requirements for abort return capability. HitL testing of the CSSS concept demonstrated adequate cooling but design improvements wrt to PGS interfaces and crew comfort are warranted. 12/18: Mainstream Engineering Awarded a 2018 Phase I SBIR (80NSSC18P1960) to investigate ways cooling garments could be optimized.
D	Enhancing	Bio-med sensor	Need a radiation hardened, wearable biomedical system which does not require the crew to shave.	11/15/16: Options were evaluated by CSSS. There should be an engineering report on the topic but it cannot be located at this time. 7/18/17: Enhancing capability for xEMU Lite (can meet requirements with EMU system). No planned work in this area. 9/12/18: Heart rate only is the planned biomed capability for xEMU. Current design is an adapted wireless commercial system that doesn't require shaving.

Lunar Surface				
T/D/K	Enabling/Enhancing	Gap Name	Description	Current Status
D	Enabling	Dust Tolerant Bearings	Need pressure enclosure rotating bearings that prevent surface dust and regolith from entering the bearing race over extended hours and EVAs of long duration surface missions in order to preserve. After dust exposure, mechanism must fail gracefully, not catastrophically so as to maintain the torque and range of motion of the bearing within acceptable limits for use.	<p>5/31/2016: A test procedure and setup has been developed to test the torque variance in wrist bearings when exposed to dust; it still needs to be validated. The High Performance Glove Disconnect (HPGD) System was developed in FY14 and included a dust seal. A revised dust-tolerant wrist bearing design is included in the ILC HPEG glove and will undergo testing in the summer of FY16. 7/18/17: Dust tolerant bearings are part of the space suit RFI being released in summer 2017. Must track EVA-RD-001 updates to understand whether this requirement will be enabling or enhancing for xEMU. FY18 plan includes refinement of test methodology.</p> <p>9/11/2018: Dust-proof shoulder and upper arm bearings with dust-proofing are being procured for the xEMU Demo effort through phase III SBIR with Air-Lock, Inc (NNX16CJ09C). Significant testing required to see if gap is closed with current design.</p>
D	Enabling	Mass/Strength Optimized Composites	Need mass/stress-optimized structures for upper torso and brief. Surface impact and fall requirements in conjunction with optimizing mass are the key driving requirements when selecting a technology.	<p>10/24/2016: A small amount of effort has been allocated un FY17 to assess HUT redesign efforts to improve packaging and reduce mass. A proposal was submitted to GCD Program to request funds to specifically evaluate high strength, low-mass composite structures. Waiting to hear back on award. Additionally, this could also be addressed as part of overall EVA architecture trades on suit pressure, suitport/suitlock interfaces, pre-breathe time, etc. 7/18/17: Waiting to hear back on GCD seedling proposal evaluation. Currently have 3 Phase I SBIRs working on this topic. Phase I concludes in FY18 and will likely result in at least 1 Phase II proposal.</p> <p>9/12/2018: STMD GCD seed funding awarded for FY19 for composites development using new/optimized materials. Z-2.5 HUT is aluminum, xEMU DVT HUT may be S-glass until new composites setup is optimized.</p>

D	Enabling	Dust Tolerant Mechanisms	Need protection of relief valves, purge valves, disconnects, actuators and other mechanisms to preclude dust from hampering motion / function. These types of functional mechanisms are required for long-duration EVA operations on the planetary surface.	<p>10/24/2016: Active dust clearing function (forced gas) was assumed during early connector designs for CxP. This feature is not currently included in the xEMU SCU connector. Two Phase 1 SBIRs (Airlock, Inc. and Honeybee) were funded this year to investigate possible design solutions. PGS has not yet invested much effort in this area to understand scope/difficulty of this problem. It may require actual technology development to solve.</p> <p>9/11/2018: SBIR work for dust-proof connectors completed (insert more information). PGS is currently revising designs for dust-proof interfaces and bearings as part of the xEMU Demo effort. Current mechanism designs must be tested for dust compatibility.</p>
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T	Enabling	Tool Transport on Surface EVAs	Need EVA tools caddy device for each destination based on results of a trade study to determine if, and what type of, a tool caddy is needed, as compared to leaving EVA Tools on the local vehicle (rover, MOEV, truss-mounted tool box, etc) and having the crew translate/walk back and forth with tools in hand.	NEEMO 18-19 evaluated a prototype EVA Sample Bag Dispenser. NEEMO 20 evaluated an Integrated Geology Sampling System that included a “briefcase” that housed various sampling end effectors. NEEMO 20 evaluated utilizing a robotic asset (ROV) to carry tools and samples for the EVA crewmembers. NEEMO 21 took initial look at sled/cart options for large equipment transport using several variations: No wheels, 2 wheels, 4 wheels, rope handle, and solid handle (handles were an issue). Tool caddy worked well, but adjustability will be a critical feature to accommodate different crew preferences; packing plan for caddy was critical. Evaluated sling bag options for small items & easy access (sample markers, hand tools, electronics, etc.) & conceptually good, but challenging to use with the dive system. Need to determine the tool compliment for each phase of the EVA operations, and how those tools are best transported and stowed. NEEMO 22 evaluated Modular Equipment Transport System (METS) for large and small equipment transport. Included includes 4-wheeled transporter and crew-worn tools on forearm and thigh. Recommendations/Forward Work: Look into developing a harness that could be attached to the suit or worn over the suit in order to carry tools. Knowledge gap for Mars environment: Need definition for amount of in-situ analysis to be performed on samples. Need definition of level of containment for samples and need programmatic definition of contamination limits for forward and reverse contamination. Need EVA Tools to perform in-field sample assessment (high grading). Need EVA Tools to package and label samples for return to Earth. Need an EVA Tool set to store and manage volatile samples.
K	Enabling	Incapacitated Crewmember Operations	Integration: Need to develop methodology for transfer/transport of an incapacitated crewmember at each destination and how to transfer them onto the ingress/egress hardware, or through side hatch, and doff suit. Knowledge: Rescue protocol has not been identified for each destination. Determine how to address rescue of incapacitated crewmember on single person EVA scenarios. How does a 5th percentile strength crewmember rescue a 95th percentile mass crewmember?	Past analogs have assessed portions of rescue (Devon Island/Haughton Mars Project 2006, NEEMO 14, LER testing in JSC B9, DSH testing). During LER timeframe, work was done for crew rescue in lunar scenarios; however, preliminary assessments of ingress via suit port vs. side hatch showed suit port ingress as more acceptable. SEV design changes were implemented in aft cabana based on analog testing to assist in lifting and aligning incapacitated crew with suitport in partial gravity. Needs further work geared toward different DRMs and looking at varying numbers of crew, surface assets, surface terrain types. NEEMO 20: Add results from N20. Add findings from NEEMO 21 and 22; LESA. Add recommendations (if agreed upon) for next steps from Incapacitated Crew Rescue EEWG presentation by S. Chappell Unfunded. Microgravity knowledge gap: Closed Surface operations knowledge gap: Open

K	Enabling	Required Suit System Center of Gravity and Mass	Need to determine the integrated center-of gravity and mass limitations for effective planetary exploration. How does the gravity field effect the performance of a given suit? Will the same suit design work on the surface of the Moon and on the surface of Mars?	11/15/2016: Z-2 mobility will be evaluated at reduced gravities at the ARGOS facility in 2017. Add link to HRP EVA risk 11/22/2018 Z-2 Testing did not occur at the ARGOS in 2017, there are no current plans for ARGOS planetary configuration testing for xEMU.
T	Enabling	Lunar Surface EPG Shell Material System	Need suit material layups capable of long duration exposure to dust, and abrasive activities without compromising mobility (walking, kneeling, etc). Integrated design and constructions methodologies should mitigate penetration of abrasive material (over-tape out-layer stitch holes, environmental seals, etc).	5/31/2016: Abrasion testing of the HPEG-IILC protoype layups will occur in the summer of FY16. A test procedure and setup has been developed to expose materials to wear from abrasive dust. This procedure and setup has been demonstrated in one series of tests, but the findings have yet to be analyzed in detail. It is anticipated that iterations will be necessary. SBIR phase I complete with phase II in progress to address self-healing bladder and cut-resistant RTV replacement for glove palms. 7/18/17: HPEG final report expected 9/30/17 Divide this into Moon and Mars specific EPGs 9/12/2018 : Phase II STTR for Lunar surface EPG system is in its 2nd year. Limited EPG development in xEMU project.
T	Enhancing	Pressurized EVA Sizing Adjustments	Need ability to adjust fit of gloves and boots while pressurized. This particularly critical for suitport operations but would benefit traditional EVA ops as well.	11/15/16: Z2 includes second generation adjustable boot design that works well at 4.3psid but is very difficult above that pressure. Adjustment mechanisms are included on HPEG gas-pressurized gloves but have not yet been tested (planned for late FY17). 7/18/17: This is an enhancing capability unless suitport concept is implemented. 9/12/2018: HPEG final report completed, includes some recommendations on sizing. EVA boots are a phase 1 SBIR topic for FY19.

T	Enabling	Body Waste Management Solutions	<p>During the xEMU ISS Demo SRR there were several RIDs written against the NASA-STD-3001 Volume 2 allocation matrix in the PTRS with regards to missing flow down of body waste management standards (Reference RID 251). Originally SSP 51073, Exploration EVA Suit Systems Requirement Document Baseline listed these standards as Applicable, but met through operational mitigation. The xEVA System Panel was assigned several actions to address the flow down of these standards (reference AI 041918-064 through AI 041918-072 located on the xEVA System Panel Action Tracker Database - https://eisd.sp.jsc.nasa.gov/EVA/Pages/xEVA-System-Action-Database.aspx).</p> <p>SA assisted in burn down of these action items and brought the EVA/SA consolidated recommendations to the FACB on 09/19/18 for final approval. This resulted in generation of SA-18-076 Memo and associated enclosure (see attachments). An Action was assigned to SA at the 11/29/18 TCM to review all of the NASA-STD-3001 V2 Body Waste Management standards applicable to the EVA Suit and reach an agreement on the values associated with EVAs (e.g. for a single EVA). These should be updated in the next revision of the NASA-STD-3001 V2 Section 11 standards for the suit.</p> <p>There are a couple items that would lead to an EVA terminate, such as vomit and diarrhea. Need to ensure that there is a focus urine management.</p>	New Gap per SSP 51073 Revision A process and EVA-CR-00050 Comments 35, 61, and 62
K	Enabling	Orthostatic Intolerance Countermeasures Solutions	<p>It was decided that during the EVA-CR-00050, SSP 51073 Exploration EVA Suit Systems Requirements Document to Revision A, Technical Concurrence Meeting (TCM) on 11/29/18 to open a new gap for Orthostatic Intolerance Countermeasures solutions. This gap is to address a comment (Comment 63) received during the CR review that requested to change the applicability of the NASA-STD-3001 V2 flow down of standard V2 7042 to the PTRS from Applicable to Not Applicable as this capability was nominally addressed by the Launch, Abort, and Entry (LEA) suit. Orthostatic Intolerance Countermeasures are not applicable for microgravity EVA operations.</p> <p>During the Dec 11, 2018 EEWG, discussion to make this gap more broad, as Orthostatic Intolerance is just one piece of a bigger countermeasure and physiological deconditioning picture.</p>	New Pending Gap per SSP 51073 Revision A process (EVA-CR-00050 Comment 63)

D	Enabling	Dust-tolerant Quick Disconnects	Need low mating force, small, dust tolerant quick disconnects that improve on the current state of the art, the EMU Service and Cooling Umbilical (SCU). Fluids include (2) 3750 psia oxygen ports, (3) 35 psi water, (1) 80pin electrical connection with a mandate that the connections be capable of mating/demating under all pressure combinations.	7/18/17: Quick disconnect meeting fluid interface requirements is under development as part of xEMU Lite project. Dust tolerance is a goal of that effort but not actively being worked or required to meet needs of DTO (enhancing capability).
T	Enabling	Cut/Puncture Resistant Softgoods	Need cut and puncture resistant softgoods for space suit pressure garment applications for planetary surface environments. Longer cycle lives are required than current materials can provide. Gloves and knees are particularly susceptible to cuts.	11/15/16: HPEG does not address increased cut/puncture resistance, self-healing, moisture removal, or active heating components. Phase II SBIR with Nanosonic investigating self-healing materials ends FY18. 7/18/17: Phase II STTR awarded to continue investigating puncture resistance with Shear-thickening fluid enhanced fabrics. 12/18: Phase II STTR for EPG development ongoing with STF Technologies (80NSSC17C0025), Phase II SBIR with Nanosonic in closeout (NNX16CJ07C). The developed system was a gel-encapsulated self-healing bladder. A silicone RTV replacement for glove padding was also developed.
T	Enhancing	Suitport System Concept Development	Need development of suitport-style concepts for planetary EVAs from vehicles or Habitats. The NASA suitport concept was developed around a rear-entry suit concept with a rigid Suit Interface Plate (SIP).	12/18: The current xEMU DEMO architecture is not built around the suitport concept and would require substantial redesign to accommodate. The suitport architecture should be explored and developed outside the xEMU primary path. Potential topics for initial research or collaboration might include, 1. Hatch opening mechanism (hinges, lock/unlock, and self don/doff), 2. Elegant integration of SIP (permanent or removable), 3. Build vibration model for suits dangling off suitport, or 4. Elegant solutions for heat sink on SIP.
K	Enabling	External Environments Handbook	Need properties of dust environment at each destination. Need a NASA-endorsed handbook that describes dust environment for each destination. Need definition of each destination's environmental hazards, including dust constituents. What is the chemical composition of the dust and its characteristics, to include particle size and shapes? Do the properties change when exposed to a habitable environment (pressure, humidity, etc)? Need radiation environments definition at all locations; unknown material degradation due to radiation beyond LEO; this applies to softgoods, hardgoods, and electronics.	10/12/2016: XX is attempting to populate and baseline an environments standard for community review and buy-in. Initial draft and ToC available. CSSS completed TDS #1139, System Level Radiation Requirements Analysis which includes cis-lunar and mars radiation environments. CxP DSNE describes lunar environment with some limited maturity; document not finalized. Both AES EVA and CSSS have draft environment spec books that have been compiled from agency resources. Neither book is complete, nor endorsed. Neither project has significant resources available to finalize the books. 9/12/18 Significant work is still required, DSNE is largely unpopulated for these topics.

T	Enhancing	Scratch Resistant Visor System	Need visor that can be on-orbit maintained and potentially repaired and reused after use in an abrasive or dusty environment.	<p>5/30/16: Z-2 was delivered with a protective visor that is capable of rapid R&R. 7/18/17: Add reference to prior SBIR P1 report and NCSU student report. This capability would be enhancing for ISS and DSG.</p> <p>12/18: Z-2.5 Incorporates a scratch resistant coating, testing is underway. This system is not expected to be the ultimate solution.</p>
K	Enhancing	Defining Suit-Human Interactions	Need an in-suit ground sensor package to provide data on human-to-suit interactions and therefore, improve the ability to design suits which are less likely to injure suit occupants. Specifically desire to understand the ergonomic implications of exploration space suit architectures, notably rear-entry, waist belt, shoulder straps, PLSS interface, and indexing of the suit to the person (sizing, padding, etc.).	<p>5/31/2016: Current scope does not include assessment by an ergonomist to assess Z-2 during analog operations (ARGOS, rock pile) with geology and other exploration tasks. 8/8/17: HRP has funded MIT to evaluate “shoulder injury” and injury countermeasures specifically from 2014-2017.</p> <p>12/18: Requires update on H3PO work in this area.</p>

Appendix B – Draft Agendas for the EEWG

Date	Topic
Q1 Week 2	EVA Integrated Test Schedule Review
Q1 Week 4	HRP Status (ABF & H3PO)
Q1 Week 6	Analog Team Integrated Test Status (READY)
Q1 Week 8	EVA Environments Status
Q1 Week 10	EVA SMT Gap Review
Q1 Week 12	NASA Programs Updates (ISS, Gateway, ACSC)
Q2 Week 2	EVA Integrated Test Schedule Review
Q2 Week 4	HRP Status (ABF & H3PO)
Q2 Week 6	Analog Team Integrated Test Status (READY)
Q2 Week 8	EVA Environments Status
Q2 Week 10	EVA SMT Gap Review
Q2 Week 12	NASA Programs Updates (ISS, Gateway, ACSC)
Q3 Week 2	EVA Integrated Test Schedule Review
Q3 Week 4	HRP Status (ABF & H3PO)
Q3 Week 6	Analog Team Integrated Test Status (READY)
Q3 Week 8	EVA Environments Status
Q3 Week 10	EVA SMT Gap Review
Q3 Week 12	NASA Programs Updates (ISS, Gateway, ACSC)
Q4 Week 2	EVA Integrated Test Schedule Review
Q4 Week 4	HRP Status (ABF & H3PO)
Q4 Week 6	Analog Team Integrated Test Status (READY)
Q4 Week 8	EVA Environments Status
Q4 Week 10	EVA SMT Gap Review
Q4 Week 12	NASA Programs Updates (ISS, Gateway, ACSC)

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