Characterize Human Forward Contamination

Completed Technology Project (2014 - 2017)

Project Introduction

Let's face it: wherever we go, we will inevitably carry along the little critters that live in and on us. Conventional wisdom has long held that it's unlikely those critters could survive the space environment, but in 2007 microscopic animals called Tardigrades survived exposure to space and in 2008 Cyanobacteria lived for 548 days outside the International Space Station (ISS). But what about the organisms we might reasonably expect a crewed spacecraft to leak or vent? Do we even know what they are? How long might our tiny hitch-hikers survive in close proximity to a warm spacecraft that periodically leaks/vents water or oxygen—and how might they mutate with long-duration exposure? Unlike the Mars rovers that we cleaned once and sent on their way, crew members will provide a constantly regenerating contaminant source. Are we prepared to certify that we can meet forward contamination protocols as we search for life at new destinations?

In FY15 we drafted an internal strategic plan to roadmap the test, analysis, and modeling needed to characterize human forward contamination, and in FY16 we prototyped and tested an EVA tool to collect samples for forward contamination analysis. In FY17 we proposed advancing the EVA swab kit's flight certification far enough to qualify for X-project flight funding to conduct external ISS life support system vent and EVA suit sampling/analysis. Understanding what life signatures may be leaking/venting from our current life support systems will inform exploration hardware designs going forward.

The focus of this project's road-mapping effort was "what can we do now with what we have?" For example, the micro-organisms *inside* the ISS are well-characterized…but no one has ever swabbed an ISS external vent to find out what (if anything) has managed to get *outside*. We can swab ISS vents now, without having to develop new hardware. If we take a sample and find nothing, that's good news!—it means that our environmental control and life support (ECLS) systems may already meet forward contamination requirements. If we do find organisms *outside* the ISS, it will be interesting to see how they compare with what we typically find *inside*. Are they the same? Or have they mutated? What corrective measures can we take to prevent external contamination? Once we know what manages to escape a typical spaceship, we can expose it to various destination environments and see how it's likely to behave. We can go one step further, and test those organisms in a spacecraft-induced environment to understand whether proximity to a warm, venting spaceship makes

An astronaut collects microbial samples from his spacesuit wrist joint to characterize the types of microbes found on human systems.

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a difference; that will tell us how far away we must land from a sensitive area to mitigate forward contamination. We can also bring the modeling community into play and overlay destination weather models onto bacterial growth models to estimate how far microbes could be transported by, say, a small dust storm on Mars.

Another opportunity might be to take a sample from an Exploration Extravehicular Activity (EVA) Suit during development testing and follow similar steps as outlined above: what organisms come out of a suit vent or leak from the suit? How close can EVA crew be to a sensitive site without compromising the science objectives? Data would tell us what modifications might be required to the suit *now*--early in the development phase—and avoid an expensive redesign later.

This project expected to produce a comprehensive test, analysis and modeling plan. To support future testing, we also needed to develop a specialized tool to collect swab samples. On Earth, this type of sampling is typically done with a simple swab, much like a sterile Q-tip®, that is wiped across a surface and stored in a sterile vial. But handling a small swab and vial while wearing spacesuit gloves is difficult and the swab itself will have to withstand extreme temperature swings combined with near vacuum pressures that can cause plastics to become brittle. What's more, keeping track of multiple samples--and preventing cross-contamination between--is even more challenging in microgravity, where items will float away if not restrained. In line with the project's "what can we do now with what we have?" theme, the team planed to repurpose existing flight hardware as much as possible, and to piggy-back onto other engineering evaluations to collect data as cost-effectively as possible.

Anticipated Benefits

Preventing--or at least understanding--human forward contamination will help engineers meet planetary protection protocols as they design hardware, but will also help the science community understand how close exploration crews can get without compromising science objectives. These insights will help shape architectures and operations for future exploration missions.

Test, analysis, and modeling derived from this project will be of interest to both government and commercial exploration ventures.

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Johnson Space Center (JSC)

Responsible Program:

Center Innovation Fund: JSC CIF

Project Management

Program Director:

John M Falker

Project Manager:

Michelle A Rucker

Principal Investigator:

Michelle A Rucker

Co-Investigators:

Mary Sue Bell
Brian Glass
Anthony Hood
Stanley Love
Mark Lupisella
Margaret Race
Aaron Regberg
Andrew Schuerger
Kasthuri Venkateswaran

Project Closeout - Executive Summary

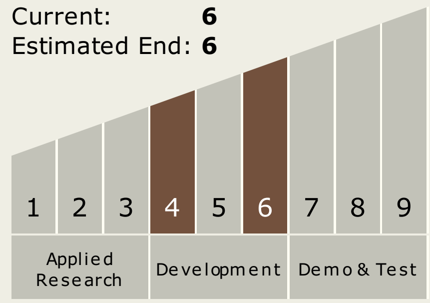
Initially, this project was scoped to simply develop a strategic plan—to roadmap the tests, analyses, and modeling needed to help close human forward contamination knowledge gaps. The draft plan was delivered to NASA's Planetary Protection office in 2015, and will be updated as existing gaps are closed or new gaps are identified. In the process of developing the plan, it became clear that a new type of tool would be required to help close these knowledge gaps.

On Earth, microbial sampling is simple: a researcher dons sterile gloves and swipes the surface of interest with a sterile, soft-tipped swab, often wetted with a sterile solution to improve sample collection. The swab is placed into a sealed, sterile container and transported to an analysis laboratory. Unfortunately, sampling surfaces *outside* of a spacecraft is not as simple. First, the swab must be designed for use with large, bulky Extravehicular Activity (EVA) gloves or interface with robotic manipulators. In microgravity environments, the swab must be tethered to prevent inadvertent loss of swab materials. The construction must be compatible with spacecraft cabin flammability and toxicity requirements and EVA temperatures and vacuum. Both the swab and container must remain sterile when transiting from a spacecraft pressure cabin to vacuum and back again. There is currently no American EVA swab tool approved for use outside of a spacecraft. Russia's Central Engineering Scientific Research Institute (TSNIIMASH) and the Institute of Biomedical Problems (IBMP) have developed the "Test" swab kit to evaluate exterior surfaces on ISS Russian elements, but this kit can only obtain two samples, and there is limited published information on sterilization levels or methods.

In 2016 the project team developed a prototype EVA microbial sampling kit that pairs a single tool handle with a bank of sterile swab tips, allowing a user to collect up to eight microbial samples per kit during an EVA excursion. The project team minimized development costs by repurposing a retired Space Shuttle Program tile repair tool designed to quickly snap into different attachments by means of a spring-loaded mechanism that engages a mating device in each end effector. This allows the handle to snap onto a fresh swab end effector, much like popular shaving razor handles can snap onto a disposable blade cartridge. A dual-action mechanism in the handle, which can easily be operated with one hand while wearing bulky EVA gloves, mitigates the risk that a swab will be inadvertently released in microgravity. Swab end effectors are housed in individual sterile containers; a 0.22 micron pore microbial filter at the bottom of each

Technology Maturity (TRL)

Start: **4**
Current: **6**
Estimated End: **6**



Technology Areas

Primary:

- Human Health, Life Support, and Habitation Systems (TA 6)
  - └ Environmental Control and Life Support Systems and Habitation Systems (TA 6.1)
    - └ Air Revitalization (TA 6.1.1)

Other/Cross-cutting:

- Human Health, Life Support, and Habitation Systems (TA 6)
  - └ Extravehicular Activity Systems (TA 6.2)
- Human Exploration Destination Systems (TA 7)
- Ground and Launch Systems (TA 13)

Continued on following page.

container allows it to equalize atmospheric pressure, but prevents contaminants from rushing into the container when passing from the EVA environment into a pressurized cabin.

The project further minimized costs by piggy-backing onto suited flight crew training exercises in 2016 and 2017 to validate tool interfaces with pressurized EVA suits, and perform engineering evaluations of the EVA Swab Kit. To date, the prototype EVA swab kit has been operated by 17 different test subjects, during 13 separate test events involving four types of spacesuits. All but one of these tests was conducted with differential pressure across the space suits (higher suit internal pressure); three data sets were collected under suit external vacuum conditions. Test subjects included volunteers as well as both American and international partner astronauts training for International Space Station (ISS) missions. Suits used during these evaluations included the Mark III advanced suit, the Extravehicular Mobility Unit (EMU) design currently used on board ISS, the Modified Advanced Crew Escape System (MACES), and the Orion Crew Survival System. Spacesuit microbial samples collected during these evaluations (as well as pre- and post-test baseline samples of the test chambers), are currently being analyzed. Microorganisms that were found to be viable after several hours of vacuum exposure *during* these tests will be of particular interest to researchers. Culture analyses and microorganism Deoxyribonucleic Acid (DNA) sequencing results will be provided to the science community to support planetary protection protocol development for future human missions to Mars. No attempt was made to change normal suit cleaning or handling procedures, so this data represents a baseline against which improved suit design, cleaning, or handling protocols may be assessed. A technical paper entitled "EVA Swab Tool to Support Planetary Protection and Astrobiology Evaluations" is scheduled to be published in March, 2018 at the IEEE Aerospace Conference in Big Sky, Montana. A detailed internal test report, and several technical papers detailing spacesuit microbial analysis findings will also be published in 2018.

Design improvements identified during spacesuit ground testing were incorporated into a revised prototype tool design, and raised the tool's Technology Readiness Level to 6. In 2017, the project team received a Johnson Space Center (JSC) Director's Commendation innovation award, and was granted a NASA@work Challenge award that led to an ISS Payload Integration Agreement for an ISS flight experiment in 2018. Armed with an EVA-compatible surface sampling

Technology Areas *(cont.)*

- └ Environmental Protection and Green Technologies (TA 13.2)
  - └ Curatorial Facilities, Planetary Protection, and Clean Rooms (TA 13.2.5)

Target Destinations

The Moon, Mars, Others Inside the Solar System

Supported Mission Type

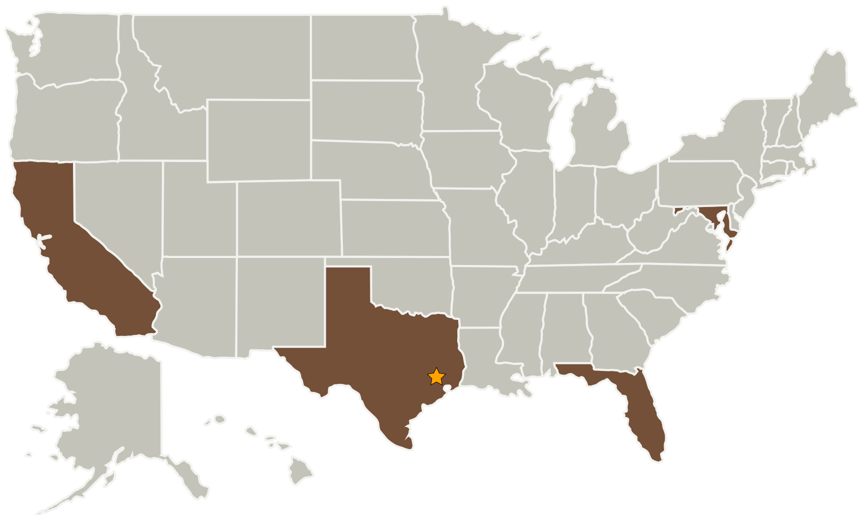
Planned Mission (Pull)

tool and insights about EVA suit microbial characterization, researchers will be well-positioned to collect micro-organisms found *outside* a crewed spacecraft. Taking the same approach used during ground testing, the EVA swab kit could be an add-on to planned EVA excursions, on a non-interference basis, to collect samples at relatively little cost. Sample containers will be returned to Earth for analysis, but could eventually be paired with the Biomolecule Sequencer for on-board swab analysis. There are more than a dozen Environmental Control and Life Support System external vents on the ISS. Some vent waste products while others are intended to equalize cabin pressure. If an EVA opportunity allows, microbial samples from any of these external vents would provide baseline crewed spacecraft data, against which future mitigation strategies—such as vent port filters—may be assessed. Samples collected at various distances from particular vent ports or airlock hatches could help characterize microbial dispersion patterns. Understanding the viability of micro-organisms at various distances from spacecraft openings will aid in understanding the effects of spacecraft-induced environments and inform future mitigation strategies or design concepts.

Although intended as a tool to support human forward contamination planetary protection protocols, other potential EVA Swab Kit uses have been identified. For example, Russian research has identified plankton on Russian ISS segment external surfaces [3], but to date no samples have been collected on American segment external surfaces for comparison. Several private firms have also expressed interest in partnering with NASA to search for extremophile bacteria on external spacecraft surfaces using the EVA swab kit. If paired with a sterile robotic manipulator, the EVA swab kit could be used to collect and preserve space-exposed materials to support astrobiology experiments on uncrewed science missions, or on crew-controlled telerobotic surface rovers. By replacing the foam swab tip with a sticky-tape type of end effector, this kit could also be used to collect residue from micrometeoroid or orbital debris impacts for analysis. This would be particularly helpful in performing damage assessments of hardware that cannot be brought inside a spacecraft or returned to Earth for analysis.

This project was a collaborative effort across four different NASA field centers and two external organizations, involving both scientists and engineers. This project provided an opportunity for one of NASA's 2017 new-hires and three student interns to perform hands-on laboratory analysis, work with suited astronauts in a vacuum chamber setting, and participate in flight hardware design.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Johnson Space Center(JSC)	Lead Organization	NASA Center	Houston, TX
Ames Research Center(ARC)	Supporting Organization	NASA Center	Moffett Field, CA
Goddard Space Flight Center(GSFC)	Supporting Organization	NASA Center	Greenbelt, MD
Jet Propulsion Laboratory(JPL)	Supporting Organization	NASA Center	Pasadena, CA
SETI Institute	Supporting Organization	Academic	Mountain View, CA
The University of Florida	Supporting Organization	Academic	

Primary U.S. Work Locations	
California	Florida
Maryland	Texas

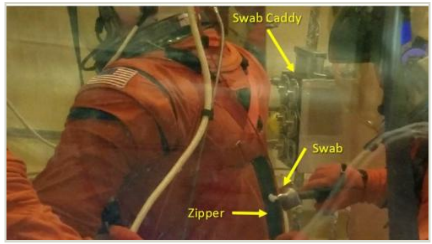
Images

EVA Swab Kit Development Team
(Left to Right) Michelle Rucker, Drew Hood, Mary Walker

EVA Swab Kit Ground Testing
Designer Drew Hood assists a suited ISS astronaut during EVA Swab Kit evaluations.

EVA Swab Kit in JSC's Space Station Airlock Test Article

EVA Swab Kit Mark III Suit Evaluation
Suited engineering evaluation of the EVA Swab Kit with a Mark III spacesuit.



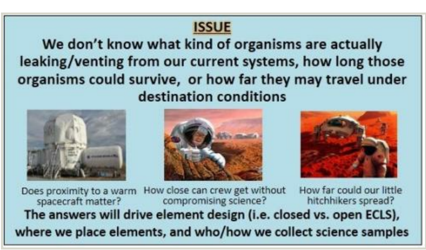
EVA Swab Kit Vacuum Chamber Evaluation
Suited crew evaluations of prototype EVA Swab Kit under vacuum conditions

EVA Swab Kit Vacuum Testing
A suited test subject demonstrates EVA Swab Kit operation under external vacuum conditions.

EVA Swab Tool
Shuttle-era tool handle with a swab end effector installed

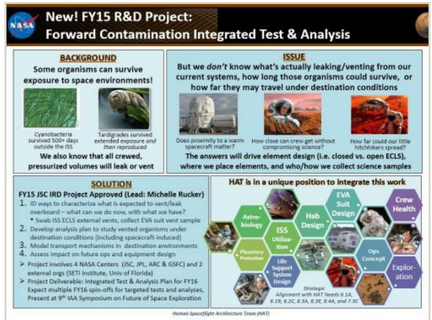
Human Forward Contamination Research
An astronaut collects microbial samples from his spacesuit wrist joint to characterize the types of microbes found on human systems.

Integrated Systems Engineering
Integrated Systems Engineering Approach

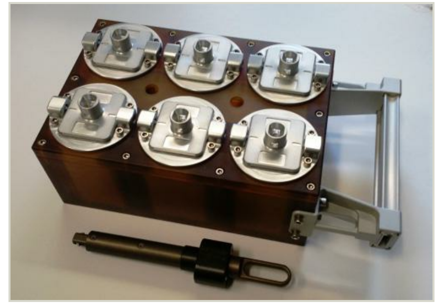


Issue Statement
Issue Statement

JSC Team Members
(Back row, left to right) Alida Andrews, Michelle Rucker, Mary Walker, Mary Sue Bell. (Front Row, left to right) Aaron Regberg, Justin Connolly, Drew Hood

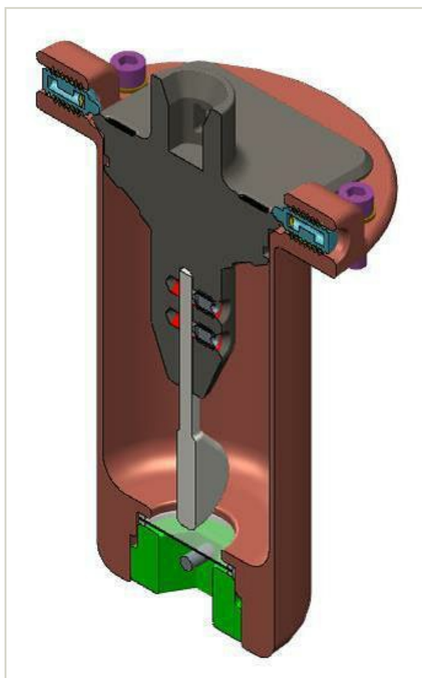


One-Page Project Overview
Forward Contamination Project Overview



Prototype EVA Swab Kit
8-Sample Caddy (6 on one side, 2 on reverse side - not shown) and Tool Handle

Student Interns Supporting Human Forward Contamination Project
Anna Sorg (left) and Justin Connolly (right) guide a suited ISS astronaut during EVA Swab Tool evaluations in the Space Station Airlock Test Article chamber at NASA's Johnson Space Center.



Swab Container Cut-Away View
Cut-Away view of a sterile swab container, showing the swab end effector in place.

What Microbes Are Growing on Your Mars Potato?
Andy Weir, author of "The Martian," was among the panelists that selected this project as runner-up for the "People's Choice Award"

Stories

“People’s Choice” Honorable Mention - awarded to Michelle Rucker for “EVA Swab Tool Prototype Development”
(https://techport.nasa.gov/file/21490)

Links

Beer Microbes Live 553 Days Outside ISS
(http://www.bbc.com/news/science-environment-11039206)

Creature Survives Naked In Space
(https://www.space.com/5817-creature-survives-naked-space.html)

EVA Swab Tool to Support Planetary Protection and Astrobiology Evaluations
(https://www.aeroconf.org/)

NASA Office of Planetary Protection
(https://planetaryprotection.nasa.gov/)

Space Station Research Shows That Hardy Little Space Travelers Could Colonize Mars
(https://www.nasa.gov/mission_pages/station/research/news/eu_tef/)