Microbial Monitoring for Spacecraft Cabins - MMS

Problem Statement

OBJECTIVE: Develop a prototype system for spacecraft microbial monitoring for long duration human missions.

DESCRIPTION: With the advent of molecular methods, emphasis is now being placed on nucleic acids to rapidly detect microorganisms. However, the sensitivity of current gene-based microbial detection systems is low (~100 gene copies per reaction), requires elaborate sample process steps, involves destructive analyses, and requires fluids to be transferred and detection systems are relatively large size. Recent advancements in the metabolomics field have potential to substitute (or augment) current gene-based microbial detection technologies that are multistepped, destructive, and labor intensive (e.g., significant crew time). NASA is soliciting nongene-based microbial detection technologies and systems that target microbial metabolites and that quantify the microbial burden of surfaces, air, and water inside for long-duration deep-space habitats.

PICK ONE SUB-TOPIC APPLICATION AREA TO FOCUS ON FOR YOUR EXAM/PROPOSAL.

1) Potable water:
A simple integrated, microbial sensor system that enables sample collection, processing, and detection of microbes or microbial activity of the crew potable water supply is sought. A system that is fully-automated and can be in-line in an Environmental Control and Life Support System-(ECLSS-) like water system is preferred.

2) Habitat surfaces:
Future crewed habitats in cislunar space will be crew-tended and thus unoccupied for many months at a time. When crew reoccupies the habitat they will want to quickly, efficiently, and accurately assess the microbial status of the habitat surfaces. A microbial assessment/monitoring system or hand-held device that requires little to no consumables is sought.

3) Airborne contamination:
Future human spacecraft, such as Gateway and Mars vehicles, may be required to be dormant while crew is absent from the vehicle, for periods that could last from 1 to 3 years. Before crews can return, these environments must be verified prior to crew return. These novel methods have the potential to enable remote autonomous microbial monitoring that does not require manual sample collection, preparation, or processing.

For this exam, focus on the following…
Per the instructions below and the additional guidance provided during your Candidacy Exam training sessions, prepare a research and development proposal, that if funded will allow you to ***Develop a prototype system for microbial monitoring of one of the three application areas above. Phase 1 deliverables should be: reports demonstrating proof of concept, test data from proof-of-concept studies, concepts, and concept design(s) for Phase 2. Phase 1 tasks should answer critical questions focused on reducing development risk prior to entering Phase 2 prototyping.***

State of the Art and Critical Gaps:
The state of the art on the International Space Station (ISS) for microbial monitoring is culturing and counting, as well as grab samples that are returned to Earth. NASA has invested in DNA-based polymerase chain reaction (PCR) systems, partially robotic in some cases, to eliminate the need for on-orbit culturing. However, a fully automated system is still not ready and there is still a gap for a low- or no-crew time detection system.

Relevance / Science Traceability:
The technologies requested could be proven on the ISS and would be useful to long-duration human exploration missions away from Earth, where sample return was not possible. The technologies are

applicable to Gateway, Lunar surface, and Mars, including surface and transit. This subtopic is directed at needs identified by the Life Support Systems (LSS) Capability Leadership Team (CLT) in areas of water recovery and environmental monitoring, functional areas of ECLSS. The LSS Project is under the Advanced Exploration Systems (AES) Program, Human Exploration and Operations Mission Directorate (HEOMD).

REFERENCES:

1. A list of targeted contaminants for environmental monitoring can be found at "Spacecraft Water Exposure Guidelines for Selected Waterborne Contaminants" located at: https://www.nasa.gov/feature/exposure-guidelines-smacs-swegs
2. Advanced Exploration Systems Program, Life Support Systems Project: https://www.nasa.gov/content/life-support-systems
3. NASA Environmental Control and Life Support Technology Development and Maturation for Exploration: 2018 to 2019 Overview", 49th International Conference on Environmental Systems, ICES-2019-297 https://ttu-ir.tdl.org/bitstream/handle/2346/84496/ICES-2019-297.pdf(link is external)
4. National Aeronautics and Space Administration, 2020 NASA Technology Taxonomy, https://www.nasa.gov/offices/oct/taxonomy/index.html
5. NASA Standard 3001 - Requirements: https://www.nasa.gov/hhp/standards

You are the Chief Technology Officer of a company that has specialized in creating low volume customized high reliability microbial sensors for specific applications in demanding environments. Your CEO believes that the company's expertise in microbial sensors, relevant materials, processing, and devices could provide a research and development path to meet NASA objectives in their solicitation. Your job is to define the research and development needed for new base technologies that would provide the platform for many future microbial detection and monitoring technologies, and perhaps even expansion into terrestrial environment markets (commercial travel, clinics/hospitals, etc.).

While meeting the NASA performance requirements are your priority, the cost of customized systems for microbial detection and monitoring could be high, initially, as compared to off the shelf commercial systems. In order to have potential to be competitive in other market applications which value compact, high-performance, it is desirable if your approach can be easily modified or adapted for lower price-point markets.

Your job as CTO is to deliver a complete proposal with your plan for the company to compete in this area to your CEO by your deadline.

YOUR DELIVERABLE

Your task is to write an internal proposal for your corporate officers describing your idea for research and development. The proposal should include all components, sections, etc. per your Candidacy Exam Template and SOP/Guidance documents.

Most Importantly – The fundamental rationality and reasonableness of your proposed solution is of critical importance. The significance and novelty of your creative solution, one that moves the boundaries of knowledge outward, is also of critical importance.

The list below is just a minimum list of issues you might consider and provides additional guidance regarding what you should address in the relevant sections of your proposal (written exam). There may be many more. The point is that your proposal ***should contain the evidence*** needed to make an effective and compelling case to your CEO in order to ensure that they make the right decision.

The guidance below can be used to help you with the preparation of some of the more unfamiliar content required per the Template document. At a minimum, and within the guidelines provided by the SOP and Template documents, be sure you address all of the following additional items where relevant in your written exam response.

Current Science and Technologies – What is already being done in this area by other researchers, companies and governmental institutions? Describe the current state-of-the-art for both the science and the implementation. Use diverse resources such as science literature, journals, conference proceedings, the internet, patents and other sources of existing public knowledge. ***Cite all references you use and use quotes for any word-for-word transfer to your report.***

Your Design Approach – What is the basis for your design approach to the problem? Why is your technology better than existing technologies? What technology attribute(s) make it likely to be selected by NASA? Address scientific *and* engineering aspects of these questions. Where relevant, consider: device size, weight and power (SWAP) requirements; materials of construction; critical components and considerations that comprise the complete device-level or subsystem-level solution; and what are the required prototyping and/or production methods, tools and costs? ***Even if you are not an expert in all of the technological areas required to bring the end-product to fruition, you should at least be able to intelligently discuss the other critical components, considerations and R&D requirements.***

Research & Development Plan – Describe a set of tasks and/or tests you will complete to demonstrate that your approach is effective and that your implementation of the solution is meritorious of further R&D. ***This is essentially your design of experiments. What are your objectives? What are the tasks required to achieve those objectives?*** Where applicable answer the following:

i) What are the key product specifications that you are targeting and how do they compare to the specifications of the existing solution(s) if any exist?
ii) What mathematical models and/or simulation constructs will you use to validate your approach, especially if prototyping and test trials are costly?
iii) What are the key dependent and independent variables that you must utilize and evaluate to confirm the proposed solution works?

Above all, be specific and detailed about the key tasks to confirm feasibility and validity of what you are proposing.

Cost Analysis – Identify cost and market issues that will impact the pricing strategy of the solution you have proposed. Identify Strengths, Weaknesses, Opportunities and Threats (SWOT) in the market place. If you are unfamiliar with the typical SWOT marketing analysis, I encourage you to 'google it'. Consider such things as: the major cost items that would impact the implementation; which elements of your implementation solution would be handled in-house versus externally-sourced; major risk elements that could drive up costs if the primary path item fails; costs of IP licensing needed, etc. Provide justification and/or reasoning behind your decisions. Avoid subcontracting design, manufacture or assembly of any *proprietary* component outside the company, because the CEO is concerned with potential IP leakage. Utilizing suppliers of common materials or devices is acceptable.

Hint – Clearly state your hypothesized solution. Identify its innovation(s) and advantages relative to state of the art. Describe both existing data, and work needed to support each aspect of the hypothetical solution. Consider theoretical, fabrication, and characterization aspects: for each, identify software/equipment and methods to use, parameters to vary, anticipated outcomes, and possible alternatives in the event of unsatisfactory results. Discuss material, process, device, and systems aspects of your solution. *Refine* your hypothesized solution as you accumulate information and prepare the manuscript. **Remember**: clearly distinguish what is known from what is hypothesized or not known. What is needed to distinguish the important things to know?

Refer to the 2021 MSEN PhD Candidacy Exam SOP and Guidelines and the MSEN PhD Candidacy Exam Template documents for all additional instructions.