Statement by

James A. Pawelczyk, Ph.D.
Associate Professor of Physiology, Kinesiology and Medicine
The Pennsylvania State University

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The International Space Station: Addressing Operational Challenges

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Abstract

During this decade of International Space Station (ISS) operations, NASA has made enormous strides to develop and implement a research program that will take humans to Mars. The evolving exploration architecture incorporates a space life sciences strategy aligned with the National Research Council's recent Life and Physical Sciences Decadal study. Research remains constrained by competing priorities, limited funding, available crew time, and powered up- and down-mass. To capitalize on the remaining life of the ISS, and to keep the United States at the forefront of exploration, a robust ground-based research program that fully engages the help of the external science community must be aligned with a flight research program designed to keep humans healthy in fractional gravity environments for periods of time exceeding a year. By doing so we can achieve the penultimate goal of the ISS program; to endow future space explorers with the knowledge, skills and abilities to operate independently from Earth.

Mr. Chairman and Members of the Sub-Committee:

Good morning. I thank you for the opportunity to discuss the status of research using the International Space Station. I have been a space life sciences researcher for more than 25 years, regularly funded by grants from NASA. From 1996-1998 I took leave from my academic position at The Pennsylvania State University to serve as a payload specialist astronaut, or guest researcher, on the STS-90 Neurolab Spacelab mission, which flew on the space shuttle Columbia in 1998. I have more than 15 years of experience advising

NASA on its life sciences strategy and portfolio, either as a direct consultant or through committees of the National Academies of Science, Engineering and Medicine. I help evaluate NASA's Bioastronautics Research Program for the Institute of Medicine. I am also inaugural member of the National Research Council's (NRC) newly constituted Committee on Biological and Physical Sciences in Space (CBPSS). Part of our charge is to monitor NASA's progress in implementing the recommendations contained in, "Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era," published by the NRC in 2011[1].

The ISS provides a unique platform for research. Past NRC studies have noted the critical importance of the ISS's capabilities to support the goal of long-term human exploration in space. These capabilities include the ability to perform experiments of extended duration, the ability to continually revise experiment parameters on the basis of previous results, the flexibility in experimental design provided by human operators, and the availability of sophisticated experimental facilities with significant power and data resources. The ISS is the only platform of its kind, and it is essential that its presence and dedication to research for the life and physical sciences be fully employed for as long as it is practicable to do so.

To prepare for this hearing, you asked four specific questions:

1. What are the opportunities and challenges in conducting space life and physical science research on the ISS and what should be done to address them?
2. What are some of the most critical areas of ISS research in space life and physical sciences to enabling the long-term goal of sending humans to the surface of Mars, and what is the status of progress on that research?
3. How are priorities for research on the ISS established and is there a clear and well understood process for aligning ISS resources with those priorities?
4. What are the implications of the proposed extension of ISS operations to 2024 on research and what criteria should Congress use to consider the proposed extension?

In the time allotted, I'd like to share my generally positive view of NASA's progress, and provide some specific suggestions to maximize the use of this extraordinary national resource that has been orbiting our planet every 90 minutes for the past 17 years. My comments will not stray far from my areas of expertise in the life sciences, but many of them should be applicable to the physical sciences as well.

1. *What are the opportunities and challenges in conducting space life and physical science research on the ISS and what should be done to address them?*

The 2009 report from the Review of U.S. Human Spaceflight Plans Committee (the "Augustine Commission") emphasized that future astronauts will face three unique stressors[2]:

- prolonged exposure to solar and galactic radiation;
- prolonged periods of exposure to microgravity; and,

[1] http://www.nap.edu/catalog/13048/recapturing-a-future-for-space-exploration-life-and-physical-sciences
[2] http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf

- confinement in close, relatively austere quarters along with a small number of other crew members who must live and work as a cohesive team for many months while having limited contact with their family, friends and culture.

All of these stressors are present in the ISS environment. Martian operations add more stressors: a dusty, dim, energetic environment and a gravitational field that is a little more than a third of our own. Research to address the biological response to fractional gravity is perhaps the area most impacted by changes to the ISS program over the decades. Unless we improve our research centrifuge capabilities on the ISS, we accept a risk of sending humans to Mars with little or no knowledge of how mammalian biology responds in a gravitational field other than Earth's.

My colleagues in the science community report that two of the major challenges to the biology research portfolio are limited access to the ISS and limited crew time. Some types of research, particularly that employing small mammals, is very time consuming to execute. Animal husbandry for a single rodent experiment can easily outstrip available ISS crew time for research during an increment. We can reasonably anticipate that competition for crew time will become worse as the facility ages, and demands on crew time to perform necessary maintenance become more acute.

Access to the ISS for research is not just a matter of access to space, it is a matter of competing programs. ISS research time is allocated in roughly equal proportions between NASA sponsored, peer-reviewed science and projects sponsored by the Center for the Advancement of Science in Space (CASIS), regardless of what that research might be. The outcome is that National Laboratory research and peer-reviewed, NASA-sponsored research vie for scarce resources such as crew time and positions on the flight manifest; in some cases forcing NASA research to lower-fidelity Earth-based analogs such as bed rest research for muscle atrophy and bone demineralization.

The extension criteria report requested by Congress in the NASA Authorization Act of 2015 creates opportunities to better coordinate NASA and CASIS sponsored research. For example, the ISS Program Office could require an experimental definition phase to maximize science return by combining compatible experiments and expanding biospecimen-sharing experiments to answer the most pressing research questions.

2. ***What are some of the most critical areas of ISS research in space life and physical sciences to enabling the long-term goal of sending humans to the surface of Mars, and what is the status of progress on that research?***

The biological risks associated with exploration-class spaceflight are far from being mitigated. This conclusion is based on analysis of 40 years of NASA-sponsored research.

Since the days of Skylab, NASA-funded investigators conducted an aggressive and successful biological research program that was robust, comprehensive, and internationally recognized. Beginning with those early efforts, and continuing with our international partners on the *Mir* and the ISS, we have built a knowledge base that defines the rate at which humans adapt during spaceflight up to six-months duration, with four data points exceeding one-year duration. Right now, we are expanding the one-year database! To prepare for Mars, we need to extend the duration further – up to three years - using a combination of astronaut volunteers and small mammals such as rats and mice.

In *Life of Reason*[3], George Santayana warned that, "those who cannot remember the past are condemned to repeat it." We should not forget the precipitous drop in NASA-sponsored research in the first decade of the millennium. The 2001 peak of 1014 separate research tasks was slashed to just 364 in 2010. Space biology and the physical sciences were particularly hard hit, losing about 80% of their research portfolio.

Congress heard the research community's concerns, and we are most thankful for your response. The NRC's Life and Physical Sciences (LPS) Decadal Survey - completed in 2011 as a response to a request from Congress introduced in 2008 authorization language - prompted a sea change in NASA's approach to biological and physical sciences research.

The LPS Decadal summarized and sequenced 65 high priority research tasks. Furthermore, the Decadal study created two notional research plans aligned with specific priorities; one being a goal of rebuilding a research enterprise and the other a goal of a human mission to Mars. More about these goals later.

3. ***How are priorities for research on the ISS established and is there a clear and well understood process for aligning ISS resources with those priorities?***

My response to this question considers general aspects of peer-reviewed research projects that are solicited through open competition. All NASA-sponsored space life and physical sciences research is conducted in this way.

Developing strategic priorities for ISS research is not a new concept. Notable examples from this millennium include:

- The NASA-sponsored Research Maximization and Prioritization Task Force, commonly known as ReMAP, which reported its findings in 2002, representing the breadth of translational research in the biological and physical sciences.
- The ISS utilization studies organized by the National Research Council in 2005.
- Most recently, the Life and Physical Sciences (LPS) Decadal Research Plan; the first decadal survey of NASA's life and physical sciences programs. The guiding principle of the study was, "to set an agenda for research in the next decade that would use the unique characteristics of the space environment to address complex problems in the life and physical sciences, so as to deliver both new knowledge and practical benefits for humankind as it embarks on a new era of space exploration." Furthermore, the LPS Decadal organizers were tasked with

[3] http://www.gutenberg.org/ebooks/15000

establishing priorities for an integrated portfolio of biological and physical sciences research in the decade of 2010-2020.

Why have we asked the prioritization question so many times, and why must we do so again? Because space research informs two broad, often competing, goals: One centers on intrinsic scientific importance or impact; research that illuminates our place in the universe, but cannot be accomplished in a terrestrial environment. The other goal values research that enables long-term human exploration of space beyond low-earth orbit, and develops effective countermeasures to mitigate the potentially damaging effects of long-term exposure to the space environment. Over the past 25 years, other review panels, both internal and external to NASA, have defined similar goals. In the case of the LPS, research was categorized as either (1) required to enable exploration missions or (2) enabled or facilitated because of exploration missions. I prefer the more contemporary synonyms of "discovery" and "translational" research.

Throughout the history of the United States space program both goals have been important, but their relative importance has changed over time. In the early part of the Apollo era, the limited amount of biological and physical research that occurred was focused on the health and safety of astronaut crews in a microgravity environment. Until late in the Apollo program, significant research questions that did not contribute directly to a successful Moon landing received lower priority. In contrast, more regular access to space provided by the space shuttle afforded an opportunity for discovery research to take higher priority; an emphasis that fared poorly in the austere NASA budgetary environment of the mid-2000's.

Thus, the relative priority of these two goals of research - enabling long-term human exploration of space (translation) and answering questions of intrinsic scientific merit (discovery enabled by space research) – shifts according to NASA's programmatic goals.

I make note of the fact that section 201 NASA Authorization Act of 2015 articulates a translational goal of sending humans to Mars, while section 718 emphasizes discovery research. The key question is this: *Shall discovery or translational research takes precedence in the mature years of the ISS research program?* If it is translational research to prepare for a human trip to Mars, then the ISS research portfolio should be tailored accordingly.

The LPS Decadal Survey provides a very detailed scheme to evaluate the importance of proposed research on the International Space Station. It includes eight unique criteria to prioritize research[4], as follows:

- *Positive Impact on Exploration Efforts, Improved Access to Data or to Samples, Risk Reduction.* The extent to which the results of the research will reduce uncertainty about both the benefits and the risks of space exploration
- *Potential to Enhance Mission Options or to Reduce Mission Costs.* The extent to which the results of the research will reduce the costs of space exploration

[4] http://www.nap.edu/catalog/13048/recapturing-a-future-for-space-exploration-life-and-physical-sciences

- *Positive Impact on Exploration Efforts, Improved Access to Data or to Samples.* The extent to which the results of the research may lead to entirely new options for exploration missions.
- *Relative Impact Within a Research Field.* The extent to which the results of the research will provide full or partial answers to grand science challenges that the space environment provides a unique means to address.
- *Needs that are Unique to NASA Exploration Programs.* The extent to which the results of the research are uniquely needed by NASA, as opposed to any other agencies.
- *Research Programs That Could Be Dual-Use.* The extent to which the results of the research can be synergistic with other agencies' needs.
- *Research Value of Using Reduced-Gravity Environment.* The extent to which the research must use the space environment to achieve useful knowledge.
- *Ability to Translate Results to Terrestrial Needs.* The extent to which the results of the research could lead to either faster or better solutions to terrestrial problems or to terrestrial economic benefit.

Some of these criteria emphasize discovery; others translation. The LPS Decadal Survey prioritizes specific research tasks for each criterion. Again, the Survey appropriately stopped short of weighting or prioritizing criteria against each other because of the programmatic implications. That responsibility – to prioritize either discovery research or Mars - falls largely to the executive and legislative branches. When this question is decided, then the LPS decadal should be a useful tool to program research for the remaining life of the ISS.

Operationally, the ISS Program Office prioritizes all the research to be conducted on each ISS increment. It is a well understood process: CASIS receives a 50% allocation, followed by human research, then technology demonstrations. What resources remain are allocated to the Biological and Physical Sciences Program and the Science Mission Directorate payloads. Both the Human Research and Biological and Physical Science utilize the LPS Decadal criteria for prioritization within their respective programs, but it is not apparent the extent, if any, that LPS Decadal criteria are used to prioritize research across the four programs.

Lastly, it is worth noting that ISS research expenditures, which in FY 2012 constituted about 8%, or $225M, of ISS program costs, are not anticipated to keep pace with overall cost growth of the ISS program.

4. ***What are the implications of the proposed extension of ISS operations to 2024 on research and what criteria should Congress use to consider the proposed extension?***

To evaluate the proposed extension, one of the first tests that Congress should apply can be answered with a yes or no. "Is NASA prepared to operate a robust research program through 2024?" In my opinion, the answer is an unqualified, "yes!" The scope of change in NASA life and physical sciences in the past four years has been remarkable. Allow me to highlight some notable examples:

- In 2011 NASA reorganized the remnants of a once robust life and physical sciences program to form the Space Life and Physical Sciences Research and Applications Division (SLPSRA). The program is formulated to execute high quality, high value research and application activities in the areas of space life sciences, physical sciences and human research. This reorganization acknowledges – in point of fact, celebrates – both the discovery and translational outcomes of research in the biological and physical sciences.

- Consistent with recommendations in the LPS Decadal, the Biological and Physical Sciences Program has restarted regular research announcements for ground-based and flight experiments. As a rule, these proposals are externally peer reviewed. In FY2014, 30 proposals were funded; 9 of them flight experiments.

- NASA is making greater use of advisors in the National Academies of Science, Engineering and Medicine. In October of 2014 the NRC instituted a new Committee on Biology and Physical Sciences in Space (CBPSS) chaired by Betsy Cantwell (University of Arizona) and Rob Ferl (University of Florida). Part of the Committee's charge is to monitor the progress in implementation of the recommendations contained in, the LPS Decadal.

- The Human Research Program has been aligned with a global exploration strategy. Annual solicitations for research have resumed. The past four quarters for which summaries are available included 212 research publications and more than 277 research proposals.

- We now have an American astronaut on a one-year mission to the ISS, with a unique opportunity to examine his genomic response to this environment.

- The technical content of the Human Bioastronautics Roadmap is in the middle of a five-year review of its 33 risks and 299 research gaps relevant to health and operations in space. The project is being conducted by the Institute of Medicine.

- NASA's Human System Risk Board tracks a subset of 23 risks that require additional research. While all but one have some level of risk mitigation for a one-year stay on the Moon, about half (N=11) do not have any substantive level of risk mitigation for three-year planetary operations.

I think it's reasonable to conclude that NASA has planned its life and physical sciences enterprise to take advantage of ISS research capabilities. The greatest remaining knowledge gaps are for Design Reference Missions on Mars for more than one year.

A recent NASA Office of the Inspector General (OIG) report[5] identified several concerns for continued ISS operations through 2024. There are four aspects of the report that I'd like to address:

First, the OIG found that ISS extension to 2024 could permit NASA enough time to mitigate an additional seven risks of long duration spaceflight. Nevertheless, extended utilization was not expected to fully mitigate another 11 human health risks prior to 2024, and two additional risks could not be mitigated using the ISS. The OIG concluded that NASA**,** "needs to prioritize its research aboard Station to address the most important risks in the time available." I think this conclusion misses an important point. The likelihood and consequences of at least 11 of the 13 unmitigated risks are dependent on the tasks required of a crew during a Mars Design Reference Mission. Today, there are simply too many degrees of freedom in the task set to establish useful risk criteria. Therefore, before the capabilities of the ISS to mitigate these risks can be evaluated, the risk must be better understood by performing a thorough task analysis of Martian operations.

Second, the report did not address powered down mass to any great extent. This is a critical need when biological samples, including live organisms, are to be returned to the ground for additional study.

Third, the OIG emphasized average crew time as a metric to quantify research utility. Although there are other metrics, including number of investigations, use of allocated space, up-mass, down-mass, and power, thermal, and data usage; in general, NASA does not consider these measures primary indicators of research utilization[6]. What is missing is a method to evaluate the *efficiency* of on-orbit research. Specifically, what percentage of crew time allocated to research is used to conduct it, compared to ancillary functions for such as setting up and stowing equipment? A similar focus has improved extravehicular operations on the ISS. I suspect that we will find that some of the highest priority research, such as studies using small mammals, is also the least efficient; requiring substantial amounts of crew time to set up experiments. If this is true, then increasing efficiency, for example, by improving coordination between NASA and CASIS, could be another way to capture more crew time for research in high priority areas.

Fourth, the OIG notes that research time is constrained with a six person crew. To maximize research utilization, we need to think about a seventh scientist crew member when commercial crew systems can support him or her.

Summary

We desperately need to increase research capabilities in space by translating findings from cell culture to reference organisms and mammalian models such as mice and rats to future flight crews. Translational research is the "gold standard" of the NIH, and it is what the research community, and the American people, should expect from the

[5] http://oig.nasa.gov/audits/reports/FY14/IG-14-031.pdf
[6] https://oig.nasa.gov/audits/reports/FY13/IG-13-019.pdf

International Space Station. We need the capability to house and test model organisms on the ISS for extended periods of time, and whenever possible, to expose them to loading forces that approximate Mars. But equally important, we need adequate time for crew to prepare and conduct these experiments. The potential return is immense; the application of this research to our aging public could become one of the most important justifications for an extended human presence in space.

My LPS Decadal Survey colleagues and I contend that NASA can and should continue to restore a high level of programmatic vision and dedication to life and physical sciences research, to ensure that the considerable obstacles to human exploration missions to Mars can be resolved. This will depend on NASA embracing life and physical sciences research as part of its core exploration mission and re-energizing a community of life and physical scientists and engineers focused on both discovery and translational research.

To maximize ISS research, it is of paramount importance …

- That the life and physical sciences research portfolio supported by NASA, both extramurally and intramurally, receive high attention.
- That NASA's research management structure be optimized to meet its discovery research, translational research, and commercialization goals. The utility of a coherent research plan that is appropriately resourced and consistently applied to enable exploration cannot be overemphasized. This will require improved coordination with CASIS.
- That the research portfolio be based on both discovery and translational programmatic priorities, and with specific destination(s) and mission tasks in mind.
- That there is sufficient external oversight to help NASA reach its research goals.

My top recommendations are the following:

- Articulate a timeframe for delivering and completing an operational risk mitigation plan for a multi-year human mission to Mars, and vet both the plan and the timeframe with the external scientific community.
- Review the essential resources for extended mammalian research on the ISS, including a seventh crew member; a scientist-astronaut whose nominal responsibilities are science programming.
- Extend biological science experiments to cover a substantial portion of a mammalian life cycle, and incorporate fractional (Martian) gravity exposure where possible.

Mr. Chairman, given sufficient resources, I am optimistic that NASA can deliver another decade of rigorous translational research. It's what the scientific community expects, and the American people deserve. I sincerely thank you for your vigilant support of the nation's space program, and the opportunity to appear before you today.