The International Space Station after 2024: Options and Impacts

Statement by

Robert J Ferl, Ph.D.
Distinguished Professor and Director
Interdisciplinary Center for Biotechnology Research
The University of Florida

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Abstract

The past several years have seen the maturation of the International Space Station as a functioning research platform, a platform that provides unique science capabilities that serve both to enable exploration and to advance fundamental life and physical sciences. Concomitantly, the recent evolution and expansion of the private-sector spaceflight community brings an added dimension to the utilization of ISS in Low Earth Orbit as well as additional potential platforms for microgravity research. As NASA prepares to move out of LEO and into the exploration of deep space, understanding the pace of results from microgravity and spaceflight-related research to enable deep space exploration is imperative. The unique environment of microgravity must be available to complete needed research that delivers results across the continuum of science from discovery through exploration applications, drawing innovation from all segments of this research into NASA's future needs. This complex set of considerations is especially important during discussion of options after this current era where ISS operations still dominate the research opportunities in space, and as we discuss the ISS as an integral element of NASA's exploration of deep space. The variables having the largest impact on being able to assess what science will be able to deliver by 2024 are availability of crew time on the ISS, the stability of grant support for the science, and the prioritization of microgravity science and exploration needs within ISS operations.

Mr. Chairman, Ranking Member, and Members of the Subcommittee:

Good morning. Thank you for the opportunity to submit testimony and participate in the discussion surrounding the options for and impacts of microgravity space science after 2024. This is a very important subject and the discussion is timely, due to the rapid evolution and diversification of spaceflight capabilities available to our nation, as well as the functional maturation of the International Space Station.

I speak to you today as a scientist with more than 25 years of spaceflight related research, largely funded by grants from NASA and having made use of many spaceflight and spaceflight-related platforms. My research is dedicated to the intertwined goals of 1) understanding the impacts spaceflight has upon terrestrial life to better develop safer deep space capabilities for human exploration, and 2) expanding what we know about the limits of terrestrial biology as we consider both human expansion in the solar system and by extension our place in the universe.

My comments today are informed not only by the research I have carried out but also by consultative roles I have played associated with NASA program development for many years. I was a member of a writing committee for National Research Council[1] decadal survey recommendations contained in "Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era," published by the National Academies in 2011[2] (referred to hereafter as the Decadal or Decadal Survey). This Decadal Survey lays out a comprehensive portfolio of life and physical sciences research that is enabled by spaceflight and that enables further spaceflight exploration. I am currently the Co-Chair (with Dr. Elizabeth Cantwell of Arizona State University) of the National Academies' Standing Committee on Biological and Physical Sciences in Space (CBPSS). In addition, I Co-Chair (with Mr. Daniel Dumbacher of Purdue University and formerly of NASA) the National Academies' Committee on A Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Sciences Research at NASA[3], which will be completed by the end of 2017. I am a recent past President of the American Society for Gravitational and Space Research (ASGSR), the society of research scientists most closely aligned with the science portfolio under discussion today.

It should be noted that I speak to you today in my capacity as an academic scientist. While my comments are informed by and deeply influenced by my experience and association with the committees of the National Academies and by my association with the ASGSR, I speak solely from my personal perspective—and I should add that nothing I say today should be construed as previewing any findings of the Academies midterm assessment study.

My comments are guided by overarching questions which are stated here then expanded in the narrative to follow. The answers to these questions emphasize space life and physical sciences as they

[1] Now more commonly referred to as The National Academies of Sciences, Engineering and Medicine.
[2] https://www.nap.edu/catalog/13048/recapturing-a-future-for-space-exploration-life-and-physical-sciences
[3] http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_174910

enable exploration, as moving into deep space is a major part of the discussion at this hearing. Yet the microgravity research that benefits Earth is an equally important part of this area of science.

1. What is the status of space life and physical sciences research and how is this status affected by NASA deep space exploration goals and timetables?
2. Is the ISS uniquely required for space life and physical sciences research?
3. How would privatized low earth orbit systems influence space life and physical science?
4. What are the opportunities and challenges that Congress should consider as it decides whether or not to extend ISS beyond 2024?

I will be sharing a positive view regarding the current status and activities on the ISS, a view richly informed by very recent experiments conducted on the ISS. These experiments draw directly upon the ISS as a critical, unique and extraordinarily capable research platform. These experiments also emanate from NASA programs that have been designed to further the science of the Decadal Survey. My comments are also informed by past experiments on the ISS and Space Shuttle, as well as experiments on spaceflight analog platforms, and ground-based experiments in extreme terrestrial environments as planetary exploration analogs. Most of my direct experience and expertise is in the life sciences. However the operations and practical discussions, as well as the community status, are applicable to the physical sciences. The challenges that need to be met to move us towards deep space exploration are complex and multi-disciplinary. The integration of life and physical sciences in ISS research is part of what my community believes will be necessary to solve the issues of deep space exploration.

1. *What is the status of critical ISS research in space life and physical sciences that is needed to enable deep space exploration and produce fundamental research that is enabled by microgravity? Can sufficient progress be expected to be made by 2024 on the enabling research, or is additional time on the ISS needed? What will be required to complete the enabling research by 2024?*

For the purposes of today's discussion, I offer the following observations. The Space Life and Physical Sciences Research and Applications Division (SLPSRA) within NASA was formed only six years ago, in 2011, in alignment with Decadal Survey. It should be noted that space life and physical sciences has always been a program within NASA, though over the years it has been its own enterprise directorate or in the science directorate, and is now a division within the Human Exploration and Mission Operations Directorate. SLPSRA initially sought to revive and invigorate NASA's microgravity space life and physical sciences portfolio and reestablish the community of science needed to conduct these areas of research described in the Decadal Survey. It has been very successful in this regard. There again exists a vibrant science community that is engaged in SLPSRA research projects and programs, and is ready for more growth. SLPSRA is closely associated with the Human Research Program and SLPSRA integrates science activities across many disciplines in support of microgravity research, making progress in a wide range of science that supports NASA's needs while creating STEM excitement and recruiting new scientists. The ISS maturation as a laboratory has moved beyond facility management to include a strong effort to track its science impacts. A simple perusal of the ISS science website[4], for example, reveals a regular outpouring of science happenings in space, and results and scientific publications are noted and measured as major output metrics, similar to the metrics used by other national research agencies.

[4] https://www.nasa.gov/mission_pages/station/research/index.html

SLPSRA has also engaged with the National Academies to monitor progress of Decadal recommended science. SLPSRA has activated its programs, fueled the community and is now producing major science discoveries, all in what is essentially a few short years. It is my personal assessment that the status of the overall Decadal portfolio is in a healthy state of growth and accomplishment, and becoming more so as the access to ISS increases.

Space life and physical sciences contribute effectively to NASA research and technology needs. While the time between now and 2024 will see tremendous progress in science in support of exploration, NASA's need for exploration-related science will neither cease nor be fully met. NASA works to enhance and enable exploration by undertaking research to improve our understanding of and reduce the risk associated with putting humans in extreme extraterrestrial environments. Meeting this challenge is not a simple matter of identifying risks and establishing tolerance thresholds for future astronauts. It is a matter of continual evaluation and discovery of principles that enhance the overall exploration endeavor. The resulting portfolio of science activity is built upon the dual notions of research *enabling* space exploration and research that *is enabled by* space exploration—in a manner that actually breaks down the traditional notions of fundamental research versus applied research. Exploration life and physical sciences research is a body of work that is a continuum, and critical advances can and do arise from across the entire continuum. Exploration research recognizes there is seldom a direct connection between experiment intent and practical outcome. The future development of the most important exploration-related research therefore transcends the ISS question, and the need for the kinds of research supported by SLPSRA will continue throughout the evolution of spaceflight exploration, well beyond LEO and ISS.

As space exploration and utilization expands, research ahead of that exploration will be needed. As in all major technology endeavors, such as terrestrial transportation and aviation, continual research improves safety and enhances efficiency. One particularly relevant spaceflight example involves our increasing understanding of radiation effects on biology. Although we have accumulated data on the effects of radiation on biological tissues for more than 70 years, only in the past 15 have we had the ability to explore how this information translates to the spaceflight environment, and even more recently have we been able to observe the effects on the cardiovascular system and brain, and how these systems might be affected by more chronic exposure. In this and in many other areas we will continue to learn how spaceflight effects create unanticipated interactions between risks, and develop more effective solutions that mitigate those risks.

2. *Is the ISS uniquely required for space life and physical sciences research or could other space-based platforms be suitable for carrying out such research? What other types of platforms could be used?*

The short answer to whether the ISS is *uniquely required* for space life and physical sciences research*,* is yes. The ISS is currently the only space-based platform that provides extended access to the spaceflight environment, and as such, provides the only means to assess the long-term effects of this environment on terrestrial organisms, on physical systems, and on how physics and engineering principles can be utilized to mitigate the long term effects of spaceflight on biological organisms, structures and physical processes. To reiterate, the key word phrases are *extended access* and *long-term*. Extended and long-term data are crucial to inform more fully the preparations for and the future execution of successful deep space exploration activities such as crewed transit missions to the moon or Mars, as well as for private-sector endeavors such as asteroid mining, and any missions that would involve crewed vehicles and stations.

While other platforms, such as suborbital vehicles and sortie missions in orbital vehicles, can fulfill important research niches (such as the evaluation of biological and physical responses to the initial transition from unit gravity to microgravity) none, at present, can maintain the sustained spaceflight environment over long periods of time such as is required to fully support an exploration initiative. It is, however, possible that these other platforms could be employed to lower the pressure on ISS resources. These possibilities and their challenges are discussed below.

It is also important to note that the ISS is now a fully functioning laboratory. It has a well-trained crew that appreciates science. It has well equipped science bays. NASA has processes and procedures for getting samples up, sample processing on orbit, and bringing samples down. It has increasingly sophisticated onboard analytic capabilities, such as the recently demonstrated DNA sequencing. The ISS is equipped with many unique science facilities, launched at great expense but providing considerable payback. Keeping them on orbit lets those facilities serve multiple investigations over many years. But relaunching those facilities for sortie flights or to other platforms would reiterate the costs. So while it is possible to argue that other platforms may provide microgravity research capabilities, the costs would need to be compared to the current model of simply launching samples to existing facilities that are maintained on orbit on the ISS.

The current model relies heavily on international partnerships and the US commercial launch sector for access to and from the ISS. Some of these partnerships are only a few years old and have not had the time to be a well measured part of the discussion. Yet it is likely these partnerships need to continue, and perhaps be enhanced in order for research science to fully exploit the capabilities of the ISS.

Moreover, successful science in space is more than just a well-appointed platform. A trained and trainable crew is required. A steady cadence of launch opportunities that keeps pace with science advancement is critical, a cadence that enables and supports the cycle wherein hypotheses are tested and answered, leading to new insights and the next cycle of question and answer. In addition, strong, regular, grant program management at the agency level is necessary to keep the science community vibrant and engaged. Currently the ISS, with some notable exceptions listed below, together with SLPSRA, does this. Any transition to other platforms would have to keep these points in clear focus.

3. *What would be the impact on research if NASA were to turn low Earth orbit over to the private sector?*

The potential transition of LEO to the private sector is a compelling notion. However the notion is complex and nuanced when considering the spectrum of microgravity science under discussion. Without careful consideration of this notion, we risk assurance that the nation's exploration goals could be met.

Could a private space laboratory serve the needs of space life and physical sciences? Fundamentally, yes. Essentially it does not matter to the science community who the operator of the laboratory is, whether private or government. What matters on the practical level is the cost and reliability of research access. Government laboratory facilities are dedicated to providing access at reasonable costs to all research. Private sector laboratory facilities seek a more immediate return on investment, which affects costs and priority of access. What matters on a strategic level is continued stewardship of the space life and physical sciences portfolio by the United States in general and by NASA in particular. Similar to the Decadal Studies that guide the science in the Science Mission Directorate of NASA, the "Recapturing a Future for Space Exploration" Decadal Survey guides SLPSRA as the primary steward of space life and physical sciences. Our exploration of space will constantly pull innovation from this area of science and NASA stewardship of space life and physical sciences must, I believe, be maintained. The goals of the private sector are driven by fundamentally different outcomes than those which service the exploration needs of NASA. In order for a private or commercial LEO operation to serve the microgravity life and physical sciences, agreements would have to be in place that ensure that NASA's needs receive the priority and access necessary to ensure science success. This is especially true for "long-range studies of the potential benefits to be gained from, the Opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes.[5]" Transition to a private-sector, commercial platform provider would therefore require care and attention to assure that the space life and physical sciences research necessary to meet NASA exploration initiatives remain as clear priorities.

Could private research supplant NASA stewardship of the portfolio of science covered by the Decadal? Not likely. While the goals of the private sector may overlap with exploration science on occasion, the time-scales and risks of research are not typically embraced by the private sector. It is likely that there would be a tendency toward prioritizing profit-directed investigations, as is entirely appropriate for the shareholders of a company, but which would be inconsistent with the needs of NASA. Similarly, it seems unlikely that expansion of the northwestern United States enabled by the Lewis and Clark expedition would have been so remarkably successful without government sponsorship.

Is commercial research a part of the research portfolio covered by the Decadal Survey on space life and physical sciences? Yes, most likely. In point of fact, that type of collaboration is already occurring today. The research enterprise consists of science carried out by industry researchers, federal researchers, and academic researchers. Any of these scientists that comprise the community as a whole may conduct science in support of NASA goals. And certainly we have seen an increase in the research scientists of private companies doing microgravity research, suggesting that scientist participation across the range of government and private activities can contribute to and compete to provide research in support of SLPSRA and NASA's exploration research goals.

Therefore a shift to private-sector platform providers as part of an increasingly privatized LEO ecosystem could be part of a successful microgravity sciences program. However, I am convinced NASA will need to maintain stewardship of space life and physical sciences, in order to ensure that our national scientific enterprise continues to meet NASA needs, priorities and timeframes - regardless of the academic, industrial or governmental location of the scientists conducting the work.

4. *What, in your view, are the opportunities and challenges for the future of space life and physical sciences, and what issues should Congress consider regarding those opportunities and challenge as it decides whether or not to extend ISS beyond 2024?*

The strategic science challenges and opportunities for the space life and physical sciences largely remain as articulated in the Decadal Survey. While tremendous progress has been made in some areas over

[5] NATIONAL AERONAUTICS AND SPACE ACT OF 1958, Pub. L. No. 85-568, 72 Stat. 426-438 (Jul. 29, 1958)

these last six years, there is plenty of work that remains undone, particularly in the physical sciences and larger-scale biological systems such as mammalian studies. Generally stated, the biological and physical systems work on the ISS is just reaching an acceptable rate of progress. The physics and chemistry of the manufacturing revolution that is underway are just beginning to be explored for adaptation to space. The integration of biological and physical systems that feed forward to exploration scenarios is in its infancy. The high fidelity evaluations of the molecular, genetic, and epigenetic responses of biological organisms and systems to long-term spaceflight (primarily humans, human pathogens, and plants) is just now close to fully underway.

The primary questions regarding the movement toward those strategic science goals can, in my opinion, be reduced to several essential tactical and operational issues. Any serious projections of science accomplishments and science remaining by 2024 must come to grips with these issues.

The first issue is crew time. At present, crew time available to science is often cited as the single biggest limitation to the conduct of science on the ISS. This is the one area where the ISS itself has yet to reach its envisioned science potential. All too often, space life and physical science waits near the bottom of a queue for crew time. Some experiments that are highly important to the pursuit of Decadal-recommended science need crew time beyond what the SLPSRA program is allotted. The result is that some funded science can be situated such that it never makes it out of the queue, and may be dropped altogether. So, I believe the first issue that Congress may wish to consider is the mechanisms for getting more crew on the ISS. The importance of this cannot be overstated – in my opinion the amount of crew time available for space life and physical science is the single biggest factor in evaluating the possibility of accomplishing the science needed before heading to deep space.

A closely related issue is competing program priorities in the allocation of ISS resources. Additional crew on the ISS would create the potential for more space life and physical sciences, but only if science priorities are kept in balance with other programs. The establishment of the ISS National Laboratory effectively brings non-NASA science to the ISS, which greatly increases the reach of microgravity science toward Earth-directed goals and extends the value of the ISS investments. Yet the National Lab, too, draws upon the limited ISS resources. It is my personal view that Congress should examine the prioritization of resources across the spectrum of ISS users when considering the prospects of getting enough science accomplished out of the space life and physical sciences to effectively reach for deep space by 2024.

The "Recapturing a Future for Space Exploration" Decadal Survey provides a comprehensive set of research priorities for the space life and physical sciences. While an entire chapter (Chapter 11) is dedicated to the capabilities of the ISS, it should be noted that the Decadal recognizes that ground-based experiments are necessary in some areas. In addition, some microgravity and spaceflight related studies are well suited for platforms other than the ISS. A robust consideration of ground studies and all available microgravity platforms would ensure that the entire portfolio moves forward, targeting to ISS those experiments that actually require its unique capabilities. Congress should examine and be mindful of the full range of platforms, analogs and ground based facilities currently and potentially available to Decadal research and should seek to enhance access to those platforms and facilities especially when such access meets the dual goals of supporting exploration research while relieving throughput stress on the ISS itself.

Lastly I also believe that Congress may wish to consider all current limitations on travel of materials and crew to and from the ISS. While additional crew members would greatly accelerate the progress of the Decadal science portfolio, other factors affects science as well. Greater access to up-mass and down-mass, especially in environmentally conditioned compartments, would clearly accelerate science. Repeatability, quicker access to space, accessible laboratory equipment that parallels ground laboratory equipment, the ability to get samples back to Earth and to the research team, all improve science on the ISS and increase our readiness for deep space science and exploration.

Dealing with each of these tactical issues, together with providing a level of strategic funding for the space life and physical sciences, has the potential to demonstrate a possibly dramatic impact on any evaluation of the amount of science to be accomplished on the ISS by 2024.

Summary and conclusions:

We are approaching a very appropriate time to consider space life and physical sciences within the context of the operational life of the International Space Station. The increasing success of ISS research is now well documented and available for evaluation, while the SLPSRA Division has years of productivity to be measured and evaluated. Over the course of this calendar year the National Academies will conduct and release its Mid Term Assessment of the Decadal Survey. This Assessment should provide deep insights that inform the questions raised in this testimony.

From a personal perspective I believe that there are key unknowns that potentially have a dramatic impact on these considerations:

- The trajectory of crew time available for research on the ISS could significantly influence any evaluation of science attainable by 2024.
- The development of commercial spaceflight outside of NASA sponsorship remains an intangible but important factor in considering the pace of microgravity science in support of deep space exploration.

And the largest unknown is the unknowable discovery that will inevitably occur as this body of space life and physical science progresses. The unique qualities of spaceflight must be deeply understood and continually explored across the spectrum of space life and physical science to extract the innovation required to best enable and enhance deep space exploration, and to return benefits to the Earth.