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NASA's Management and Utilization of the International Space Station

July 30, 2018

Report No. IG-18-021

Office of Inspector General

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NASA Office of Inspector General
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RESULTS IN BRIEF

NASA's Management and Utilization of the International Space Station

July 30, 2018

IG-18-021 (A-17-011-00)

WHY WE PERFORMED THIS AUDIT

For the past 20 years, the International Space Station (ISS or Station) has served as a platform for humans to learn about living and working in space. NASA's original vision was that the Station would conduct biological and materials research, demonstrate American leadership in space, forge international cooperation, and lead to the commercialization of low Earth orbit. To date, the ISS has accomplished many of these goals by serving as a unique, on-orbit laboratory to study the health effects of space travel on humans and demonstrate new technology – work critical to enable humans to travel deeper into space. However, maintaining and supporting the ISS consumes approximately $3-$4 billion annually, about half of NASA's annual human spaceflight budget.

The President's fiscal year (FY) 2019 budget request proposes ending direct Federal funding of the ISS beginning in 2025. If that timetable remains unchanged – an unlikely outcome in light of substantial and bipartisan congressional opposition – NASA would need to manage its remaining time aboard the ISS extremely efficiently in order to complete as much health and human performance and technology-related research as possible. In late March 2018, NASA submitted an ISS Transition Report to Congress that laid out the Agency's plan to transition the Station to commercial operations; however, in light of congressional response to that proposal, the Agency also will need to consider other options, including extending ISS operations until 2028 or beyond. And, at some future point, NASA will need to dispose of the Station via a controlled destructive reentry into the Earth's atmosphere.

In this audit, we assessed NASA's progress in maximizing utilization of the ISS to accomplish its human exploration objectives and evaluated the options and challenges associated with a transition to commercial operation, potential extension, and the Station's eventual retirement. In meeting these objectives, we interviewed Agency officials, analyzed ISS documentation, reviewed contract and cost data, and visited ISS mission operations at Johnson Space Center.

WHAT WE FOUND

NASA plans to continue using the ISS to mitigate the human health risks and technology gaps related to long-duration human spaceflight. As of February 2018, the Agency forecasts that research for at least 6 of 20 human health risks that require the ISS for testing and 4 of 40 technology gaps will not be completed by the end of FY 2024 when funding for the Station's operation is scheduled to end. In addition, research into 2 human health risks and 17 technology gaps is not scheduled to be completed until sometime during 2024, which increases the risk that even minor schedule slippage could push completion past the end of that fiscal year. This is due in part to difficulties with characterizing and mitigating the health risks and, for technology demonstrations, obtaining the required funding and on-orbit research time. To address these issues, NASA may be forced to choose among a variety of options, including extending ISS operations past 2024, relying on alternate testing methods (i.e., non-space-based), or accepting higher levels of risk for future crewed deep space missions.

In anticipation of the end of direct Federal funding for the ISS in 2025, NASA is beginning to develop plans to transition the Station to commercial operation. However, based on vehement congressional opposition to this timetable, the Agency likely will also need to consider other options including extending ISS operations until 2028 or beyond. And at some future point, NASA will need to dispose of the Station via a controlled destructive reentry into the Earth's atmosphere. Transitioning the ISS to private operation under the timetable currently envisioned presents significant challenges in stimulating private sector interest to take on an extremely costly and complex enterprise. Based on our audit work, we question the viability of NASA's current plans, particularly with regard to the feasibility of fostering increased commercial activity in low Earth orbit on the timetable proposed. Specifically, we question whether a sufficient business case exists under which private companies will be able to develop a self-sustaining and profit-making business independent of significant Federal funding within the next 6 years. Likewise, any extension of the ISS past 2024 would require continued funding in the neighborhood of \$3-\$4 billion annually to operate and maintain the Station – a significant portion of which could otherwise be redirected to develop systems needed for NASA's cislunar or deep space ambitions. In addition, extending the Station's life would challenge NASA to manage the risks associated with continued operation of the Station's aging systems and infrastructure. Furthermore, any extension will require the support of NASA's international partners, whose continued participation hinges on issues ranging from geopolitics to differing space exploration goals. Lastly, at some future date NASA will need to decommission and deorbit the ISS either in response to an emergency or at the end of its useful life. However, the Agency currently does not have the capability to ensure the ISS will reenter the Earth's atmosphere and land in a targeted location in the South Pacific Ocean.

What We Recommended

To ensure NASA is positioned to complete or develop viable alternatives to its critical human health research and technology demonstration projects, and to provide for a safe transition and disposition of the ISS, we recommended that the Associate Administrator for NASA's Human Exploration and Operations Mission Directorate (1) to the extent practicable, establish plans for additional one-year missions to the ISS; (2) ensure development of a contingency plan for each human health risk not scheduled to be mitigated prior to 2024, such as identification of alternate testing platforms, impact of health risks for astronauts, and impact to the mitigation schedule; (3) develop a contingency plan for each exploration-enabling technology demonstration not scheduled to be fully tested by 2024, such as identification of alternate testing platforms, impact to technical risk of exploration systems, and impact to the technology demonstration schedule; (4) complete all end-of-mission critical systems and open work related to nominal and contingency deorbit operations; and (5) develop options for obtaining supplemental emergency deorbit propellant support from U.S. commercial vehicles.

In response to a draft of this report, NASA management concurred with our recommendations and described planned corrective actions. We consider the proposed actions responsive for all five recommendations and will close them upon verification and completion of those actions.

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Acronyms

BEAM	Bigelow Expandable Activity Module
CASIS	Center for the Advancement of Science in Space
CRS	Commercial Resupply Services
CSA	Canadian Space Agency
ESA	European Space Agency
FY	Fiscal Year
GAO	Government Accountability Office
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
MMOD	Micrometeoroid and Orbital Debris
OIG	Office of Inspector General
ORU	Orbital Replacement Unit

INTRODUCTION

For the past 20 years, the International Space Station (ISS or Station) has served as a platform for humans to learn about living and working in space. NASA's original vision was that the Station would conduct biological and materials research, demonstrate American leadership in space, forge international cooperation, and lead to the commercialization of low Earth orbit. To date, the ISS has accomplished many of these goals by serving as a unique, on-orbit laboratory to study the health effects of space travel on humans and demonstrate new technology – work critical to enable NASA to travel deeper into space. However, maintaining and supporting the ISS costs $3-$4 billion annually or about half of NASA's annual human spaceflight budget.

The President's fiscal year (FY) 2019 budget request proposes ending direct Federal funding of the ISS beginning in FY 2025.[1] If that timetable remains unchanged – an unlikely outcome in light of substantial and bipartisan opposition in Congress – NASA would need to manage its remaining time aboard the ISS extremely efficiently in order to complete as much health and human performance and technology-related research as possible. In late March 2018, NASA submitted an ISS Transition Report to Congress that laid out the Agency's plan to transition the Station to commercial operation.[2] However, the Agency may need to consider other options, including extending ISS operations until 2028 or beyond. And at some future point, NASA will need to dispose of the Station via a controlled destructive reentry into the Earth's atmosphere.

In this audit, we assessed NASA's progress in maximizing utilization of the ISS to accomplish its human exploration objectives and evaluated the options and challenges associated with a transition to commercial operation, potential extension, and the Station's eventual retirement. See Appendix A for details on the audit's scope and methodology.

Background

NASA developed the ISS to be a laboratory, observatory, and factory in low Earth orbit. Concepts of a space station date back more than a century to early science fiction. From its beginnings in 1958, NASA hoped to build a space-based outpost that would help it learn to live and work in space for extended periods of time. Plans began to materialize in earnest in 1984 following the President's call for NASA to collaborate with international partners to build a space station within a decade. However, due to the significant costs and numerous design changes, on-orbit construction of the ISS did not begin until November 1998. NASA and its international partners – including the Canadian Space Agency (CSA),

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1 Office of Management and Budget, "An American Budget – President's Budget FY 2019," February 2018.

2 NASA, "International Space Station Transition Report," March 30, 2018.

European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA), and Russia's Roscosmos – worked together to construct, launch, and assemble the Station in orbit.[3] Crews began continuously inhabiting the ISS in November 2000 and lived there through completion of construction in May 2011 to the present day.

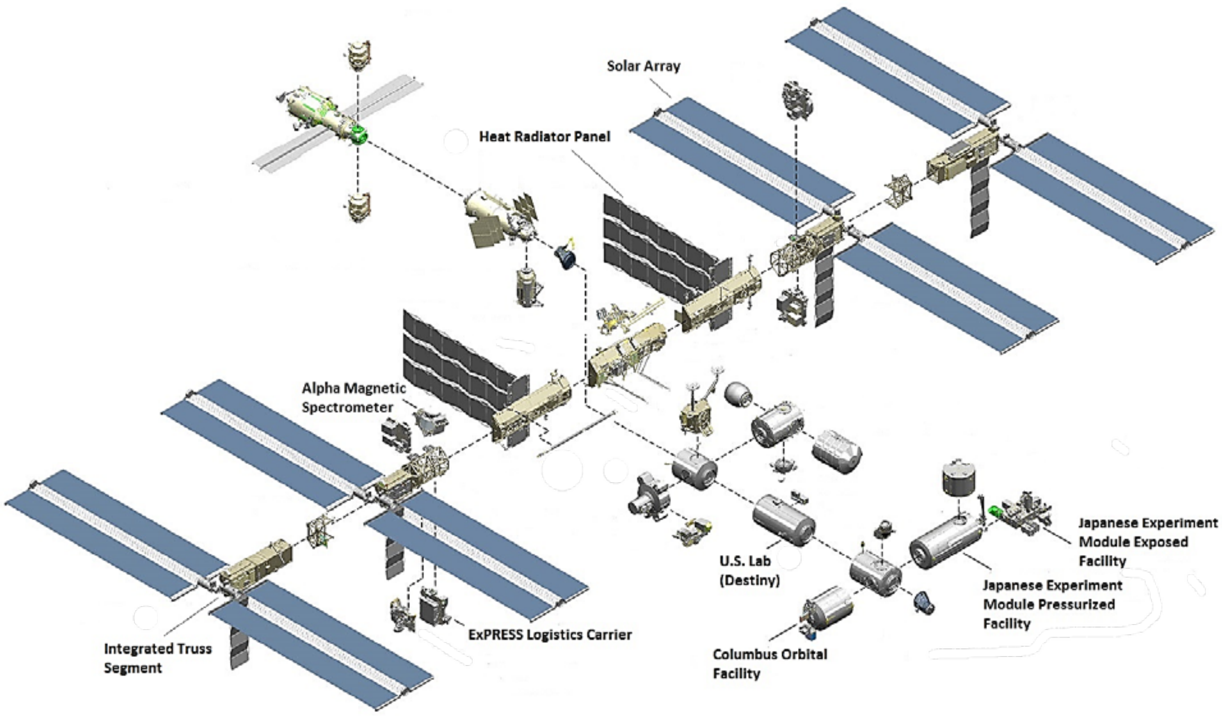
ISS Structure, Operations, and Accomplishments

The largest structure ever built in space, the ISS spans nearly a football field in length, weighs almost 1 million pounds, and has internal pressurized volume of 32,333 cubic feet – equal to that of a Boeing 747. It is comprised of two connected segments: the Russian Segment operated by Roscosmos, and the U.S. Segment operated by NASA, CSA, ESA, and JAXA. The overall structure consists of modules and connecting nodes that contain living quarters and laboratories, as well as exterior trusses that provide structural support, solar panels that provide power, and heat radiator panels that rid the Station of excess heat (see Figure 1). The ISS also has an exterior robotic arm that was used to construct the Station by grappling and moving modules or by moving astronauts into position to perform their work. In order to provide crew with a comfortable, safe environment in which to work, the Station has systems for environmental control and life support, crew health care, data management, electrical power, guidance navigation and control, thermal control, communications, and Micrometeoroid and Orbital Debris (MMOD) protection.[4] NASA and its partner agencies rotate a 3-4 person crew in the U.S. Segment, while the Russians generally maintain 2-3 cosmonauts in their segment. Both segments maintain ground support facilities around the world, while an international fleet of space vehicles delivers propellant, supplies, and science experiments to the Station. The ISS is administered by several NASA Centers through a series of agreements and international partnerships. During its time in orbit, the ISS has enabled research that led to major accomplishments in Earth observation and disaster response, kick-started the economic development of space, inspired education in science and engineering, provided a better understanding of many aspects of human health including aging, trauma, and disease, and led to the design and development of innovative materials and robotics.

[3] The countries that comprise the European Space Agency are Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxemburg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland, and the United Kingdom. During ISS construction, NASA's Space Shuttles and Russia's Proton rockets delivered pieces of the structure to low Earth orbit for assembly.

[4] MMOD consists of millions of particles of man-made debris and naturally occurring micrometeoroids that circle the Earth at velocities averaging 22,000 miles per hour.

Figure 1: ISS Configuration



Source: NASA Office of Inspector General (OIG) summary of NASA information.

Research Facilities

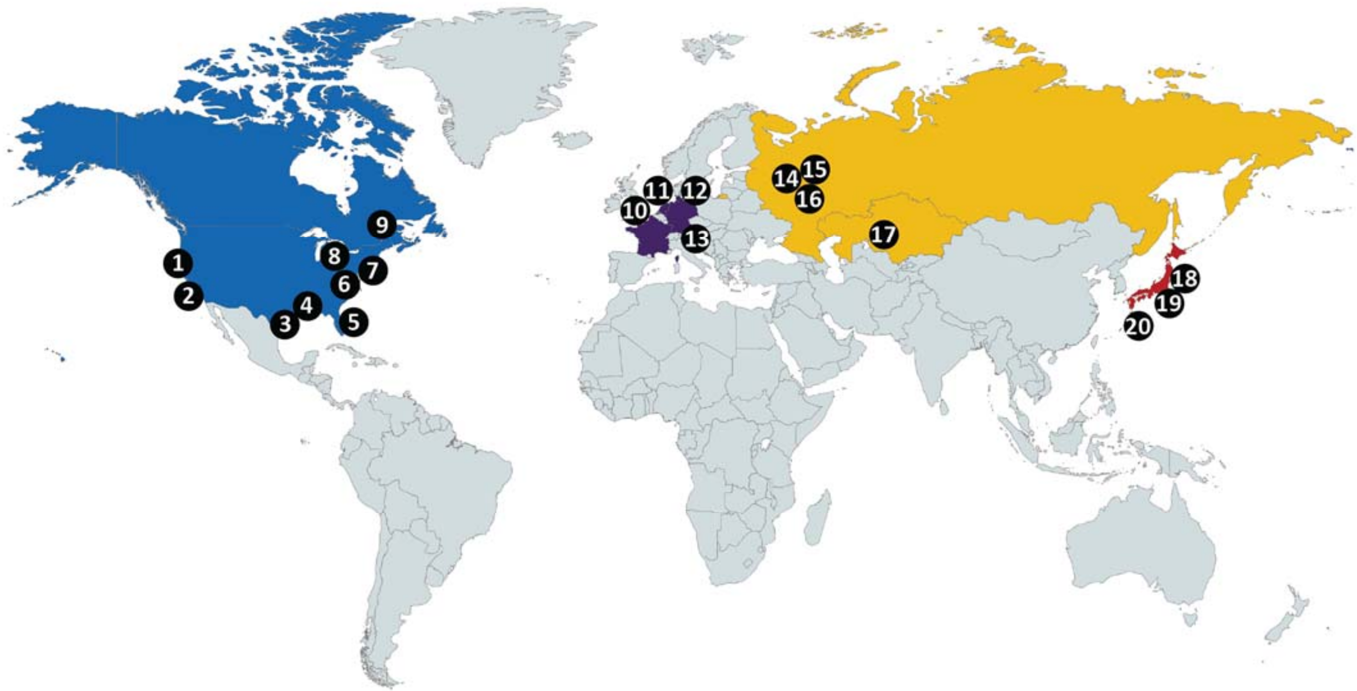
The ISS provides researchers the unique ability to study the effects of long-term exposure to microgravity and other extreme conditions, including temperature, vacuum, and space radiation. The Station has research space inside and outside the spacecraft. Inside research is conducted in the Destiny, Kibo, and Columbus modules, which consist of racks that provide power, data, and temperature control. Twenty-three racks are available to NASA to support investigations into biological sciences, human health, physical sciences, and materials. Research outside the Station – where experiments are exposed to the vacuum of space and orbital debris – typically relates to astronomy and Earth observation.

Ground and Launch Support

The ISS is supported by worldwide ground-based facilities and infrastructure providing services such as mission control, payload operations, crew development, and launch support (see Figure 2). NASA's mission control at Johnson Space Center is the primary control center for the U.S. Segment, while the control center for the Russian Segment is located in Korolev, Russia. Several international partners also have operations control facilities, including ESA's Columbus Control Center, which operates the ISS Columbus Module; JAXA's Tsukuba Control Center, which operates the Kibo Module; and CSA's Mobile Servicing System Operations Complex, which monitors the robotic arm. NASA payload operations, which controls the operation of on-orbit U.S. experiments and coordinates partner experiments, are primarily performed at the Payload Operations and Integration Center at Marshall Space Flight Center. Payload operations activities are also performed at CSA's Payload Telescience Operations Center and

ESA's User Support and Operations Centers. A number of sites are used for ISS crew training, including NASA's Johnson Space Center, JAXA's Tsukuba Space Center, and Roscosmos' Gagarin Cosmonaut Training Center. In addition, launch support is provided at NASA's Kennedy Space Center and Wallops Flight Facility, JAXA's Tanegashima Space Center, and Roscosmos' Baikonur Cosmodrome.

Figure 2: ISS Supporting Ground Facilities



1. **Telescience Support**
   Mountain View, California
2. **SpaceX Control**
   Hawthorne, California
3. **ISS Mission Control**
   Houston, Texas
4. **Payload Operations**
   Huntsville, Alabama
5. **Launch Control**
   Cape Canaveral, Florida
6. **Orbital ATK Control**
   Dulles, Virginia
7. **NASA Headquarters**
   Washington, D.C.
8. **Telescience Support**
   Cleveland, Ohio
9. **CSA Headquarters**
   Saint-Hubert, Quebec
10. **ESA Headquarters**
    Paris, France
11. **ESA Research and Technology**
    Noordwijk, Netherlands
12. **European Astronaut Center**
    Cologne, Germany
13. **Control Center**
    Oberpfaffenhofen, Germany
14. **Roscosmos Headquarters**
    Moscow, Russia
15. **ISS Mission Control**
    Korolev, Russia
16. **Training Center**
    Star City, Russia
17. **Launch Control**
    Baikonur, Kazakhstan
18. **Kibo HTV Control Center**
    Tsukuba, Japan
19. **JAXA Headquarters**
    Tokyo, Japan
20. **H-II Launch Control**
    Tanegashima, Japan

Source: NASA OIG summary of NASA information.

U.S. and international spacecraft deliver cargo and crew to the Station. NASA's Space Shuttle, which transported crew and many of the ISS modules to space during the Station's assembly phase, was retired in 2011. Since that time, the Russian Soyuz has been the only vehicle capable of transporting crew to the ISS. NASA and its commercial partners, Space Exploration Technologies Corporation (SpaceX) and The Boeing Company (Boeing), are in the process of developing crew transportation systems. In contrast, NASA's commercial cargo providers, SpaceX and Orbital ATK Incorporated, have been servicing the ISS since 2012 and 2014, respectively.[5] In 2016, NASA awarded follow-on cargo resupply contracts worth up to $14 billion to the same two companies while adding a third – Sierra Nevada Corporation (Sierra Nevada). For its part, Roscosmos utilizes the Progress spacecraft for its cargo resupply missions, with NASA occasionally flying a small amount of cargo on this vehicle as well. JAXA's H-II Transfer Vehicle – launching about once a year – provides additional cargo transportation capability for the U.S. Segment, while ESA's Automated Transfer Vehicle provided cargo to the ISS from 2008 until its retirement in 2015. See Table 1 for a summary of the vehicles servicing the ISS.

Table 1: ISS Servicing Vehicles

	Russia		Japan	U.S.	
	Soyuz	Progress	HTV	Orbital ATK Cygnus[a]	SpaceX Dragon 1[a]
					
Primary Payload	Crew	Cargo	Cargo	Cargo	Cargo
Upmass Capability	3 crew	2,250 kg	5,500 kg	3,500 kg	3,310 kg
Launch Location	Baikonur Cosmodrome	Baikonur Cosmodrome	Tanegashima Space Center	Wallops Flight Facility	Kennedy Space Center

Source: NASA OIG summary of NASA information.

[a] Denotes current cargo capability under Commercial Resupply Services-1 (CRS-1) contract. Spacecraft are expected to have increased cargo capabilities under the CRS-2 contract.

ISS International Partnerships and Agreements

The ISS is managed under a system of international agreements that govern the interactions of the partners – NASA, CSA, ESA, JAXA, and Roscomos. An initial intergovernmental agreement signed in 1998 provides the basic framework for development, operation, and utilization of the Station. Memoranda of understanding, also signed in 1998 between NASA and each partner, apportioned responsibility for development of various ISS elements. For example, the United States and Russia produced the foundational elements of the Station, while ESA and JAXA provided additional laboratories and CSA developed the robotic servicing arm. The memoranda of understanding also defined the distribution of operating costs for the U.S. Segment, with NASA paying 76.6 percent, JAXA 12.8 percent, ESA

[5] These dates represent the first mission for each provider under Commercial Resupply Services-1 (CRS-1) contracts. Prior to these missions, each provider conducted a demonstration mission to the ISS under their Commercial Orbital Transportation Services agreements. Orbital ATK was acquired by Northrop Grumman Corporation in June 2018 and the company has been renamed Northrop Grumman Innovation Systems. In this report, we refer to the company as Orbital ATK.

8.3 percent, and CSA 2.3 percent. Over the years, the partners signed additional agreements to coordinate other aspects of their participation in ISS activities. In addition, the Space Station Program Control Board and its subsidiary boards, panels, and working groups provide forums for participants to discuss issues such as safety, mission assurance, and research integration.

The NASA Authorization Act of 2005 designated the U.S. Segment as a National Laboratory and directed NASA to increase utilization of the lab by other Federal entities and foster commercial interest in conducting research on the Station.[6] Subsequently, the NASA Authorization Act of 2010 directed NASA to work with a nonprofit organization to manage 50 percent of the Agency's available research resources on the ISS.[7] In August 2011, NASA signed a cooperative agreement with the Center for the Advancement of Science in Space, Inc. (CASIS), and dedicated $15 million annually to manage all non-NASA research on the ISS.[8]

Agency and Contract Support

The ISS Program office, which resides within NASA's Human Exploration and Operations Mission Directorate, is responsible for the Agency's exploration activities in low Earth orbit and operates primarily out of Johnson Space Center with support from Glenn Research Center, Ames Research Center, Kennedy Space Center, and Marshall Space Flight Center. The U.S. sections of the ISS are managed through 53 contracts, the earliest of which began in 1986 when NASA started Station design and development. The Program's largest contract – a $19.1 billion, 26-year agreement with Boeing – provides engineering, subsystem management, and maintenance and repair of failed hardware.

Major Accomplishments

Of the Station's many accomplishments, perhaps the most significant are the United States' continuous human presence in low Earth orbit over the past 17 years and the level of sustained international cooperation in building and maintaining the ISS for more than 20 years. The ISS has contributed to the nation's understanding of the capabilities needed to live in space and spurred the development of commercial space transportation with more than half of the ISS's cargo capabilities provided by commercial providers as of June 2018. The ISS has also played a major role in developing requirements for future habitation and exploration systems. To date, NASA has sponsored research aboard the ISS in the areas of life and physical sciences, human health, astrophysics, Earth sciences, space science, and commercial research and development for pharmaceuticals, materials, manufacturing, and consumer products. In addition, the One-Year Mission in which one American astronaut and one Russian Cosmonaut resided on-orbit for a year is providing new insights into how the human body adjusts to weightlessness, isolation, radiation, and the stress of long duration spaceflight (see Figure 3). Major commercial developments aboard the ISS include the Bigelow Expandable Activity Module (BEAM), cube satellites, and 3D printing.[9] The ISS has also been used in disaster response on Earth by providing near-real time mapping support for recovery and humanitarian aid efforts.

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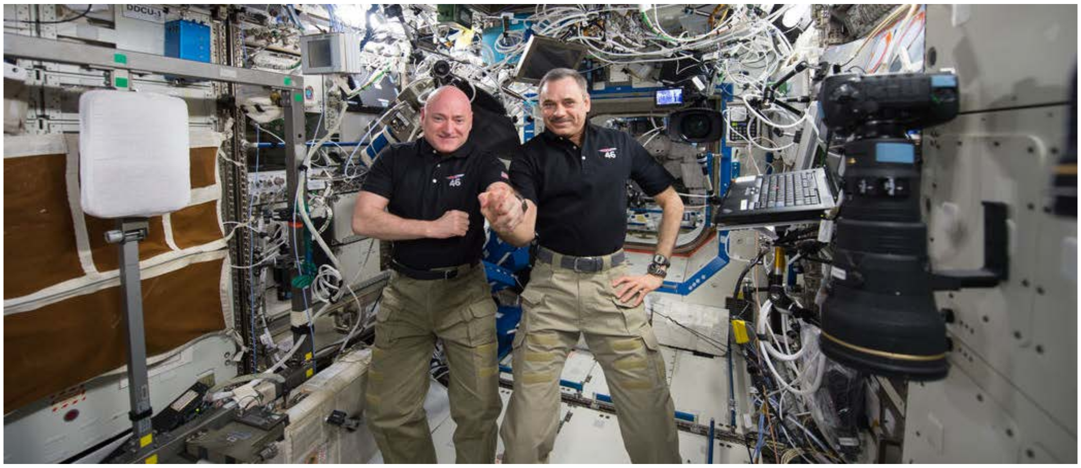
[6] National Aeronautics and Space Administration Authorization Act of 2005, Pub. L. No. 109-155 (2005).

[7] National Aeronautics and Space Administration Authorization Act of 2010, Pub. L. No. 111-267 (2010).

[8] CASIS is a nonprofit organization based in Melbourne, Florida, tasked with promoting ISS research to companies, research institutions, and other government agencies. The NASA Office of Inspector General (OIG) has conducted two audits of CASIS in the last 5 years: NASA OIG, "NASA's Management of the Center for the Advancement of Science in Space" (IG-18-010, January 11, 2018) and NASA OIG, "NASA's Efforts to Maximize Research on the International Space Station"(IG-13-019, July 8, 2013).

[9] BEAM is an expandable habitat being tested for future spaceflight missions that greatly decreases its transport volume. Cubesats provide a cost effective platform for science investigations, new technology demonstrations, and advanced mission concepts using a class of nanosatellites that come in a standard size of 10x10x10 centimeters and are extendable to larger sizes. 3D printing creates three-dimensional objects from plastics or metals, creating an on-demand "machine shop" in space.

Figure 3: NASA Astronaut Scott Kelly and Russian Cosmonaut Mikhail Kornienko Aboard the ISS in January 2016



Source: NASA.

Remaining Research Tasks and Impact of Maintaining the ISS on Future Exploration Plans

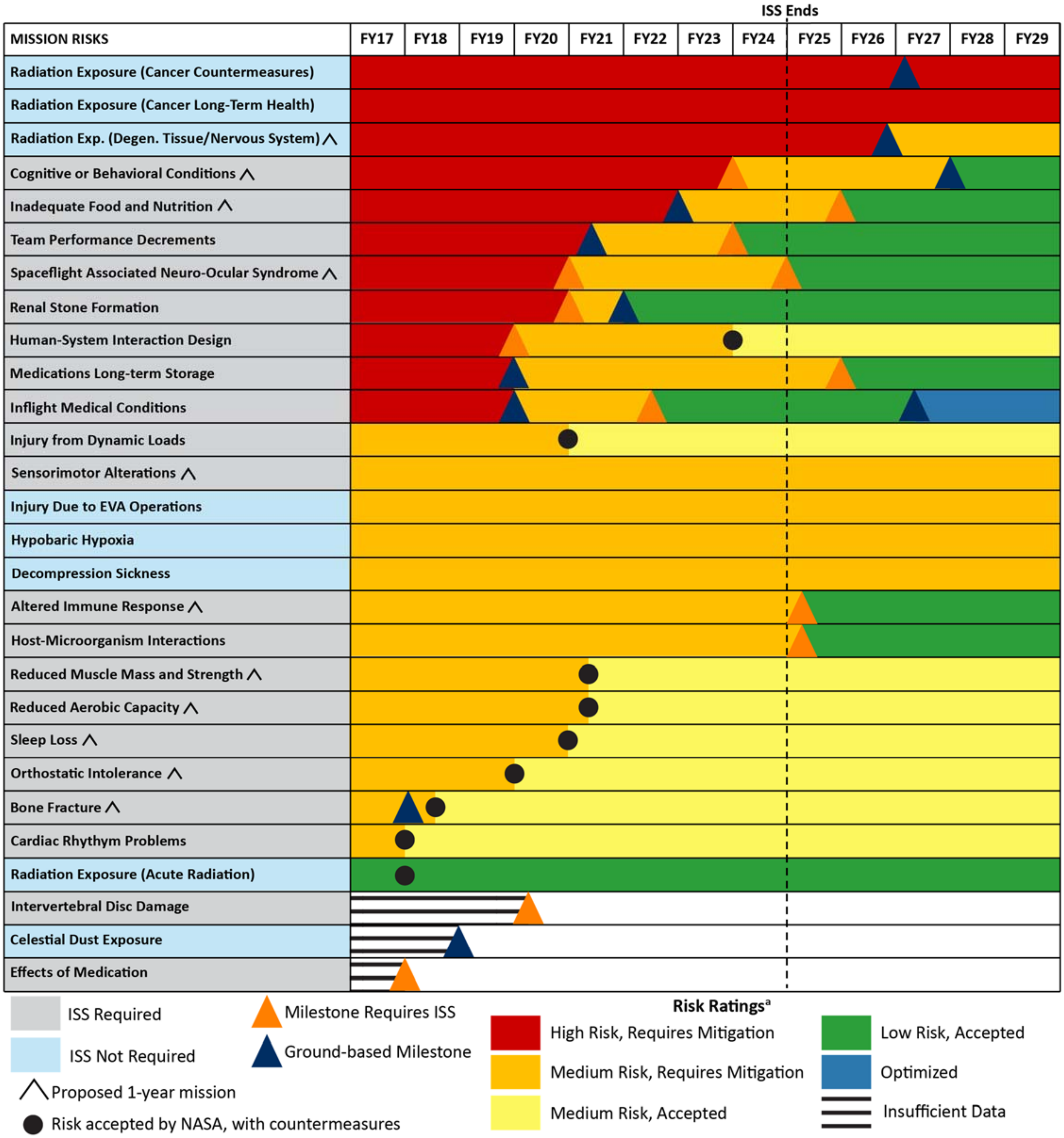
After nearly 20 years in orbit, the ISS is nearing a crossroads when NASA needs to make decisions regarding crucial, unfinished research needed to enable deep space travel and competition for funding by the next generation of exploration systems to enable that travel. In order to travel deeper into space for extended periods of time, NASA is working to understand and mitigate the human health risks that environmental factors such as radiation have on astronauts. The Agency is also using the ISS's microgravity and vacuum environments as a test bed to demonstrate technologies for potential use in future space systems. Balanced against all of these accomplishments and opportunities are the tremendous costs required to maintain the ISS and – absent a significant increase in NASA's overall funding – the necessity to redirect much of those funds to future space missions beyond low Earth orbit.

Human Health Research

Understanding and mitigating risks to astronaut health and performance for long-duration spaceflight has been a top priority for the Station since its inception. Multiple NASA offices have a role in developing procedures, medications, devices, and other strategies to mitigate these risks. The Human Research Program within the Human Exploration and Operations Mission Directorate serves as the Agency's primary resource for addressing human health and performance issues related to space travel.

To track its progress in mitigating health risks such as space radiation exposure, sensorimotor alterations, and cardiac rhythm problems, NASA created an "Integrated Path to Risk Reduction" in 2014. The plan's matrix assigns a rating denoting likelihood and consequence of occurrence. "High Risk" threats are listed in red, "Medium Risk" threats in yellow, and "Low Risk" threats in green. Risks requiring research on the ISS are listed in gray, and ISS-specific milestones are displayed as orange triangles. The Agency updated the plan most recently in February 2018 (see Figure 4).

Figure 4: Integrated Path to Risk Reduction



Source: NASA OIG summary of Human Research Program, February 2018, Integrated Path to Risk Reduction.

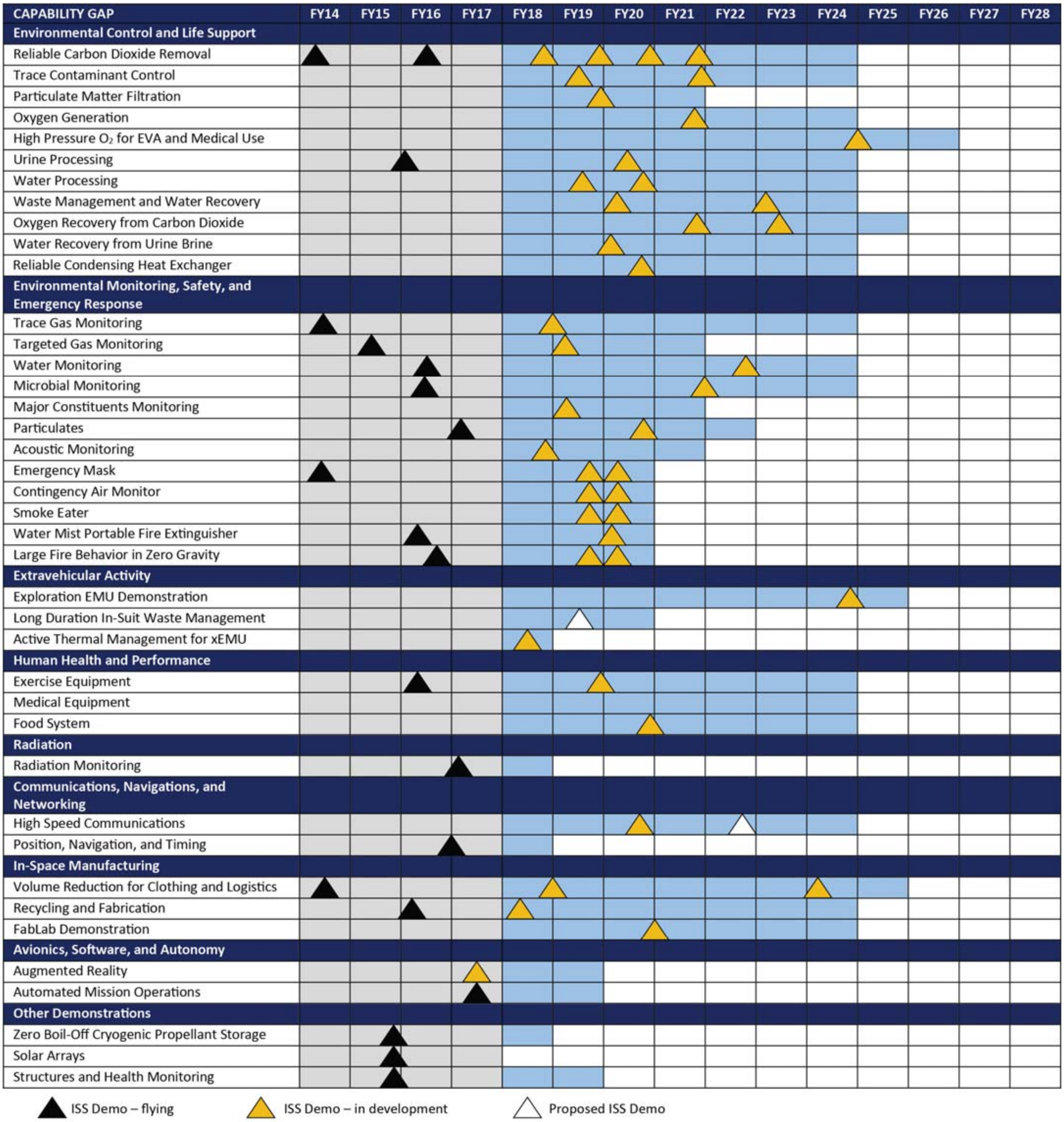
[a] Each risk is given a rating based on the likelihood of the risk occurring and the potential consequence of the risk occurring. Risks are assigned a "likelihood" rating of 1 to 3: 1 for low likelihood (less than 0.1 percent); 2 for medium likelihood (between 0.1 percent and 1 percent); or 3 for high likelihood (equal to or more than 1 percent). Risks are also assigned a consequence rating of 1-4 (low to high) basec on assessment of the risk's in-mission health and performance outcomes and long-term health outcomes. The risks are then assigned a color based on their composite likelihood and consequence ratings – red for "High Risk," yellow for "Medium Risk," and green for "Low Risk." More information on each of these risks can be found on HRP's website: https://humanresearchroadmap.nasa.gov.

Technology Demonstrations

In addition to conducting research on human health risks, NASA also undertakes technology demonstrations that need to occur on-orbit to aid in the development of exploration systems for missions to the Moon or Mars. In 2013, the Agency created 14 System Maturation Teams to address specific technology capability areas such as propulsion and life support systems required for NASA to undertake its long-term human exploration goals. In turn, NASA uses the work of these teams to prioritize its technology development investments. In addition, the ISS Program coordinates with the teams to perform technology demonstrations, including tests of thermal control systems, air and carbon dioxide monitoring, and waste purification systems.

In 2017, the ISS Division, which provides strategic guidance to the ISS Program, compiled an "ISS Technology Demonstration Plan" to track capability gaps that must be closed to enable long-duration space missions. The plan shows the dates of in-development and proposed demonstration flights on the ISS. The capability gaps are denoted in dark blue with their associated technologies listed below them. Triangles indicate anticipated launch dates with colors denoting whether the demonstration is currently on-orbit, in development, or proposed and not yet approved. The Agency updated the plan most recently in January 2018 (see Figure 5).

Figure 5: ISS Technology Demonstration Plan



Source: NASA OIG summary of ISS Division, January 2018, ISS Technology Demonstration Plan.

Impact of Maintaining the ISS

Through our previous audit work, we found that given NASA's budget projections for FY 2019-2023, continuing to support the ISS at a cost of $3-$4 billion per year past the end of FY 2024 will likely have significant ramifications on the Agency's ability to fund and the timetable for other human exploration priorities, including missions to the Moon or Mars.[10] Other non-NASA groups reached similar conclusions in their evaluations of the Agency's exploration plans. Specifically, the National Research Council reported that a continuation of flat budgets for human spaceflight is insufficient for NASA to execute any Mars exploration until the end of the ISS Program.[11] The Planetary Society, a non-profit organization dedicated to advocacy and education issues related to space, reached a similar conclusion.[12] During a March 2017 hearing before the House Committee on Science, Space, and Technology, members questioned NASA officials and other space experts on the Station's costs and the impacts those costs may have on the Agency's future exploration objectives.[13] Congress also directed NASA in the NASA Transition Authorization Act of 2017 to submit an ISS Transition Report detailing the impact of extending the service life of the ISS beyond 2024 on its deep space exploration capabilities.[14] In addition, the President signed a memorandum referred to as Space Policy Directive-1 in December 2017 that calls for a return of humans to the Moon for "long-term exploration and utilization." Finally, the Administration's FY 2019 budget submission proposed ending direct Federal funding for the ISS beginning in FY 2025 and includes $150 million in FY 2019 to support development of new commercial low Earth orbit platforms and capabilities.

NASA's Plan for ISS Transition

As debate swirls about whether to extend ISS operations past the current expiration date of October 1, 2024, NASA and other stakeholders are in the process of developing plans for not only its future but the future of the broader low Earth orbit economy. In response to a congressional directive in the NASA Transition Authorization Act of 2017, NASA submitted an ISS Transition Report in late March 2018 that described its high-level plans for transitioning the ISS after direct funding ends. The report discusses NASA's future plans for operations, research, and development in low Earth orbit; NASA's vision for low Earth orbit in 2024 and beyond; key issues with the Station's end of mission and NASA's transition to commercial low Earth orbit platforms; the low Earth orbit commercial marketplace; the Station's role in human exploration of deep space; benefits from ISS research; and an evaluation of the technical and cost implications of continuing to operate the ISS past FY 2024.[15]

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[10] NASA OIG, "NASA's Plans for Human Exploration Beyond Low Earth Orbit" (IG-17-017, April 13, 2017).

[11] National Research Council, "Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration," 2014.

[12] The Planetary Society, "Humans Orbiting Mars," 2015.

[13] Hearing before the Subcommittee on Space, Committee on Science, Space, and Technology, House of Representatives, "The ISS After 2024: Options and Impacts," March 2017.

[14] NASA Transition Authorization Act of 2017, Pub. L. No. 115-10 (2017).

[15] The ISS Transition Report fails to address two key requirements of the Congressional reporting directive: (1) the actions and costs required to deorbit the ISS and (2) the impact to NASA's deep space exploration capabilities if the ISS is extended beyond 2024.

In its ISS Transition Report, NASA envisions a sustained U.S. commercial marketplace for human spaceflight in low Earth orbit where the Agency is one of many customers for privately-owned and operated platforms and crew and cargo transportation. The platforms and spacecraft would be primarily sustained by commercial revenue rather than relying on NASA as their main source of funding. In line with this vision, the Agency is considering a range of options for the future of the ISS, including transitioning its operations to private industry, augmenting it with privately developed modules, combining portions of the current platform with a new private platform, or deploying an entirely new platform and deorbiting the ISS. NASA is also considering whether its long-term research requirements, while similar to those of the current ISS Program, could be met with various types of modules or platforms that do not require a vehicle as complex as the ISS.

NASA plans to move forward with this approach in FY 2018 by identifying the Agency's long-term requirements for low Earth orbit and soliciting industry input on meeting these requirements. As part of this process, NASA plans to request market analysis and business plans from private industry to gauge the depth of possible low Earth orbit commercial markets.

NASA Positioned to Complete Most But Not All ISS Research to Enable Long-Duration Spaceflight by 2024

NASA plans to continue using the ISS to mitigate the majority of previously identified human health risks and technology gaps related to long-duration human spaceflight for as long as possible. As of February 2018, the Agency forecasts that research for at least 6 of 20 human health risks that require the ISS for testing and 4 of 40 technology gaps will not be completed by the end of FY 2024 when funding for the Station's operation is scheduled to end. In addition, research into 2 human health risks and 17 technology gaps is not scheduled to be completed until around 2024, which increases the risk that even minor schedule slippage could push completion past the end of that fiscal year. This is due in part to difficulties with characterizing and mitigating the health risks and, for technology demonstrations, obtaining the required funding and on-orbit research time. Complicating matters is the fact that the completion of needed research could be further jeopardized by increasing demands on the Station's crew and research space and by potential cargo and crew launch delays and failures. As a result, NASA may be forced to choose among a variety of options, including extending operation of the ISS past 2024, relying on alternate testing methods (i.e., non-space-based), or accepting higher levels of risk for future missions.

NASA is Utilizing the ISS to Make Considerable Progress Mitigating Human Health Risks in Space and Maturing Key Technologies

NASA continues to perform well against metrics that track on-orbit research and overall use of the ISS such as crew time dedicated to research, number of investigations, and use of allocated research space (see Table 2). In 2013, we reported that NASA's performance against each of these metrics was moving in an upward trend, and since that time the Agency has continued to perform well.[16] For example, NASA has generally met or exceeded its goal of 35 hours of crew time per week devoted to research and recently set a record with 63.2 average hours per week devoted to research from April 2017 to September 2017.[17] In addition, the number of scientific investigations performed on-orbit have increased from a low of 65 in 2012 to a high of 171 in 2014, and the crew has averaged 109 investigations every six months over the last 3 years.[18] We also found that the occupancy rate of internal ISS research space has generally increased since tracking began in 2012, including a peak of 91 percent during the period of September 2017 to February 2018. However, the occupancy rate of external research space historically has been lower, with rates fluctuating between 53 and 60 percent between 2014 and 2017 before rising to 80 percent in 2018. Nonetheless, since both metrics were first tracked in 2012, NASA has met its target of a combined internal and external research occupancy rate of 75 percent.

[16] IG-13-019.

[17] Station metrics generally are measured in "increments" equating to a six-month crew rotation aboard the ISS.

[18] An "investigation" includes a science experiment, technology demonstration, or other research activity on-orbit.

Table 2: ISS Utilization Metrics

Increment Pair	Date	Crew Time Spent on Research (Average Weekly Hours)	Number of U.S. Investigations	Internal Occupancy Rate (Percent)	External Occupancy Rate (Percent)
Target metric		35	N/A	75 (combined internal and external occupancy)	
21/22	10/2009 to 3/2010	24.9	87	Not tracked	Not tracked
23/24	3/2010 to 9/2010	23.5	73	Not tracked	13
25/26	9/2010 to 3/2011	23.5	80	Not tracked	13
27/28	3/2011 to 9/2011	24.1	119	Not tracked	27
29/30	9/2011 to 4/2012	36.0	72	70	27
31/32	4/2012 to 9/2012	36.3	65	70	31
33/34	9/2012 to 4/2013	38.1	116	71	40
35/36	4/2013 to 9/2013	40.3	123	80	40
37/38	9/2013 to 3/2014	43.5	133	81	40
39/40	3/2014 to 9/2014	42.3	171	81	47
41/42	9/2014 to 3/2015	38.2	113	81	60
43/44	3/2015 to 9/2015	38.4	101	67	60
45/46	9/2015 to 3/2016	38.3	92	70	53
47/48	3/2016 to 9/2016	44.0	103	83	60
49/50	9/2016 to 4/2017	45.3	102	85	53
51/52	4/2017 to 9/2017	63.2	135	89	73
53/54	9/2017 to 2/2018	54.3	121	91	80

Source: NASA OIG summary of ISS Program information.

NASA expects to further improve utilization of the ISS for research purposes as a result of its purchase of Soyuz flights to the ISS that increased the crew size on the U.S. Segment from 3 to 4 in Fall 2017 and Spring 2018.[19] The flights are also expected to mitigate the impact of delays in the development of commercial crew vehicles, which are not expected to become operational until 2019.

Through increased utilization of research space on the ISS and increased crew time devoted to research, NASA is on track to complete 14 of 20 (70 percent) human health risks and 36 of 40 (90 percent) technology demonstration gaps that need to occur on the ISS before the end of FY 2024. As of the February 2018 update to the Human Research Program's Integrated Path to Risk Reduction, NASA was positioned to reduce all human health risks requiring the ISS to at least Medium Risk by 2024.[20] For example, to address the risk of sleep loss experienced by astronauts during spaceflight, NASA initiated studies aboard the ISS to measure the impact of how lighting and other environmental factors impact an astronaut's sleep cycle. Other high-level human health risks the Agency expects to mitigate by 2024 using ISS research include risks related to treatment of serious medical conditions while aboard the ISS,

[19] NASA purchased these seats from Boeing, who obtained the seats from a Russian company, RSC Energia, as part of a settlement for a legal dispute involving a matter unrelated to the ISS.

[20] Each risk is given a rating based on the likelihood of the risk occurring and the potential consequence of the risk. The risks are then designated as "High Risk," "Medium Risk," or "Low Risk" based on their composite likelihood and consequence ratings.

reduced muscle mass, reduced aerobic capacity, orthostatic intolerance, and cardiac rhythm problems.[21] With respect to technology demonstrations, NASA's ISS Technology Demonstration Plan forecasts the Agency will complete demonstrations for all technologies under the radiation and avionics, software, and autonomy capability gaps by the end of FY 2020 – four years before funding for the ISS is scheduled to end at the close of FY 2024.

Not all Human Health Risks and Technology Gaps will be Addressed by 2024

Despite NASA's efforts, multiple human health risks and technology gaps will remain after the end of FY 2024 when funding for the Station's operation is scheduled to end. Specifically, as of the February 2018 update to the Integrated Path to Risk Reduction, NASA forecasts that research for 6 of 20 human health risks requiring the ISS will not be complete by the end of 2024.[22] In addition, another 2 risks will not be complete until sometime in 2024, increasing the potential that schedule slips could push their completion past the end of that fiscal year. Similarly, the Agency's ISS Technology Demonstration Plan estimates that 4 of 40 technology demonstration gaps will not be completed by 2024. In addition, we found that another 17 technology gaps could be at risk due to schedule slippage because their completion dates are throughout 2024. Furthermore, the Agency's Integrated Path to Risk Reduction and Technology Demonstration plans assume steady progress in reducing the risks; however, the plans have undergone several revisions since their inception that often push out the schedules for certain risks and demonstrations.[23]

Human Health Risk Gaps

Under the Agency's current plan, at least 8 human health risks will continue to need testing on the ISS in the 2024 time frame or after, including research into cognitive or behavioral conditions, inadequate food and nutrition, team performance decrements, spaceflight associated neuro-ocular syndrome, long-term storage of medication, sensorimotor alterations, altered immune responses, and host-microorganism interactions (see Figure 6).[24] According to NASA officials, while it would be optimal to conduct research for 5 of these 8 risks onboard the ISS, the Agency may be able to use ground-based testing methods to finish the research if the ISS is no longer available. NASA has developed preliminary plans for such ground-based testing, but it has not created detailed contingency plans that would address factors such as cost, schedule, and technical risks if the Agency was required to rely on these alternate platforms instead of the ISS. Furthermore, officials stressed that three risks – spaceflight associated neuro-ocular syndrome, sensorimotor alterations, and altered immune response – will need

[21] Orthostatic intolerance refers to the risk that astronauts may experience difficulty maintaining blood pressure while in an upright position after they have been exposed to a microgravity environment for an extended period of time and then reintroduced to an increased gravity environment.

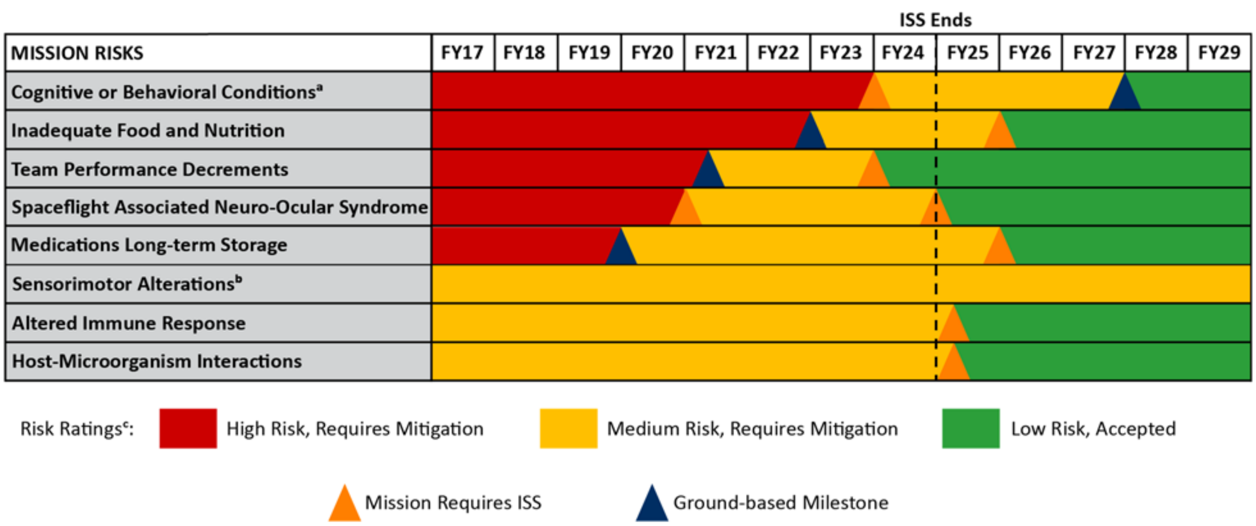
[22] These risks include cognitive or behavioral conditions, inadequate food and nutrition, long-term storage of medications, sensorimotor alterations, altered immune response, and host-microorganism interactions.

[23] We did not independently review the progress being made in each human health and technology demonstration area in this audit.

[24] Team performance decrements refers to the risk that the conditions on space missions may lead to inadequate functioning within a team, such as poor cooperation, coordination, and communication, and the associated impact to performance and behavioral health. Spaceflight associated neuro-ocular syndrome is induced by the microgravity environment and causes intracranial pressure changes that can lead to vision alterations. Sensorimotor alterations refer to the risk of impairment of functions like eye-head-hand control as a result of long-duration spaceflight. Host-microorganism interactions refer to the potential increased risk of susceptibility to certain viruses in the spaceflight environment.

to be fully tested in a microgravity environment due to a lack of suitable ground-based testing methods. If these risks cannot be tested on the Station, NASA could be forced to accept higher health risks than planned for future exploration missions.

Figure 6: Select Human Health Risks Requiring the ISS for Mitigation



Source: NASA OIG summary of Human Research Program, February 2018, Integrated Path to Risk Reduction.

[a] NASA is investigating whether the ISS will be required to mitigate cognitive or behavioral conditions risk from Medium Risk to Low Risk.

[b] Research into countermeasures for the sensorimotor alterations risk is currently on hold.

[c] Each risk is given a rating based on the likelihood and potential consequence of the risk occurring. Risks are assigned a "likelihood" rating of 1 to 3: 1 for low likelihood (less than .1 percent); 2 for medium likelihood (between .1 percent and 1 percent); or 3 for high likelihood (equal to or more than 1 percent). Risks are also assigned a consequence rating of 1-4 (low to high) based on assessment of the risk's in-mission health and performance outcomes and long-term health outcomes. The risks are then assigned a color based on their composite likelihood and consequence ratings.

Several NASA officials also stressed that additional one-year missions may be required to increase the fidelity of human health risk data and further characterize risks. According to the Integrated Path to Risk Reduction, as many as 11 human health risks would benefit from these additional one-year missions because they would provide more data than standard 6-month ISS missions on how spaceflight impacts the human body over extended periods of time.[25] For example, NASA's lone one-year mission conducted from March 2015 to March 2016 revealed previously unknown phenomena, including changes in astronaut gene expression, evidence of increased problems with fine motor skills, and slower recovery of mobility functions upon returning to Earth. A NASA official explained that the Agency would need to initiate these one-year missions by 2019 in order for them to be complete by 2024. As of April 2018, NASA had yet to formalize plans for such missions.

[25] The 11 risks that would benefit from additional one-year missions include space radiation exposure, cognitive or behavioral conditions, inadequate food and nutrition, spaceflight associated neuro-ocular syndrome, sensorimotor alterations, altered immune response, reduced muscle mass, reduced aerobic capacity, sleep loss, orthostatic intolerance, and bone fracture.

Spaceflight Associated Neuro-Ocular Syndrome

According to NASA officials, the top human health risk that requires ISS-based testing through 2024 or later is research into spaceflight associated neuro-ocular syndrome.[26] This risk occurs with astronauts on long-duration ISS missions who experience changes in eye structure and vision deficits. The underlying cause of these changes is unknown and therefore NASA is using the ISS to characterize the condition and develop countermeasures. NASA officials stressed the importance of ISS testing for this risk due to its unique microgravity environment. The Agency is investigating ground-based testing methods. However, the Agency's current Integrated Path to Risk Reduction predicts that countermeasures will not be fully tested on the ISS until the end of FY 2024, which leaves no margin for delay. NASA officials stated that predicting when this risk will be resolved is difficult because researchers have struggled to understand and mitigate it. The officials further stated that additional one-year missions are needed to better understand this risk. Current mitigation options are limited to preflight screening, corrective lenses (in-flight and post-flight), aerobic exercise on-orbit, reduced sodium diet in-flight, frequent on-orbit ocular assessments, and reduction of carbon dioxide levels. Among the countermeasures NASA is investigating are mechanical interventions, such as Lower Body Negative Pressure or selected compression devices worn on the lower body to redistribute body fluids. If NASA is not able to mitigate this risk, astronauts may face vision deterioration on long-duration exploration missions, likely impacting mission performance. Several NASA officials we spoke with stated that if mitigation options are not identified the risk could be a "showstopper" for long-duration crewed missions.

Research into Spaceflight-Associated Neuro-Ocular Syndrome

Source: NASA.

Sensorimotor Alterations

Another human health risk that requires the ISS for testing is research into sensorimotor alterations or the impairment of certain motor functions such as balance due to the transition from a microgravity environment to an increased gravity environment. This risk manifests itself with astronauts returning to Earth from the ISS who experience balance and coordination issues, making it difficult to walk and perform other simple motor tasks for up to several days after they land.[27] According to the Integrated Path to Risk Reduction, NASA has put research into sensorimotor alterations on hold because mitigation strategies are only needed for missions that involve a Mars landing, and the Agency does not anticipate such a landing until at least the late 2030s. NASA officials cautioned, however, that the ISS is the best platform to conduct this research to prepare for future Mars landings because ground-based methods are currently not able to sufficiently replicate the effects of microgravity and spaceflight.

[26] This risk was formerly known as "vision impairment due to intracranial pressure."

[27] Astronauts returning from 1-2 week Space Shuttle missions also experienced this phenomenon, but their symptoms generally dissipated within hours to days of landing.

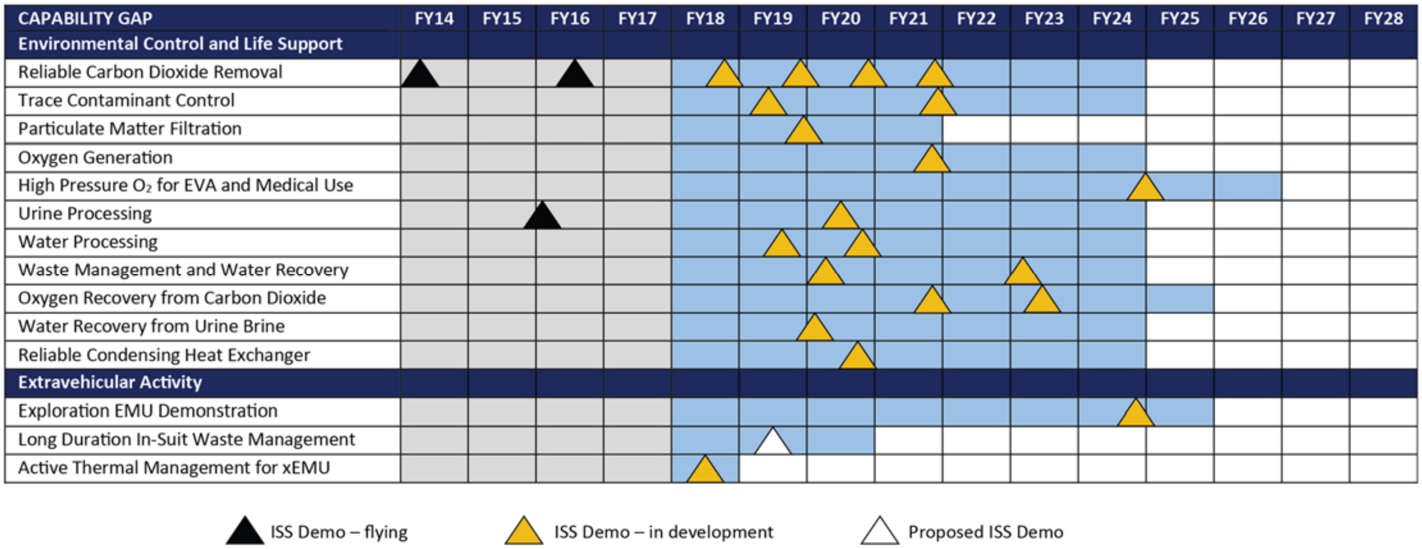
Altered Immune Response

The third human health risk that requires the ISS for testing through 2024 or later is research into altered immune responses. Crew experiencing this risk have noted changes to their immune systems, including atypical allergic symptoms and hypersensitivity reactions. NASA officials believe that altered immune response represents a significant risk for orbital missions 6 to 12 months in duration and exploration missions of extended duration due to prolonged exposure to stressful hazards such as isolation, confinement, and elevated radiation levels. NASA is researching the clinical significance of altered immune response and plans to use the ISS to characterize risks and identify countermeasures. The Agency does not expect to mitigate this risk until FY 2025 because of the time needed to obtain inflight evidence to supplement post-flight data. NASA officials also said additional one-year missions are needed to further understand this risk; however, no plans have been formalized for such missions. The Agency is also investigating this health risk using research in Antarctica to determine if the phenomenon is triggered by the space environment or simply extreme environmental conditions, but scientists are unsure whether a ground analog sufficiently simulates the space-induced phenomenon.

Technology Demonstration Capability Gaps

Research on the 21 technology demonstration capability gaps scheduled to be completed in FY 2024 or later include technologies related to environmental control and life support; environmental monitoring, safety, and emergency response; extravehicular activity; human health and performance; communications, navigation, and networking; and in-space manufacturing. Although the Technology Demonstration Plan projects these gaps will be largely complete by the end of 2024, the Agency has little schedule margin to absorb delays. To the point, the NASA Advisory Committee noted in July 2017 that "while projections show that the work should be complete by 2024, the committee believes that it is likely that exploration development work on the ISS will need to be continued until 2028 or later." In addition, the leaders of several of the capability gap teams we spoke with expressed skepticism on projected funding and suggested that demonstrations likely would continue after 2024 because many of these systems require on-orbit runtimes of one year or longer to collect sufficient data. Although the Agency may be able to find alternate testing platforms for some of these technologies, 14 gaps in the environmental control and life support and extravehicular activity areas will require extensive testing aboard the ISS due to the unique impact of microgravity on fluid dynamics (see Figure 7). Furthermore, while NASA has developed preliminary plans for alternate testing platforms, the Agency has not created detailed contingency plans that would address factors such as cost, schedule, and technical risks that would exist if the Agency was required to rely on alternate platforms instead of the ISS.

Figure 7: Select Exploration-Enabling Technology Demonstrations Requiring the ISS



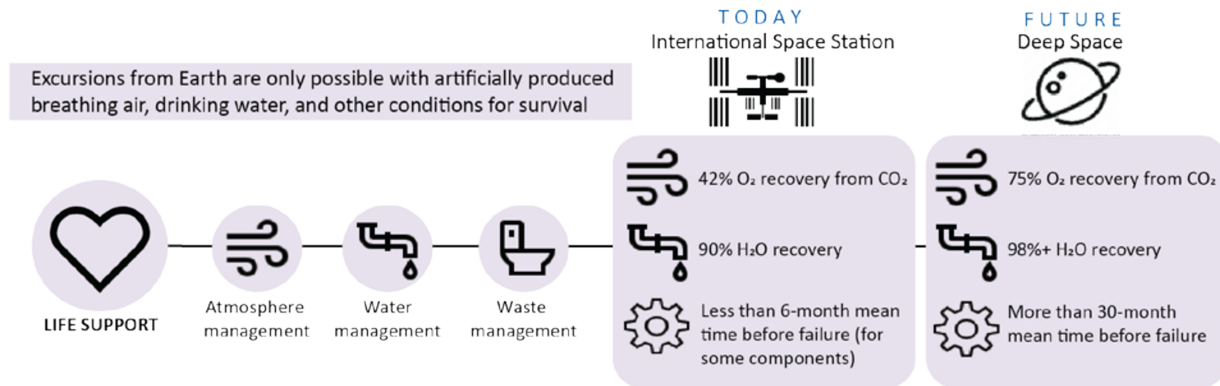
Source: NASA OIG summary of ISS Division, January 2018, ISS Technology Demonstration Plan.

Environmental Control and Life Support

One of the key areas that will require the ISS for testing through 2024 or later is the development of technologies for future space-based environmental control and life support systems. The Agency's ISS Technology Demonstration Plan projects that 10 of 11 environmental control and life support technologies that require testing on the ISS are not expected to be complete until the end of 2024 or later. NASA officials said this timetable is due in part to the demonstrations not having funding priority until recently. Furthermore, some of the experiments require multiple years to test on the ISS.

The Agency is working to develop or improve technologies for carbon dioxide removal, urine and water processing, water and oxygen recovery, and dust filtration. Each of these technologies is critical because future deep space exploration missions will not have the ability to regularly resupply necessities such as oxygen and water. Current systems on the ISS have a 42 percent oxygen and 90 percent water recovery capability, which will need to be improved to at least 75 percent oxygen recovery and 98 percent water recovery for long duration missions (see Figure 8). Furthermore, some components of the ISS's environmental control and life support system have an average life span of less than six months before expected failure, requiring regular replacements using cargo resupply flights from Earth. Future systems will require technologies that can last more than 30 months before failure. NASA officials said it is critical to test these technologies on the ISS because fluid systems behave differently in microgravity compared to Earth. The officials further stated that if the demonstrations are not completed prior to 2024, testing could continue on the ground but with higher risk of not understanding system performance and failure rates in the relevant environment.

Figure 8: Development of Exploration Life Support Technology



Source: NASA OIG summary of NASA information.

Exploration Extravehicular Mobility Unit Demonstration

Another key technology demonstration area that will require the ISS for testing through 2024 or later is the development of an exploration extravehicular mobility unit, more commonly known as a spacesuit. Although the spacesuit currently used on the ISS for extravehicular activities (spacewalks) is suitable for operations in low Earth orbit, it does not offer the mobility, durability, or functionality planetary or cislunar missions will require.[28] The Agency is currently developing an advanced portable life support system that provides air to the spacesuit and is connected to a hard upper torso, which is worn over the astronaut's chest (see Figure 9). The ISS Technology Demonstration Plan schedule projects the Agency will not begin testing the advanced spacesuit on-orbit until the end of FY 2024 and will not complete testing until the end of FY 2025. As we reported in April 2017, NASA's spacesuit development efforts have struggled from a lack of operational requirements, stable funding, and stable plans.[29] NASA officials stressed that testing of the suit's portable life support system in microgravity is critical to developing the spacesuit. Without adequate microgravity testing, NASA will need to accept higher levels of risk during future exploration missions, potentially impacting astronaut health and safety as well as mission success.

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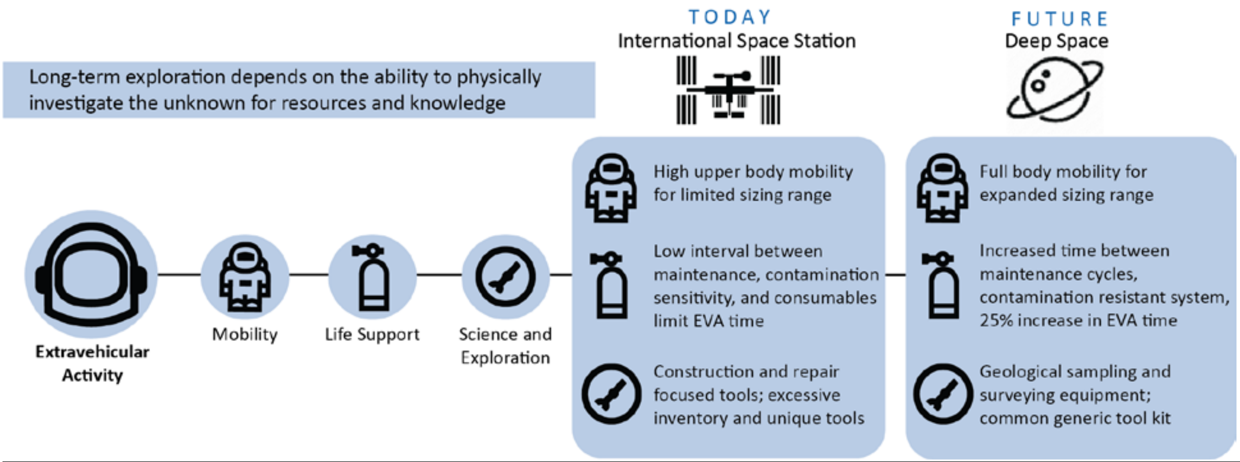
[28] Cislunar space is the area between Earth and the Moon or the Moon's orbit.

[29] NASA OIG, "NASA's Management and Development of Spacesuits" (IG-17-018, April 26, 2017).

Figure 9: Development of Extravehicular Activity Technology



Source: NASA OIG summary of NASA information.

Recurring Challenges Could Spur Delays That Lead to Additional Human Health and Technology Gaps

Recurring issues with increased demand on the Station's crew and research space, limited transportation options and launch delays, and requirements to accommodate CASIS and international partner research increase the risk of further schedule delays to the Station's critical on-orbit research. We previously reported on NASA's efforts to maximize research on the ISS and impacts to resupplying the Station following launch failures by NASA's commercial suppliers Orbital ATK and SpaceX.[30] In addition, the Government Accountability Office (GAO) has examined the Agency's difficulties over the years increasing utilization on the ISS. On its own, the ISS Program has identified crew time and external payload sites and cold stowage as constraining factors to maximizing Station utilization.

Crew Time

Although NASA has generally met or exceeded its goal of 35 hours per week dedicated to research aboard the ISS, the amount of crew time available for research continues to be a major factor limiting greater utilization on-orbit given that many investigations require participation by the crew in some capacity, particularly human health research. Although NASA plans to continue allocating an average of 35 hours of crew time per week to research, NASA's planning documents show that until commercial crew vehicles are fully operational – expected in the second half of 2019 – the research it plans to conduct will exceed this allocation, requiring an average of 66.2 hours of crew time per week. These findings are consistent with a 2015 GAO report that noted that NASA will have difficulty meeting an expected increase in demand for crew time, as demand may exceed capability.[31]

[30] IG-13-019; NASA OIG, "NASA's Response to Orbital's October 2014 Launch Failure: Impacts on Commercial Resupply of the International Space Station" (IG-15-023, September 17, 2015); and NASA OIG, "NASA's Response to SpaceX's June 2015 Launch Failure: Impacts on Commercial Resupply of the International Space Station" (IG-16-025, June 28, 2016).

[31] GAO, "International Space Station: Challenges to Increased Utilization May Affect Return on Investment" (GAO-15-722T, July 10, 2015).

Crew Transportation

In the near term, NASA has worked to meet the increased need for crew time by purchasing a Soyuz seat for a fourth U.S. astronaut in Fall 2017 and Spring 2018.[32] Once commercial crew providers are operational, NASA plans to continuously maintain four astronauts in the U.S. Segment rather than the current three. As we have previously reported, having a fourth crew member essentially doubles the amount of crew time that can be dedicated to research.[33] However, as GAO reported in January 2018, delays in the development and certification of commercial crew vehicles could result in these vehicles not being available to ferry crew to the ISS before NASA's current contract for Soyuz seats ends in 2019.[34] NASA does not plan to purchase Soyuz seats past 2019, so if commercial crew providers are not ready by then NASA could face a gap in its access to the ISS.

External Payload Sites and Cold Stowage

A limited number of external payload sites and limited capability to store research samples also affects the Station's utilization. According to Program planning documents, projected demand for the Station's 23 external payload sites is expected to exceed capability sometime in 2018. External investigations – such as NanoRacks-Gumstix, which tests whether a commercial-off-the-shelf computer processor can withstand the radiation environment of the ISS – have utilized long testing durations to maximize the amount of data collected. However, extended runtimes for experiments may no longer be an option due to a projected increase in demand, requiring the removal of investigations in order to make room for new ones. NASA plans to remove 10 such investigations between 2019 and 2022. NASA is investigating the potential for creating additional external payload sites to accommodate the projected demand while Program officials are developing methods to set priorities for all external payloads.

The Station's cold stowage capabilities also are a limiting factor in increasing on-Station research with projected accumulation of samples exceeding current cold stowage capabilities in 2019. This limitation may impact the type or amount of science that can be performed on-orbit over the next several years.[35] The ISS Program has flown additional freezers and is modifying its existing freezers to provide more volume for cold stowage on the ISS, a solution expected to mitigate most of this risk.

Cargo Transportation and Launch Delays

ISS utilization is also affected by NASA's ability to transport cargo to the Station and back to Earth. Currently, SpaceX's Dragon is the only vehicle capable of returning pressurized cargo to the ground (downmass).[36] As a result, the Agency is projecting up to 13 metric tons of additional on-orbit accumulation by 2022. For context, the maximum pressurized downmass capability of SpaceX's current Dragon vehicle is 3,310 kg – meaning it would take about four flights to completely reduce the backlog. However, the four most recent SpaceX missions have only returned between 1,628 kg and 2,477 kg of

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[32] NASA purchased these seats from Boeing, who obtained the seats from Russian Company RSC Energia as part of a settlement for a legal dispute involving a matter unrelated to the ISS.

[33] IG-13-019.

[34] GAO, "NASA Commercial Crew Program: Continued Delays Pose Risks for Uninterrupted Access to the International Space Station" (GAO-18-317T, January 17, 2018).

[35] Cold stowage provides controlled environments that meet temperature requirements during ascent, on-orbit operations, and return, such as freezers, refrigerators, and incubators.

[36] SpaceX's Dragon is capable of either returning pressurized cargo to Earth or disposing of cargo during reentry. Orbital ATK's Cygnus is only capable of disposing of cargo during reentry.

downmass per mission, leaving little room to begin reducing the 13 tons of accumulated pressurized cargo. NASA and its partners are trying to address the backlog by better identifying hardware for return or disposal to make room on returning SpaceX flights for new investigations. In addition, once the three Commercial Resupply Services-2 (CRS-2) partners begin servicing the ISS, their vehicles are required to have both pressurized and unpressurized cargo delivery as well as increased ability to transport downmass or dispose of cargo.[37] Despite this expected increase in capability, Agency planning documents indicate that the Station's downmass and disposal requirements will have difficulty keeping pace with new deliveries (upmass). Furthermore – as we have described in our prior work – cargo launch failures and launch delays impact the upmass available on-orbit, which affects the Station's utilization.[38] For example, the Orbital ATK cargo mission failure in 2014 resulted in the loss of approximately 2,293 kg of cargo (including supplies, equipment, and experiments) while SpaceX's 2015 failure resulted in the loss of approximately 2,478 kg of cargo. These failures resulted in significant delays to the contractor's cargo resupply missions, resulting in delays affecting researchers' ability to obtain samples and data. Specifically, the failed Orbital ATK mission carried 727 kg of science investigations, including a human health study to examine blood flow in space and biological and specimen samples for testing in microgravity. Similarly, the failed SpaceX mission carried 573 kg of research equipment, including an investigation to study plant growth in space.

CASIS and International Partner Commitments

CASIS and international partner commitments also impact NASA's ability to fully utilize the ISS. While its own research seeking to mitigate human health risks and complete technology demonstrations receive the highest priority of any research performed on-orbit, NASA must also abide by its agreements with CASIS and international partners, commitments that reduce the amount of research resources available to NASA. Each of NASA's three international partners for the U.S. Segment is responsible for paying for the portion of ISS operating costs commensurate with the percentage of the Station's research resources it uses. For example, NASA uses 76.6 percent of the Station's research resources, so it pays 76.6 percent of the U.S. Segment's operating costs. Although a significant portion of total Station research time, the NASA Authorization Act of 2010 requires at least 50 percent of these resources, including upmass and crew time, be allocated to the CASIS-managed National Laboratory, limiting the time and capabilities available to NASA for mitigating risks associated with future space exploration goals. While our prior work found that CASIS has used on average only 52.7 percent of the crew time allocated from September 2013 to April 2017, its use of crew time has increased since 2016 to 72.8 percent between March 2016 and September 2016 and 68.1 percent between September 2016 and April 2017.[39] Any allocation unused by CASIS can be used by NASA for its own research.

[37] Pressurized cargo is stored at an Earth-like atmospheric pressure environment, while unpressurized cargo is mounted external to the spacecraft and can be exposed to the space environment.

[38] IG-15-023 and IG-16-025.

[39] IG-18-010.

NASA Faces Challenging Options for Transitioning, Extending, or Retiring the ISS

The ISS is currently scheduled to continue operations until October 2024 after which NASA intends to transition the Station to commercial operation. However, based on congressional interest the Agency likely will also need to consider other options including extending ISS operations until 2028 or beyond. And at some future point, NASA will need to dispose of the Station via a controlled destructive reentry into the Earth's atmosphere. Each of these options comes with its own set of challenges. Specifically, transitioning the ISS to private operation under the timetable currently envisioned presents significant challenges in stimulating private sector interest to take over an extremely costly and complex enterprise. Likewise, any extension of the ISS past 2024 would require continued funding in the neighborhood of $3-$4 billion annually to operate and maintain the Station – a significant portion of which could otherwise be redirected to develop systems needed for NASA's cislunar or deep space ambitions. In addition, extending the Station's life would challenge NASA to manage the risks associated with continued operation of the Station's aging systems and infrastructure. Furthermore, any extension will require the support of NASA's international partners, whose continued participation hinges on issues ranging from geopolitics to differing space exploration goals. Lastly, at some future date NASA will need to decommission and deorbit the ISS either in response to an emergency or at the end of its useful life. However, the Agency currently does not have the capability to ensure the ISS will reenter the Earth's atmosphere and land in a targeted location in the South Pacific Ocean.

Transition to Private Operation

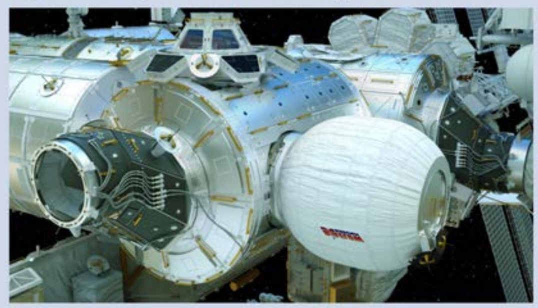
NASA's current plan for the ISS past 2024 is to transition responsibility for operating the Station – in whole or in part – to a commercial entity. NASA would then become one of many public and private users of the low Earth orbit platform. The President's FY 2019 budget request proposes ending direct Federal funding to the ISS in 2025 and would provide $150 million in FY 2019 to develop programs to support development of new commercial low Earth orbit platforms and capabilities. NASA's high-level plans to transition the Station to commercial operation by 2025 are outlined in its ISS Transition Report submitted to Congress in March 2018.[40] The Agency expects such a transition to offset some of NASA's substantial annual investment in ISS operations while providing more cost-effective Station operations through increased private sector investment, thereby spurring greater commercial development of low Earth orbit. However, the Agency is in the very early stages of implementing its ISS commercialization plan and, in our judgement, the likelihood NASA will be able to privatize significant portions of the ISS on the timetable outlined in its Transition Report is highly unlikely.

One of NASA's long-standing goals is to use the Station to spur commercial development and commercial operations in space. To date, NASA has taken several initial steps to increase commercialization of the ISS and low Earth orbit. For example, to stimulate non-NASA activity aboard

[40] International Space Station Transition Report.

the Station, CASIS, established in 2011, seeks to facilitate and encourage commercial companies, academia, and other Government and non-Government actors to use the ISS for their individual research or commercial purposes. In addition, NASA uses commercial partners Orbital ATK and SpaceX to deliver cargo to the ISS, and is working with commercial partners Boeing and SpaceX to transport astronauts to the ISS in 2019.[41] These activities represent NASA's most significant investment in the commercialization of low Earth orbit, given that cargo and crew transportation account for approximately $1.7 billion or roughly 50 percent of the Station's annual costs. In addition, in April 2016 NASA deployed the BEAM – an expandable habitation module developed by the Bigelow Corporation – for an initial two-year baseline period, and later extended by another three years with the possibility of two one-year extensions, as a test-bed for new technology demonstrations and on-orbit stowage. Long-term testing of BEAM is expected to provide NASA valuable performance data on microbial growth, Micrometeoroid and Orbital Debris (MMOD), radiation, and the structural integrity of an expandable soft-goods module. Moreover, NASA's partnership with Bigelow enables the company to demonstrate its technology for future commercial applications in low Earth orbit. Lastly, NASA has also spurred commercial participation in operations and maintenance of the Station through arrangements such as Johnson Space Center's Research, Engineering, and Mission Integrated Services contract, which transitioned payload integration to commercial operators.

Bigelow Expandable Activity Module



Source: NASA.

NASA has also engaged private industry directly regarding potential future commercialization of the ISS. For example, in July 2016 NASA issued a Request for Information seeking industry ideas to stimulate economic development through the use of unique ISS capabilities, such as unused common berthing mechanism attachment ports – the mechanical attachment system used to mate and de-mate ISS modules.[42] In August 2017, NASA hosted an ISS Stakeholder Workshop to engage interested parties regarding NASA's plans for the future of the ISS. The discussions focused on the supporting infrastructure that NASA would need to provide for commercial modules to connect to the ISS. The dialogue between NASA and potential stakeholders also focused less on a specific end-date for the ISS and more about a sequence of ISS services and elements that could transition to the commercial sector. One high-level takeaway voiced by the private space sector was that if it had to assume all the costs for launch services, continued commercial presence in low Earth orbit would not be an affordable option given the expense. Commercial users indicated that NASA needs to do more to encourage public-private partnerships by defining these relationships and specifying in greater detail the future role of the Government to help reduce uncertainty. In May 2018, NASA released a Research Announcement soliciting industry concepts, business plans, and viability studies for development of commercial platforms in low Earth orbit, as well as industry input on the role the Federal Government should play in the commercialization of low Earth orbit.[43]

[41] In the early 2020s, Sierra Nevada will join SpaceX and Orbital ATK as an ISS commercial resupply contractor.

[42] Solicitation Number: NNJ16ZBG006L, "Advancing Economic Development in Low Earth Orbit via Commercial Use of Limited Availability, Unique International Space Station Capabilities," July 1, 2016.

[43] Solicitation Number: 80JSC018LEOCOM, "Study for Commercialization of Low Earth Orbit," May 17, 2018.

Despite the initial steps NASA has taken to increase commercialization of low Earth orbit, a great deal of uncertainty remains regarding exactly what privatization of the ISS would look like. In its ISS Transition Report, NASA outlined a range of options, including transitioning ISS operations to private industry, augmenting the Station with privately developed modules, combining portions of the current platform with a new private platform, or deploying an entirely new platform and deorbiting the ISS. NASA is also assessing whether its long-term research requirements, while similar to those of the current ISS Program, could be met with platforms or modules that do not require a vehicle as complex and expensive as the ISS. Although NASA has begun to solicit industry input regarding the future of the ISS and plans to coordinate with the Departments of Commerce and Transportation on these efforts, detailed plans remain in the early stages of development.[44]

Based on our audit work, we question the viability of NASA's plans as outlined in its ISS Transition Report, particularly with regard to the feasibility of fostering increased commercial activity in low Earth orbit on the timetable proposed. Specifically, we question whether a sufficient business case exists under which private companies will be able to develop a self-sustaining and profit-making business independent of significant Federal funding. In particular, it is unlikely that a private entity or entities would assume the Station's annual operating costs, currently projected at $1.2 billion in 2024. Such a business case requires robust demand for commercial market activities in low Earth orbit, a scenario NASA admits would require expansion beyond the more traditional microgravity research and applications into broad sectors of the economy such as space tourism, satellite servicing, manufacturing of goods, and research and development, all of which have yet to materialize. Unless such demand expands markedly, future private low Earth orbit platforms likely will not be viable without significant ongoing Government support.

In its ISS Transition Report, NASA includes several overly optimistic assumptions related to revenues and costs of operating a future private low Earth orbit platform that call into question the validity of the analysis. Specifically, NASA's ISS Transition Report describes a 2018 review performed by the Science and Technology Policy Institute, a group that performs science and technology analysis for the White House Office of Science and Technology Policy, to determine whether a private space station could generate sufficient revenues to cover its operations and capital costs.[45] The review identifies revenue-generating activities such as support of the satellite sector and space-based manufacturing and included "high" and "low" estimates of revenues that could be generated by these activities. The review projects annualized revenues from a low of about $460 million to a high of roughly $1.2 billion. However, over half of the low estimate and more than a third of the high estimate is attributed to the potential for "manufacturing exotic optical fibers," a manufacturing process that is currently being studied on the ISS.

The analysis also includes unrealistic cost assumptions for launching astronauts and cargo. For example, the Science and Technology Policy Institute report assumes the cost of launching one astronaut in 2025 at about $20 million. However, the most recent cost for a single seat on Russia's Soyuz spacecraft was roughly $81 million and NASA estimated that it would pay its commercial providers SpaceX and Boeing approximately $58 million once their vehicles become operational in late 2019.[46] In addition, the Science and Technology Policy Institute report assumes that cargo transportation will cost about

[44] NASA is working with the Departments of Commerce and Transportation on a strategy to further enable cooperation with international and private industry partners to develop infrastructure and policies to spur economic growth in space.

[45] Science and Technology Policy Institute, "Market Analysis of a Privately Owned and Operated Space Station," February 2018.

[46] SpaceX and Boeing costs represent the average price-per-seat when the contract was originally awarded in 2015. NASA expects this cost to increase by the time of the companies' first crewed flights.

$20,000 per kilogram, whereas NASA is currently paying approximately $63,000 per kilogram to SpaceX and Orbital ATK. The analysis ultimately concludes that the profitability of a commercial platform like the ISS in low Earth orbit is questionable and will be highly dependent upon generating sufficient revenue from commercial activities and keeping operation costs low. However, the report noted that venture capitalists interviewed for the analysis said they would have little interest in financing a space station until projected revenues materialize.

Lastly, the scant commercial interest shown in the Station over nearly 20 years of operation gives us pause about the Agency's current timetable. This concern is illustrated by the Agency's limited success in stimulating non-NASA activity aboard the Station through CASIS, whose efforts we recently reported as falling short of expectations.[47] Apart from these challenges, the amount of cost savings NASA may realize may be less than expected given that significant expenditures – particularly crew and cargo transportation and civil servant costs – will likely continue even if many of the Agency's low Earth orbit activities transition to a privatized ISS or another commercial platform.

Extension and Continued Operations

An alternative to ending direct Federal funding of the ISS in 2025 is extending its operations beyond 2024. NASA originally targeted the Station's service life for approximately 15 years from the time its first elements were placed into orbit until its originally scheduled end of mission in 2015. Several elements such as Harmony and Tranquility were launched later in the assembly sequence and were not yet built when the first elements were placed into orbit in 1998. This meant that some modules were already nearing the end of their design lives when ISS assembly was completed in 2011. Since that time, NASA extended the Station's original service life on two occasions: the first when ISS construction was nearing completion in 2011. Under the NASA Authorization Act of 2010, the ISS mission was extended until 2020 in order to continue research and maximize NASA's return on its investment.[48] For that extension, NASA and its international partners certified that the Station's structure and hardware were sufficient to continue operations until at least 2020. The second extension occurred when the President approved a continuation of ISS operations until 2024, and the extension was subsequently included in the U.S. Commercial Space Launch Competitiveness Act.[49] In addition, the NASA Transition Authorization Act of 2017 directs the Agency to evaluate the feasibility of extending the Station's service life through at least 2028.[50] As of June 2017, Boeing had certified all major U.S. structural ISS elements for life extension to 2028 with the exception of an external stowage platform and six truss segments and their various appendages, a review it expects to complete in 2019. Critical operational capabilities such as electrical power, environmental control and life support, and thermal control have also been assessed and cleared through 2028.

[47] IG-18-010.

[48] Pub. L. No. 111-267.

[49] U.S. Commercial Space Launch Competitiveness Act, Pub. L. No. 114-90 (2015).

[50] Pub. L. No. 115-10.

Operation of the ISS Past 2024 Will Require Continued Significant Funding

One challenge to continuing ISS operations past 2024 is the significant funding required to operate and maintain the Station. Congress directed the Agency in the NASA Transition Authorization Act of 2017 to include in its ISS Transition Report "the impact on deep space exploration capabilities, including a crewed mission to Mars in the 2030s, if the preferred service life of the ISS is extended beyond 2024 and NASA maintains a flat budget profile." Despite this directive, the ISS Transition Report is silent on this issue. Nonetheless, in previous work we have found that any extension of the ISS's service life beyond 2024 will continue to require $3-$4 billion or about half of NASA's annual human spaceflight budget unless the Agency receives a marked increase in funding or can dramatically reduce ISS operations and maintenance costs. As a result, NASA managers will face significant challenges operating the ISS under its current model while attempting to fund NASA's other potential space exploration initiatives such as the Lunar Orbital Platform-Gateway, a lunar orbit/landing, and preparations for a crewed Mars mission.

In December 2017, the President signed Space Policy Directive-1, which directs the United States to "lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."[51] This Directive added lunar missions to the destinations for NASA's human exploration missions. Previously, the Agency had been planning for missions focused on sending astronauts to Mars and its vicinity.

A decision to extend the ISS without significant funding increases for NASA or sizable reductions in ISS operations and transportation costs likely will have a significant impact on NASA's ability and timetable to implement Space Policy Directive-1. We previously reported on a feasibility study conducted by NASA's Jet Propulsion Laboratory to estimate costs for a crewed landing on the Martian moon Phobos in 2033, a 1-month Mars surface stay in 2037, and 1-year surface stays in 2041 and 2046.[52] We found that, assuming funding for NASA's human exploration program remains constant, a continuation of ISS funding through 2028 will require either increased funding in the 2020s to develop exploration systems needed for Mars missions or will require the Agency to push out the timeline for its Mars exploration plans. In the same audit, we reported on a high-level feasibility study by NASA's Office of the Chief Financial Officer that showed a 4-year extension of the ISS to 2028 could push out the schedule for NASA's Mars plans by at least 3 years. Figure 10 shows that extension of the ISS from 2024 to 2028 would continue to require a significant portion of NASA's Space Exploration and Operations funding.

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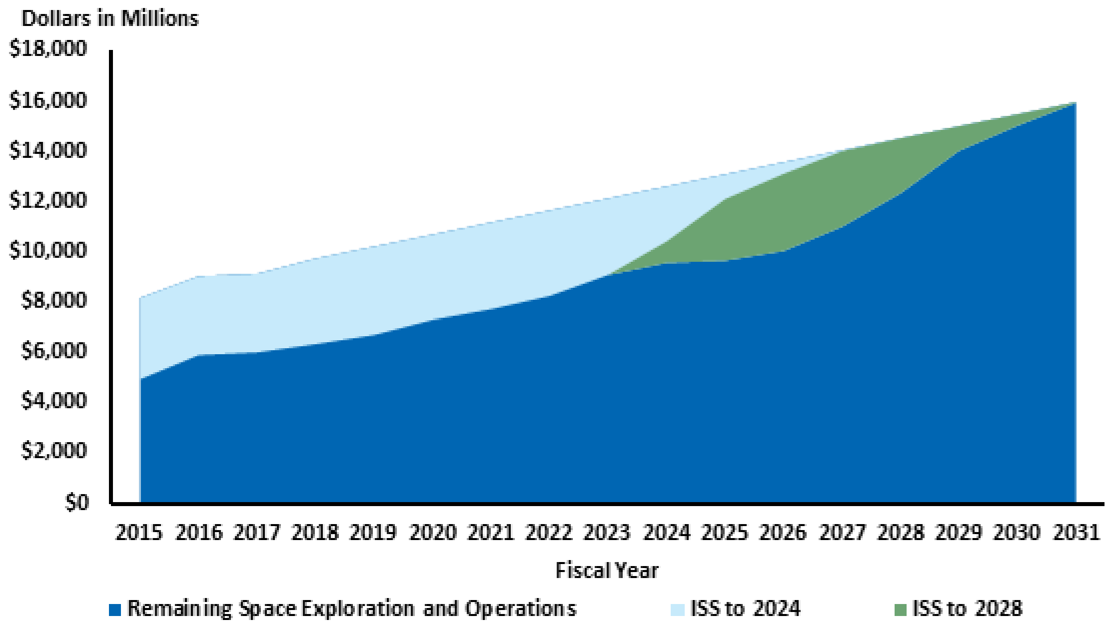
[51] White House, "Presidential Memorandum on Reinvigorating America's Human Space Exploration Program," December 11, 2017.

[52] IG 17-017.

Figure 10: ISS Funding Commitment For Extension to 2028 Assuming Constant Budget



Source: NASA OIG Analysis of NASA budget information.

Note: Remaining Space Exploration and Operations budget includes funding for the Space Launch System, Orion Multi-Purpose Crew Vehicle, Ground Support and Development, and other activities related to human spaceflight. ISS to 2024 figures are based on the 2019 President's Budget request, which proposes terminating direct funding to the ISS by 2025 while the ISS to 2028 figures are based on program manager budget recommendations planning for the ISS end of life in 2028.

However, NASA officials cautioned that even if the Agency ceases ISS operations by 2025, it is unlikely that much of the funding currently devoted to the ISS Program would become available for other activities. Specifically, even with termination of most Station activities, NASA would still be required to pay for any remaining Agency activities in low Earth orbit including any crew and cargo transportation services – projected to cost $1.8 billion in 2024. Further, NASA officials stated that significant funding would be required even after 2024 to maintain offices and infrastructure that are currently funded by the ISS Program but would likely be needed by future exploration programs. For example, in 2017 the ISS Program provided approximately $251 million in funding for the Flight Operations Directorate, which currently provides astronaut crew training as well as overall planning, directing, and managing of human spaceflight missions, but is expected to support future exploration missions beyond low Earth orbit.

NASA has worked over the past 10 years to reduce costs of supporting the ISS, particularly crew and cargo services – the Program's most expensive element. At the start of the ISS Program, transportation to the ISS (via the Space Shuttle) averaged $1.4 billion per year, a cost that was not counted as part of the ISS budget.[53] Since the Shuttle's retirement in 2011, the ISS Program has spent about $1 billion of its average $3 billion annual budget on transportation for crew and cargo. In addition, NASA officials point to more than $170 million annually they have saved since 2007 through de-scoping, renegotiating, and combining contracts. For example, NASA renegotiated the Program's largest contract for engineering

[53] In the years immediately prior to the Space Shuttle's retirement, NASA flew an average 4 Space Shuttle flights per year with each mission carrying up to 8 passengers and 25 tons of cargo, almost tripling the crew capabilities of the Soyuz and almost seven times more than the cargo capabilities of the SpaceX Dragon.

support with Boeing in 2010, reducing requirements and saving an estimated $67 million per year. In addition, by combining its mission support, program integration, and infrastructure operations contracts, NASA estimates it has saved on average $59 million per year since 2013. NASA also awarded a new contract in 2015 to support spaceflight operations, thereby reducing costs by an average $46 million per year. While these steps represent significant cost reductions, as shown in Table 3, the ISS Program is expected to continue to cost the Agency $3 – $4 billion per year until its retirement.

Table 3: ISS Annual Costs

Account	Current Average	Projected 2024
Operations and Maintenance	$1.3 billion	$1.2 billion
Crew and Cargo Transportation	$1.7 billion	$1.8 billion
Multi-User Systems and Support[a]	$0.3 billion	$0.4 billion
National Laboratory (CASIS)	$15 million	$15 million
Total[b]	**$3.4 billion**	**$3.4 billion**

Source: NASA.

[a] Multi-User Systems and Support includes costs for payload integration.
[b] Totals do not sum exactly due to rounding.

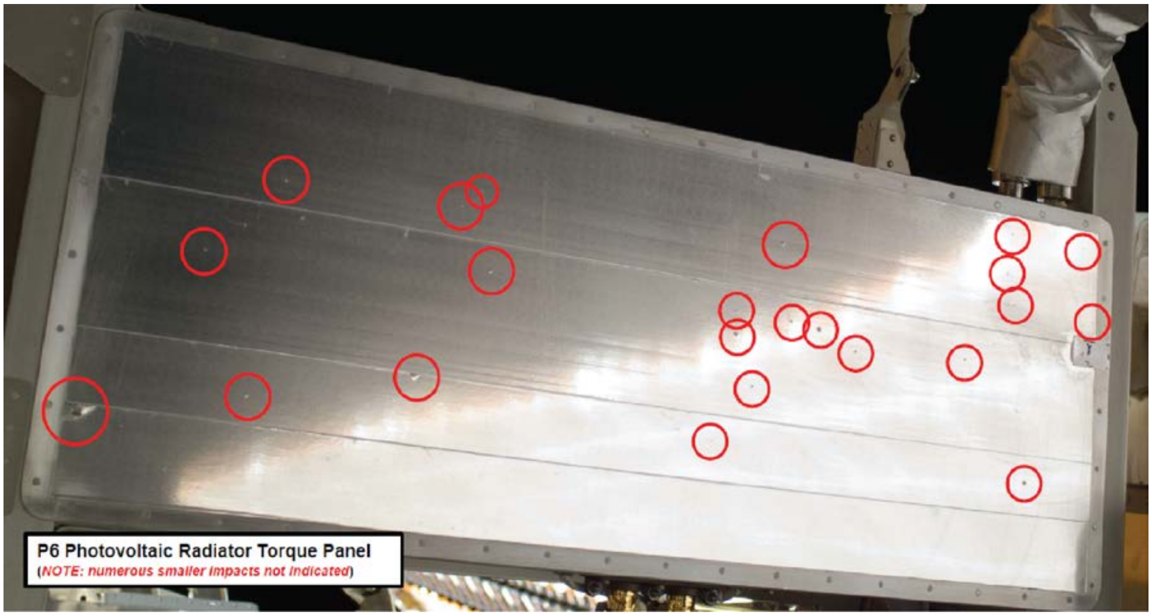
Managing Risks of Hardware Failures

By 2028, the original elements of the Station will be 30 years old, and will have operated for 3 decades in a harsh microgravity environment that creates adverse impacts on hardware due to ionizing radiation, extreme temperature changes, and the hazards of MMOD. While many systems have been replaced or upgraded and the Agency has not identified any issues that would preclude extending ISS operations through 2028, the risk of MMOD strikes, equipment failures, hardware degradation, and technological obsolescence persists with continued operations beyond 2024.

According to NASA, MMOD strikes are the primary threat to the Station's integrity because a direct strike can cause catastrophic and irreversible depressurization or other significant damage with immediate life-threatening risks to astronauts inside the ISS. Millions of man-made and naturally occurring particles circle the Earth at velocities averaging 22,000 miles per hour. The U.S. Government is also tracking more than 500,000 pieces of man-made debris, which consists of nonfunctional spacecraft, abandoned launch vehicle stages, and other mission-related debris that orbit the Earth. As the amount of MMOD increases, so does the risk to the ISS. Specifically, NASA found that the aggregate risk from MMOD collision during an extravehicular activity has doubled since the Station's first extension in 2011. In addition, the risk of MMOD penetrating the Station is 33 percent with a 6 percent chance of a catastrophic result over the next 10 years.[54] Although the exterior of the ISS is protected from MMOD strikes by several hundred aluminum and ceramic cloth and Kevlar fabric shields on its front and sides, the aft and nadir (Earth-facing) sides as well as any visiting vehicles are less protected and at greater risk. To gauge this ongoing risk, NASA routinely conducts external surveys of the ISS using video cameras and during astronaut spacewalks (see Figure 11). In addition, NASA has improved the Station's capability to maneuver to avoid objects large enough to be tracked, reducing the amount of notice necessary to maneuver from over a day down to a few hours.

[54] A catastrophic hazard refers to any condition that may cause a disabling or fatal personnel injury, or cause loss of the ISS.

Figure 11: MMOD Impact Damages Observed on ISS Radiator Panel (November 2012)



Source: NASA.

U.S. and Russian structural and technical feasibility assessments have also pointed to the risk of equipment failure with continued ISS operations beyond 2024. Although NASA reported it has observed a decline in the Station's overall failure trends, individual failure rates can be difficult to measure and the risk of unanticipated failures will always have the potential to disrupt planned operations. ISS equipment failure rates depend on various factors such as design complexity, component age, operating condition, and severity of environmental stress factors. Given that on-orbit diagnosis of operating hardware is inherently limited, NASA performs extensive analyses to evaluate the likelihood and impact of potential failures and refines these failure predictions annually using actual on-orbit hardware performance data. Despite these measures, the Station also faces unanticipated failures that in the past have resulted in major parts and subsystems failing sooner than anticipated, forcing the Agency to revise its plans about upgrades and replacements. For example, a few days after an extravehicular activity in May 2017, a computer critical to manipulating the Station's solar arrays failed. This unanticipated failure resulted in an unplanned spacewalk to replace the malfunctioning unit, increasing risks to the crew and diverting them from planned research. In addition, several components of the Station's environmental control and life support system have experienced unanticipated failure or degraded performance resulting in significantly reduced component lifetimes.

Unanticipated failures can also have significant implications on NASA's ability to repair or replace components. The Station's maintenance protocols depend on the availability of Orbital Replacement Units (ORU) or subsystems that can be readily replaced when the item either fails or passes its design life. Maintaining a stock of these replacement units on board the ISS saves time when repairs are needed, but also requires the transportation and stocking of more units than are likely to be used, since ORUs must be available in the event of a failure. Transportation of relatively large ORUs such as radiators and truss assemblies to the Station has become more difficult since retirement of the Space Shuttle due to the payload hatch size on current cargo delivery vehicles.[55]

[55] Radiators transfer heat from the Station to space to achieve thermal control and maintain acceptable temperatures. Truss assemblies provide attachment points for solar arrays, thermal control radiators, and external payloads.

Component degradation, manufacturers no longer in business, and changes in technologies over the past 20 years on a one-of-a-kind on-orbit spacecraft like the ISS also present the risk of hardware becoming technologically obsolete. This can result in additional challenges to support ISS operations which, according to ISS officials, often necessitate costly development or redesign of new hardware. For instance, the U.S.-owned, Russian-operated Functional Cargo Block – a 55,000-pound module that stores propellant needed for attitude control and deorbit maneuvers – is critical for propulsion of the ISS. The Functional Cargo Block has seen an increase in issues with old and dysfunctional parts that require replacement, such as in the summer of 2017 when the Compressor System Avionics Unit failed and affected propellant refueling operations for nearly two months. In addition, we previously reported that the Station's solar arrays are degrading faster than originally predicted.[56] Given the steady decline in power generation of the arrays and the expected increase in future demand, NASA engineers had to develop solutions for what happens when the current arrays cannot satisfy requirements and need to be replaced with a more advanced system. NASA plans to supplement current ISS power using a new Roll Out Solar Array that will be launched in a stowed configuration for transport to the ISS in existing delivery vehicles. NASA has also developed other system upgrades that are necessary to operate the ISS beyond 2020, including lithium ion batteries, oxygen and nitrogen resupply tanks, communication systems, and docking systems.

Continued Operation of the ISS Past 2024 Requires Support of International Partners

Any extension of ISS operations past 2024 would also require continued support from NASA's international partners, whose continued participation hinges on issues that range from the state of international politics to differing space exploration goals. The United States and its partners are committed to operating the ISS through 2024. However, continuing ISS operations beyond this date will require each partner to navigate their respective governmental bureaucracies for approval to extend existing agreements.

Although it is too early to determine if NASA's international partners would continue their support for the ISS beyond 2024, future participation by the current ISS coalition of Roscosmos, ESA, CSA, and JAXA faces a variety of significant challenges. For example, Russia's future involvement with the ISS is murky given the current state of relations between the U.S. and Russia. The Iran, North Korea, and Syria Non-Proliferation Act of 2000 (Non-Proliferation Act) bans U.S. payments to Russia in connection with the ISS unless the President determines that Russia is taking steps to prevent foreign transfers of weapons of mass destruction, missile technology, and advanced conventional weapons technology to Iran. The current exemption to the Non-Proliferation Act must be extended prior to December 31, 2020, in order for NASA to continue paying Russia for propellant and U.S. crewmember travel to the Station on the Russian Soyuz vehicle.

[56] NASA OIG, "Extending the Operational Life of the International Space Station Until 2024" (IG-14-031, September 18, 2014).

Russia's continued role is critical to sustaining Station operations due to its provision of the Station's propulsion system, propellant, and crew transportation. The propulsion system is needed to periodically reboost the Station into a higher orbit, conduct MMOD avoidance maneuvers, and eventually ensure a controlled deorbit of the Station.[57] In addition, with the retirement of ESA's Automated Transfer Vehicle in 2015, Russian Progress vehicles became the only vehicles capable of resupplying propellants needed for these maneuvers.[58] Lastly, Russia is the only partner currently capable of providing crew transport to and from the ISS.

Continued participation by NASA's other international partners beyond 2024 also faces challenges by partners prioritizing activities with NASA and other space agencies on exploration missions beyond the ISS. For example, ESA has announced its intent to partner with NASA on the Lunar Orbital Platform-Gateway and other lunar activities. In addition, ESA and the China Manned Space Agency entered into an agreement in 2015 with the goal of flying European astronauts on the Chinese space station planned for operation in 2022. Furthermore, in May 2018, the United Nations and China Manned Space Agency issued an announcement to United Nations member states providing an opportunity to conduct scientific experiments on board the future Chinese space station. Additionally, in November 2016, JAXA and the Indian Space Research Organization signed a Memorandum of Understanding to promote collaboration in the space field. These and other collaborations could impact partners' interest in and ability to extend ISS financial and operational arrangements beyond 2024.

Decommission and Deorbit

NASA ultimately will need to deorbit the Station at the end of its useful service life (nominal deorbit) or sooner in the event of an emergency (contingency deorbit). Ideally, deorbit will occur via a controlled, destructive reentry into the Earth's atmosphere. Prior to initiation of the deorbit sequence, all crew aboard the ISS would return to Earth and the deorbit would be accomplished by computer systems executed by Mission Control-Moscow.[59] During descent through the Earth's atmosphere, the ISS would burn, break up, and vaporize into fragments. NASA estimates that 16 percent of the ISS would likely survive the thermal stresses of reentry and fall to Earth. The total weight of the debris is projected to be between 53,500 and 173,250 pounds.

Nominal Deorbit

NASA estimates a controlled reentry or nominal deorbit of the ISS will take up to 2 years to execute and cost approximately $950 million. Controlled entry normally is achieved by using more propellant than for routine operations to position the spacecraft to enter the atmosphere at a steep flight path to confine the debris field. If successful, the vehicle will enter the atmosphere at a more precise latitude and longitude in order to position the debris footprint over an uninhabited region, preferably in the ocean. All of NASA's controlled ISS deorbit plans require the Station to be able to control its attitude using its thrusters. Once the burn sequence begins, the deorbit maneuver relies on software to automatically execute propulsion system and propellant transfer procedures. The Agency's target

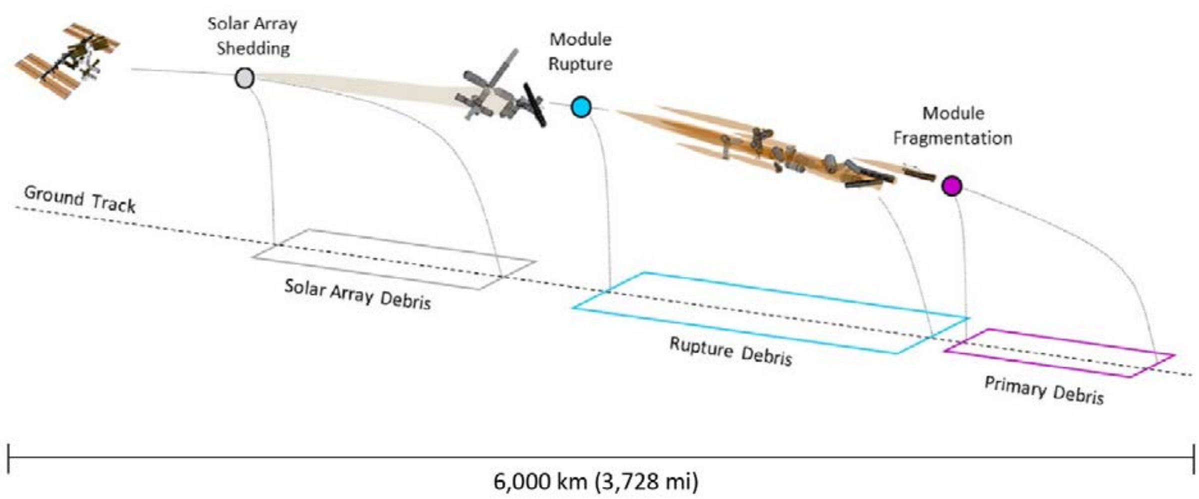
[57] As a result of atmospheric drag, the Station is constantly slowed and must be boosted periodically to maintain its altitude.

[58] Beginning in late 2021, NASA analysis estimates ISS propellant delivery requirements may exceed the delivery capability of Russia's Progress vehicles. As a result, NASA is investigating the feasibility of using Orbital ATK's Cygnus vehicle to provide reboost capability with a demonstration on the ISS as early as July 2018.

[59] Mission Control-Moscow operates the ISS Russian segment that houses many of the Station's propulsion and avionics systems necessary for deorbit.

location for full deorbit of all ISS debris is a 6,000 km or less footprint in an uninhabited region of the South Pacific Ocean (see Figure 12). Environmental impacts are projected to be small as any toxic liquids or materials are expected to burn up during the reentry process. Some fragments of the returning vehicle, however, could have sufficient kinetic energy to cause damage to people and structures, including ships.

Figure 12: ISS Nominal Deorbit Debris Field



Source: NASA.

Given the technical and operational complexities involved with deorbiting the largest man-made structure ever built in space, NASA has not finished the necessary tasks to execute a nominal deorbit of the Station. Upon completion of the ISS in 2011, the Aerospace Safety Advisory Panel began reporting that it is a "foregone conclusion" that the ISS will need to be safely deorbited at some point in the future and that neither NASA nor its international partners had a comprehensive plan for how to do so.[60] In January 2017, NASA completed a draft plan to address various nominal and contingency deorbit scenarios; however, this plan has not been finalized and is pending review by Roscosmos. In the meantime, NASA engineers continue to work on the technical details of various deorbit scenarios, including:

- Attitude control analyses to determine how much propellant should be reserved for deorbit operations.
- Low altitude determination study to verify if ISS sensors will be able to accurately identify the ISS's altitude during deorbit.
- Final burn controllability assessment to determine how much propellant the ISS will need for the final series of deorbit burns.
- ISS survivability at vacuum analysis to determine what systems need to remain functional to accomplish a safe deorbit.

[60] The Aerospace Safety Advisory Panel was established under Section 6 of the National Aeronautics and Space Administration Authorization Act of 1968, as amended (51 U.S.C. § 31101). The Panel provides advice and makes recommendations to the NASA Administrator on matters related to safety.

- Flight control procedures that define how NASA would interface with Russia during deorbit.
- Analysis of MMOD strikes that could push the Station out of its planned altitude to determine how much propellant should be retained to regain attitude control.

We also note that Congress directed the Agency, in the NASA Transition Authorization Act of 2017, to identify the necessary actions and estimate the costs to deorbit the ISS once it reached the end of its service life. However, the ISS Transition Report issued in March 2018 did not explicitly address these issues.

Contingency Deorbit

In the case of an emergency, NASA does not have the ability to ensure a targeted reentry of the ISS due to a major MMOD strike or other extreme events. NASA officials informed us that an emergency deorbit of the ISS would take approximately six months and would use all propellant from onboard the ISS and from any visiting vehicles. If possible, the planned reentry profile would be similar to that of a controlled deorbit maneuver. While for many emergency situations the Station's debris footprint size and shape would remain the same as a controlled deorbit, catastrophic explosions on board the ISS or collisions could result in substantial dispersion of ISS components before reentry, resulting in the spread of reentry debris over a larger area, possibly including land masses. For planning purposes, NASA is working with its international partners to study debris field areas ranging from 6,000 to 12,000 km or roughly the distance from Anchorage, Alaska, to Orlando, Florida; or from Los Angeles, California, to Sydney, Australia, respectively.

As part of its emergency planning, NASA has assessed the major ISS anomalies that could lead to evacuation of ISS crew and estimates the mean probability of three major contingencies over a 6-month period: MMOD strike causing depressurization (1 in 120), fire (1 in 46,000), or toxic release of ammonia (1 in 5.6 million). In the event of a significant MMOD strike, NASA engineers envision a high likelihood of irreversible depressurization of the Station. In this scenario, the ISS would need to be safely deorbited as soon as practical, since many of the avionics systems necessary to deorbit the Station are located in the pressurized Russian segment and are only estimated to remain operational for approximately 180 days after sudden depressurization. For these and other reasons, the entire crew is expected to evacuate the ISS immediately following any MMOD strike event.

For several years, NASA has been developing the software and hardware changes necessary to enable a controlled deorbit of the Station; however, the Agency does not currently have the capability to ensure a targeted deorbit of the ISS to a specific safe location in the event of an emergency. Additionally, deorbiting the ISS within 180 days in a contingency scenario will likely require more propellant than the ISS currently has the capability to support until modifications can be made to dock multiple Russian Progress vehicles with the ISS at vacuum.[61] A common practice at the time the ISS was built was to rely on the low probability of orbital debris impacting a populated area to protect those on Earth. Since that time, international norms and treaties have made this approach unacceptable. NASA's deorbit work currently consists of a series of analyses, software updates, and operations procedures. However, until the required adaptations to the Station hardware are complete, the ISS remains susceptible to a premature deorbit in the event of an unrecoverable emergency requiring permanent evacuation of the

[61] "At vacuum" refers to any ISS module pressure so low that the crew has to evacuate the ISS or is no longer able to perform the procedures necessary to enable a Progress departure or docking.

crew. Until these actions are completed, the capability to safely deorbit the ISS in the event of an emergency remains in doubt. Among the remaining mitigation factors that need to be developed are:

- Modifications to Station hardware to meet the requirement of docking multiple Progress vehicles at vacuum.
- Software updates to enable simultaneous firing of multiple Progress and Service Module engines for the final deorbit burn.
- Completion of analysis and development of software updates and reconfiguration procedures for the U.S.-owned, Russian-operated Functional Cargo Block propellants.
- Completion of ongoing work to develop the ISS deorbit plan, including determining the propellant costs for attitude control at low altitudes since deorbiting the ISS within 180 days in a contingency scenario will likely require more propellant than the ISS currently has the capability to support until modifications can be made to dock multiple Progress vehicles.
- Completion of ongoing work to ensure the automatic execution of propellant transfer.

Furthermore, NASA indicates ISS propellant delivery requirements may exceed the currently planned delivery schedule of the Russian Progress vehicles beginning in late 2021. Without an alternative, NASA runs the risk of having insufficient propellant to ensure a controlled deorbit of the Station in the event of an emergency.

CONCLUSION

During its nearly 20 years on-orbit, the ISS has served as a research platform in low Earth orbit that has assisted NASA in advancing its deep space ambitions by conducting human health experiments and technology demonstrations. But such celestial research comes at a steep cost: each year the Station remains operational costs NASA roughly half of the Agency's annual human spaceflight budget – an outlay that may limit funding for development of systems needed to visit the Moon and other destinations beyond low Earth orbit.

Each of the options for transitioning or retiring the ISS present NASA with distinct challenges and associated costs that must be balanced. The President's FY 2019 budget request proposes ending direct Federal funding of the ISS in 2025, at which point NASA plans to transition the Station to commercial operations. While this proposal faces a steep uphill climb for approval in Congress, in our judgment NASA's current plan to transition the Station to commercial operation by 2025 is fraught with challenges and uncertainty. Chief among these is whether commercial activities in low Earth orbit will be sufficiently established by that time and whether NASA is able to reduce the cost of operating the ISS enough to make business sense for commercial entities.

Like the Agency's current plan of transitioning ISS operations to commercial operations, NASA's other option for the ISS – extension past 2024 under the current operating model or deorbit – also faces significant challenges. Any extension of the ISS past 2024 will require continued, significant funding to operate and maintain the Station, acceptance of increased levels of risk stemming from its aging hardware, and assurances about the continued support of international partners. Should NASA choose to decommission and deorbit the ISS, we are concerned that the Agency has not finalized the necessary capabilities to safely bring the Station back to Earth.

Regardless of NASA's choice, the Agency must take advantage of whatever time remains on the Station to maximize its potential. We are encouraged that the Agency has continued to perform well against metrics that track utilization aboard the Station. Nonetheless, we are concerned that several human health risks and technology demonstrations will not be completed by 2024, possibly committing the Agency to extending the costly operations of the Station, relying on alternate testing methods, or accepting higher levels of risk. NASA's ability to complete these tasks could be further challenged by increasing demands of the crew and research space as well as any potential launch delays or failures. In our judgment, clearly articulated contingency plans for each human health risk and technology demonstration not scheduled to be mitigated prior to 2024 would enable internal and external stakeholders to make more informed decisions regarding the future operation of the Station and completion of critical research.

RECOMMENDATIONS, MANAGEMENT'S RESPONSE, AND OUR EVALUATION

To ensure NASA is positioned to complete or develop viable alternatives to critical human health research and technology demonstration projects, and to provide for a safe transition and disposition of the ISS, we made the following recommendations to the Associate Administrator for NASA's Human Exploration and Operations Mission Directorate:

1. To the extent practicable, establish plans for additional one-year missions to the ISS.
2. Ensure there is a contingency plan for each human health risk not scheduled to be mitigated prior to 2024, such as:
    a. Identification of alternate testing platforms,
    b. Impact of health risks for astronauts, and
    c. Impact to the mitigation schedule.
3. Ensure there is a contingency plan for each exploration-enabling technology demonstration not scheduled to be fully tested by 2024, such as:
    a. Identification of alternate testing platforms,
    b. Impact to technical risk of exploration systems, and
    c. Impact to the technology demonstration schedule.
4. Complete all end-of-mission critical systems and open work related to nominal and contingency deorbit operations.
5. Develop options for obtaining supplemental emergency deorbit propellant support from U.S. commercial vehicles.

We provided a draft of this report to NASA management who concurred with our recommendations and described planned corrective actions. We consider the proposed actions responsive for all five recommendations and will close them upon their verification and completion.

In its response, NASA management suggested our discussion of the likelihood the Agency will meet its proposed 2024 timetable for generating sufficient commercial interest in managing the ISS is premature and that studies NASA is pursuing this year with industry will inform the ability of the commercial market to take an active role in such low Earth orbit research activities. While we acknowledge that the Agency's planning efforts are in an early stage, we stand by our conclusions that it will be difficult for NASA to foster commercial interest in managing the Station or assuming its annual operating costs of $1.2 billion on the timetable proposed. Doing so would require a sufficient business case under which private companies would be able to develop a self-sustaining and profit-making business independent of significant Federal funding. To date, we found little evidence that private companies would be willing to take on such extraordinary costs.

Management's comments are reproduced in Appendix B. Technical comments provided by management have also been incorporated, as appropriate.

Major contributors to this report include Ridge Bowman, Space Operations Director; Michael Brant, Project Manager; David Balajthy; Alyssa Sieffert; and Dimitra Tsamis. Matt Ward provided editorial and graphics assistance.

If you have questions about this report or wish to comment on the quality or usefulness of this report, contact Laurence Hawkins, Audit Operations and Quality Assurance Director, at 202-358-1543 or laurence.b.hawkins@nasa.gov.

Paul K. Martin
Inspector General

Appendix A: Scope and Methodology

We performed this audit from April 2017 through June 2018 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives. Our overall audit objective was to assess NASA's progress in maximizing utilization of the ISS to accomplish its human exploration objectives and to evaluate the options and challenges associated with a transition to commercial operation, potential extension, and the Station's eventual retirement.

To gain an understanding of the ISS program, utilization, and challenges, we conducted interviews with Agency officials including the Director of the ISS Division, the ISS Program Manager, Office of International and Interagency Relations, Office of Safety and Mission Assurance, members of the Commercial Crew Program, a member of the NASA Advisory Council, and other ISS Program and Center officials. Our review was primarily conducted at Johnson Space Center and NASA Headquarters.

To conduct a comprehensive assessment of NASA's completion of ISS research tasks, we reviewed the ISS Technology Demonstration Fly-Off Plan, the Human Research Program's Integrated Path to Risk Reduction, and ISS utilization metrics including crew time, occupancy rate, and scientific investigations. To review the Agency's strategy for achieving its research goals, we reviewed the Agency's Consolidated Operations and Utilization Plan and the ISS Science Prioritization Desk Instruction.

In our evaluation of NASA's options and associated challenges with the Station's eventual retirement, we reviewed the Memoranda of Understanding between NASA and its international partners; congressional testimony and legislation impacting the ISS; and publicly available documents relating to commercial interest in the ISS. To assess the Agency's plans for deorbiting the ISS, we reviewed the ISS Deorbit Work Schedule and the ISS Program's draft Deorbit Strategy and Contingency Action Plan. To understand the technical and safety threats to the ISS vehicle, we reviewed various analyses, assessments, hazard reports, risk assessments, risk charts, and structural health and life extension reports. Additionally, we reviewed briefing presentations, conference and white papers, meeting minutes, and other documents from NASA's Electronic Document Management System and the NASA Technical Reports Server.

For our review of the steps taken by NASA to reduce ISS operating costs, we reviewed cost and contract data obtained from Business Objects and the Enhanced Procurement Data Warehouse procurement report system. Additional documents we reviewed included the results of the 2010 ISS Operations Cost Streamlining Tiger Team, the results of the Report by the ISS Management and Cost Evaluation Task Force to the NASA Advisory Council, Commercial Crew Development Space Act Agreements, and Commercial Resupply Services contracts.

Use of Computer-Processed Data

We relied on computer-processed data such as cost data obtained from Business Objects. We corroborated information with other sources where possible and performed audit steps to validate the accuracy of a limited amount of data contained in the databases, however, the data is only as accurate as that entered by the database personnel. The accuracy of the data did not affect our conclusions.

Review of Internal Controls

We reviewed and evaluated the internal controls associated with NASA's management of ISS utilization and end of mission planning. We identified no control weaknesses.

Prior Coverage

During the last 5 years, the NASA Office of Inspector General and the Government Accountability Office have issued 17 reports of significant relevance to the subject of this report. Unrestricted reports can be accessed at https://oig.nasa.gov/audits/reports/FY18/index.html and http://www.gao.gov, respectively.

NASA Office of Inspector General

Audit of Commercial Resupply Services to the International Space Station (IG-18-016, April 26, 2018)

NASA's Management of the Center for the Advancement of Science in Space (IG-18-010, January 11, 2018)

NASA's Management and Development of Spacesuits (IG-17-018, April 26, 2017)

NASA's Plans for Human Exploration Beyond Low Earth Orbit (IG-17-017, April 13, 2017)

NASA's Commercial Crew Program: Update on Development and Certification Efforts (IG-16-028, September 1, 2016)

NASA's Response to SpaceX's June 2015 Launch Failure: Impacts on Commercial Resupply of the International Space Station (IG-16-025, June 28, 2016)

NASA's International Partnerships: Capabilities, Benefits, and Challenges (IG-16-020, May 5, 2016)

NASA's Efforts to Manage Health and Human Performance Risks for Space Exploration (IG-16-003, October 29, 2015)

NASA's Response to Orbital's October 2014 Launch Failure: Impacts on Commercial Resupply of the International Space Station (IG-15-023, September 17, 2015)

Extending the Operational Life of the International Space Station Until 2024 (IG-14-031, September 18, 2014)

NASA's Management of the Commercial Crew Program (IG-14-001, November 13, 2013)

NASA's Efforts to Maximize Research on the International Space Station (IG-13-019, July 8, 2013)

Commercial Cargo: NASA's Management of Commercial Orbital Transportation Services and ISS Commercial Resupply Contracts (IG-13-016, June 13, 2013)

Government Accountability Office

NASA Commercial Crew Program: Continued Delays Pose Risks for Uninterrupted Access to the International Space Station (GAO-18-317T, January 17, 2018)

NASA Commercial Crew Program: Schedule Pressure Increases as Contractors Delay Key Events (GAO-17-137, February 16, 2017)

International Space Station: Measurable Performance Targets and Documentation Needed to Better Assess Management of National Laboratory (GAO-15-397, April 27, 2015)

International Space Station: Challenges to Increased Utilization May Affect Return on Investment (GAO-15-722T, July 10, 2015)

Appendix B: Management's Comments

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

JUL 25 2018

Reply to Attn of: Human Exploration and Operations Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Human Exploration and Operations Mission Directorate

SUBJECT: Agency Response to OIG Draft Report, "Audit of NASA's Management and Utilization of the International Space Station" (A-17-011-00)

NASA appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "Audit of NASA's Management and Utilization of the International Space Station" (A-17-011-00) dated June 22, 2018.

In the draft report, the OIG makes five recommendations to the Associate Administrator for Human Exploration and Operations intended to ensure NASA is positioned to complete or develop viable alternatives to critical human health research and technology demonstration projects and to provide for a safe transition and disposition of the International Space Station (ISS). The report also discusses concerns that the timeline for commercial activity might not be achievable, although there are no findings or recommendations associated with this discussion. NASA believes that this discussion is premature and the study activities that NASA is pursuing this year with industry will inform the ability of the commercial market to take an active role in low-Earth orbit. The data today does not fully support the discussion in the report.

Specifically, the OIG recommends the following:

To help improve the effectiveness of NASA's management and utilization of ISS, the OIG recommends the Associate Administrator for Human Exploration and Operations:

> **Recommendation 1:** To the extent practicable, establish plans for additional one-year missions to the ISS.
>
> **Management's Response:** Concur. NASA accepts an action to pursue planning studies to identify options for the implementation of additional one-year missions to the ISS leveraging United States Crew Vehicles, which could be leveraged to achieve additional long duration spaceflight participants and increase associated dataset sample size.

Estimated Completion Date: December 31, 2018.

Recommendation 2: Ensure there is a contingency plan for each human health risk not scheduled to be mitigated prior to 2024, such as: (1) identification of alternate testing platforms; (2) impact of health risks for astronauts, and (3) impact to the mitigation schedule.

Management's Response: Concur. Although the Path to Risk Reduction was developed with the end of ISS in mind, the Human Research Program (HRP) recognizes that there is some risk that research requiring the ISS may not be completed prior to the end of the ISS Program. HRP has concurrent investments in identifying appropriate ground analogs for Spaceflight Associated Neuro-Ocular Syndrome SANS and Immune, which are two of the risks requiring the long duration microgravity provided by the ISS. Recent results from ground-based research in a bed rest environment revealed a potential ground-based analog for SANS. Current investments in Antarctic research may identify a ground analog for space-flight induced immune changes. In some cases, risk reduction research requires access to microgravity that can also be provided during the Gateway Program, but in other cases, the long duration exposure to microgravity that is only provided by ISS will be required. These cases are currently under assessment and HRP is in the process of developing, documenting, and managing the programmatic risk to delivery of the human risk mitigation strategies as well as the schedule and residual risk associated with the inability to complete on ISS. In addition, NASA is currently developing its long-term low-Earth orbit requirements for research and technology development across the Human Exploration and Operations (HEO) Mission Directorate, Science Mission Directorate, and Space Technology Mission Directorate. This activity will continue in the near future.

Estimated Completion Date: The risk mitigation plans for those risks where long duration ISS is absolutely required, and HRP may be unable to complete the research prior to the end of ISS will be completed by November 30, 2018.

Recommendation 3: Ensure there is a contingency plan for each exploration-enabling technology demonstration not scheduled to be fully tested by 2024, such as: (a) identification of alternate testing platforms, (b) impact to technical risk of exploration systems, and (c) impact to the technology demonstration schedule.

Management's Response: Concur. ISS and the rest of the HEO Mission Directorate will coordinate to develop contingency plans for the items on the ISS Technology Demonstration Plan.

Estimated Completion Date: The contingency plans will be completed by November 30, 2018.

Recommendation 4: Complete all end-of-mission critical systems and open work related to nominal and contingency deorbit operations.

Management's Response: Concur. The ISS Program has developed Space Station Program 51066 "ISS Deorbit Strategy and Contingency Action Plan" in cooperation with our international partners to document the proposed ISS nominal and contingency deorbit strategy. This document outlines the remaining open work necessary to accomplish the desired nominal deorbit footprint.

Estimated Completion Date: December 31, 2020

Recommendation 5: Develop options for obtaining supplemental emergency deorbit propellant support from U.S. commercial vehicles.

Management's Response: Concur. NASA has partnered with Northrop Grumman to prove out the capability of a commercial visiting vehicle (VV) providing a reboost service to the ISS. A Detailed Test Objective (DTO) to reboost the ISS using the OA-9 Cygnus spacecraft is planned for mid-July. A VV berthed at Node 1 Nadir (N1N) has an ability to provide this reboost service since the ISS center of gravity is fairly close to the thrust vector of a VV berthed at N1N. Successfully accomplishing this DTO will prove that a VV can provide a reboost and, conversely, would also prove out the ability of a commercial VV to provide an emergency deboost. A deboost would simply require the ISS to yaw 180 degrees so that the thrust vector provides a retrograde burn as opposed to a posigradeburn.

Once the commercial VV reboost DTO is complete, the ISS Program plans to submit a Request For Information (RFI) to industry for a mission service that can provide a full reboost or deboost capability. The RFI will be initiated in late 2018/early 2019. Proposals will be developed for down selecting options in 2020.

Estimated Completion Date: December 31, 2020

Once again, thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Michelle Bascoe on (202) 358-1574.

William H Gerstenmaier

William H. Gerstenmaier

APPENDIX C: REPORT DISTRIBUTION

National Aeronautics and Space Administration

Administrator
Associate Administrator
Acting Deputy Associate Administrator
Acting Chief of Staff
Chief Health and Medical Officer
Associate Administrator, Human Exploration and Operations
Director, International Space Station
Program Manager, International Space Station

Non-NASA Organizations and Individuals

Office of Management and Budget
Deputy Associate Director, Energy and Space Programs Division

Government Accountability Office
Director, Office of Acquisition and Sourcing Management

Congressional Committees and Subcommittees, Chairman and Ranking Member

Senate Committee on Appropriations
Subcommittee on Commerce, Justice, Science, and Related Agencies

Senate Committee on Commerce, Science, and Transportation
Subcommittee on Space, Science, and Competitiveness

Senate Committee on Homeland Security and Governmental Affairs

House Committee on Appropriations
Subcommittee on Commerce, Justice, Science, and Related Agencies

House Committee on Oversight and Government Reform
Subcommittee on Government Operations

House Committee on Science, Space, and Technology
Subcommittee on Oversight
Subcommittee on Space

(Assignment No. A-17-011-00)