National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) Research and Utilization Plan for the International Space Station (ISS)

A Report to the Committee on Science of the United States House of Representatives and the Committee on Commerce, Science, and Transportation of the United States Senate

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Executive Summary

This Research and Utilization Plan presents the mission of the International Space Station (ISS), and describes the scientific investigations, strategic research, commercial opportunities, and technology developments to be accomplished. This plan was prepared in response to Congressional direction (Public Law No: 109-155) for a "research plan for NASA utilization of the ISS and the proposed final configuration of the ISS, including an identification of microgravity research that can be performed in ground-based facilities and then validated in space, and an assessment of the impact of having or not having a life science centrifuge aboard the ISS." It should be noted that this report does not address the plan for operating a segment of the ISS as a "national laboratory" (ref. section 507 of Public Law No: 109-155); that topic will be addressed in a separate report to Congress. Also, this report is not intended to address the comments and recommendations made by the National Research Council in their publication, *Review of NASA Plans for the International Space Station* (2006). Those items will be addressed in a separate response to the Council.

In January 2004, the announcement of the Vision for Space Exploration (VSE) focused the Agency on a bold new mission: implementing a sustained and affordable human and robotic program to explore the solar system.

The ISS mission objectives corresponding directly to these VSE objectives are as follows:

1. Research, Development, Test, and Evaluation of Biomedical Protocols for Human Health and Performance on Long-Duration Space Missions.
2. Research, Development, Test, and Evaluation of Systems Readiness for Long-Duration Space Missions.
3. Development, Demonstration, and Validation of Operational Practices and Procedures for Long-Duration Space Missions.

This Research and Utilization Plan provides a top-level description of the NASA approach to meet these objectives and fulfill our mission. A systematic approach, utilizing a combination of Government, academic, international, and industrial resources (both on Earth and in space) and a stable investment strategy are planned.

Completing assembly of the ISS by the end of the decade, including meeting the commitments to our international partners, is a first step in NASA's implementation of the VSE. NASA will use the Space Shuttle to complete the ISS assembly prior to its retirement in 2010. The final configuration will support a six-person crew beginning in 2009 with the delivery of additional crew quarters, galley, and waste management systems. NASA will also use the commercial sector and the flexibility in the partner agreements to provide supplies and crew transport to the ISS.

The ISS is NASA's long-duration flight analog; the six-month ISS mission increments are temporal and operational analogs for Mars transit. At the completion of assembly, the ISS will be capable of supporting research and technology development programs which meet the Agency's needs for crew health and safety, technology advancement, and for operational experience essential for long-duration missions beyond low-Earth orbit. NASA is using the ISS as a laboratory for research in human health and countermeasures as well as applied physical science. Beyond technical and research applications, the ISS is providing NASA with experience in managing international partnerships for long-duration human missions.

NASA's ISS research portfolio has always focused on developing knowledge, technologies, and countermeasures that ensure the safety, health, and optimum performance of astronauts and their space vehicles. Prior to the VSE, the portfolio consisted of a mix of both high technology readiness level (TRL) and countermeasure validation studies with near-term applications and usage, as well as lower TRL and fundamental research for which the potential benefits and impacts to spaceflight vehicles and operations may be years, even decades, in the future. With the transition to VSE, NASA's plans for research and utilization of the ISS have undergone significant changes. The resulting approach is still evolving and in active transition to focus available resources on risk reduction associated with the NASA exploration architecture. However, at assembly complete, NASA will be well positioned to take maximum advantage of the window of opportunity provided by the ISS to continue both exploration and non-exploration research and operations development as humanity becomes truly space-faring.

Legislative Language

Public Law No: 109-155

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION AUTHORIZATION ACT OF 2005

SEC. 506. ISS RESEARCH.

The Administrator shall--

(1) carry out a program of microgravity research consistent with section 305;
(2) consider the need for a life sciences centrifuge and any associated holding facilities; and
(3) not later than 90 days after the date of enactment of this Act, transmit to the Committee on Science of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate the research plan for NASA utilization of the ISS and the proposed final configuration of the ISS, which shall include an identification of microgravity research that can be performed in ground-based facilities and then validated in space and an assessment of the impact of having or not having a life science centrifuge aboard the ISS.

SEC. 305. MICROGRAVITY RESEARCH.

The Administrator shall--

(1) transmit the report required by section 506;
(2) ensure the capacity to support ground-based research leading to space-based basic and applied scientific research in a variety of disciplines with potential direct national benefits and applications that can be advanced significantly from the uniqueness of microgravity and the space environment; and
(3) carry out, to the maximum extent practicable, basic, applied, and commercial ISS research in fields such as molecular crystal growth, animal research, basic fluid physics, combustion research, cellular biotechnology, low-temperature physics, and cellular research at a level that will sustain the existing United States scientific expertise and research capability in microgravity research.

SEC. 204. ISS RESEARCH.

Beginning with fiscal year 2006, the Administrator shall allocate at least 15 percent of the funds budgeted for ISS research to ground-based, free-flyer, and ISS life and microgravity science research that is not directly related to supporting the human exploration program, consistent with section 305.

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The ISS and Implementation of the Vision for Space Exploration

Introduction

In January 2004, the announcement of the Vision for Space Exploration (VSE) focused the Agency on a bold new mission: implementing a sustained and affordable human and robotic program to explore the solar system.

Two years later, NASA is well on the way to turning the Vision into reality. NASA has unveiled plans for the next generation spacecraft, the Crew Exploration Vehicle (CEV), which builds on the best of Apollo and Space Shuttle technology. NASA is returning the Space Shuttles to flight and has celebrated the fifth anniversary of continuous crew operations on the ISS.

Completing assembly of the ISS by the end of the decade, including meeting the commitments to our international partners, is a crucial first step in NASA's implementation of the VSE. NASA has refocused ISS research to meet Agency mission needs. As humans venture further into space, the next generation of long-duration human exploration missions will need crew that can sustain the rigors of space, spacecraft systems with high reliability, and operational experience at the crew-systems interface. The ISS mission objectives corresponding directly to these Agency needs are summarized as follows:

1. Research, Development, Test, and Evaluation of Biomedical Protocols for Human Health and Performance on Long-Duration Space Missions.
2. Research, Development, Test, and Evaluation of Systems Readiness for Long-Duration Space Missions.
3. Development, Demonstration, and Validation of Operational Practices and Procedures for Long-Duration Space Missions.

The ISS also serves as a training ground in areas ranging from systems engineering and development, to research planning and implementation, technology development, and real-time operations. ISS provides valuable lessons for current and future engineers and managers -- real-world examples of what works and what does not work in space. The international collaboration provides valuable insights into how our Partner countries approach building, operating, and maintaining spacecraft. As such, the ISS is a cornerstone in advancing knowledge about how to live and work in space for long, continuous periods of time and will remain critical to our future exploratory journeys.

Background

It should be noted that even before the VSE was formally implemented, much of NASA's research portfolio conducted on the ISS focused on developing knowledge, technologies, and countermeasures that ensure the safety, health, and optimum performance of astronauts and their space vehicles. The portfolio consisted of a mix of both high TRL and countermeasure validation studies, with near-term applications and usage, as well as lower TRL and fundamental research with potential benefits and impacts to spaceflight vehicles and operations that will occur years, even decades, in the future.

Prior to the VSE, the NASA research program content underwent a series of reviews, including reviews by the National Academies and other NASA advisory committees, to ensure that ISS utilization focused on the highest priorities for the Agency. A committee formed from the non-NASA community of researchers performed a major content review of NASA's life and physical sciences research priorities during the Research Maximization and Prioritization Task Force (ReMap) in 2002 and provided comprehensive rankings and recommendations at that time.

Beginning in the fall of 2004 and concluding in early 2005, in direct response to the VSE, a Zero Based Review (ZBR) was conducted of the Human Systems Research & Technology (HSRT) portfolio. The ZBR was conducted to reprioritize HSRT content to support the VSE. All research tasks were collected and subdivided, rated with weighting factors and criteria for exploration-relevant research, and a series of nonadvocate panels then examined the ZBR process. As a result of the ZBR, research not directly supporting exploration priorities was shifted to a lower priority ranking, targeted for gradual phaseout of the program.

The ZBR created a research baseline that was employed in the Exploration Systems Architecture Study (ESAS). The ESAS Technology Assessment Report was a further narrowing of the ZBR priorities to very specific requirements emphasizing near-term needs for a return to the Moon. These reviews indicate that much of NASA's pre-VSE utilization of ISS was already serving to implement the Agency's new priorities.

Mission Need - Exploration

When he announced the VSE, the President declared that "the United States will launch a refocused research effort on board the ISS to better understand and overcome the effects of human space flight on astronaut health, increasing the safety of future space missions."

The ISS is NASA's long-duration testbed for lunar missions as well as a flight analog for Mars transit. The six-month ISS mission increments are temporal and operational analogs for Mars transit. NASA is using the ISS as a laboratory for research with direct applications to exploration requirements in human health and countermeasures as well as applied physical sciences for fire prevention, detection, and suppression; multiphase flow for fluids such as propellant; life support; and thermal control applications. Beyond technical and research applications, the ISS is providing NASA and its partners with experience in managing international partnerships for long-duration human missions.

NASA's biomedical research activities have always focused on the understanding and development of risk management solutions for coping with human limitations in the space environment and protecting health consequences after space flight exposure. With the realignment of the Agency's mission to the VSE and the logistical and operational realities for ISS utilization resulting from Space Shuttle retirement in 2010, the biomedical research activities have required some modification in order to continue providing these solutions. These activities have been refocused under the ISS Medical Project (ISSMP). The ISSMP maximizes return of essential human risk-reduction information from ISS, including developing, demonstrating, and verifying effective space flight countermeasures and medical technologies.

NASA is also conducting advanced technology evaluations onboard the ISS to help further the state-of-the-art in areas such as structural engineering and battery technology, which will have direct impact on exploration vehicle and habitat designs. For example, strain gauges are being added to the truss structure planned for future assembly missions to provide verification of structural loads predicted by computer programs. The ISS program plans to fly batteries incorporating advanced technology to provide improved performance and longer life. Light-Emitting Diode (LED) lighting systems will replace existing lighting technologies on ISS. A new state-of-the art system for monitoring cabin air in the ISS will demonstrate new technologies and ensure astronaut safety. Much of this work is a continuation of, or a refocusing of, technology developments and evaluations that preceded the VSE.

ISS is demonstrating new capabilities to sustain spacecraft operations over long time periods, which will be critical for lunar/planetary habitats and Mars transit vehicles. Periodic photographic surveys of the outside of the ISS are performed and compared with previous pictures to understand the degradation of the vehicle over time. The ISS team is performing and logging preventive maintenance on spacecraft systems to better understand the slow decay of vital systems. The team is also demonstrating repair of systems in space that were previously thought to be not repairable. The Expedition crews recently successfully repaired a malfunctioning space suit, replaced treadmill bearings, and replaced an Elektron subassembly. These repairs were thought not feasible in space and are a testimony to both ground and flight teams that developed procedures and training for these events.

Additional ongoing exploration-enabling demonstration and development activities on the ISS include: flight demonstration and operation of new space vehicles; remote maintenance and sustainability procedures; Extra-Vehicular Activity (EVA) technology and capability; autonomous rendezvous and docking; life support systems; robotics and human systems displays and controls; and crew health and safety improvements.

The ISS is providing knowledge and skills to overcome the inevitable contingencies that will arise in exploration missions beyond low-Earth orbit. Challenges in returning the Space Shuttle to flight have taught NASA engineers and scientists to adapt their ISS research to new operations realities, and the ISS partners have learned how to overcome challenges within an international partnership.

The ISS provides real-world examples on what works and what does not, creating valuable lessons for current and future engineers and managers. The ISS gives us a glimpse at how our partners approach building spacecraft, and NASA is learning many lessons from our Partner countries in building, operating, and maintaining spacecraft as cooperative endeavors.

Non-Exploration Utilization

The ISS has been and will continue to be used, although at a reduced level, for non-exploration-related life and microgravity science research when the uniqueness of the microgravity and space environment unmask phenomena that cannot be observed or studied in the normal Earth environment. While exploration-related research typically investigates mature Countermeasure Readiness Level (CRL) or TRL questions directly linked to the VSE, non-exploration research investigates fundamental scientific phenomena (biological and physical) associated with microgravity in the space environment. The knowledge gained from fundamental research has the potential of uncovering information that may lead to novel applications both on Earth and in space exploration. NASA's research portfolio includes both to ensure continuing advances in the scientific and technical goals of both the VSE and the search for basic microgravity and space environment effects in the life and physical sciences.

To maximize the capabilities and depth of the non-exploration fundamental research, NASA's research portfolio includes ground-based, free flyer and ISS research. The ground-based research content includes microgravity and space flight environment simulations and the supporting research facilities, as well as ground research directly linked to flight research. The utilization of free flying (uncrewed) research platforms has the potential to expand the number of microgravity and space environment research opportunities and allows for independent verification of fundamental results observed on the ISS.

ISS Configuration

The ISS has been continuously crewed for more than five years and is about 50 percent complete with approximately 180 metric tons of mass on orbit. There are 15 elements on orbit today, nine elements ready for launch at the Kennedy Space Center in Florida, and seven elements in process. With the completion of assembly there will be approximately 457 metric tons of mass on orbit, including the international partner elements: the Japanese Experiment Module, the European Columbus Module, the Canadian Special Purpose Dexterous Manipulator robotic manipulator, and the Russian Multipurpose Laboratory Module.

NASA will use the Space Shuttle to complete the ISS assembly prior to its retirement in 2010. During the assembly period, Russian Progress vehicles will be used to fill expected logistics shortfalls, and Russian Soyuz vehicles will be used for crew exchange. Assembly priorities are to complete the truss segments and power infrastructure, deploy the international partner elements, and provide logistics to sustain the ISS. The final configuration will support growth to six crew in 2009 with the addition of crew quarters, galley, and waste management systems.

ISS Configuration Evolution

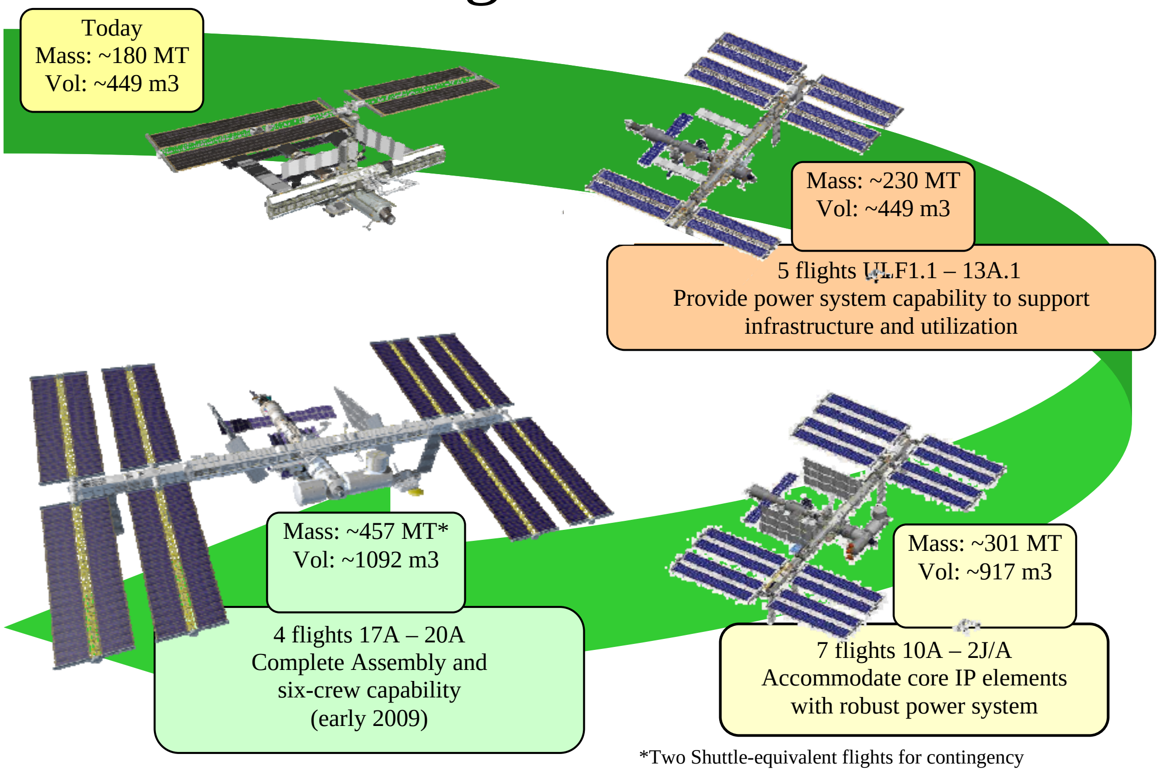

Figure 1: ISS Configuration Evolution

NASA will also use the commercial sector and the flexibility in the partner agreements to provide supplies and crew transport to the ISS. This multicapability approach will include potential Commercial Orbital Transportation Services capabilities, purchase of international partner transportation services, and the CEV. The European Automated Transfer Vehicle (ATV) and Japanese H-II Transport Vehicle (HTV) will conduct initial flight demonstrations to the ISS during the assembly period.

Research Capabilities

At the completion of assembly, the ISS will support science and technology programs which meet the Agency's needs for crew health and safety, technology advancement, and for operational experience essential for long-duration missions beyond low-Earth orbit. The ISS research capabilities will include physical accommodations for internal pressurized rack sites and external unpressurized attachment sites, and utility resources such as power and thermal, data transmission, and crew time.

The ISS currently has eight U.S. research facility racks on orbit, including two Human Research Facility racks, five multiuser racks, and the Microgravity Sciences Glovebox. (For more information on these facilities, refer to Appendix E.) Seven additional U.S. research facilities, four European facilities, and three Japanese facilities will be delivered throughout the remaining assembly period. The external unpressurized accommodations will be phased in later during the assembly period with delivery of the external logistics/payload carriers. ISS payloads are controlled and operated through the Payload Operation Integration Center located at the Marshall Space Flight Center. From their home sites, researchers can monitor and control their payloads using the Telescience Resource Kit, a PC-based telemetry and command system.

ISS Post Assembly Complete Payload Accommodations

Internal Pressurized Rack Sites	**Station-Wide**	**U.S. Share**
U.S. Laboratory	13 ISPRs *	13 ISPRs
Japanese Experiment Module	11 ISPRs	6 ISPRs
European Columbus Orbital Facility	10 ISPRs	5 ISPRs
Total	34 ISPRs	24 ISPRs
External Un-pressurized Attachment Sites		
U.S. Truss	10 sites	10 sites
Japanese Exposed Facility	10 sites	5 sites
European Columbus Orbital Facility	4 sites	0 sites
Total	24 sites	15 sites

Microgravity Science Glovebox & EXPRESS Rack 3A

Utility Resources	
Power/thermal:	25 kW_{avg}
Data Transmission**:	150 Mbps downlink (Ku band)
Transmission coverage:	70 – 75% of orbit
Crew time:	35 hours/week
Transportation:	In work

*ISPR: International Standard Payload Rack
**research usage shared with system operations

Figure 2: ISS Post Assembly Complete Payload Accommodations

Space Transportation and Crew Time

Utilization of the ISS is constrained by transportation of upmass and downmass to and from the ISS and crew time available for payload operations. Since the Columbia accident, the ISS program has relied on the Russian Soyuz and Progress vehicles to transport crews, supplies, and experiments to ISS. Upmass and downmass opportunities have been limited and have impacted NASA’s ability to perform research on the ISS.

The Space Shuttle flight, STS-114, in August 2005 brought vital research supplies, spare parts, and experiments to the ISS. Equally as important, the Space Shuttle returned samples, hardware, and other items from the ISS. The approaching Space Shuttle flight, STS-121, will reestablish regular Space Shuttle flights to the ISS.

Crew size and crew time limitations have also constrained utilization of the ISS. Since the Columbia accident, the ISS has operated with a crew of two due to logistical constraints. The reduced crew has had less time available to perform utilization activities because of the level of operations and maintenance overhead associated with the routine operations of ISS. Crews have volunteered their time on weekends to perform science in an effort to boost utilization. Overhead tasks are being reviewed and reduced in an effort to increase utilization time. As regular Space Shuttle flights resume, the crew complement will return to three, and utilization activities will increase to pre-accident levels. With the addition of crew quarters, galley, and waste management systems, crew size will have the potential to increase to six by 2009.

Detailed Discipline Research & Utilization Plans

The remainder of this document is broken into discipline-specific sections: Human Research, Technology Development, Non-Exploration Research, Operations Demonstrations and Development, Commercial Opportunities, and Education and Public Outreach. Each of these sections goes into a more detailed description of the research, exploration-enabling development, and utilization activities planned in these areas. In addition, there are sections describing non-NASA utilization of the ISS, specifically by other U.S. Government agencies and the ISS international partners. Finally, the last section contains a discussion of the ISS life sciences centrifuge as specifically requested in Section 506 of the 2005 NASA Authorization Act.

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Human Research

Introduction

The risks to humans traveling, living, and working in space increase with the duration of the mission and its distance from Earth; exploration missions with destinations to the surface of the Moon and Mars pose new and unique challenges to ensuring the health, safety, and productivity of those individuals. The Human Research Program (HRP) was formed in response to NASA's alignment with and implementation plan for the VSE and to focus its biological research investment on the highest risks to astronaut health and performance in support of exploration missions. The HRP contains the evolution of biological research activities initiated prior to the VSE and new initiatives designed to produce deliverables that specifically enable NASA's exploration architecture. The goal of the HRP is to provide human health and performance research, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration. HRP meets these goals through an integrated program of intramural and extramural research using both ground analogs and research on the ISS.

Cosmonaut Alexander Y. Kaleri, Soyuz flight engineer, after Soyuz capsule landing on April 30, 2004.

This section will give an overview of the process by which the HRP utilizes the ISS as part of the overall countermeasure development process. It begins with an overview of the sources for research and countermeasure development requirements, with particular emphasis on the Office of the Chief Health and Medical Officer (OCHMO) Space Flight Health Standards. Then, the process by which countermeasures evolve from concepts, through ground analog testing and to final flight validation on ISS, is described. Finally, the section ends with an outline of NASA's future approach for HRP utilization of the ISS.

Research and Countermeasure Development Requirements

One of the primary sources for HRP technical and research requirements is the Space Flight Health Standards developed and controlled by the OCHMO. The Chief Health and Medical Officer (CHMO) is charged with ensuring the health and safety of NASA employees in space and on the ground by developing health and medical policy, establishing guidelines for health and medical practice in the Agency, providing oversight of health care delivery, assuring professional competency Agency-wide, and reviewing and approving research requirements and deliverables. The CHMO also monitors human and animal research and clinical practice to ensure that the Agency adheres to the highest medical and ethical standards and satisfies all regulatory and statutory requirements.

The OCHMO has established Space Flight Health Human Performance Standards which establish acceptable medical risk from the harmful health and performance effects of space flight. These standards drive operational and vehicle design requirements, aid in medical decision making during space missions, and guide the development of countermeasures, interventions, and procedures to amend and prevent the negative health and performance effects of space flight. The process by which OCHMO developed the standards was modeled on that used by the United States Occupational Safety and Health Administration (OSHA). Standards are based on the best available scientific and clinical evidence, including research findings, lessons learned from previous space missions, analog environments, current standards of medical practice, risk management data, and expert recommendations. Crew health-related standards address all mission phases and target physiological and behavioral and performance systems at risk from exposure to the space environment. An initial set of standards are in the development and approval process, and it is anticipated that additional standards may be developed as needed.

An assessment of each standard is underway using a risk management approach that addresses whether further research is needed to meet a standard with confidence. This assessment is a methodical review of the evidence base behind each standard, associated uncertainties, and planned approaches for meeting the standard. These assessments may identify research requirements associated with refining standards or requirements aimed at providing countermeasures and capabilities to maintain crew health within the established limits. All standards will be periodically and regularly reviewed and may be updated as new evidence emerges.

In addition, the HRP derives requirements from Design Reference Mission definitions and Concept of Operations documents associated with the exploration architecture. HRP seeks to reduce or eliminate risks to completion of the exploration missions and to astronaut health during and long after the missions. The Bioastronautics Roadmap (http://bioastroroadmap.nasa.gov/index.jsp) defines and categorizes the specific science discipline risks that affect exploration missions. Design Reference Missions and Concepts of Operation provide a baseline of mission activities and durations for determining mission risks, operational requirements, required countermeasures, and needed medical care capabilities. With the Space Flight Health Standards, these documents provide the framework upon which the HRP research and technology development requirements are determined. Successful implementation of HRP requirements will result in countermeasures and other needed capabilities for ensuring crew health and safety for each class of exploration mission.

Countermeasure Development and Maturation

This section describes the overall countermeasure development process and the linkage of ground-based research to ISS research and utilization. The development of countermeasures follows a pathway of maturation, or countermeasure readiness levels (CRL), by which ideas and concepts emerging from basic research are developed into flight operations. The countermeasure development process begins with the identification of the biomedical issues and priorities identified from the HRP technical and research requirements. This includes basic and applied research to develop countermeasure concepts (Levels 1–3); evaluation of those concepts and initial demonstration of effectiveness through standardized studies and ground analogs (Levels 4–6); countermeasure validation in spaceflight on the ISS (Levels 7-8); and finally, operational implementation and transition to use by the flight surgeons and astronauts (Level 9).

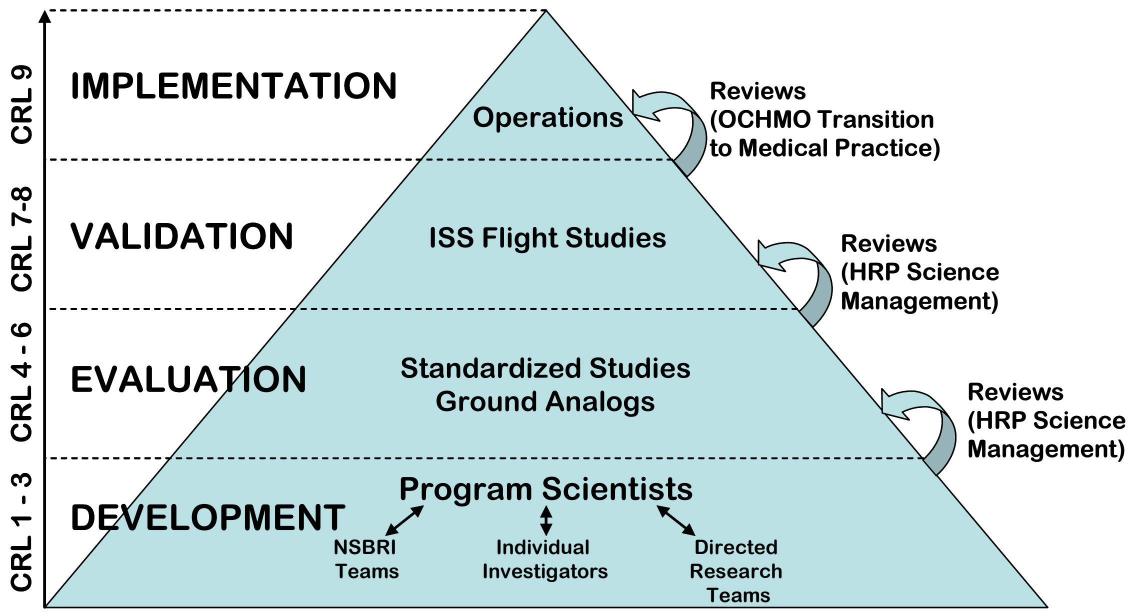


Figure 3: Countermeasure Development Process

HRP activities focus on operational issues and solutions to operational problems to support an outcome-oriented approach. HRP research is primarily focused on evaluation of countermeasure concepts at CRLs of 4 through 8. To best meet the VSE goals and objectives, the HRP will move away from the historical model of individual investigator-driven research acquired through broad research announcements to a more focused and timely approach to ensure success. HRP will follow a new paradigm of appropriate, directed research with greater integration between operations and research communities. Directed research may take the form of assigned tasks through the National Space Biomedical Research Institute (NSBRI), other external researchers, in-house research, and focused solicitations through NSBRI or other external researchers. NASA Research Announcement (NRA) and Announcement of Opportunity (AO) processes will be used in nontime-critical situations. All research (in-house and external) will be subject to independent peer review/nonadvocate review, using the established NASA processes for research acquisition, reviewing for scientific merit, and likelihood of providing the desired outcome. Existing research in work prior to the VSE that is well aligned and leading to capabilities for reducing exploration risks has been retained and will be supplemented by research into other strategic areas.

Countermeasure Evaluation – Ground Analogs

NASA has increased its reliance on ground-based analogs that simulate the effects of microgravity on human systems for countermeasure evaluation, including analog environments, computer simulations, lunar dust simulations, and longitudinal studies. The primary analog for human physiology research is head-down bed rest. In this analog, test subjects are placed in bed at a 6 degree head down tilted position for anywhere from a few days to a few months, depending on which physiological system or which countermeasure is under study. The studies are conducted in a standardized manner, including the collection of a standard set of clinical and physiological measurements on every test subject, in order to obtain an accurate assessment of the integrated physiological response to bed rest and for the assessment of the effects of system-specific countermeasures on other systems. By this approach, NASA is able to evaluate countermeasures in larger sample sizes, perform preliminary evaluations of possible in-flight protocols, and identify the details of individual strategies before flight resources are requested.

Bed rest test subject performing an exercise protocol.

Countermeasure Validation - ISS Utilization and Research

The ISS provides a unique, important opportunity for collection of data on human health and performance and for validation of countermeasures after they have been evaluated in an appropriate ground analog. ISS human research is being focused under the ISSMP. ISSMP is designed to maximize the opportunity provided by the ISS for human health and performance evaluations and is highly integrated with NASA's medical operations for both support of ISS crew and planning for exploration. It is the HRP's "go-forward" approach for ISS utilization given the resource realities -- most significantly, a reduced number of Space Shuttle flights and Space Shuttle retirement in 2010 which limits available up and down mass, and a delay in crew size increase to six, which reduces the total number of available space flight test subjects and the available crew time.

The goals of ISSMP are to perform human research on the ISS to:

- Address the highest risks to mission success and to long-term crew health associated with exploration missions.
- Understand the significant effects of long-duration spaceflight on the human body so that medical standards and protocols to manage exploration risks can be developed.
- Determine "Space Flight Normal" for relevant body systems during long-duration flight by conducting longitudinal monitoring with standard measures, including the initial period, first month, and at significant intervals thereafter (including pre- and postflight periods).

These standard measures enable exploration medical standard development, and an integrated assessment of physical (exercise), pharmacological, and/or nutritional countermeasures against effects of spaceflight which impact mission success or crew health. These countermeasures will include concepts to ensure adequate neurosensory function during all mission phases, approaches to offset decreased bone and muscle strength (combining physical, pharmacological, and nutritional components, as appropriate), reliable and effective exercise equipment and protocols, and protection against circulatory orthostatic intolerance. HRP also intends to develop and verify optimized shielding, procedural, pharmacological, and/or nutritional countermeasure(s) to protect crews from radiation exposures, and devise and verify strategies to ensure optimal crew (individual and group) behavior and performance.

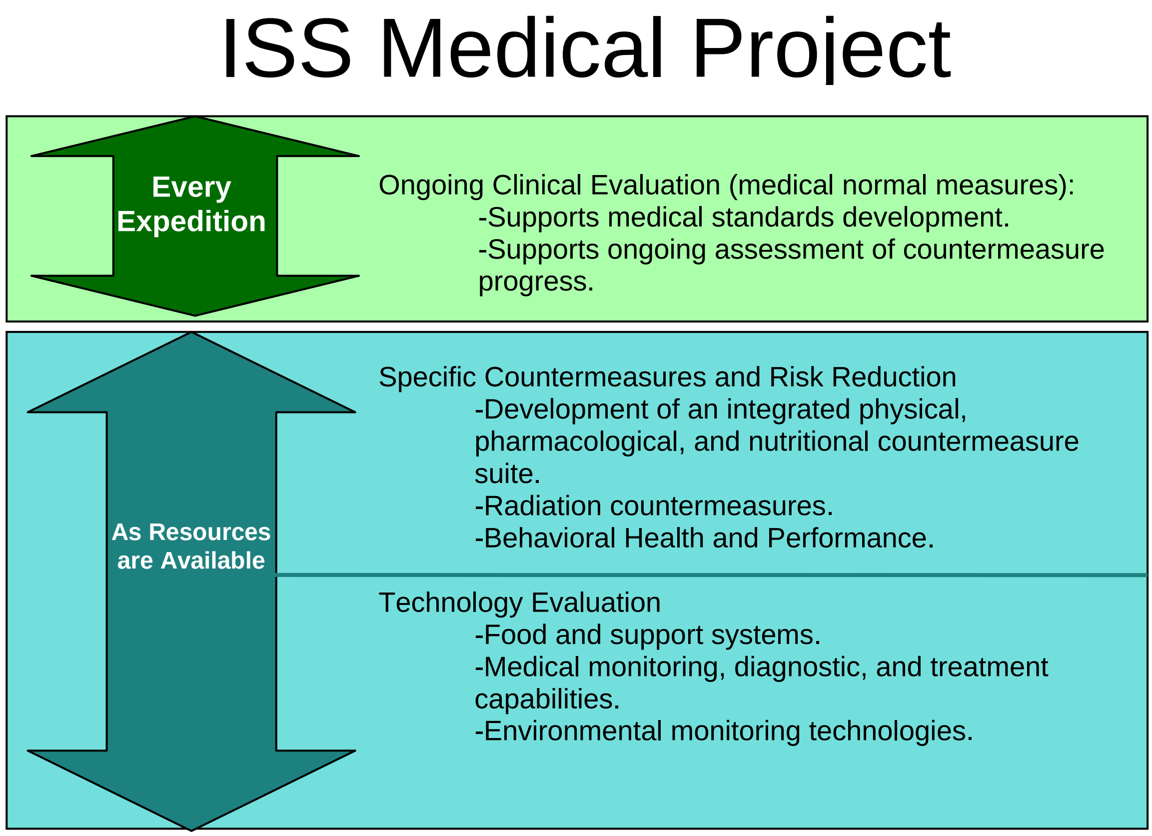


Figure 4: ISS Medical Project

NASA is also heavily engaged with our international partners in the area of human research and countermeasure development. NASA and Russia have renewed their interest in a stronger human research partnership. NASA's membership and participation in the International Space Life Sciences Working Group (ISLSWG), http://exploration.nasa.gov/about/islswg.html, continues to be an important avenue for collaboration on shared research goals. One of the guiding principles of the ISLSWG is to optimize the utilization of flight resources by avoiding unnecessary duplication of equipment, by sharing equipment and flight opportunities, and by cooperating with all partners whenever possible. Several of our ISLSWG partners, including the European

Space Agency (ESA), the German Aerospace Center (DLR), and the Japan Aerospace Exploration Agency (JAXA), have contributed flight hardware to the Human Research Facility suite of equipment. (For more information on HRF, see Appendix E.) ESA and JAXA have ISS laboratory modules with life sciences facilities scheduled for launch after 2007. Both have facilities that HRP will find useful in implementing its research goals, and HRP intends to take advantage of NASA's already good ISLSWG working relationship with ESA and JAXA to negotiate future utilization of those facilities. In addition, cooperation with ESA and Russia on a countermeasure evaluation proposal is being defined, and a draft charter for a research working group to collaborate with the Countermeasures subpanel to the ISS Multilateral Medical Operations Panel is under review by NASA, ESA, and Russia.

Countermeasure Operations – Transition to Medical Practice

At several key points in the countermeasure development process, a candidate countermeasure will go through scientific management reviews before advancing into the next phase of maturation. The final review is governed by the CHMO and is defined as the Transition to Medical Practice (TMP) review. The TMP review process is designed to assess the effectiveness and operational readiness of medical research and technology products and deliverables. It provides a clear channel for human health and medical-related flight and ground research results for transition to tools available to support Agency human space flight programs. The TMP review process is applied to newly proposed medical procedures, practices, processes, countermeasures, or technologies resulting from NASA-sponsored research that are designed to maintain the health and/or support the medical care of space flight crews.

Conclusion

NASA's life sciences research program has undergone significant changes with the transition to VSE. The resulting HRP portfolio is still evolving and in active transition to focus available resources on risk reduction associated with the NASA exploration architecture. The plan to pursue appropriate directed research and to focus deliverables on capabilities to set and meet Space Flight Health Standards will position HRP to effectively meet exploration objectives. In the newly formed ISSMP, HRP is well positioned to take maximum advantage of the window of opportunity provided by the ISS.

Technology Development

Introduction

As humans travel far from Earth on long-duration space missions and live for increasing periods on the Moon and other planetary surfaces, new technologies will be necessary to ensure mission success and mission safety. While most technology development projects and supporting research are performed in Earth-based laboratories, a significant number are conducted on the ISS. The ISS is a unique testbed for research requiring long-duration exposure to the space environment and for technology development as it provides the ability to demonstrate functionality and resolve performance problems in reduced gravity. NASA's Exploration Technology Development Program (ETDP) will focus research and technology investments on those areas that support the development of enabling technology for the CEV and lunar missions.

The ETDP uses a maturation process following Technology Readiness Levels (TRLs). At lower TRLs, the technology concept is formulated, and proof of concept for the critical function is demonstrated. At mid TRLs, component and subsystem validation is completed in a relevant environment, either ground or space. At the high TRLs, system prototype and, ultimately, flight-qualified demonstrations are completed in ground or space. This leads to an actual system that is flight proven. Several needed technologies for the VSE are currently at mid TRLs, but many more technologies still must be developed. Applied research in the physical sciences provides the necessary building block information to inform future technology developers of novel ways to develop necessary systems, thus reducing overall spacecraft mass and improving performance (e.g. Thermal Control and Propellant Storage). While most work in ETDP focuses on mid to high TRL where specific technologies will be delivered (e.g. Environmental Monitoring Control, and Oxygen Generation and Water Recovery), additional applied research activities will also be conducted.

The projects in the ETDP have been guided by recommendations from the National Research Council (NRC) and internal NASA program assessments, notably the Exploration Systems Architecture Study. Several important vehicle technologies, such as propellant storage, fire safety, and thermal control, have been recommended as higher-priority research in the NRC reports, *Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies* (2000); *Engineering Research and Technology Development on the Space Station, Committee on Use of the International Space Station for Engineering Research and Technology Development, Aeronautics* (1996); and *Space Engineering Board and Assessment of Directions in Microgravity and Physical Sciences Research at NASA* (2003). Also, the National Research Council report, *Advanced Technology for Human Support Technology in Space* (1997), calls for the development of technologies that reduce the dependence on resupply (approaching closed loop) for life support systems and space flight demonstration tests of environmental monitoring and control devices. These systems are under development in the ETDP and will be tested on the ISS.

ISS facilities, including the Fluids and Combustion Facility and the Microgravity Science Glovebox, were developed to conduct experiments that will provide engineering data and scientific knowledge supporting technologies needed for exploration. The currently funded experiments are planned to be launched by 2010 or earlier. A formulation and selection process for future experiments will be defined and implemented to make optimal use of the ISS. A detailed description of the facilities is provided in Appendix E.

This section describes the ETDP areas that require the ISS for either applied research or technology demonstration. In applied research, the areas include: Fire Prevention, Detection and Suppression, Thermal Control, Propellant Storage, and Structural Response of the ISS. Technology demonstrations include: Materials Survivability, Inspection and Repair in the Space Environment, Environmental Monitoring and Control, and Oxygen Generation and Water Recovery Systems.

Applied Research

Fire Prevention, Detection and Suppression (FPDS)

The FPDS program will develop technology that will improve the prevention, detection, and suppression of fires in space. This technology area will develop hardware, design rules and requirements, and procedures that include fire prevention and characterization of material flammability, fire signatures and detection, and fire suppression and response. Each of these areas has knowledge and products that will be delivered to exploration systems developers to ensure crew health and safety.

ISS experiments which will support the activities of FPDS include the Droplet Flame Extinguishment Experiment (FLEX) which will investigate fire suppression and the Smoke Aerosol Measurement Experiment (SAME) which will investigate smoke detection in space. The FLEX investigation will provide the initial screening of fire suppressants in varying atmospheric (O_2 concentration and pressure) and flow conditions. The FLEX investigation will use the Multi-User Droplet Combustion Apparatus (MDCA) facility, which is a multiuser “mini-facility” designed to be inserted into the combustion chamber of the Combustion Integrated Rack on the Fluids and Combustion Facility of the ISS. The objective of the SAME investigation is to improve the reliability of future spacecraft smoke detectors by making measurements of the smoke particulate size distribution to enable rational design of smoke detectors. SAME will operate in the ISS Microgravity Science Glovebox (MSG).

Thermal Control (TC)

The TC program will develop two-phase (liquid-vapor) energy transport systems to reduce space craft mass and volume. Studies have shown that two-phase thermal management systems are lighter for higher heat rejection needs. Furthermore, they provide the ability to have isothermal temperature control for thermal busses which provides designers additional flexibility, in terms of placement of temperature-sensitive heat sources, and can significantly reduce the size of radiators that are governed by their absolute temperature raised to the fourth power.

Several ISS research and utilization activities are planned for TC. Two are pool boiling experiments, the Microheater Array Boiling Experiment (MABE) and the Nucleate Pool Boiling Experiment (NPBX). Boiling is an effective means of cooling because most of the heat transfer is from the latent heat of vaporization as opposed to heating and pumping a single-phase fluid which is typically used in for space-based thermal control, energy conversion, and water recovery systems. Pool boiling is the limiting case of flow boiling, hence the pool boiling will provide significant information in determining flow boiling characteristics, including the heat transfer coefficient and limiting cases of flow boiling that are critical towards safe operation of devices such as in the event of a pump failure and subsequent loss of flow. The Constrained Vapor Bubble (CVB) experiment will study flow induced by capillary forces. The CVB experiment uses an innovative design that will enhance the performance of future heat pipe systems by eliminating the need for wicks and by enabling volume and mass-efficient packing geometry (from cylindrical to honeycomb design). Heat pipes currently designed for space are conservative because of the lack of understanding of the thermal performance limit and capacity to recover from thermal overloads (dry out and rewetting).

Propellant Storage (PS)

The PS program will conduct investigations that will lead to the design of lighter weight cryogenic storage tanks. The state-of-the-art for propellant transfer and management has not advanced significantly since the 1960s. To compensate for uncertainty in design, high pressure, heavy, oversized tanks are used to accommodate supercritical storage and propulsion (thruster resettling) or positive displacement techniques (bladders) are used to force propellant to a specific location. Propellant systems for space exploration applications, such as an extended stay on the Moon or a Mars transit mission, will require an order of magnitude larger propellant storage than in present spacecraft. Stored propellants may include cryogenic liquids, such as methane, oxygen, or hydrogen. Zero boil off technologies will be important to ensure long-term storage of these propellants.

A suite of fluid physics flight experiments, the Capillary Flow Experiments (CFE), have been developed to investigate capillary flows and phenomena in low gravity. The CFE data will be useful to future spacecraft designs, particularly pertaining to fluids management systems such as fuels/cryogen storage systems, thermal control systems, water recycling, and materials processing in the liquid state. NASA’s current plans for exploration missions assume the use of larger liquid propellant masses than have ever flown on interplanetary missions. Under low-gravity conditions, capillary forces can be exploited to control fluid orientation so that such large mission-critical systems perform predictably. CFE investigates capillary flow in complex containers, critical wetting in discontinuous structures, and large-scale length contact line damping. CFE will provide first-ever flight validation of “Surface Evolver”, the only code that predicts surface shapes in microgravity. This code is used by Lockheed Martin-Denver, for example, in propellant tank design.

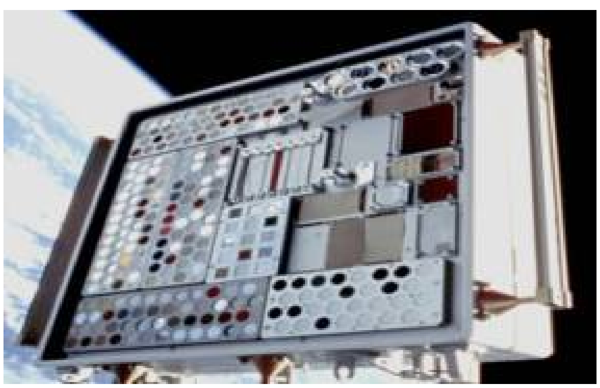
Structural Response of the ISS

This activity will measure the structural response of the ISS trusses and modules as it progresses through the assembly sequence. Both strain gauges and accelerometers are used for this purpose. Accelerometers measure responses on the inboard and outboard trusses and pressurized modules during docking and other loading events, while the strain gauges measure loading on inboard trusses and in Node 1 ("Unity"). Both the U.S. and Russian segments are instrumented. The data are used for model validation. These models are used to predict loads and structural life of the ISS and will be valuable in the design of the CEV and other future human spacecraft.

Technology Demonstrations

Materials Survivability, Inspection, and Repair in the Space Environment (MSIR)

The MSIR program will test and evaluate new materials, components and processes that need an in-space environment evaluation. The space environment poses many hazards to the exposed surfaces of spacecraft, including intense ultraviolet radiation, corrosive attacks from atomic oxygen, radical temperature swings, and strikes from micrometeoroids and orbital debris. NASA studies of the exposure of materials to the space environment for long periods of time have taken advantage of the Russian Space Station Mir and the ISS as a location to place, mount, and retrieve sets of test materials.


MISSE

The Materials International Space Station Experiment (MISSE) has two Passive Experiment Carriers (PECs) with approximately 900 specimens that were mounted outside the ISS airlock in August 2001 and returned in August 2005. A new PEC was mounted on the ISS in August 2005. Two more PECs will be brought up by Space Shuttle flight STS-121/ULF1.1, and two additional PECs are planned to be brought to ISS on a subsequent Space Shuttle flight. Analyses of exposed sample survivability will be conducted upon return of samples.

Environmental Monitoring and Control (EMC)

Currently, there are limited capabilities on ISS to perform real-time monitoring of air and water quality. This limitation stems to a certain degree from the failure of specific systems on orbit. Lack of timely chemical and microbial detection in the crew atmosphere, or elsewhere in the air processing system, can lead to delayed response by the crew or by automated response equipment, leading to increased hazards to the crew. The EMC Program will provide more reliable and capable, compact, real-time monitoring technology for microbial, air, and water contaminants. The program will develop a suite of miniaturized sensors for environmental monitoring of crewed vehicles and habitats. These sensors will operate autonomously with minimal or no crew intervention. The ISS will be utilized to demonstrate and validate that the developed technologies will operate in a "Relevant Environment" autonomously and maintenance-free for period of greater than three months. The focus is on EMC technologies that have been matured to a Technology Readiness Level appropriate for "Technology Demonstration" on the ISS. Specific sensors will be carried forward beyond a technology demonstration to operational status. Sensors being developed include the following: Vehicle Cabin Air Monitor (VCAM); Electronic Nose, which is an event detector for ISS air quality; Colorimetric Solid Phase Extraction Water Monitor, which will measure silver and iodide in ISS water; and Lab-On-a-Chip, which is a portable test system that will monitor surfaces on ISS for bacterial contamination.

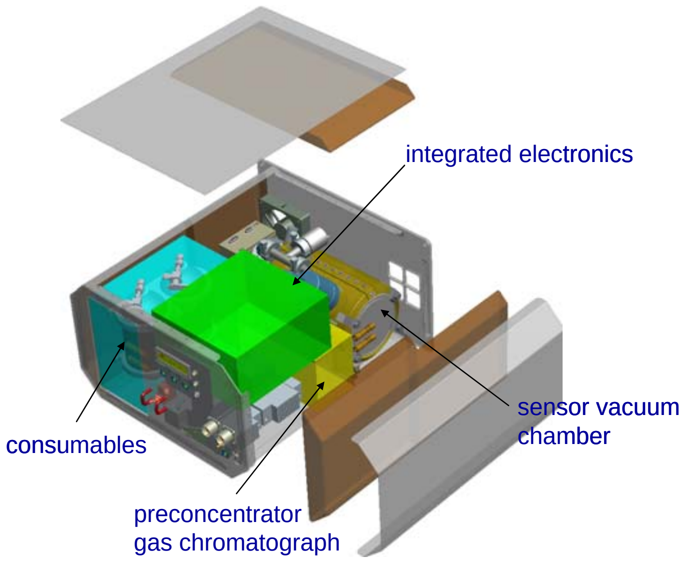


Figure 5: Vehicle Cabin Air Monitor

Oxygen Generation and Water Recovery Systems

This technology demonstration will develop, operate, and sustain a "closed-loop" life support system on the ISS similar to a system necessary for future, long-duration human spaceflight missions to the Moon and Mars. The new system will generate oxygen from water and recover water on the ISS from condensate and urine. This will sustain additional crew members onboard.

The oxygen generation system will be launched on the upcoming STS-121 Space Shuttle mission, and the water recovery system will be completed and delivered in 2007, with a launch planned for 2008. These regenerative environmental control and life support systems will be packaged into three racks and initially installed in the ISS Destiny lab module.

The oxygen generation system will use water to generate breathable oxygen for crewmembers, replacing oxygen lost due to crewmember metabolic consumption, as a consequence of experiments, and during airlock depressurization. During normal operations, it will provide enough oxygen to support six crewmembers. The system is designed to operate with little monitoring. Current operational capabilities for water recovery include the recycling of humidity condensate which accounts for less than 50 percent of the wastewater stream. With the deployment of the advanced water recovery system, which includes the Vapor Catalytic Distillation assembly and multifiltration beds, both the humidity condensate and urine can be recovered on the ISS. This will increase the recovery to greater than 80 percent of the wastewater.

Figure 6: New Oxygen Generation and Water Recovery System for ISS

Conclusion

The Exploration Technology Development activities on the ISS will deliver critical components for future exploration systems and will also provide engineers the knowledge to design efficient space technologies that will reduce mass and improve reliability. Near-term deliverables in life support technologies are a focus of the current program. In the longer term, as human space exploration widens in scope, the engineering design knowledge and data that are produced by applied research on the ISS will enable the design and delivery of integrated space flight systems that can function reliably in mission-critical roles.

Non-Exploration Research

Introduction

This section covers NASA's non-exploration ground-based, free flyer, and ISS life and microgravity science research portfolio and represents an investment portfolio that is consistent with the NASA Authorization Act of 2005 (Public Law No. 109-155).

The relationship between fundamental and applied research is in reality fairly seamless rather than sharply divided. However, NASA has found need to divide its ISS research portfolio into the general groupings of exploration and non-exploration research. Exploration research focuses on application-driven research that is directly linked to the VSE. Non-exploration research focuses on hypothesis-driven research that has the potential for advancing life and physical science not directly linked to the VSE. Exploration research typically focuses on higher TRL/CRL activities, while non-exploration research investigates more fundamental life and physical sciences phenomena associated with the space environment. NASA's research and development investment program is similar to the investment portfolios of mature technology and pharmaceutical corporations. While this portfolio model relies on a diverse investment in fundamental research that can lead to future applications, the bulk of the capital investment is in developing and bringing to fruition a few select goals. This process is illustrated in the pharmaceutical product development figure below:

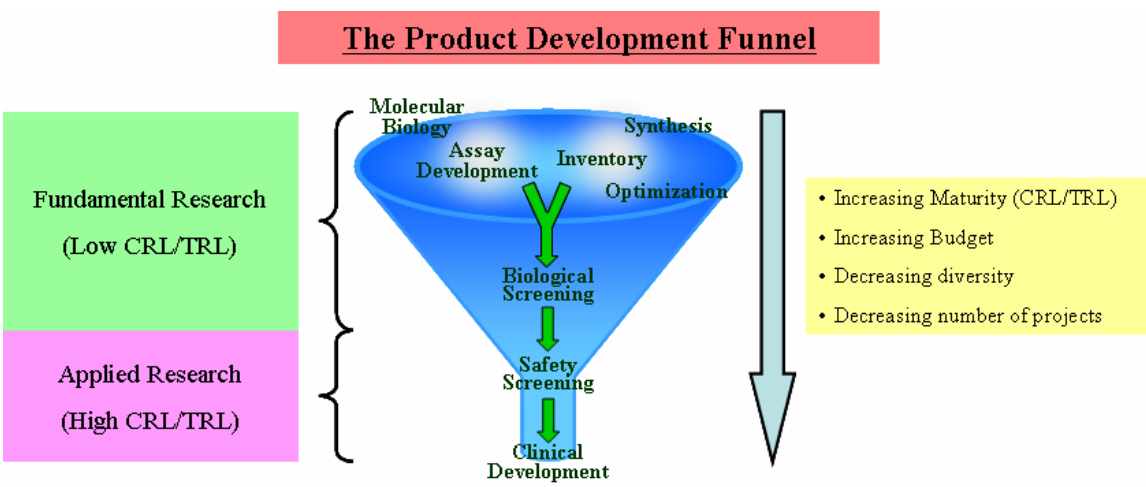


Figure 7: The Product Development Funnel

To maximize the capabilities and depth of the fundamental research, NASA's non-exploration ISS research portfolio includes ground-based, free flyer, and ISS research. The ground-based research includes microgravity and spaceflight environment simulations as well as activities directly supporting ISS research. The utilization of free-flying (uncrewed) research platforms expands the number of microgravity and space environment research opportunities and allows for independent verification of fundamental results observed on the ISS. NASA has a long history of leveraging its resources to expand its fundamental research portfolio and plans to continue to pursue these collaborations to the maximum extent possible.

The remainder of this section will describe the process for determining the non-exploration research content, and how that portfolio will be implemented on the ISS, ground, and free flyer platforms.

Non-Exploration Research Content Approach

NASA's non-exploration research represents a wide array of scientific disciplines covering the biological and physical sciences. A strategic approach has been devised that leverages previous investments and increased collaborative partnerships between diverse groups in Government (such as the National Institutes of Health (NIH), the National Science Foundation (NSF), the Department of Defense (DOD), and the Department of Energy (DOE)), industry, academia, and NASA's international partners. This planned approach should result in significant near- and long-term benefits that complement, but are not duplicative of, other aspects of NASA ISS utilization research. This plan includes a rigorously managed program of basic, applied, and commercial research in fields such as animal research, basic fluid physics, combustion research, cellular biotechnology, and cellular research. The research will be supported at a much lower level than in the past, but it should help to sustain the existing U.S. scientific expertise and research capability in microgravity research.

The implementation plan for NASA's non-exploration ISS research utilizes existing fundamental research in NASA's portfolio and develops future opportunities and advancements in non-exploration research. The primary selection pool of candidate investigations consists of peer-reviewed, fundamental, non-exploration research that was part of NASA's portfolio prior to the ZBR and ESAS reviews.

Research Platforms

The ISS will be utilized to the maximum extent possible, and to adjust for Space Shuttle utilization limitations, ground-based and free flyer research opportunities will also be pursued. This approach will sustain, to the maximum extent feasible, national capabilities to conduct fundamental non-exploration research and preserve and promote commercial, small business, and international collaborations. Each of these platforms is discussed below.

ISS Research

Non-exploration ISS research will initially focus on completing a core group of small and diverse microgravity experiments that are near completion and are, or are ready to be, manifested for flight on Space Shuttle to the ISS. In addition, NASA plans on continuing its current international partner research collaborations. This will maximize return from the ISS by sharing international partner facilities in the U.S. laboratory Destiny and also sharing ISS facilities in the Columbus Laboratory Facility, and the Japanese Experimental Module (JEM) Facility and the JEM Exposed Facility.

ISS Expedition 8 Astronaut Mike Foale performing the Yeast GAP-1 experiment.

Life sciences research on ISS will include investigations ranging from microorganism and cellular research to plant and animal (nonrodent) research. Currently manifested experiments include microgravity and space environment effects on microorganisms using molecular, cellular, and virulence investigations and plant and animal research using molecular, cellular, and organismal-level investigations.

Physical science research on ISS will include investigations ranging from basic fluid physics to combustion and materials science. Planned investigations include the study of phase separation in the area of colloids, flammability with liquid fuels, and analysis of microstructure changes during solidification in the microgravity environment.

Existing NASA and international partner facilities on the ISS that support exploration-related research will also be leveraged to support non-exploration research. These facilities include, for example, the Fluids and Combustion Facility, the MSG, and the European Modular Cultivation System, which will support plant experiments.

Ground-Based Research

The ground-based research portfolio will ensure that a solid base of diverse nonhuman research efforts will be funded and conducted. This ground-based research will be linked to and will lead to space-based basic and applied research in a variety of areas that are not directly related to supporting the human exploration program.

Life and physical sciences ground-based research will focus on a range of topics that are required for investigations using the unique microgravity and space environment afforded by the ISS. The topics covered in life science will include research in areas such as microbiology, virology, immunology, molecular biology, cellular research and biotechnology, genetics, physiology, and animal research. The topics covered in physical science will include research in areas such as interfacial phenomena, granular flow, dynamics and stability, complex fluids, flammability, ignition characteristics, other combustion research, and materials science research areas of metals, glasses, ceramics, and semiconductors. NASA is funding over 70 peer-reviewed grants ending in 2006 that have fundamental non-exploration life and physical sciences focus. In addition, NASA will maintain animal non-exploration microgravity and space environment analog-based ground research capability.

Free Flyer Research

The Free Flyer program can provide cost-effective flight opportunities for fundamental, non-exploration payloads that cannot be flown on ISS due to transportation limitations or safety concerns. The planned free flyer research approach involves implementation of a free flyer microgravity research program based on a variety of collaborative partnerships between Government, industry, academia, and our international partners. This free flyer research effort will range from research missions involving international collaborations that utilize spacecraft such as the Russian Foton, to potential multidisciplinary microsatellite experiments launched on U.S. commercial or DOD vehicles. The free flyer efforts will be space-based basic and applied scientific research covering disciplines with potential direct national benefits and applications that can be advanced significantly from the uniqueness of microgravity and the space environment.

Free flyer opportunities as secondary payloads on U.S. launch vehicles are anticipated and have the potential for resulting in a readily available, low-cost alternate approach to carry small scientific payloads into space that would complement utilization of Space Shuttle and ISS. This approach would also address a diversity of collaborative opportunities between Government, industry, and academia to provide reasonable access to space and might substantially reduce the wait time for new instruments and experiments. These secondary payloads include use of small modular instruments for a variety of life or physical science experiments ranging from 2 to 20 kg.

Other ongoing free flyer collaborative efforts involve larger instruments and payload capability and could support much larger research efforts, such as those needed to conduct rodent experiments. NASA is collaborating on the Russian Foton M2 and Foton M3 missions by sharing life sciences biospecimens. Such collaborations are made possible by our participation in the U.S.-Russian Joint Working Group on Space Biomedicine, Life Support Systems, and Microgravity Sciences. In addition, NASA is working with ESA on Foton M3 physical science collaborative research. As national and international free flyer opportunities develop, NASA will continue to develop collaborations and partnerships that will maximize fundamental life and/or physical sciences return for the particular opportunity. Such collaborations will maximize the space flight opportunities available for fundamental research. They also allow for independent verification of results obtained on the ISS by allowing for a comparison between space vehicle effect and space environment effect.


Recovery of a Russian Bion Free Flyer that contained Russian-U.S. collaboration experiments.

Conclusion

NASA's non-exploration investment portfolio is limited, but seeks to preserve existing U.S. scientific expertise and research capability in microgravity research and provide results that will feed into ISS and/or free flyer experiments. The knowledge gained from non-exploration fundamental research has the potential of uncovering information that may lead to novel applications both on Earth and in space exploration.

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Operations Demonstrations and Development

ISS - Experienced in Exploration

Through the Shuttle-Mir and ISS programs, NASA has acquired experience in building and operating complex space vehicles. In areas ranging from space systems engineering, assembly, operations, and maintenance, to international partner relationships and management, the knowledge gained from this experience can be applied directly to future mission needs.

The ISS is an ideal platform to test protocols and procedures that will enable greater crew autonomy and reduce dependence on the ground support team. Training tools, crew and robotic operations, time delayed or intermittent ground communications, and on-orbit repair and maintenance can be demonstrated and validated in space. The ISS can support demonstrations of new capabilities and tools required for sustaining spacecraft operations, including remote vehicle management, logistics management, in-space assembly and inspections, and flight demonstrations of new crew and cargo transportation vehicles.

The ISS also provides a unique opportunity to flight test components and systems in the space environment and to optimize subsystem performance. It is the only space-based test bed available for critical exploration spacecraft systems such as closed-loop life support, EVA suit components and assemblies, advanced batteries and energy storage, and automated rendezvous and docking.

The ISS provides valuable lessons for current and future engineers and managers -- real world examples of what works and what does not work in space.

Crew Operations

High performing crews are critical to successful long-duration missions. Specialized skills and training of international crewmembers, as well as advanced protocols, procedures and tools will reduce the risks to future exploration missions.

Mission Objective	Capabilities Needed for Moon	Capabilities Needed for Mars	ISS Role
Crew Operations and Training	• Integrated international crews. • Evolved operations tools and processes. • Skills based intravehicular activity (IVA) and EVA training; evolved onboard training tools.	• Integrated international crews. • Streamlined operations tools and processes. • Computer-based IVA and EVA training.	• Develop and demonstrate protocols and procedures with international crews. • Develop and demonstrate skills-based and onboard training tools.
Extra Vehicular Activity (EVA)	• Improved EVA suit materials and on-orbit maintainability. • Enhanced suit mobility/flexibility; self don/doff.	• Highly reliable, maintainable suits; resilient to Mars dust. • Reduced crew prep times for EVAs.	• Prototype new EVA suit materials, components, and subassemblies. • Verify procedures for on-orbit repair and maintenance, self donning/doffing, and airlock management.

Effective on-board training is one of the keys to future long-duration exploration missions. The ISS provides a platform to develop efficient methods to convey new information to crewmembers and influence the volume and types of preflight crew training. The interaction of the crew with mission control is also a significant element that can make a space mission highly successful. The ISS provides an environment to improve the interaction between crew and ground and make missions safer and more effective. Working for months with crewmembers from other countries and cultures is an important aspect of the ISS program. Developing methods to work with our partners on the ground and in space is critical to providing additional capabilities and solutions to design challenges.

Spacecraft Systems Operations

Efficient, reliable spacecraft systems are critical to reducing crew and mission risks. Optimizing systems performance and characterizing system performance in space will reduce mission risks and advance capabilities in long distance and autonomous vehicle and systems management.

Mission Objective	Capabilities Needed for Moon	Capabilities Needed for Mars	ISS Role
Advanced Habitation and Life Support Operations	• Closed-loop life support and environmental control. • Evolved medical care and countermeasures. • Long-distance crew provisioning and resupply.	• Long-duration crew accommodations. • Long distance crew provisioning and resupply. • Advanced environmental control and life support. • Long-distance medical care and long-duration countermeasures.	• Evolve crew accommodations and planning systems for provisioning, food, and clothing. • Characterize operating conditions for next-generation closed-loop life support. • Validate advanced health care and countermeasures.
Communications Operations Protocols	• Remote systems management. • Systems monitoring tools for reduced ground support. • Autonomous crew operations.	• Remote systems management. • Radiation-hardened hardware. • Autonomous crew operations. • Autonomous systems monitoring tools.	• Develop operations procedures for remote vehicle management and intermittent communications. • Characterize operating conditions for radiation-hardened hardware and networks. • Validate autonomous crew operations and reduce ground support.
Advanced Power Systems and Energy Management	• Improved batteries and power systems. • Efficient energy generation storage.	• Next-generation power systems. • Efficient energy generation and storage.	• Validate and test advanced battery cells, solar energy, photovoltaic arrays, and improved energy storage.
Propulsion		• Next-generation propulsion systems.	• Demonstrate and test advanced concepts and prototypes.

Demonstrating and developing confidence in systems for water and waste recovery, oxygen generation, and environmental monitoring technologies are important as the distance and time away from Earth is extended. The ISS is NASA's closed-loop life support test bed for demonstrating these advanced capabilities in the space environment. Maintaining crew health is key for long-duration flights, and the ISS provides demonstration and continuous operation of these systems. Already, much has been learned about developing exercise equipment and its effectiveness for maintaining crew fitness. More must be learned before long-duration missions on the Moon or to Mars are attempted.

The ISS has the largest solar arrays ever deployed for a spacecraft. Understanding how the ISS solar arrays and the other power system components perform is key in moving toward longer stays on the Moon and en route to Mars.

Crew-System Interface Operations

Demonstration and validation of the human-machine interfaces will enable sustained spacecraft operations over long periods of time. Advances in crew and robotic operations, on-orbit maintenance and repair, in-space assembly, and demonstrations of new crew and cargo transportation vehicles are essential to expand beyond low-Earth orbit.

Mission Objective	Capabilities Needed for Moon	Capabilities Needed for Mars	ISS Role
Automation, Robotics and Human-Machine Interface	• Combined crew and robotic operations. • Robotic exploration aids and EVA support. • Ground-controlled robotic operations.	• Autonomous crew and robotic operations with time delayed communications. • Combined airlock and robotic operations.	• Validate robotic designs, concepts, tools, and operational scenarios for long-distance assembly and maintenance tasks.
Advanced Transportation, Rendezvous and Docking Operations	• Highly reliable docking mechanisms. • Autonomous rendezvous and docking systems.	• Next-generation transportation systems. • Highly reliable autonomous rendezvous and docking systems.	• Demonstrate and test tools and ground-controlled robotic operations to improved crew efficiency.
Assembly Operations	• Reliable in-space assembly operations.	• Autonomous in-space assembly operations.	• Demonstrate procedures for in-space assembly systems; self-deploying systems; inspection and control.
Systems Maintenance; Repair; Logistics Re-supply and Sparing	• Component commonality to support field repair without logistics resupply. • Reduced resupply requirements and trash generation. • Evolved logistics and inventory management.	• Maximum component commonality to support on-orbit maintenance and repair. • Reduced in-route and onsite resupply requirements. • Autonomous logistics and inventory management tools.	• Demonstrate test, repair and maintenance operations on orbit. • Evolve logistics management, maintenance and sparing concepts.

The Canadarm 2 robotic arm provides the ability to assemble large ISS elements in flight. Ground control of certain robotic activities is enabling more efficient use of valuable crew time. Development of displays and control are important for future spacecraft systems' designs. Software tools play a role in helping crews virtually practice EVA or robotic tasks before ever donning a spacesuit or powering up the robotic arm.

ISS also provides a real-world laboratory for logistics and maintenance concepts for future spacecraft. ISS crews have had to demonstrate repair capabilities due to the Columbia accident and the reduced flow of logistics for the ISS. Crews and their ground maintenance counterparts have devised unique solutions that have kept the ISS functioning despite logistic shortfalls.

Commercial Opportunities

Introduction

The goals for commercial utilization of the ISS are to help sustain space exploration, by making it affordable, and to foster a market for commercial services. In the past, "commercial utilization" has been defined as research supported in full or in part by private companies for purposes related to commerce either in space or on Earth, with the expectation that eventually, companies would fully fund their research. This goal of full support for commercial ISS research has not been realized as was originally envisioned due to several factors, such as lack of crew time and long development time between the initiation of an experiment and its eventual flight on the ISS. Principal among these reasons has been a lack of sufficient and reliable transportation for crew and cargo to the ISS.

Objectives

One of the goals of the VSE is to "pursue commercial opportunities for providing transportation and other services supporting the ISS." To support this goal, NASA is developing a diversified approach to alternative vehicles that would service the ISS once the Space Shuttle is retired in 2010. The CEV and its cargo variants will provide crew and cargo transportation to the ISS. In addition, an alternative, commercial means to provide crew and cargo transportation services is being pursued through the Commercial Orbital Transportation Services (COTS) project.

Commercial Orbital Transportation Services (COTS)

On January 18, 2006, NASA released the Space Act Announcement for Phase I of the COTS Project. The project has a $500 million commitment in the budget through FY 2009 to develop a commercial space transportation capability. Over 90 companies have expressed interest in COTS. If the Space Act Agreements produce successful demonstrations, NASA could start purchasing commercial cargo and eventually crew services as early as 2010.

The Commercial Crew/Cargo Project consists of two phases. During Phase I, NASA will enter into funded Space Act Agreements with one or more U.S. companies to develop and demonstrate the vehicles, systems, and operations to support a human space facility, such as the ISS. Under Phase I, NASA seeks proposals for Earth-to-orbit demonstrations of any one or a combination of four capabilities:

- Unpressurized external cargo delivery and disposal.
- Pressurized external cargo delivery and disposal.
- Pressurized internal cargo delivery and return.
- Crew transport.

Alternative Options

Planning for the future, NASA intends to extend its use of commercially developed capabilities and services to other NASA needs, such as in-space fuel delivery to support human exploration missions.

NASA is also negotiating with the Russians for Progress flights through 2009 and Soyuz flights through 2011. The necessary resources to pay for these flights are reflected in the FY 2007 ISS crew/cargo budget request.

As mentioned in the non-exploration research section, free flyer opportunities as secondary payloads on U.S. launch vehicles are anticipated and have the potential for resulting in a readily available, low-cost alternate approach to carry small scientific payloads into space that would complement utilization of the Space Shuttle and the ISS. This approach would also address a diversity of collaborative opportunities between Government, industry, and academia to provide reasonable access to space and might substantially reduce the wait time for verification of new instruments and experiments.

Implementation Plan

Implementation of commercial utilization will be guided by an assessment of need to support the VSE and the ISS mission objectives discussed earlier in this document. Commercial research and development projects are currently focused in the areas of autonomous medical care and monitoring, biotechnology, fire suppression, *in situ* resource utilization, pharmaceutical development, synthesis of advanced materials, and spacecraft systems technology. Some of the facilities under review are described in Appendix E. An assessment of fit and need into the current missions will be conducted. In all cases, the commercial research will be coordinated closely with NASA's exploration and non-exploration research to ensure relevance to NASA's needs and to look for opportunities to leverage NASA resources with those of the commercial partners.

Conclusion

The VSE has brought a new emphasis to alternate access to space with the development of the CEV and COTS projects. It has also brought about a focused alignment and prioritization of our research and technology investment dollars, including future commercial research funding. Commercial utilization program funding is currently under assessment to ensure alignment with NASA needs.

Education and Public Outreach

The ISS supports a variety of educational and public outreach activities to teach students about science, math, technology, and engineering principles in the unique environment of space. Many of the human research, technology development, and commercial utilization payloads incorporate educational components which reach thousands of K–12, undergraduate, and graduate students each year. These programs are designed to promote science education and hands-on experience at all levels. Web-based programs, virtual reality simulations, and actual science experiments on ISS enable students to conduct and compare their ground-based experiments with experiments being conducted in space.

Students participating in an educational project.

Cooperative educational programs with museums and science centers around the world help students discover how familiar objects perform differently in space and learn ways that humans adapt to use these objects in space. On-orbit educational activities include demonstrations of Newton's Law, fluids, magnets, tools, musical instruments, crew living and working in space, recycling, laboratory safety, and effects of space on tomato seeds. The ISS crews' video clip demonstrations supplement science curricula around the world. Similar educational payload activities are being planned to support the first flight of an Educator Astronaut.

An image-based educational program allows middle school students to direct and control a digital camera mounted in a window of the ISS to capture images of the Earth. The images are archived on the Web and used by educators to support curriculums in physics, technology, geography, weather, environment, and Earth science. To date, nearly 940 schools and 26,000 students from the United States, Europe, Japan, New Zealand, and Canada have participated in the middle school program.

The ISS crews participate in live in-flight education video downlinks. Similar to a videoconference, students pose questions related to classroom studies and watch from their school or science center as crewmembers discuss and demonstrate science, technology, engineering, and math concepts in space. Members of the education communities, NASA Centers, other Government agencies (notably the Department of Education), and the ISS international partners sponsor these events. The downlinks support national and state education standards and are provided at no cost to the host organization. During the last year, over 42,000 students from the U.S. and Japan participated in downlinks.

An amateur radio program also offers formal and informal opportunities for students and adults to experience the excitement of talking directly with crewmembers on the ISS. Amateur radio organizations and space agencies in the U.S., Russia, Canada, Japan, and Europe sponsor these unique educational experiences. Crew members make school contacts via ham radio similar to the in-flight education video downlinks. Crewmembers also make random contacts with Earth-bound ham radios during their breaks, presleep time, and before and after mealtime. The deorbit of an instrumented Russian space suit, SuitSAT, captured the attention of students and ham radio operators around the world.

The ISS is a valuable platform for supporting crew photography of the Earth and NASA's public outreach program. The astronaut-acquired imagery provides insight into natural Earth processes and documents human activities on the planet. This program captures spontaneous events such as the flooding from the hurricane in New Orleans, the damage resulting from the tsunami in Asia, and volcanic eruptions. Images have been used to map coral reefs, seasonal changes, and plankton blooms. The handheld photography also captures human impacts on the Earth – such as urban land use, agricultural expansion, deforestation, and destruction of New York City's Twin Towers on 9/11. The ISS imagery continues forty-plus years of time series imagery which has been ongoing since human spaceflight began in 1961. In 2005, NASA's Web site, "The Gateway to Astronaut Photography of Earth" (http://eol.jsc.nasa.gov/), received an average of 17 million hits per month.

Hurricane in the Gulf of Mexico.

Other U.S. Government Agency Participation

The ISS provides a valuable platform for research and technology development applications which support other U.S. Government agencies.

The DOD has been utilizing the ISS for technology development experiments since the early ISS increments. These basic technology development activities take advantage of the ISS's on-orbit location and access to the crew for payload deployment, servicing, and reconfigurations. These experiments validate new technologies for current and future space systems and are consistent with the "peaceful purposes" objectives of the ISS program. Potential technology applications include precise and autonomous timekeeping and space navigation without Global Positioning System, atmospheric changes and measurements, first alert sensor demonstrations, autonomous formation flying technologies, advanced solar cell technologies, engine plume modeling, materials exposure sampling, and satellite inspections and servicing.

Artist's depiction of DOD autonomous flying formation technologies.

The ISS may also serve as a space-based platform for the DOE-sponsored Alpha Magnetic Spectrometer (AMS). The 16-nation international collaboration is building a high-energy particle physics and astrophysics experiment designed to search for previously undetected forms of anti-matter and dark matter. The AMS was originally scheduled to fly to the ISS on the Space Shuttle. However, due to the need to launch higher-priority payloads on the limited number of Space Shuttle flights remaining before its retirement in 2010, AMS was removed from the Shuttle launch manifest. NASA is exploring the use of alternative expendable launch vehicles to carry the AMS to the ISS, though an alternative launch is not currently baselined or funded. Preliminary costs associated with alternative launch options have been developed, but a formal cost estimate of such alternative launch options still needs to be conducted. NASA has not determined whether such a launch would be the most effective use of the Agency's limited funds.

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International Partners

ISS partner utilization is based on the principle of each partner providing ISS elements and/or resources and receiving an allocation of utilization resources in return. Canada, Europe, and Japan's space agencies actively share flight research data and hardware in the following multilateral forums: the International Space Life Science Working Group and the International Microgravity Strategic Planning Group. NASA is also responsible for providing payload launch services and on orbit resources to the Italian Space Agency (ASI) and ESA resulting from cooperative and offset barter agreements. In exchange for the ASI contribution of three Multi-Purpose Logistics Modules and the ESA contribution of Nodes 2 and 3, NASA is providing ASI and ESA with Space Shuttle launch services, crew time, and on-orbit resources for both the pressurized laboratory and the external un-pressurized attachment sites. ASI and ESA are using these opportunities to pursue research and technology development activities focused on life sciences and crew performance, robotics, solar observations, and materials exposure.

<u>The Canadian Space Agency (CSA)</u>: Canada's utilization program focuses on life and physical science research with a small commercial applications program. In exchange for providing the Mobile Servicing System currently onboard the ISS, CSA receives 2.3 percent of ESA, JAXA, and NASA user accommodations. Instead of providing rack-level hardware for ISS research, CSA has arrangements with ESA, JAXA, and NASA to provide research equipment and ground support in exchange for access to on-orbit research data.

<u>The European Space Agency (ESA)</u>: ESA manages a robust ISS utilization program focused on life and physical science research with some education programs. ESA is developing the Columbus Module that will accommodate up to 12 research racks on the ISS. ESA is currently developing five research racks for the Columbus. NASA will have access to 46.7 percent of ESA's Columbus accommodations and plans to install several research racks in the module, including both HRF racks, the MSG, and an "Expedite the Processing of Experiments to Space Station" (EXPRESS) Rack. ESA will have rights to 8.3 percent of non-Russian on-orbit resources once the Columbus Module is activated on orbit. Until then, ESA has entered into numerous arrangements with NASA and the Russian Federal Space Agency (Roscosmos) for launch of ESA hardware as well as for on-orbit crewtime and utilization resources. ESA also manages the flight program for individual European national research programs.

<u>The Japan Aerospace Exploration Agency (JAXA)</u>: JAXA's ISS utilization program is focused on life science, physical science, commercial applications, and education. JAXA has developed the Japanese Experiment Module (JEM) for conducting its research program aboard the ISS. The JEM will consist of both pressurized and exposed modules for research. At present, the JEM will contain three internal racks and three external research payloads. NASA will have access to 46.7 percent of the JEM research facilities and plans to install the "Minus Eighty (Degrees Celsius) Laboratory Freezer for ISS" (MELFI) and 2 to 3 EXPRESS Racks in the module. JAXA will have rights to 12.8 percent of non-Russian on-orbit resources once the JEM is activated on-orbit. Until then,

JAXA has entered into numerous bilateral arrangements with NASA, ESA, and Roscosmos for launch of experiment equipment as well as for on-orbit crewtime and resources to conduct their experiments.

The Russian Federal Space Agency (Roscosmos): The Roscosmos utilization program is focused largely on biomedical research and provision of utilization services via commercial contracts with the private sector and other space agencies. NASA has no utilization rights to Russian modules. Likewise, Russia has no utilization rights to U.S., European, or Japanese modules.

ISS Life Science Centrifuge

As stated in section 506 of PL109-155, this plan shall include “an assessment of the impact of having or not having a life science centrifuge aboard the ISS.” That point is addressed in this section.

Placement of a life science centrifuge, such as the Centrifuge Accommodations Module (CAM), on ISS would enable NASA to obtain early data on the affect of microgravity on the health and behavior of living beings during long-duration exposure. These data would be valuable in studying the effects of chronic exposure to partial gravity, similar to that of the Moon and/or Mars, on a living organism’s muscles, bones, heart, and other biomedical body systems and would provide:

- Identification of potential health risks of living in fractional-g.
- Valuable information for predicting medical care needs (such as bone fracture healing) for humans adapted to “off-Earth” habitation.
- Predictions of how effective partial-g will be as a countermeasure to the detrimental effects of space flight.

Other important information that could be gained from the CAM includes:

- Determination if there is a gravity “threshold”, or a minimum amount of gravity, that when applied either intermittently or continuously would alleviate microgravity physiological effects during spaceflight or upon return to earth; and
- Differentiation of the effects of gravity from other space variables that contribute to the overall physiological changes observed in the microgravity environment.

This information is not available from any simulation environment on Earth, and if there is no CAM, this knowledge will not be available before astronauts perform exploration missions, possibly delaying the informed development of medical countermeasures.

The benefit to life sciences was one of several factors NASA took into account when making the decision to not continue with the CAM. Those factors included the following:

- The incompatibility of the resource requirements necessary to implement research in the CAM (up/downmass, the ability to transport live specimens, cold stowage) and the resources available with a reduced number of Space Shuttle flights and Space Shuttle retirement in 2010.
- The costs and financial burden associated with the CAM research and supporting infrastructure relative to the total available research budget.
- The relative priority of the research that can be accomplished in the CAM compared to other ISS research and utilization necessary for implementation of the VSE.
- The schedule requirements for lunar and planetary habitats vs. the availability of knowledge and deliverables from the CAM research.

The decision to not continue with the CAM is consistent with NASA's prioritization, within NASA's allocated budget, of effective implementation of VSE goals to reduce the overall critical risks associated with space exploration.

While the full research program centered around the life sciences centrifuge and the questions it was intended to address will not be fully realized, there will be new, but reduced, NASA research opportunities in biomedical science. The life sciences research portfolio content has shifted from lower CRLs to higher CRLs with more specific, directed outcomes than was required in the past. In addition, 15 percent of the funds budgeted for ISS research will be allocated to a combination of ground-based, free flyer, and ISS life and microgravity science research that is more fundamental in nature. In addition, the research programs of the international partners still contain a large percentage of more fundamental research, and the intent is to leverage off of their research results. The ideal program would include a life sciences centrifuge on ISS, but the logistical realities preclude that. Alternative opportunities, such as those described in the Non-Exploration Research section of this report can provide some fundamental new knowledge in biological and biomedical sciences, including information about responses to fractional gravity.

Appendices

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Appendix A: ISS Configuration

Included are the ISS Configuration, Assembly Sequence, and Joint Statement by the Heads of Agencies at their meeting on March 2, 2006.

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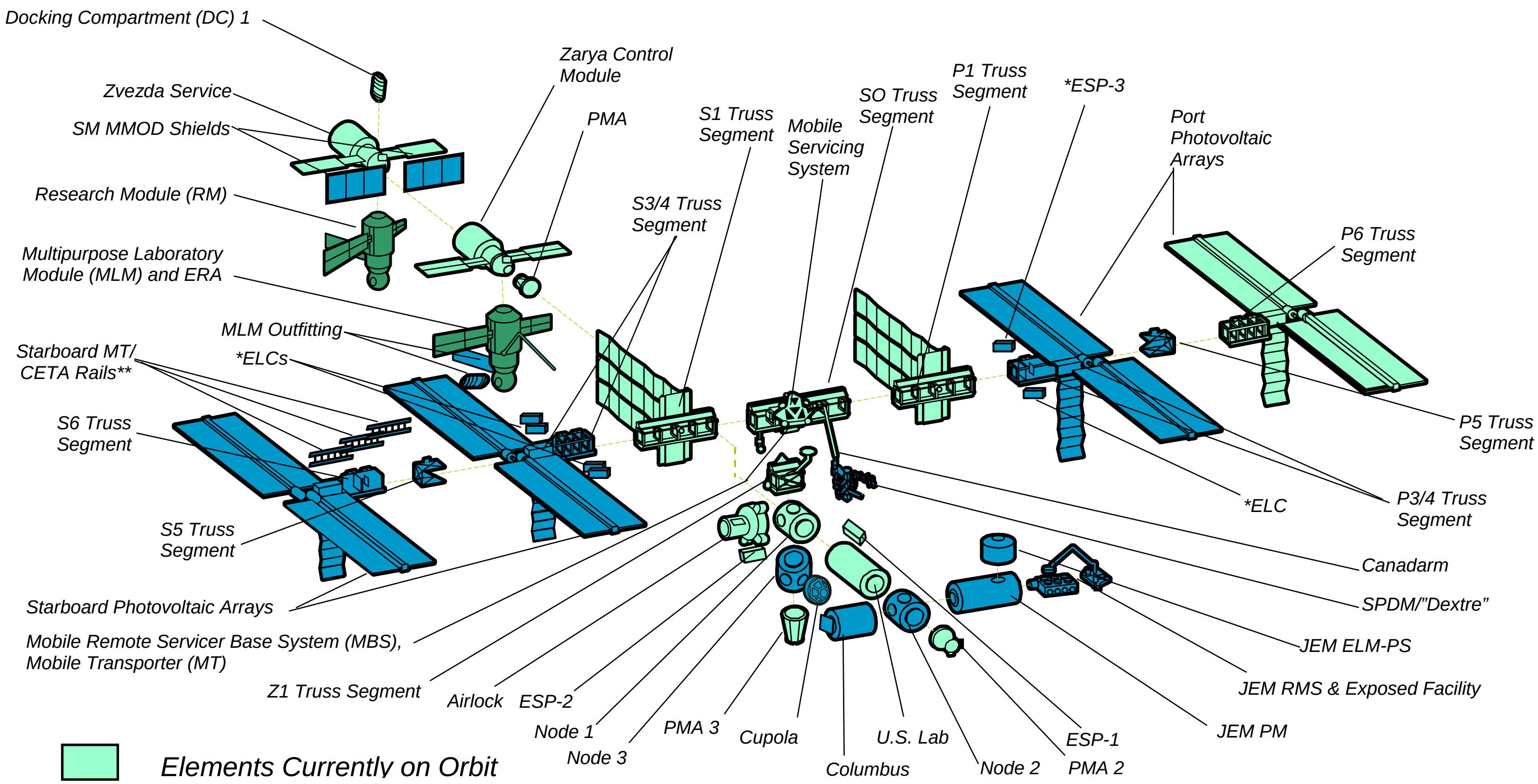
ISS Configuration



Elements Currently on Orbit

Elements Pending US Shuttle Launch

Elements Pending Russian Launch

*** For Reference Only**

**** Starboard MT/CETA Rail deletion is under review**

ISS Assembly Sequence

Flt	Delivered Elements/Milestones
ULF1.1	MPLM-P (OGS, 2 ISPRs, RSPs/RSRs); ICC (PM, TUS RA, 2 FGB); LMC (TPS DTO)
12A	P3/4
12A.1	P5; SHAB (Single); ICC (3 SMDPs)
13A	S3/S4 w/ PVR
13A.1	S5; SHAB (Single); ESP3 (NTA, BCDU) (P6 move<TBC>)
ATV1	ATV1
10A	Node 2 (4 Sys racks, 2 ZSRs, 2 RSRs); Sidewall (PDGF)
1E	Columbus Module (3 Sys Racks, 4 RSPs<TBD**>, 5 ISPRs); MPESS-ND (NTA <TBD**>, 2 EPF P/Ls) -- Rtn MPESS-ND (NTA<TBD**>)
1J/A	ELM PS (3 ISPRs, 4 JEM PM System, 1 JEM RSR); SLP-D1 (SPDM/"Dextre", SPDM EOTP) -- Rtn: SLP-D1
1J	JEM PM (4 JEM Sys racks, JEM RMS)
15A	S6
ULF2	MPLM-P (WRS1, WRS2, WRS 1&2 Outfitting, ARED, ARED Outfitting, 1 JEM ICS Rack, 3 ISPRs, RSR/RSPs); LMC (TBD)
3R	Multi-purpose Laboratory Module (MLM) w/ ERA
2J/A	JEM EF; ELM ES (EF P/L, ICS, SFA); SLP-D2 (6 Batteries) -- Rtn: SLP-D2
17A	MPLM-P (3 Crew Qtrs, JAXA Outfitting, Galley, WHC, TVIS2, TVIS2 Outfitting, CHeCS2, 1 ISPR, RSR/RSPs); LMC (ATA) -- Rtn: LMC (ATA)
	Establish Six Person Crew Capability
HTV1	HTV1
ULF3	ELC1 (MLM Outfitting, Pre-positioned Spares); ELC2 (Utilization, Pre-positioned Spares)
19A	MPLM-P (N3 Avionics Rack-2, N3 ARS, JAXA Outfitting, 2 ISPRs, RSR/RSPs); LMC (ATA) -- Rtn: LMC (ATA)
*ULF4	ELC3 (Utilization, Pre-positioned Spares); ELC4 (SM MMOD Wings, Utilization, 6 Batteries) -- Rtn ELC1 (NTA, EPF P/L)
20A	Node 3 w/ Cupola (N3 Avionics Rack-1)
*ULF5	ELC5 (Stbd MT/CETA Rails, Utilization, Pre-position Spares); ELC1 (Utilization, Pre-Positioned Spares/Corrective Maintenance)
	ISS Assembly Complete
9R	Research Module

* Two Shuttle-equivalent flights for contingency

** The number of RSPs and the NTA manifesting on 1E are under review

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Joint Statement
International Space Station
Heads of Agency
March 2, 2006
Kennedy Space Center, Florida

The heads of space agencies from Canada, Europe, Japan, Russia and the United States met at Kennedy Space Center, Florida, on March 2, 2006, to review International Space Station (ISS) cooperation and endorse a revision to the ISS configuration and assembly sequence. At today's meeting, the Heads of Agency were also briefed on the status of ongoing ISS operations and flight hardware development activities across the partnership. The partners reaffirmed their agencies' commitment to meet their mutual obligations, to implement six person crew operations in 2009, and an adequate number of Shuttle flights to complete the assembly of ISS by the end of the decade. The partners also affirmed their plans to use a combination of transportation systems provided by Europe, Japan, Russia, and the United States in order to complete ISS assembly in a timeframe that meets the needs of the partners and to ensure full utilization of the unique capabilities of the ISS throughout its lifetime.

The ISS Heads of Agency expressed their appreciation for the outstanding work being conducted by the ISS on-orbit crews and ground support personnel, commending them for their creativity in making full use of available resources to operate the ISS, prepare for assembly missions and carry out scientific research aboard the ISS. The uninterrupted flow of Russian vehicles, the outstanding performance of Canadarm2, the successful Shuttle logistics flight, and the resourcefulness of all of the partners' ground-based engineers, researchers and operations personnel have served to highlight the strength of the ISS partnership and the importance of international cooperation in space operations.

The partners look forward to the upcoming Space Shuttle flight of the STS-121 mission and a return to ISS assembly activity and a permanent crew of three. They also noted the upcoming launch of key ISS elements such as: three additional power trusses to support overall ISS needs and the needs of the partners, the European Space Agency Automated Transfer Vehicle, the U.S. Node 2, the European Space Agency Columbus Module, the Canadian two-armed Special Purpose Dexterous Manipulator Dextre, the Japanese Experiment Module Kibo, the Russian Multipurpose Laboratory Module and the Japanese H-2 Transfer Vehicle. These elements of the ISS Program will bring to fruition the partnership's goal of operation and utilization of a permanently inhabited civil International Space Station.

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Appendix B: Synopsis of U.S. Experiments on ISS (Expeditions 0 – 12*)

ASSURING THE SURVIVAL OF HUMANS TRAVELING FAR FROM EARTH

Radiation Studies.
Physiological Studies—bone and muscle, pulmonary function.
Physiological Studies—other effects of space flight - telemedicine, countermeasures immunosuppression, decompression sickness, drug delivery, diagnostic medicine.
Psycho-Social Studies.

EXPANDING UNDERSTANDING OF THE LAWS OF NATURE AND ENRICHING LIVES ON EARTH

Microgravity Studies - fluids, particle growth, colloids, crystals, proteins, magnetic fields, enhanced materials, dust particles, biophysical and biochemical processes.
Roll of gravity on living systems - cellular biology, genetic changes, microbes.
Effects of gravity on plant life – tissue growth, food sources.

CREATING TECHNOLOGY TO ENABLE THE NEXT EXPLORERS TO GO BEYOND WHERE WE HAVE BEEN

Adaptive technologies, materials and coatings, computer networks, vibration measurements and isolations, fabrication and repair, and rendezvous and docking.

EDUCATING AND INSPIRING THE NEXT GENERATION TO TAKE THE JOURNEY

Education demonstrations, Earth photography.

* 90 Investigations as of February 2006

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Appendix C: ISS Research Websites of Interest

ISS Research: From the ISS Program Scientist
http://exploration.nasa.gov/programs/station/

ISS Space Operations News
http://scipoc.msfc.nasa.gov/

ISS Research Status Reports 2003 - 2006
http://www.scipoc.msfc.nasa.gov/statuschron.html

ISS Science: Why do Research off the Planet?
http://spaceflight.nasa.gov/station/science/index.html

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Appendix D: ISS Results -- Scientific Publications

(As compiled by the ISS Program Science Office)

*The following are **91** ISS scientific results publications listed by payload or on-orbit activity*.

ADUM: Fincke, E.M., Padalka, G., Lee, D., van Holsbeeck, M., Sargsyan, A.E., Hamilton, D.R., Martin, D., Melton, S.L., McFarlin, K., Dulchavsky, S.A. Evaluation of Shoulder Integrity in Space: First Report of Musculoskeletal U.S. on the International Space Station. Radiology. 234(2):319-322, 2005.

ADUM: Chiao, L., Sharipov, S., Sargsyan, A.E., Melton, S., Hamilton, D.R., McFarlin, K., Dulchavsky, S.A. Ocular examination for trauma; clinical ultrasound aboard the International Space Station. Journal of Trauma. 58(5):885-889, 2005.

ADUM: Foale, C. M., Kaleri, A. Y., Sargsyan, A. E., Hamilton, D. R., Melton, S., Margin, D., Dulchavsky, S. A. Diagnostic instrumentation aboard ISS: just in time training for non-physician crewmembers. Aviation Space and Environmental Medicine 76:594-598, 2005.

ADVASC: Zhou, W., Durst, S.J., DeMars, M., Stankovic, B., Link, B.M., Tellez, G., Meyers, R.A., Sandstrom, P.W., Abba, J.R. Performance of the Advanced ASTROCULTURE™ plant growth unit during ISS-6A/7A mission. SAE Technical Paper Series. Paper # 02ICES-267, 2002.

ADVASC: Link, B. M., Durst, S. J., Zhou, W., Stankovic, B. Seed-to-seed growth of Arabidopsis Thaliana on the International Space Station. Advances in Space Research. 31(10):2237-2243, 2003.

ADVASC: Zhou, W., Corbin, T. Advanced Astroculture™ Plant Growth Unit: Capabilities and Performances. 35th International Conference on Environmental Systems, Rome, Italy. Jul. 11 - 14, 2005.

ARIS-ICE: Bushnell, G.S., Fialho, I.J., Allen, J.L., Quraishi, N. Microgravity Flight Characterization of the International Space Station Active Rack Isolation System. AIAA Microgravity Measurements Group Meeting, The World Space Congress, Houston, TX. Oct 10 - 11, 2002.

ARIS-ICE: Bushnell, G.S., Fialho, I.J., McDavid, T., Allen, J.L., Quraishi, N. Ground And On-Orbit Command and Data Handling Architectures For The Active Rack Isolation System Microgravity Flight Experiment. AIAA 53rd International Astronautical Congress, The World Space Congress, Houston, TX. IAC-02-J.5.07, Oct 10 - 19, 2002.

ARIS-ICE: Fialho, I.J., Bushnell, G.S., Allen, J.L., Quraishi, N. Taking H-infinity To The International Space Station: Design, Implementation and On-orbit Evaluation of Robust Controllers For Active Microgravity Isolation. AIAA Guidance, Navigation and Control Conference, Austin, TX. Aug 2003.

BBND: Koshiishi, H., Matsumoto, H., Koga, K., Goka, T. Evaluation of Low-Energy Neutron Environment inside the International Space Station. Technical Report of Institute of Electronics, Information, and Communications Engineers SANE2003-79: 11-14, 2003. [Japanese]

BPS: Musgrave, M.E., Kuang, A., Tuominem, L.K., Levine, L.H., Morrow, R.C. Seed Storage Reserves and Glucosinolates in Brassica rapa L. Grown on the International Space Station. Journal of the American Society for Horticultural Science. 130(6): 848-856. 2005

CBOSS-01-Ovarian: Hammond, H.K., Becker, J., Elliot, T.F., Holubec, K., Baker, T.L., Love, J.E. Antigenic Protein in Microgravity-Grown Human Mixed Mullerian Ovarian Tumor (LN-1) Cells Preserved in a RNA Stabilizing Agent. Gravitational and Space Biology. 18(2):99-100, 2005.

CEO: Quod, J-P., Bigot, L., Blanchot, J., Chabanet, P., Durville, P., Nicet, J-B., Wendling, B. Research and monitoring of the coral reefs of the French islands of the Indian Ocean. Assessment activities in 2002. Mission carried out in Glorieuses. Réunion: IFRECOR (l'Initiative Française pour les Récifs Corallines). 2, 2002. [French]

CEO: Robinson, J.A., Evans, C.A. Space Station Allows Remote Sensing of Earth to within Six Meters. Eos, Transactions of the American Geophysical Union. 83:185-188, 2002.

CEO: Cembella, A.D., Ibarra, D.A., Diogene, J., Dahl, E. Harmful Algal Blooms and their Assessment in Fjords and Coastal Embayments. Oceanography. 18(2):160-173, 2005

CEO: Stumpf, R.P., Holderied, K., Robinson J.A., Feldman, G., Kuring, N. Mapping water depths in clear water from space. Proceedings of the 13th Biennial Coastal Zone Conference. 2003.

CEO: Stefanov, W.L., Robinson J.A. Vegetation Density Measurements From Digital Astronaut Photography. International Archives of the Photogrammetry, Remote Sensing, and Spatial Information Sciences. 34:185-189, 2003.

CEO: Andrefouet, S., Gilbert, A., Yan, L., Remoissenet, G., Payri, C., Chancerelle, Y. The remarkable population size of the endangered clam Tridacna maxima assessed in Fangatau Atoll using in situ remote sensing data. ICES Journal of Marine Science. 2005.

CEO: Andréfouët, S., Robinson J.A., Hu, C., Salvat, B., Payri, C., Muller-Karger F.E. Influence of the spatial resolution of SeaWiFS, Landsat 7, SPOT and International Space Station data on landscape parameters of Pacific Ocean atolls. Canadian Journal of Remote Sensing. 29:210-218, 2003.

CEO: Lulla, K. 2003 Nighttime Urban Imagery from International Space Station: Potential Applications for Urban Analyses and Modeling. Photogrammetric Engineering and Remote Sensing. 69:941-942, 2003.

CFE: Weislogel, M.M. Preliminary Results from the Capillary Flow Experiment Aboard ISS: The Moving Contact Line Boundary Condition. Proceedings of the 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2005-1439, Jan 10-13, 2005.

CGBA-APS: Benoit, M.R., Li, W., Stodieck, L.S., Lam, K.S., Winther, C.L., Roane, T.M., Klaus, D.M. Microbial antibiotic production aboard the International Space Station. Applied Microbiology Biotechnology. Online: 1-9 2005.

CPCG-H: Vallazza, M., Banumathi, S., Perbandt, M., Moore, K., DeLucas, L., Betzel, C., Erdmann, V. Crystallization and Structure Analysis of Thermus flavus 5S rRNA helix B. Acta Crystallographica. Section D, Biological Crystallography. 58:1700-1703, 2002.

CPCG-H: Krauspenhaar, R., Rypniewski, W., Kalkura, N., Moore, K., DeLucas, L., Stoeva, S., Mikhailov, A., Voelter, W., and Betzel, C. Crystallization under microgravity of mistletoe lectin I from Viscum album with adenine monophosphate and the crystal structure at 1.9Å resolution. Acta Crystallographica. Section D, Biological Crystallography. 58:1704-1707, 2002.

CPCG-H: Nardini M., Spano S., Cericola C., Pesce A., Damonte G., Luini A., Corda D., Bolognesi M. Crystallization and preliminary X-ray diffraction analysis of brefeldin A-ADP ribosylated substrate (BARS). Acta Crystallographica. Section D, Biological Crystallography. 58:1068-1070, 2002.

CPCG-H: Miele, A.E., Federici, L., Sciara, G., Draghi, F., Brunori, M., Vallone, B. Analysis of the effect of microgravity on protein crystal quality: the case of a myoglobin triple mutant. Acta Crystallographica. Section D, Biological Crystallography. D59: 928-988, 2004

DAFT: Urban, D., Griffin, D., Ruff, G., Cleary, T., Yang, J., Mulholland, G., Yuan, Z. Detection of Smoke from Microgravity Fires. Proceedings of the International Conference on Environmental Systems. 2005-01-2930, 2005.

DOSMAP: Reitz, G., Beaujean, R., Dachev, Ts., Deme, S., Luszik-Bhadra, M. Heinrich, W., Olko, P. Dosimetric Mapping. Conference and Exhibit on International Space Station Utilization, Cape Canaveral, FL. AIAA-2001-4903, Oct 15-18, 2001.

EPO: National Aeronautics and Space Administration Educational Product. International Toys in Space - Science on the Station DVD. ED-2004-06-001-JSC, 2004.

EXPPCS: Manley, S., Cipelletti, L., Trappe, V., Bailey, A.E., Christianson, R.J., Gasser, U., Prasad, V., Segre, P.N., Doherty, M.P., Sankaran, S., Jankovsky, A.L., Shiley, B., Bowen, J., Eggers, J., Kurta, C., Lorik, T., Weitz, D.A. Limits to Gelation in Colloidal Aggregation. Physical Review Letters. 93(10):108302, 2004.

EXPPCS: Manley, S., Davidovitch, B., Davies, N.R., Cipelletti, L., Bailey, A.E., Christianson, R.J., Gasser, U., Prasad, V., Segre, P.N., Dohert, M.P., Sankaran, S., Jankovsky, A.L., Shiley, B., Bowen, J., Eggers, J., Kurta, C., Lorik, T., Weitz, D.A. Time-Dependent Strength of Colloidal Gels. The American Physical Society - Physical Review Letters. 95(4); 048302(4), 2005.

EXPPCS: Weitz, D., Bailey, A., Manley, A., Prasad, V., Christianson, R., Sankaran, S., Doherty, M., Jankovsky, A., Lorik, T., Shiley, W., Bowen, J., Kurta, C., Eggers, J., Gasser, U., Serge, P., Cipelletti, L., Schofield, A., Pusey, P. Results From the Physics of Colloids Experiment on ISS. NASA TM. 2002-212011: IAC-02-J.6.04, 2002.

EarthKAM: Hurwicz, M. Case Study: Attack Of The Space Data -- Down To Earth Data Management At ISS EarthKAM. New Architect 38, Aug 1, 2002.

Education-SEEDS: Levine, H.G., Norwood, K.L.L., Tynes, G.K., Levine, L.H. Soybean and Corn Seed Germination in Space: The First Plant Study Conducted on

Space Station Alpha. Proceedings of the 38th Space Congress, Cape Canaveral, FL. 181-187, May 2001.

Environmental Monitoring: Castro, V.A., Thrasher, A.N., Healy, M., Ott, C.M., Pierson, D.L. Microbial Charcterization during the Early Habitation of the International Space Station. Microbial Ecology. 47:119-126, 2004.

Environmental Monitoring: La Duc, M. T., Sumner, R., Pierson, D., Venkat, P., Venkateswaran, K. Evidence of pathogenic microbes in the International Space Station drinking water: reason for concern? Habitation. 10:39-48, 2004.

Environmental Monitoring: Plumlee, D., Mudgett, P., Schultz, J., James, J. ISS Potable Water Sampling and Chemical Analysis: Expeditions 4-6. 33rd International Conference on Environmental Systems, Vancouver, Canada. SAE Technical Paper 2003-01-2401, July 2003.

Environmental Monitoring: Perry, J., Peterson, B. Cabin air quality Dynamics on Board the International Space Station. 33rd International Conference on Environmental Systems, Vancouver, Canada. SAE Technical Paper 2003-01-2650, July 2003.

Environmental Monitoring: James, J. Toxicological Assessment of the International Space Station Atmosphere with Emphasis on Metox Canister Regeneration. 33rd International Conference on Environmental Systems, Vancouver, Canada. SAE Technical Paper 2003-01-2647, July 2003.

Environmental Monitoring: Plumlee, D., Mudgett, P.D., Schultz, J.R. Chemical Sampling and Analysis of ISS Potable Water: Expeditions 1-3. 32nd International Conference on Environmental Systems, San Antonio, TX. SAE Technical Paper 2002-01-2537, 2002.

FMVM: Ethridge, E., Kaukler, W., Antar, B. Preliminary Results of the Fluid Merging Viscosity Measurement Space Station Experiment. Proceedings of the 44th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2006-1142, Jan 9-12, 2006.

Foot: Cavanagh, P.R., Maender, C., Rice, A.J., Gene, K.O., Ochia, R.S., Snedeker, J.G. Lower-Extremity Loading During Exercise on the International Space Station. Transactions of the Annual Meeting of the Orthopaedic Research Society 0395, 2004.

H-Reflex: Watt, D.G., Lefebvre, L. Effects of altered gravity on spinal cord excitability. First Research on the International Space Station, Conference and Exhibit on International Space Station Utilization, Cape Canaveral, FL. AIAA 2001-4939, Oct 15-18, 2001.

H-Reflex: Watt, D.G. Effects of prolonged exposure to microgravity on H-reflex loop excitability. Proceedings of the 14th IAA Humans in Space Symposium, Banff, Alberta. May 2003.

H-Reflex: Watt, D.G. Effects of altered gravity on spinal cord excitability (final results). Proceedings of the Bioastronautics Investigators' Workshop, Galveston, TX. Jan 2003.

ICE-First: Higashitani, A., Higashibata, A., Sasagawa, Y., Sugimoto, T., Miyazawa, Y., Szewcyk, N.J., Viso, M., Gassett, G., Eche, B., Fukui, K., Shimazu, T., Fujimoto, N., Kuriyama, K., Ishioka, N. Checkpoint and physiological apoptosis in germ cells proceeds normally in spaceflown Caenorhabditis elegans. Apoptosis. 10(5):949-954, 2005.

ISSI: Grugel, R., Cotton, L.J., Segre, P.N., Ogle, J.A., Funkhouser, G., Parris, F., Murphy, L., Gillies, D., Hua, F., Anilkumar, A.V. The In-Space Soldering Investigation (ISSI): Melting and Solidification Experiments Aboard the International Space Station. Proceedings of the 44th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2006-521, Jan 9-12, 2006.

Interactions: Kanas, N., Ritsher, J. Leadership Issues with Multicultural Crews on the International Space Station: Lessons learned from Shuttle/Mir. Acta Astronautica. 56:932-936, 2005

Interactions: Ritsher, J., Kanas, N., Ihle, E. Psychological adaptation and salutogenesis in space: Lessons from a series of studies. 15th Humans in Space Symposium: Benefits of Human Presence in Space. Graz, Austria, Book of Abstracts. 22, May 22-26, 2005.

Interactions: Ritsher, J. B., Kanas, N., Gushin, V. I., Saylor, S. Cultural differences in patterns of mood states on board the International Space Station. 56th International Astronautical Congress. Fukuoka, Japan. Oct. 17-21, 2005.

Interactions: Clement, J., Ritsher, J. B. Operating the ISS: Cultural and leadership challenges. 56th International Astronautical Congress. Fukuoka, Japan. Oct. 17-21, 2005.

Interactions: Kanas, N., Salnitskiy, V. P., Ritsher, J. B., Gushin, V. I., Weiss, D. S., Saylor, S., Marmar, C. Human interactions in space: ISS versus Shuttle/Mir. 56th International Astronautical Congress. Fukuoka, Japan. Oct. 17-21, 2005.

Interactions: Kanas, N., Salnitskiy, V., Ritsher, J., Gushin, V., Weiss, D., Saylor, S., Marmar, C. Psychosocial interactions during ISS missions. 15th Humans in Space Symposium: Benefits of Human Presence in Space. Graz, Austria, Book of Abstracts. 21, May 22-26, 2005.

MACE-II: Davis, L. Economical and Reliable Adaptive Disturbance Cancellation. Requires DOD Clearance to view this paper. AFRL-VS-TR-2002-1118 Vol. I, AFRL-VS-TR-2002-1118 Vol. II Pt. 1, AFRL-VS-TR-2002-1118 Vol. II Pt. 2, AFRL-VS-TR-2002-1118 Vol. II Pt. 3, Sep 2002.

MACE-II: Ninneman, R., Founds, D., Davis, L., Greeley, S., King, J. Middeck Active Control Experiment Reflight (MACE II) Program: Adventures in Space. AIAA Space 2003 Conference and Exhibition, Long Beach, CA. AIAA 2003-6243, 2003.

MAMS: Del Basso, S., Laible, M., O'Keefe, E., Steelman, A., Scheer, S., Thampi, S. Capitalization of Early ISS Data for Assembly Complete Microgravity Performance. Proceedings of the 40th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2002-606, Jan 14-17, 2002.

MAMS: DeLombard, R., Kelly, E.M., Hrovat, K., Nelson, E.S., Pettit, D.R. Motion of Air Bubbles in Water Subjected to Microgravity Accelerations. Proceedings of the 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2005-722, Jan 10-13, 2005.

MEPS: Le Pivert, P., Haddad, R.S., Aller, A., Titus, K., Doulat, J., Renard, M., Morrison, D.R. Ultrasound Guided, Combined Cryoablation and Microencapsulated 5-Fluorouracil, Inhibits Growth of Human Prostate Tumors in Xenogenic Mouse Model

Assessed by Fluorescence Imaging. Technology in Cancer Research and Treatment. 3(2):135-42, 2004.

MEPS: Morrison, D.R., Haddad, R.S., Ficht, A. Microencapsulation of Drugs: New cancer therapies and improved drug delivery derived from microgravity research. Proceedings of the 40th Space Congress, Cape Canaveral, FL. Apr 2003.

MFMG: Pojman, J.A. Miscible Fluids in Microgravity (MFMG): A Zero-Upmass Experiment on the International Space Station. Proceedings of the 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2005-718, Jan 10-13, 2005.

MISSE-1 and 2: Finckenor, M.M. The Materials on International Space Station Experiment (MISSE): First Results from MSFC Investigations. Proceedings of the 44th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2006-472, Jan 9-12, 2006.

Nutritional Status: Smith, S., Zwart, S.R., Block, G., Rice, B.L., Davis-Street, J.E. The nutritional status of astronauts is altered after long-term space flight aboard the International Space Station. Journal of Nutrition. 135(3):437-443, 2005.

Other ISS Research: Sargsyan, A.E., Hamilton, D.R., Jones, J.A., Melton, S., Whitson, P.A., Kirkpatrick, A.W., Martin, D., Dulchavsky, S.A. FAST at MACH 20: Clinical Ultrasound Aboard the International Space Station. The Journal of Trauma, Injury, Infection, and Critical Care. 58(1):35-39, 2005.

Other ISS Research: D'Aunno, D.S., Dougherty, A.H., DeBlock, H.F., Meck, J.V. Effect of Short- and Long-Duration Spaceflight on QTc Intervals in Healthy Astronauts. The American Journal of Cardiology 91: 494-497 2003

PCG-EGN: Barnes, C.L., Snell, E.H., Kundrot, C.E. Thaumatin crystallization aboard the International Space Station using liquid-liquid diffusion in the Enhanced Gaseous Nitrogen Dewar (EGN). Acta Crystallographica. Section D, Biological Crystallography. 58(Pt 5): 751-760, 2002.

PCG-EGN: Ciszak, E., Hammons, A.S., Hong, Y.S. Use of Capillaries for Macromolecular Crystallization in a Cryogenic Dewar. Crystal Growth & Design 2(3):235-238, 2002.

PESTO: Paul, A., Levine, H.G., McLamb, W., Norwood, K.L., Reed, D., Stutte, G.W., Wells, H.W., Ferl, R.J. Plant molecular biology in the space station era: Utilization of KSC fixation tubes with RNAlater. Acta Astronautica. 56:623-628, 2005.

PESTO: Stutte, G.W., Monje, O., Goins, G.D., Tripathy, B.C. Microgravity effects on thylakoid, single leaf, and whole canopy photosynthesis on dwarf wheat. Planta 1-11, 2005.

PESTO: Stutte, G.W., Monje, O., Anderson, S. Wheat (Triticum Aesativum L. cv. USU Apogee) Growth Onboard the International Space Station (ISS): Germination and Early Development. Proceedings of the Plant Growth Regulation Society of America. 30:66-71 2003.

PESTO: Monje, O., Stutte, G., Chapman, D. Microgravity does not alter plant stand gas exchange of wheat at moderate light levels and saturating CO2 concentration. Planta. Online, Jun 2005.

PESTO: Monje, O., Stutte, G.W., Goins, G.D., Porterfield, D.M., Bingham, G.E. Farming in Space: Environmental and Biochemical Concerns. Advances in Space Research. 31:151-167, 2003.

PFMI: Strutzenberg, L.L., Grugel, R.N., Trivedi, R. Observation of an Aligned Gas - Solid Eutectic during Controlled Directional Solidification aboard the International Space Station - Comparison with Ground-based Studies. Proceedings of the 42nd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2005-919, 2005.

PFMI: Grugel, R.N., Anilkumar, A.V., Cox, M.C. Morphological Evolution of Directional Solidification Interface in Microgravity: An Analysis of Model Experiments Performed on the International Space Station. Proceedings of the 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2005-917, Jan 10-13, 2005.

PFMI: Grugel, R.N., Anilkumar, A.V. Bubble Formation and Transport during Microgravity Materials Processing: Model Experiments on the Space Station. Proceedings of the 42th AIAA Aerospace Sciences Meeting & Exhibit, Reno, NV. AIAA 2004-0627 Jan 5-8, 2004.

PFMI: Cox, M.C., Anilkumar, A.V., Grugel, R.N., and Hofmeister, W.H. Isolated Wormhole Growth and Evolution during Directional Solidification in Small Diameter Cylindrical Channels: Preliminary Experiments. Proceedings of the 44th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2006-1140, Jan 9-12, 2006.

PFMI: Grugel, R.N., Anilkumar, A.V., Lee, C.P. Direct Observation of Pore Formation and bubble mobility during controlled melting and re-solidification in microgravity, Solidification Processes and Microstructures. A Symposium in Honor of Wilfried Kurz. The Metallurgical Society, Warrendale, PA. 111-116, 2004.

SAMS-II: DeLombard, R., Hrovat, K., Kelly, E.M., Humphreys, B. Interpreting the International Space Station Microgravity Environment. Proceedings of the 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2005-0727, 2005.

SUBSA: Churilov, A.V., Ostrogorsky, A.G. Solidification of Te and Zn doped InSb in space. 42nd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 200-1388, 2004. (Also published in the Journal of Thermophysics and Heat Transfer, 19(4); 547-547, 2005)

SUBSA: Ostrogorsky, A., Marin, C., Churilov, A., Volz, M., Bonner, W.A., Spivey, R.A., Smith, G. Solidification Using the Baffle in Sealed Ampoules. 41st Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2003-1309, 2003.

SUBSA: Spivey, R.A., Gilley, S., Ostrogorsky, A., Grugel, R., Smith, G., Luz, P. SUBSA and PFMI Transparent Furnace Systems Currently in use in the International Space Station Microgravity Science Glovebox. 41st Aerospace Sciences Meeting and Exhibit. AIAA 2003-1362, 2003.

SUBSA: Churilov, A.V., Ostrogorsky, A.G. Model of Tellurium- and Zinc-Doped Indium Antimonide Solidification in Space. Journal of Thermophysics and Heat Transfer. 19(4); 542-547, 2005. (Also published at the 42nd AIAA Meeting, 2004-1388, 2004)

Subregional Bone: Lang, T., LeBlanc, A., Evans, H., Lu, Y., Gennant, H., Yu, A. Cortical and Trabecular Bone Mineral Loss from the Spine and Hip in Long-duration Spaceflight. Journal of Bone and Mineral Research. 19(6):1006-12, 2004.

ZCG: Akata, B., Yilmaz, B., Jirapnogphan, S. S., Warzywoda, J., Sacco, Jr., A. Characterization of zeolite Beta grown in microgravity. Microporous and Mesoporous Materials. 71:1-9, 2004.

ISS Sorties

*The following are **6** ISS scientific sorties listed by payload or on-orbit activity.*

CBTM: Gridley, D.S., Nelson, G.A., Peters, L.L., Kostenuik, P.J., Bateman, T.A., Morony, S., Stodieck, L.S., Lacey, D.L., Simske, S.J., Pecaut, M.J. Genetic models in applied physiology: selected contribution: effects of spaceflight on immunity in the C57BL/6 mouse. II. Activation, cytokines, erythrocytes, and platelets. Journal of Applied Physiology. 94(5):2095-2103, 2003.

CBTM: Bateman, T.A., Morony, S., Ferguson, V.L., Simske, S.J., Lacey, D.L., Warmington, K.S., Geng, Z., Tan, H.L., Shalhoub, V., Dunstan, C.R., Kostenuik, P.J. Molecular therapies for disuse osteoporosis. Gravitational and Space Biology Bulletin. 17 2004.

CBTM: Harrison, B.C., Allen, D.L., Girten, B., Stodieck, L.S., Kostenuik, P.J., Bateman, T.A., Morony, S., Lacey, D.L., Leinwand, L.A. Skeletal muscle adaptations to microgravity exposure in the mouse. Journal of Applied Physiology. 95(6):2462-2470, 2003.

CBTM: Pecaut, M.J., Nelson, G.A., Peters, L.L., Kostenuik, P.J., Bateman, T.A., Morony, S., Stodieck, L.S., Lacey, D.L., Simske, S.J., Gridley, D.S. Genetic models in applied physiology: selected contribution: effects of spaceflight on immunity in the C57BL/6 mouse. I. Immune population distributions. Journal of Applied Physiology. 94(5):2085-2094, 2003.

Latent Virus: Mehta, S.K., Cohrs, R.J., Forghani, B., Zerbe, G., Gilden, D.H., Pierson, D.L. Stress-induced Subclinical Reactivation of Varicella Zoster Virus in Astronauts. Journal of Medical Virology 72:174-179, 2005.

Latent Virus: Pierson, D.L., Stowe, R.P., Phillips, T.M., Lugg, D.J., Mehta, S.K. Epstein-Barr Virus Shedding by Astronauts During Space Flight. Brain, Behavior, and Immunity. 19:235-242, 2004.

ISS Research Summary and Review Publications

The following are review publications summarizing ISS research results.

Rhatigan, J.L., Robinson, J.A., Sawin, C.F. Exploration - Related Research on ISS: Connecting Science Results to Future Missions. NASA/TP-2005-213166. 1-34, 2005. (Also published at the 44th AIAA Meeting, 2006-344, 2006)

Pellis, N.R., North, R.M. Recent NASA Research Accomplishments Aboard ISS. 54th International Astronautical Congress of the International Astronautical Federation, the IAA and the International Institute of Space Law, Bremen, Germany. IAC-03-T.4.07 Sep 29 - Oct 3, 2003.

Rhatigan, J. Research Accomplishments on the International Space Station. AIAA/ICAS International Air and Space Symposium and Exposition: The Next 100 Years, Dayton, OH. AIAA 2003-2703, 2003.

Robinson, J.A., Rhatigan, J.L., Baumann, D.K. Recent Research Accomplishments on the International Space Station. Proceedings of the IEEE Aerospace Conference, Big Sky, MT. Paper #310, Mar 5 - 12, 2005.

Rhatigan, J.L., Robinson, J.A., Sawin, C.F. Exploration - Related Research on ISS: Connecting Science Results to Future Missions 44th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2006-344, 2006. (Also published as a NASA/TP 2005-213166)

ISS Exploration Publications

The following are publications about lessons learned on ISS and how they apply to future exploration missions.

Walz, C., Uri, J., Baumann, D. Far from home--human presence on the ISS as a preparation for a lunar base and beyond. Proceedings of the 1st Space Exploration Conference, Orlando, FL. AIAA 2005-2549, Jan 30 - Feb 1, 2005.

Carrasquillo, R.L. ISS ECLSS Technology Evolution for Exploration Proceedings of the 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA-200-0337 Jan 10 - 13, 2005.

Kitmacher, G.H., Rosenberg, I., Gerstenmaier, W. ISS: A partner in enabling space exploration through reduction of risk. Proceedings of the 1st Space Exploration Conference, Orlando, FL. AIAA 2005-2550, Jan 30 - Feb 5, 2005.

Sanchez, M.J., Voss, J.S. From ISS to the Moon, Mars, and Beyond--applying lessons learned. Proceedings of the 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. AIAA 2005-705, Jan 10 - 13, 2005.

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Appendix E: ISS Research Facilities and Hardware

The information provided in this appendix is intended to be a brief overview and description of the major facilities and hardware that will be utilized by NASA for research on ISS. It is by no means a comprehensive list of all of the individual research hardware items that are necessary to conduct the research. It is also not inclusive of the facilities and major hardware items that will be provided and primarily utilized by the international partners in implementation of their national research programs.

Human Research Facility (HRF) Racks

The HRP has ownership of or access to a number of facilities on ISS. The two primary facilities are the two HRF Racks. HRF Rack 1 was launched to ISS in March 2001, and it is outfitted with the Gas Analyzer System for Metabolic Analysis Physiology (GASMAP), an ultrasound device, the HRF Workstation computer system, and a portable laptop computer. HRF Rack 2 was launched to ISS in July 2005, and it is outfitted with the Pulmonary Function System (PFS), a refrigerated centrifuge, the Space Linear Acceleration Mass Measurement Device (SLAMMD), and an upgraded HRF Workstation computer system. In addition to the Racks, the HRF suite of hardware includes the Ambulatory Data Acquisition System, Foot Ground Interface equipment, the Joint Excursion System, the Lower Extremity Monitoring Suit, a Continuous Blood Pressure Device, and Activity Monitors. The HRF Racks are intended to be modular in their design and capability, allowing for the upgrade or change-out of research equipment as requirements change. Additional information about the HRF racks and the associated research equipment can be found at http://hrf.jsc.nasa.gov/hardware.asp.

HRF Rack 1

HRF Rack 2

Fluids Combustion Facility

The Fluids and Combustion Facility (FCF) is an ISS research facility designed to support physical, biological, and technology experiments in space. The FCF consists of two modular, reconfigurable racks called the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR). The capabilities of the CIR and FIR and plans for their utilization will support the VSE.

The FIR provides a large, contiguous volume for experimental hardware, easily reconfigurable diagnostics, customizable software, active rack-level vibration isolation, and data acquisition and management. It can also serve as a platform for experiments that address human health and performance, medical technologies, and biosciences.

The FIR will accommodate experiments that address critical research and technology needs for advanced life support (i.e., air revitalization, water reclamation, etc.), power, propulsion, and spacecraft thermal control systems. Experiments will address boiling heat transfer, multiphase flow, liquid vapor interface control, and liquid/vapor evaporation/condensation, as they relate to the technology needs of various exploration spacecraft subsystems. The first planned FIR payload is the Constrained Vapor Bubble (CVB) experiment which will utilize the Light Microscopy Module (LMM). The LMM is an automated, fully motorized subrack mini-facility based on the Leica RXA microscope. The LMM is capable of supporting biological investigations to identify spacecraft contaminants and performing microscopic observations of materials. The CVB experiment will provide an understanding of the thermal and fluid physics principles underlying change of phase heat transfer systems controlled by interfacial phenomena under microgravity conditions.

Combustion Integrated Rack **Fluids Integrated Rack**

The CIR will accommodate experiments that address critical needs in the areas of spacecraft fire safety (i.e., fire prevention, detection, and suppression), incineration of solid wastes, power generation, flame spread, soot and polycyclic aromatic hydrocarbons, *in situ* resource utilization, environmental monitoring, and materials synthesis. The CIR provides a large environmental chamber in which the space environment or Lunar, Mars, or other planetary surface environments can be simulated. Other features include digital cameras, a gas chromatograph, and, after initial crew set-up, it can be operated from the ground. The CIR can also serve as a test bed to mature systems and concepts for exploration missions and provides a platform for on-orbit fabrication and repair activities. Initial experiments performed in the CIR will provide data to support design decisions for exploration spacecraft. The first experiment to be performed in the CIR is the Droplet Flame Extinguishment in Microgravity experiment (FLEX), which uses the Multi-User Droplet Combustion Apparatus (MDCA). The experiment will utilize the spherically-symmetric geometry of droplet combustion as a model environment for quantifying the efficacy of gaseous fire suppressants in microgravity. The subrack payload for doing the experiment, MDCA, contains the payload hardware and software necessary for conducting the FLEX experiment. It consists of two components: a chamber insert assembly and an avionics box. The chamber insert assembly is a framework for the mounting of internal components such as the droplet dispensing and deployment mechanisms and radiometers. It connects to the chamber by mounting on guide rails. The avionics box provides for command, control, and data handling of the experiment.

Microgravity Science Glovebox (MSG)

MSG offers scientists the capability to conduct investigations, test science procedures, and develop new technologies in microgravity. The MSG provides an enclosed work area, about the size of a microwave oven, for these small-scale investigations. The MSG also provides a work area with two levels of containment--physical barrier and negative pressure--between the crew working space and the microgravity investigations. The MSG provides a sealable, controlled workspace for performing investigations that require hands-on attention, while protecting the astronaut researcher and the rest of the crew. Fluids, powders, bioproducts, and irritants are among the materials that may be used by researchers during their investigations. It is a facility designed to support investigations and demonstrations in five microgravity research disciplines: materials science, biotechnology, combustion science, fluid dynamics, and fundamental physics. Within MSG, while investigations are being conducted, three video cameras can record the development of the investigation. These data may be transmitted to the principal investigators on Earth, allowing them to instruct the crew to make experimental adjustments if necessary. Gravity dominates everything on Earth, from the way life has developed to the way materials interact. But aboard a spacecraft orbiting the Earth, the effects of gravity are barely felt. In this "microgravity environment," scientists can conduct experiments that are all but impossible to perform on Earth. In this virtual absence of gravity, space flight gives scientists a unique opportunity to study the states of matter (solids, liquids, and gases), and the forces and processes that affect them.


MSG

Minus Eighty (Degrees Celsius) Laboratory Freezer for ISS (MELFI)

The MELFI will provide the Space Station with refrigerated volume for storage and fast-freezing of life science and biological samples. Samples are stored in four dewars that are cooled by controlling the flow of liquid nitrogen into a series of tubes running through the dewars. The temperature in the dewars can be controlled independently at three operating modes: +4°C, -26°C, and -80°C. One MELFI unit will be launched to ISS on the upcoming STS-121 Space Shuttle mission, and three additional units are available for future launch and utilization.


MELFI

Expedite the Processing of Experiments to Space Station Rack (EXPRESS Rack)

The EXPRESS Rack is a standardized payload rack system that transports, stores, and supports ISS experiments in several disciplines including biology, chemistry, physics, ecology, and medicine. It provides simple, standard interfaces to accommodate modular-type payloads. Standard hardware and software interfaces simplify the analytical and physical integration processes and facilitate simpler ISS payload development.

The EXPRESS Rack provides power, data, command and control, video, water cooling, air cooling, vacuum exhaust, and nitrogen supply to payloads. With standardized hardware interfaces and streamlined approach, the EXPRESS Rack enables quick, simple integration of payloads aboard the ISS. Payloads within an EXPRESS Rack can operate independently of each other, allowing for differences in temperature, power levels, and schedules. The EXPRESS Rack provides ISS accommodations for large payloads, as well as small subrack payloads. Each rack can be divided into segments, as large as half rack or as small as a breadbox. Experiments contained within EXPRESS Racks may be controlled by the ISS crew or controlled remotely from the ground. Five EXPRESS racks are currently on the ISS in various configurations, and three more are available for future launch and outfitting. Additional Information can be found at: http://www.nasa.gov/centers/marshall/news/background/facts/expressrack.html.

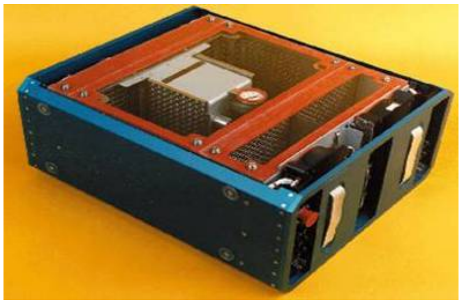

EXPRESS Rack

Commercial Utilization Facilities and Payloads

The following are descriptions of Research Partnership Center (RPC) payloads that are ready to fly and have principal investigators waiting to do experiments on them. These projects will comprise the initial commercial research program on the ISS. Additional experiments and payloads will be developed and flown as needs and opportunities arise.

Commercial Generic Bioprocessing Apparatus (CGBA): This payload is already on the ISS and only needs periodic refurbishing and sample resupply. CGBA will be used for biotechnology experiments supporting cell, tissue, and small organism commercial and exploration-related research. It has been used to support NASA-Ames researchers and the JAXA Granada Protein Crystallization experiments, as well as commercial research.


CGBA



CBTM

Commercial Biomedical Testing Module (CBTM): CBTM has flown on Space Shuttle (STS-108), where it was used to perform rodent testing on bone-loss prevention drugs developed by commercial partners. It will be used on the ISS for preclinical biomedical testing of potential countermeasures for bone loss and muscle atrophy and to support development of drugs by the pharmaceutical industry to treat osteoporosis and muscle-wasting diseases.

Commercial Protein Crystal Growth (CPCG): This is a high-throughput version of the commercial protein crystal growth hardware that has flown many times on the Space Shuttle. For this plan, it could be installed on ISS and used by commercial partners in their structure-based drug design programs. The apparatus will also be available for use by NASA researchers.

CPCG

HDMAX Ultra-High Definition Digital Video and HDMAX Evolved Operational Camera System (HEOCam): This system was developed by two of the RPCs in partnership with a company that flies external cameras on Space Shuttle and with a major entertainment firm. It was selected by the U.S. Navy for port surveillance and by NASA for Space Shuttle inspection, although its operational flight debut has been delayed with return to flight. The camera has considerable potential for detailed observation of experiments on the ISS.

HDMAX

Space Dynamically Responding Ultrasonic Matrix System (Space-DRUMS™): This full Express Rack payload was developed by an RPC industrial partner to process ceramic and composite materials in space of a form and microstructure that cannot be produced on Earth. Other companies and space agencies of other countries are interested in processing materials in this system, which also has important applications to NASA's exploration programs in *in situ* resource utilization and in-space fabrication and repair.

Space-DRUMS™

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Appendix F: NASA Technical Report, "Exploration-Related Research on ISS: Connecting Science Results to Future Missions"

The following pages are an excerpt (abstract, table of contents, and introduction) from the NASA Technical Report, "Exploration-Related Research on ISS: Connecting Science Results to Future Missions". The full report may be found at: http://ston.jsc.nasa.gov/collections/TRS/_techrep/TP-2005-213166.pdf

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NASA/TP—2005–213166

Exploration-Related Research on ISS: Connecting Science Results to Future Missions

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Table of Contents

Abstract

In January, 2004, the U.S. President announced *The Vision for Space Exploration*, and charged the National Aeronautics and Space Administration (NASA) with using the International Space Station (ISS) for research and technology targeted at supporting U.S. space exploration goals. This paper describes:

- What we have learned from the first four years of research on ISS relative to the exploration mission,
- The on-going research being conducted in this regard, and
- Our current understanding of the major exploration mission risks that the ISS can be used to address.

Specifically, we discuss research carried out on the ISS to determine the mechanisms by which human health is affected on long-duration missions, and to develop countermeasures to protect humans from the space environment. These bioastronautics experiments are key enablers of future long duration human exploration missions. We also discuss how targeted technological developments can enable mission design trade studies. We discuss the relationship between the ultimate number of human test subjects available on the ISS to the quality and quantity of scientific insight that can be used to reduce health risks to future explorers. We discuss the results of NASA’s efforts over the past year to realign the ISS research programs to support a product-driven portfolio that is directed towards reducing the major risks of exploration missions.

The fundamental challenge to science on ISS is completing experiments that answer key questions in time to shape design decisions for future exploration. In this context, exploration-relevant research must do more than be conceptually connected to design decisions—it must become a part of the mission design process.

1 Introduction

While NASA has always engaged in space exploration research, *The Vision for Space Exploration* [1] has brought with it specific mission definitions, corresponding timelines, and focused research objectives. The International Space Station is a key element in supporting this focused research. What may not be evident is the amount of ISS scientific research and development that is targeted towards exploration objectives. We have arranged our discussion topically so that the reader can understand accomplishments and progress in each area of research. We devote the beginning of each topical section to discussion of what has been learned and the latter portion of each section to what is currently on-going in this regard. Also, the shorthand name or acronym for each experiment is in bold text for ease of use.

Prior to the announcement of *The Vision for Space Exploration*, NASA, along with the I international partners, had envisioned the ISS as a “world-class” microgravity laboratory available to a broad-based user community spanning academic, industrial, commercial and educational elements [2]. Indeed, the breadth of the potential user community that NASA had courted was often cited as a source of resulting disenfranchisement for those who had committed resources to the use of ISS (e.g., [3]). Research objectives for ISS ranged from the pursuit of basic, fundamental scientific understandings of microgravity physics, to targeted commercial technology developments. While this range encompassed the research necessary to further space exploration, *The Vision for Space Exploration* and subsequent definition of specific missions for NASA have included a much more focused use of the ISS. Human health research efforts on ISS have been guided by the *Bioastronautics Roadmap* [4], a synopsis of the risks of space exploration to human health (on ISS, reference lunar, and reference Mars exploration missions) and the research questions that need to be addressed to reduce these risks. NASA is now evolving specific research mission objectives to accomplish on ISS within a specific timeframe. Section 3 of this article addresses the approach to determine how the ISS can be used to address specific, targeted risks to human health on long-duration exploration missions.

In addition to the focus on human health, NASA is beginning to address technology development issues for exploration missions. Experiments to improve environmental monitoring, fire detection and suppression, and inspection and repair techniques will provide information critical for exploration vehicle designs.

The ISS can be viewed as an experiment in and of itself in many respects, as it is a unique, one-of-a-kind space vehicle. We note that ISS achievements are not limited to the scientific research discussed in this paper and refer the interested reader to broader treatments of the engineering, operational, and human accomplishments from the International Space Station [5, 6, 7, 8] in order to understand the full scope of the contribution of ISS to the path of evolution of NASA's exploration objectives.

Appendix G: Acronym List

Acronym	Definition
ADUM	Advanced Diagnostic Ultrasound in Microgravity
ADVASC	Advanced Astroculture™
AMS	Alpha Magnetic Spectrometer
AO	Announcement of Opportunity
ARIS-ICE	Active Rack Isolation System - ISS Characterization Experiment
ASI	Italian Space Agency
ATV	Automated Transfer Vehicle
BBND	Bonner Ball Neutron Detector
BPS	Biomass Production System
CAM	Centrifuge Accommodation Module
CBOSS-01-Ovarian	Cellular Biotechnology Operations Support Systems: Evaluation of Ovarian Tumor Cell Growth and Gene Expression
CBTM	Commercial Biomedical Testing Module
CEO	Crew Earth Observations
CEV	Crew Exploration Vehicle
CFE	Capillary Flow Experiments
CGBA	Commercial Generic Bioprocessing Apparatus
CGBA-APS	CGBA - Antibiotic Production in Space
CHMO	Chief Health and Medical Officer
CIR	Combustion Integrated Rack
COTS	Commercial Orbital Transportation Services
CPCG	Commercial Protein Crystal Growth
CPCG-H	CPCG – High Density
CRL	Countermeasure Readiness Level
CSA	Canadian Space Agency
CVB	Constrained Vapor Bubble
DAFT	Dust and Aerosol Measurement Feasibility Test
DEXTRE	Special Purpose Dexterous Manipulator
DLR	German Aerospace Center
DOD	Department of Defense
DOE	Department of Energy
DOSMAP	Dosimetric Mapping
EarthKAM	Earth Knowledge Acquired by Middle School Students
EMC	Environmental Monitoring and Control
ENose	Electronic Nose
EPO	Education Payload Operations

ESA	European Space Agency
ESAS	Exploration Systems Architecture Study
ETDP	Exploration Technology Development Program
EVA	Extravehicular Activity
EXPPCS	EXPRESS Physics of Colloids in Space
EXPRESS	Expedite the Processing of Experiments to Space Station
FCF	Fluids and Combustion Facility
FDA	Food and Drug Administration
FIR	Fluids Integrated Rack
FLEX	Droplet Flame Extinguishment Experiment
FMVM	Fluid Merging Viscosity Measurement
Foot	Foot/Ground Reaction Forces During Space Flight
FPDS	Fire Prevention, Detection and Suppression
GASMAP	Gas Analyzer System for Metabolic Analysis Physiology
HEOCam	HDMAX Evolved Operational Camera System
H-Reflex	Effects of Altered Gravity on Spinal Cord Excitability
HRF	Human Research Facility
HRP	Human Research Program
HSRT	Human Systems Research & Technology
HTV	H-II Transport Vehicle
ICE-First	International Caenorhabditis elegans Experiment: Physiological Study of Nematode Worms in Weightlessness
Interactions	Crewmember and Crew-Ground Interaction During International Space Station Missions
ISLSWG	International Space Life Sciences Working Group
ISPR	International Standard Payload Rack
ISRU	*In-Situ* Resource Utilization
ISS	International Space Station
ISSI	In Space Soldering Investigation
ISSMP	ISS Medical Project
ITAR	International Traffic in Arms Regulations
IVA	Intravehicular Activity
JAXA	Japan Aerospace Exploration Agency
JEM	Japanese Experiment Module
LED	Light-Emitting Diode
LEO	Low-Earth Orbit
LMM	Light Microscopy Module
MABE	Microheater Array Boiling Experiment
MACE-II	Middeck Active Control Experiment-II
MAMS	Microgravity Acceleration Measurement System

MDCA	Multi-user Droplet Combustion Apparatus
MELFI	Minus Eighty (Degrees Celsius) Laboratory Freezer for ISS
MEPS	Microencapsulation Electrostatic Processing System
MISSE	Materials International Space Station Experiment
MIT	Massachusetts Institute of Technology
MSG	Microgravity Sciences Glovebox
MSIR	Materials Survivability, Inspection and Repair
NASA	National Aeronautics and Space Administration
NPBX	Nucleate Pool Boiling Experiment
NRA	NASA Research Announcement
NRC	National Research Council
NSBRI	National Space Biomedical Research Institute
OCHMO	Office of the Chief Health and Medical Officer
OGS	Oxygen Generation System
OSHA	Occupational Safety and Health Administration
PCG-EGN	Protein Crystal Growth-Enhanced Gaseous Nitrogen Dewar
PEC	Passive Experiment Carrier
PESTO	Photosynthesis Experiment and System Testing and Operation
PFMI	Toward Understanding Pore Formation and Mobility During Controlled Directional Solidification in a Microgravity Environment
PFS	Pulmonary Function System
PS	Propellant Storage
R&D	Research and Development
ReMAP	Research Maximization and Prioritization
RPC	Research Partnership Center
SAME	Smoke Aerosol Measurement Experiment
SAMS-II	Space Acceleration Measurement System-II
SEEDS	Space Exposed Experiment Developed for Students
SLAMMD	Space Linear Acceleration Mass Measurement Device
Space-DRUMS	Space Dynamically Responding Ultrasonic Matrix System
STS	Shuttle Transportation System
SUBSA	Solidification Using a Baffle in Sealed Ampoules
TC	Thermal Control
TMP	Transition to Medical Practice
TRL	Technology Readiness Level
VCAM	Vehicle Cabin Air Monitor
VSE	Vision for Space Exploration
WRS	Water Recovery System
ZBR	Zero Based Review
ZCG	Zeolite Crystal Growth

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Appendix H: Report Team

This report was prepared by a team composed of staff from the Exploration Systems Mission Directorate, the Space Operations Mission Directorate, and the Office of External Relations at NASA HQ. They are:

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