S. HRG. 109–1086

INTERNATIONAL SPACE STATION RESEARCH BENEFITS

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

UNITED STATES SENATE

ONE HUNDRED NINTH CONGRESS

FIRST SESSION

APRIL 20, 2005

Printed for the use of the Committee on Commerce, Science, and Transportation

U.S. GOVERNMENT PRINTING OFFICE

61–670 PDF WASHINGTON : 2010

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
Fax: (202) 512–2104 Mail: Stop IDCC, Washington, DC 20402–0001

SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED NINTH CONGRESS

FIRST SESSION

TED STEVENS, Alaska, *Chairman*

JOHN McCAIN, Arizona
CONRAD BURNS, Montana
TRENT LOTT, Mississippi
KAY BAILEY HUTCHISON, Texas
OLYMPIA J. SNOWE, Maine
GORDON H. SMITH, Oregon
JOHN ENSIGN, Nevada
GEORGE ALLEN, Virginia
JOHN E. SUNUNU, New Hampshire
JIM DeMINT, South Carolina
DAVID VITTER, Louisiana

DANIEL K. INOUYE, Hawaii, *Co-Chairman*
JOHN D. ROCKEFELLER IV, West Virginia
JOHN F. KERRY, Massachusetts
BYRON L. DORGAN, North Dakota
BARBARA BOXER, California
BILL NELSON, Florida
MARIA CANTWELL, Washington
FRANK R. LAUTENBERG, New Jersey
E. BENJAMIN NELSON, Nebraska
MARK PRYOR, Arkansas

LISA J. SUTHERLAND, *Republican Staff Director*
CHRISTINE DRAGER KURTH, *Republican Deputy Staff Director*
DAVID RUSSELL, *Republican Chief Counsel*
MARGARET L. CUMMISKY, *Democratic Staff Director and Chief Counsel*
SAMUEL E. WHITEHORN, *Democratic Deputy Staff Director and General Counsel*
LILA HARPER HELMS, *Democratic Policy Director*

SUBCOMMITTEE ON SCIENCE AND SPACE

KAY BAILEY HUTCHISON, Texas, *Chairman*

TED STEVENS, Alaska
CONRAD BURNS, Montana
TRENT LOTT, Mississippi
JOHN ENSIGN, Nevada
GEORGE ALLEN, Virginia
JOHN E. SUNUNU, New Hampshire

BILL NELSON, Florida, *Ranking*
JOHN D. ROCKEFELLER IV, West Virginia
BYRON L. DORGAN, North Dakota
E. BENJAMIN NELSON, Nebraska
MARK PRYOR, Arkansas

CONTENTS

INTERNATIONAL SPACE STATION RESEARCH BENEFITS

WEDNESDAY, APRIL 20, 2005

U.S. SENATE,
SUBCOMMITTEE ON SCIENCE AND SPACE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 10 a.m. in room SR–253, Russell Senate Office Building, Hon. Kay Bailey Hutchison, Chairman of the Subcommittee, presiding.

OPENING STATEMENT OF HON. KAY BAILEY HUTCHISON, U.S. SENATOR FROM TEXAS

The CHAIRMAN. I am told that Senator Nelson will be here briefly, but we all need to try to stay as close to on time as possible.

I want to welcome our distinguished panel and say that I am very pleased to be chairing my first hearing as Chairman of the Science and Space Subcommittee. We have chosen as the subject of our first hearing the tremendous scientific potential represented by the International Space Station and its position as one of the leading elements of the President's new Vision for Space Exploration.

The journey, of course, begins where we are now. And we have to make sure that we have a strong foundation for the journey ahead. We all look forward to having the Space Shuttle return to flight next month and to continue the assembly and utilization of the Space Station. In fact, our next hearing is going to focus more on the prospects for future Space Shuttle operations.

I have made my concerns known regarding the possibility of an extended hiatus between the time when the Shuttle is currently planned to be retired from service and the availability of a certified replacement crew launch vehicle. I think we cannot allow that kind of hiatus. Right now it is estimated to be 5 years. I think that is a national security threat to our country. And so I intend to pursue everything that I can to assure that we look at ways to shorten that timeframe.

Second, I am committed to ensuring that the investment we have made as a nation in the International Space Station is rewarded to the greatest extent possible by fulfilling the purposes for which it is designed. I think it is important that we not just say this is a tool for the Moon and Mars exploration-related research. I think the facility is capable of doing so much more for our Nation and for the world. I think we need to come back and look at the original purpose of the Space Station which was for scientific, industrial, engineering disciplines as well as Earth observation and supporting future exploration possibilities.

So, I want to go back to the original concept of the Space Station and look for all of the ways that we can fully utilize it. And one of the things I want to talk to you about today is other scientific value that we might be able to gain from experimentation aboard the Space Station. So, we are looking today at the current state of planning for the International Space Station and also on the potential and the vital scientific research aboard this unique international laboratory.

I look forward to hearing from all of you. We assembled you because we think you are the ones who can shed the most light on ISS research plans. So, we're looking forward to having this testimony as the basis for our re-authorization of NASA this year with the full capabilities of the International Space Station as one of key elements of the NASA re-authorization.

So, with that let me say, I am very pleased that my ranking member is the only one of us in the Senate who has been to space, since John Glenn left. And I am so pleased that you are my ranking member. We do have a complete meshing of commitment and ideas and visions for the future of NASA. And you will see a reinvigorated subcommittee that is overseeing and working with the leaders at NASA to fully utilize our capabilities and make sure that our investment is not wasted.

So, thank you very much for being here. And I would like to turn it to my ranking member, Senator Nelson, for any statement he might wish to make.

STATEMENT OF HON. E. BENJAMIN NELSON, U.S. SENATOR FROM NEBRASKA

Senator NELSON. Madam Chair, some of my critics were hoping that I was taking a one-way trip.

[Laughter.]

The CHAIRMAN. Well, Senator Nelson, I was going to say that your lateness would not be tolerated if you were still an astronaut, but since you are a Senator we are used to it.

[Laughter.]

The CHAIRMAN. So, I know you—I know you had a good reason to be somewhere else. Do you have any comments?

Senator NELSON. Just a couple. Kay and I are both excited about the new NASA Administrator. And that he has a vision and that he really is a rocket scientist. And that science is important to him. And that part of our problem in the past is that there was an atmosphere that pervaded NASA that did not encourage two-way communication. And thus, we saw the destruction of *Challenger* in 1986 because they were not listening to the people on the line. And again 18 years later that information from the bottom was not flowing up. And we think that the new Administrator has a sensitivity to that and we think that is going to be very good.

And we also think that he is committed to a balanced space program; manned and unmanned. And that in the human space programs a major component is the International Space Station. And the value that holds not only for us in the development of technologies and in the furtherance of science but also what it does for our relations with other countries that will participate with us.

So, the Chair and I are absolutely linked on all of this. And it is my privilege to serve as the Democratic leader of this subcommittee with my Chair, because we are of one mind. And we are also of one mind that space is not a partisan subject. Space is a subject that we can gather and have our differences over policy issues, but it has nothing to do with ideology and it has nothing to do with partisanship.

And so I am looking forward to your leadership and looking forward to the work of this Space Subcommittee. Thank you.

The CHAIRMAN. Thank you. Thank you, Senator Nelson. The first panel is Mr. William Readdy, Associate Administrator for the Space Operations Mission Directorate at NASA. You will be the only one giving testimony, I understand, but you are accompanied by Dr. Howard Ross, the Deputy Chief Scientist at NASA and Lieutenant Colonel Mike Fincke, Active Duty Astronaut at NASA, of course. And we welcome all three of you.

Mr. Readdy.

STATEMENT OF WILLIAM F. READDY, ASSOCIATE ADMINISTRATOR FOR SPACE OPERATIONS, NASA

Mr. READDY. Thank you, Madam Chairman and Senator Nelson, thank you for the opportunity to appear before you this morning. With your indulgence, given your commentary I'd like to digress a little bit. I just got off a plane from Florida. I was at the Design Certification Review for the Space Shuttle, for return to flight. Now, that in and of itself is just another milestone that we're completing, but I have you to thank for this.

When the new Administrator came onboard, he told us exactly what his priorities were and they were return to flight; build the International Space Station; honor our international commitments; and to reduce the gap of human space flight capability.

When he was informed that we were having the Design Certification Review yesterday, he got on the plane Monday night, came down and sat through the entire thing. I have to tell you that his questions were piercing, and it showed a total grasp of the information that was being presented. I think he was impressed with the technical depth that we went into. But he also had some questions of his own as you might expect, as he was coming up to speed with where we have been in the last two and a half years.

But we have you all to thank for that, because sitting in this chair 8 days ago, if you can believe that, 8 days ago Dr. Michael Griffin was here at his confirmation hearing. As you urged, his confirmation process happened very expeditiously. Probably as expeditiously as anyone can remember. He was on the job on Thursday where he spelled out those same priorities.

And I'm pleased to tell you that he was able to come to the Design Certification Review, because of his expeditious confirmation. And I think it points to the wisdom of his selection by the Administration as the nominee and now the appointee as the 11th NASA Administrator.

With me, as you mentioned, is Dr. Howard Ross, who's the Deputy Chief Scientist here at NASA. I think he has become renowned for his ability to communicate the benefits of International Space Station and the science that's performed.

Quite obviously Colonel Mike Fincke who just returned from 6 months onboard that magnificent International Space Station and unfortunately was removed from the planet Earth for the birth of his little daughter, Tarali, I guess who's now about 10 months old. But it's an indication that life goes on. It's also an indication that this is not about us sitting here at this table. This is about the future. This is about the legacy for our Nation in space.

Those benefits that you discussed, they're industrial, engineering and certainly science that will accrue from that laboratory that we're building up in space will be significant and both of these gentleman will be able to expand somewhat on that here in the testimony.

Immediately after Dr. Griffin came onboard, that very evening, we launched Expedition 11 to the International Space Station. The crew of Sergei Krikalev, as the Russian Commander who was also onboard the very first expedition to International Space Station as they turned on the lights and started setting up shop onboard.

It's been 1,630 days of continuous human presence onboard the International Space Station. And now jointly we have five crewmen onboard; three from Expedition 11 and the visiting crew member from Italy, Roberto Vittori. The science officer and flight engineer for this increment is John Phillips from NASA.

So, we have five crewmen onboard. I'll be leaving on Saturday for Russia to assist at the deorbit landing/return of Expedition 10 after their highly successful 6-month increment onboard International Space Station. Commander Leroy Chiao and his flight engineer, and Soyuz pilot, Salizhan Sharipov, are coming home on Sunday.

Now last year President Bush gave us a very bold challenge and Vision. Those priorities, I think, are what we're here to talk about today. Obviously, return to flight of the Space Shuttle is essential to continue assembly of International Space Station, to help realize those goals. That's part of a stepping stone strategy to go beyond low–Earth orbit and back to the Moon and beyond. Quite obviously it's very important for us to continue that effort. No one certainly foresaw the tragedy that occurred on February 1, 2003. The Space Station at this moment is half built. The other half is at the Kennedy Space Center with the exception of the Columbus module; it's still over in Europe, yet to be delivered. But half of the Space Station is already the size of a jumbo jet orbiting the Earth every 90 minutes. And right now it just happens to be the brightest morning star in the sky.

It is a magnificent piece of engineering prowess, demonstrating our ability to assembly large structures in space that we'll certainly need in the future. But it is only half built. At the moment, as Colonel Mike Fincke will tell you, it is having to rely exclusively on Progress vehicles for resupply. We had to scale the crew back from three to two, which we have done here for the last several increments. We're looking forward to Shuttle return to flight, also to return the crew size to three. Then as we increase the capability of the Space Station to enhance that all the way up to six.

The very character of exploration really counts on the ability to observe. There are no better observers than humans. I think Dr. Ross will talk a little bit more about that.

Our ability to do other things, as you mentioned, the daily operations that will allow us to go from hours away from this planet, which is International Space Station at 240 nautical miles, to days away from the planet; the Moon, the lunar surface, which is still in Earth orbit. Then make the leap beyond that to hundreds and hundreds of days away from this planet, which requires an incredible sophistication and reliability in the systems that we must operate for life support, for example; for autonomous operations. All of which, I think, have been demonstrated at least initially here onboard International Space Station. One of the things that they have demonstrated is we have a lot to learn. We've got a long way to go before we would consider regenerative life support systems carefree.

As you've seen and Mike can attest the Elektron, which generates oxygen for the Space Station, requires an incredible amount of tender loving care and maintenance to keep in operation. That clearly isn't acceptable when you're on the lunar surface nor when you're hundreds of days away from home en route to Mars.

This Space Station is also critical to understanding some of the challenges that we have in human health. He can also attest to some of the ravages of long duration space flight and what it takes in terms of counter measures to maintain your health such that you could function when you return to a gravity field.

I remember sending him a note after he passed, I guess about a month on orbit. I flew three times, so I had 28 days of space flight experience. In his rookie flight, by the way, in his first month he'd already surpassed me and was going even further down the road having performed four space walks in his 6-month increment. So, we're building a tremendous amount of experience that we will need as we go into the next decade of exploration.

The gathering of knowledge and validating our research is something Dr. Ross can talk to. But that's vital. To exploit, to reap the science benefit of that research platform that we have to continue assembly so that we can put an increased crew aboard is, obviously, one of our goals.

The closed-loop life support, as I mentioned earlier, is one of the things that will enable that to happen. It will enable us to go from a crew size of three, ultimately to six, in addition to some additional habitable volume. As you know spin-offs often occur from the technologies that we build intended for space. For example, the water processing assembly; that's part of the Regenerative Life Support System. That's being used right now, fielded by Hamilton Standard, who's our contractor, to purify water in Iraq and in some of the tsunami-ravaged areas of the world. The ability to take spoiled water, the ability to take brackish water, polluted water and turn it in to potable water is something that is of immediate benefit here on this planet. We, obviously, are hoping to fly that here in the near term.

International Space Station as you also mentioned is very, very important for turning the swords to plowshares and international cooperation. Who would have thought that a decade or so ago that the Russians would be our stalwart partners in this endeavor? That when the *Columbia* tragedy occurred, that they would be there and provide the crew transport to and from and the resupply necessary to continue Space Station operations as well as to preserve the Space Station in an assembly-ready configuration for when the Shuttle does return to flight. And we have great plans for Space Station utilization as we build that second half.

Inspiring the next generation is, obviously, one of NASA's missions. Inspiring my children, your children, Mike's children all over the world. That is something that they have taken on, I think, with vigor onboard the International Space Station. They talk routinely to school children around the world. They have a Earth Knowledge Acquired by Middle School Students, (EarthKAM) which allows the schools all over to command pictures to be taken from the International Space Station for scientific purposes and the study of geography. One that I think I enjoyed, and my children certainly did, while Mike Fincke was onboard, was "Saturday Morning Science." The ability to stimulate interest in science by performing experiments in the unique environment of microgravity. Finally, Senator Nelson, as you know the, "The PESTO Experiment," where dwarf wheat was cultivated on the Space Station and the outreach that that had was significant.

In terms of the Vision, obviously, the first step is returning the Shuttle to safe flight and we're about that. We're milestone driven. And having completed the Design Certification Review, that's one more milestone that we have completed toward returning to flight. And we think next month we can begin getting the Space Station assembled and honoring our international commitments.

I'd like to thank you for the opportunity to testify before you this morning. My two colleagues and I will be pleased to take your questions.

[The prepared statement of Mr. Readdy follows:]

PREPARED STATEMENT OF WILLIAM F. READDY,
ASSOCIATE ADMINISTRATOR FOR SPACE OPERATIONS, NASA

Madam Chairwoman and members of the Subcommittee, thank you for the opportunity to appear before you today to discuss the benefits of the International Space Station.

On January 14, 2004, President George W. Bush announced the *Vision for Space Exploration.* The President's directive gave NASA a new and historic focus and clear objectives. The fundamental goal of this directive for the Nation's space exploration program is ". . . to advance U.S. scientific, security, and economic interests through a robust space exploration program." In issuing this directive, the President committed the Nation to a journey of exploring the solar system and beyond, returning humans to the Moon, and sending robots and ultimately humans to Mars and other destinations. He challenged us to establish new and innovative programs to enhance our understanding of the planets, to ask new questions, and to answer questions as old as humankind.

Returning the Space Shuttle to flight and completing the International Space Station are the first steps in the Vision for Space Exploration, a stepping stone strategy toward new exploration goals. Using the Station to study human endurance in space and to test new technologies and techniques, NASA will prepare for the longer journeys to the Moon, Mars and beyond.

Today marks the 1,630th day of continuous human presence on the International Space Station. That is 11 international crews and over four years of research, discovery and experience in orbit. I am here today to tell you that NASA is progressing towards making the Vision a reality.

Just a few days ago NASA passed another important milestone for the Space Station. Expedition 11, Commander Sergei Krikalev and Flight Engineer John Phillips, docked to the Station this past Sunday to begin their six month stay onboard. European Space Agency astronaut Roberto Vittori traveled with them to the Station, and will return with the Expedition 10 crew, Commander Leroy Chiao and Flight Engineer Salizhan Sharipov. Chiao, Salizhan and Vittori will return home next Sunday, April 24. The Expedition 10 crew spent 191 days onboard the Station.

In addition, the Space Shuttle is in final preparations to fly again next month. Our return to flight also positions us to return to station assembly. NASA will complete the International Space Station by the end of the decade and meet its obligations to our international partners.

NASA will utilize the ISS to perform the necessary research and testing to help fulfill our exploration objectives. The very character of exploration and discovery begins with the ability to observe. We send humans into space because they are our best tools for observation. Crews on the International Space Station have gained firsthand knowledge of space-based life and they are bringing that information back to all of us.

While we can to some extent simulate living conditions in space here on the ground, there is no substitute for experience in the actual space environment. Simply put, to learn how to live in space, we must live in space. Every experiment, every spacewalk, every repair and every piece of hardware assembled teaches us something new. A full time human presence aboard the ISS offers us a tremendous opportunity to study human survival in the hostile environment of space and assess how to overcome the technology hurdles to human exploration beyond Earth orbit.

Assembly and Transportation

The development of ISS elements and systems is virtually complete; only the assembly process remains. The return to Space Shuttle operations means that NASA can once again begin construction work on the International Space Station. The first two Space Shuttle flights will focus on carrying cargo to the Station and testing new techniques for Orbiter repair. Following those two flights, the crew of STS–115 will restart the assembly of the International Space Station by carrying truss elements to orbit. From there, already completed Station elements will be sent into orbit on the Space Shuttle. The assembly sequence will complete the Station as efficiently and economically as possible, and with the minimum number of Shuttle flights necessary. As we make progress on construction of the Station, we will also work towards increasing the number of crew onboard to three members as soon as possible and working towards a six-person crew capability.

The President's Commission on Implementation of U.S. Space Exploration Policy recommended that ". . . NASA recognize and implement a far larger presence of private industry in space operations with the specific goal of allowing private industry to assume the primary role of providing services to NASA, and most immediately in accessing low-Earth orbit." Consistent with this recommendation, NASA is seeking to acquire commercial services as soon as practical and affordable to fulfill its transportation requirements for cargo to and from the ISS. NASA is developing a Request for Proposal (RFP) to be released in 2005. The RFP will seek to develop an initial operating capability for commercial services for cargo transportation to the ISS as soon as practical and affordable. NASA will also utilize partner capabilities for cargo transportation. The European Automated Transfer Vehicle will make its first visit to the ISS in 2006. The Japanese H2A Transfer Vehicle will also visit the ISS by the end of the decade.

Operational Experience

The International Space Station is more than just a science laboratory. The Station is critical to understanding human health, system performance and logistical support in the real environment of space.

Moreover, operating the Station with a limited re-supply capability has taught us much about how NASA might plan missions to more distant destinations where cargo re-supply options are limited. In any risky venture, experience and practice are vital. A mission to Mars will take at least 6 months in one-way transit; our Space Station crews experience that duration of exposure during each of their stays. Through the process of building and living on the Station, NASA has learned the following, all of which are vital to exploration:

- Assembly of Large Structures—Example: Automated and manual docking with various vehicles, including those built by other countries.
- Extensive Extravehicular Activity—Example: Performance of two types of Space Suits.

- Behavior of Crews—Examples: A range of crew sizes (two, three, and eventually six), genders, ethnicities, citizenship, and lengths of time in space—in various stages of ISS assembly/capabilities.
- Responses to Situations That Threaten Mission and/or Life-Examples: solar storms; loss of gyroscope; Elektron oxygen generator malfunctions; gradual depressurization episodes; water usage restrictions.
- Health Maintenance of Crew—Examples: nutrition; sleep; exercise; human physiological adaptation.
- Long-Term System and Subsystem Performance and Maintenance—Example: Environmental Control and Life Support Systems built in various combinations of systems from various nations.
- Practice of Operational Medicine—Example: majority of crew take some medication in flight; we and they rely on telemedicine and monitoring with limited onboard supplies and capabilities.
- Training for Long-Term Missions—Examples: efficacy of preflight versus onboard training; skills versus task training.
- Emergency Awareness and Preparedness—Examples: Depressurization Alarms and Repairs; Fire Alarms and Drills.

ISS Research: Knowledge Gathering and Validation

U.S. research activities aboard the Station will be focused to support the new exploration goals, with an emphasis on understanding how the space environment affects astronaut health and capabilities, and on developing appropriate countermeasures to mitigate health concerns. We will also use the Station to develop and demonstrate improved life support systems and medical care.

Human space flight research to date has identified a series of significant threats to human health associated with space travel. These health risks include bone loss and muscle atrophy; radiation exposure; and changes to fluid balances and blood pressure regulation. These changes may represent significant challenges on return to gravity and are of particular concern for future space travelers who will travel beyond access to Earth-based medical care. Behavioral and human performance concerns also exist. NASA's focused research program accelerates the evaluation of remediation methods for crew health problems and enables a better understanding of the requirements for health care systems for providing medical care during long duration human space exploration.

For example, NASA is using portable ultrasound equipment in new ways on the Space Station that are already translating to use back on Earth. Ultrasound is a fast and safe method to diagnose conditions inside the body. It uses sound waves to gain information about medical conditions ranging from gallbladder disease to kidney stones. What we are testing is a way to monitor and diagnose patients remotely by non-specialists working with an expert on Earth. Through such an approach, portable ultrasound machines can also be used to extend medical care into challenging areas such as remote rural or military locations. The remote procedure already has been tested on members of the Detroit Red Wings of the National Hockey League. The Red Wings conducted a test of these techniques to diagnose player injuries in the team's locker room rather than transporting athletes to a local hospital for an X-ray, CT or magnetic resonance imaging (MRI).

Among the most vital technological systems for any future space exploration mission is the life support system that must provide space travelers with a controlled Earth-like environment within the hostile environment of space. Any planned mission beyond Low Earth orbit will need to include a system for recycling water and air that is both very reliable and highly efficient. The ISS research program will test critical technologies in the design of such a closed-loop type system.

NASA research also benefits those of us here on Earth. One of the most important needs for the ISS is access to clean water. The Marshall Space Flight Center is currently developing a Water Processor Assembly (WPA) as part of the US Enhanced Crew Life Support System. This system will reclaim waste waters from fuel cells, from urine, from oral hygiene and hand washing, and by condensing humidity from the air. It will produce recycled water that will be cleaner than what we drink presently on Earth. Fresh water is an exceedingly scarce commodity in many locations around the world and the U.S. Now, the same technology we are using to build the WPA is being used to develop recycling systems for humanitarian purposes in nations lacking a reliable water supply, such as those Asian countries affected by the December 2004 tsunami. A source of clean, inexpensive and readily available water is just as important here on Earth as it is on the ISS, and as it will be on the Moon or the journey to Mars.

Future crews going to the Moon or Mars will need to be self-sufficient. Access to clean water is just one thing they will need in their journeys beyond Low Earth orbit. Others include monitoring and recycling air, waste sterilization procedures, longer shelf life for food products and renewable food sources. These applications can be tested on the ISS before we apply them to longer trips to the Moon and Mars. After all, it is better to learn 240 miles up than 240,000 miles out.

During long-duration missions in space and on planetary surfaces, crews must be able to live and work productively in safe and habitable environments. Performance of tasks by isolated crew—individual and teams—must be efficient, teachable, and reliable. These processes yield potential Earth benefits as well, including:

- Advances in emergency habitat and shelter deployment for a wide range of purposes (e.g. natural disaster, war refugee relief, temporary emergency safe haven for rescue crews.)
- Evaluation and design of self-contained, remote, and hazardous environments.
- New clinical methods for human reaction and interaction in isolated and confined environments.
- Advancement for process controls, tele-operations, and robotic systems development.
- Human performance modeling applies to the medical community's enhanced rehabilitation and therapeutic practices.
- Identification, measurement, analysis, mitigation and tracking of programmatic risks.

The International Space Station and Exploration

Led by the Exploration Systems Mission Directorate, NASA is currently in the process of focusing and prioritizing International Space Station research and technology development efforts on areas that best contribute to the Vision for Space Exploration. Through rigorous examination by technical and program managers at Headquarters and NASA field centers, we have identified 22 areas of research and technology that can take advantage of the Station as a testbed to reduce the risk associated with future human exploration missions. The Station will specifically contribute to the Vision for Space Exploration in areas such as: testing and validating performance of closed loop life support systems; testing and validating both pharmaceuticals and new exercise systems to maintain astronaut health, and; demonstrating technologies necessary for future space systems such as thermal control, power generation, and management of cryogenic fuels in space.

In order to best utilize limited resources, NASA is phasing out some activities that do not directly support the Vision for Space Exploration and reallocating resources to the higher priority areas. The Agency is emphasizing applied research and technology development in the following areas: space radiation health and shielding, advanced environment control and monitoring, advanced Extra Vehicular Activities suits and tools, human health and countermeasures, advanced life support, and space human factors and behavioral health. NASA's highest priorities for research on the Station have been identified as medical research with human subjects and microgravity validation of environmental control and life support technologies.

NASA also currently has a Space Shuttle Program/International Space Station (SSP/ISS) Scenario Study underway to examine alternate scenarios for the SSP and ISS as first steps to the Vision for Space Exploration. The study has been providing assessments that will support decision making for research, engineering, international and fiscal considerations. Two cycles have already been completed. The third cycle involves assessment of specific scenarios for US exploration research mission requirements. It is currently in the final stages of being documented for review and decision by Agency leadership.

NASA also studied long-term plans for Station utilization. In 2003, the Agency began to look at how it might turn some of the tactical operations of the Station research management over to a consortium. Because of the realignment of Station science and research to focus its activities to support the Vision for Space Exploration, the Agency chose not to further develop those plans. However, NASA has retained all of the studies and guidelines for use should it decide to move in that direction in the future.

International Partnership

The International Space Station is a cooperative effort. International crews work together daily—not just to keep the Station running, but to perform groundbreaking research. Joint research activities include the completion of a record-breaking 31-

day experiment called PromISS–3 that utilized the Microgravity Sciences Glovebox, a sealed laboratory with built-in gloves for conducting experiments in space. International crews have also worked together to deploy a microsatellite during a spacewalk, install research equipment onboard the Station, perform medical experiments and test on orbit systems. They also work together to inspire the next generation of explorers through programs such as:

- Amateur Radio on the ISS (ARISS)—an international project that allows students to talk by amateur radio with ISS crewmembers.
- Earth Knowledge Acquired by Middle School Students (EarthKAM)—allows students to control a digital camera mounted in a window on the Station; photos are available on the Internet for viewing and study by students around the world.
- High School Students United with NASA to Create Hardware (HUNCH)—High school students build training hardware that meets a specific need in NASA's Space Station payload training program.

At the recent International Space Station Partnership Heads of Agency (HOA) meeting on January 26, 2005, the Partners reviewed the status of ongoing Space Station operations and NASA's plans for Space Shuttle return to flight. The partners reaffirmed their agencies' commitment to meet their ISS obligations; to complete Station assembly by the end of the decade; and to use and further evolve the ISS in a manner that meets their research and exploration objectives. Our Space Station partnership is strong, as demonstrated by the fact that Space Station operations and research have continued without interruption throughout our significant preparations for return to flight.

The Station is preparing us for future human exploration in many ways. It is an exploration research and technology test bed. It is a platform that represents an unprecedented accomplishment for space engineering and on orbit assembly of unique and complex spacecraft. The Station is a model of space operations, linking mission control centers on three continents to sustain 24/7 space flight on-orbit operations by an international team speaking several different languages. Perhaps the most significant contribution of the ISS is that it is a foundation for international partnerships and alliances between governments, industry, and academia in space exploration. In this regard, the ISS was assembled on orbit with modules and other elements from Canada, Russia and the U.S. that were never connected on the ground. Additional elements from Europe and Japan will join the on-orbit structure when assembly resumes. The success of the assembly is a tribute to the engineering excellence and successful cooperation of the international team.

As the United States implements the Vision for Space Exploration, the Administration recognizes the value of effective cooperation with Russia to further our space exploration goals. At the same time, we have to appropriately reflect U.S. nonproliferation policy and objectives in our relationship with Russia. The Administration is thus interested in seeking a balanced approach that continues to protect our nonproliferation goals while advancing potential U.S. cooperation with Russia on the Vision for Space Exploration. Such a balanced approach must consider the Iran Nonproliferation Act of 2000 (INA), which currently complicates cooperation with Russia on the International Space Station, and will also have an adverse impact on cooperation with Russia on our future space exploration efforts related to human space flight. To that end, the Administration looks forward to working with Congress to ensure that the Vision for Space Exploration is able to succeed while remaining fully consistent with broader U.S. national security and nonproliferation goals.

Summary

As stated at the beginning of my testimony, returning the Space Shuttle to flight and completing the International Space Station are the first steps in the Vision for Space Exploration, a stepping stone strategy toward new exploration goals. Using the Station to study human endurance in space and to test new technologies and techniques, NASA will prepare for the longer journeys to the moon, Mars and beyond.

Thank you for the opportunity to testify today, and I look forward to responding to any questions you may have.

The CHAIRMAN. Thank you very much. We have been out of our Space Shuttle now for 2 years. And I wanted to ask you what you have learned that might tell us what would happen if we were out for a longer period of time, about our ability to send people up in the numbers that we would want for our own experimentation and research; as well as the maintenance of the Station. How has that 2-year hiatus been for us and what have we learned from it?

Mr. READDY. I'd like to start out and then I'll defer to Colonel Mike Fincke who has firsthand experience and can fill it in.

For starters, we did have to decrew to two from the three that we had onboard, because the logistics simply would not permit us to continue to supply them with food and water and other spare parts necessary to maintain the International Space Station during the hiatus. So, we were living literally from one Progress resupply vehicle to the next.

So, that was a severe impact. But out of those necessities comes some ingenuity and inventiveness on the part of the ground teams that we had. Not only from the science perspective but certainly from an operational perspective. Not only the TsUP, the flight control center in Moscow but also the flight control center there in Houston, and the experimental Payload Control Center there in Huntsville.

They all got together and they were able to kind of form a virtual third crew member by performing an awful lot of those tasks from the ground; doing an awful lot of replanning, off-loading the crew members so that whereas before we thought with three crew you'd have perhaps the equivalent of a half crew member devoted to science. Here with two crew you had the equivalent of half a crew member devoted to science, which showed that we could adapt and do a much better job when forced to, of utilizing crew time more effectively for those things that they must do uniquely onboard the International Space Station.

The CHAIRMAN. Could that be sustained over a longer period of time, that kind of efficiency?

Mr. READDY. Well, I'll defer to Mike.

The first thing, though, is we started out with a sufficiency of logistics and we started eating into that until we were barely sufficient from expedition to expedition, as you remember. I'm sure you and your colleagues read in the newspaper about we're waiting for the next Progress for spare parts; we're waiting for the next Progress for water, for food, or whatever.

So, that kept us right on the edge and we could not do science re-supply, for example. We had extremely limited down mass available to be able to perform science operations. And we were living from the residual amount of supplies that we had onboard the Space Station before.

So, Mike?

STATEMENT OF LT. COLONEL MIKE FINCKE, ACTIVE DUTY ASTRONAUT, NASA

Colonel FINCKE. It's a huge honor and pleasure to be here today. Thank you for the invitation. Six months in flight and aboard the beautiful, amazing International Space Station was a big honor and I'm glad to have a chance to share it a little bit today and what we've learned.

With only two people it was kind of tough. We had to maintain the Space Station. They threw in a couple extra space walks for us and even so we were able to with the ingenuity, and working together with the outstanding team in Houston and Huntsville, Alabama, we were able to get a lot of work done. We were able to get a strong science program and it was pretty amazing.

We also became self sufficient. We learned how to fix things like our space suits, and the oxygen generator. We need to know how to do those things for the Moon. With these efficiencies and with this new teamwork and ways that we figured things out on our expedition and what Leroy and Salizhan have done in Expedition 10, when we get another person aboard the Space Station and even more, we're going to be able to do a heck of a lot more science. And I'm looking forward to that.

The CHAIRMAN. Do you think that after this experience that working toward six is still the right goal or do you think that you can do major things with fewer than six crew?

Mr. READDY. I think we could do major things with two crew as Mike pointed out; three crew, obviously, more and six is our objective. When we get the Shuttle flying again, it's amazing the difference that makes in terms of logistics; just the routine things. The first two flights in addition to being test flights of the modifications that we've made here during the interval on the return to flight, also are logistics. The intent is to have an over-sufficiency of supplies onboard to restock the science and to build back to three permanent crew members.

As we put Regenerative Life Support onboard, as we increase the habitable volume, of course, we do expect to get to six crew members. Part of that is in addition to the science and technology that we'll be pioneering on International Space Station, the other thing that we must do is in order to learn how to live and work in space and live and work in space for long periods of time, you must actually live and work in space for long periods of time. That means that we need a large number of crew members so that we can understand that.

At this point in terms of exercise and other things that the crew needs, it's still very empirical how to decide exactly how much time you must devote to keep crew members healthy. Through the resistive exercise, we think we have found something that it is more efficient in terms of maintaining muscle mass and bone mass over long periods of time. Maybe Dr. Ross would like to comment?

STATEMENT OF DR. HOWARD ROSS, DEPUTY CHIEF SCIENTIST, NASA

Dr. ROSS. The medical benefits that we continue to learn on the International Space Station contribute broadly back here on Earth as well. From the Space Station experience so far we've been able to determine how much bone loss takes place. Something we had a sense of before, but for the first time we have good statistics. And in addition, we know where that bone loss is taking place.

We're using equipment such as ultrasound equipment in ways that it was never envisioned here on Earth to use. And that particular equipment that Colonel Fincke used in orbit, in fact, has shown some really promising applications both in space so that there would be less mass required, safer and more portable equipment. And he can comment here about the Earth applications of that particular device.

Colonel FINCKE. Yes. So, I'm not an ultrasonographer, but with the help of tele-medicine, having a specialist on the ground talk me through it, I only had a few hours of training on the machine—I was able to take clinical quality images of our bones and our internal organs with the ultrasound machine.

So, for the first time we were able to image our bones, because we have bone loss and we were able to see that with clinical quality images.

The same techniques can be applied directly to rural medicine. That way you don't need the doctor out in the field you just need a technician and then talk to the doctor in a big city. In addition to rural medicine it's valuable for the military and we've even started working it with sports teams. I think the Detroit Red Wings had a chance to practice some of these things. So, there's direct application with our experience with ultrasound.

The CHAIRMAN. Are you able, from all the observations you have had with people in space and the bone loss, to remedy some of that to build it back in the areas where you are losing the most? And has that come from the research in space?

Mr. READDY. Go ahead.

Dr. ROSS. One of the things we've learned is that you cannot always count on what we knew or thought would work on Earth. We really do need to test them in space on the International Space Station. We have, in fact, through the work done to date improved the exercise regimens that the crew goes through so that the bone loss that is experienced is mitigated substantially by what we have learned. Same thing from nutrition. We know how important improved nutrition is for a crew up there.

In the future we plan to use some of the techniques or test some of the techniques that we have developed on orbit for use on Earth to treat osteoporotic people. That's particularly the drugs that they can take, the bisphosphonates that in fact should mitigate some of this, but we need to test it in space. We've found over and over that space continues to surprise us.

The CHAIRMAN. I would like to ask you, Dr. Ross, what other areas of scientific research do you see as possible if we unleash the Space Station to its full potential?

Dr. ROSS. Well, let me talk more generally then about the benefits of Space Station, to put it in a context of the full benefits of human space flight. Just give me a brief moment to digress.

Yesterday we recalled the events from 10 years ago with the Federal Building in Oklahoma City. Few people know that NASA technology was used in the rescue and recovery efforts by fire fighters and other emergency workers that could very quickly use some of the devices that came from Shuttle technology to cut through cables, cut through steel. And it helped with the rescue and recovery.

The same was true at the World Trade Center recovery efforts; the same technology got used. Furthermore, the safety of the food that each of us eats, the system that's used to assure its safety was developed by NASA and was adopted only five or six years ago by the Food and Drug Administration and the United States Department of Agriculture. And we watched national salmonella incidences go way down.

So, it's from that legacy that we build on what the Space Station is now capable of. And it is a broad sweep of things. We just talked about ultrasound. There was an experiment on the Station called, "FOOT" and the principal investigator from the Cleveland Clinic Foundation, Dr. Peter Cavanagh, has said it is giving him insight into the role of exercise in treating osteoporosis for both on orbit and on Earth. And I want to be clear: The bone loss that occurs in crew is roughly ten times the rate that occurs here on Earth. So, it's quite a serious problem.

Much of our work with plants in space has spun off back here on Earth. As far as the future science, there is certainly human——

The CHAIRMAN. What do you mean plants?

Dr. ROSS. I'm sorry. Agriculture. There was an experiment——

The CHAIRMAN. You mean a better quality of more resistant type strain?

Dr. ROSS. One of the reasons we would like to grow plants in orbit is to help with the life support system so that as part of the regenerative of life support system, we have the carbon dioxide taken up by the plants and return oxygen, if you will. In addition there are psychological benefits simply to watch something grow other than your own hair when you're in space. Furthermore, it can be a food source. But it's been difficult in the past in space to grow plants correctly. We on the Space Station, for the first time, are able to do that quite well.

The principal investigator, Gary Stutte from in Florida in fact, was able to spin off benefits for new growth media that are used to help nurture agriculture here on Earth. New sensors for measuring soil moisture, oxygen sensors, the commercial companies have picked up. Research communities and soil physics are using his work. Even people trying to look at the effects of climate change are using some of the models that got developed from that experiment. So, the simple subject of, "Can we grow a plant in space?" has in fact let us back here benefit quite substantially.

The CHAIRMAN. I am going to finish this and then go to the next round. We are taking longer in our rounds, but Colonel Fincke, you are a member of the American Geological Society. And I wondered if that would be an area for scientific research on the Space Station?

It's not ever mentioned in any of the NASA material, but it seems that if we are going to use what we learn on the Moon to prepare to go to Mars that taking some of the matter from the Moon and looking at it in the Space Station might have some benefits. Is there a research path there?

Colonel FINCKE. Yes. And first and foremost we've been using the Space Station to look at our own beautiful planet. I took 21,000 pictures in my spare time. We have a beautiful planet. But when we go to the Moon, the Moon is incredible with its amount of resources. It has a lot of things; an abundance of metals like titanium and iron that are bigger preponderance on the Moon than on the planet, on Earth. So to be able to use those resources of the Moon for lunar bases and things like that as well as to maybe even use those resources sometime back here on the planet Earth. Those are outstanding, incredible possibilities.

The Space Station can help along the way. It takes a while and it takes some effort and energy to get the samples back and forth to the Moon, down to the planet Earth. We may be able to certainly do some research on the materials and melt them and do all the things that we can only do in zero-g or reduce gravity aboard the International Space Station.

As we go forward and understand how we're going to explore the Moon and beyond, I think this will be an important part of understanding the resources from the Moon and how the Space Station will play in there.

The CHAIRMAN. I was interested in your thoughts on what would it take to justify the International Space Station to be designated as a national lab?

I would be interested in Dr. Ross or Mr. Readdy telling us if NASA has ever looked at that as a way to assure that the scientific basis is going to be a priority and a long-term priority?

Dr. ROSS. In the recent past before the announcement of the Vision, we looked at broadening the community of people that were involved with the International Space Station and issued a request for information that listed all the potential tasks that we could turn over to a national laboratory of like situation; an institute if you will. A research institute.

That list was being reviewed, commented upon by industry, by all comers if you will. Then we suspended the process, frankly, when the Vision got announced as the purpose of the International Space Station became more focused, if you will, in support of the Vision.

Some of the tasks there are really quite challenging to use in a national laboratory model. Private medical data, for example, that we gather is something we wouldn't easily use through an institute the same with international agreements. But in the long run as the Station evolves over time certainly, I know we've had internal discussions, that we would want to come back and look at it again. This is a postponement, if you will, or a suspension of the activities. It's not necessarily a termination.

The CHAIRMAN. Well, could it—could not the scientific experiments that you could do in a national lab at the Station be done in a way that it would enhance what you are also doing to prepare for exploration of the Moon and then beyond?

Dr. ROSS. Well, certainly we're proud of all the experiments that we go on now. Everything gets peer reviewed and it is a broad array of experiments. To the extent we can broaden the community, broaden the number of people, increase the number of people who are aware of what we can do on the International Space Station and then subsequently do experiments, that's, of course, a good thing.

The CHAIRMAN. Is there something more that—or let me ask this. Do you see a prototype for how you would have a national lab designation? Different labs are run, some by university, some by private corporations, some with consortia. Do you see a best way to approach this that might not only fulfill the Vision, but also give more emphasis to science?

Dr. ROSS. The agency in the past has looked at eight different models of FFRDC's versus other non-governmental organizations running this. I don't think we settled on one exact model, in fact, the process we were going through was going to attempt to compete and elicit what would be the best model.

So, I don't think we settled on one yet. But again if we come back to this in the future that's something that would be wrung out of the process.

The CHAIRMAN. I would like for—to ask you to submit for the record the preliminary research that was done so that we get an idea of where you are going to determine if that might be a part of a re-authorization.

[The information referred to follows:]

ISS UTILIZATION MANAGEMENT CONCEPT DEVELOPMENT STUDY

On January 10, 2003, NASA submitted a report to Congress in response to direction accompanying the FY 2001 and FY 2003 VA-HUD-Independent Agencies Appropriations Acts (Pub. L. 106–377 and Pub. L. 107–73, respectively). The report reflected the results of a seven-month, study-assessing options for ISS utilization management. The study set the following objectives for ISS utilization management: (1) to facilitate the pursuit of flight research; (2) to optimize research opportunities within current capabilities of ISS and with future enhancements for greater capabilities; and, (3) to increase the long-range productivity of science, technology, and commercial research and development aboard the ISS. Designation of the ISS as a National lab was not considered as part of the study.

As a key part of the NASA study, the scope of utilization work was defined as twenty-one principle functions ranging from development of strategic plans to archival of research samples. A few functions, such as policy development and safety certification, were determined to be inherently governmental. The other functions were analyzed as candidates for delegation to a non-governmental organization.

Ten potential business models were evaluated. Two business models—a research institute and a federally funded research and development center (FFRDC)—emerged as the best choices. A scoring process based upon an agreed upon set of evaluation criteria resulted in the research institute ultimately emerging as the preferred business model.

The resulting NASA report* was based on a thorough qualitative and quantitative analysis of the study results and extensive discussions with senior managers across the Agency. In the report, NASA recommended the establishment of a non-governmental organization, specifically a non-profit institute, to perform research leadership functions including significant aspects of research planning, manifesting, prioritizing, resource allocation, advocacy, outreach, and archiving.

A two-phase contracting approach was recommended. A phase one contract would be implemented to focus on science, technology, and commercial (S/T/C) leadership functions. The phase two contract, if implemented, would maintain the S/T/C leadership focus and add responsibility for the additional utilization management functions. Factors influencing the decision on the recommended approach included the importance of maintaining an institute focus on the S/T/C leadership functions, the need to clearly establish requirements for the additional utilization management functions, and the belief that a single entity should ultimately have the end-to-end authority and accountability for the competitively-sourced functions.

Future ISS Research

The International Space Station is not anticipated to have excess utilization capacity beyond meeting the needs of the Vision for Space Exploration and our international partners through the middle of the next decade. Over the next several years, as the Space Station research agenda focused on the Vision is achieved, it will be beneficial to reexamine the next set of research priorities. Until that time, it would not be practical to expand the Space Station research functions to cover the wider agenda of a National research facility.

The CHAIRMAN. Did you have anything else to add on that, Mr. Readdy?

Mr. READDY. No.

---

*The information referred to has been retained in Committee files.

The CHAIRMAN. Senator Nelson.

Senator NELSON. Thank you, Madam Chairman. I am curious, since you had less bone loss, Colonel Fincke, what were some of the things that you did specifically in order to lessen that bone loss?

Colonel FINCKE. I think our studies are showing that compared to when we first started flying up to Space Station Mir and had American astronauts on the Russian space station from that time on when we've had Americans and human beings altogether in space where we're learning a lot of things.

Our exercise countermeasure program is pretty outstanding. Gennady and I worked out for two and a half hours every day. Resistive exercise combined with cardiovascular exercise like running or on a stationary bike.

I honestly believe that the data show, or at least—certainly in my experience, because I exercised I came back feeling strong, feeling healthy and with minimum but still some bone loss. And we're working hard to figure out why these things happen. The images from the ultrasound machine will be helpful. And we're still working on this, because we need to understand the mechanisms why it happens and how to counteract it, because when we go to the Moon and Mars it's a long time on the lunar surface and it's a long trip to Mars.

Senator NELSON. How did you get the resistance in the exercise?

Colonel FINCKE. There's a machine called the resistive exercise device or the "RED." It consists of a cylinder that's about this big, two feet by maybe about I don't know one foot in diameter. There are two of these devices. They have some rubberized components on the inside. We can dial a certain resistance and then pull on some cords.

From that we've had a very clever team on the ground that we can do all the things like upper body strength exercises to the really important one which we're doing—what are referred to as squats. All that stress on our bones and muscles while we're doing these squat exercises really helped our hips not to lose bone so fast. We could dial up exercise up to some very high weights just to keep us progressing.

Senator NELSON. And on a treadmill, is it still the old style treadmill where you put on a harness with bungee cords that forces you down?

Colonel FINCKE. Yes, Senator. For the last month—that's exactly how I did it for the first 5 months. For the last month we actually—I ran out of bungees. In other words, they couldn't pull me down hard enough, so we used a device that's on the treadmill called the "Subject Loading Device." And I could dial in or type in how many pounds I wanted to pull me down so I could be running effectively at my own weight on the ground. I was doing that up in space.

So, we've come a long way with our exercise equipment and we still have a long way to go, however.

Senator NELSON. Did your crew mate exercise as diligently as you did?

Colonel FINCKE. Yes. He was——

Senator NELSON. And he had a similar less bone loss?

Colonel FINCKE. I'm not privy to his medical data, but he seemed to be looking and feeling pretty good when he came back home.

Senator NELSON. That is very, very encouraging.

Mr. Readdy, one of the things that Senator Hutchison and I had hammered at the confirmation hearings of Dr. Griffin was that we are concerned about this proposed hiatus between the time that the Space Shuttle would be stopped in 2010 and then who knows what time that the crew exploration vehicle would be ready. And, of course, Dr. Griffin had indicated that he was going to try to speed that up so that there was not much of a hiatus.

Your current plan is that it may have the option, the CEV may have the option of docking with the Space Station. Why would that not be part of the plan so that we can still continue to use the Space Station without having to rely just on another nation's, specifically the Russian vehicle, to get to the Space Station after the year 2010?

Mr. READDY. Sir, first of all I have to compliment our Russian partners, because they have done exactly what they committed to do in terms of providing the Soyuz vehicles for crew rotation as well as crew rescue and Progress vehicles for resupply. But you're both absolutely right on that score.

I know the Administrator committed to you both when he was doing his visits that we're going to accelerate the crew exploration vehicle and he's conducting the review already of that. He's named people to start reviewing the baseline plan that we had had for Project Constellation, to accelerate that program so that we can minimize the gap.

You're quite right as that International Space Station ought to have access from U.S. vehicles as well.

Senator NELSON. So, my question was, well why is that just an option? Why are we not actually planning that?

Mr. READDY. No. The previous baseline did show that as an option, I think, in the request for proposal. But I think Dr. Griffin is actively reviewing that as we speak.

Senator NELSON. Well, that is encouraging too. After you fully assemble the Space Station and on the timeline that's what year now?

Mr. READDY. 2010, Sir.

Senator NELSON. OK. Then what is the role of the Space Station once we have it fully assembled and supposedly the Space Shuttle is over and done with?

Mr. READDY. Well, as you know from your own personal experience, the Space Shuttle is a very unique vehicle and it's not without risk. That was pointed out, obviously, and the loss of our colleagues on the *Challenger* and then again on *Columbia*.

The *Columbia* Accident Investigation Board pointed out that it's inherent design has risk associated with it. Our job is to use the Space Shuttle for those missions that it's uniquely qualified to do. Those include assembly of International Space Station where you need robotic capability, you need crew capability to do the space walks, you need the rendezvous docking and the environment of the payload bay in order to take those very large modules up to Space Station.

So, as the Vision was being formulated our input to that vision was we should minimize the number of Space Shuttle flights to those essential to complete International Space Station and honor our international commitments.

As the Space Station is completed, we expect to be able to do logistics not only from our international partners, the Russians certainly with their Progress vehicles, the Europeans next spring with Autonomous Transfer Vehicle *Jules Verne* which is right now over in Holland being completed. They're working with the Ariane which is now the ten-ton version has just returned to flight here 2 months ago. So, they're on track to provide a redundant logistics leg. I know a number of American contractors are looking at that capability to see if it would launch on our launch vehicles as well.

Then our Japanese partners similarly returned to flight on their H–II launch vehicle in February. They are progressing well on their HTV, which is a H–II transfer vehicle that in addition to mating with the U.S. portion of the Space Station allowing much larger transfer of pressurized cargo also has the capability of taking up un-pressurized cargo such as gyrodynes and batteries and things like that.

Clearly, we would also like, United States industry and entrepreneurs to supply us with the possibility of logistics here from the United States. And we are putting out a request for proposal here at the end of the summer with the expectation that by the end of the year we would be able to do that probably around the year 2009.

The role of the Space Shuttle Orbiter at that point would not be required. Clearly eliminating the gap that both of you have mentioned and crew exploration vehicle and making sure it has the possibility of docking at Space Station is a critical part of that.

Senator NELSON. Is the present thinking that the CEV is going to launch on an EELV or some Shuttle-derived vehicle?

Mr. READDY. Admiral Steidle would be better to comment on that than I. But the initial plan that they have provided to us and industry are two competing designs. Spiral One would not in fact be a crude vehicle. It would be a demonstration of the capability, and I think, they're silent on what launch vehicle would be required to do those demonstrations.

Downstream, though, I think the expectation is that the crew exploration vehicle would be of such a size in mass that would require heavy lift launch vehicle and that could be one of the EELV derivatives or it might wind up being some kind of Shuttle-evolved design.

Senator NELSON. There has been some concern expressed about the RCS system accidentally activating while the Space Shuttle Orbiter is docked to the International Space Station. Could you discuss the things that we should be worrying about and what we are going to do?

And particularly once you have got all the mass up there that has been assembled.

Mr. READDY. Certainly. The Senator is referring to the reaction control system, RCS. These are 44 thrusters that are on the Space Shuttle Orbiter, they're used to maneuver the Space Shuttle. When docked to the International Space Station we also use the vernier or the lower thrust versions of those to re-orient the Space Station. So, operation of those jets is not anything that we wouldn't have planned to do normally.

I think the failure mode that you're referring to is the jet driver, the reaction control jet driver device. One of the outcomes of the *Columbia* accident was we established a NASA Engineering and Safety Center. They surfaced a failure mode that, as yet, they haven't quantified whether it's a one-in-a-thousand or one-in-ten-thousand chance that this driver device, which is what translates either the pilots input or the computers input into firing of the appropriate reaction control jet. Whether through failure of one of the electronic devices in it, it might inadvertently command a jet to fire.

As you mentioned, the concern would be that it would perhaps put too large a load into the docking interface and the International Space Station.

Well, I'd offer three things. For the first two flights, which are logistics flights that is not an issue given the configuration of Space Station even were the jets to fire inadvertently. But given the fact that we acknowledge that there's the possibility, however remote of this failure occurring, we turn off the reaction control jet drivers as soon as we're docked to help alleviate that as a possibility.

Further, we would also secure the manifolds to the reaction control jets so that they wouldn't have any propellants. As an additional measure, though, as the Space Station increases in mass and future configurations after STS–115, what we will also do is a software modification to the Orbiter orientation system such that the pulse size of the jets of the primary thrusters would be insufficient to cause any kind of structural issue.

Senator NELSON. And Colonel Collins is satisfied with where we are on this?

Mr. READDY. Yes, sir.

Senator NELSON. How about the—presently you have two gyroscopes that are operational and one of those possibly, is going to fail. How are we going to get replacement gyros to the Station, if the—if this return to flight were to be postponed?

Mr. READDY. To start out, I'd like to complete my answer to your previous question in terms of Eileen Collins and STS–114. I just want to make very clear that the failure mode that you describe is not an issue for STS–114, it's not an issue for STS–121 either; the second test flight. We have controls in place so that we don't think it's a credible issue for subsequent flights either.

In terms of your question about the gyroscopes or the control momentum gyros, Mike Fincke actually had an opportunity to do a space walk while he was up there and I'll ask him for his commentary here in a moment.

There are four gyros onboard the International Space Station. They are the non-propulsive means of orienting the Space Station and pitch, roll, and yaw.

There are propulsive ways to do that using the thruster jets that are part of the Russian part of International Space Station. Those function perfectly fine. We've got over a year of propellants and so that's really not an issue were other gyros to fail. We do not use the gyros to orient the Space Station during shuttle docking; so that's not an issue.

It turns out to be one of redundancy management. As you point out STS–114 does have a replacement gyro onboard. And the complement of two that are functioning right now could be enhanced to three if we take the power supply and instead of making it independent for each of the gyros if we tie it to another gyro. Here I'm starting to get way outside my personal knowledge, so I'd like Colonel Fincke to comment.

Colonel FINCKE. The Space Station's equipped with four gyroscopes. One of them is hard-failed. We think it's something maybe in the bearings or something. That one's been down for a while and that's the one that's going to be replaced by this next crew.

The one that we worked on, the failure mode was different. It's a power supply problem. And we went out and we changed out the power supply and a year later the power supply we replaced it with showed the same design defect. So, that gyroscope spun down.

So, the trick is to get if we wanted to, if we thought we needed to get this other gyroscope back and up running there's two different ways to get power to it. We could do the same kind of space walk that Gennady and I performed, or we could take a shorter space walk and jumper over the power like Mr. Readdy was suggesting.

So, it could be done by a Space Station crew. So if we really needed to get another gyroscope up and running it would require a space walk. To do a task that we've already done on either different way we have experience doing that.

So, it's a big deal to do a space walk. It takes some operational planning, some a little bit of Station resources, in general it's well understood issue and quite achievable.

Mr. READDY. To complete that thought, it is planned for STS–114 not only to replace the failed gyroscope but also to do what he described as really kind of hot wiring the gyroscope that has a faulty power supply so that we would be back in operation with all four gyros.

Senator NELSON. Back on my original question about your exercise regime. With this successful regime that you employed that Dr. Ross was talking about, how long did it take you where you could stand up and walk once you returned?

Colonel FINCKE. I felt even though we were in space for over 187 days that I could have walked off the Soyuz spacecraft. I was feeling very good, very strong. So there were no strength issues. The only issue I had was really a balance issue. My inner ear just wouldn't balance me so I was walking a little bit zig-zag. But other than that I felt I could have walked off that spacecraft.

Senator NELSON. I was zig-zag as well and I was only up 6 days. [Laughter.]

Senator NELSON. Dr. Ross, are we within the magnetic field of the Earth in the Space Station so that we don't have to worry about protection on solar flares?

Dr. ROSS. Oh, we are within the magnetosphere, but we still have to worry about solar flares. There was an incident just this past January where the crew had to organize themselves, if you will, against the solar storm.

Senator NELSON. And how do they do that?

Dr. ROSS. Put sufficient shielding in the path. We know the direction that the radiation is coming from in such cases. So they put sufficient material, if you will, in the path.

Senator NELSON. What is that shielding material?

Dr. ROSS. Today it's all of the different equipment that's on the Space Station. Primarily aluminum in the long run we hope to go to materials like polyethylene or more advanced materials that have even better shielding capabilities.

Senator NELSON. Will that be a component in the design of the CEV, especially if it is to leave Earth's orbit?

Mr. READDY. Clearly, we have to protect the crewmen. As soon as you leave the magnetosphere, of course you're subject to a much, much higher radiation. When we're talking about voyages that would be hundreds of days, yes, we do need to work on radiation protection.

Senator NELSON. Madam Chairman, thank you so much.

The CHAIRMAN. Thank you. Last question. Just to sort of summarize, if we had a 5-year hiatus in being able to deliver and return payload to the International Space Station, would science not be hurt as well as the security risks of being unable to go in space when we know other countries are going to be putting people in space more and more; even China and India possibly?

Dr. ROSS. I guess the answer to your question is it depends what alternatives are available at the time. Certainly there is pursuit right now of other launch vehicles that would provide the cargo transportation to and from the Space Station. That would mitigate any problems associated with the science.

The CHAIRMAN. Being unmanned is——

Dr. ROSS. Yes.

The CHAIRMAN. Yes.

Dr. ROSS.—unmanned. The same thing if we would have to continue to rely on the Russians as far as crew transport that's, you know, that's the major concern of course. And to try to expand the number of crew members.

So, yes, it would be a concern until we explore all the alternatives. I couldn't tell you how much science would be hurt.

The CHAIRMAN. But about the people not being there in sufficient numbers to do the experiments?

Dr. ROSS. We hope by 2009 that the people will be there in sufficient numbers. We're planning on six people by that time. As I understand it, I can defer this to Bill, to keep it populated with six people through the lifetime of the Station.

The CHAIRMAN. Using Russian vehicles?

Mr. READDY. Right now it appears that Russian vehicles are the interim answer. Yes, ma'am. But as I said before, the Administrator's committed to accelerate the CEV program so that we minimize the gap.

The CHAIRMAN. Yes. But my point was if we did not have the gap minimized would it not hurt our scientific——

Mr. READDY. We would certainly be dependent on someone else.

The CHAIRMAN.—capacity?

Mr. READDY. Yes, ma'am.

Senator NELSON. And Madam Chairman, if I might, that of course is our dual concern. In the geopolitics of today that's not a problem, because we have this bond, this close relationship with the Russians. But what is the geopolitics of planet Earth going to look like in the year 2012? And that's why jointly the two of us feel very strongly we need to accelerate the CEV.

The CHAIRMAN. Thank you very much. We appreciate your being here and helping us get started.

And I do want to have all of the work that you have done on a national lab and anything that you would want to add that might be useful from a scientific standpoint that might be done in a national lab configuration.

Dr. ROSS. Absolutely.

The CHAIRMAN. Thank you.

Dr. ROSS. Thank you.

Mr. READDY. Thank you, Madam Chairman, Senator Nelson.

The CHAIRMAN. Thank you. I would like to call our second panel, Marcia Smith, Senior Analyst at the Congressional Research Service; Dr. Jeffrey Sutton, Director of the National Space Biomedical Research Institute in Houston; and Dr. Mary Ellen Weber, Vice President of the University of Texas, Southwestern Medical School in Dallas.

I am very pleased to have your testimony and I want to say to Ms. Smith, particularly, I appreciated in your written remarks and maybe you will be going over this orally, but describing the mission of the Space Station through the different presidents was very enlightening to me. And I want to go back to the Ronald Reagan Vision. I'll just state that right now.

So, with that, let me welcome you and ask for your testimony.

STATEMENT OF MARCIA S. SMITH, SENIOR ANALYST, CONGRESSIONAL RESEARCH SERVICE

Ms. SMITH. Thank you very much, Madam Chairwoman. And thank you for inviting me here today to testify about the Space Station program. You asked that I focus my remarks on how the rationale behind the program has changed over the years, particularly in terms of it's expected benefits. Essentially, what was promised and whether those promises are likely to be met under the current plan.

I would ask that my written testimony be submitted for the record and I will try to summarize it's key points in the next 5 minutes.

Ms. SMITH. When he initiated the Space Station program in 1984, President Reagan said, "A Space Station will permit quantum leaps in our research in science, communications, in metals, and in lifesaving medicines which could be manufactured only in space."

Originally, the Space Station was to consist of three orbiting facilities; an occupied base, an automated co-orbiting platform, and another automated platform in a polar orbit. NASA Administrator Beggs said in 1984 that it would have eight functions; a laboratory in space, a permanent observatory to look down upon the Earth and out at the universe, a transportation node, a servicing facility, an assembly facility, a manufacturing facility, a storage depot, and a staging base for more ambitious future missions.

Repeated cost growth led to many changes in that concept over the next 5 years. By the end of 1989 only the laboratory function remained. President George H.W. Bush, the senior President Bush, made a major space policy address announcing his Moon/Mars program that year and spoke glowingly of what was then known as Space Station Freedom's role in that vision.

But the Space Station continued to be down-sized. A redesign in 1990 to 1991 raised concern in the scientific community, because it excluded plans for a centrifuge. Reports from the Space Studies Board and the White House Office of Science and Technology Policy stressed the need for a centrifuge. The Chairman of the SSB told this Committee in 1991 that, ". . . a centrifuge is the single most important facility for space biology and medicine research." NASA restored a 2.5 meter centrifuge to the design.

In 1993 as President Clinton took office, additional cost growth was revealed. He directed another redesign and in June 1993 approved a scaled-down version of Space Station Freedom. Congress agreed to proceed with the redesign program, but by narrow margins in the House. Then in September 1993, Vice President Gore announced that Russia would join the program. This design including Russian contributions is the Space Station under construction today, the International Space Station.

In 1997 NASA Administrator Goldin told this Committee that, ". . . the ISS has unique characteristics where we could do research and bio-medicine, biotechnology, advanced materials, combustion research, advanced communications, and advance engineering and Earth science that we could do on no other platform. This is a place where we use the absence of gravity to understand the laws of physics and chemistry and biology much better and rewrite text books."

Assembly of the Space Station began in 1998 and permanent occupancy by three-person crews began in 2000. But in 2001 as President Bush took office more cost growth was revealed. The White House decided to truncate construction, canceling plans to build certain U.S. hardware including a crew return vehicle. The decision not to build the CRV affected plans to increase the size of the Space Station crew.

The number of crew is important in terms of how much research could be conducted since, according to NASA prior to it's recent experience with the two-person crews, that with a three-person crew it takes two and a half people to operate the station, meaning that only one half of one person's time would be allocated to research.

The 2003 *Columbia* accident led to a re-examination of the fundamental rationale of the human space flight program. That review led in turn to President Bush's January 2004 announcement of a Vision for Space Exploration. The full extent to which the Vision, if adopted, would effect the Space Station program is not clear yet. What is known is that the scope of research would be narrowed to only that which supports the Vision. There would be fewer years during which NASA would conduct research and the Shuttle would not be available to support scientific operations after 2010.

What is not known yet are details of the new research program, and therefore, what benefits can be expected from it, what the ISS crew size will be and how many will be NASA astronauts; whether the centrifuge will be completed, and what capabilities may be available from other partners or the U.S. commercial sector to take cargo to and from ISS instead of the Shuttle.

Therefore, the extent to which Space Station research will rewrite text books, as Mr. Goldin forecast in 1997, remains to be seen. Thank you very much.

[The prepared statement of Ms. Smith follows:]

PREPARED STATEMENT OF MARCIA S. SMITH, SENIOR ANALYST, CONGRESSIONAL RESEARCH SERVICE

Madam Chairwoman, Members of the Subcommittee, thank you for inviting me to testify here today about the space station program. You asked that I focus my remarks on how the rationale behind the program has changed over the years, particularly in terms of its expected benefits—essentially, what was promised, and whether those promises are likely to be met under the current plan.

The space station program has been an international endeavor since its inception. Today, Russia, Canada, Japan, and 10 European countries[1] are partners with the United States in building the International Space Station (ISS). My testimony will not address how the non-U.S. partners have won support from their governments, or what benefits they expect, however. The focus here is on how NASA and the White House have explained the rationale for and expected benefits from the program to the U.S. Congress. My testimony would not be complete, though, without noting that the other partners are vital to NASA's use of the space station. NASA is dependent on Russia for crew and cargo transportation to and from ISS while the space shuttle is grounded. Under President Bush's Vision for Space Exploration, NASA will continue to be dependent on Russia to enable NASA astronauts to remain aboard the space station for long duration missions, and to have them there at all once the space shuttle is terminated in 2010. In addition, some of the research facilities that will be available to U.S. researchers are in Europe's Columbus module and Japan's Kibo module. Also, Japan is building a centrifuge and its accommodation module for NASA in exchange for NASA launching Japanese hardware. However, NASA reportedly is reconsidering whether it needs the centrifuge.

Rationale for and Expected Uses of the Space Station

Four Presidents have shaped the space station program—Ronald Reagan, George H.W. Bush, Bill Clinton, and George W. Bush—so I have separated this historical discussion into the time periods of those administrations. This is not meant to suggest that they were the only forces affecting the program. Congress has played a strong role in the space station's evolution through funding decisions and oversight. The two space shuttle tragedies—*Challenger* in 1986 and *Columbia* in 2003—also impacted the program. Perhaps the biggest influence has been the incessant cost growth and schedule delays that have characterized the program since its earliest days. Assembly was originally planned for completion by 1994; now it is 2010. NASA estimated the space station would cost $8 billion (FY 1984 dollars) when it first came to Congress to obtain approval for the program. Congress now has appropriated approximately $35 billion (FY 1985–2005, in current dollars), and NASA estimates it will cost another $10 billion through the end of construction in FY 2010. (Estimates do not include shuttle launch costs.)

The cost growth and schedule delays over the past 21 years have subjected the space station to repeated downsizings and consequent reductions in its capabilities.

It is not possible in this short statement to review comprehensively the record of statements made to Congress by the White House and NASA about the rationale for building a space station and what could be expected from it. The examples herein are illustrative. For your convenience, I have summarized the various changes to the space station's configuration in a table appended to this statement.

---

[1] Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, and Switzerland. The United Kingdom signed the Intergovernmental Agreement that governs the program, but is not financially participating in it, so the number of participating European countries is sometimes listed as 11.

Reagan Administration

The space station program, today known as the International Space Station (ISS), was formally initiated by President Ronald Reagan in his January 25, 1984 State of the Union Address. President Reagan directed NASA to build a permanently occupied space station "within a decade" and to invite other countries to join in the project. He explained his reasons for wanting to build such an orbiting facility in this way:

> America has always been greatest when we dared to be great. We can reach for greatness again. We can follow our dreams to distant stars, living and working in space for peaceful, economic, and scientific gain. Tonight, I am directing NASA to develop a permanently manned space station and to do it within a decade.
>
> A space station will permit quantum leaps in our research in science, communications, in metals, and in lifesaving medicines which could be manufactured only in space. We want our friends to help us meet these challenges and share in their benefits. NASA will invite other countries to participate so we can strengthen peace, build prosperity, and expand freedom for all who share our goals. [2]

NASA officials at this time articulated the need for a new space station [3] by using the motto that it was "the next logical step" in the space program. Indeed, in 1969, Vice President Agnew had chaired a Space Task Group to recommend goals for the post-Apollo space program. Briefly, the plan was to build a space station, a reusable space transportation system to service it, and to send people to Mars. Budget constraints led President Nixon to approve only one element of that plan in 1972—development of a reusable space transportation system, which became known as the space shuttle. NASA declared the space shuttle "operational" in 1982, and then was ready to proceed with the next step, building a space station.

Two months after the State of the Union Address, then-NASA Administrator James Beggs testified to the House Appropriations Committee that the cost estimate for the space station was $8 billion (FY 1984 dollars), and identified the eight functions that the space station would serve:

- a laboratory in space, for the conduct of science and the development of new technologies;
- a permanent observatory, to look down upon the Earth and out at the universe;
- a transportation node where payloads and vehicles are stationed, processed and propelled to their destinations;
- a servicing facility, where these payloads and vehicles are maintained, and if necessary, repaired;
- as assembly facility where, due to ample time on orbit and the presence of appropriate equipment, large structures are put together and checked out;
- a manufacturing facility where human intelligence and the servicing capability of the Station combine to enhance commercial opportunities in space;
- a storage depot where payloads and parts are kept on orbit for subsequent deployments; and
- a staging base for more ambitious future missions. [4]

---

[2] Ronald W. Reagan. State of the Union Address. January 25, 1984. Text available on the University of California Santa Barbara (UCSB) American Presidency Project website at: *http://www.presidency.ucsb.edu/ws/index.php?pid=40205.*

[3] The space station approved in 1984, and currently under construction, is NASA's second space station. The first NASA space station was Skylab, launched in 1973. Skylab was not intended to be permanently occupied. Visited by three 3-person crews in 1973–1974, it made an uncontrolled reentry through Earth's atmosphere in 1979, spreading debris on Australia and the Indian Ocean. The space station approved in 1984 was intended to go beyond Skylab, to a permanently occupied facility with sequential crews onboard year-round. Meanwhile, the Soviet Union had launched the world's first space station in 1971 (Salyut 1). By 1984 when President Reagan announced the plan to build NASA's space station, the Soviets were operating their sixth successful space station (Salyut 7). In 1986, they launched the first element of the modular Mir space station. Several other modules were added to the Mir complex over many years, and Mir was permanently occupied from 1989–1999 (including multi-month visits by seven NASA astronauts, and nine dockings between Mir and NASA's space shuttle). Mir made a controlled deorbit into the Pacific Ocean in 2001.

[4] U.S. Congress. House. Committee on Appropriations, Subcommittee on HUD-Independent Agencies. Department of Housing and Urban Development—Independent Agencies Appropriations for 1985, Part 6, National Aeronautics and Space Administration. March 27, 1984. Washington, U.S. Govt. Print. Off., p. 8

This original concept envisioned three separate space station facilities: an occupied base for eight crew members in a 28.5° orbit, an automated co-orbiting platform nearby, and an automated "polar platform" in orbit around Earth's poles (an orbit typically used for Earth observations). By the fall of 1985, NASA had settled on a "dual-keel" design for the facility, with four laboratory and habitation modules. Over the next several months, NASA approved other details, including a few changes from that baseline design. Among the changes was reducing the number of U.S. modules from four to two (but the new U.S. modules would be larger so the total habitable volume was relatively unchanged), with plans for two more modules to be provided by Europe and Japan. NASA also agreed to add a U.S. Flight Telerobotic Servicer at Congressional urging, to supplement Canada's planned Mobile Servicing System.

In 1985, as you may recall Senator Nelson, NASA's Associate Administrator for Space Station, Phil Culbertson, told you at a hearing you convened on the space station and space science, that a "fundamental concept upon which the space station has been and will continue to be defined is that it will be designed, operated, and evolved in response to user requirements."[5] Mr. Culbertson explained that NASA had worked closely with prospective users for the previous three years, and established a Task Force on Scientific Uses of the Space Station, to advise NASA on what the scientific community wanted and needed. He listed the following as examples of the planned scientific uses: Earth observations; astronomical observations; basic biological and physiological research, including the effect of long duration exposure to microgravity conditions; research on the processing and behavior of materials in microgravity, including crystals and pharmaceuticals (with research to be conducted on the occupied base, and full scale commercial production either on the occupied base or on spacecraft serviced from the occupied base); and applications and technology research such as advanced communications, energy conversion, propulsion, controls, and human factors.

Funding challenges, and the January 1986 Space Shuttle *Challenger* tragedy, soon impacted the space station design. In late 1986, the dual-keel design was reaffirmed, but emphasis was placed on building a single-keel first because of the reduction in the number of shuttle flights, and the reduced amount of cargo that would be allowed aboard the shuttle, in the wake of the *Challenger* tragedy. An emphasis on early accommodation of experiments, fewer spacewalks, an extended "safe haven" concept with the possibility for "lifeboats" for emergency return to Earth (not made a requirement at this time reportedly for cost reasons), and increased use of automation and robotics, were made part of the program.

In 1987, in response to continued cost growth, the program was split into two phases. Phase I, to be completed by 1996, would include a single keel of the occupied base (including the four modules), and the polar platform. The second keel, the co-orbiting platform, and solar dynamic power were deferred to Phase 2, on which further decisions were anticipated in 1991.

In 1988, Canada, Europe, and Japan formally joined the program after three years of negotiations. Canada agreed to build a Mobile Servicing System (Canadarm2), while Europe and Japan each agreed to build laboratory modules (Columbus and Kibo, respectively). The partners named the space station *Freedom*. In return for providing services such as electrical power and crew and cargo transport, NASA obtained utilization rights to half of the research facilities in the European and Japanese modules.

George H.W. Bush Administration

On July 20, 1989, six months after taking office, the senior President Bush made a major space policy address on the 20th anniversary of the Apollo 11 landing on the Moon. He called on the United States to return humans to the Moon and someday go to Mars. Space Station *Freedom* featured prominently in the President's vision for the future of the space program. This excerpt may be helpful in comparing the role envisioned for the space station as part of a program of human space exploration at that time, versus today. The senior President Bush said:

> In 1961 it took a crisis—the space race—to speed things up. Today we don't have a crisis; we have an opportunity. To seize this opportunity, I'm not proposing a 10-year plan like Apollo; I'm proposing a long-range, continuing commitment. First, for the coming decade, for the 1990s: Space Station *Freedom*, our critical next step in all our space endeavors. And next, for the new century: Back to the Moon; back to the future. And this time, back to stay. And then

[5] U.S. Congress. House. Committee on Science and Technology. Space Science and the Space Station. September 24, 1985. Washington, U.S. Govt. Print. Off., 1985, p. 6.

> a journey into tomorrow, a journey to another planet: a manned mission to Mars.
>
> Each mission should and will lay the groundwork for the next. . . .
>
> And to those who may shirk from the challenges ahead, or who doubt our chances of success, let me say this: To this day, the only footprints on the Moon are American footprints. The only flag on the Moon is an American flag. And the know-how that accomplished these feats is American know-how. What Americans dream, Americans can do. And 10 years from now, on the 30th anniversary of this extraordinary and astonishing flight, the way to honor the Apollo astronauts is not by calling them back to Washington for another round of tributes. It is to have Space Station *Freedom* up there, operational, and underway, a new bridge between the worlds and an investment in the growth, prosperity, and technological superiority of our nation. And the space station will also serve as a stepping stone to the most important planet in the solar system: planet Earth.
>
> . . .
>
> The space station is a first and necessary step for sustained manned exploration . . . But it's only a first step. And today I'm asking . . . Vice President, Dan Quayle, to lead the National Space Council in determining specifically what's needed for the next round of exploration. . . . The Space Council will report back to me as soon as possible with concrete recommendations to chart a new and continuing course to the Moon and Mars and beyond.
>
> . . . Why the Moon? Why Mars? Because it is humanity's destiny to strive, to seek, to find. And because it is America's destiny to lead.[6]

Despite this glowing endorsement of Space Station *Freedom*, on a practical level, the program continued to experience cost and schedule problems, resulting in more changes that further reduced its capabilities. In 1989, the same year as the President's speech, NASA indefinitely postponed Phase 2, and the polar platform was transferred out of the space station program and into NASA's Office of Space Science and Applications.

By this time, five years after the program began, of the eight functions identified by Administrator Beggs in his 1984 testimony, only one remained: a single-keel occupied base to serve as a laboratory. Construction of that base was, in turn, divided into two phases: an "initial phase" with reduced capabilities (crew size was reduced from eight to four, electrical power reduced from 75 kw to 37.5 kw, and an open-loop instead of a closed-loop life support system would be used); and an "assembly complete" phase when full capabilities would be restored. NASA asserted that the capabilities envisioned in the 1987 Phase 2 program (dual-keel etc.) could still "evolve" sometime in the future to support expeditions to the Moon and Mars.

In 1990–1991, the space station was further downsized because of continued cost problems, weight growth, and growing estimates of the number of spacewalks needed for its construction. The U.S. modules were reduced in size from 44 feet to 27 feet in length; the total length of the facility was reduced from 493 feet to 353 feet; the Flight Telerobotic Servicer was canceled; crew size was formally reduced to four; and electrical power was formally reduced from 75 kw to 56 kw. A "lifeboat" was added to the station's design, but was not included in the cost estimate. The "assembly complete" designation was abandoned in favor of a concept that the station would continually evolve in an undefined and unbudgeted "follow-on phase."

The 1990–1991 downsizing raised concern in the scientific community. Among other things, the redesign excluded plans for a centrifuge. The Space Studies Board (SSB) of the National Research Council issued a report saying that the limited microgravity research that could be conducted on the redesigned station did not merit the investment required. The SSB said that while it strongly endorsed the need for a space station to study the physiological consequences of long-term space flight, the redesigned station did not have the necessary facilities to do so. It cited the following as "absolutely fundamental to the acquisition of the data necessary to determine the feasibility of long-term human space exploration"—

- a dedicated life sciences laboratory with adequate scientific crew to conduct research;
- a variable speed centrifuge of sufficient radius to accommodate small primates;

---

[6] George H.W. Bush. Remarks on the 20th Anniversary of the Apollo 11 Moon Landing. Text available from the Bush Library website at: *http://bushlibrary.tamu.edu/research/papers/1989/89072000.html.*

- sufficient numbers of experimental subjects (humans, plants and animals) to address the stated scientific goals; and
- sufficient laboratory resources, i.e. power, equipment, space, and atmosphere, to support the above research requirements.[7]

In testimony to this subcommittee on April 16, 1991, SSB Chairman Louis Lanzerotti noted that "For over twenty years, virtually every internal and external life sciences advisory group to NASA has emphasized the absolutely critical need for a centrifuge in space. A variable force centrifuge (VFC) is the single most important facility for space biology and medicine research."[8]

The White House Office of Science and Technology Policy issued its own report, which essentially agreed with the Academy's findings, and similarly emphasized the need for a centrifuge.[9] In response, NASA restored a 2.5 meter centrifuge to the design.

Clinton Administration

As President Clinton took office in 1993, NASA announced $1 billion in cost growth in the Space Station *Freedom* program. In response, the President directed NASA to redesign the space station again to reduce costs. Many in the space community consider this to be the most crucial year in the space station's history, as the continued cost growth, schedule delays, and redesigns took their toll on congressional support for the program.

Ultimately, a scaled-down version of the *Freedom* design was selected. President Clinton issued a statement announcing the decision on June 17, 1993 that included the following rationale for proceeding with the program:

> At a time when our long-term economic strength depends on our technological leadership and our ability to reduce the deficit, we must invest in technology but invest wisely, making the best possible use of every dollar. That's why I asked for a review of NASA's space station program. . . . I instructed NASA to redesign the space station program in a way that would preserve its critical science and space research and ensure international cooperation, but significantly reduce costs and improve management.
>
> NASA has met that challenge . . .
>
> I am calling for the U.S. to work with our international partners to develop a reduced-cost, scaled-down version of the original Space Station *Freedom*. At the same time, I will also seek to enhance and expand the opportunities for international participation in the space station project so that the space station can serve as a model of nations coming together in peaceful cooperation. . . .
>
> To make maximum use of our investments and meet the scientific goals we have set, the specific design we will pursue will be a simplified version of Space Station *Freedom* . . .
>
> There is no doubt that we are facing difficult budget decisions. However, we cannot retreat from our obligation to invest in our future. Budget cuts alone will not restore our vitality. I believe strongly that NASA and the space station program represent important investments in that future and that these investments will yield benefits in medical research, aerospace, and other critical technology areas. As well, the space station is a model of peaceful international cooperation, offering a vision of the new world in which confrontation has been replaced with cooperation.[10]

A week later, on June 23, 1993, the House voted to continue the space station program by a one-vote margin as it considered a NASA authorization bill. A week after that, on June 28, it voted to support the program by a somewhat wider (24 vote) margin when considering NASA's appropriations bill for that year. Two

[7] U.S. National Academy of Sciences. National Research Council. Space Studies Board. Space Studies Board Position on Proposed Redesign of Space Station *Freedom*. Letter report to NASA Administrator Richard Truly, March 14, 1991. pp. 1–3.

[8] U.S. Senate. Committee on Commerce, Science, and Transportation. Subcommittee on Science, Technology, and Space. NASA's Plan to Restructure the Space Station Freedom. Hearing. April 16, 1991. S. Hrg. 102–268. Washington, U.S. Govt. Print. Off., 1997, pp. 52–53.

[9] White House. Letter from Dr. D. Allan Bromley, Assistant to the President for Science and Technology, to the Honorable Dan Quayle, Vice President of the United States. March 11, 1991. Dr. Bromley's report called not only for a centrifuge able to accommodate animals, but a larger one for human subjects.

[10] William J. Clinton. Public Papers of the President. June 17, 1993. Available from the Government Printing Office at: ***http://www.gpoaccess.gov/pubpapers/index.html.***

months later, on September 21, 1993, the Senate voted to continue the program 59–40.

By the time of the Senate vote, the space station had changed again, however. On September 2, Vice President Gore announced that Russia had agreed to join the space station partnership as part of broader cooperation in human space flight and other science and technology areas. Some of the expected benefits of bringing Russia into the space station program were in the foreign policy arena and, while important, are not the focus of your hearing this morning, so I will not discuss them here. In terms of the capabilities of the new space station design, NASA said that, in comparison with the design announced in June 1993, the space station would be ready one year sooner, cost $2 billion less,[11] have 25 percent more usable volume and 42.5 kilowatts more electrical power, and accommodate six[12] instead of four crew members.

Mr. Daniel Goldin, the Administrator of NASA from 1992–2001, often stated that this redesigned space station—now referred to simply as the International Space Station (the name *Freedom* was dropped in 1993)—would have "world-class" research capabilities. In 1997, he articulated the expected scientific payoff in response to questions posed at a hearing before this Subcommittee:

> . . . We happen to be building a station in Earth orbit that has unique characteristics where we could do research in biomedicine, biotechnology, advanced materials, combustion research, advanced communications and advanced engineering and Earth science that we could do on no other platform.
>
> We already have results back from our very early missions on the Mir space station . . . [W]e have been getting absolute breakthroughs in the kind of science we have in the areas of cancer research, pharmaceutical research.
>
> We have even built a half-centimeter piece of human cartilage in the bioreactor. . . . We have done incredible research in combustion.
>
> The key to it is time on orbit and the absence of gravity. The International Space Station is going to provide that capacity.
>
> Furthermore, we're going to have exploration of space. . . . In the process of understanding how people can adapt to space, we study healthy physiology in an abnormal environment and compare it to abnormal physiology or sick people in a normal environment here. This is yielding great results, and, in fact, it is so exciting that the American Medical Association has signed a cooperative agreement with NASA to take advantage of the International Space Station to help upgrade medical techniques right here on Earth.
>
> . . . This is a place where we use the absence of gravity to understand the laws of physics and chemistry and biology much better and rewrite textbooks.[13]

After further discussion, he cautioned that " . . . I cannot tell you that I could give any American a cure for cancer. . . . " or make other promises because NASA engages in long term, high risk research for which the payoff could be 10–20 years in the future.[14]

The basic design of the space station remained unchanged throughout the Clinton Administration. But cost growth and schedule delays remained a constant companion. In 1997, NASA began to shift funds from space station research into space station construction.

In 1998, the first two elements of the space station were launched. A 19-month hiatus followed, waiting for Russia to launch its "Service Module" that provides crew quarters. With the successful launch of the Service Module in 2000, successive space station crews took up residency, initiating permanent occupancy of ISS.

George W. Bush Administration

As President George W. Bush took office in 2001, NASA again announced significant cost growth, not unlike the situation when President Clinton took office in 1993. With space station construction already under way, redesign options were lim-

[11] Initially, NASA and the White House said that Russia's participation would save 2 years and $4 billion, but later lowered it to 1 year and $2 billion. The estimated savings were based on the fact that NASA was spending about $2 billion per year on the program, so accelerating the schedule by one year would save that amount. For more information, see CRS Issue Brief IB93017.

[12] Although NASA said six at the time, the revised intergovernmental agreements that formally brought Russia into the program in 1998 call for a permanent space station crew of seven.

[13] U.S. Senate. Committee on Commerce, Science, and Transportation. Subcommittee on Science, Technology, and Space. International Space Station. Hearing. September 18, 1997. S. Hrg. 105–792. Washington, U.S. Govt. Print. Off., 1997, pp. 12–13.

[14] Ibid, p. 15.

ited. The Bush Administration decided to truncate ISS construction at a phase called "core complete," which included the launch of certain U.S. components, and the hardware under construction by other ISS partners. The White House said that if NASA could demonstrate better program management, it would consider adding "enhancements" to the station later.

Three major U.S. elements were cancelled then or the next year: a Crew Return Vehicle for returning astronauts to Earth in an emergency; a Propulsion Module; and a Habitation Module. The Administration also cut the budget for space station research by $1 billion, and directed NASA to reprioritize its research program accordingly. NASA created a Research Maximization and Prioritization (ReMaP) Task Force to do so. Its report was completed in 2002.

Mr. Goldin, who remained Administrator for most of the first year of the Bush Administration, told the House Science Committee that the downscaled space station still would support the "high priority goals of: (1) permanent human presence in space, (2) accommodation of all international partner elements; and (3) world-class research in space."[15] One major concern was the decision to terminate the Crew Return Vehicle (CRV), which was needed if the crew size was going to increase from three to six or seven. The size of the crew was considered vital to the amount of scientific research that could be conducted there, since NASA estimated that it took "2½" astronauts to operate and maintain the facility, leaving only half of one person's time for research when the crew size was limited to three. Mr. Goldin said that "human-tended science would be greatly degraded" with a three-person crew, but he expressed hope that a solution would be found so that the larger crew size could be restored.[16]

Mr. Sean O'Keefe became NASA Administrator in December 2001, with a mandate, inter alia, to "fix" the space station program. Eleven months later, he won White House support to submit a FY 2003 budget amendment that called for adding $706 million to the ISS program for FY 2004–2007: $660 million to boost program reserves to ensure sufficient funds to finish the core complete configuration, and $46 million in FY 2004 for "long-lead" items to preserve the option of increasing crew size beyond three.[17] In December 2002, he and the heads of the other partners' agencies agreed on a process for selecting a final ISS configuration by December 2003, including how to increase the crew size.

The crew size limitation is based on the number of astronauts who can be returned to Earth in an emergency by a single Russian Soyuz spacecraft. In this context, it is referred to as a "lifeboat" or "crew return" capability. Russia is committed to having one Soyuz docked with ISS at all times throughout its lifetime to serve as a lifeboat for three people. The U.S. Crew Return Vehicle (CRV) was to serve the same function for another four. The Bush Administration had terminated the CRV, however. Without it, the only option for augmenting lifeboat services is for Russia to provide additional Soyuz spacecraft. Each Soyuz can only remain in orbit for 6 months. Today, Russia launches two Soyuzes per year. To enable crew size to increase to six, it would have to launch four per year. Russian space officials said that they could not afford to build and launch the additional Soyuzes, and needed to be compensated. NASA, however, is not permitted to pay Russia for ISS-related activities unless the President certifies that Russia is not proliferating certain technologies to Iran under the Iran Nonproliferation Act.[18] The other partners did not offer to pay for the additional Soyuzes, leaving the situation in a stalemate, where it remains today.

Debate over the long term plans for the ISS was soon complicated by the February 1, 2003 space shuttle *Columbia* tragedy. The *Columbia* tragedy has affected the space station program in many ways. One outcome is that it led to a review of the reasons that the United States engages in human space flight at all. That review resulted in an announcement by President Bush of a new Vision for Space Exploration on January 14, 2004. The President said:

---

[15] U.S. Congress. House. Committee on Science. Space Station Cost Overruns. Hearing, April 25, 2001. Washington, U.S. Govt. Print. Off., p. 74.

[16] U.S. Congress. House. Committee on Science. Subcommittee on Space and Aeronautics. NASA Posture. Hearing, May 2, 2001. Washington, U.S. Govt. Print. Off., p. 31.

[17] The ISS increases were proposed to begin in FY 2004. By the time Congress deliberated the FY 2004 budget, ISS construction was suspended because of the *Columbia* tragedy, and Congress cut $200 million from the ISS budget. The budget amendment also initiated an Orbital Space Plane program that would have been able to take crews to and from ISS, but it was terminated a year later.

[18] The relationship between the ISS and the Iran Nonproliferation Act is discussed in CRS Report RS22072.

> Today I announce a new plan to explore space and extend a human presence across our solar system. We will begin the effort quickly, using existing programs and personnel. We'll make steady progress—one mission, one voyage, one landing at a time.
>
> Our first goal is to complete the International Space Station by 2010. We will finish what we have started, we will meet our obligations to our 15 international partners on this project. We will focus our future research aboard the station on the long-term effects of space travel on human biology. The environment of space is hostile to human beings. Radiation and weightlessness pose dangers to human health, and we have much to learn about their long-term effects before human crews can venture through the vast voids of space for months at a time. Research onboard the station and here on Earth will help us better understand and overcome the obstacles that limit exploration. Through these efforts we will develop the skills and techniques necessary to sustain further space exploration.
>
> To meet this goal, we will return the Space Shuttle to flight as soon as possible, consistent with safety concerns and the recommendations of the *Columbia* Accident Investigation Board. The Shuttle's chief purpose over the next several years will be to help finish assembly of the International Space Station. In 2010, the Space Shuttle—after nearly 30 years of duty—will be retired from service. [19]

A NASA budget chart released the same day as the President's speech showed NASA completing its use of the space station by FY 2017. Funds now devoted to the space shuttle and space station programs could thereby be redirected to fulfilling the "Moon/Mars" goals enunciated in the Vision. So although the *Columbia* tragedy was a catalyst for a new Vision for the human space flight program, if that Vision is implemented, it also would spell the end of the space shuttle and ISS programs (from a U.S. perspective that is; the other partners might continue to use ISS after NASA completes its utilization).

If the Vision is adopted, the full extent of its impact on U.S. use of ISS is not yet clear. What is known is that the scope of research would be narrowed to only that which supports the Vision; there would be fewer years during which NASA will conduct research; [20] and the shuttle would not be available to support scientific operations by taking experiments and equipment up to the ISS ("upmass") or back to Earth ("downmass") once construction is completed. NASA's ReMaP Task Force cited lack of upmass capacity as one of the limiting factors on conducting high priority research.

What is not known is details of the new research program and therefore what benefits can be expected from it, what the ISS crew size will be, whether the centrifuge will be completed, and what capabilities may be available from other partners or the U.S. commercial sector to take cargo to and from ISS instead of the shuttle.

Conclusion

The space station was originally presented to Congress as a facility that would have eight functions. Within five years, that had been reduced to one—a laboratory for world-class research. That research program has been affected by reductions in funding (in the late 1990s by shifting funds from research into construction, and in 2001 as part of the cost-cutting in response to cost growth in the overall program), and now by the direction of President Bush, narrowing the scope to only research that supports the Vision.

The extent to which space station research will "rewrite textbooks" as forecast by Mr. Goldin in 1997 remains to be seen.

---

[19] President Announces New Vision for Space Exploration Program. Available at: *http://www.whitehouse.gov/news/releases/2004/01/20040114–3.html.*

[20] Space Station *Freedom* was designed with a 30 year lifetime. When the program was redesigned in 1993, NASA shortened the operational lifetime of the new station to 10 years (the modules are designed for 15 years—5 years during assembly, and 10 years of operation). Under the Vision, NASA officials say the agency will complete its use of the ISS by 2016, six years after construction is completed.

Major Program Changes to the U.S. Portion of the International Space Station*

Calendar Year	Nature of Change	Reason
	Reagan Administration	
Fall 1985–May 1986	Original space station concept envisioned three elements: an occupied base for 8 crew members in a 28.5° orbit, an automated co-orbiting platform nearby, and an automated "polar platform" in orbit around Earth's poles. The original reference design for the occupied base was called the "Power Tower," but a "dual-keel" approach was chosen instead as the baseline design in the fall of 1985; the details were approved by NASA in May 1986. Changes included: arrangement of truss structure and modules modified to place modules at center of gravity; solar dynamic power added to photovoltaic arrays; number of U.S. laboratory and habitation modules reduced from 4 to 2, with plans for 2 more provided by Europe and Japan (the new U.S. modules would be larger than the original design, however, so total habitable volume relatively unchanged); U.S. Flight Telerobotic Servicer added at congressional urging to supplement Canada's planned Mobile Servicing System.	Cost and user requirements. NASA stated that the dual-keel design would provide a better microgravity environment for scientists, more usable area for attached payloads, and better pointing accuracy. Cost estimate maintained at $8 billion ($FY 1984).
Late 1986	Dual-keel design reaffirmed, but emphasis on building single-keel first in recognition of reduced availability of shuttle flights and reduced amount of cargo that would be allowed aboard the shuttle in the wake of the *Challenger* tragedy. Emphasis on early accommodation of experiments; fewer spacewalks; extended "safe haven" concept with the possibility for "lifeboats" for emergency return to Earth (not made a requirement at this time reportedly for cost reasons); increased use of automation and robotics; "lead center" management approach replaced with dedicated program office for the space station in Reston, VA.	January 1986 space shuttle *Challenger* tragedy and concern by astronauts at Johnson Space Center about the number of hours of spacewalks, or "EVAs"; quality and quantity of living space; standard of safety for "safe havens" (to which astronauts would retreat in emergencies such as depressurization or dangerous sunspot activity); lack of "lifeboats" for emergency return to Earth when the space shuttle was not docked with the station. Cost estimate unchanged.
1987	Program split into "phase 1" and "phase 2," with single keel of occupied base built in phase 1 and second keel delayed until phase 2; polar platform part of phase 1; co-orbiting platform and solar dynamic power pushed into phase 2.	Rising program costs and expected budget constraints. Cost estimate had risen to $14.5 billion ($FY 1984) for research and development. New design estimated to cost $12.2 billion ($FY 1984) for Phase 1 and $3.8 billion ($FY 1984) for Phase 2, saving money in the near term, but costing more in the long term.

Major Program Changes to the U.S. Portion of the International Space Station*—Continued

Calendar Year	Nature of Change	Reason
George W. Bush Administration		
1989	Phase 2 indefinitely postponed; polar platform transferred from space station program to NASA's Office of Space Science and Applications (was for Earth observation studies). Only remaining element is single-keel occupied base, divided into an initial phase with reduced capabilities (e.g. crew reduced from 8 to 4; electrical power reduced from 75 kw to 37.5 kw; use of open-loop instead of closed-loop life support system) and an assembly complete phase when "full capabilities" would be restored. NASA asserted that the capabilities envisioned in the 1987 Phase 2 program (dual-keel etc.) could still "evolve" sometime in the future to support expeditions to the Moon and Mars.	Cost growth and expected budget constraints. NASA termed this a "rephasing." Cost for Phase I estimated at $19 billion real year dollars,* or $13 billion FY 1984 dollars, for R&D; NASA estimated total program costs through assembly complete at $30 billion real year dollars.
1990–1991	U.S. modules reduced in size (from 44 feet to 27 feet); "pre-integrated truss" chosen in effort to reduce EVA requirements; total length reduced (from 493 feet to 353 feet); Flight Telerobotic Servicer canceled; crew size formally reduced to 4; electrical power reduced (from 75 kw to 56 kw); "lifeboat" added to the station's design but not included in the cost estimate; "assembly complete" designation abandoned with concept that station would continually evolve in an undefined and unbudgeted "follow-on phase."	Beginning in 1990, concerns developed over rising program costs, weight, and too many EVAs for maintenance. In Dec. 1990, NASA estimated program costs through assembly complete at $38.3 billion real year dollars. Congress directed NASA to restructure the station. New plan released in March 1991. NASA stated it would cost $30 billion real year dollars through 1999, though this was no longer the time when assembly would be completed (see column to the left). GAO estimated total program costs through 30 years of operation at $118 billion.

Major Program Changes to the U.S. Portion of the International Space Station*—Continued

Calendar Year	Nature of Change	Reason
Clinton Administration		
1993	Space Station Freedom program terminated. New design developed (initially called Alpha), which NASA said would use 75 percent of Freedom's hardware and systems. Russia added as another international partner in a second phase of the 1993 activity. Program renamed International Space Station Alpha, and, later, simply International Space Station (ISS). Two U.S., 1 European, 1 Japanese, and 5 Russian modules (3 for science) accommodate crew of 6; Canada to build Mobile Servicing System; station located in 51.6o orbit (to allow access from Russia); operating period shortened from 30 to 10 years and annual operating costs reduced; "assembly complete" designation reinstated (but no "follow-on phase" or "evolution" or capabilities envisioned by the 1987 Phase 2 plan); space station management changed to "host center" (later "lead center") at Johnson Space Center, TX; Reston, VA office closed.	Cost growth and foreign policy considerations. There were two phases of space station program changes in 1993. The first (February-September) was prompted by $1.08 billion cost overrun (which NASA termed "cost growth") and resulted in a new design, tentatively called Alpha, involving the original space station partners (U.S., Canada, Europe and Japan). This design was released on Sept. 7, but 5 days earlier, the White House announced plans to merge the space station program with Russia's primarily for foreign policy reasons. In November, a new "Russian Alpha" design was announced including Russia as a partner. NASA said with Russian involvement, "Russian Alpha" would be ready 1 year sooner, cost $2 billion less (a figure GAO disputes), and have more scientific utility than the Sept. 7 Alpha version. NASA's current estimate of program costs for FY 1994–2002 (assembly complete) is $17.4 billion real year dollars, not including launches or civil service salaries (adding those costs would raise it to $47.9 billion, using average shuttle costs). Monies spent prior to FY 1993 ($11.4 billion) and operational costs for 10 years ($13 billion) are not included. [All funding figures from NASA.]
2001–2002	ISS construction to be terminated after completion of "U.S. Core" and attachment of European and Japanese modules.Propulsion Module canceled. Habitation Module and Crew Return Vehicle indefinitely deferred pending demonstration of improved program management (later canceled). Could mean that crew size would be limited to 3 instead of 6 or 7 because only one Russian Soyuz (which can accommodate 3) would be available as a lifeboat. Smaller crew size would limit amount of science that could be conducted. Funding for research program cut $1 billion cut. At December 2002 "Heads of Agency" meeting, partners agree that crew size should be restored to six, but no details on how to accomplish it.	Cost growth of $4 billion over estimate made in its FY 2001 budget submission. ISS had been estimated to cost $17.4 billion (real year dollars) when it began in 1993 (FY 1994). NASA's estimate rose to $21.3 billion and then $22.7 billion in 1998, to $23.4–26 billion in 1999, and to $24.1–26.4 billion in 2000. NASA's March 2001 plan to discontinue construction after the "U.S. Core" is completed and attachment of the European and Japanese module results in a cost estimate of $22–23 billion and a "completion" date of November 2003-October 2004. Hardware being built for NASA by Europe and Japan (Node 3 and Centrifuge Accommodation Module, respectively) as part of barter agreements could be launched if NASA has sufficient funding for integration costs.

Major Program Changes to the U.S. Portion of the International Space Station*—Continued

Calendar Year	Nature of Change	Reason
2004	Construction of ISS to be completed by 2010, and shuttle program thereupon to be terminated, so shuttle will not be available during the ISS operational phase to rotate crews, bring supplies or new equipment and experiments, return results of experiments, or return equipment needing repair. U.S. ISS research program to be reformulated to support only the Vision. If crew size is to increase, will be via additional Soyuz spacecraft, but no details on how to accomplish that (NASA prohibited from making payments to Russia for ISS because of the Iran Nonproliferation Act). New Crew Exploration Vehicle (CEV) to be built to take crews to the Moon; Earth-orbit capability by 2014. Between 2010 (when shuttle is terminated) and 2014, U.S. will rely on Russia for crew transport to ISS. NASA to rely on other partners, and U.S. commercial sector, to take cargo to and from ISS after shuttle retirement. No commitment to use CEV to service ISS, although it is an option. According to NASA budget chart, U S use of ISS to end by FY 2017.	President Bush's announcement of the Vision for Space Exploration, which directs NASA to focus its activities on returning humans to the Moon by 2020 and someday sending them to Mars and "worlds beyond."

Prepared by CRS, based on information from NASA, historical CRS publications, congressional hearings, and articles in the trade press.

According to NASA's budget books (e.g., page SI–6 of the FY 2001 budget book), estimates in "real year dollars," reflect current and prior year spending unadjusted for inflation, plus future year spending that includes a factor accounting for expected inflation.

The CHAIRMAN. Thank you. Dr. Weber.

STATEMENT OF MARY ELLEN WEBER, PH.D., VICE PRESIDENT, UNIVERSITY OF TEXAS, SOUTHWEST MEDICAL CENTER

Dr. WEBER. Thank you very much. I had the great privilege of being a member of our Nation's Astronaut Corps for 10 years and even greater privilege to fly on two Space Shuttle flights, the second of which was the third construction flight for the Space Station. And although I'm now with Southwestern Medical Center, my heart and my passion will always be in space. And I'm so thrilled that your Subcommittee is taking up this hearing and this topic.

For thousands of years people have looked up at the heavens and tried to imagine what was out there. What could possibly be those points of light? And our generations are so incredibly fortunate to be the ones alive at what is just a blink of time in the history of humankind.

This is the beginning of the quest to creating a space-faring civilization. Anything this momentous cannot be accomplished in a day or a week or a year or even a decade. It's a very long road ahead of us. And we as a country and as a society have to be patient.

Someone recently lamented to me that we really hadn't come very far in aviation because 50 years ago it took a few hours to fly across the country and now it takes about the same amount of time. But what they were ignoring is the fact that we have created this enormous, tremendous infrastructure that doesn't just move a few hundred people once a day. We move millions of people every day. And in fact, we've embraced aviation as a part of our society, as part of our economy. And this is where we are with the space program as well. We need to create an infrastructure to bring space travel to our society to make it an integral part of our economy, and to be contributing to our economy.

It's really easy to simply focus on the flashy events; the Super Bowl, the World Series and to ignore and diminish the smaller events, the regular season games, the daily practice. And when we look at space travel, certainly going to other planets is the most alluring thing we can do in our quest to explore space. But to diminish what we've done with the Space Shuttle and the Space Station is a tremendous mistake. These programs are giving us this necessary infrastructure for us to go on and do the big flashy major events.

The Space Shuttle for the past two decades has focused on the most dangerous and most risky aspect of any space venture; that of leaving and returning to a celestial body. It is the most risky and the most dangerous because of the irrefutable fact that you have to go mind numbingly fast. You have to go 25 times the speed of sound to get into space.

For the past two decades we've been learning how to leave and return to a planet. About 100 flights. And it may sound like a lot, but it is just the first step and we've learned with *Challenger* and *Columbia* that we have much to learn.

You heard Mr. Readdy talk about the benefits of the International Space Station and the operational experience and knowledge that we're gaining. How to operate in weightlessness. How can our bodies, bodies that have evolved over millions of years, how can they operate in weightlessness? And we're also mastering the ground operations of coordinating this colossal collaboration between nations across the entire world. And this is going to be the same thing we need to do if we ever want to go on to the Moon and Mars; such an enormous venture is going to require the same kind of collaboration.

But aside from the operational lessons that we've learned, the Shuttle and Station have provided some very important opportunities scientifically. We have the chance to probe biological and material systems by varying a force that we could otherwise not vary. This is information we cannot possibly get on the ground. Will all research experiments aboard the Space Station make a dramatic impact on our society? That's very unlikely. Research—ground-based research—doesn't work that way either.

But for Congress to continue to make an investment in space and to get us to the Moon and on to Mars I believe that it's essential that we receive an economic return from space research. While I was at NASA, I became intensely involved in these efforts to attract private sector investment in space research. And even on the ground, bridging the gap between the laboratory and the marketplace is truly one of the most daunting challenges and I think one of the most under-appreciated challenges. And when you put that laboratory up in space it definitely presents some even more formidable hurdles.

From my experience in working with one particularly successful effort with a VC firm—this one resulted in the most ever paid to NASA for a single space experiment—I believe that there is still some low hanging fruit out there. Good opportunities for the private sector to invest. However, in order to do this right with all of these hurdles, NASA has to be diligent in it's approach to attracting this investment and making the business case. NASA must find compelling needs in the marketplace. Rather than starting with the phenomenon we see in space, we have to start with the needs that the marketplace has.

Only if there is an extremely compelling need will it justify the expense and the overhead and the inaccessibility right now to space. And even more important than that, NASA really must focus on identifying specific sources of revenue from these space experiments.

I have continually heard the phrase, "Well what we think is that that they'll be able to figure out something up on space that will help them with the process down on the ground." And that's not enough. It simply doesn't work that way. There needs to be a specific question identified that, if answered in that space experiment, will be a source of some revenue for that investor.

And finally, it is NASA's responsibility to identify these needs and sources of revenue, not the investors. Now, this may seem like a simple concept, but from my experience this would actually be a paradigm shift for NASA. Very often and historically NASA has put the onus on the investors to come up with how they can make money and put the onus on them to pitch the idea to NASA. Credible top tier investors simply don't work this way.

What we've seen is that a lot of investors with motives other than creating a viable business are the ones that solicit NASA. And this is a major hurdle if we truly want to be successful at commercializing space experiments and getting that private sector investment in.

Now, I mention that I believe there are a couple of areas of low hanging fruit for commercialization. If I—if I have time I'd like to just talk about a couple of those areas.

The CHAIRMAN. Very briefly. If you could just give us maybe a couple of points and then I wanted to go to Dr. Sutton and then do questions and try to bring those out. But I would like to know the two points. Thank you.

Dr. WEBER. The NASA bio-Reactor is an area of research in which you can grow human tissues outside of the human body. Not cells like we did in eighth-grade biology class, but real tissues. Tissues with cells that are differentiating, functioning like the organs in our body. This is a tremendous step forward in trying to understand the cellular sources and mechanisms for disease.

The other area of research is in protein crystal growth. The whole idea behind protein crystal growth is not in the crystals themselves but in the structures of the proteins that you can get from these experiments. Protein structure-based drug design is prolific today. This is how we have gotten the most exciting, most effective drugs out there including those that fight AIDS, the recent drugs that fight flu. But the bottom line is not all proteins can be crystallized on the ground. And in space we have the opportunity to grow them more perfectly and get those structures.

So, tissue growth and protein structure, I think, are the two lowest hanging pieces of fruit. And with that if I could just close with this:

Despite all the tangible benefits from the space program, I really think that the most important comes from deep within the human spirit. There is no better example of this than what happened 2 years ago with *Columbia*.

As you might expect, the entire Astronaut Corps was deeply moved by these events. We lost colleagues and had our deepest fears realized. What was surprising to me was the impact that it had on the entire world. The news programs literally shut down for anything but this event. I had friends in other countries that received condolences simply because they were Americans. People wept who never had ever met an astronaut. And these were seven lives. Just seven lives. And it's really—the people were not weeping for those lives, they were weeping for the loss, the potential loss of moving our society forward beyond the bounds and into new territory.

[The prepared statement of Dr. Weber follows:]

PREPARED STATEMENT OF MARY ELLEN WEBER, PH.D., VICE PRESIDENT, UNIVERSITY OF TEXAS, SOUTHWEST MEDICAL CENTER

For thousands of years people have looked to the heavens trying to imagine what could be out there, what could those points of light possibly be. We are the generations—those fortunate to be alive at this blink of time in the history of the universe—at the dawn of humanity's quest to become a space-faring civilization. Momentous endeavors such as this cannot be accomplished in day, or a year, or even a decade, and yet it is a time when it seems everyone seeks only instant gratification.

Someone recently lamented to me that we really had not come very far, since fifty years ago it took several hours to fly across the country, and it still does today. However, this is ignoring that an enormous infrastructure has been created, that simply flying a few hundred people a few thousand miles is an entirely different undertaking than moving millions about the globe each and every day. Indeed, aviation has progressed from simply a remarkable feat lasting mere seconds to become an inextricable part of billions of lives and an infrastructure without which our economy simply could not function. Likewise, in creating a space-faring civilization, it is not merely the one-time feats of venturing into new territory that matter. Creating the infrastructure and operations that will enable space to be woven into our daily lives is the more difficult—and perhaps more important—feat.

It is easy to only applaud the flashy events, the Super Bowl, golf's major tournaments, or the Olympic gymnastics. But to eliminate the arduous tedious daily practice, the minor competitions, or the daily workouts would eliminate the major events entirely. Similarly, creating new space vehicles that will take us once again beyond Earth orbit is certainly an alluring attention-getting element of the centuries-long quest to become a space-faring civilization. Yet we cannot eliminate or diminish the value and benefits of programs such as the Space Shuttle or the International Space Station. These programs provide necessary elements for success in the major events of human planetary exploration. They have been extremely important, both necessary to prepare us and the next generations to whom we will pass the baton.

The Shuttle program has focused on *the* most dangerous, challenging, and risky aspects of any space venture—leaving from and returning to a celestial body. The challenge, danger and risk arises from the irrefutable fact that to go into space, you must go mind-numbingly fast, at least 25 times the speed of sound, and then return. The required speed alone creates a need for amazing power and technologies and for complex operations coordinated around the world. Understanding and developing technologies, which will allow us to control complicated and delicate operations at these incredible speeds and over vast distances, will take decades and perhaps centuries. For two decades, with the Shuttle, we have been mastering launch and reentry, learning lessons—and learning just how much we have yet to learn—over the course of a hundred or so flights. It is only the beginning, a small and critical step in the long journey to becoming a space-faring civilization.

Similarly, the International Space Station is allowing us to master yet another important aspect of space travel to other heavenly bodies—long-term, non-stop operations in space. This involves mastering living and working in space, including the challenges of performing in weightlessness and the debilitation that happens to a body that has evolved for millions of years to use the strong force of gravity. It also involves mastering long-term, non-stop operations on the ground that involve multiple agencies and countries. The importance of this cannot be diminished, since undoubtedly, venturing to other planets will involve such enormous collaborations. The Station has moved us forward lightyears in our ability to operate globally, and to understand and withstand long-duration space travel.

Aside from the operational lessons that we have learned, the Shuttle and Station have provided us an unparalleled scientific opportunity in research experiments. We have the chance to probe biological systems and physical materials by varying a force that we could not otherwise vary. Will all research experiments aboard the Station make an immediate and dramatic impact? Unlikely. Even ground-based research does not work that way. But I would like to highlight just two types of research done in space that promise great rewards and promise to return the investment many times over. Both tie in to the next big wave in biomedical research, that of understanding the basis for disease both at a cellular and molecular level.

The first area of research I would like to highlight is growing human tissues outside the human body, using the NASA bioreactor. Of course for over a hundred years, we have been able to grow cells—we all did it back in Petri dishes in eighth grade biology—but cells are not the same as tissues. In fact, when a cluster of cells gets large enough, they begin to differentiate, to take on different roles in the larger organ. Consider a cancer tumor. It has a blood vessel system and glandular structures that enable it to secrete chemicals, chemicals important for metastasis. In the NASA bioreactor, we have the opportunity to grow many types of tissues, outside the human body, on a large scale, with cells differentiated, and the Station allows us to do it for months on end. This is an unprecedented opportunity to gain answers about the cellular basis for diseases affecting every organ of the human body. Hundreds of researchers across the country are studying many different types of tissue, using a ground-based NASA bioreactor, and those that get to fly their experiments in space have an incredible opportunity to study the largest, most stress-free, and highest-fidelity tissues.

The second area of research is protein crystal growth, and these experiments have been flying since almost the beginning of the Shuttle program. The end result is not crystals themselves, but structures of protein molecules. Proteins are enormous gangly molecules with thousands of atoms, and nothing happens in our bodies without proteins being involved. Each protein has an active site, a specific place in a specific structure that allows it to combine in a specific way with other proteins to either make something good or bad happen in our bodies. If we knew the complete structure and that active site, it would be relatively simply to come up with a chemical to fit within that site to prevent something from happening.

Protein crystals are the way to determine the structure. Imagine shining light on a glass prism; from the pattern of colors on the wall, we could determine the shape of that prism. For protein crystals, the dimensions are much, much smaller, so instead of light, we use x-rays to reveal their shape. With either glass prisms or protein crystals, any flaws in them will disturb the resulting pattern and prevent the true structure from being revealed. This is why growing protein crystals in space is so beneficial. The protein crystals are extremely delicate, and in the environment of space, they can grow more quiescently and more perfectly to reveal more accurate—and in some cases, the only available—structures.

Protein-structure-based drug design is now being done all over the world, and it has been the source of some of the most effective drugs for some of the most challenging diseases. These include HIV drugs that can eliminate the presence of the virus and make possible a relatively symptom-free life for many years. Another example is a recently introduced prescription flu drug that can make any strain of flu possibly a one- or two-day annoyance instead of a serious multi-week, sometimes lethal, illness. Hundreds of billions of dollars are lost each year in this country due to common but untreatable illnesses, and the use of space to discover even one effective drug would return many-fold the $16 billion we spend each year on the entire space program.

It is critical to put in perspective the level of this $16 billion investment in space exploration and research. In fact, it is exceedingly small compared to the other agency budgets that must focus on the here and now. For instance, we have spent far more paying farmers *not* to grow crops than we have each year on our entire Shuttle program. There are good reasons to provide farm subsidies, and yet there are equally compelling reasons to invest even more in space research, an activity that has yielded substantial return on investment over the past four decades.

For research in general, either space-based or ground-based, finding immediate applications is a challenge that requires patience. Yet there is a prevailing demand for instant gratification in our society, with Wall Street and corporations responding almost exclusively to current quarter earnings. Since I received my Ph.D. in 1988, virtually all elite corporate basic research centers America have vanished—including those at Bell Labs, Exxon, Xerox, and Texas Instruments. Instead, research is supported only if it can be tied to business units, with researchers having to justify their existence only by having a positive impact on profit and loss in the current quarter. The most important discoveries in our society would never have been made if subjected to such restrictions. Research, like the quest to become a space-faring civilization, is a long but critical road. Since companies must focus on the here and now, it is the responsibility of our government to look to the future, to invest in research and activities that will pay dividends in the long run.

For Congress to continue to make this investment, however, I believe that receiving an economic return from it is absolutely vital. Therefore, while at NASA, I became intensely involved in efforts to attract private sector investment in space research. Commercializing research is always a daunting prospect, but space presents some additional formidable challenges. In some successful ventures—one involving the bioreactor that resulted in the most ever paid to NASA for a single experiment—we learned successful private investment is possible with the right approaches. I have been asked to comment on lessons learned. First, the bridge between the laboratory—space-based or otherwise—and the marketplace must be built starting from the marketplace. This contrasts markedly with prior NASA efforts, in which amazing scientific phenomena observed were the starting point, with finding potential links to processes here on Earth second. Second, there must be an extremely compelling market need, since only with intense need will there be sufficient upside to bear the cost, the bureaucratic overhead, and the rare accessibility to space. "Nice-to-have" just is not good enough to warrant the investment. Third, there must be a specific source of revenue. The phrase repeated to me over and over, "hopefully they can learn something up there that might be applied to a process here on the ground," simply does not work. For instance, exactly what question, if answered from a space experiment, will lead to revenue? What physical lightweight product can be produced? Is there a "gold standard" that can be identified in space that will guide product development on the ground? Fourth, it is NASA's responsibility to identify that need and revenue source, not the investor's. While this may seem a simple concept, time and again, NASA has put the onus on investors to create the value proposition and business plan, and market it to NASA. Top-tier credible investors simply do not work this way, leading only investors with motives other than viable business prospects to solicit NASA.

Despite all tangible benefits from the space program, I believe the most important comes from deep within the human spirit. There is no better testament to the importance of this than from the tragedy of *Columbia,* just two years ago. As one might expect, the entire astronaut corps and NASA family was deeply affected. It is a small community, and not only did we lose colleagues and friends, this loss was a deep and pervasive fear realized. What was entirely unexpected however—at least for me—was the effect this tragedy had on the world. The entire world essentially came to a halt. No other news was covered. People wept, people who had never met an astronaut. Friends I had in other countries at the time received condolences, simply because they were Americans. I received condolences from people I did not know. *Columbia* captivated and moved our entire society. But the reality is that seven lives were lost. Seven lives. It happens all the time. People across our Nation and around the world did not weep for the loss of seven lives. I strongly believe people wept for something far deeper in us all, a deep rooted need to progress our civilization, to go beyond our bounds, beyond our own lives and the lives of our children. People wept because a part of this was lost, and because our whole space endeavors would be at risk.

I have been exceedingly fortunate to have had a small but exciting role in our quest to create a space-faring civilization. But we are all pioneers, everyone in our country because of the bold commitment that we have made to space. For many years I have felt great pride that it would be our generations upon which future generations would look with envy that we started it all. But we are now at a pivotal point in the quest. We are now retiring the Shuttle, and even with the most promising budget proposal, there is still insufficient funding to get us much beyond test flights with a new vehicle. I greatly fear that rather than being the generations to have started it all, we will be the generations to bring it to a grinding halt. We simply cannot let that happen.

The CHAIRMAN. Thank you, Dr. Weber. Dr. Sutton, I want to thank you for being here and I know you have had a loss at NSBRI with your CFO Jim Cooper passing away suddenly this week. And certainly my sympathies go out to you.

STATEMENT OF JEFFREY P. SUTTON, M.D., PH.D., DIRECTOR, NATIONAL SPACE BIOMEDICAL RESEARCH INSTITUTE (NSBRI)

Dr. SUTTON. Madam Chairman, thank you very much for your condolences. And distinguishing Ranking Member thank you for the wonderful opportunity to come here today and present my testimony.

I have the privilege to serve as the Director of the National Space Biomedical Research Institute, or NSBRI. NSBRI is a non-profit organization that engages outstanding scientists, engineers, and physicians from approximately 70 leading institutions across the country to work on focused integrated teams that develop ways to decrease biomedical risks associated with long-duration space missions. We're headquartered in Houston and we work closely with NASA in our science, technology, and education programs.

Many view the ISS as the most sophisticated engineering structure ever constructed in the history of humankind. It provides a unique precious resource for the United States to develop innovative technologies, knowledge and infrastructures to support U.S. space exploration goals. It's an invaluable test bed for exploration in science.

The NASA Administrator has affirmed that the completion of the ISS is a priority, in a matter consistent with commitments to our international partners and the needs of human exploration. And as you know this view is consistent with the President's Vision for Space Exploration. And in the Vision, one of the three main items listed for the ISS places emphasis on understanding how the space environment affects astronaut health and capabilities and developing countermeasures.

In the wake of events following the tragic loss of *Columbia* and her valiant crew, progress and discovery concerning crew health aboard the ISS continues. As we heard from the previous panel, experience is being gained on the reliability of critical hardware systems including life support. There's increased emphasis on autonomy, on performing in-flight maintenance rather than replacing parts from the ground. And the innovation continues to have a strong presence as illustrated by the recently published first scientific report ever submitted from space involving the testing and evaluation of ultrasound as an exploration medical capability.

Now with a shift in emphasis of the human space program from low–Earth orbit to destinations beyond, new priorities and exciting mission possibilities arise. In my view, it's imperative in developing a balanced over-all program of science, exploration and aeronautics to capitalize on the unique test platform of and the Nation's investment in the ISS.

The strategic planning process for ISS should integrate with plans for other systems such as transportation. Strategic goals should take into account the continuity of scientific and technological development of deliverables currently in the pipeline. Some of these products have long lead times toward maturation and operational integration to satisfy standards and requirements. ISS provides a critical resource to help define requirements for exploration needs and for on orbit check-out of select technologies and requisite interfacing with the human system.

Human flight testing may be required for many months or even years given current design reference missions to Mars which potentially expose humans to micro-gravity for periods well in excess of current ISS mission durations. The ISS is a critical training and educational platform for crew to familiarize themselves with the space environment and operational demands for extended periods of time.

It's worth noting that not all highly meritorious research and development for human exploration requires ISS resources. It will, therefore, be a challenging yet necessary task to prioritize projects. What do we need to do that could only be done on the ISS? What is feasible? What is the cost of not pursuing certain ISS scientific inquiries given the opportunity? And what are the benefits to Earth?

As my colleagues have mentioned the path toward exploration class human space missions captures the imagination, it adds to the marvelous recent successes of NASA's robotics program, and it inspires the next generation. Fostering a broad interest in science and engineering is essential to our national mission and wellbeing. And a strong future workforce in technology helps fuel our economy. There are several management models which may increase private sector involvement in the ISS. Some details concerning involvement in the human health and biomedical sector are included in my written testimony.

In closing, it's recognized that difficult decisions must be made to enable a bold, sustainable and affordable space program. ISS presents an unprecedented opportunity to bring to light innovative discoveries that advance our Nation and civilization. Thank you.

[The prepared statement of Dr. Sutton follows:]

Prepared Statement of Jeffrey P. Sutton, M.D., Ph.D., Director, National Space Biomedical Research institute (NSBRI)

Madam Chairman, Ranking Member and distinguished Members of the Subcommittee:

Thank you for the opportunity to present testimony on the benefits of human spaceflight as it relates to the International Space Station (ISS) and beyond. As Director of the National Space Biomedical Research Institute (NSBRI), my statement addresses each of the topics outlined for this hearing. These are (1) benefits of human spaceflight in the context of ISS development and current ISS operations, (2) future opportunities using the ISS for operations, engineering, commercial and scientific research and applications that support exploration and other national missions, and (3) possible management transition opportunities that increase private sector involvement in the ISS. The issues are complex, but important, as NASA moves forward under the leadership of its new Administrator, Dr. Michael Griffin.

Benefits of Human Spaceflight in the Context of ISS Development and Current ISS Operations

The ISS is the most sophisticated engineering structure ever constructed in the history of humankind. It provides a unique, precious resource for the U.S. and its international partners to develop innovative technologies, knowledge and infrastructures to support U.S. space exploration goals. The ISS has now been continuously crewed for more than four years, and it is an invaluable test bed for exploration.

The NASA Administrator has outlined the need for an exciting, outward-focused, destination-oriented space program, which includes both human and robotic exploration and aeronautics. Dr. Griffin has also affirmed that the completion of the ISS, in a manner consistent with commitments of international partners and the needs of human exploration, is a priority. This view is consistent with the President's Vision for Space Exploration, articulated on January 14, 2004. One of the three main activities listed for the ISS in low-Earth orbit is to focus U.S. research and use of the ISS on supporting space exploration goals, with emphasis on understanding how the space environment affects astronaut health and capabilities, and developing countermeasures.[1]

While the extent of scientific research and development being performed on ISS is limited in the wake of events following the tragic loss of *Columbia* and her valiant crew, important progress and discovery are nevertheless taking place. Experience is being gained on the reliability of critical hardware systems, including life support. There is increased emphasis on autonomy and performing maintenance inflight rather than replacing parts from the ground.

Innovation continues to have a strong presence, as illustrated by the recently published, first scientific report ever submitted from space, involving the testing and evaluation of ultrasound as an exploration medical capability.[2] The study was made possible by the unique, long-duration exposure to microgravity afforded crew members aboard the ISS.

Future Opportunities Using the ISS for Operations, Engineering, Commercial and Scientific Research and Applications That Support Exploration and Other National Missions

With a shift in emphasis of the human space program from low-Earth orbit to destinations beyond, new priorities and exciting mission possibilities arise. It is imperative in developing a balanced, overall program of science, exploration and aeronautics to capitalize on the unique test platform of, and Nation's investment in, the ISS.

The strategic planning process for ISS should integrate with plans for other systems, such as transportation, wherein the Shuttle retires and the Crew Exploration Vehicle (CEV) seamlessly comes into service. Strategic goals should also take into account continuity of scientific and technological product development for deliverables currently in the pipeline and which are, or can be, targeted at meeting specific exploration requirements. Some of these products, such as countermeasures which mitigate biomedical risks, have long lead times toward maturation and operational integration to satisfy medical standards and requirements.[3] ISS also provides a critical resource to define requirements for exploration needs and for on-orbit check-out of select technologies for the CEV and requisite interfacing with the human system.

Human flight testing may be required for many months, or even years, given current design reference missions to Mars which potentially expose humans to microgravity for periods well in excess of current ISS mission durations. Thus, to adequately test systems and reduce risk of failures, there may well be a need to main-

[1] The other two activities listed for the ISS in low-Earth orbit are: (1) complete assembly of the ISS, including the U.S. components that support U.S. space exploration goals and those provided by foreign partners, planned for the end of this decade and (2) conduct ISS activities in a manner consistent with U.S. obligations contained in the agreements between the U.S. and other partners in the ISS.

[2] *Radiology* 2005; 234(2):319–322. The study involved a collaboration between the ISS increment 9 crew, academia (MI) and industry (TX). The results have implications for assessing physiological adaptation to long-duration microgravity exposure and for remote medical imaging by non-medical personnel in harsh environments, including space and war zones.

[3] A NSBRI bedrest study in spinal cord injury patients has demonstrated the effectiveness of a single infusion of a bisphosphonate medication to inhibit bone loss for a one-year period (MD). The countermeasure requires further evaluation but is promising to counteract bone loss on exploration missions, as well as having potential benefit for the bone loss and fracture risk of persons immobilized by spinal cord or brain injury, stroke, or neuromuscular or developmental disorders.

tain the ISS, perhaps with commercial and increased partner support, beyond those times currently being proposed.

Not all highly meritorious scientific research and development, engineering and operational systems for human exploration require ISS resources.[4] It will be a challenging yet necessary task to prioritize the advanced space technologies, capabilities and knowledge requiring the ISS as a test bed for exploration. What do we need to do that can only be done on the ISS? What is feasible, given cost, schedule and task? What is the cost of not pursuing certain ISS scientific inquiries given the opportunity? What are the benefits to life on Earth from enabling technologies developed for exploration and validated aboard ISS?

The ISS is a training and educational platform for crew to familiarize themselves with the space environment and operational demands for extended periods of time. The path toward exploration class human space missions is invigorating and captures the imagination. It adds to the marvelous recent successes of NASA's robotics program, and if properly executed with integration of the unique capabilities of the ISS, can further inspire the next generation of space scientists, engineers and explorers. Fostering a broad interest in science and engineering is essential to our national mission and well-being, and a strong future workforce in technology helps fuel our economy.[5]

Possible Management Transition Opportunities That Increase Private Sector Involvement in the ISS

There are several management models which may increase private sector involvement in the ISS, such as the proposed ISS Research Institute considered by NASA approximately two years ago. With increased emphasis for exploration on focused, prioritized requirements, corporate participation, development of new capabilities in stages, and management rigor, it is timely that a discussion of management transition opportunities occur now. Given the integrated nature of ISS and exploration, any business model for private sector involvement for BS should link to plans for exploration. Key sectors include, but are not limited to, aerospace transport, advanced propulsion, power generation and energy storage, automation and robotics, and materials.

The following comments pertain to a management opportunity for ISS biomedical research and countermeasures for human exploration. In 1997, NASA awarded a competitive cooperative agreement to the National Space Biomedical Research Institute to "lead a national effort for accomplishing the integrated, critical path, biomedical research necessary to support long-term human presence, development, and exploration of space and to enhance life on Earth by applying the resultant advances in human knowledge and technology acquired through living and working in space."[6] The NSBRI is a private, non-profit organization that engages scientists and engineers from approximately 70 universities across the country to work on teams to develop countermeasures to health-related problems and physical and psychological challenges men and women face on long-duration space flights. The product-oriented approach to research and development, which is primarily ground-based, is leading to a number of operationally relevant countermeasures now ready for testing and evaluation aboard the ISS. A number of projects have industry partners. The Institute works with an Industry Forum and User Panel, and there is strong program oversight and management rigor, to maximize the likelihood of success and return on investment.

NSBRI engages NASA and other stakeholders throughout the countermeasure development process. This ensures requirements are in place and met, and that the highest priorities of risk are addressed and reduced. Projects are openly solicited and competitively awarded. There is synergy among science and technology projects, as well as integration with an educational program that spans from kindergarten to undergraduate and graduate levels, to post-doctoral training. The NSBRI is productive, cost-effective, scalable and provides NASA with an opportunity to partner

---

[4] For example, a rugged, portable, lightweight radiation detection instrument is under development by NSBRI/NASA and the United States Naval Academy (MD) to enable real-time measurement of radiation risk in space and estimate risk of damage to body tissue. A preliminary version is scheduled to launch September 2006 on a MidSTAR–I spacecraft. The instrument is applicable on Earth for homeland security, jobs with high potential for radiation exposure and monitoring radiation as part of cancer radiotherapy. A post-doctoral student at Memorial Sloan-Kettering Cancer Center (NY) is working on the cancer application.

[5] Between 1998 and 2002, the number of science and engineering doctoral degrees awarded to U.S. citizens at U.S. institutions fell 11.9 percent to 14,313, according to the *Commission on Professionals in Science and Technology,* a nonprofit research group.

[6] NASA Cooperative Agreement Notice 9–CAN–96–01.

with non-government entities to utilize ISS for exploration goals and provide maximum return on valuable resources invested.

In closing, it is recognized that difficult decisions must be made to enable a bold, sustained and affordable space program. ISS presents an unprecedented opportunity to test and validate critical technologies for human exploration and to bring to light the innovative discoveries that advance our Nation and civilization.

NATIONAL SPACE BIOMEDICAL RESEARCH INSTITUTE SELECT PROGRAM ACCOMPLISHMENTS/EARTH IMPLICATIONS

Background

The National Space Biomedical Research Institute (NSBRI), funded by NASA, leads a research program to develop countermeasures, or solutions, to the health-related problems and physical and psychological challenges men and women face on long-duration spaceflights. The research results and medical technologies developed have impact for similar conditions experienced on Earth, such as osteoporosis, muscle wasting, shift-related sleep disturbances, balance disorders, and cardiovascular and immune system problems.

Select Program Highlights

Needle-Free Blood and Tissue Measurement Sensor Progresses to NASA Evaluation

This patented NSBRI device allows accurate, noninvasive blood and tissue measurements not impacted by body fat or skin color. An extension of this work, in collaboration with NASA Johnson Space Center, will adapt the sensor for monitoring in-flight functional changes during exercise and assessing injury. This type of lightweight, portable device will be of use in ambulances, .intensive care units and on the battlefield. Another Earth benefit is its ability to detect, without a needle, reduced blood flow in diabetics. (Massachusetts and Texas)

Blue Light: Potential Use for Sleep and Circadian Rhythm Disruptions

NSBRI researchers have discovered that certain wavelengths in the blue portion of the visible spectrum alter melatonin production, thereby affecting the human circadian pacemaker. “Blue light” lamps are predicted to be more effective for regulating circadian rhythm than those currently used pre-launch and represent a potential in-flight countermeasure for adaptation to shifts in sleep cycle required by astronauts during spaceflight. NSBRI is working with an industry partner to study further the use of blue light. On Earth, lighting countermeasures developed for spaceflight can be modified for therapeutic or architectural applications and to facilitate adaptation to shift work. (Pennsylvania and Massachusetts)

Ultrasound Training for Non-Physicians

Diagnosing and managing acute health problems is challenging in space and on Earth. An NSBRI project in collaboration with NASA Johnson Space Center is evaluating the use of ultrasound for medical applications during spaceflight. The work has produced successful training sessions and interactive DVD refresher modules so that non-physician astronauts can successfully use ultrasound in remote medical needs for diagnosis of problems. On Earth, this training system could be used for remote-guided medical evaluation under isolated conditions. (Michigan and Texas)

Drug Advances in Evaluation as Countermeasure

NSBRI investigators demonstrated in ground-based simulation studies that the drug midodrine appears to be a promising agent for post-flight orthostatic hypotension (a drop in blood pressure causing light-headedness and fainting upon standing). A significant number of astronauts experience this condition upon return to gravity. This study is now approved for flight investigation. (Massachusetts and Texas)

Zoledronate: Possible Solution for Bone Loss in Space

In studies of spinal cord injury patients, NSBRI researchers demonstrated the effectiveness of a single, 15-minute IV dose of zoledronate in decreasing bone loss over a one-year period. These researchers are collaborating with NASA scientists and flight surgeons to further evaluate and validate the drug as a countermeasure for bone loss on long-duration missions, as well as in individuals subjected to long periods of bed rest. (Maryland and Texas)

Ultrasound Surgery—No Scalpels or Stitches

This NSBRI project on high-intensity, focused ultrasound, known as HIFU, demonstrates the usefulness of this technique to control bleeding, destroy unwanted tissue or tumors, and dissolve kidney stones with pinpoint accuracy. Treatment does not affect surrounding tissue and could one day allow bloodless surgery in space, emergency rooms and on the battlefield. (Washington)

Protein Linked to Muscle Loss

The way in which muscles atrophy during weightlessness in space has similarity with muscle wasting in diseases such as cancer, AIDS and diabetes. NSBRI-funded investigators identified atrogin-1, a muscle-specific protein whose levels go up during muscle atrophy. Recently, studies by this group have narrowed in on the molecular regulator of atrogin–1, a family of proteins called FOXO, thereby making this protein family a potential target for therapeutic approaches to combat muscle loss. (Massachusetts)

Evaluation of Shoulder Integrity in Space: First Report of Musculoskeletal US on the International Space Station [1]

By E. Michael Fincke, M.S., Gennady Padalka, M.S., Doohi Lee, M.D., Marnix van Holsbeeck, M.D., Ashot E. Sargsyan, M.D., Douglas R. Hamilton, M.D., Ph.D, David Martin, RDMS, Shannon L. Melton, BS, Kellie McFarlin, M.D. and Scott A. Dulchavsky, MD, Ph.D

Investigative procedures were approved by Henry Ford Human Investigation Committee and NASA Johnson Space Center Committee for Protection of Human Subjects. Informed consent was obtained. Authors evaluated ability of nonphysician crewmember to obtain diagnostic-quality musculoskeletal ultrasonographic (US) data of the shoulder by following a just-in-time training algorithm and using real-time remote guidance aboard the International Space Station (ISS). ISS Expedition–9 crewmembers attended a 2.5-hour didactic and hands-on US training session 4 months before launch. Aboard the ISS, they completed a 1-hour computer-based Onboard Proficiency Enhancement program 7 days before examination. Crewmembers did not receive specific training in shoulder anatomy or shoulder US techniques. Evaluation of astronaut shoulder integrity was done by using a Human Research Facility US system. Crew used special positioning techniques for subject and operator to facilitate US in microgravity environment. Common anatomic reference points aided initial probe placement. Real-time US video of shoulder was transmitted to remote experienced sonologists in Telescience Center at Johnson Space Center. Probe manipulation and equipment adjustments were guided with verbal commands from remote sonologists to astronaut operators to complete rotator cuff evaluation. Comprehensive US of crewmember's shoulder included transverse and longitudinal images of biceps and supraspinatus tendons and articular cartilage surface. Total examination time required to guide astronaut operator to acquire necessary images was approximately 15 minutes. Multiple arm and probe positions were used to acquire dynamic video images that were of excellent quality to allow evaluation of shoulder integrity. Postsession download and analysis of high-fidelity US images collected onboard demonstrated additional anatomic detail that could be used to exclude subtle injury. Musculoskeletal US can be performed in space by minimally trained operators by using remote guidance. This technique can be used to evaluate shoulder integrity in symptomatic crewmembers after strenuous extravehicular activities or to monitor microgravity-associated changes in musculoskeletal anatomy. Just-in-time training, combined with remote experienced physician guidance, may provide a useful approach to complex medical tasks performed by nonexperienced personnel in a variety of remote settings, including current and future space programs.

Supplemental material: *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*

Medical care capabilities for the International Space Station (ISS) and future exploration space missions are currently being defined (1,2). Although rigorous astronaut selection procedures reduce the chance of chronic health problems, acute conditions can occur during spaceflight (3,4). The probability of a crewmember developing a medical condition that may affect their performance or require care may be increased during long-duration or exploration missions.

Some alterations in musculoskeletal integrity take place during prolonged exposure to microgravity, despite the generally successful exercise countermeasures (5).

[1] From the National Aeronautics and Space Administration, Johnson Space Center, Houston, Tex (E.M.F., G.P.); Texas Diagnostic Imaging, Dallas, Tex (D.L.); Departments of Radiology (M.v.H.) and Surgery (K.M., S.A.D.), Henry Ford Hospital, 2799 W Grand Blvd, Detroit, MI 48202; and Wyle Laboratories, Houston, Tex (A.E.S., D.R.H., D.M., S.L.M.). Received September 30, 2004; revision requested October 12; revision received October 14; accepted October 15. Supported by NASA Flight Grant NNJ04HB07A and the National Space Biomedical Research Institute Grant SMS00301.

Insidious reduction in bone, muscle, and tendon mass that has been observed during spaceflight may heighten the risk of musculoskeletal injury. In addition, strenuous physical work during spacewalks, combined with upper body and arm motion constrained by the current spacesuits, further raises the likelihood of shoulder injury.

The assessment of musculoskeletal integrity is difficult in space because of limited medical training of the crew and a lack of radiographic and magnetic resonance imaging capabilities on either the transport vehicles or the ISS (6,7). However, a multipurpose diagnostic ultrasonographic (US) system is available within the Human Research Facility (HRF) of the ISS. We evaluated the ability of a nonphysician astronaut operator to perform shoulder US by using remote guidance techniques. This report documents the first shoulder US examination ever performed in microgravity of spaceflight.

Astronaut Training

The ability of two nonphysician astronaut crewmembers to perform shoulder musculoskeletal US was evaluated in the HRF of the ISS during ISS Expedition 9. The investigative procedures were approved by the Henry Ford Human Investigation Committee and the NASA Johnson Space Center Committee for the Protection of Human Subjects. Both crewmembers received briefings and acknowledged their informed consent before the mission, as did other human participants.

Astronaut crewmembers attended a 2.5-hour US familiarization session approximately 4 months before this evaluation to include a brief didactic presentation on the basics of US examination and the experiment-specific principles of remote guidance. The crewmembers also participated in a hands-on US session in the Payload Development Laboratory at the Johnson Space Center, Houston, Tex, where they performed abdominal and musculoskeletal US on a human subject via remote guidance from an experienced sonologist (A.S. and D.L., with 15 and 10 years of experience in musculoskeletal US, respectively). The hands-on sessions were designed to closely simulate in-orbit experiments. Real-time US images were transmitted to the remote sonologist, who guided the astronauts through the necessary positioning, probe placement and manipulation, and equipment adjustments to obtain optimal images. Identical remote-guidance "cue cards" were available to the guiding experienced sonologist on the ground and the operator onboard. The cards included keyboard prompts, anatomic reference points, and other essential information to increase remote guidance efficiency.

Imaging, Evaluation, and Communication

The ground and in-flight US examinations were both performed with flight-modified HDI–5000 US systems (ATL; Philips Medical Systems, Bothell, Wash) by using high-frequency (5–12 MHz) linear probes. Images were viewed by the operator on a flat-panel monitor and were transmitted simultaneously to remote US-guidance sonologists (A.S., D.L.) via local circuits (ground familiarization session) or through satellite broadband transmission (flight session). Flight communications include a 1.6-second transmission delay due to distance, data relaying, and conversions. Still and video cameras in the U.S. Laboratory module automatically recorded the US session, but recorded images and video were downloaded to the experiment team only after completion of the experiment.

The astronauts were asked to develop specific restraining techniques for both the subject and the operator, which would allow access to the upper arm and shoulder area, provide stability for the examination, allow unrestricted use of the keyboard, and help avoid operator hand fatigue.

The astronaut US operator completed a 1-hour computer-based US "refresher" course by using the Onboard Proficiency Enhancement (OPE) compact disk developed by the evaluation team 1 week before the US session. Information regarding OPE navigation, time on task, and query responses was stored on the ISS computer and was downlinked to the evaluation team before the US session to allow the team to refine the procedure or highlight certain procedural components to facilitate the upcoming US evaluations.

The US session was completed during scheduled Ku-band (video) and S-band (voice) communications. Dynamic US video was routed through the ISS communications system to the Telescience Center at the Johnson Space Center, where the ground-based experienced sonologist viewed the video output from the US machine with near real-time (1.6-second delay) conditions. Two-way audio communication with the US operator was used to guide US probe placement and adjust US device settings.

A full unilateral shoulder musculoskeletal examination was conducted, which included transverse and longitudinal views of the biceps and supraspinatus tendons and the articular cartilage surface. The examination was initiated with the probe positioned at the distal end of the clavicle in a longitudinal attitude. The probe was "steered" with remote experienced sonologist voice commands to achieve the desired images. After acquisition of the four views of the shoulder area, the subject and operator aboard the ISS switched roles, and the examination was repeated.

Examination completeness was evaluated initially by the ground-based experienced musculoskeletal sonologist by viewing the real-time downlinked US video stream. Full-resolution US frames were saved during the examination and were downlinked to the Telescience Center at a later time. These images were subsequently reviewed by an outside musculoskeletal US specialist (M.v.H.) to verify the diagnostic quality of the examination and the ability to exclude injury on the resultant images.

Findings

The astronaut crewmembers used foot restraints and hand pressure to maintain positioning and freedom of movement in the microgravity environment (Fig 1). This positioning technique allowed the subject to help with keyboard adjustments and provided rapid switching of the subject and operator when the examination was complete (Movie 1, *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*). No hand fatigue was reported, which had been noted by previous crewmembers who performed abdominal, cardiac, and thoracic US on the ISS, most likely as a result of the additional effort required when restraint is not optimal.

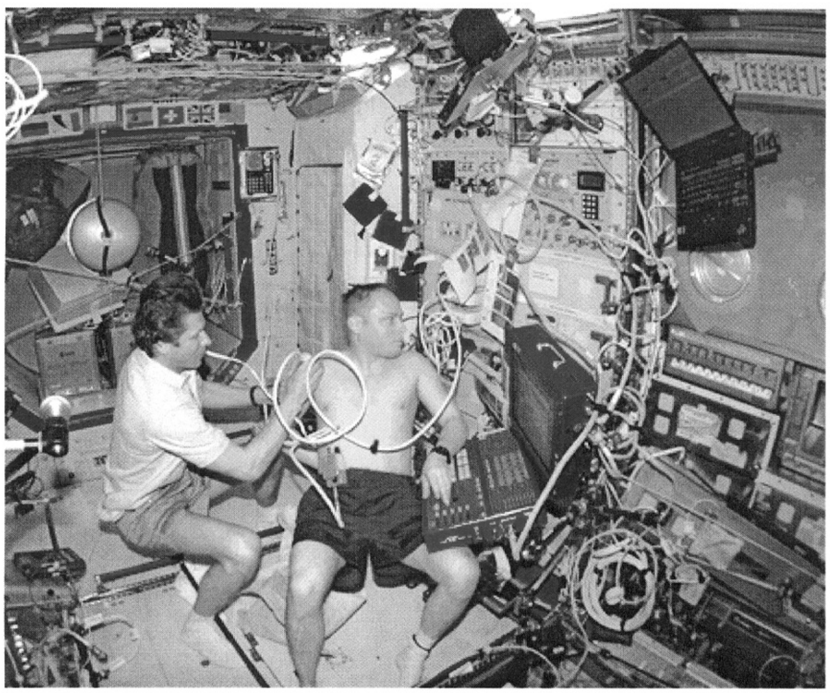

Figure 1. Cabin view obtained with a still camera of the HRF on the ISS. Commander Gennady Palalka performs a musculoskeletal US examination on Mike Fincke by using an HRF US unit (blue flat-screen monitor and keyboard).

Remotely guided shoulder musculoskeletal US examinations were completed by the two nonphysician astronaut operators in less than 15 minutes each (Movie 2, *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*). The downlinked real-time US video stream provided good-quality images of all of the areas of the shoulder that could be used to exclude substantial rotator cuff abnormalities (Movie 3, *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*). Full-resolution US frames, which were reviewed after the US session by the team, provided excellent-quality detail of all of the shoulder views (Figs 2–5). The still US images could be used to exclude subtle shoulder injury.

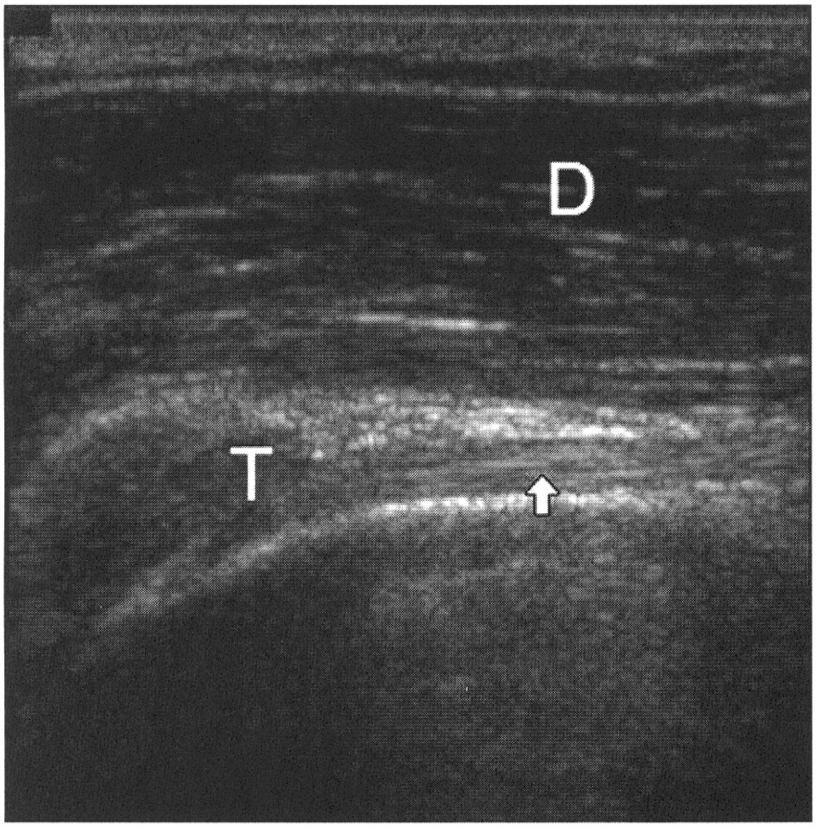

Figure 2. Full-resolution US images of the shoulder were downlinked from the ISS to mission control after the US examination. This image demonstrates a longitudinal view of the biceps tendon. The proximal intracapsular end of the long biceps tendon (T) is displayed on the observer's left. Within the normal tendon, a distinct fibrillar pattern is noted (arrow). D = deltoid muscle.

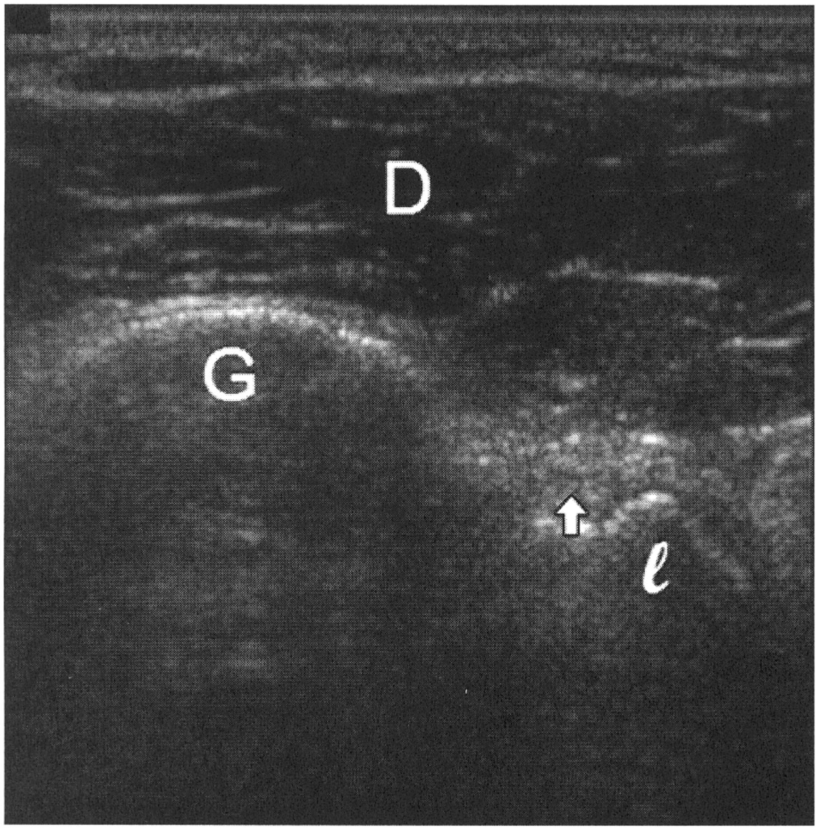

Figure 3. On this transverse view of the extracapsular biceps, the echogenic round shape of the tendon (arrow) is recognized between the lesser tuberosity (*e*) and the greater tuberosity (G). D = deltoid muscle.

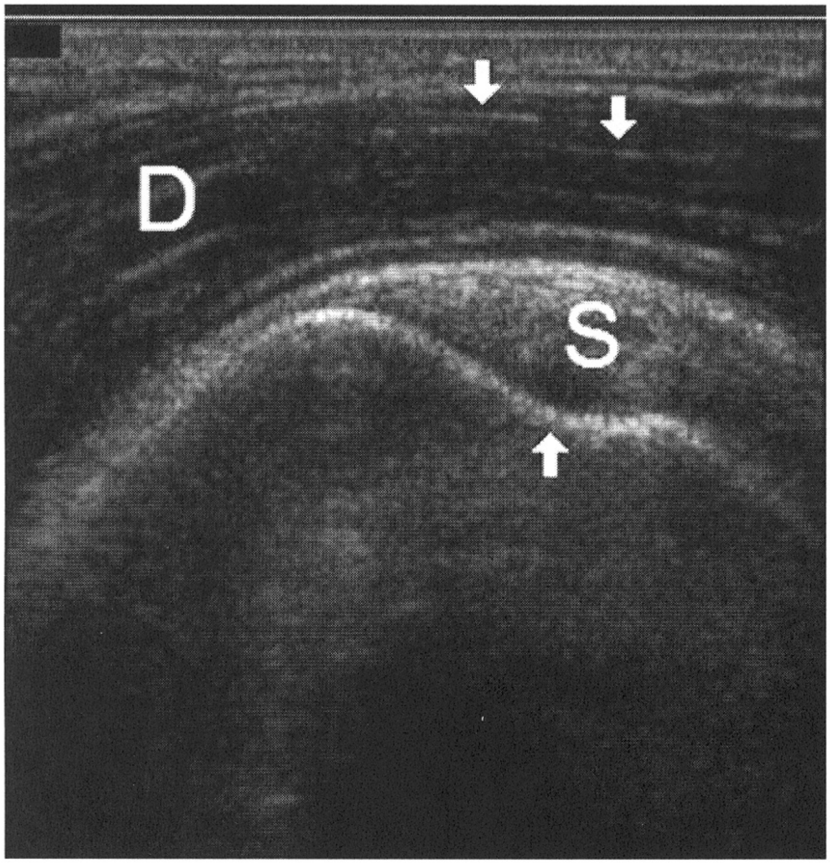

Figure 4. With the transducer placed over the long axis of the deltoid muscle (D), note the longitudinal striations (upper arrows) of the fibrofatty septa in between the muscle bundles. Supraspinatus tendon (S) is displayed in its long axis deep to the deltoid. The tendon rests on the bright echogenic surface of the proximal humerus. The humeral head shows on the medial aspect (observer's right) and the greater tuberosity more laterally. The anatomic neck is recognized on the groove (lower arrow) between these bone surfaces.

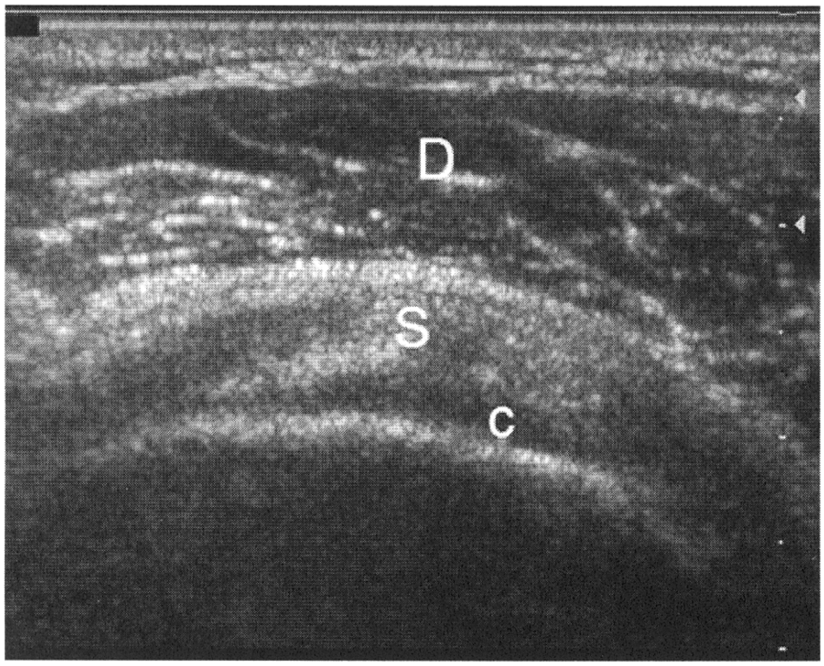

Figure 5. With the transducer turned perpendicular to the position in Figure 4, the examination of the supraspinatus (S) is completed with transverse views of the cuff. The deltoid muscle (D) is separated from the supraspinatus by alternating hypo- and hyperechoic lines, representing bursa and peribursal fat. The echogenic supraspinatus rests on hypoechoic hyaline cartilage over the echogenic humeral head surface (c).

Discussion

The ability to provide medical care aboard a spacecraft is challenging because of limitations in crew medical training, medical equipment, and environmental constraints in microgravity (1–5). The crews of the ISS receive training in a wide variety of tasks, ranging from maintaining spacecraft systems to conducting research to performing emergency medical procedures. A crew medical officer, who is generally not a physician, receives approximately 40 hours of additional training in medical diagnosis and therapeutics. Therefore, accurate communication during an illness or trauma is critical, particularly if real-time imaging is to be employed.

US is currently used in many trauma centers to diagnose abdominal injury (8,9). The technique has been shown to be accurate and sensitive in the identification of intraabdominal hemorrhage, even when performed by nonradiologists or nonphysicians (10). NASA investigators have similarly demonstrated that US can be used by nonphysicians to diagnose thoracic injury or bone fracture. The performance of US examinations and interpretation of images for the detection of abdominal bleeding or long-bone fracture do not require extensive training. Conversely, musculoskeletal US is substantially more complex and requires specialized expertise during both data acquisition and image interpretation.

Basic ultrasonic imaging has been completed on both U.S. and Russian spacecraft (5,11,12). NASA investigators have demonstrated a wide array of diagnostic US applications in microgravity experiments on animal models and human volunteers during parabolic flight on KC–135 aircraft. Results of these investigations suggest that the sensitivity and specificity of these US applications are not degraded in microgravity and may even be enhanced in certain circumstances. More comprehensive US examinations (*e.g.,* abdominal, musculoskeletal, and cardiac) require considerably more operator experience to perform and interpret autonomously. Since extensive US training with frequent refresher practice is not feasible in many situations, including remote medicine or the space program, alternative paradigms of US examination are required for this application.

Remote US guidance by experienced sonologists virtually couples a modestly trained US operator with a remote sonologist. The US operator is trained in basic US operation and gross requirements of the US examination. The operator places the US probe in a predetermined and familiar starting point (aided by topologic reference cue cards), and the video stream from the US device is split between the onsite monitor and a remote location, where it is viewed by the experienced sonologist. Optimal probe position and device settings are guided with voice commands from the remote sonologist to obtain the necessary US images.

The remote guidance paradigm substantially reduces initial and refresher operator training requirements and allows experienced sonologist input during the conduct of the examination. We combined remote guidance with a focused review of complex US to complete the shoulder musculoskeletal examinations. The unique software used for OPE evaluation in this project streamlined equipment setup and subject and operator positioning and facilitated the successful completion of the complex US tasks by means of remote guidance. This "just-in-time" training approach allowed preflight and in-flight training time to be reduced substantially. The OPE program was constructed in modules that allow future HRF refinements or equipment alterations to be modified electronically as required. The program also can be used as a framework for other complex tasks that require focused skills or complex instructions. The self-reporting feature of the program allowed the experienced sonologists on the ground to assess operator familiarity with the procedures to better prepare for and conduct the session.

The evaluation of shoulder integrity with the use of US is the standard of care at many institutions and is used by professional athletic teams to evaluate injuries to athletes. Astronaut crewmembers may be at risk of shoulder injury during long-duration spaceflight because of decreases in muscle and tendon mass and exertion during space walks. The extravehicular activity suits that are worn constrain upper body and arm movement. Construction requirements on the ISS and future exploratory missions involving extravehicular activities can increase strain on the shoulder joint. A reliable method for evaluation of shoulder integrity during long-duration space missions would increase medical care capabilities for this operationally relevant concern.

Shoulder musculoskeletal US was performed rapidly and accurately by the two astronaut crewmembers aboard the ISS. The average time to perform the examination was less than 15 minutes. The conduct of the examination was not appreciably different than similar examinations in a terrestrial environment and was aided by innovative restraint techniques developed by the crewmembers (Movie 4, *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*). The quality of the near real-time US video transmitted to the Telescience Center was very good and could be used to exclude substantial shoulder musculoskeletal injury. Still US images were obtained during the examination and were downlinked to the team afterward. These high-fidelity images were of excellent diagnostic quality and could be used to exclude subtle changes in shoulder integrity.

The ability of the ISS crew to perform complex US tasks aboard the ISS supports the hypothesis that a nonphysician crewmember with modest training in US can perform high-fidelity diagnostic-quality examinations when directed by a ground-based experienced sonologist. The images acquired by the astronaut in this study were of excellent content and quality, and in a "real" medical scenario, they would have provided essential information to guide clinical decision making. There were no discernible differences between the US examinations performed in orbit and those performed in standard terrestrial conditions when the images were evaluated by the experienced sonologists involved in this trial.

The optimal training of crewmembers for the ISS and later exploration-class missions is still being defined. This initial US experience suggests that limited training, combined with onboard proficiency enhancement and directed remote guidance, may be an effective technique for performing complex tasks. The examination was conducted within a strictly limited time frame, which would probably be the case in most terrestrial situations, such as in some remote and most military settings.

The unique constraints imposed by the space environment require the development of detailed training, diagnostic, and therapeutic strategies. Although some of the aerospace procedures currently investigated by NASA are appropriate only for the space environment, many other spaceflight-derived techniques are readily transferable to the Earth, including rural, military, and emergency medical care. The remotely guided US concept, with crew medical officers or comparably trained first responders as operators, is an important and clinically relevant advancement in space medicine, with profound ramifications for emergency or clinical medicine (Audio 1, *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*).

References

1. Davis JR. Medical issues for a mission to Mars. Aviat Space Environ Med 1999; 70:162–168.[Medline]

2. Grigoriev AI, Egorov AD. The theory and practice of medical support of long-term space missions. Aviakosm Ekolog Med 1997; 31:14–25. [Russian].[Medline]

3. NASA. Medical intervention and care ISS Medical Operations Requirements Document SSP 50260, clause 4.1. Rev B ed. Houston, Tex: NASA, 2003.

4. Grigoriev AI, Bugrov SA, Bogomolov VV, et al. Medical results of the Mir year-long mission. Physiologist 1991; 34(suppl 1):S44–S48.[Medline]

5. Gazenko OG, Shul'zhenko EB, Grigor'ev AI, At'kov OI. Medical studies during an 8-month flight on the orbital complex "Saliut-7"—"Soiuz-T." Kosm Biol Aviakosm Med 1990; 24:9–14. [Russian].

6. Harris BA, Jr, Billica RD, Bishop SL, et al. Physical examination during space flight. Mayo Clin Proc 1997; 72:301–308.[Medline]

7. Sargsyan A. Medical imaging In: Barratt MR, Pool SL, eds. Principles of clinical medicine for space flight. New York, NY: Springer Verlag, 2003.

8. Patel JC, Tepas JJ, 3rd. The efficacy of focused abdominal sonography for trauma (FAST) as a screening tool in the assessment of injured children. J Pediatr Surg 1999; 34:44–47; discussion, 52–54.[Medline]

9. Scalea TM, Rodriguez A, Chiu WC, et al. Focused assessment with sonography for trauma (FAST): results from an international consensus conference. J Trauma 1999; 46:466–472.[Medline]

10. Boulanger BR, Kearney PA, Brenneman FD, Tsuei B, Ochoa J. Utilization of FAST (Focused Assessment with Sonography for Trauma) in 1999: results of a survey of North American trauma centers. Am Surg 2000; 66:1049–1055.[Medline]

11. Atkov OY. Ultrasound techniques in space medicine. Aviat Space Environ Med 1987; 58(9 pt 2):A69-A73.[Medline]

12. Jadvar H. Medical imaging in microgravity. Aviat Space Environ Med 2000; 71:640–646.[Medline]

The CHAIRMAN. Thank you very much. Just for the record, I would like—you gave a very good piece in your written testimony on some of the accomplishments of NSBRI that I think are very interesting, particularly I thought that Colonel Fincke already talked about one of them, your ultrasound training for non-physicians. He was a good case in point.

The possible solution for bone loss in space and particularly the potential for ultrasound surgery are very interesting. Could you elaborate on those two as evidence of some of the research that does have tangible results on Earth?

Dr. SUTTON. Right. Well, thank you very much.

First of all, I just want to clarify and emphasize that the wonderful research and development that's taking place is a partnership that doesn't belong to NSBRI and I note in a sense that it's a collaboration between government and academia, as well as industry. And it—what's so wonderful is that it actively engages the customers all the way along in the process; specifically the astronauts and the flight surgeons.

With respect to bone loss in space, while it is true that there are excellent countermeasures currently in place, it's nevertheless a concern that some bone loss does occur. That it seems to be monotonic in time. And we don't know what the effects of gravitational—fractional gravitational forces, such as one-sixth G or one-third G are going to be.

What the NSBRI has been engaged in is using spinal cord injury patients as a model for astronauts in the zero-g environment, because spinal cord injury individuals tend to lose bone in places that emulate the loss, such as in pelvic regions and in lower extremities.

And so there was a bed rest study that was funded through NSBRI/NASA that looked at a single intravenous infusion of a bisphosphonate compound and then looked at the extent of bone loss a year later. And indeed while there was some bone loss in those individuals that received the drug it was significantly less compared to those individuals that did not. This is an example of research and development that's done in a wonderful ground-based analog setting that is now primed and ready for testing and evaluation in the ISS. That testing and evaluation process can only be done in the micro-gravity environment at this point.

The ultrasound story is a very interesting one. And it feeds from some of the work that Colonel Fincke talked about. We are very fortunate to have a naval acoustic physicist, one of the outstanding investigators, Dr. Larry Crum as part of NSBRI. He's at the University of Washington in Seattle. He was one of the key physicists who developed the technology behind a device that actually Dr. Becker and myself when we were flying up for this hearing saw an ad for the device, it's called "SonoSite." It's in the commercial market. There was a big ad in the *Wall Street Journal* for this device.

What Dr. Crum and his colleagues are doing is moving the sensing part to the next level by using the exact technology and the same platform as the effector in being able to use ultrasound at higher energies to be able to do completely non-invasive bloodless surgery that is guided by the ultrasound images.

So, here's a situation where a person is thinking about how to deliver autonomous care in very remote harsh environments. Whether it be in space where there are clear applications or in harsh settings such as war zones. And what the individual has done is to look at the evolution of surgery from large open operations to small key hole procedures and take the next bold step, the type of step that changes text books of how procedures are done and to say, "We're going to go completely non-invasive and that the user does not have to be a surgeon or necessarily medically trained."

It's a wonderful story.

The CHAIRMAN. It is. It is incredible. I want to pursue the national lab issue with you as I did with the last panel. And ask you, Dr. Sutton, what would your thoughts be about preserving a broader range of research capabilities aboard the ISS and operating it as a national laboratory?

Dr. SUTTON. My personal views are that I think it's a wonderful idea. NSBRI was engaged for its opinions while some of the initial work was being done, and although we clearly are not on the inside, I think that the NSBRI presents a wonderful model created and established by NASA. We've had some growing pains, but have worked them out and have established a very strong effective partnership between academia and industry and NASA. I think that the idea of consortium, institutions, organized in a way that allows investigators who have wonderful ideas to come forward and use this precious resource in an organized fashion that's managed well, that's going to give absolutely outstanding results to help us achieve the missions for exploration as well as advanced scientific knowledge, is a great one and I applaud it.

The CHAIRMAN. Do you have links right now between some of your component institutions and a direct link into the Space Station where you are talking back and forth or discussing experiments or something that has happened on an experiment, or is that something that we would look to for the future?

Dr. SUTTON. The answer is, yes, we do have direct links and we're extremely thankful to our NASA collaborators.

The example of the ISS ultrasound experiment is a good one. In this case the principal investigator, Dr. Scott Dulchavsky is an NSBRI investigator who worked with the astronauts. We have introduced specific positions that are liaisons between the academic and industrial communities and folks in the operational environment including the Station. This has been a wonderful breakthrough.

We're very fortunate that, for example, in the case that I just cited that Dr. Jonathan Clark, Flight Surgeon at NASA, functions as a NASA/NSBRI space medicine liaison.

The CHAIRMAN. Dr. Weber, you have had some experience with UT Southwestern and Sandia labs; do you have any thoughts about how you would structure a national lab so that you could get the most benefit and also to connect it to a consortium like the NSBRI?

Dr. WEBER. I think the biggest challenge with the national lab— I've been involved not just flying in space, but in the experiment side at NASA and the infrastructure there. The biggest challenge whether it's a national lab or otherwise is selecting which experiments get to fly and those that don't. And I think certainly we have models for how we could bureaucratically structure a lab, but I think the most important element going forward would be to decide what you wanted to accomplish with the lab.

Do you want to have it be a conduit for commercialization? A conduit for getting private sector investment, or do you want it to be like a more traditional national lab in which we are working on problems and issues in the interest of our national security? And so my biggest concern in structuring that would be exactly what is the mission of that national lab?

The CHAIRMAN. Do you think the medical experimentation would necessarily be for private investment? I mean it would not be just security issues that you would want to look at. Obviously, the medical science is an important part of the International Space Station.

So, would you say that all of that would go toward trying to get private investment or can you also see that as a government function for future exploration, for example?

Dr. WEBER. There are two types of medical experiment—medical experiments that take place up in space. You've heard mostly about the types that are involving how do we keep astronauts flying? How do we address the issues of astronauts being weightless? And to me that's almost a national—if not a national security a national interest question. The technologies—that's almost—the results that we use on the ground are almost in the spin-off category. We're doing experiments to answer questions in space for a government need and then from that learning bringing it back down to the ground.

The two areas that I brought up are really not spin-off technologies. Those are really biomedical research where you're trying to look at things not in the interest of the astronauts' health, but in the interest of what we can glean from it. And those would have—those would be more ripe for commercialization.

The CHAIRMAN. OK. Thank you very much. Senator Nelson.

Senator NELSON. Thank you, Madam Chairman.

Dr. Sutton, I am curious, you said, " . . . take it from the Earthly lab to the Space Station." Are you talking about taking a paraplegic into space and injecting this material? Is that what you were referring to?

Dr. SUTTON. No, sir. The—what I'm referring to is the fact that there are some excellent ground-based analogues for research and development that allow good scientific ideas to go forward, to obtain results, to assess those results. And, if they look promising, to then move them to the next step where that next step engages the unique resources of the International Space Station; namely long duration exposure to micro-gravity for humans.

So, the idea is to fundamentally be more selective in the types of experiments that are flown to——

Senator NELSON. Well, give me an example of one of those experiments.

Dr. SUTTON. Well, if we take, for example, that we're talking about a particular drug, and it is a promising drug that could decrease even further the extent of bone loss that occurs. And that it would be given in conjunction with other countermeasures; exercise countermeasures and so forth.

So, rather than go right to the step of administering the drug in the space environment, what one can do is to do an analogue—a study on Earth that is far less expensive. To look at the usefulness and the effectiveness of this particular agent. If the agent doesn't work in an analogue population then maybe it's something that should not be tested in the space environment.

Senator NELSON. Well, did I misunderstand you that the use of this drug you said on paraplegics on Earth shows some improvement of lessening bone loss?

Dr. SUTTON. Absolutely. Yes, it's truly dramatic.

Senator NELSON. So your proposal is to take it to space and do what?

Dr. SUTTON. And test it in the space environment.

Senator NELSON. By testing it on——

Dr. SUTTON. The astronauts.

Senator NELSON.—what?

Dr. SUTTON. On the astronauts, sir.

Senator NELSON. OK. Dr. Weber, protein crystal growth. Charlie Walker who is seated behind you did the first experiment on protein crystal growth and I had the privilege of participating in that later on. And I was given to believe that although he and I, and I assume others, had some dramatic examples of growing larger and more pure crystals in the zero-gravity of orbit, that its application, given the expense of doing that in space versus what you could do on Earth, that there really wasn't much of an application. But you are indicating something otherwise. Tell us about that.

Dr. WEBER. Only a fraction of all the proteins of interest that might be good drug targets can be crystallized here on the ground. And I mentioned that protein crystal growth was prolific around the country, at drug companies and such. This is an activity that is indeed going on on the ground. But there are some percentage of proteins that we can't get that information on the ground. And this is actually, in my opinion, the best way that you want to do space experimentation. Since we can't fly all the experiments, you want to find those things which you have a large base of information about how it works on the ground and you only take up the one experiment that you can't do the ground that can yield tremendous value.

The reason why I point to protein crystal growth as being a low hanging fruit is this: I talked about this revenue stream that you have to identify if you're going to be successful with commercialization. Well, it's tough to manufacture in space, it costs a lot of money per pound to go into space; ten thousand or more dollars per pound.

So, manufacturing is a dicey proposition. However, with protein crystal growth, if you get that tiny little protein, if you can bring back to the ground even one tiny crystal you can get the answer you need that can result in a drug that has literally a hundred billion dollar impact on our economy——

Senator NELSON. Right.

Dr. WEBER.—in a given year. So it's the perfect way.

Senator NELSON. Get the answer you need through an electron microscope or x-ray diffusion, something like that?

Dr. WEBER. Exactly. The way it works is if you have—and I'm sure you know this. But the way it works, like if you had a glass prism, if you shine light on it from the pattern on the wall you could calculate what the shape of that prism is. If you shine x-rays on a protein crystal you can figure out where these hundreds and hundreds of molecules are sitting and you can get that structure.

And this is—if you think about it, HIV drugs they are now so effective that people can't detect the HIV in their blood stream any more and they can lead relatively symptom-free lives for a very long time. This is how effective drugs can be through structure-based drug design. And there are many examples of this.

We used to, for a long time, drug companies threw darts at a dart board in order to come up with a possible drug. Now we can logically, intelligently come up with where that active site is and come up with a chemical that fits into that active site and stops whatever bad is happening from happening.

Senator NELSON. Do we have candidates in these proteins that we cannot get their structure on one-gravity that we think that we can get their structure by taking them to zero-gravity?

Dr. WEBER. Absolutely. Larry DeLucas at University of Alabama at Birmingham, he runs one of our most successful commercial centers for space. And he has drug companies coming to him all the time with drug targets. And he has a certain smorgasbord of techniques that he can use to try to do them on the ground. And I'm told that there are a number of candidates and there are proteins that indeed he can't crystalize, nobody can crystalize and those are the ones typically that we send up on experiments in space.

Senator NELSON. Why are we not doing that right now?

Dr. WEBER. With the way the Station is right now it's only half complete, you heard that testimony. The RACKS for doing this, are at Kennedy Space Center. And we need more crew time and we need more cargo capability to really make this a viable option.

There are very sound reasons, despite all the great work that two crew members can do and have done on the Space Station, there is so much more. Even if we can get that Shuttle flying again and finish the Space Station and even get three crew members it would open up the flood gates in a sense.

Senator NELSON. Do you in fact know and it is too bad that Mr. Readdy is not still here, we would ask him, that in fact this is going to be on the manifest once we start flying again with three crew members?

Dr. WEBER. I don't know. I left NASA 2 years ago and—so I'm not—I am not up to date on the latest manifest and plans and such.

Senator NELSON. Well, we will ask that question. Madam Chairman, it would sure make your and my job a lot easier in getting money for NASA if we suddenly had a breakthrough on unlocking the architectural secrets of these proteins that we can't get here on Earth. If we did that up there on the Station, boy that would be a page-one story.

The CHAIRMAN. Well, I agree. And also you just look at this list of things that have been accomplished and they are huge breakthroughs. They are huge. I think this is exactly what we need to focus on, build on, and make more available.

Senator NELSON. Let me just ask a couple more questions. For any of you, what Space Station research are you concerned about that may be cut?

Dr. SUTTON. I'll take a crack at that. In my testimony I talked about the pipeline and I'm going to limit my remarks in the biomedical area.

There is a wonderful body of ground-based research that it's working it's way through a developing pipeline that is just about to hit a stage that is ready for ISS. There's a capital investment that's been made, there's an intellectual investment that's been made. There is clear proof of principles, demonstrables, and deliverables that hit at high priority items on what is the bio-astronautics road map, which lays out various risks.

My concern is that budget reductions in that pipeline will significantly impede progress. In a business model, one actually begins to invest more capital as one moves very promising products toward operations or toward actual delivery to the customer. And the concern is that with budget reduction some of the most promising products that hit at the highest risk areas being bone behavioral health, advanced medical capabilities, nutrition, and cardiac issues will be cut.

And what might happen is that if cuts take place now there's loss of the teams that are moving these products forward. And what ends up sometimes happening is that when production slows down the teams disperse and one ends up spending more money in the long run trying to engage people back because there are issues of confidence and a lack of stability that has been lost.

Senator NELSON. Let me ask any of you, in the sequence in which the Station will continue to be assembled, does it assemble the elements to your satisfaction in the order in which you can get the research done that you think that needs to be done?

Dr. SUTTON. In a word, yes.

Senator NELSON. OK. Thank you.

The CHAIRMAN. Thank you very much. We appreciate all of our panelists. It has been a very informative session and one that will help us with our re-authorization priorities. Thank you.

Dr. SUTTON. Thank you very much.

[Whereupon, at 12 p.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF HON. DANIEL K. INOUYE, U.S. SENATOR FROM HAWAII

Today's hearing will examine what it takes to make the International Space Station a productive orbiting laboratory and what we expect to learn once this facility becomes fully operational. Whether we are learning about bone loss or combustion, this research will lead to unexpected benefits on Earth.

As you know, I am a longtime supporter of the Space Station and space research. However, there are several barriers that could keep the Station from becoming the world class laboratory it should be. Meeting future transportation needs is at the top of the list. After all, U.S. astronauts cannot conduct research on the Station if they and their equipment can not get there.

Likewise, a prolonged gap between the retirement of the Shuttle and the launch of a new crew exploration vehicle is unacceptable. We must have access to the laboratory we built.

After all, the Space Station offers tremendous opportunities. Space Station researchers are devising new imaging techniques that use ultrasound rather than X-ray or MRI to diagnose patients. Long-duration microgravity research can lead to fundamental advances in physics, materials, the life sciences, and the health and safety of our astronauts.

We have just confirmed an Administrator who I believe is more than ready to meet those challenges. Like the Members of the Committee, Administrator Griffin is looking to keep the Nation's space program strong and vital.

NASA is currently developing plans to utilize the Station. I look forward to receiving those plans and working with Dr. Griffin to make the most of our investment in the International Space Station.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KAY BAILEY HUTCHISON TO WILLIAM F. READDY

Question 1. The charter of the ISS Strategic Roadmap Committee describes the purpose of the Committee as being:

> " . . . to provide advice and recommendations to NASA on completing assembly of the International Space Station and focusing research on supporting space exploration goals, with emphasis on understanding how the space environment affects human health and capabilities, and developing countermeasures."

This appears to be a very narrow definition of the mission of the Space Station. Is it NASA's view that the space station is only to support research that enables humans to go to the Moon, Mars and beyond?

Answer. NASA's utilization of U.S. crew time and research capability aboard the International Space Station is focused on supporting future human space exploration goals. Based on the recently completed Zero Base Review of the Human System Research and Technology portfolio, the highest priorities for research on the Space Station include space radiation health and shielding; advanced environment control and monitoring; advanced Extra Vehicular Activities suits and tools; human health countermeasures to the effects of long-duration space travel; advanced life support systems; exploration medical care; and, space human factors. The Space Station acts as a test bed for engineering and operations concepts, and will demonstrate technologies necessary for future space systems such as thermal control. power generation, and management of cryogenic fuels in space. Altogether, NASA has identified 22 areas of research and technology that can take advantage of the Space Station as a test bed to reduce the risk associated with future human exploration missions. Currently, the Shuttle/Station Configuration Options Team is conducting a study, which is considering previous work done in the Zero Base Review and, examining configuration options for the ISS. As part of the study, this team is looking at ISS assembly, operations, and use and considering such factors as International Partner commitments, research utilization, cost, and ISS sustainability. This study will be completed later this summer.

Question 2. How has the fundamental mission of ISS changed since January 14, 2004, with the announcement of the Vision for Exploration?

Answer. In one sense, the fundamental mission of the International Space Station has not changed. The Space Station is still a continuously crewed, on-orbit research platform designed to house scientific experiments and new technology development, as well as facilitate international cooperation. What changed with the announcement of the Vision for Space Exploration is the focus for the science and technology work done by US astronauts. The Vision for Space Exploration directed NASA to focus U.S. research and use of the International Space Station on supporting space exploration goals, with emphasis on understanding how the space environment affects astronaut health and capabilities.

Question 3. Apart from the laboratory facilities aboard the space station, a key to space station research is the crew time available for conducting that research. Please provide the current projections for the number of crew members planned to be aboard the space station and the amount of crew time that will be available for research, for the U.S. and its international partners. Indicate the optimum number of crew for conducting the maximum level of ISS research using available and planned on-orbit research facilities. Provide this information for each remaining stage of ISS assembly and utilization.

Answer. As we make progress on construction of the Station, we will also work towards increasing the number of crew onboard to three space members as soon as possible and working towards a six-person crew capability. How soon we increase crew size is dependent on additional life support capability and on the availability of a rescue capability.

The amount of crew time available to the European Space Agency (ESA), the Japanese Aerospace Exploration Agency (JAXA), and the Canadian Space Agency (CSA) is based on the provisions of the ISS Memoranda of Understanding. In accordance with these provisions, ESA will receive 8.3 percent of the non-Russian crew assignments after the launch of its Columbus module; JAXA will receive 12.8 percent of non-Russian crew assignments after the launch of its Japanese Experiment Module elements; and CSA began accruing 2.3 percent of the non-Russian crew assignments after its Space Station Remote Manipulator System was launched in April 2001.

Under the ISS Agreements, Space Station crew rights are shared equally between Russia and the U.S. during the assembly period. Following completion of assembly, Russia will have a right to a crew of three and may make separate arrangements with any of the other ISS Partners for these crew flight opportunities. Russia will use its Soyuz vehicle to provide crew transportation and rescue. NASA is responsible for crew transportation and rescue for the remainder of the ISS crew after completion of assembly. The ISS Partnership has agreed that the Russian Soyuz vehicle can continue to be used for crew transportation and serve as the Space Station Crew Return Vehicle (CRV) for the U.S. segment of the ISS; assuming that an agreement can be reached between NASA and the Russian Federal Space Agency on this issue, and that this can be accomplished without violating the provisions of the Iran Nonproliferation Act.

Since the Soyuz carries a maximum of three people, one factor in crew size will be based on the number of Soyuz docked to the Station to provide a crew rescue capability. Additional life support capability is another factor in increasing crew size. The U.S. Regenerative Environmental Control and Life Support System (ECLSS) will need to be installed and tested on orbit before the Station crew grows to more than three people.

Question 4. Provide a summary of the current plans for delivering ISS crews to orbit, providing for their safe return in the event of an emergency and supporting research with payload delivery and retrieval capabilities from this point forward, over the planned life of the ISS.

Answer. The Russian Soyuz vehicle is currently being used for crew transport, and will continue to serve as the Space Station Crew Return Vehicle (CRV). NASA continues to assess its future requirements for crew and cargo transportation in support of the Space Station. The CEV is being developed to be capable of ferrying astronauts to the Space Station.

The first CEV missions to Earth orbit will include docking with the ISS. NASA's Exploration Systems Mission Directorate will be responsible for developing and acquiring both crew and cargo services to support the Space Station. A key element in the future of the ISS program is the purchase of alternate cargo transportation services to supplement the Space Shuttle, and the development of new crew transportation capabilities to replace Shuttle when it retires. Because the ESMD has the mission to develop and acquire such crew and cargo capabilities for the Space Station and beyond, NASA has transferred management responsibility for the activities and budget of ISS Cargo/Crew Services to Exploration Systems Mission Directorate from the Space Operations Mission Directorate.

NASA is currently examining alternative configurations for the Space Station that meet the goals of the Vision for Space Exploration and the needs of our international partners, while maintaining safety as our highest priority. In May 2005, we initiated the Shuttle/Station Configuration Options Team (SSCOT). This team is conducting a 60-day study of the configuration options for the ISS and assessing the related number of flights needed by the Space Shuttle before it retires no later than the year 2010. The scope of the Shuttle/Station Configuration Options Team study spans ISS assembly, operations, and use and considers such factors as international partner commitments, research utilization, cost, and ISS sustainability. This team is expected to complete its work in June, with those results integrated into the ongoing Exploration Systems Architecture Study (ESAS).

ESAS will focus on four primary areas, including a complete assessment of the top-level CEV requirements and plans to enable the CEV to provide crew transport to the ISS and to accelerate the development of the CEV and crew launch system to reduce the gap between Shuttle retirement and CEV initial operating configuration.

NASA is also working across the ISS partnership to identify opportunities to augment the flight rate of the International Partner transportation vehicles, including the Russian Progress vehicle, the European Automated Transfer Vehicle (ATV), and the Japanese H-IIA Transfer Vehicle (HTV). The ATV is scheduled to be launched on Europe's Ariane V rocket for its demonstration flight to the ISS in 2006. The HTV is planned to be launched on Japan's H-IIA rocket for a demonstration flight to the ISS in the 2008–2009 timeframe. In return for performance of common systems operations on the ISS, NASA anticipates that it will have upmass allocations on some ATV and HTV missions. (ATV, HTV, and Progress are not designed for returning cargo to the Earth).

Question 5. Describe the impact to scientific research aboard ISS if the Space Shuttle is retired in 2010 without the immediate availability of U.S.-developed replacement capabilities for the transfer of crews and cargo to and from the ISS. Indicate the degree to which crew size and allocable research time are affected in any interim period between Shuttle retirement and an operational follow-on replacement capability. Also, indicate whether size and/or weight limitations of interim cargo delivery and return capabilities impact ISS research options. Assuming that efforts to narrow the gap between Shuttle retirement and a follow-on capability will be successful provide a series of the requested impact assessments in any remaining gap in one-year increments, from 2010 to 2015.

Answer. During the assembly period, crew rights are shared equally between Russia and the U.S. as stipulated in the ISS Agreements. As far as size of crew, since the Soyuz carries a maximum of three people, one of the factors in increasing crew size will be determined based on the number of Soyuz docked to the Space Station to provide a crew rescue capability (the other factor being is to increased life support capability). The ISS Partnership has agreed that the Russian Soyuz vehicle can continue to be used for crew transportation and serve as the Station Crew Return Vehicle (CRV) for the U.S. segment of the ISS; assuming that an agreement can be reached between NASA and the Russian Federal Space Agency on this issue and that this can be accomplished without violating the provisions of the Iran Nonproliferation Act.

Following completion of assembly, Russia will have a right to a crew of three and will use its Soyuz vehicle to provide crew transportation and rescue. NASA is responsible for crew transportation and rescue for the remainder of the ISS crew after completion of assembly. To answer questions such as research impacts post-Shuttle and ISS crew/cargo services, NASA is conducting two studies. In May 2005, we initiated the Shuttle/Station Configuration Options Team (SSCOT). SSCOT is currently examining alternative configurations for the Space Station that meet the goals of the Vision for Space Exploration and the needs of our international partners, while maintaining safety as our highest priority. This team is conducting a 60-day study of the configuration options for the ISS and assessing the related number of flights needed by the Space Shuttle before it retires no later than the year 2010. The scope of the Shuttle/Station Configuration Options Team study spans ISS assembly, operations, and use and considers such factors as international partner commitments, research utilization, cost, and ISS sustainability. This team is expected to complete its work in June, with those results integrated into a second study. the Exploration Systems Architecture Study (ESAS).

ESAS will focus on four primary areas, including a complete assessment of the top-level CEV requirements and plans to enable the CEV to provide crew transport to the ISS and to accelerate the development of the CEV and crew launch system to reduce the gap between Shuttle retirement and CEV initial operating configuration.

Question 6. The President has stated that an important requisite to the Vision for Exploration is ensuring that the United States honors its international commitments in the development of ISS. How does a refocusing of the Space Station to support the U.S. Vision for Exploration affect the research plans and commitments of our international partners in the space station program?

Answer. Refocusing Space Station science goals to support human space exploration does not necessarily have an immediate impact on the research plans of our international partners. Any use of U.S. resources is detailed in separate agreements with our partners. These agreements outline things such as crew time and facility and power use; they do not restrict the content or focus of the research performed (within the normal safety guidelines). However, NASA anticipates that our ISS Partners may also adjust the focus of some of their research in the longer term in order to advance their exploration plans and enhance their participation in future NASA programs.

Question 7. Describe the status of studies conducted by NASA, or at NASA's request, to identify alternative operations and research management schemes for ISS. Specifically, describe the status of non-governmental organization (NGO) alternatives, as well as any other alternatives similar in form to a Federally-Funded Research and Development Center (FFRDC) or an ISS Research Institute.

Answer. On January 10, 2003, NASA submitted to Congress a study of International Space Station (ISS) utilization management in compliance with FY 2001 and FY 2003 VA-HUD-Independent Agencies Appropriations Acts (Pub. L. 106–377 and Pub. L. 107–73, respectively). The study was a seven-month, inter-Center team assessment of options for ISS utilization management. The study set the following objectives for ISS utilization management: (1) to facilitate the pursuit of flight research; (2) to optimize research opportunities within current capabilities of ISS and with future enhancements for greater capabilities, and (3) to increase the long-range productivity of science, technology, and commercial research and development aboard the ISS. Enclosure 1 is the January 2003 study.*

As a key part of the NASA study, the scope of utilization work was defined as twenty-one principle functions ranging from development of strategic plans to archival of research samples. A few functions, such as policy development and safety certification, were determined to be inherently governmental. The other functions were analyzed as candidates for delegation to a non-governmental organization.

Ten potential business models were evaluated. Two business models—a research institute and a Federally Funded Research and Development Center (FFRDC)—emerged as the best choices. A scoring process based upon an agreed upon set of evaluation criteria resulted in the research institute ultimately emerging as the preferred business model.

While NASA initially recommended the establishment of a non-governmental organization, specifically a non-profit institute, to perform research leadership functions including significant aspects of research planning, manifesting, prioritizing, resource allocation, advocacy, outreach, and archiving, the Agency rescinded plans for a non-profit institute based on a Presidential announcement.

On January 14, 2004, the President announced the Vision for Space Exploration—a vision that gives NASA a new focus and clear objectives. As a part of this Vision, the President has directed that U.S. research on the International Space Station (ISS) be focused on supporting space exploration goals, with an emphasis on understanding how the space environment affects astronaut health and the development of countermeasures and exploration capabilities.

The Vision for Space Exploration is in accord with the recently released report of the National Research Council entitled, "Issues and Opportunities Regarding the U.S. Space Program." Their recommendations align closely to the Vision, also specifically calling for an exploration research agenda for the ISS.

Given a highly focused research agenda for the ISS, NASA reassessed its original need and plan for an International Space Station Research Institute (ISSRI). The original plans discussed above had called for establishing an ISSRI with the primary objective of providing U.S. research leadership for a diverse U.S. community performing a broad range of research on the ISS. With a more focused research agenda for the ISS, NASA stopped activity on the procurement efforts for the ISSRI.

* The information referred to has been retained in Committee files.

Question 8. Concerns have been expressed by the Japanese about the possible elimination of the Centrifuge Accommodation Module (CAM), which they are building for the United States in exchange for the launching of their core research facility, the Japanese Experiment Module (JEM/"Kibo"). Are these concerns justified? What is the current status of the CAM and its scientific capabilities?

Answer. NASA has completed a Zero Base Review (ZBR) of the Human Systems Research and Technology Program (HSR&T) to ensure that future investments are aligned with exploration objectives and that biological and physical research planned for the ISS is driven by the unique capabilities of the ISS. The objective of the ZBR was to prioritize needs for each phase of the planned exploration strategy, and to rebalance the research portfolio accordingly. The ZBR employed a methodical, disciplined process to align research tasks to exploration requirements and was informed by NASA medical policies and the National Academies-reviewed Bioastronautics Roadmap. The review identified critical research priorities to reduce risk for long-duration human spaceflight, and has given NASA confidence that a significant part of ongoing BPR research directly supports the Vision. However, certain tasks will be discontinued, others will be augmented, and still new ones will be started in order to fill priority areas identified during the review. These high-priority areas include space radiation health and shielding, advanced environmental control and monitoring, advanced extra-vehicular activities, human health and countermeasures, advanced life support, exploration medical care, and space human factors. The highest priorities for research on ISAS have been identified as medical research with human subjects and microgravity validation of environmental control and life support technologies. Lower-priority tasks, which are now subject to reduced funding include basis research using model organisms (such as cells or rodents), and fundamental research in physics, material science, or basic combustion—with no direct link to exploration requirements. Additional refinement to the research and development portfolio may take place in the future as a result of a Shuttle/Station Configuration Options Study currently underway.

The Shuttle/Station Configuration Options Team study is 60-day study of the configuration options for the ISS in the context of potential future flight rates for the Space Shuttle Program and within the Presidential constraint to cease flight of the Shuttle fleet no later than the end of FY 2010. The scope of this study spans across ISS assembly, operations and utilization, and supersedes all prior NASA studies in these areas. S/SCOT will then feed into ESAS.

While we cannot comment on any potential changes to the ISS configuration (including CAM) until the completion of these ongoing studies, we can report that the CAM recently completed its Critical Design Review (CDR) and the Centrifuge Rotor CDR is scheduled for late 2005.

Question 9. Provide a brief summary of the research that has been conducted up to this point aboard the ISS, including an indication of which science disciplines are represented by that research.

Answer. See Enclosure 2 for activities from Expedition 1 through 11. *

Question 10. Describe the criteria and process being used to re-plan research aboard the Space Station within the Vision for Exploration. What is the timetable for providing a clear definition of NASA's future plans for space station research?

Answer. Explorations Systems Mission Directorate (ESMD) conducted a study to develop an International Space Station (ISS) Research & Technology development investment strategy with the goal of optimizing ISS utilization to support the Vision for Space Exploration. A Strategy-to-Task-to-Technology (STT) process was employed as the primary means for allowing stakeholders to prioritize Exploration objectives and distill a research and technology portfolio for meeting those objectives. STT is a top-down approach to requirements definition that links weighted strategic objectives to successive levels of operational objectives, tasks and technologies to meet those tasks. The ISS study had broad representation from all relevant ESMD offices as well and Space Operations Mission Directorate (SOMD) and the Office of the NASA Chief Health and Medical Officer (OCHMO). The process succinctly conelates the informed opinions of the stakeholders leading an assessment of the benefit of various research and technology (R&T) activities on ISS used to guide ISS research.

With the research benefits in hand, ESMD then identified ISS resources needed to carry out the R&T activities. An analysis of the benefit and the resource requirements allowed ESMD to determine research priorities based on the best research benefits vs. the cost of ISS resource requirements.

---

* The information referred to has been retained in Committee files.

This cost-benefit analysis has been provided to a recently formed Shuttle/Station Configuration Options Study team, who has been charged to develop a series of specific configuration options for the International Space Station (ISS) in the context of potential future flight rates for the Space Shuttle Program. The study is operating under the constraint to cease Shuttle flights no later than FY 2010 while maintaining safety as the Agency's highest priority. The scope of the Shuttle/Station Configuration Options Team study spans ISS assembly, operations, and use and considers such factors as International Partner commitments, research utilization, cost, and ISS sustainability. This study will be completed later this summer in time to inform key Agency decisions.

Question 11. Identify any decisions that have been made since January 4, 2004 regarding what previously planned research, within which science disciplines, will not be supported aboard the space station. Indicate whether that research can be accomplished by some other means, either on Earth or in a free-flying orbital capability, and describe the impact of any changes in such research on the investment of time and funds expended by the principal investigator(s) and supporting institutions.

Answer. Immediately following the President's announcement of the Vision for Space Exploration, the Office of Biological and Physical Research (OBPR) initiated a reorganization of its research and technology development programs.

The previously discipline-based research programs with objectives targeting fundamental and applied research for microgravity physics, for applications to Earth-based practices, and for the basic understanding of biology in space, were reorganized into product line-based efforts to enable space technologies in the areas of life support and habitation and human health and performance during long-duration missions beyond low-Earth orbit.

An initial reduction of the OBPR research portfolio was submitted to Congress in the FY04 Second Operating Plan change letter June 25, 2004) and subsequent detailed description. Elements of ISS research that were deselected included non-exploration related fundamental physics (low-temperature and atomic physics), basic materials science in solidification and phase transformation, and fundamental combustion science and fluid physics. The principal investigators associated with deselected research were provided enough funding and time to transition their activities to other areas by retaining them in the program for a reasonable time period. Most of this research cannot be accomplished on the ground. The OBPR research program was subsequently transferred to the Exploration Systems Mission Directorate and renamed Human Systems Research and Technology.

NASA has recently completed a Zero-Based Review (ZBR) of the Human System Research and Technology (HSR&T) portfolio that includes the bulk of the planned ISS research activities. This rigorous programmatic assessment identified a number of ground-based and ISS-based existing research tasks that were programmatically classified as non-Exploration related and slated for phase-out. These areas were in fundamental space biology and cellular biotechnology. Some of this research can be accomplished on the ground and by using free flying space platforms. All principal investigators associated with the phased-out research areas have been given time and funding necessary to reorient their activities.

Question 12. What other disciplines, besides geology and life science disciplines would benefit from an orbiting research laboratory?

Answer. There is no doubt that several disciplines could benefit from an orbiting research laboratory. However, logistics support, volume, electric power, and crew time to support research in orbiting laboratories are limited and extremely costly. As a result, the President has directed NASA to focus U.S. research and use of the International Space Station on supporting space exploration goals, with emphasis on understanding how the space environment affects astronaut health and capabilities and developing countermeasures. In addition to the life sciences disciplines, the following disciplines will use the ISS: materials science, combustion research, and fluids physics. These disciplines have been retained because they directly contribute to the achievement of exploration objectives, not because of their intrinsic scientific value. Specifically, the following ISS facilities are currently expected to be continued: the Combustion Integrated Rack, the Fluid Integrated Rack, and the Microgravity Science Glovebox. The ISS is not anticipated to have excess utilization capacity beyond meeting the needs of the exploration vision and our International Partners through the middle of the next decade. Over the next several years, as the ISS research agenda focused on the Exploration Vision is achieved, it will be beneficial to re-examine the next set of research priorities. Until that time, it would not be practical to expand the ISS research functions.

Question 13. During the hearing, reference was made to a water processing facility developed for use on ISS, which was the basis for a device, or system used to purify water in Iraq and in the region affected by the December 2004 tsunami. Please provide additional information regarding that technology and how that ISS-generated development has been successfully employed in terrestrial applications.

Answer. The technology component of the ISS water processor that is common to the disaster relief system planned for deployment in Iraq this summer is the Microbial Check Valve (MCV), an iodinated resin that treats the water for microbial contamination. This resin was originally developed for NASA by the small business called "Umpqua," and the rights were subsequently sold to Novation/Haas. The charity, Concern for Kids, is working with Novation/Haas to produce and deploy multiple ground-based water filtration units in Iraq this coming summer. The MCV technology is attractive in this application because it has the added benefit of providing villagers with iodine that is a deficiency in their current diet, and it is a compact, reliable method for controlling microorganisms. Concern for Kids plans to use the terrestrial units to service villages on a rotation-type schedule where the unit will be transported via truck from village to village. processing existing village water supplies.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BYRON L. DORGAN TO WILLIAM F. READDY

As you may know, University of North Dakota has been developing AgCam, a sensor intended to operate on the International Space Station (ISS). AgCam was designed to go into the Window Observational Research Facility (WORF).

Question 1. Is the WORF scheduled for a launch on the Space Shuttle? When?

Answer. NASA is currently assessing its plans for the utilization of the ISS, and focusing its research and technology development goals towards those activities that most closely support the Vision for Space Exploration. In this environment of limited opportunities for the launch of facility-class payloads, it is critical that utilization planning align as closely as possible with the needs of the human exploration planning effort. The only missions for which specific payloads have been manifested on the Space Shuttle are the first two Return to Flight missions. Consistent with the Vision, the Space Shuttle will be retired by 2010. Prior to its retirement, it will be utilized primarily for the assembly of the ISS. Our top priority will be to make each flight safer than the last. As we noted in our November 3, 2004, correspondence to you on this topic, in the event that a future flight opportunity does become available on the Space Shuttle, the WORF facility will be considered for delivery to the ISS. The University of North Dakota has been apprised of the situation and is aware that NASA cannot commit to the flight of WORF on the Space Shuttle.

Question 2. If the WORF cannot be launched to the ISS, could AgCam be accommodated some other way?

Answer. The AgCam hardware has been designed and built to be operated in the WORF. The WORF would provide resources such as power, thermal control, data and mounting positions for operations of the AgCam. The hardware as designed could not operate independently of the WORF. It might be possible to redesign the AgCam hardware and its operations concepts, but the University would require additional funding, testing, and development time; even with such a redesign, it is unclear whether the redesigned hardware could achieve the expected scientific value without the WORF.

Question 3. What are the plans for Earth observations from the International Space Station?

Answer. While NASA is not pursuing new Earth sciences research on the ISS because of the limited launch opportunities on the Space Shuttle, we are continuing with two Earth observations programs already on-orbit.

1. The Earth Knowledge Acquired by Middle Schools (EarthKAM) program allows middle school students to command, via computer, a digital camera mounted in a window of the ISS and integrate Earth images taken by the camera with inquiry-based learning for 5th–8th grade students. Photos are made available on the Web for viewing and study by participating schools around the world. Educators use the pictures in conjunction with curricula for projects involving Earth Science, geography, physics, math, and technology. To date, over 80 schools with more than 1,600 students from the United States, Japan, Germany, and France have participated in the EarthKAM program.

2. The Crew Earth Observations (CEO) program continues, with the ISS crew photographing various Earth sites on a daily basis. Hand-held photography of

the Earth from human spaceflight missions, spanning more than 40 years, provides insights and documents changes on the Earth. The ISS crew members are building on this time series of imagery, which was started in 1961.

○