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THE INTERNATIONAL SPACE STATION

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BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED EIGHTH CONGRESS

FIRST SESSION

OCTOBER 29, 2003

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THE INTERNATIONAL SPACE STATION

WEDNESDAY, OCTOBER 29, 2003

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

The Subcommittee met, pursuant to notice, at 2:10 p.m. in room SR–253, Russell Senate Office Building, Hon. Sam Brownback, Chairman of the Subcommittee, presiding.

OPENING STATEMENT OF HON. SAM BROWNBACK, U.S. SENATOR FROM KANSAS

Senator BROWNBACK. I want to thank you all for joining us here this afternoon. This is the second hearing today on NASA and space station issues. I appreciate having the opportunity to hear from our witnesses regarding the safety and the future of the International Space Station.

It has been a big day on the Hill for the space industry. This morning, Senator McCain held a hearing on the future of NASA, and the House held a hearing on the management issues at NASA. This afternoon, we'll be talking about the future of NASA, but our focus is specifically on the International Space Station, ISS.

In just the past week, there has been a lot of public discussion about the International Space Station. *The Washington Post* last week reported on the safety factors aboard the International Space Station. The *Post* reported that prior to the Expedition 8 crew being launched to the space station, two NASA health and environment officials objected to the launch citing concerns of potential degradation of the environmental monitoring and health maintenance systems. There have been follow-up articles on this issue in the *Post,* including an editorial by NASA Administrator Sean O'Keefe. All these articles will be made a part of the record.

This hearing was planned before the press began to report the initial concerns at NASA, but this hearing is turning out to be quite timely. I'm pleased that Mr. Readdy is here today, along with the rest of our panel. I'm looking forward to a candid discussion between all witnesses on this subject.

I'd like to thank all the witnesses for being here today. It's my hope that this hearing will help to clarify and alleviate the immediate concerns we share here in Congress with regard to the astronauts' safety aboard the station.

The recent reports draw our attention to the safety issues on the space station and whether or not the mission and scientific research done aboard the station is enough to sustain a national vision for space exploration.

Last week, I met with Mr. Readdy. He was kind enough to come to my office, and I asked him to provide me with a list of experiments being conducted aboard the ISS. I have gotten some feedback, and I will be questioning Mr. Readdy in our discussion about this today, and I do want to get a full list of all the experiments being done or conducted on the ISS so that we can have a full vetting about the quality of the science aboard it.

I also want to talk today about the Orbital Space Plane, the OSP, and how that program relates to the space station. Some of our colleagues in the House recently sent a letter to Administrator O'Keefe urging him to defer the current program until the White House and Congress are able to complete a review of the Nation's space program. OSP was originally expected to cost about $4 billion, but NASA has stated they are prepared to spend up to $14 billion to complete the project by 2008. However, it's difficult to decipher exactly what America will be getting from the OSP, and it's even more difficult to try to justify such a vehicle when the International Space Station is not yet complete.

I'm afraid that letter is right, from my colleagues on the House side, we must ensure the money we are putting toward new space vehicles is going to result in furthering the Nation's space program.

I've noted this morning's hearing—I don't have the chart here with me today, but we've previously, over the past decade, started five replacement programs of one type or another for the space shuttle, discontinued all five of them at a cost of $5 billion, and not much to show for it. I don't want to start another one and get in the middle and stop and waste another billion, two billion, or more dollars.

Obviously, we have a lot to talk about. I'd like to welcome our witnesses. Before I introduce the witnesses, I'll go to my colleague from Florida for his opening statement.

STATEMENT OF HON. BILL NELSON, U.S. SENATOR FROM FLORIDA

Senator NELSON. Thank you, Mr. Chairman.

Welcome. I would like, in the course of this hearing, to have some assurances that what happened over the course of the past decade, where the Space Station budget and the Space Shuttle budget were blended together under the human spaceflight budget, so that it became less transparent, so that money was moved around out of the Space Shuttle into the Space Station on some of the cost overruns—some assurance that that doesn't occur again. We need the separation so that Congress can fulfill its responsible role of oversight of the Executive Branch of government, and some of the tragic consequences that flowed therefrom. And there are not my words. This is the Gehman Commission's report.

I'd also like, as the Chairman has indicated, to get you all to comment on the space plane and where are we going and how much is it going to cost, from just a crew return vehicle so we can get more people onboard, to a true follow-on, in the spirit of the Gehman Commission report, where you will launch humans to and from orbit in a vehicle that is designed to be less costly and more safe than the experiences of the space shuttle. We had an estimate when Mr. Readdy testified in front of this Committee back in September 2001, September 11, that I think the factor was something like one in 350, and we were moving to a figure of one in 500, or one in a thousand, as the ratio of catastrophe. Well, we know now that what it was, was two in 113. And so if the Gehman Commission report is being accepted by NASA as the Administrator has indicated, that the idea is to have a new space plane to get to and from orbit that is safer and use other means, perhaps including the space shuttle as the cargo means, and at some point maybe an automated space shuttle, is that what we're thinking as we look to servicing the station?

And then, third, I would like to have discussed how does the space station fit in with a seamless timeline as we direct ourselves to the bold new vision ahead, which is going to Mars? What are we going to do with this that will not impede us striking out in that bold new venture? Now, we all know it's going to take a President to make this decision, and until a President does it and puts the juice behind it, it's not going to happen. But I don't want a future President, or this President, for that matter, to use the space station as an excuse that we're not going to go to Mars.

Mars is a long time planning. This is a 20-year project. We had testimony this morning that said that it should be a 10-year——

Senator BROWNBACK. Ten-year.

Senator NELSON.—project. I think that's a little ambitious, but, nevertheless, we need to start, and we need to start tomorrow. And if it takes us 20 years, we need to start tomorrow.

So I'd like some commentary on that and how does the space station fit in with all that.

Senator BROWNBACK. Thank you.

We'll go to our panel. We welcome each of you here. First to testify will be Mr. William Readdy. He's the Associate Administrator for Spaceflight, National Aeronautics and Space Administration, NASA, and Mr. Readdy himself has flown aboard the Space Shuttle. Delighted to have you here. Mr. Allen Li is Director of Acquisition and Sourcing Management, U.S. GAO. Thank you very much for coming. Dr. Robert Park is Director of Information, American Physical Society, and delighted to have you here, Dr. Park. Dr. James Pawelczyk, Associate Professor of Physiology, Kinesiology, at Pennsylvania State University. Thank you very much for joining us. And Mr. Arthur Zygielbaum—I hope I got that close—Director, National Center for Information Technology and Education, University of Nebraska.

Gentlemen, thank you very much for joining us.

Mr. Readdy, I look forward to your testimony.

STATEMENT OF WILLIAM F. READDY, ASSOCIATE ADMINISTRATOR FOR SPACEFLIGHT, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION; ACCOMPANIED BY MARY KICZA, ASSOCIATE ADMINISTRATOR FOR BIOLOGICAL AND PHYSICAL RESEARCH

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

I appreciate the opportunity to appear before you today to discuss the International Space Station and the impact the *Columbia* accident has had on ISS operations.

I'm joined by my colleagues, behind me, Brian O'Connor, who is the Associate Administrator for Safety and Mission Assurance; Mary Kicza, Associate Administrator for Biological and Physical Research; and Dr. Richard Williams, who's the Chief Health and Medical Officer.

Senator BROWNBACK. Good. You might pull that microphone a little closer to you. It's not the best technology.

Mr. READDY. Without question, our near-term goals are to return the Space Shuttle safely to flight, to build, operate, and maintain the International Space Station, and reap the scientific harvest from that research.

A couple of weeks ago, on a very cool Saturday in Kazakhstan, we watched Mike Foale and his crew mates lift off in the Baikonur Cosmodrone, and they're now onboard the International Space Station. This crew will be the crew that continues the fourth year of continuous crewed operations, and the fifth year overall, for International Space Station.

Then, just Monday evening, Expedition 7 returned on target to their landing site in Kazakhstan. The landing went very, very smoothly, I can report to you, although we were prepared for all contingencies. We brought back the samples that we promised during the Flight Readiness Review.

Ed Lu is in great shape. I talked to him just this morning, over in Star City, where he's in the rehabilitation facility undergoing medical tests and completing his debriefings.

Interestingly enough, in terms of exploration, during their 6-month mission they traveled 73 million miles. Well, the distance between the Earth and Mars right this minute is 56 million. So clearly demonstrating long-duration spaceflight is necessary to anything we'll do.

Twenty-six experiments were conducted, and Expedition 7 included: materials and International Space Station experiments, which is an external payload to measure the impacts of long-duration space exposure; protein crystal growth; space soldering; miscible fluids in microgravity; hand-posture analysis; educational payloads; fluid dynamics investigations; and obviously examination of the crew members themselves. And I could go on and on. Mary Kicza is prepared to go into much greater detail than I, and we've included more in our written statement.

The collaborative endeavors are increasing as the ISS will come of age, and potential research is increasing when we get the shuttle back to flying again.

There have been recent comments concerning dissenting views expressed prior to the launch of the Expedition 8 mission. In the aftermath of the *Columbia* tragedy, we have learned our process worked. There was open dissent, debate, and resolution at the lower levels. We put in place sample return and mitigation efforts in order to make sure that those concerns were addressed. The dissenting views were discussed in an open forum. The associated risk level was determined low and acceptable and, prior to atmospheric measurements, had indicated no deviation from normal. Interviews with the crews indicated that there was no environmental problem. Russian onboard monitoring systems indicated no deviations. So having heard all the concerns, mitigating actions planned, means for monitoring onboard, we made a balanced risk decision to launch the increment. We made our decision based on all these factors and in full agreement with the Flight Readiness Review Board to proceed.

The Flight Readiness Review Board and the Stage Operations Review Board that precede it, accumulate a total of over a hundred signatures. I have to emphasize that the dissenting views were heard in the Life Sciences Level 3 Board and were addressed prior to our Level 1 Flight Readiness Review Board.

The process worked. It was rigorous and diligent. Concerns were raised and addressed. Now that we know that there's obviously more of a spotlight on the agency in the aftermath, and we know that there's significant interest here in Congress, even though we've reviewed those, addressed them, we will obviously be more proactive in providing the information here on the Hill.

And while we all recognize that space travel is not risk free, and, in fact, the Soyuz launch vehicle that Mike Foale and his crew mates launched on, was the 420th successful flight out of 430, which equates to 98 percent.

The subsystem redundancies onboard International Space Station that have been fundamental to the design in the earliest phases have all combined to make a safe environment. It was always planned, though, to be maintained with the shuttle, with large flying replaceable units. But we have found ISS to be a highly reliable and maintainable platform.

Interestingly, our partnership with the Russians, that was initiated almost exactly 10 years ago, has increased our reliability by having functional redundancy in various areas, including crew transportation, logistics, life support, and exercise equipment.

Now, with respect to consumable commodities, our conservation efforts have been very successful. Water does still remain the most critical consumable, but we will continue our close management and periodic progress re-supply flights.

NASA and its international partners continue to build, integrate, and prepare flight hardware according to the program's original schedules. Space station processing at the Kennedy facility continues. And if you look at what you have in front of you there in the schematic—and for the TV, there is a poster of it—what that shows is the hardware that is currently on orbit, and the crosshatched is the hardware that's at the Kennedy Space Center ready for integration.

The International Space Station is already larger than a jumbo jet and, at year five, already has more volume than the Sky Lab ever had or than the Mir and is obviously more capable than Mir at its 15-year end of life.

ISS assembly was 50 space walks so far. If you think about a jumbo jet final assembly, it takes months, in order to finally assembly them, and that's with parts that are made on this planet rather than assembled in orbit by space-walking astronauts.

We look forward to the day when ISS is completed, allowed to demonstrate its research potential. In the meantime, all the international partners continue to collaborate on how to best support our near-term on-orbit operations until the shuttle returns to flight.

While the Columbia Accident Investigation Board was conducting its investigation of the *Columbia* accident, the ISS program had already begun an intensive internal effort to examine its processes and risks, with the objective of identifying the existence of any risks that had already not been reduced to the lowest possible level and to make sure that we were proactive.

As a result of the findings of the CAIB, some of those continuous improvement initiatives were already underway, but in the meantime we have released NASA's Implementation Plan for International Space Station Continuing Flight. And this is the continuing flight team, and it's led by Mr. Al Sofgi at our headquarters. The intent here is that that be a living document. We look forward to releasing it next week on the Web, publicly.

In a letter to the President, Nobel laureate, Samuel Ting, Cabot professor of Physics at Massachusetts Institute of Technology, along with his distinguished colleagues, recently wrote a letter, "The value and interest of human explorations of space for which space station is essential has been put forth with considerable clarity and power in the debates taking place since the *Columbia* disaster." He went on to recognize the value of the astronauts as researchers and their ability to repair, modify, or respond to unexpected developments. STS–107 was a clear example of that.

The ISS program is taking all necessary steps to be ready to resume ISS research, outfitting, and final assembly when the space shuttle fleet is certified safe to return to flight. While the necessary corrective actions are being taken, though, productive research is continuing on orbit, even with a crew of two, and we are safely exchanging crews aboard the Soyuz vehicles.

International Space Station, though, cannot be considered only a platform for research, but also a demonstration of the potential for international cooperation, exploration, and discovery. We have 16 partner nations in International Space Station.

Over in the great hall of the Library of Congress, there's a quote from Edward Young, "Too low they build who build beneath the stars." We're the architects of the future, building a base for our children's exploration and discovery among those stars.

There are those who advocate that NASA should have a goal for space travel by humans to other parts of the solar system. It must be stressed by us, and recognized at large, that the ISS is that gateway to exploration beyond low-Earth orbit. In our critical path review of challenges that must be resolved to ensure the long-term health and safety of crews in space for those long-duration missions, there were ten red items which cannot be avoided unless countermeasures are developed. These challenges must be overcome if we're to pursue extended missions beyond low-Earth orbit. Virtually all these challenges will require research from the experiments that can best be carried out on the International Space Station.

Yesterday, we were at the Kennedy Space Center with the *Columbia* families to dedicate Space Mirror Memorial to the *Columbia* crew, and they were all of one voice when they said that we must continue to build, operate, and maintain the International Space Station in order to reap the scientific harvest of the seeds that their loved ones planted, the research aboard *Columbia*.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Readdy follows:]

PREPARED STATEMENT OF WILLIAM F. READDY, ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE FIGHT, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. Chairman and Members of the Committee, my colleagues Bryan O'Connor, Associate Administrator for Safety and Mission Assurance, Mary Kicza, Associate Administrator for Biological and Physical Research, Dr. Richard Williams, Chief Health and Medical Officer, and I appreciate the opportunity to appear before you today to discuss the status of the International Space Station (ISS) and the impact the *Columbia* accident has had on ISS operations.

On February 1, 2003 we lost the crew of the Space Shuttle *Columbia*. These were my friends and colleagues. I, along with the entire NASA family, will work tirelessly to honor their memory. We are dedicated to improving our programs and our Agency, while we safely return the Shuttle to flight and maintain the ISS in orbit. We will continue the mission of human exploration and discovery, to which the crew of the Space Shuttle *Columbia* committed their lives, and continue to learn through this tragic experience, so that one day the risks of human space flight will be reduced to a level similar to conventional transportation vehicles.

I also want to recognize the families of the *Columbia* crew for their strength and continued support of our historic endeavor. Their contribution to the mission has been the most dear and their fortitude is exemplary to all of us who will press onward in respect for their courage.

Current Status

As a result of the *Columbia* accident on February 1, 2003, the Space Shuttle fleet has been temporarily grounded. The International Partnership has fully embraced the challenge of keeping the ISS crewed and supplied while the Space Shuttle Program works through and implements the needed changes. The Partners have met frequently at the technical and management levels to coordinate efforts toward maintaining a safe, functional research platform. These meetings have focused the resolve of an international community engaged in one of the most illustrious models of global cooperation for peaceful purposes.

In late February, the ISS Partnership agreed to an interim operational plan that will allow crewed operations to continue. This plan called for a reduction of the crew size to two and for crew exchanges to be conducted on the previously scheduled semi-annual Soyuz flights. This reduction was required to keep adequate food and water reserves and live within the consumables that could be supplied by Progress vehicles. It also called for additional Progress vehicles over the 2003–2004 timeframe. In response, Russian Soyuz and Progress vehicles have succeeded in providing reliable crew and cargo access to and from the ISS to date. We remain confident these vehicles will continue to carry out their critical mission until the Space Shuttle Fleet returns to flight.

On orbit, the ISS is demonstrating its capability to operate safely. The sub-system redundancies that have been fundamental to the design since its earliest phases, in combination with the orbital replacement unit (ORU) architecture, have consistently proven their worth. We have found the ISS to be a highly reliable and maintainable platform that is exceeding our originally conservative engineering projections. ORU failures are lower than first projected and backup sub-systems are reliably coming on line in response to need. Numerous specific examples are available to substantiate this experience. On occasion, we have experienced anomalies with lower criticality level components; however, the Progress resupply missions have enabled replacement in such instances.

With respect to consumable commodities, our conservation efforts have been very successful. Original conservative projections indicated water to be our most critical consumable. This condition arose because the visiting Space Shuttles previously supplied surplus water to the ISS as a by-product of their on-board fuel cell electrolysis process. Water remains our most critical consumable; however, close management and periodic Progress re-supply missions have alleviated the severity of this challenge. Our current estimates for future water consumption are now based on actual operating experience since the *Columbia* accident. We are closely monitoring this key provision and plan to adjust our Progress re-supply mission requirements in CY 2004 to reflect the improved conditions. All experience clearly indicates the ISS is operating in a reliably stable and consistently safe mode.

On October 20, the Expedition 8 crew, U.S. Commander Michael Foale and Russian Flight Engineer Alexander Kaleri, arrived at their new home orbiting at about 230 miles above the Earth. They were joined by European Space Agency taxi astronaut Pedro Duque, who spent 8 days aboard the Station engaged in a variety of research tasks. The Expedition 7 crew, Commander Yuri Malenchenko and U.S. Science Officer Ed Lu, along with Pedro Duque, were returned safely to Earth on October 28. Lu and Malenchenko traveled nearly 73 million miles during their six-month stay aboard the ISS, 22 million miles further than the distance between the Earth and Mars.

NASA and its International Partners continue to build, integrate, and prepare flight hardware according to the Program's original schedules. This past Summer, NASA's European-built Node 2 and the Japanese Experiment Module (JEM) arrived for processing at Kennedy Space Center (KSC) and by Fall, these important elements had successfully completed the third stage of Multiple Element Integration Testing. With these arrivals, the Space Station Processing Facility (SSPF) at Kennedy Space Center is once again packed to capacity with ISS flight hardware, much the same as it was during the 18-month gap that occurred following ISS First Element Launch (FEL). Today there are more than 80,000 pounds of ISS flight hardware waiting for Space Shuttle integration and an additional 102,000 pounds in preparation for integration at the SSPF. The ISS Program will once again be at an extraordinarily high state of readiness to resume assembly when the Space Shuttle fleet resumes service.

With these arrivals, we look forward to the day when the ISS is completed and allowed to demonstrate its research potential. In the meantime, all of the International Partners continue to collaborate on how to best support near-term ISS on-orbit operations until the Space Shuttle returns to flight. The first two Shuttle flights, STS–114, LF–1 and STS–121, ULF–1.1, will carry out key activities related to Shuttle return to flight, as well as support ISS logistics and utilization. Once we have completed these two missions and fully implemented any necessary changes to ensure risks have been minimized to the lowest possible level, assembly will resume with Shuttle flight 12A.

The Space Shuttle fleet is essential for completing the construction phase of the ISS. Nonetheless, we are assessing long-term options for alternate crew and cargo access to the ISS.

Activities in Response to the Columbia Accident Investigation Board

The Columbia Accident Investigation Board (CAIB) addressed the causes of the *Columbia* accident and has thoroughly documented its findings. The Space Shuttle Return to Flight Planning Team is now focused on the necessary changes to the Space Shuttle Program based on the CAIB's comprehensive report and our own efforts to "raise the bar." The CAIB report also contains areas applicable to NASA activities broader than the Shuttle Program. Recognizing this, the ISS Continuing Flight Team (CFT) was chartered, immediately following release of the report, to review all CAIB recommendations, observations, and findings for applicability to the ISS Program. This team will ensure that all necessary steps are taken to apply the lessons learned from the *Columbia* accident to the ongoing operation of the ISS. Representatives from all NASA field centers supporting human space flight, as well the astronaut and safety assurance offices, are members of the team. The ISS Program Office will also serve as the liaison to the International Partners, in order to draw all parties engaged in ISS operations into the effort.

While the CAIB was conducting its investigation of the *Columbia* accident, the ISS Program had already begun an intensive effort to examine its processes and risks with the objective of identifying the existence of any risk that has not already been reduced to the lowest possible level and ensuring focused management attention on the residual risks that cannot be eliminated. As the findings of the CAIB emerged, they were continuously assessed by the ISS Program for applicability. Some of these continuous improvement initiatives already underway since the *Columbia* accident were consistent with CAIB findings, while some were a direct result of the experience the ISS Program has gained from three years of crewed operations. The first release of the CFT Implementation Plan documents the status of responses to the CAIB Recommendations, as well that of the ISS Continuous Improvement initiatives.

Flight Readiness for ISS Expedition 8

A Stage Operations Readiness Review (SORR) routinely precedes all ISS Flight Readiness Reviews (FRRs). During the increment 8 SORR a wide range of cost, schedule and technical elements were examined in depth. Included among these was the status of the ISS on board environmental monitoring system, which provides very high accuracy information on atmospheric composition and presence of trace elements. The current system is not operating at full capacity and the need to replace it on an upcoming Progress re-supply mission was discussed. This requirement was formally accepted, without issue, at the subsequent FRR. The associated risk level was determined acceptable, since prior atmospheric measurements indicated no deviations from normal; Russian on-board monitoring systems indicated no deviations; and the crew was not experiencing any indication of changes in the cabin environment. In addition, the status of crew health countermeasures was reviewed at the SORR. These countermeasures include the use of an on board treadmill and associated resistive exercise devices. Each of these devices was operating at various degrees of reduced capacity and needed to be repaired, upgraded or replaced. Evaluations weighing potential equipment maintenance actions against upcoming replacement opportunities were underway.

At the October 2 Expedition 8 FRR, each subsystem was reviewed for safety and performance capability. During this free and open review, individuals with dissenting opinions were encouraged to come forward with all information pertinent to the decision process. Those who did were commended for their diligence and participation. Their positions were taken very seriously and analyzed in the total context of the decision by experienced subject area experts. Based on the review process, the FRR culminated in a Certification of Flight Readiness, which validated that the Expedition 8 was ready for launch and the Increment. In addition to the multilateral FRR process, a special task force of the NASA Advisory Council independently reviewed the safety and operational readiness of the ISS, the flight readiness of the Expedition 8 crew, and the Russian flight control team's preparedness to accomplish the upcoming mission. This U.S.-Russian Joint Commission, chaired by Lieutenant General T.P. Stafford and Academician N.A. Anfimov, found the crew to be fully trained and medically certified. They also reported the ISS to be safe and operationally ready to support crew arrival.

Subsequent to these comprehensive reviews by subject area experts, the ISS Program conducted yet another full program review in the final days before 7S Soyuz launch. The purpose of this additional review was to check the progress of actions underway and ensure all possible steps were in motion to guarantee a successful and hazard-free mission. As a result of these multiple reviews, we are highly confident that mitigation plans are proceeding as planned to reduce and closely manage the remaining risks. The entire ISS team has participated in these open communications forums and all are in agreement that the most judicious and effective path to maintaining crew safety and spacecraft survivability is the path we are currently pursuing.

ISS Research Progress

The ISS Program is taking advantage of every opportunity to manifest research, supplies, and experiments on the Russian Soyuz and Progress vehicles. The opportunities have allowed investigations to continue in bioastronautics and physical sciences. We have collaborated with our International Partners to share hardware, in order to optimize the overall research output on the ISS under the constrained conditions that resulted from the grounding of the Space Shuttle fleet. Despite these conditions, the research program continues to progress. As of the end of August 2003, approximately 1,551 hours of combined crew time have been dedicated to research and approximately 74 investigations have been initiated or completed. During Increment 7, the ISS crew averaged 10 hours per week performing research tasks.

Today, undergraduate and graduate students and academic and industrial scientists at U.S. research institutions around the country are at work developing approximately 1,000 projects in support of the ISS research program. These students are the U.S. scientists and technologists of the future working under the tutelage of experienced scientists with a vision for the future. Our objective is to reach out still further, through avenues like a new research institute that will one day manage an investigator cadre for the ISS similar to that which Space Telescope Science Institute currently does for the Hubble. This planned development will open direct participation in the space program to more Americans than ever and transform young people's fascination with space into longstanding careers in innovative science and technology.

The International Space Station is not only a platform for research, but also a demonstration of the potential for international cooperation, exploration and discovery. Indicative of this are experiments currently underway in the Granada Crystallization Facility. This facility was built in Europe, has a principal investigator funded by Japan, and is housed under temperature-controlled conditions in the Commercial Generic Bioprocessing Apparatus, which is provided by a U.S. commercial research partnership. Such collaborative endeavors are increasing as the ISS comes of age and the research potential is revealed with each stage of growing capability.

Projects like Peter Cavanaugh's experiments on astronaut bone loss in space, and the effectiveness of exercise in reducing the tendency to lose mass from bones that on Earth bear our weight, but in space have very little to do. Professor Cavanaugh is the chair of the Biomedical Engineering Department at the Cleveland Clinic. His research is helping medical science understand the mechanisms that lead to the loss of bone mass and strength. In his case the direct cause is the weightless environment, but the knowledge this research will produce may contribute to the development of more effective therapies for bone degeneration faced by the 44 million of Americans who, according to the National Osteoporosis Foundation, have either low bone mass or osteoporosis.

Industry-sponsored experiments are also being conducted that might have an impact on bone loss treatments, plant growth, pharmaceutical production, and petroleum refining. Some of the first ISS experiments are ongoing and some have already returned to Earth. Detailed post-flight analysis continues, while the future continues to hold promise for growth in applications as the ISS capability approaches full fruition.

Recent fluid physics experiments on the Shuttle and on the ISS looked at colloidal systems, small particles that are suspended in liquids. Professor Alice Gast, the vice president for Research at MIT is doing research on magnetic colloids and Professor David Weitz of Harvard University and Professor William Russell, Dean of the graduate school at Princeton University are collaborating on colloid research looking at fundamental structures in these types of materials. Each of these experiments has yielded unexpected results that could never have been observed on earth. According to Professor Weitz, the ISS research led to his group's work that was published very recently in *Science:*

> *The [colloidisome] structures we make here are inspired very much by what we learn from our ISS work, and we are following this up to investigate better drug encapsulation and delivery mechanisms. Some offshoots of this work are also summarized in two of our other papers about making delivery structures from colloidal particles.*

Other practical uses of colloids in the long term include faster computers and communication.

Equally as interesting, Dr. Rafat Ansari of NASA, who worked with these experiments, found an unusual use for one of its instruments. When his father developed cataracts, which are assemblies of small particles in the eye, Dr. Ansari realized that the instrument being developed as part of the colloids experiment might be able to detect these cataracts—possibly earlier than ever before. The device is now in clinical trials with a National Institute of Health/NASA collaboration to assess the effectiveness of new, non-surgical therapies for early stages of cataract development. Cataracts affect 50 million people annually. The NIH highlighted this collaborative NIH/NASA research to Congress in 2001 as a key technology for them. The instrument is also being adapted as a pain-free way to identify other eye diseases, diabetes, and possibly even Alzheimer's. Perhaps most poignant is the fact that Dr. Ansari was inspired to pursue scientific research by a single moment in his life—when, as a small boy in Pakistan, he saw people walk on the moon. It shows once more what we have said all along: human space flight produces and inspires more than just high quality science.

The Research Maximization And Prioritization (ReMAP) Task Force established priorities and goals for NASA's Office of Biological and Physical Research (OBPR) and for ISS research across disciplines. The findings and recommendations of its report provide a framework for prioritizing a productive research program for OBPR and for the ISS. The committee was unanimous in the view that the ISS is unprecedented as a laboratory and is the only available platform for human tended research on long-duration effects of microgravity. In several areas of biological and physical research, solutions to important questions require microgravity. ISS provides a unique environment for attacking these problems "*as only NASA can.*" We have testimonials to this, not only from independent ReMAP members, but also from the National Research Council, various technical societies, and Nobel Laureates.

In fact, Nobel Laureate, Dr. Samuel C.C. Ting, Cabot professor of Physics at the Massachusetts Institute of Technology, along with his distinguished colleagues, recently captured the essence of the national policy challenge in a letter to President George Bush:

The value and interest of the human explorations of space, for which the space station is essential, has been put forth with considerable clarity and power in the debates taking place since the Columbia disaster; however, we believe that a narrow view has dominated the debates about the scientific importance of the ISS. The debate has focused on the earliest work without properly considering the great potential and crucial importance of the Space Station for future science.

Conclusion

The ISS program is taking all steps necessary to be ready to resume ISS research outfitting and final assembly when the Space Shuttle Fleet is certified to safely return to flight. While the necessary corrective actions are being taken, productive research is continuing on orbit and we are safely exchanging crews for continued operations.

I was inspired by a quote inscribed on the wall of the Great Hall in the Library of Congress, from Edward Young's *Night Thoughts.* "Too low they build, who build beneath the stars." We are truly the architects of our future, building a base for our children's exploration and discovery among the stars. There are those who advocate NASA should have a goal for space travel by humans to other parts of the solar system. It must be stressed by us, and recognized at large, that the ISS is the gateway to exploration beyond low-Earth orbit. NASA's current draft of a Critical Path Roadmap of challenges addresses the following risks associated with long-term crew health and safety in space: the effects of radiation, physiological changes, medical practice problems, and behavior and performance problems. Reducing these risks will be accomplished by identifying and developing countermeasures where applicable. Virtually all of these challenges will require research from experiments that can best be carried out on the ISS.

I'd like to thank Mr. Li, for his General Accounting Office assessment of the ISS, and Mr. Zygielbaum, for his work with the Aerospace Safety Advisory Panel, for providing their respective assessments of NASA's programs. I would also like to thank Dr. Pawelczyk and Dr. Park for their perspectives on the ISS research.

Mr. Chairman, members of the committee, thank you for the opportunity to appear before you today. My colleagues and I are prepared to address your questions.

Senator BROWNBACK. Thank you, Mr. Readdy.

Mr. Li?

STATEMENT OF ALLEN LI, DIRECTOR, ACQUISITION AND SOURCING MANAGEMENT, U.S. GENERAL ACCOUNTING OFFICE

Mr. LI. Chairman Brownback, Senator Nelson, and Members of the Subcommittee, good afternoon. With me today are James Beard and Rick Cederholm from my Huntsville team.

In the past 8 months, attention has mostly centered, and deservedly so, on the cause of the *Columbia* accident and the corrective steps NASA will take. Less prominent has been the impact on the space station and the cultural changes NASA is considering. That is why we are pleased that you have asked us today to focus on, one, the state of the space station brought on by the grounding of the shuttle, and, two, our views on how Congress can assess NASA's cultural changes to improve safety.

As requested, I will summarize my prepared statement.

First, the challenges facing the space station. Mr. Chairman, simply put, the grounding of the shuttle has placed the space station in a survival mode. The impact of the grounding of the shuttle is evident in five areas.

One, NASA cannot resolve known safety concerns onboard the station while the shuttle fleet is grounded. For example, NASA has had to delay plans to fly additional shielding to protect the Russian service module from space debris, a risk that increases each year shielding is not installed.

Two, assembly is at a standstill. Prior to the *Columbia* accident, NASA had planned to assemble the core complete configuration of the station by early 2004. Assuming a return to flight around fall of 2004, core complete will not occur before early 2006.

Three, research is limited. Outfitting of U.S. research facility racks is halted. Currently, seven of the 20 planned racks are installed. With the fleet grounded, three major facilities could not be launched in March of this year as planned. And because new and additional hardware cannot be transported, NASA has had to rely on existing science facilities, facilities that have already experienced some failures. For example, the freezers onboard the station have failed several times. A larger cold temperature facility had been planned for launch in March 2003.

Four, the amount of science materials that can be transported to and from the space station is limited. According to NASA officials, they plan to send about 93 kilograms of science material to the station on the next Russian Progress flight scheduled for January 2004. However, returning samples will be delayed until the shuttle returns to flight.

Five, the station's total cost will be higher. To date, NASA has not fully estimated the potential increased cost and future budget impact due to the grounding of the shuttle. NASA maintains that an assessment of total impact cannot be made prior to 2005, when the Fiscal Year 2006 budget request is submitted. While the total cost is presently unknown, there are some areas where additional cost is likely. A significant increase is expected because of the 2-year delay in completing assembly. In addition, partner funding is uncertain. This may result in NASA paying a larger share of certain program costs to reflect additional partner contributions necessitated by the grounding of the shuttle.

Turning now to our second topic, assessing NASA's cultural changes to improve safety. As the Subcommittee recalls, the Columbia Accident Investigation Board found that NASA's history and culture resulted in organizational practices that were detrimental to shuttle safety. The challenge facing NASA in addressing needed changes will be monumental.

In that regard, we suggest the use of a framework that is graphically depicted in our prepared statement. The framework has four interrelated anchors, namely leadership, human capital, program performance, and review and monitoring. Each of these four anchors has crucial attributes that, put together, help characterize NASA's organization and culture.

For example, the leadership anchor encompasses the agency's core values and top management's expectations, such as the importance of character, integrity, and support of safety measures.

Major facets of the human capital anchor include hiring skilled staff, understanding skilled efficiencies, and establishing and maintaining needed skills.

The program performance anchor includes results achieved, oversight of contractors, and infrastructure maintenance. In essence, this is how NASA carries out what it does. But program performance also requires sound financial management to provide decisionmakers with accurate information with which to make tradeoffs and long-term investments.

The review and monitoring anchor reflects oversight and reinforcement that should be a shared responsibility between program officials, associate administrators, the NASA Administrator, and independent groups.

Mr. Chairman, we believe this framework can be useful in assessing NASA's planned organizational and cultural changes by matching key areas in which changes are envisioned and identifying those that are not addressed.

This concludes my statement. I will be happy to answer any questions at the end of the panel.

[The prepared statement of Mr. Li follows:]

GAO HIGHLIGHTS

NASA—SHUTTLE FLEET'S SAFE RETURN TO FLIGHT IS KEY TO SPACE STATION PROGRESS

Why GAO Did This Study

Since its inception, the International Space Station has experienced numerous problems that have resulted in significant cost growth and assembly schedule slippages. Following the *Columbia* accident and the subsequent grounding of the shuttle fleet in February 2003, concerns about the future of the space station escalated, as the fleet has been key to the station's assembly and operations.

In August 2003, the Columbia Accident Investigation Board drew a causal link between aggressive space station goals—supported by the National Aeronautics and Space Administration's (NASA) current culture—and the accident. Specifically, the Board reported that, in addition to technical failures, *Columbia's* safety was compromised in part by internal pressures to meet an ambitious launch schedule to achieve certain space station milestones.

This testimony discusses the implications of the shuttle fleet's grounding on the space station's schedule and cost, and on the program's partner funding and agreements—findings we reported on in September 2003. The testimony also proposes a framework for providing NASA and the Congress with a means to bring about and assess needed cultural changes across the agency.

What GAO Found

Since the grounding of the shuttle fleet last February, the space station has been in a survival mode. Due to the limited payload capacity of the Russian launch vehicles—which the program must now rely on to transport crew and supplies to and from the station—on-orbit assembly is at a standstill and on-board research has been limited. Moreover, certain safety concerns on board the station cannot be corrected until the shuttle fleet returns to flight. For example, NASA has had to delay plans to fly additional shielding to protect the on-orbit Russian Service Module from space debris—a risk that increases each year the shielding is not installed.

To date, NASA has not fully estimated the increased costs and future budget impact incurred due to the grounding of the space shuttle fleet. However, it projects that additional costs of maintaining the space station while the shuttle fleet is grounded will reach almost $100 million for Fiscal Years 2003 and 2004. It has also identified a number of factors that will affect costs—including the need to extend contracts to complete development and assembly of the station. Delays in completing the assembly of the station—which will be at least 2 years—are likely to incur significant additional program costs. At the same time, partner funding is uncertain, which may result in NASA paying a larger share of certain program costs.

Although the full impact of the shuttle fleet's grounding on the space station is still unknown, it is clear that the station's future is dependent on the shuttle fleet's return to flight. NASA must carefully weigh this future against the risks inherent in its current culture. As we reported early this year, NASA's organization and culture has repeatedly undermined the agency's ability to achieve its mission. The Columbia Accident Investigation Board similarly found that NASA's history and culture have been detrimental to the shuttle fleet's safety and that needed improvements at NASA go beyond technical enhancements and procedural modifications. The cultural change required for NASA to consider the numerous technical and administrative recommendations made by the Board could be the agency's greatest challenge to date.

In an effort to help NASA as it undergoes this change—and the Congress as it assesses NASA's future corrective actions—we have provided a framework for establishing appropriate operating principles and values and program direction, securing and maintaining a sufficient and skilled workforce, establishing proper performance targets, and ensuring adequate monitoring.

PREPARED STATEMENT OF ALLEN LI, DIRECTOR, ACQUISITION AND SOURCING MANAGEMENT, UNITED STATES GENERAL ACCOUNTING OFFICE

Mr. Chairman and Members of the Subcommittee:

We are pleased to be here today to discuss the challenges facing the International Space Station in the wake of the *Columbia* accident. The grounding of the shuttle fleet this past February escalated concerns about the future of the space station—which, since its inception, has experienced numerous problems that have resulted in significant cost growth and assembly schedule slippages. The shuttle fleet has been key to the station's assembly and operations, and without it, the program must rely on Russian launch vehicles to transport crew and supplies to and from the station. As requested, my testimony today will discuss the implications of the shuttle fleet's grounding on the space station's schedule and cost and on the program's partner funding and agreements—findings we reported on to the full Committee in September 2003.[1]

You asked how the Congress can assess the cultural changes that the National Aeronautics and Space Administration (NASA) is considering as the agency proceeds with its efforts to safely return the shuttle fleet to flight. As you know, the Columbia Accident Investigation Board reported in August 2003 that in addition to technical failures, *Columbia's* safety was compromised in part by the shuttle program's fluctuating priorities and arbitrary schedule pressures to achieve certain space station milestones.[2]

The Board characterized NASA's emphasis on maintaining the launch schedule to support construction of the station as a "line in the sand" and found evidence that structural inspection requirements for the shuttle were reduced and other requirements were deferred in order to meet an ambitious schedule. NASA's recent revision to its return to flight plan recognizes that to ensure safety in all its programs, a cultural change is needed across the agency. Today, I am proposing a framework intended to provide NASA and the Congress with a means to assess cultural change in the context of NASA's overall mission.

In summary, the grounding of the shuttle fleet last February has basically put the space station in a survival mode. Due to the limited payload capacity of the Russian launch vehicles, on-orbit assembly is at a standstill and on-board research has been limited. Moreover, certain safety concerns on board the station cannot be corrected until the shuttle fleet returns to flight. NASA estimates that additional costs of maintaining the space station while the shuttle fleet is grounded will reach almost $100 million for Fiscal Years 2003 and 2004. However, significant additional program costs are likely to be incurred because completing assembly of the station will be delayed by at least 2 years. At the same time, partner funding is uncertain—which may result in NASA paying a larger share of certain program costs—and partner agreement on the final station configuration has been delayed by approximately one year.

While the space station's future is clearly dependent on the shuttle fleet's return to flight, NASA must carefully weigh this future against the risks inherent in its current culture. As we reported in January 2003, NASA's management challenges and risks reflect a deeper need for broad cultural change to eliminate organizational stovepipes and hierarchy, which have repeatedly undermined the agency's ability to achieve its mission.[3] The Columbia Accident Investigation Board similarly found in its August 2003 report that NASA's history and culture resulted in organizational practices that have been detrimental to the shuttle fleet's safety. The cultural sea change required for NASA to consider the numerous technical and administrative recommendations made by the Board could be the agency's greatest challenge to date. In an effort to help NASA as it undergoes a cultural change—and the Congress as it assesses NASA's future corrective actions—we have provided a framework for establishing appropriate operating principles and values and program di-

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[1] U.S. General Accounting Office, *Space Station: Impact of the Grounding of the Shuttle Fleet,* GAO–03–1107 (Washington, D.C.: Sept.12, 2003).

[2] Columbia Accident Investigation Board, *Report Volume 1* (Washington, D.C.: Aug. 2003).

[3] U.S. General Accounting Office, *Major Management Challenges and Program Risks: National Aeronautics and Space Administration,* GAO–03–114 (Washington, D.C.: Jan. 2003).

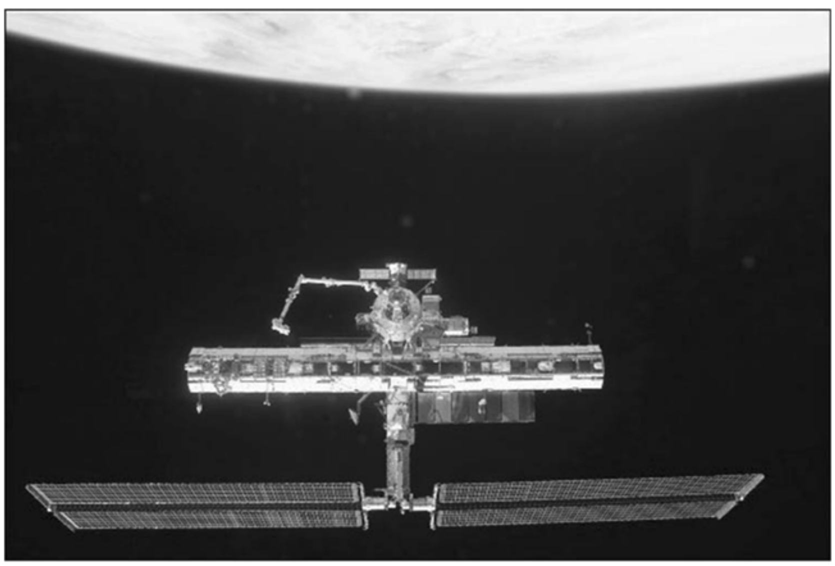
rection, securing and maintaining a sufficient and skilled workforce, establishing proper performance targets, and ensuring adequate monitoring.

Background

In 1998, NASA and its international partners—Canada, Europe, Japan, and Russia—began on-orbit assembly of the International Space Station, envisioned as a permanently orbiting laboratory for conducting materials and life sciences research and earth observations under nearly weightless conditions. The International Space Station program has three key goals: (1) maintain a permanent human presence in space, (2) conduct world-class research in space, and (3) enhance international cooperation and U.S. leadership through international development and operations of the space station. Each of the partners is to provide hardware and crew, and each is expected to share operating costs and use of the station.[4]

Since October 2000, the space station has been permanently occupied by two or three crewmembers, who maintain and operate the station and conduct hands-on scientific research. The space station is composed of numerous modules, including solar arrays for generating electricity, remote manipulator systems, and research facilities. The station is being designed as a laboratory in space for conducting experiments in near-zero gravity. Life sciences research on how humans adapt to long durations in space, biomedical research, and materials-processing research on new materials or processes are under way or planned. In addition, the station will be used for various earth science and observation activities. Figure 1 shows the International Space Station on orbit.

Figure 1: International Space Station On Orbit



Source: NASA.

Since Fiscal Year 1985, the Congress has appropriated a total of about $32 billion for the program. When the station's current design was approved in 1993, NASA estimated that its cost would be $17.4 billion.[5] By 1998, that estimate had increased to $26.4 billion. In January 2001, NASA announced that an additional $4 billion in funding over a 5-year period would be required to complete the station's assembly and sustain its operations. By May 2001, that estimated cost growth increased to $4.8 billion. In an effort to control space station costs, the administration announced in its February 2001 Budget Blueprint that it would cancel or defer some hardware

[4] In 1996, NASA and the Russian Aviation and Space Agency signed a "balance protocol" listing the services that each side would provide to the other during assembly and operations.
[5] All amounts are stated in current-year dollars.

and limit construction of the space station at a stage the administration calls "core complete."

In November 2001, the International Space Station Management and Cost Evaluation Task Force—appointed by the NASA Administrator—made a number of recommendations to get costs under control. NASA implemented most of the recommendations, and the task force reported in December 2002 that significant progress had been made in nearly all aspects of the program, including establishing a new management structure and strategy, program planning and performance monitoring processes, and metrics. NASA was postured to see results of this progress and to verify the sufficiency of its Fiscal Year 2003 budget to provide for the core complete version of the station when the *Columbia* accident occurred.

Grounding of the Shuttle Fleet Will Result in Additional Schedule Delays and Cost

With the shuttle fleet grounded, NASA is heavily dependent on its international partners—especially Russia—for operations and logistics support for the space station. However, due to the limited payload capacity of the Russian space vehicles, on-orbit assembly has been halted. The program's priority has shifted from station construction and research to maintenance and safety, but these areas have also presented significant challenges and could further delay assembly of the core complete configuration. While NASA maintains that its Fiscal Year 2004 budget will remain unchanged, the schedule delays that have resulted from the grounding of the shuttle fleet will come at a cost.

Program's Priority Has Shifted From Station Construction and Research to Maintenance and Safety

The space shuttle fleet has been the primary means to launch key hardware to the station because of its larger payload capacity. With the shuttle fleet grounded, current space station operations are solely dependent on the Russian Soyuz and Progress vehicles. Because the payload capacity of the Soyuz and Progress vehicles are significantly less than that of the U.S. shuttle fleet,[6] operations are generally limited to rotating crew and transporting food, potable water,[7] and other items to the station. The Russian vehicles are also used for logistics support.

On-orbit assembly of the station has effectively ceased. Prior to the *Columbia* accident, NASA had planned to assemble the core complete configuration of the station by February 2004. NASA officials estimate that assembly delays will be at least a "month for month" slip from the previous schedule, depending on the frequency of flights when the shuttles resume operations. Assuming a return to flight around fall 2004, the core complete configuration would not be assembled before early 2006.

While the space station crew's primary responsibility is to perform routine maintenance, the two crewmembers on board will conduct some research, according to an interim space station research plan developed by NASA. However, due to the grounding of the shuttle fleet and the station's reliance on the Russian vehicles, this research will be curtailed. For example:

- *Outfitting of U.S. research facilities halted:* Currently, 7 of the 20 planned research facilities are on orbit. With the fleet grounded, three major research facilities—which, according to NASA, complete the outfitting of the U.S. laboratory—could not be launched in March of this year, as planned.[8] At this time, it remains unknown when the full configuration of the 20 research facilities will be on board the station.
- *Existing hardware failures:* Because new and additional hardware cannot be transported, NASA has to rely more heavily on existing on-orbit science facilities—facilities that have already experienced some failures. For example, the refrigerator-freezers on board the station, which serve as the main cold storage units, have failed several times, according to NASA officials. A larger cold temperature facility was one of three facilities that had been planned for launch in March 2003.
- *Limited science material:* Currently, there are very limited allocations for science materials to be transported to or from the space station by the Russian

[6] At about 36,000 pounds, the shuttle's payload capacity is roughly 7 times that of Russia's Progress vehicle and almost 35 times the payload capacity of its Soyuz vehicle.

[7] Potable water is a constraint to sustaining station operations. For example, crewmembers currently have a limit of two liters of water per day per crewmember.

[8] The research facilities that were packed in a logistics module awaiting launch had to be removed from the flight module and serviced.

Soyuz and Progress vehicles.[9] According to NASA officials, they plan to send about 93 kilograms (just over 200 pounds) of science material to the station on the next Progress vehicle scheduled for launch in January 2004. However, returning samples from investigations will be delayed until the shuttle fleet returns to flight because of the Soyuz's limited storage capacity.

NASA also cannot resolve known safety concerns on board the station while the shuttle fleet is grounded. For example, NASA has had to delay plans to fly additional shielding to protect the on-orbit Russian Service Module from space debris—a risk that increases each year the shielding is not installed. NASA is studying alternatives for launching and installing the debris protection panels earlier than currently planned. In addition, a failed on-orbit gyro—one of four that maintains the station's orbital stability and control—remains on board because the shuttle flight that was to carry a replacement gyro to the station and return the failed unit for detailed analysis was planned for March of this year—1 month after the grounding of the shuttle fleet.

Cost Implications Have Yet to Be Determined, but Increases Are Likely

To date, NASA has not fully estimated the potential increased costs and future budget impact incurred due to the grounding of the space shuttle fleet. However, it has identified a number of factors that will likely result in increased costs—including the need to extend contracts to complete development and assembly of the station.

NASA has requested $1.71 billion for Fiscal Year 2004 for the space station. The request is based, in part, on near completion of the hardware development for the U.S. core configuration and the transition to on-orbit operations. Soon after the *Columbia* accident, NASA stated that it would maintain budget requests at current levels until the shuttle returns to flight. NASA estimates the impact to the station program from the *Columbia* accident to be $22 million in Fiscal Year 2003 and up to $72 million in Fiscal Year 2004. NASA maintains that an assessment of total impact cannot be accomplished prior to the Fiscal Year 2006 budget submission in February 2005.

However, the considerable uncertainty about when the shuttle will return to flight, what the payload capability will be, and how many flights can be achieved each year greatly impact the total cost to the station program. NASA anticipates that by keeping a crew on board the station while the shuttle fleet is grounded and the continued development of space station hardware will incur additional costs. For example, NASA officials told us there are approximately 80,000 pounds of hardware at Kennedy Space Station ready for integration to the space station and another 106,000 pounds there being processed.

Uncertainty of the Shuttle's Return-to-Flight Date Delays Partner Agreements

While long-term plans are not well defined at this time, alternative funding may be needed to sustain the station—let alone achieve the station's intended goals. International agreements governing the space station partnership specify that the space agencies of the United States, Canada, Europe, and Japan are responsible for funding the operations and maintenance of the elements that each contributes, the research activities each conducts, and a share of common operating costs. Under current planning, NASA will fund the entire cost of common supplies and ground operations, then be reimbursed by the other partners for their shares.

Depending on contributions made by the partners while the shuttle fleet is grounded, the share that each partner contributes to the common operations costs may have to be adjusted and could result in NASA's paying a larger share of those costs. For example, the European Automated Transfer Vehicle is scheduled to begin flying in September 2004. If that vehicle takes on a larger role in supporting the station than currently planned, the European share of common operations costs could be reduced with the other partners paying more.

At the same time, NASA and its partners must develop a plan for assembling the partners' modules and reaching agreement on the final station configuration. Prior to the *Columbia* accident, options for the final on-orbit configuration were being studied, and a decision was planned for December 2003. NASA officials told us the process has been delayed, and NASA and its partners agreed on a program action plan in October 2003 that will ultimately lead to an agreement on the final on-orbit configuration in December 2004.

[9] Currently, science material is flown on a space and weight available basis. For example, if food or other life support items were not depleted between flights, science material might be transported.

Proposed Framework for Guiding and Assessing Cultural Change

Clearly, the space station's future is dependent on the shuttle fleet's safe return to flight. In the past, we have reported on challenges facing NASA's shuttle program—especially in maintaining an adequate shuttle workforce.[10] In January 2003, we reported that NASA needed to shift its overall orientation from processes to results, organizational stovepipes to matrixes, management hierarchy and control to flatter structures and employee empowerment, and reactive behavior to proactive approaches. The Columbia Accident Investigation Board's report and recommendations similarly indicate that needed improvements to the shuttle program go beyond technical enhancements and procedural modifications. Specifically, the Board found that despite several schedule slippages and rapidly diminishing schedule margins, NASA remained committed to 10 shuttle launches in less than 16 months to achieve the space station's core complete status by February 2004—a target date set in mid 2001. According to the Board, this schedule-driven environment influenced managers' decisions about the potential risks to the shuttle if a piece of foam struck the orbiter—an event that had occurred during an October 2002 shuttle flight and one that was ultimately identified as the technical cause behind *Columbia's* breakup. The Board concluded that cultural issues—including lapses in leadership and communication, a dogged "can do" attitude, and reliance on past successes—were critical factors that contributed to the accident.

In its September 8, 2003, response to the Board's findings,[11] NASA stated that it would pursue an in-depth assessment to identify and define areas where the agency's culture can be improved and take aggressive action." NASA indicated that it would take actions to achieve several goals:

- Create a culture that values effective communication and remove barriers to the expression of dissenting views.
- Increase its focus on the human element of change management and organizational development.
- Ensure that existing procedures are complete, accurate, fully understood, and followed.
- Create a robust system that institutionalizes checks and balances to ensure the maintenance of the agency's technical and safety standards.

Most recently, on October 15, 2003, NASA indicated that the agency is also assessing if cultural change is needed agency-wide. However, the agency offered no further details beyond its previous commitments.

As NASA works to change its culture, and as the Congress assesses the adequacy of NASA's corrective actions, applying a framework could prove beneficial. Such a framework should recognize NASA's operating principles and values, describe the direction of NASA's programs, focus attention on securing and maintaining skills for its employees, provide safety targets, show key results, and acknowledge the importance of internal and external review. The following framework—similar in concept to GAO's framework for ensuring the quality of its work—is anchored in four main areas: leadership, human capital, program performance, and monitoring and review.

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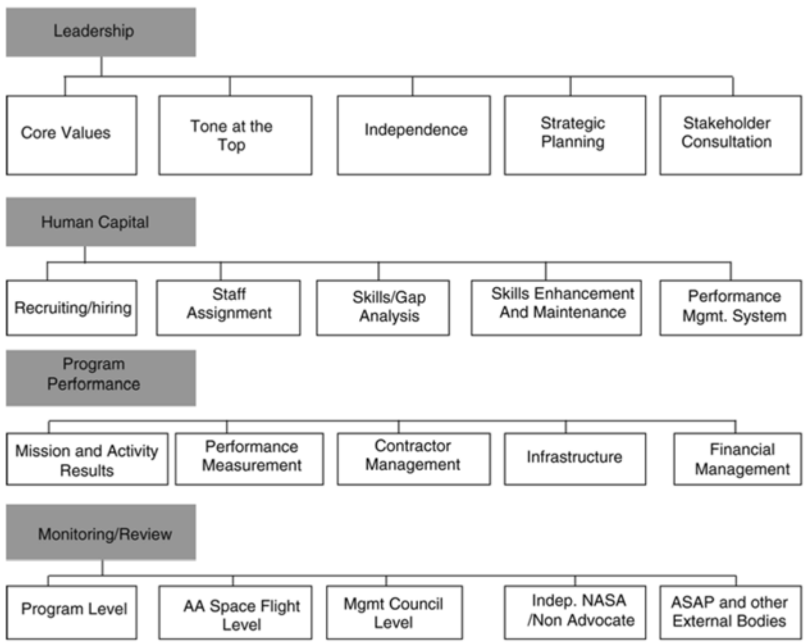
[10] U.S. General Accounting Office, *Space Shuttle: Human Capital and Safety Upgrade Challenges Require Continued Attention,* GAO/NSIAD/GGD–00–186 (Washington, D.C.: Aug. 15, 2000).

[11] See NASA, *NASA's Implementation Plan for Space Station Return to Flight and Beyond* (Oct., 2003).

Figure 2: Framework for Quality



Source: GAO.

- *Leadership:* The leadership anchor encompasses the agency's core values, including safety as NASA's highest priority; and the expectations that top management sets, such as stressing the importance of character, integrity, and support of safety assurance measures. This anchor also stresses the need to encourage staff to raise safety concerns, regardless of the staff member's formal organizational relationships or job responsibilities. Strategic planning and stakeholder consultation have importance only if championed by NASA's leadership. The leadership anchor helps address the question "What do we do?"
- *Human Capital:* Securing and assigning skilled staff, understanding short-and long-term skill deficiencies, establishing and maintaining skills, as well as assessing individual employee performance are major components of a comprehensive human capital anchor. NASA's efforts at developing a strategic human capital plan and legislative proposals related to human capital would be included in this anchor. The human capital anchor helps address the question "Who will do it?"
- *Program Performance:* While the primary focus of program performance is often related to mission-related activities, such as flight processing and major modifications, effective program performance also measures results achieved, oversight of contractors, infrastructure maintenance, and sound financial management to provide decision makers with accurate information with which to make resource tradeoffs and long-term investments. The program performance anchor helps address the question "How do we translate what we do into processes and procedures—that is, how do we operationalize our work?"
- *Monitoring and Review:* The oversight and enforcement of safety is a shared responsibility between program officials, Associate Administrators, the NASA Administrator, and independent groups such as non-advocate reviews and the Aerospace Safety Advisory Panel. The monitoring and review anchor helps address the question "How is this reinforced?"

We believe this framework can serve to identify the priorities agency leadership must communicate, the human capital activities needed to ensure that expected employee performance is achieved, the safety processes and procedures that need to be operationalized as part of program performance, and the scope of enforcement responsibilities. As such, use of this framework can help the Congress monitor the corrective actions NASA will undertake to strengthen the agency's culture.

Mr. Chairman, this concludes my prepared statement. I will be happy to answer any questions you or other members of the subcommittee may have.

Senator BROWNBACK. Thank you very much, Mr. Li, for your comments. We'll look forward to questions.

Dr. Park?

STATEMENT OF ROBERT L. PARK, DEPARTMENT OF PHYSICS, UNIVERSITY OF MARYLAND

Dr. PARK. Mr. Chairman, Members of the Committee, 10 years ago, in this very room, I appeared before this Committee to testify on the redesigned space station. If I repeated that testimony today, it would still be relevant. The substance of my testimony at that time was that a permanently manned space station in Earth orbit cannot be justified on the basis of science alone. That is still the case. What has changed is that the ISS, although still unfinished, is now in orbit.

A space station once seemed to be an inevitable step in the conquest of space. It would relay communications around the globe, track weather systems, detect military movements, provide navigational assistance, and study the heavens free of atmospheric distortion. All these things are now done routinely and far more cheaply with the unmanned satellites.

The International Space Station is just a microgravity laboratory. For most manufacturing processes, gravity is not an important variable. Gravitational forces are generally too weak, compared to inner atomic forces, to have much effect. A possible exception was thought to be the growth of protein molecular crystals, which are of enormous importance in modern medical research.

In the days following the *Columbia* tragedy, NASA repeatedly cited protein crystal growth as an example of important microgravity research being conducted on the shuttle. NASA knew better.

In 1992, a team of Americans that had grown protein crystals on Mir concluded that every protein that crystalizes in space can also be crystalized right here on Earth. Nevertheless, in 1997 Larry DeLucas, a University of Alabama at Birmingham chemist and a former astronaut, testified before the Space Committee of the House that a protein structure determined from a crystal grown on the shuttle was essential to development of a new flu medication that was in clinical trials. It simply was not true. Science magazine learned that the crystal had not been grown in space, but in Australia.

In 1998, the American Society for Cell Biology, to which protein crystallographers all belong, called for the cancellation of the space-based crystal growth program, stating that no serious contribution to knowledge of protein structure or to drug discovery or design have been made in space.

On March 1, 2000, the National Research Council, which was asked to study the science plan for the space station, concluded that the enormous investment in protein crystal growth on the shuttle and Mir has not led to a single unique scientific result.

Nevertheless, the final flight of *Columbia* carried yet another commercial protein crystal growth experiment for the group at the University of Alabama in Birmingham. Research scheduled for the ISS also includes protein crystal growth studies by the same group.

The only microgravity research that cannot be done robotically is that involving the affect on humans. Microgravity is far more deleterious to human health than anyone had suspected.

By now, you have probably all seen the white paper by Dr. Lawrence Kuznetz. It critiques the human life sciences research aboard the ISS and the shuttle. Intended as an internal critique for his colleagues, the paper was leaked to the public. Kuznetz, a professor at Baylor College of Medicine and a flight project research manager for NASA, finds that few, if any, of the experiments have valid controls. "The line between real and wishful science," he writes, "is continually being blurred." He puts the blame directly on NASA management.

Microgravity research planned for the ISS is merely an extension of research conducted on the space shuttle for over the past 20 years. The research is not wrong, it is just not very important. No field of science has been significantly affected by research carried out at great cost on the shuttle or on Mir. Much of it has never even been published in leading peer reviewed journals.

Human progress is measured by the extent to which machines replace humans for work that is dangerous or menial. In any case, the only conceivable new destination for human explorers is Mars. Conditions on other planets or other moons are too extreme for humans to ever set foot on them. They are too hot, or their gravity would crush a human, or radiation levels are much too intense.

Meanwhile, the exploration of space can't wait for astronauts. Telerobots are robust extensions of their human operators giving us a virtual presence in places no human could ever venture. The accomplishments of the astronauts on the ISS will be inconsequential. It is the scientists who control the telerobots, having become virtual astronauts, who will explore the universe. To explore where no human can ever set foot is the great adventure of our time.

Thank you.

[The prepared statement of Dr. Park follows:]

PREPARED STATEMENT OF ROBERT L. PARK, DEPARTMENT OF PHYSICS, UNIVERSITY OF MARYLAND

Mr. Chairman, Members of the Committee:

It has been ten years since I last appeared before this committee to testify on the International Space Station program. I began my 1993 testimony with a statement adopted by the elected Council of the American Physical Society:

> "It is the view of the American Physical Society that scientific justification is lacking for a permanently manned space station in Earth orbit." APS, 20 January 1991

The APS recently reaffirmed its statement, but the ISS, though still unfinished, is now in orbit. The question is, what do we do now?

A space station once seemed to be an inevitable step in the conquest of space. From such a platform it would be possible to relay communications around the globe, track weather systems, detect military movements, provide navigational assistance to ships and planes, and study the heavens free of atmospheric distortion. All these things and more are now done routinely using unmanned satellites, and these robotic spacecraft are doing the job far better and far more cheaply than would ever be possible with a manned space station.

Microgravity

The International Space Station is an orbiting laboratory for the study of a microgravity environment. There are two quite separate justifications for a microgravity laboratory: One is to examine the biomedical effects of extended human exposure to microgravity; the other is to determine whether microgravity offers any advantage in manufacturing.

There had been speculation that certain manufacturing processes that are difficult or impossible on Earth might be easier in microgravity. For most manufacturing processes, however, gravity is simply not an important variable. Gravitational forces are generally far too weak compared to interatomic forces to have much effect.

A possible exception was thought to be the growth of molecular crystals, specifically protein crystals. The structure of protein molecules is of enormous importance in modern medical research. Protein crystals make it possible to employ standard X-ray crystallographic techniques to unravel the structure of the protein molecule. It had been speculated that better protein crystals might be grown in zero gravity. Unlike the interatomic forces within a molecule, molecules are bound to each other by relatively weak forces; the sort of forces that hold water droplets on your windshield. Gravity, it was supposed, might therefore be important in the growth of protein crystals.

Indeed, in the days following the Columbia tragedy, NASA repeatedly cited protein crystal growth as an example of important microgravity research being conducted on the shuttle. NASA knew better. It was 20 years ago that a protein crystal was first grown on Space Lab 1. NASA boasted that the lysozyme crystal was 1,000 times as large as one grown in the same apparatus on Earth. However, the apparatus was not designed to operate in Earth gravity. The space-grown crystal was, in fact, no larger than lysozyme crystals grown by standard techniques on Earth.

But the myth was born. In 1992, a team of Americans that had done protein crystal studies on Mir, commented in *Nature* (26 Nov 92) that microgravity had led to no significant breakthrough in protein crystal growth. Every protein that crystalizes in space also crystallizes right here on Earth. Nevertheless, in 1997, Larry DeLucas, a University of Alabama at Birmingham chemist and a former astronaut, testified before the Space Subcommittee of the House that a protein structure, determined from a crystal grown on the Shuttle, was essential to development of a new flu medication that was in clinical trials. It simply was not true. Two years later *Science* magazine (25 June 99) revealed that the crystal had been grown not in space but in Australia.

Meanwhile, the American Society for Cell Biology, which includes the biologists most involved in protein crystallography, called in 1998 for the cancellation of the space-based program, stating that:

> "No serious contributions to knowledge of protein structure or to drug discovery or design have yet been made in space." ASCB, July 9, 1998

Hoping to regain some credibility, an embarrassed NASA turned to the National Academy of Sciences to review biotechnology plans for the Space Station. On March 1, 2000, the National Research Council, the research arm of the Academy, released their study. It concluded that:

> "The enormous investment in protein crystal growth on the Shuttle and Mir has not led to a single unique scientific result." NRC, 1 March 2000

It might be supposed that at this point programs in space-grown protein crystals would be terminated. It was a shock to open the press kit for STS–107 following the Columbia accident, and discover that the final flight of Columbia carried a commercial protein crystal growth experiment for the Center for Biophysical Science and Engineering, University of Alabama at Birmingham. The Director of the Center is Lawrence J. DeLucas, O.D., Ph.D. If I go to the NASA website and look for research planned for the ISS, I once again find protein crystal growth under the direction of the Center for Biophysical Science and Engineering and Dr. Lawrence J. DeLucas.

Biomedical Research

The microgravity environment has been found to be far more deleterious to human health than anyone had suspected. Indeed, in the first heady early days of the space age there was speculation that someday heart patients might be sent into orbit to rest their hearts, which would not have to pump blood against the force of gravity. On the contrary we find that not only is the heart severely stressed in zero gravity, osteoporosis, muscle atrophy, immune suppression, sleep disorders, diarrhea and bouts of depression and anxiety are endemic to the space environment.

By now you have all probably seen the "White Paper" by Dr. Lawrence Kuznetz that critiques the human life-sciences research aboard the ISS and the Shuttle. Intended as an internal critique for his colleagues, the paper was leaked to the public. Kuznetz, a professor at the Baylor College of Medicine, and flight projects research manager for a NASA academic consortium, finds that few if any of the experiments have valid controls. "The line between real and wishful science," he writes, "is continually being blurred." He puts the blame directly on NASA management. The stated objective of the life sciences research planned for the ISS is to develop "countermeasures" for the staggering number of health risks facing astronauts, particularly those might who might someday venture beyond the relative safety of low-Earth orbit. "Under the worst of circumstances," he writes, "ISS will be in the ocean without a single countermeasure in the books for the cardiovascular, neurovestibular, pharmacokinetics, behavior and other major disciplines. Then again, we could get lucky."

It is unfortunate that in our democracy, conscientious public servants, willing to risk their careers by leaking documents to the public, may be the only the only protection we have against self-serving and misleading public pronouncements by government agencies. What's behind this is the NASA conviction that the public will not support a space program that does not involve putting humans in space. Research planned for the ISS is merely an extension of the sort of science conducted on the Space Shuttle over the past 20 years.

The research is not wrong, it is just not very important. No field of science has been significantly affected by research carried out on the Shuttle or on Mir at great cost. Much of it has never even been published in leading peer-reviewed journals.

The real objective of the most expensive science laboratory ever constructed is to provide astronauts with something to do. Ned Ludd, an English laborer who destroyed weaving machinery in 1779 to preserve jobs, would have cheered. But human progress is now measured by the extent to which machines are used to replace humans to perform tasks that are dangerous or menial.

Even if shielding is added to spacecraft to protect against radiation, and a long axis spacecraft is rotated to provide artificial gravity at great cost, the only conceivable new destination for human explorers is Mars. Conditions on other planets or their moons are too extreme for humans to ever set foot on them. They are too hot, or their gravity would crush a human, or radiation levels are much too intense.

Mars is no garden of Eden either, but the 1997 Pathfinder mission to Mars gave us a glimpse of the future. Pathfinder landed on Mars carrying a lap-sized robot named Sojourner. The tiny robot caught the imagination of people everywhere. Sojourner was a telerobot. Its brain was the brain of its human operator 100 million miles away on Earth. Its senses were the senses humans gave it. The whole world saw Mars through Sojourner's eyes. It had an atomic spectrometer for a nose that could sniff the rocks to see what they were made of, and thermocouples that could feel the warmth of the midday sun in the sand beneath its wheels. It never stopped for lunch or complained about the cold nights. Trapped in their space suits, human explorers could have done no more. Two much more sophisticated telerobots are now on their way to Mars.

Meanwhile, the exploration of space can't wait for astronauts. Our robots have already visited every planet save distant Pluto, testing the Martian soil for traces of life, and mapping the hidden surface of the cloud-shrouded planet Venus with radar eyes. Long before a human expedition to Mars could be launched, the robots will have finished their exploration.

We must ask what it means to "be there." Telerobots are robust extensions of their frail human operators, giving us a virtual presence in places no human could ever venture. The accomplishments of the astronauts on the ISS will be inconsequential. It is the scientists who control the telerobots, having become virtual astronauts, who will explore the universe. To explore where no human can ever set foot is the great adventure of our time.

Senator BROWNBACK. Thank you, Dr. Park.

Dr. Pawelczyk, please?

STATEMENT OF JAMES A. PAWELCZYK, PH.D., ASSOCIATE PROFESSOR OF PHYSIOLOGY AND KINESIOLOGY, PENNSYLVANIA STATE UNIVERSITY

Dr. PAWELCZYK. Mr. Chairman, Senator Nelson, and Members of the Committee, good afternoon.

I'm a life scientist and a former payload specialist astronaut who did perform cutting-edge experiments in space, and I thank you for the opportunity to discuss the progress that NASA has made in strengthening its ISS research program.

In the life sciences community, we speak of translational research, and that elucidates molecular and genetic mechanisms and scales these principles to larger and more complex systems. The journey starts with a single isolated process, and it ends with a large organism where hundreds of effects interact. Translational research is the gold standard of the NIH, and it's exactly what the research community expects from the ISS.

NASA launched the Research Maximization and Prioritization Task Force, which is known as ReMAP, to achieve just this goal. ReMAP established two high-priority research areas for the ISS, illuminating the nature of the universe at its most fundamental levels, and enabling human exploration of space.

Despite some dissent, the majority of participants supported our primary recommendation. And I quote, "If enhancements to ISS beyond the U.S. core complete, are not anticipated, NASA should cease to characterize the ISS as a science-driven program." Three constraints led us to this conclusion: up-mass to the station, power on the shuttle, and crew time.

Now, since ReMAP concluded its work just over a year ago, NASA has adopted many of our recommendations, and allow me to cite three examples of the progress they've made.

First, budgets have been realigned. Most notably, funding for facilities that house mice and rats in variable gravity has been restored. These habitats will provide, for the first time in history, our only ability to study the long-term effects of Mars-like gravity on mammals, and this is an absolutely essential step before we make human trips to Mars.

Second, research that could be done without the shuttle has been relocated to other platforms, such as Progress or photon rockets, and this has reduced the backlog of current flight experiments in the fundamental space biology division of the Office of Biological and Physical Research by more than 25 percent.

Third, NASA is working proactively to reduce the time required to prepare an ISS scientific payload. Earlier this year, a team of external scientists and NASA managers built a set of recommendations that put investigators in direct contact with payload developers, engineers, and the ISS crew members. Satisfaction of the research community will become part of the performance plan of senior management. If the investigator's a customer, NASA has taken a crash course in customer service.

The overall message, in my view, is positive. The seeds of a science-driven culture are being sown at every level of this agency.

We still need to embellish translational research on the ISS, and one example stands out. Osteoporosis afflicts astronauts at rates ten times greater than postmenopausal women. Using astronauts as human subjects, experiments now onboard the ISS will allow us to calculate stresses in the hip, a common location for this problem. At the other end of the translational spectrum, a cell science program is thriving, thanks to NASA's celebrated bioreactors. In the next 5 years, we'll be able to study reference organisms such as mice and rates, bridging the gap between cell culture and human flight operations. The potential return here is immense. The application of this research to our aging American public could become one of the most important justifications for an International Space Station.

Mr. Chairman, Mr. Nelson, given sufficient resources, I am convinced that NASA will deliver the rigorous translational research program that the scientific community requires and the American people deserve.

I sincerely thank you for your vigilant support of the Nation's space program and for the opportunity to appear before you today.

[The prepared statement of Dr. Pawelczyk follows:]

PREPARED STATEMENT OF JAMES A. PAWELCZYK, PH.D., ASSOCIATE PROFESSOR OF PHYSIOLOGY AND KINESIOLOGY, PENNSYLVANIA STATE UNIVERSITY

Abstract

NASA is working proactively to improve its science culture, with excellent results. Despite laudable efforts to optimize the International Space Station for research, enhancements beyond the "core complete" configuration will be necessary to assure a robust and vigorous science program that meets the expectations of the external science community.

Mr. Chairman and Members of the Committee:

Good afternoon. I thank you for the opportunity to discuss the progress that NASA has made in strengthening research on board the International Space Station. I have been a life sciences researcher for 20 years, including my work as a payload specialist astronaut, or guest researcher, on the STS–90 Neurolab Spacelab mission, which flew on the space shuttle *Columbia* in 1998. I am a standing member of NASA's Life Sciences Advisory Subcommittee, and last year I served as a member of the Research Maximization and Prioritization (ReMAP) Taskforce.

My area of expertise is blood pressure regulation. Without the nervous and cardiovascular systems that are so uniquely tuned to humans, none of us would be leaving our chairs today without passing out. Similar problems affect up to 500,000 Americans, and develop in as many as 70 percent of astronauts after spaceflight. Nationwide, only a handful of laboratories are capable of studying this problem by inserting microelectrodes in humans to record signals from nerve fibers, or by measuring the release of neurotransmitters from nerve terminals. Five years ago, we made the space shuttle one of those laboratories. I offer you personal testament, and the incredible success of the Neurolab mission, as evidence that cutting-edge research can be performed m space.

Based on the favorable response from the scientific community toward Neurolab, Congress authorized preliminary funding to develop another research mission, which became STS–107. Like the rest of the NASA family, I lost friends and colleagues on February 1, 2003. We owe the crew of STS–107 our very best efforts to assure that their dedication, their sense of mission, will continue.

Translational research: the goal of the ISS

A popular "buzzword" in the biological research community has been the word "translational." In this context, research elucidates molecular and genetic mechanisms, and scales, or translates, these principles to larger and more complex structures. In the life sciences, translational research spans the distance from molecular biology to medicine, with the steps of cell biology, organismal biology, and integrative physiology lying somewhere between. It's a journey of discovery from small to large; from studying a single process in isolation to a large organism where many processes interact. Complexity exists at each and every step along the path, illuminated by techniques that let us see further, and with greater clarity.

A corollary to this description is that single experiments rarely, if ever, change the course of science. A robust research program includes all elements of translational research, delivering the fruits of the lab bench to everyone. Translational research is the "gold standard" of the NIH, and it is what the research community, and the American people, should expect from the ISS.

The challenge of simultaneous operations and construction

While I was training for STS–90 in 1996 and 1997 I learned of NASA's plan to provide an early science capability on board the ISS. The simple analogy is moving into a house while it is still under construction; although it's possible, it's not optimal. At the time I wondered about the wisdom of this decision, but in hindsight I must agree that it was a sensible, albeit challenging, approach to provide rapid return on taxpayer investment. It was a calculated gamble that left NASA open to criticism. As research hours began to accumulate, some scientific groups complained vociferously that the research on the ISS was neither "world class" nor "cutting edge." ISS costs were creeping out of control, culminating in a $981 million realignment of research funding from the Office of Biological and Physical Research to the Office of Spaceflight for continued ISS construction. Fiscal accounting was cumbersome, and research success was in jeopardy.

The ISS Management and Cost Evaluation (IMCE) Task Force chaired by Tom Young was a direct response to these problems. The most important impact to the scientific community was the proposal of a "core complete" configuration that controlled near-term costs by reducing the ISS crew complement from 6–7 to 3 and postponing or eliminating the infrastructure necessary to support the larger crew. The IMCE Task Force further recommended that NASA constitute a review group to prioritize the remaining ISS resources for the best research possible. To return to the building analogy, some bedrooms were deleted, other rooms were left partially finished, and NASA needed to get the house inspected before the money ran out.

The ReMAP Process

In response to the IMCE report, NASA adopted the core complete milepost and launched the Research Maximization and Prioritization Task Force, commonly known as ReMAP, in the spring and summer and 2002. Chaired by Rae Silver of Columbia University, the Task Force included two National Medal of Science awardees, one Nobel prize winner, and more than a dozen members of the National Academy of Sciences, representing the full breadth of translational research in the biological and physical sciences.

ReMAP affirmed two broad, often overlapping, top priorities for the type of research that should be conducted on board the International Space Station. Both are consistent with the historical mission of NASA. One is the category of intrinsic scientific importance or impact, research that will illuminate our place in the universe, and the nature of that universe at the most fundamental levels. In the other category we valued research that enables human exploration of space, the logical outgrowth of the National Aeronautics and Space Exploration Act of 1958. It should be no surprise to you that over the past 15 years other review panels, both internal and external to NASA, have named similar goals. What was unique to ReMAP was our challenge to consider both the physical sciences and biological sciences simultaneously. This resulted in spirited debate and intellectual foment of the highest caliber.

The ReMAP Task Force, in my opinion, was well constituted. Despite some dissent, the vast majority of participants supported our primary recommendation:

> *"If enhancements to ISS beyond 'US core complete' are not anticipated, NASA should cease to characterize the ISS as a science driven program."*

The ISS, would not be, in the Task Force's opinion, a world-class science facility.

Three constraints led us to this conclusion: The first was up-mass: a shuttle schedule of four flights per year, as proposed by the IMCE for cost containment, was simply not sufficient to carry the equipment and research samples necessary to sustain a translational research program while assembling and maintaining the ISS. The second was power on the shuttle: Some experiments, such as those that utilize animal surrogates, require power while they are transported to the space station. An insufficient amount of powered space was available. Finally, there was the issue of crew time. Normal space station operations were estimated to require the full time effort of approximately 2½ crewmembers, leaving just 20 person-hours per week available for research.

Progress since ReMAP

The ReMAP report was well received, and NASA is using it as a blueprint for changing ISS research. Since the Task Force's conclusion in June 2002, NASA has made excellent progress in the areas of management and prioritization that will optimize research on the ISS. In September 2002, the NASA Advisory Council endorsed NASA's response to ReMAP.

At that time no Federal agency ranked worse than NASA on the Executive Branch's Management Scorecard. Today, only 10 of 27 agencies rank better overall.

People in this agency understand the need to improve, and they're responding. The NASA culture is evolving, in favor of safety *and* science. Allow me to cite a few examples:

First, several low priority research efforts have been descoped or eliminated, and unfunded, higher priority items have received Phase I funding. Most notable is the restoration of limited funding for the core of the Advanced Animal Habitat, which houses mice and rats for microgravity and variable gravity research. These habitats can be mounted on the life sciences centrifuge, scheduled for delivery in FY07 or FY08, and will provide for the first time in human history the ability to study the long-term effects of fractional (moon or Mars-like) microgravity conditions on a variety of biological organisms.

Second, integrative research has been revitalized, including renewed collaboration with the Russian Institute for Biomedical Problems. A Joint Working Group meeting is taking place in Moscow today and tomorrow. Within NASA, a joint Cell Sciences and Genornics Council has been formed between the Physical Sciences and Fundamental Space Biology Divisions of OBPR to coordinate genomic and cell biology research. The need for such coordination is acute. Recent cell culture experiments by Timothy Hammond at Tulane University suggest that the activity of more than 15 percent of the human genome changes during microgravity exposure. This is not just a simple statistic; it's a profound demonstration that gravity alters gene expression of cells, which *must* affect our basic structure and composition. We've barely begun to explore what these changes mean. This is a research area where biology, physical sciences, and informatics naturally blend, and NASA's problem-based approach is a model for NIH and NSF to emulate.

Third, research that can be done without reliance on the shuttle has been relocated to other platforms in a renewed effort of international collaboration and cooperation. A biological version of the hitchhiker payload experiments has been developed, which can be placed on Progress or Foton rockets. This move alone reduces the backlog of flight experiments in the Fundamental Space Biology Division of OBPR by more than 25 percent.

Fourth, NASA is working proactively to reduce the time required to prepare an ISS scientific payload for flight. Earlier this year NASA constituted a Station and Shuttle Utilization and Reinvention Team. Comprised of representatives of the scientific community and senior management from seven NASA centers, this group was tasked with developing a set of recommendations that strengthen NASA's emphasis on the research community and remove impediments to ISS utilization. The eight top recommendations, which will be implemented in coming months, represent an enlightened view that puts research investigators in direct contact with payload developers, engineers, and ISS crewmembers. The investigator is the customer, and NASA has taken a crash course in customer service.

Fifth, the program of ground-based research has been reinvigorated, with no less than 7 solicitations for research proposals in the life and microgravity sciences announced in FY03. The final complement of proposals will depend on funding of the Human Research Initiative that is part of the President's FY04 budget submission to Congress.

Sixth, the seeds of a science-driven culture are being sown at every level of the Agency. A Deputy Associate Administrator for Science has been established in the Office of Biological and Physical Research. The ISS now has a full-time program scientist on the ground who represents the research community on issues related to ISS budget, construction, and maintenance. A crew science officer, currently Ed Lu, takes ownership for the science experiments in-flight. Satisfaction of the research community is to become part of the performance plan of all Associate Administrators, Center Directors, and the ISS and Shuttle Program Managers. The message is simple and powerful: throughout NASA, science deserves a seat at the table.

Challenges for the future

I am pleased with NASA's recent efforts to increase science productivity, and Sean O'Keefe and his senior management deserve credit for their leadership during such trying times. The international partners have helped NASA continue its flight research programs despite the shuttle stand down, and they are to be applauded for their commitment. The ISS program has concluded that at least five shuttle flights can be supported with a three-orbiter fleet, which should ameliorate the upmass constraint identified by ReMAP. Estimates for crew time available to conduct research continue to hover at 10 hours per week, and this situation needs to be corrected. The assembly complete configuration, which supports a six-person crew, should increase research time by an order of magnitude or more.

If there's one type of technology that is revolutionizing biology today, it is imaging technology. Fluorescent tags permit us to visualize the movement of ions in living cells, computerized tomography, magnetic resonance imaging, and ultrasound allow us to reconstruct deep anatomy with unprecedented detail, and magnetic and electron spin resonance spectroscopy allow us to track the flux of energy and molecules in living systems. NASA-funded researchers employ all of these techniques, but investigators and the American public need better access to this imagery when such approaches are used in space. The goal should be remote operation of experiments by ground investigators, concurrent with preparation of samples by trained astronauts in space, and real-time delivery of images that are sure to inspire and educate the American public much like the Hubble Space Telescope has done.

We need to embellish translational research on the ISS, and one example stands out. Osteoporosis afflicts astronauts at rates 10 times greater than post-menopausal women. Using astronauts as human subjects, research now being conducted on the ISS will determine stresses in the hip, a common location for osteoporosis. In December 2003, NASA will host a subgroup discussion at the American Society of Cell Biology to discuss the mechanisms by which cells sense mechanical force. NASA's celebrated bioreactor program, a revolutionary way to culture cells, is sure to be a part of this conference. Working from both the "beginning" and "end," these efforts make serious headway on a path of translational research. But we need to fill in the missing pieces by extrapolating the cell and human findings to reference organisms and mammalian models such as mice and rats. We need the capability to house these organisms on the ISS and that's expected within five years. But equally important, we need time for crew members to prepare and conduct these experiments, and that time can be found only when the ISS moves beyond the core complete configuration. The potential return is immense; the application of this research to our aging public could become one of the most important justifications for an International Space Station.

Mr. Chairman, members of the Committee, given sufficient resources, I am convinced that NASA will deliver the rigorous translational research program that the scientific community expects, and the American people deserve. I sincerely thank you for your vigilant support of the Nation's space program, and the opportunity to appear before you today.

Senator BROWNBACK. Thank you very much.

Dr. Zygielbaum, please?

STATEMENT OF ARTHUR I. ZYGIELBAUM, DIRECTOR, NATIONAL CENTER FOR INFORMATION TECHNOLOGY AND EDUCATION, UNIVERSITY OF NEBRASKA

Mr. ZYGIELBAUM. Yes. Mr. Chairman, distinguished Members of the Subcommittee, I'm honored to have been invited to testify about International Space Station safety.

I am testifying as a private citizen. By way of background, I am on the faculty at the University of Nebraska, Lincoln. I moved there in 1998 after nearly 30 years at the Jet Propulsion Laboratory, NASA's facility in Southern California. I became a consultant to the NASA Aerospace Safety Advisory Panel in 2001, and a full member of the panel a few days after the Challenger—or the *Columbia* disaster, in February. As you're aware, I resigned from that panel last month.

To cut to the chase, is space station safe? Unfortunately, the answer cannot be stated as yes or no. For something as complex as space station or the space program or even driving to work, the answer is, "Probably." We can only take actions to reduce the risk of an incident, or, in the vernacular, "a bad day." The proposals that I'm going to make reflect some opinions of the ASAP panel and members. They're designed to improve safety by reducing risk.

ISS safety needs to be addressed in the context of NASA, as well as in and of itself. ASAP members, by their resignation last month, and many other groups, have called for independent NASA safety—

an independent NASA safety oversight body. An independent oversight body can provide effective checks and balances against the forces that erode safety—for example, changing culture, budget and schedule pressure, and so on. ASAP could not provide that oversight. Its $500,000 annual budget allowed members and consultants only two to 5 days per month in meetings or in field work. Despite that, ASAP's annual reports had, for over three decades, identified technical problems and deficiencies in safety organizations and processes. As an advisory body, ASAP lacks sufficient authority, in terms of resources, time, and reporting, to meet an oversight responsibility.

Unlike ASAP, a, for want of a name, NASA safety board should consist of a full-time board with the ability to hire a small number of full-time researchers to aid in field work, reviews, and investigations. It should have a budget independent of NASA's. It could report to the NASA Administrator, but, for more independence, it probably should report to Congress.

Currently in NASA, a project or program manager can issue a waiver to safety-critical requirements to accommodate technical difficulties or challenges in budget and schedule. At its last meeting, ASAP recommended that NASA move waiver authority for safety-critical requirements to an appropriate independent safety organization. This is very similar to the CAIB recommendation on independent technical authority. To get a waiver, a program manager would apply to that safety organization. This would isolate safety-critical decisions from pressures of budget and schedule.

A big caveat. Nothing in what I said with regard to an oversight board or safety waivers should be construed to remove or weaken the safety functions integral to engineering, management, and operations in NASA's projects.

Accountability for safety must remain with the implementing authority.

Several weeks ago, headlines proclaimed that I, as an ex-NASA advisor, declared that ISS was in critical danger. I'd like to clarify that. What I said was that ASAP had seen three incidents that might indicate a trend.

As reported in the ASAP 2002 annual report, the indications were difficulties in communications, disagreement in safety processes, and misunderstanding of space station configuration between the Russian and American space station organizations. None of these incidents individually seriously endangered ISS. The panel was concerned that they had occurred and could be an indication that more dangerous incidents might follow.

Space station is a complicated spacecraft. It is managed in a decentralized manner in accord with international agreements by committees and strong interpersonal relationships.

As space station grows to core complete and beyond, technical and operational complexities will increase, coordination will become more critical, and, driven by the complexity, the chances of an accident will increase. Had I remained with ASAP, I would have argued for a recommendation that NASA and its partners investigate mechanisms to create a centralized international space station management structure and an independent international safety oversight board.

Let me note that ASAP was also concerned about having sufficient Russian Soyuz and Progress supply vehicles during this period of shuttle unavailability. In addition, we were concerned about the availability of spare parts.

Space station is a development vehicle. The reliability and interoperability of systems is being learned through experience. Sufficient up and down mass capability must be available to replace failed hardware and crew consumables as this experience is gained. If space station were to become unhabitable, the crew can turn off the lights and come home, but that would fail to protect our investment in ISS and the safety of those on the ground should the result be an uncontrolled reentry.

As an engineer, I appreciate the incredible challenges that have been overcome by the International Space Station partners. The proposals I have made are intended to reduce risk and assure the continued safe operation of the space station.

I'd like to close by thanking the Chair and the Subcommittee for the opportunity to have made these remarks.

[The prepared statement of Mr. Zygielbaum follows:]

PREPARED STATEMENT OF ARTHUR I. ZYGIELBAUM, DIRECTOR, NATIONAL CENTER FOR INFORMATION TECHNOLOGY AND EDUCATION, UNIVERSITY OF NEBRASKA

Mr. Chairman and Distinguished Members of the Subcommittee:

I am honored to have been invited to testify with regard to the safety of the International Space Station. Although I am testifying as a private citizen, I am a member of the administrative faculty, an associate professor of computer science and engineering (a courtesy title) and head of a research center in educational technology at the University of Nebraska-Lincoln (UNL). My testimony does not reflect any position or opinion of University of Nebraska-Lincoln. I joined UNL in January 1998 after spending nearly 30 years at the NASA/CALTECH Jet Propulsion Laboratory. While at JPL I held positions in electronic and software engineering as well as in line and program management. In August 2001 I was appointed as a consultant to the NASA Aerospace Safety Advisory Panel (ASAP). Three days after the Columbia tragedy, the NASA Administrator appointed me as a full member of the Panel. As you are aware, I resigned that appointment about a month ago.

In presenting my view of space station safety, I will first address the International Space Station (ISS) program within the context of NASA safety. Second, I will address specific issues impacting ISS safety and some over-sensationalized headlines attributed to me. My major points will be to recommend the establishment of independent safety oversight for NASA and the creation of a centralized, but international, management structure for the International Space Station.

Is ISS safe? The answer cannot be "yes" or "no". For an enterprise as complex as space station, or the space program, or even driving to work, the answer is "probably." We can only act to reduce the risk of an accident—a bad day. The actions proposed in this testimony are designed to reduce risk by providing a back-stop function for safety and by reducing the pressure to cave in to the ever present pressures of limited time and resources.

I. ISS Safety as a part of NASA Safety

The International Space Station program exists within the organization and culture of NASA. Its safety organization and assignment of safety responsibilities is similar to that in other NASA programs, including the Space Shuttle. The Challenger and Columbia disasters can be traced, at least in part, to allowing safety margins to erode in the face of budget and schedule pressure. The Aerospace Safety Advisory Panel has repeatedly called for independence of safety organizations and for clear and clean lines of safety responsibility, accountability and authority to provide the checks and balances that resist such erosion.

Independent Safety Oversight

The call to establish greater independence for NASA's safety organization is not a new one. The 1999 Shuttle Independent Assessment Team stated "NASA's safety and mission assurance organization was not sufficiently independent." The Rogers

Commission investigating the Challenger disaster called for independent oversight. The Columbia Accident Investigation Board (CAIB) report included the following, "NASA's safety system lacked the resources, independence, personnel, and authority to successfully apply alternate perspectives to developing problems. Overlapping roles and responsibilities across multiple safety offices also undermined the possibility of a reliable system of checks and balances."

The Aerospace Safety Advisory Panel could not provide the needed oversight. The Panel's $500,000 annual budget only allowed panel members to spend 2–5 days per month in meetings or in the field. In 1978, Herbert Grier, ASAP Chairman, testified to this very Senate Subcommittee, "The Panel's objective, and the limitation on the members' time, indicate that we can be expected to review NASA operations only to the extent necessary to judge the adequacy of the NASA management system to identify risks and to cope with them in a safe, efficient manner."

In the words of the CAIB, the Aerospace Safety Advisory Panel was "not very often influential." Despite the fact that ASAP's Annual Reports had for at least three decades identified technical problems and deficiencies in safety organization authority, accountability, responsibility, independence and funding, an attempt was made in a Senate Appropriations Committee report to hold ASAP accountable for not identifying the cultural problems found by the CAIB. ASAP was an advisory group—by definition to answer questions asked of it—to give advice. When my colleagues and I resigned from ASAP it was to facilitate the establishment of a safety oversight group with needed independence and authority. It was to establish an oversight group whose authority matched its responsibility.

An independent oversight board can provide effective checks and balances against the forces that erode safety—changing culture, budget, schedule, aging equipment, inadequate processes, etc. The Navy's technical warrant process, the National Transportation Safety Board (NTSB), and the Nuclear Regulatory Commission are all examples of oversight organizations providing strong checks and balances to implementing organizations.

Unlike ASAP, the, for want of a name, NASA Safety Board should be full-time and include a small staff of researchers to aid in field work, reviews, and investigations. It should have sufficient funding to hire its own research personnel and to task NASA safety experts for specific studies. The Board must have the ability to communicate with all levels of NASA management in order to ask questions and examine safety-related processes and standards. While the Board could report to the NASA Administrator, it could be chartered under Congress, like the NTSB and the National Research Council, to achieve greater independence. It would act as a final authority in issues related to safety.

From our experience in ASAP, this Board must be constituted outside the Federal Advisory Committee Act (FACA). While FACA's purpose in controlling committees is laudable, it has several provisions that would weaken an oversight group. In particular, FACA requires that a Federally Designated Official accompany committee members in any fact finding activities. The act also requires that all recommendations to the government be first aired in a public meeting. These restrictions impede investigation and effectively prohibit dealing with sensitive programmatic or personnel issues.

Waiver Authority

In response to a request by the NASA Administrator during our March 2003 annual meeting, ASAP began a study of NASA's safety organization and culture. I headed the Safety Organization and Culture Team (SOCT) that was assigned that task. The Team's initial findings and recommendations were presented publicly at Kennedy Space Center last September. The report, which was approved by ASAP as a whole, is appended to this testimony.

Although there were many initial findings, the Team reached one clear initial conclusion: isolate the obligation to meet safety critical requirements from the pressures to meet schedules and budgets. Issued before the Columbia Accident Investigation Board Report, the single initial recommendation was nonetheless strongly in concert. Quoting from the Team report:

> "It is traditional in NASA for project and program managers to have the authority to authorize waivers to safety requirements. Safety critical waiver authority should reside with an independent safety organization using independent technical evaluation. Moving this authority would increase the management oversight of safety-related decisions and would strongly support the creation of a well-respected and highly-skilled safety organization.

Recommendation:

> ASAP recommends that NASA institute a process change that requires that waiver requests to safety critical requirements be submitted by project and program managers to a safety organization independent of the program/project. That organization would have sole authority, excepting appeal outside the program/project potentially moving up to the level of the Administrator."

In the present NASA organization, if safety personnel identify a safety critical problem, they report it to a project manager who has the authority to ignore or waiver the requirement. The safety organization could appeal to the next level of *project or program* management to override the waiver.

ASAP proposes that safety is paramount. Under the proposed recommendation, once a safety critical problem is identified by safety personnel, the project manager would have to apply to the safety organization for a waiver. If it is not granted, he or she would appeal to the next higher level in the *safety* organization.

The project manager's responsibility for setting and enforcing technical requirements would remain unchanged. The authority to issue waivers to safety critical requirements would move to a safety organization. The responsibility to meet safety critical requirements would thereby not be easily weakened in response to cost, schedule, or other influence.

This process is similar to the Technical Warrant process used in the U.S. Navy Sea Systems Command. A technical authority is created who holds final authority for waivers and changes to technical requirements. The technical authority is an expert who is isolated from the project manager's schedule and budget pressures. (I am now part of an Independent Review Team examining the state of this process for the Navy.)

Caveat

Nothing in the suggestions for an oversight board or independent waiver authority should be construed to remove responsibility for safety from project and programs. Oversight boards or independent authorities cannot replace safety functions integral to the engineering, management, and operation of NASA's projects and programs. Accountability for safety must remain with those who have implementing authority.

II. International Space Station: An Accident Waiting to Happen?

Several weeks ago headlines appeared world-wide stating that I, as an ex-NASA advisor, declared that the International Space Station (ISS) was in critical danger. In fact, what I stated, at a public ASAP meeting in September, was that incidents had occurred that might be a trend indicating problems with Space Station safety and operational processes.

The 2002 ASAP Annual Report included this statement, "Several events during the past year triggered the Panel's concern. For example, shortly after the docking of STS–113 with ISS, there was loss of ISS attitude control due to lack of coordination of the system configuration. In another case, lithium thionyl chloride batteries were used on board ISS over the explicit objection of several partners. Although this occurred within appropriate existing agreements and without incident, the precedent is potentially hazardous. The Panel notes that differences exist in the safety philosophies among the partnering agencies. There is the potential for hazardous conditions to develop due to disagreements."

In September a Russian controller sent commands to fire thrusters before American controllers disengaged the Control Moment Gyroscope system. The result was one attitude control system countering the actions of the other. Both attitude control incidents resulted in a relatively short loss of attitude control.

Although ISS was not seriously endangered by any of these incidents individually, the concern of the Panel was that miscommunication or misunderstandings about the system configurations could lead to extremely hazardous conditions. The Panel indicated that it would investigate this trend to understand if it was real and if actions were being taken to improve the situation.

The Russian and American organizations involved in ISS have cultural differences that impact safety. These differences are manifested in several ways. In a briefing by ISS managers, we were told that Russian safety organizations tend to fit hierarchically into their operational organizations. This differs from the American philosophy of parallel safety organizations that offer at least some level of independence. Of greater concern, however, is the sensitive nature of the interface between the American and Russian agencies. Clouded by issues of international protocol, national pride, security, and technology transfer, it was difficult for ASAP to obtain hard information about the Russian side of the command and control incidents.

ISS is a complicated spacecraft. It is a remarkable achievement. As an engineer I appreciate the difficulties that have been overcome in developing interfaces that function well across physical, electronic, and electrical connections. As a manager I am concerned about the highly decentralized management that operates space station.

Had I remained with ASAP I would have argued for a 2003 recommendation to investigate mechanisms to create a centralized international ISS management structure and an independent international safety oversight board. As ISS builds toward "core complete" and beyond, complexities will increase, coordination will become more critical, and the chance for accident will grow exponentially. A stronger management and safety structure is, in my opinion, the only means to salve this concern.

I am pleased to note that in a recent conversation with the Space Station Program Manager, William Gerstenmaier, he indicated that the Columbia tragedy had been a "wake-up call" to both the Russian and American teams. The result was improved communication and better exchange of technical information. Despite my concerns, I am amazed and in awe of how much has been accomplished by Bill, his people, and their Russian counterparts.

III. Other Issues

For the record, in its 2002 Annual Report and during meetings with NASA officials, ASAP expressed concerns and made specific recommendations that impact ISS. The recommendations included:

- Assure adequate funding for the development and maintenance of micrometeoroid/orbital debris (MMOD) software.
- Continue priority efforts to find a solution to the lack of a crew rescue vehicle in the period from 2006 to 2010, between the planned end of Soyuz production and the availability of the Orbital Space Plane.
- Review crew performance in light of apparent crew fatigue during EVA. This recommendation was sparked by a near miss collision between the ISS remote manipulator system and a docked space shuttle.
- Assure that American and Russian segment control computers can each operate safety critical functions in all segments to mitigate hazards caused by computer failure in any segment. (American computers cannot control the propulsion system in the Russian segment, for example.)

The Panel was concerned about the availability of Russian Soyuz spacecraft and Progress supply vehicles. ISS is still a developmental vehicle. As such, the reliability and interoperability of systems and components is being learned. Sufficient "up" and "down" mass capability must be available to support hardware replacement and crew consumable resupply. While a crew can turn off the lights and come home in an emergency, that is not the best answer in terms of protecting the ISS investment nor lives and property on the ground if ISS makes an uncontrolled atmospheric reentry.

IV. Final Comments

The Aerospace Safety Advisory Panel effectively came to an end when all of its members and consultants resigned last month. I am very proud of my short tenure with ASAP. Over its 36 year history, ASAP was populated by individuals outstanding in their fields of expertise and in their commitment to space exploration. As a group they identified significant safety issues that ranged from organizational problems through major technical flaws. If we were really "often not very influential" it was not for lack of technical expertise or tenacity in attempting to get a point across.

We grieved with NASA and the world at the loss of Columbia and her gallant crew. We tried to understand our role with respect to the tragedy. At no time did we attempt to identify individuals who might be responsible. Rather we focused on processes that failed and on organizational structures that were faulty. We are convinced that no one within NASA wants to be unsafe or to unnecessarily endanger people or property. Given the enormity of the disaster it is easy to forget that NASA is fundamentally safe. There are thousands of potentially dangerous processes, such as moving heavy machinery and working with caustic chemicals, accomplished safely every day by NASA personnel and contractors.

Our single-minded purpose as a Panel was to assure the safety of ongoing and future NASA projects. It is up to those who follow to assure that safety remains the number one concern of the NASA family.

APPENDIX

Aerospace Safety Advisory Panel—Safety Organization and Culture Team

INITIAL FINDINGS AND RECOMMENDATIONS

August 20, 2003

This paper documents initial findings of the Safety Organization and Culture Team. This paper also includes an initial recommendation worthy of consideration for immediate action. The Team will continue to develop these findings and issue recommendations through the Panel by benchmarking outside organizations, reviewing documents, interviewing individual NASA personnel, and discussing issues with NASA management and safety organizations.

For purposes of this study, the Team is organizing its investigation and review into three categories: Culture, Formalism of Safety, and Safety Organizations.

Initial Findings

1. Culture: Attitudes, Behavior, and Identity. The NASA "safety culture" includes safety attitudes and behavior evidenced by individuals and organizations. In addition, safety culture includes a sense of community and responsibility for that community among all individuals involved in NASA.

NASA is focused on safety throughout the agency. Notwithstanding the Columbia disaster, NASA personnel deal daily with hazardous materials, processes, and procedures. Accidents are infrequent, and, safety is explicitly prized by the agency as a whole.

However, NASA's "can do" attitude could motivate projects to continue despite resource and schedule constraints. ASAP is concerned that safety is treated as a "consumable" in the same sense as schedule and budget in the push to meet flight commitments and schedules. Work-arounds, "within family" rationale, acceptance of out of specifications conditions, etc., have became standard practice. By contrast, the U.S. Navy submarine force and nuclear reactors programs, as shown in the Navy Benchmark Study, vest safety authority in independent organizations that oversee all programs and projects. There are no waivers to safety-critical requirements in any circumstances short of dire emergency.

The Panel also notes that in its review of the Orbital Space Plane (OSP) program, safety requirements did not appear at the upper levels of program requirements documents. The program made a conscious decision to leave the formulation of those requirements to the contractors. In the absence of high level safety requirements, there is little basis for a safety comparison among proposals. Without recording such requirements, there is risk that schedule and funding pressures may lead to degradation of safety. OSP acceleration could compound this problem.

As indicated in the ASAP 2002 Annual Report, many jobs in safety organizations are not held in high regard. There is a general belief that individuals in those positions are not useful in "getting the job done."

2. Formalism of Safety. Safety formalism at NASA includes documentation of requirements and guidelines, defined processes, training and certification of personnel, and ongoing assessment and evaluation.

NASA has compiled large numbers of safety requirements and guidelines, which are published in a hierarchy of documents. The Panel is concerned that "requirements" and "guidelines" seem to be used interchangeably. While many NASA Standards and Guidelines are useful, they have been weakened over time to accommodate project constraints. Standards and guidelines must be kept vital in both senses of the word. They must be considered a necessary part of all development efforts. They must be kept updated, current, and appropriate to their intent.

Safety engineering at the systems level needs to be improved. System safety can best be achieved by eliminating and controlling hazards through specific design and operating approaches. It is compromised by inadequate systems engineering practices, and is characterized by bottom-up analysis and an over-emphasis on component engineering. While the Panel supports the use of Probabilistic Risk Assessment (PRA), the Panel cautions that the PRA is not a substitute for a rigorous system safety design process.

The NASA process for assuring compliance with safety requirements is weak. This derives from the ability to waive requirements at the program level. It is exacerbated by inadequate safety organization authority. Because safety compliance may degrade over time, strong trend analysis capability is needed. The Panel is concerned that there is insufficient authority, responsibility and accountability vested in safety organizations.

NASA needs to have stronger processes or structures in place to keep technical requirements current and validated. Similarly, the certification of systems against those requirements can diminish over time. In Shuttle, there are examples where components and procedures have changed without requisite recertification against safety and system level requirements.

3. Safety Organizations. The NASA safety organization includes implicit and explicit safety organizations spanning Headquarters, the Centers, and contractors. These organizations interrelate with each other, and with programs, projects, technical, and support organizations through lines of responsibility, authority, and accountability.

Safety organizations and related authority, responsibility, and accountability, vary from Center to Center, project to project, and program to program. The organizational architecture is constructed on an as-needed basis rather than through a defined and approved process. Standards on how to develop and operate safety organizations do not always exist or are not rigorously followed.

There is no single assignment of responsibility for compliance with safety requirements (technical and procedural). In most cases, this lies with the program/project manager. It is not likely that that manager has a strong background in safety analysis, standards, or methods. Because the manager has full authority, recommendations from safety officials can be easily over-ridden. In the Navy, for example, safety issues are under the full authority of the safety organization.

The Panel is concerned that the OSP program shows no clear ownership of system safety requirements. These requirements are caught up in a struggle between safety and systems engineering organizations. OSP safety is weakened by the lack of cooperation and clear authority and responsibility.

In some cases, safety organizations receive base funding independent of projects. In others, safety organizations depend solely on project funds. In all cases examined by the Panel, safety organizations do not have real authority in terms of control of funds spent by the project. At best, their approval is advisory to the project manager. There is, therefore, little independent assessment of safety and minimal impetus to attract top-level, highly-qualified, and well respected system safety engineers.

Initial Recommendation

Comment:

It is traditional in NASA for project and program managers to have the authority to authorize waivers to safety requirements. Safety critical waiver authority should reside with an independent safety organization using independent technical evaluation. Moving this authority would increase the management oversight of safety-related decisions and would strongly support the creation of a well-respected and highly-skilled safety organization.

Recommendation:

ASAP recommends that NASA institute a process change that requires that waiver requests to safety critical requirements be submitted by project and program managers to a safety organization independent of the program/project. That organization would have sole authority, excepting appeal outside the program/project potentially moving up to the level of the Administrator.

Senator BROWNBACK. Thank you.

Let's run the clock at 7 minutes here, and then we can go back and forth in some organized fashion.

Mr. Readdy, thank you for being here. And you've heard comments and criticism. I have two points. One is on the safety factors going to ISS. There were a lot of concerns being addressed early this week. Are you a hundred percent confident of the decision NASA made to launch this scientific crew, up to the space station on the Russian vehicle?

Mr. READDY. Yes, sir.

Senator BROWNBACK. And the critiques within your own organization challenging this decision? I think your comments are that this is the procedure that you want to have, and you think you've addressed the issues.

Mr. READDY. Absolutely. And their issues had to do with a future concern. There was no immediate concern for the astronauts. We put in place mitigation strategies to bring back the samples and interview the crew, make sure the crew was aware.

Senator BROWNBACK. At what point in time did the concerns from your organization come about? You said their issues have to do with a future concern. Do we have any sort of timeline as to when we think that the longer you maintain this system, the possibilities of failure increase?

Mr. READDY. What they were talking about is, without resupply, if these monitoring systems were to malfunction, that you would have to rely on some other backup systems, and, without quantifying it, there would be a slightly increased risk that perhaps at some point you would want to take the crew off. But these are not near-term issues.

Senator BROWNBACK. And what-term are the issues if they're not near-term? Are they six month issues? Are they one year issues?

Mr. READDY. Yes, sir. When we assessed it, we didn't think that it was an issue for the full duration of the six month increment.

Senator BROWNBACK. OK. Past that, does it become a bigger issue?

Mr. READDY. Well, at that point, we have a planned rotation of the crews onboard, and at that point we would also expect to have Progress vehicles, and that was part of our mitigation strategy, was to fly repair parts on the progresses.

If I could wind the clock back a little bit, one of the lessons that we learned during the Shuttle Mir program, from the Russians, was that logistics—just like Antarctica, for example, the scientific endeavors that are conducted in Antarctica—it's driven by logistics. A carrier battle group deployed overseas is driven by logistics. The same thing with the space station. There are no resources *in situ,* really, other than solar energy. So it's all driven by logistics. So with reduced logistics, then you have reduced ability to conduct repairs on orbit.

So we expect to manifest repair parts on a subsequent Progress in order to mitigate that. But, in the meantime, to assure ourselves that the environment onboard is safe, we have the samples to analyze.

Senator BROWNBACK. And since the media reports have come out, the other criticism—I presume there has been a doubling back again within NASA to look through—here was the decision factors for us to go, and has there been any additional thoughts of what else NASA should do?

Here I'm building off the last shuttle disaster, where, you know, somebody saw this chunk hit the wing of the shuttle, and then some people said, "Well, you should have taken a photograph," others, no, and it slid on through the system. You've doubled back, undoubtedly, again, looked again at your decision to launch to this time at the space station. Are there any other mitigating issues or things that you've decided to do since looking again at whether or not this was a safe launch to the ISS?

Mr. READDY. Well, to that end, the night before the launch we conducted an additional stage operational readiness review to make sure that in the interval between the Flight Readiness Review and the launch, that there had been no degradation, no change in status of the station. So we did that.

But I'd have to say that I was very encouraged by the whole conduct of the Flight Readiness Review, because those individuals brought their concern forward. Matter of fact, their management insisted that they bring them forward. They also were present at the Flight Readiness Review, at my request, so that they could comment on their concerns, which had been addressed in the interval between their Level 3 Life Sciences Review and the Level 1 Flight Readiness Review. Their concerns had been addressed by a mitigation plan to get the samples back in order to understand the status of the atmosphere onboard the station right now.

So I felt very comforted by the fact that we had a very open discussion, that the individuals not only came forward with their concerns, that they were satisfied with the proceedings. And we congratulated them not only publicly, but afterwards I went to both individuals and commended them for stepping forward. That's exactly the kind of behavior we want to encourage at NASA, because safety is everybody's responsibility.

Senator BROWNBACK. Mr. Li, I'm going to go into the second area of questioning that I'm curious about, and that is the value of the science that we're getting out of the space station. Dr. Park questions it, others back it. Space station dollar figure I have today, it's cost us about $32 billion to date, give or take a couple of billion, and we're not done with it.

I was given a list of the scientific experiments that have been done on the last ISS expenditure, and, to be honest, I'm quite concerned about the list, whether it's worth the risk and investment. Some of the experiments conducted include an in-flight journals on stress felt by crews on long-duration flights. I can see some of that. Demonstration explaining sound and demonstration explaining how toys function differently in space. That one stretches me to understand the significance of doing that.

And this gets to the core issue that I hear other Members of Congress raise, and that I raise all the time, is—is this cost and risk—and the risk is far more valuable and important to me than the cost; the cost is significant, but the risk of human life, is it worth the scientific knowledge we are gaining out of the space station? Has GAO done a pointed study of the value of the science we're getting out of ISS?

Mr. LI. No, Mr. Chairman, we have not. But to compound the issue that you just presented, and since you did mention the OSB, we're talking about a situation not only about the cost, is it worth the cost of the space station, it's all the support mechanisms and support systems that go along with the station also. So you would have to factor in the extra cost of the OSB and the cost of the shuttle and whatever it would take to make the shuttle safe again. Then you have that investment. You have to compare that with what benefits you would achieve.

Now, the point—the benefits that you just outlined there, to be fair to NASA, are those that have been achieved because a lot of the materials, science materials, and other facilities, are not yet on orbit. It would be more fair to be able to identify and to be able to talk about what the benefits would be once we have that core complete up there. And we have not achieved that yet.

There are many issues associated with when we're going to be getting to core complete, but if you were to take a look at only the benefits that are achieved right now, you're right, it does not look like a promising picture.

Senator BROWNBACK. We'll go 10 minute rounds, if that's all right with you, Bill. I'd like to go on with this a little bit further.

What have we learned, or are we learning or likely to learn, from the space station that will help us significantly in going to Mars if we decide to go to Mars?

Mr. LI. Well, I am not a scientist. I'm a engineer by background. But from what—my understanding is that being able to prove and to be able to investigate long-term presence in space is crucial to ever wanting to go to Mars. And the space station would provide that environment in which we would be able to make those sorts of decisions and to find out what are some of the issues associated with long-term space.

Senator BROWNBACK. Mr. Readdy, that same question?

Mr. READDY. Well, I think Mr. Li spelled it out. It comes down to being able to sustain the human body for a trip of that duration. Radiation, for example. We don't know what kind of mutations might occur. The effects of microgravity on your vestibular system, the effects of microgravity also on your circulation system, where you go from microgravity back into a-third gravity, for example. The long duration effects, quite simply, aren't known, and we need long-duration exposure onboard a research platform, like International Space Station, in order to understand those.

Senator BROWNBACK. Dr. Park, you're well known, and you've stated your position clearly in the past and again today, and I appreciate your doing that. What are we learning on ISS that is built on or that we didn't know or didn't learn from Soviet Mir or Sky Lab on this long-term viability of man in space? Are we learning new information here that's going to allow us to go to Mars?

Dr. PARK. Well, I think that was the concern that was expressed by Dr. Kuznetz in that white paper of his. The concern is that we really don't know how to find the countermeasures, as he calls it in that report. We can take a lot more urine analyses and determine how much calcium people are losing. And we've been doing that for 20 years, more than 20 years. But if we do that for a longer time, that's not going to tell us much more.

What we need are the countermeasures, and there just does not seem to be anything planned for the space station that really gets at developing countermeasures for these problems.

Senator BROWNBACK. Dr. Pawelczyk, what about those countermeasures? That would seem to be in your field of study and thought. Are we developing any of those?

Dr. PAWELCZYK. We certainly are, Senator. And, in fact, the specific example that I cited of a variable gravity research platform is only capable onboard the International Space Station. And let me explain that in a little more detail.

In about five or 6 years—Dr. Readdy can confirm the exact timeframe—we'll have a centrifuge onboard that was built by our friends, the Japanese. It has the ability to place these habitats and rotate them so that the acceleration stress we can make equal to any gravity stress we want. So we've eliminated the effects of Earth gravity, because we're in free fall, and now we can dial in 38 percent of Earth gravity, which corresponds to the gravity of the planet Mars. There's no other place to do this. And now we have the capability to keep that animal there for a long period of time and study. Can we keep a person, an animal, on Mars for 10 days, 30 days, a year and a half? These are absolutely essential pieces of information to understand in order to design that Martian mission.

Senator BROWNBACK. Mr. Nelson?

Senator NELSON. Thank you, Mr. Chairman.

Dr. Pawelczyk, I'm quite intrigued by your statement that we are learning that gravity alters gene expression of cells, which would affect our basic structure and composition. Would you expand on that, please?

Dr. PAWELCZYK. Certainly, Senator. And you've picked one of the most profound findings that we've seen from microgravity research.

Much of this work has been done as part of a cell culture, a series of experiments from Timothy Hammond at Tulane University. And using the ideas of gene expression, in essence as much of the human genome that we can fit on a chip—and we can fit a lot at this point in time—and to see whether or not genes go up or genes go down. This is the step beyond the human genome project.

What we know is that something in excess of 15 percent of the human genome that we've characterized changes a lot in space. Now, that has been tested against rigorous ground controls, and the thing that seems to cause that is the absence of gravity. And what this exactly means, I wish I could tell you. But it is absolutely profound.

We have developed, life has developed, always, in a gravitation environment. And here we see that when we take gravity away, something happens, and that's the next steps that we need. That's why we need this rigorous translational research program to identify what those genes are, what they do, alone and in combination, and how that affects the ultimate organism, in terms of bone, muscle, the cardiovascular system, all of these things that have been mentioned previously.

Senator NELSON. Is this observed scientifically, that, in fact, 15 percent of cells do change when you take away gravity? Or genes, I guess not cells.

Dr. PAWELCZYK. Fifteen—that's right. I believe the exact number is about 17 percent of—in those studies, something on the order of 10,000 genes that were characterized.

Senator NELSON. And this is over a period of how many, approximately, experiments that have been flown?

Dr. PAWELCZYK. I believe three on that. Would that be—I'm looking to Mary Kicza on that. Three different experiments flown in cell culture?

Ms. KICZA. You have an experiment just recently flown.

Senator BROWNBACK. We need to have a person come up and identify yourself so people can get the record on that, please.

Dr. PAWELCZYK. At least three, Senator.

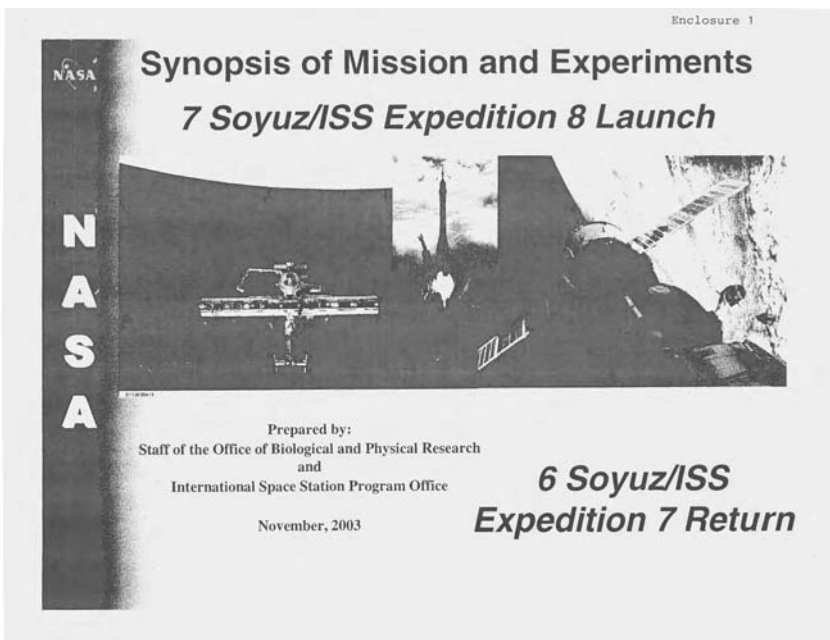
Senator NELSON. The question is—tell me something about the experiments and when did they start. You said there are three that have been done on gravity altering gene expression of cells.

Ms. KICZA. The experiment that I have specific information on is with respect to research that has been done on the International Space Station, and it has revealed that there is a significant difference in gene expression, specifically in the genetic response of human kidney cells, and that is greatly exceeding all predictions that had been made to date. That is the specific example I have. We can get you the additional information on——

Senator NELSON. OK. And what about the percent—15, 17 percent? Can you define that?

Ms. KICZA. I can provide you the information for the record. I do not have that information with me.

[The information requested follows:]



Soyuz/ISS Expedition 7 Launch

Vehicle:	6 Soyuz TMA-2
Launch Date:	April 26, 2003
Docking Date:	April 28, 2003
Purpose:	Crew Exchange & Supplies
Duration :	183 days onboard ISS
Undocking:	October 28, 2003
Landing:	October 28, 2003
Crew Size:	2

Crew Members:

Yuri Malenchenko CDR
Edward Lu, FE & Science Officer

ISS Expedition 7 Mission Objectives

- Maintain health and status of ISS crew and vehicle
- Stow cargo delivered by 6 Soyuz
- Perform U.S. and Russian Segment utilization
- Train and prepare for 11 Progress docking
- Continue on-orbit checkout of Mobile Servicing System (MSS)
- Perform U.S. and Russian development test objectives
- Perform U.S. and Russian system maintenance
- Reboost ISS altitude with Progress vehicle
- Dock 11 Progress
- Stow/transfer cargo delivered by 11 Progress
- Train and prepare for 12 Progress docking
- Load 11 Progress with trash and undock
- Update software load
- Install Russian systems

The Progress vehicle shown below is used to resupply and refuel the ISS, and remove waste/trash.

NASA

SpaceResearch.nasa.gov

OBPR

Office of Biological And Physical Research

SYNOPSES OF CURRENT ISS EXPERIMENTS

Key: Red indicates overarching objective; Blue indicates importance of experiment; Black describes experiment

Assuring the *survival* of humans traveling far from Earth:

PSYCHO-SOCIAL STUDIES: HEALTHY ASTRONAUTS ARE CRITICAL FOR PLANETARY MISSIONS

•Weekly logs that are kept by crew and ground support staff to understand the optimum relationships for long duration space flights.

•In-flight Journals maintained by crew: Studied to gain understanding of factors that may play a role in the stress felt by crews during long duration space flight.

Conclusions will be used for interplanetary mission planning (e.g. Mars Missions) and selection and training of astronaut crews for these missions.

STIDIES OF PHYSIOLOGICAL CHANGES: FUNCTIONAL ASTRONAUTS ARE CRITICAL FOR PLANETARY EXPLORATION

Detrimental physiological changes occur in humans who undergo long duration space flight—these can affect Astronaut ability to perform upon arrival in planetary gravity. Baseline data is needed for testing the effectiveness of countermeasures.

• Study on the change in bone density of astronauts during long duration space flight. Bone loss is a critical problem that must be solved to **minimize fracture risk upon arrival on other planets.**

• Study of Radiation Doses Experienced by Astronauts in Space Walks (EVA): Tracks dosage of radiation astronauts receive while they are outside the ISS during space walks.

• An experiment to look for possible changes of chromosomes in Blood Lymphocytes due to cosmic radiation. The body's ability to heal itself during and after long duration space flight must be known before radiation limits can be determined for space exploration missions.

Radiation doses outside of the protection of Earth's atmosphere can have severe long-term health consequences. Understanding of radiation effects is crucial to developing adequate countermeasures.

• Countermeasure to Mitigate Locomotor Dysfunction After Long-duration Space Flight: Testing of a proposed countermeasure to assist astronauts in their ability to walk and move around after return from a long duration mission.

• Hand Posture Analyzer- Studies the bone and muscle changes in the hand to understand the impact of long duration space flight on the functionality of the hand.

The ability of a crew to function upon landing after long duration flight is critical to planetary exploration.

NASA

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OBPR

Office of Biological And Physical Research

SYNOPSES OF CURRENT ISS EXPERIMENTS

Key: Red indicates organizing goal; Blue indicates importance of experiment; Black describes experiment

Expanding our understanding of the laws of nature and *enriching* lives on Earth

USING A LABORATORY ENVIRONMENT FOUND NOWHERE ELSE: **The US Laboratory provides the only place to study long-term physical effects in the absence of gravity.**

- Study of the fundamental phenomena responsible for the formation of certain classes of **defects in metal castings** by using a transparent, model material. Studies physical principles which control the occurrence of defects in manufacturing here on Earth and result in flaws, defects or wasted material.
- Study of the mixing of fluids when one is not soluble in the other. Addresses a classical problem that has concerned the scientific community for years.
- Study of the fundamental behavior of a magnetic colloidal fluid under the influence of various magnetic fields. These types of materials are used on Earth for vibration dampening that can be turned on or off. This technology has promise to **improve our ability to design structures, such as bridges, buildings to better withstand earthquake damage.**
- Autonomous protein crystal growth experiments to obtain long duration (slow growth) crystals in space. **This experiment has significant Industry interest** (Industry financing is 3 times that of NASA).
- A test to evaluate a new method of mixing fixatives in cell culture experiments on later missions. When cells are "fixed" (chemical activity stopped for later study on the ground by inserting a new chemical) the reactions gives off heat, which must be dissipated by hand on orbit to prevent damage to the cells to be studied. **Important for future studies of basic cell growth mechanisms.**
- Tests to assure that a piece of onboard equipment **critical to future biotechnology studies** is still functioning properly in support of experiments that will be brought to ISS later.

NASA

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SYNOPSES OF CURRENT ISS EXPERIMENTS

Key: Red indicates overarching objective; Blue indicates importance of experiment; Black describes experiment

Creating technology to *enable* the next explorers to go beyond where we have been:

• Test of the IR communications systems that will be used in a later flight to fly small satellites in formation.

We seek to better **know the environment on the space station to enable future research**.

• On-going measurements of the small accelerations (vibrations) on the ISS that result from the operation of hardware and the activities of the crew, as well as dockings and maneuvering of the ISS. Measurements will be used to generalize the types of accelerations felt on the ISS by very sensitive experiments.

• Active Rack Isolation System Testing (ARIS)- Engineering test of hardware used in scientific experiments that require a very stable (non-vibrational) environment.

• External payload to measure the impact of long duration space exposure to the space environment on various materials. DOD sponsored experiment to **understand the durability of various materials when they are exposed to space environment for future spacecraft.**

NASA

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OBPR

Office of Biological And Physical Research

SYNOPSES OF CURRENT ISS EXPERIMENTS

Key: Red indicates overarching objective; Blue indicates importance of experiment; Black describes experiment

Observing the Earth:

- Test of a camera mount at a window that prevents blurring of image due to ISS motion over ground. Allows studies of faint or dark areas such as Aurora and urban areas at night.
- Photography by crew: Provides unique perspective of some phenomena such as volcanic eruptions, hurricane structures, urban crawl based on nighttime light patterns and many more. Also of general interest to a large number of citizens as indicated by about **10-14 million hits per month on the NASA Earth Observation website.**

Educating and inspiring the next generation to take the journey:

- On-going series of educational demonstrations explaining sound, how toys function differently in space and the operation of the on-orbit Glovebox. Videos are provided to teachers around the country along with other educational materials for use in **explaining science and math to students** as well as **inspiring students to become interested in science, technology, engineering or math**. This increment included sound from musical instruments because most school children do not realize that sound will be the same inside ISS as on Earth. It included toys because they function differently in space and display different physical properties in microgravity than they do on Earth. This is a fun way to learn about the laws of nature and physics.
- Earth Knowledge Acquired by Middle School Students (EarthKam)-**Students control earth observation camera** for photographs related to in-school projects they are working on.

Senator BROWNBACK. And would you identify yourself for the record so we have——

Ms. KICZA. My name is Mary Kicza. I'm Associate Administrator for the Office of Biological Research.

Senator BROWNBACK. Thank you.

Senator NELSON. OK. Well, you know, this is rather profound if we've got something going here.

Now, Dr. Pawelczyk, you heard what Dr. Park said, that protein crystal growth, he said, has fizzled. What's your opinion?

Dr. PAWELCZYK. I think the opinion of the scientific community—and this was a area of healthy debate on the ReMAP task force—is mixed at this point. This has been a longstanding part of NASA's biological research program. As part of the ReMAP process, we actually de-prioritized the protein crystallography program, and I believe we put it at priority four, out of four. We didn't completely eliminate it, but we put it at the bottom tier.

Senator NELSON. Well, that would indicate the scientific community and NASA doesn't think that it's shown the promise that it was originally thought.

Dr. PAWELCZYK. There have been dissenting views that have been expressed in regard to that. Protein crystallization is a challenging process. There have been a number of refinements that have emerged over the years. A state-of-the-art facility has been created on the ISS, and it really becomes an issue of saying, well, if we didn't quite do the experiment right in the past, is this facility that does it absolutely correctly so we can know for sure. And I think that's the general trend of those dissenting opinions. Others would say if we've tried for 20 years, that ought to be enough.

Senator NELSON. Well, the promise of microgravity and protein crystal growth was, taking away the influence of gravity, that the crystal ought to grow larger and more pure, to use the vernacular, so that upon examination either by something like an electron microscope or X-ray diffraction, that you'd be able to unlock the secret of the architecture or the molecular structure. Has that not occurred, Dr. Park?

Dr. PARK. No, the problem has been that whatever you can grow, apparently, in microgravity, you can also grow right here on Earth for about 1 percent the cost. So it has brought nothing new.

Senator NELSON.With the same degree of success of determining the molecular structure?

Dr. PARK. Well, it is perfectly clear that you can grow crystals in space that you can determine molecular structure from, but you can grow the same crystals here on Earth.

Senator NELSON. Have we——

Dr. PARK. Really, gravity is just not the limiting factor in——

Senator NELSON. —to your knowledge, have we been able to grow a crystal in space that we were able to get the architecture from that we were not able to grow that crystal on Earth and get the same result?

Dr. PARK. No, that has not happened.

Senator NELSON. You say absolutely that hasn't happened.

Dr. PARK. I have talked recently with many of the crystallographers. They tell me that it just has not happened.

Senator NELSON. Is that why NASA has demoted that experiment to category four, Dr. Pawelczyk?

Dr. PAWELCZYK. We looked at that exact same question on the ReMAP task force, and we did not feel that we could find evidence that, in fact, there was protein crystals that had been produced in space that could not be produced on the ground. So that was part of that demoting process.

Ms. KICZA. May I offer something?

Senator NELSON. Please.

Ms. KICZA. What I'd like to indicate is, it's true, we have had protein crystal growth in our program for quite some time. First, I'd like to highlight some of the specific returns on that, and then talk about what was recommended in ReMAP and how we've responded to that.

Senator NELSON. Pull that mike to you a little closer.

Ms. KICZA. I have a soft voice, so I will try to speak up.

At least 14 patents and the creation of two biotech companies so far have resulted from NASA's investment in the protein crystal growth program. The flight program has produced the most accurate and detailed three-dimensional atomic structures of about 40 proteins, DNAs, and viruses. Of the 17,000 proteins in the Nation's protein data base, only 100 have resolution better than one angstrom. NASA-sponsored research is responsible for four of those one hundred.

The ReMAP committee, in its recommendations regarding protein crystal growth, recommended that NASA follow the instructions that were previously highlighted in an NRC report. The NRC report noted that the pace of technology on the ground was allowing many of these crystals to be grown on the ground; however, there were a limited number of types of proteins that still they were not able to grow on the ground, and they directed NASA—or recommended that NASA focus on those proteins. That's exactly what we've done. We've established an institute to help us identify those proteins, and we have identified a limited window of time for flight opportunity for those specific proteins to fly. And beyond that, we have terminated the funding for that program.

If those results are extremely promising, then obviously we would work with the research community to determine what the future action should be.

Senator NELSON. What say you, Dr. Park, to that?

Dr. PARK. Well, I couldn't hear quite all of it, but, you know, I'm interested in seeing the information. But it's certainly—the view is pretty strong with the scientific community that this has just not been worth it.

Senator NELSON. And how many of those proteins have been identified that do have promise?

Ms. KICZA. As I had said, 40 structures had been determined, and of the four that were greater than—of the 17,000, 100 were greater than one angstrom, the resolution greater than one angstrom, and four of those have been NASA's. We can provide the specifics on those proteins.

Senator NELSON. Yes. Are those the four that you're going to fly additionally?

Ms. KICZA. That's already done.

Senator NELSON. Right.

Ms. KICZA. That's the result.

Senator NELSON. So I'm asking about the ones that you said have promise that you're going to find flight opportunities for.

Ms. KICZA. Those are proteins that, on the ground, researchers are still have a difficult time crystallizing. They tend to be membrane proteins, and it's those specific types of proteins that are being selected. We can get information for the record on those particular proteins.

Senator NELSON. Are we talking about a half a dozen, a dozen?

Ms. KICZA. I don't have the exact numbers, but I would expect that there are a dozen or more.

Senator NELSON. Let's go back to the Chairman's question on justifying the ISS for a Mars mission. You talked about the animal habitat, how you could dial in .38 or whatever it is. Is it 38 percent gravity?

Dr. PAWELCZYK. Correct.

Senator NELSON. What else can we do on the space station that gets us ready to go to Mars?

Dr. PAWELCZYK. If you look at the success or failure of polar expeditions at the turn of the century, many of those were based on issues of compatibility. And although this sounds like the realm of pop psychology, it's really not. This is perhaps one of the most important parts of how humans work together. People have joked and said, "Well, if half our American society is unable to live together in wedlock, how in the world are we going to keep them together in an International Space Station or a Martian planetary spacecraft?" It's not a joking matter. It's a real issue. And some of the things you've seen—for instance, the chronicling or journaling article—in fact, much of what we've learned about expedition is from these early journals from these early explorers. So these are essential items that have the need—we need to learn how to do it, and we can only do that by staying in spaces like this.

In combination with the skeletal problems we see, the skeleton is controlled, and most of its stress actually comes from the muscles that attach to it. And unquestionably, they atrophy to a significant extent in microgravity—in particular, those of the legs and the lower body, the area where we see bone loss, as well.

We need to understand what genes are turned on there and what is it that restores muscle mass, in addition to inhibiting the loss of muscle mass. Muscle is a plastic tissue. It's turning over all the time, as are many tissues that we have. We generate, if you look at just protein turnover, roughly—we turn over our entire heart in about 3 weeks. So as this process occurs, it's very dynamic. The only way to assess that is to take away these loading conditions.

Senator NELSON. Twenty to thirty percent of muscle mass lost over X-number of days in zero gravity, 10 percent of bone mass loss—I don't know what the period of time is; I guess it's a long time. Do you know, Dr. Readdy?

Mr. READDY. Approximately 6 months, sir.

Senator NELSON. OK. And under conventional technology, the fastest that we could get to Mars would be about 6 months, maybe more like ten?

Mr. READDY. Yes, sir.

Senator NELSON. What about Franklin Chang's rocket that would get us there in 39 days?

Mr. READDY. Well, as you know——

Senator NELSON. And it could create gravity at the same time by spinning.

Mr. READDY. Yes, sir. Clearly, the duration of the trip is what impacts exploration beyond low-Earth orbit. The longer it takes, the more supplies you have to have, just like going to the Poles, just like the early explorers.

Dr. PAWELCZYK. The second part of that, Senator, of course, is how long you stay when you get there.

Senator NELSON. Right.

Dr. PAWELCZYK. If we discover, on the International Space Station, that 38 percent is good enough to protect bone, we're in great shape to stay on Mars a long time.

Senator NELSON. Right.

Dr. PAWELCZYK. If it doesn't, that completely changes the design on the planet.

Senator NELSON. Right. I misspoke. I talked about spinning as centrifugal force on some designs. And in Franklin's case, his rocket would accelerate halfway there, decelerate the other halfway, and that's what would give you the effects of gravity.

Mr. READDY. And the research that we're talking about with the centrifuge allows you to dial in that level of acceleration potentially so that you can see what the threshold is. Maybe that's sufficient, maybe it's not. We don't know.

Senator NELSON. How big is that centrifuge, by the way, going to be on the space station?

Mr. READDY. The accommodation facility for it is about the same diameter as all the other modules, so that'll give you, kind of, the shuttle payload bay as a reference. And we have pictures that we could show you.

Ms. KICZA. .8 meters.

Mr. READDY. .8 meters. Is that diameter?

Ms. KICZA. Four meters, excuse me.

Senator NELSON. Four meters. So are you going to put an astronaut in it?

Mr. READDY. No, sir. This is just for biological specimens and——

Senator NELSON. I see.

Senator BROWNBACK. Just a couple of other ones.

Mr. Readdy, when we met last week, you said that you would provide me a list of experiments that are being—a comprehensive list of the scientific experiments NASA is doing or proposing on the space station. I've gotten a partial list of that. I would like to get the complete list of information.

Mr. READDY. Yes, sir. We'll give you a more complete list.

[The information previously referred to is retained in the Committee files.]

Senator BROWNBACK. Also, I'd like to note in the recommendations of the Research Maximization and Prioritization Task Force (ReMAP), stated, in July 2002, that if enhancements to ISS beyond U.S. core complete are not anticipated, NASA should cease to characterize the ISS as a science-driven program. I don't know if you're familiar with that statement or not. Would that still be viewed as the recommendation, in the view of ISS?

Mr. READDY. ISS has to be viewed not only as a scientific research platform, but also the gateway to doing anything else in order to understand what goes on with the human body, in order to deal with the kind of autonomy that it'll take to go someplace else.

Robert Heinlein said that low-Earth orbit is halfway to anywhere in this solar system. And clearly we can learn it much closer to home, rather than embark immediately. And I don't think we would have the means to go to Mars right this minute anyhow. We have ten red risks that have to do with supporting the humans, much less the reliability of the spacecraft that they would inhabit for that long period of time. So there's clearly an awful lot that we have to do.

Dr. Pawelczyk talked about compatibility. That's one science that we have to look at. Sustaining the human body is certainly another. But the list goes on and on and on.

Senator BROWNBACK. What are some of the others?

Mr. READDY. I think Mary Kicza would probably be able to fill in——

Senator BROWNBACK. Well, why don't you submit that, then, for the record. I thought maybe you had them on the top of your mind that we could go off of that.

[The information referred to follows:]

Examples of Benefits of Recent ISS Research

Osteoporosis & Kidney Stones—Biomedical research on the ISS. Although biomedical experiments in space are goal-directed, they allow investigators to study biomedical problems that plague people on Earth, but most typically as part of a systemic disease (*e.g.,* osteoporosis, balance disorders, sensori motor disturbances, etc.). Adaptation to space results in these normally pathological conditions in healthy and fit adults, offering a window into disease mechanisms without the confounding factors of systemic decline seen in patients. In the first 7 ISS increments, significant additions have been made to our understanding of bone loss (Lang), data have been added to the kidney stone experiment (Whitson), experiments on sensorimotor readaptation have been begun (Paloski & Bloomberg), further data have been collected on crew psychosocial interaction issues (Kanas, Stuster), radiation dosimetry experiments were conducted to characterize the ISS environment, and the list goes on.

Cleaner Air—Plant research done on the ISS. A device built to clean the air in the plant chamber used on the ISS is now being used in florists and supermarkets to keep products fresh. It converts the ethylene produced by the plants into CO_2 and water. This same device has also been modified and spun off into a commercial device that kills anthrax and other pathogens. This is used now in some operating rooms in the United States.

Early Detection of Cataracts—Colloids Research on the ISS. Colloids are very small particles suspended in a liquid or gas. Over time, the particles self-assemble into a variety of structures. These structures have potential applications to next generation computer and communications systems, pharmaceuticals and a host of other industrial processes. The principal investigator for this research, Dr. David Weitz of Harvard University, recently published his results in Science, a leading scientific journal.

One of the instruments developed in support Dr. Weitz's on-orbit research is now being studied by the National Eye Institute for broad application, to detect the formation of proteins in the eye which appear to be precursors to cataract formation. This same technique is being studied for possible application in a range of noninvasive medical diagnostics, including as a means for measuring blood glucose levels in diabetics.

Precise Laser Surgery—Ground-based research in support of future experiments to be flown on the ISS: The October 27, 2003 edition of *Business Week,* page 82, highlights a new kind of glass that boosts a laser's efficiency by 20 percent at a fraction of the cost. This research, developed by Dr. Dick Weber, Containerless Research Inc., has applications that include power lasers for cutting metal, and precision medical lasers for surgery.

Cancer Research—Shuttle-based flight research that will transition to the ISS. NASA's Bioreactor—a tool developed and used by NASA to develop 3 dimensional cell and tissue cultures—has yielded 25 patents and more than 20 licenses. Over 6,000 units are now in universities, medical centers and the National Institutes of Health. Just a month ago *Nature,* a leading scientific journal, noted that the age old "Petri dish" may be rendered obsolete because we can now grow things in 3 dimensions. This was what NASA's bioreactor technology pioneered. The bioreactor most recently flew on STS–107, supporting an investigation involving prostate cancer. The investigator for the 107 research was Dr. Leland Chung from Emory University.

Senator BROWNBACK. I hope we can get the clear list and the ideas of the top priorities of what ISS is. Do we know, or are we anticipating that we're going to get the add-ons to ISS by other countries? Is this something that's likely not to take place?

Mr. READDY. Well, weeks ago, we were in Bremen, and we saw the Columbus Laboratory. We've also seen the autonomous transfer vehicle. We've seen these facilities being built. Been over to Japan while they were assembling the GEM. It's now arrived at the Kennedy Space Center. It was already integrated and checked out, in fact, during the months of August and September. So we have clear evidence that the partners are producing their hardware. Our hardware, up through U.S. core complete, is really to go at the Kennedy Space Center.

Senator BROWNBACK. So you believe we will be able to have the full complement of ISS?

Mr. READDY. Eventually. There was IMCE, International Space Station Management and Cost Evaluation, that was chartered by the Office of Management and Budget. It was headed by Tom Young, the results of which were given to the NASA, and we have gone off and implemented those. Those were a precondition to proceeding beyond U.S. core complete. We think we have answered those concerns. But clearly in the aftermath of *Columbia,* there will be impacts to the shuttle fleets being grounded.

Senator BROWNBACK. Well, there are obvious impacts on that. Now, do you have any ideas about when these extra components from other nations will be ready to put up and likely that we could put them up if you have an operational space shuttle?

Mr. READDY. Yes, sir. And we'll provide that for you. We have detailed manifests that we have built.

Senator BROWNBACK. OK.

Mr. READDY. Yes, sir.

Senator BROWNBACK. All right. Gentlemen, thank you very much.

Senator Nelson, one more question.

Senator NELSON. Mr. Readdy, I'd like a commitment from this Administration that you all will keep transparent the budget for the ISS, as separate from the budget for the space shuttle, so that we can see where the dollars are going and it is not all lumped together like it was over the past decade.

Mr. READDY. Yes, sir.

Senator NELSON. OK. Now, is that something that we need to get that commitment from the Administrator?

Mr. READDY. No, sir. You have that commitment from me. We, as a result of the IMCE, implemented a system called the CARD. We have integrated financial management. We can dive down into whatever level of detail you'd care for, sir, and we'll be happy to brief you.

Senator NELSON. When you present your budget, does it have that classification of human spaceflight and everything is lumped there together, or is it broken out on space station and space shuttle?

Mr. READDY. It is a human spaceflight account, sir.

Senator NELSON. OK. That's where it's difficult for the average American to understand the difference between the two. And what I'd like—and this being the authorizing committee, since we've got the oversight function and the authorization function—is to make that simple. I say this for the obvious reason, that what happened was that money got pulled out of the space shuttle and the safety upgrades in the past, over a period of 12 years, going back to the early 1990s, to cover the losses, the overruns in the space station. That's part of what Admiral Gehman had indicated in his report. So as you all implement that report, it is my request and I would hope that I can speak for the Chairman and the big Chairman of the Full Committee, to make it simple, that we have these accounts broken out.

Mr. READDY. Yes, sir.

Senator BROWNBACK. Good. Senator Nelson, thank you very much for joining us. Appreciate very much your discussion and clarity on this issue.

The hearing is adjourned.

[Whereupon, at 3:25 p.m., the hearing was adjourned.]

APPENDIX

Canoga Park, CA, March 2003

To Whom It May Concern
From: Mr. Masse Bloomfield

This letter concerns my ideas for NASA reusable launch vehicles (RLV) as well as what I think the objectives of our space effort should be. With the Columbia disaster, I think NASA should rethink its programs to develop an RLV. Also you might want to review the NASA budget in terms of getting a colony of men to the stars. I am going to suggest what I think the United States space program should be. I have not been satisfied with our space program as it has been directed for the last thirty years. The vision NASA has had and executed by NASA employees has been extremely short sighted and I feel much of the last thirty years has been wasted effort. With the enormous effort and billions of dollars expended by NASA in the last twenty-five years, we are no closer to returning men to the moon than we were in 1975. A dismal report at best.

The future goal I have for man is to colonize the stars. To do that, we have to colonize the planets before we go to the stars. To do that, we have to colonize the moon before we colonize the planets. To colonize the moon, we need a space tug to go from the International Space Station (ISS) to the moon. We also need a vehicle to take men and materiel to the ISS at a cost fur less that what we spend on the Space Shuttle. The Space Shuttle first flew in 1981, I believe. The development of the Shuttle began in the early 1970s. Where is the Shuttle's replacement? The Lockheed X–33, the Shuttle's replacement, has been cancelled. And as far as I know Kelly Space and Technology Company has not been funded for their idea of towing a rocket behind a 747 and launching that rocket at seven miles at around 500 miles an hours. This is about the same idea I have of using a C5A to carry a rocket to seven miles and launching it there. Also Kistler has a model of jet engines assisting a rocket for use as a launcher. What has NASA been doing for the last twenty years in getting low cost earth to low orbit launchers? I think that NASA is back to square zero on low cost launchers. It is my opinion that the first priority of NASA should be to design, develop and build a low cost earth to low orbit launcher. Before any other funds are allocated; the low cost launchershould come first.

The ISS should have two primary missions:

1. People on the ISS should have the tools to watch for asteroids that might have earth striking orbits; and
2. Be the base for moon colonization.

After these two missions have been accomplished, then go on to do the science stuff.

I am not sure what the ISS is doing now except eating up money. I doubt if it has the capability of doing either of the missions I mention above. Perhaps you might ask people at NASA why the Hubble Space Telescope is not hooked up to the ISS or planned to be hooked up to the ISS. As far as I know the ISS does not have sensors for radar, infrared or telescopes for the visual range to watch for asteroids.

We had a space station in the early 1970s called Skylab. We could have built several of them, tied them together and had the equivalent of the ISS, A bunch of Skylabs could have been constructed in a ring to provide artificial gravity. I find it difficult to understand how our current ISS can ever be spun so that we get artificial gravity, one of my major considerations for a space station.

Then there is an essential part of the colonization of the moon. We need a space tug to go from the ISS to the moon. The space tug could also be used for resupply, repair or removal of low orbit vehicles and twenty-four hour orbit vehicles. The space tug could take new satellites from low orbit to the twenty-four hour orbit. The space tug is not even on the drawing board.

I am a fan of Gerry O'Neill who wrote the book *The High Frontier* in 1977. That book outlines what the space program should be. NASA has done its best not to follow anything that O'Neill recommended. After you have read O'Neill's book, ask the staff at NASA what O'Neill recommended was wrong.

I am not a fan of robotic planetary exploration. I see it as a way to eat up money and resources and provide almost nothing to the goal of getting a man to the nearest star. We needed to explore the moon before we sent men there. Before we sent a man to the moon. we had the Surveyor vehicles that determined what the surface of the moon would be like. Since we are not considering sending men even to the moon. in my mind planetary exploration is just a boondoggle for scientists. When we are ready to send men on to Mars, we need a program to make sure what Mars is like.

The first step on the journey to the stars is a low cost reliable RLV. I believe every other program at NASA should go bare bones or be eliminated so that NASA can focus on a Shuttle replacement. The $4.8 billion in the Space Launch Initiative should not be devoted to research, but should generate hardware capable of getting to low earth orbit reliably and at a low cost. The SLI program should be developing vehicles that can be tested quickly.

I think the priorities for NASA should be:

First: Get a low-cost launch vehicle in operation as soon as possible. The Kelly towed glider rocket looks like an approach.

Second: Redo the ISS so it can be the way station between the earth andthe moon as well as a platform to watch for dangerous asteroids.

Third: Design and build a space tug the way O'Neill proposed. It shouldbe used as for repair work, resupply, removal and transporter for bothlow and twenty-four hour satellites and hopefully to take stuff to themoon.

Fourth: Target the NASA budget to these three items and scrap the rest or if not scrappable put on as low a level of effort as possible.

Fifth: On a very low priority, NASA should be working on space satellitepower stations. There should be a low-powered experimental spacesatellite power prototype on line within five to seven years. It could bethe precursor of generating electrical power from space.

To get some idea about what to do about a new RLV, you should talk to President Michael J. Gallo at Kelly Space and Technology, San Bernardino, CA 92408, the Lockheed people about reviving the X-33, the people at Kistler Aerospace in Seattle and the people who built the Roton spacecraft as well as others knowledgeable of the RLV industry about what to do about RLVs. I like the Kelly approach but other vehicles may even be better. In addition to Kelly, there is the White Knight-SpaceShipOne combination that Scaled Composites is testing now as well as the Pegasus air launched rocket to low earth orbit.

There is plenty of inertia in the system which comes from NASA itself plus the President and the President's staff. Overcoming that inertia is not going to be easy. The inertia in the system can block all kinds of innovative approaches to space activities.

It has been discouraging that even with the launch of the Space Shuttle and ISS, to see how little we have to show for the last twenty years. Perhaps you can get the X-33 restarted and perhaps see that the Kelly Astroliner has a test flight in the next three years. Perhaps funding the White Knight-SpaceShipOne and Pegasus to see if these vehicles could provide low cost pay loads to low earth orbit.

I have hopes that the United States will have the first colony on the moon and the first to have a colony on Mars. Perhaps you can use your influence to speed those colonies along. No matter what happens, be assured that men will travel to the stars. It is my hope that those men will be Americans. If we don't do things right, those men could be Chinese, Japanese or European. But in my view, men will be going to the stars.

ATTACHMENT

ISS Research Summary from Expeditions 1 - 8

Prepared by:
Office of the
International Space Station Program Scientist

March, 2004

1

ISS OVERVIEW (EXPEDITIONS 1-8)

- Expedition 1 launched on 10/31/2000 on 2R-Soyuz
- Number of Flights:
  - U.S.: 16 Space Shuttle Flights
  - Russian: 2 Proton Flights
    - 7 Soyuz Crew Flights
    - 1 Soyuz Assembly Flight
    - 13 Progress Resupply Flights
- Number of ISS Crew: 22
- Total Time on ISS: >1187 Days
- Science Operation Hours: >1600
- Number of Investigations: 82

2

ISS OBJECTIVES (EXPEDITIONS 1-8)

Science-related objectives in BLUE

- Deliver crews and establish permanent residency on ISS.
- Provide Russian assured crew return capability without the space shuttle present.
- Initiate science capability in the U.S. Laboratory.
- Support assembly operations on ISS with materials delivered on supporting flights.
- Maintain health and status of ISS crew and vehicle.
- Perform U.S., Russian and ISS partner science.
- Deliver experiment racks and stowage racks for the U.S. Laboratory using the Multi-Purpose Logistics Module.

3

SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym*; Black: Description**

ASSURING THE SURVIVAL OF HUMANS TRAVELING FAR FROM EARTH: Healthy astronauts are critical for planetary missions.

Radiation Studies: Astronauts experience increased radiation exposure in spaceflight that can cause both short-term and long-term health problems.

- **BBND**

  Neutron radiation can deeply penetrate the body and damage blood forming organs. Neutron radiation is estimated to be 20 percent of the total radiation on ISS. This study characterized the neutron radiation environment to develop safety measures to protect future ISS crews.

- **Chromosome**

  Chromosomal aberrations (changes in chromosomes) lead to increased cancer risk. To assess the genetic changes caused by radiation exposure, blood is drawn before and after long duration missions. The samples are scored for chromosomal aberrations. The results from this experiment will benefit future efforts that aim to mitigate the biological effects of radiation on astronauts involved in long duration missions. The experiment will also aid in the development of advanced materials for improved radiation shielding for future exploration missions to the Moon and Mars.

- **DOSMAP**

  Radiation levels were mapped throughout the internal environment of ISS and in the immediate vicinity of each crew member. The resulting data helped determine the best radiation shielding locations on board ISS; hence providing the crew with the best possible protection during unusually high levels of radiation due to solar flares and other cosmic phenomena.

*See pages 20-28 for list of acronyms.

4

SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

ASSURING THE SURVIVAL OF HUMANS TRAVELING FAR FROM EARTH: Healthy astronauts are critical for planetary missions.

Radiation Studies (continued):

- **EVARM**
  Characterized the radiation doses experienced by astronauts during extravehicular (spacewalk) activities. The data determined which parts of the human body are exposed to the highest radiation levels, so that routine dosage monitoring in future missions can be done on the appropriate parts of the human body.

- **Phantom TORSO**
  Provided the necessary internal measurements of radiation on simulated internal organs using a fully instrumented human anatomical male model (head and torso only) within the space station. Recordings of the internal radiation levels were taken at different altitudes, orientations, and locations. The results from this experiment provided organ absorbed dose radiation to update current analytical models and develop new models. The flight career of crewmembers may be less limited by measurements of accrued skin dose if the models can be refined estimating the radiation dose received by the internal organs.

5

SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1-8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

ASSURING THE SURVIVAL OF HUMANS TRAVELING FAR FROM EARTH: Healthy astronauts are critical for planetary missions.

Physiological Studies—bone & muscle: Weakening of bones and muscle strength is a serious side effect of extended space flight. Studies of cosmonauts and astronauts who spent many months on space station Mir revealed that space travelers can lose 1 to 2 percent of bone mass each month. The problem of bone and muscle strength loss must be overcome before astronauts are asked to perform physically challenging tasks after a long space voyage on planetary missions.

- **Biopsy**
  One of the human systems most affected by extended stays in space is the neuromuscular system. Past space missions have shown weightlessness can cause deterioration of muscle fiber, nerves and physical strength. Calf muscle biopsies are taken from the ISS crew before and after their stay on ISS. This study will allow scientists to develop a countermeasure exercise program aimed at keeping muscles at their peak performance during long duration missions.

- **FOOT**
  Mechanical loads in the joints of the lower extremities are compared during periods of typical daily activity on Earth and ISS. The loss of bone mineral in the lower extremities is widely viewed as a factor that may limit long term human habitation of space or planetary missions.

- **HPA**
  Examine the way hand and arm muscles are used differently during grasping and reaching tasks in weightlessness and look for changes that might occur during long duration space flight. Measurements will be compared to those taken before and after flight. This will lead to a better understanding of the effects of long duration space flight on muscle fatigue.

6

SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

ASSURING THE SURVIVAL OF HUMANS TRAVELING FAR FROM EARTH: Healthy astronauts are critical for planetary missions.

Physiological Studies—bone & muscle (continued):

- **H-Reflex**
  Prolonged weightlessness results in a loss of muscle strength, volume and decreased bone density, particularly in the legs. This can cause reduced spinal cord excitability, which can lead to loss of locomotor function in the legs. Spinal cord excitability was isolated and measured to study possible ways to reverse the process while still in flight. Reversal of this process will result in a healthier crew following long duration space flight.
- **Mobility**
  The treadmill is used to determine whether a specific training regimen can help astronauts recover from the effects of long duration space flight more quickly when they return to Earth. How quickly an astronaut's body readjusts to gravity after a long duration space flight is very important for any future long duration missions within our solar system.
- **Subregional Bone**
  Images of subjects are taken preflight, immediately post flight and one-year post flight to understand the effects of microgravity on bone loss due to long duration space flight. This is a long term study to understand the distribution of bone loss, the recovery of bone mass post flight, and the extent to which these changes compare to the spread of bone mineral density measures in healthy men and women enduring long duration space flight.

7

SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

ASSURING THE SURVIVAL OF HUMANS TRAVELING FAR FROM EARTH: Healthy astronauts are critical for planetary missions.

Physiological Studies—other effects of spaceflight:

- **Advanced Ultrasound**
  Ultrasound sessions on ISS are demonstrating the utility of ultrasound for telemedicine proctoring (doctors on the ground can see the ultrasound images and guide astronauts to examine each other). This technique is also identifying potential microgravity-associated organ position/size changes to guide optimal ultrasound diagnostic strategies. Results of this study will have application in future diagnosis of illness on orbit and in remote locations on Earth.
- **Epstein Barr**
  Decreased immune system response has been observed in spaceflight. This experiment determines how space flight reactivates Epstein-Barr (virus that causes Mononucleosis) from latency, which resulted in increased viral replication. This provided insight into the magnitude of human immunosuppression as a result of space flight. The effects of stress and other acute or chronic events on Epstein-Barr viral replication is evaluated.
- **PuFF**
  Pulmonary function was examined to determine the effects of long term exposure to microgravity and extravehicular (spacewalk) activity. Several ISS crews were studied measuring aspects of pulmonary function that also may be affected by long term exposure to gases or particulate matter present in the atmosphere of ISS. The study evaluated the effects of extravehicular activity, which poses a significant risk of decompression sickness and the ability of the crew to function properly following extravehicular activity.

8

SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

ASSURING THE SURVIVAL OF HUMANS TRAVELING FAR FROM EARTH: Healthy astronauts are critical for planetary missions.

Physiological Studies—other effects of spaceflight (continued):

- **Renal Stone**
  Kidney stone formation is a significant risk during long duration space flight that could impair astronaut functionality. The development of a renal (kidney) stone in an astronaut can have serious consequences since it cannot be treated as it would on Earth. Quantification of the renal stone forming potential that exists during long duration space flight and the recovery after space flight is necessary to reduce the risk of renal stone formation. This is a long term study to test the efficacy of potassium citrate as a countermeasure to renal stone formation.
- **Midodrine**
  Many astronauts experience orthostatic hypotension (dizziness caused by a decrease in blood pressure) upon return to the Earth's gravity. This can be a problem for landing on other planets as well. This experiment measured the ability of the drug midodrine, as a countermeasure, to reduce the incidence and/or severity orthostatic hypotension.
- **Xenon-1**
  After space flight, orthostatic intolerance (the inability to regulate blood pressure while upright) can occur, which can severely inhibit the functional cerebral capacity of crew members during reentry and landing. This study investigated the mechanism of this syndrome and will lay an important foundation for the development of treatments for orthostatic intolerance following space flight.

9

SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

ASSURING THE SURVIVAL OF HUMANS TRAVELING FAR FROM EARTH: Healthy astronauts are critical for planetary missions.

Psycho-Social Studies:

- **Interactions**
  Weekly questionnaires completed to identify and define important interpersonal factors that may impact the performance of the crew and ground support personnel during ISS missions. Results are used to improve the ability of future crew members to interact safely and effectively with each other and ground support personnel. The data may also be used to select and train crews for interplanetary missions.
- **Journals**
  In-flight journals maintained by crew members are studied to gain understanding of factors that may play a role in the stress felt by crews during long duration space flight. Conclusions will be used for interplanetary mission planning (e.g. Mars Missions) and selection and training of astronaut crews for these missions.

10

SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

EXPANDING OUR UNDERSTANDING OF THE LAWS OF NATURE AND ENRICHING LIVES ON EARTH: Using a laboratory environment found nowhere else, the U.S. Laboratory on the ISS provides the only place to study long term physical effects in the absence of gravity.

Protein Crystal Growth: In the microgravity environment on ISS we can grow protein crystals of high quality. When we return these to the Earth, we then study the crystals with X-ray crystallography to map the protein, and learn more about its structure. Understanding the structure of proteins in the human body, scientists can learn how these proteins fit into the overall biology of humans, and how the proteins work in the body.

- **APCF, DCPCG, PCG-EGN, PCG-STES, and CPCG-H**
  A detailed knowledge of the atomic, three-dimensional structure of protein molecules is key to a fundamental understanding of biochemistry, and has an important application in structure based drug design. Tested proteins and protein solutions that could tolerate the freeze-thaw mechanism used to initiate protein crystal experiments. Grew protein crystals under several conditions that enabled undisturbed nucleation and growth. Protein crystal growth experiments aid the generation of computer models of carbohydrates, nucleic acids and proteins, and further advance the progress of biotechnology. Understanding these results will lead to advances in manufacturing and biological processes, both in medicine and agriculture.

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SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

EXPANDING OUR UNDERSTANDING OF THE LAWS OF NATURE AND ENRICHING LIVES ON EARTH: Using a laboratory environment found nowhere else, the U.S. Laboratory on the ISS provides the only place to study long term physical effects in the absence of gravity.

- **MFMG**
  Study how miscible fluids (fluids that completely dissolve) interact in microgravity. This study will provide new knowledge that may improve the evaluation of the roles that concentration gradients and temperature gradients play in industrial processing of polymers.

- **SUBSA**
  Experimental methods of crystallizing melts in microgravity are expected to result in reduced fluid motion in the melt, leading to better distribution of subcomponents and the potential for improved technology used in producing semiconductor crystals.

- **MEPS**
  Enclosing a drug in a tiny liquid filled micro-balloon in microgravity, a process called microgravity micro-encapsulation, has been shown to provide better drug delivery and new medical treatments for solid tumors and resistant infections.

- **ZCG**
  This study examined how microgravity affects nucleation and growth of zeolite crystals while growing larger crystals for study on Earth. The three-dimensional structure of a zeolite crystal allows it to act as a sieve to selectively filter certain chemicals in applications such as petroleum processing. Larger crystals allow researchers to better define the structure and understand how it works, with a goal of producing improved crystals on Earth. Improved zeolites may have applications in storing hydrogen fuel, reduction of hazardous by-products from chemical processing, and more efficient techniques for petroleum processing.

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SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

EXPANDING OUR UNDERSTANDING OF THE LAWS OF NATURE AND ENRICHING LIVES ON EARTH: Using a laboratory environment found nowhere else, the U.S. Laboratory on the ISS provides the only place to study long term physical effects in the absence of gravity.

- **PFMI**
  Using a transparent model material, this experiment studied the fundamental phenomena responsible for the formation of certain classes of defects in metal castings. Examined the physical principles which controlled the occurrence of defects in manufacturing on Earth, in order develop methods to reduce flaws, defects or wasted material.
- **CSLM-II**
  Investigated the kinetics of competitive particle growth within a liquid matrix. During this process small particles shrunk by losing atoms to larger particles, causing the larger particles to grow (coarsen) within a liquid lead/tin matrix. This study defined the mechanisms and rates of coarsening that govern turbine blades, dental amalgam fillings, iron copper etc.
- **EXPPCS**
  Studied the kinetics of colloidal (fine particles suspended in a fluid) crystal formation and growth. These experiments may provide the critical information necessary to use colloidal precursors to fabricate novel materials in the new field of colloidal engineering. Industries using semiconductors, electro-optics, ceramics and composites may benefit.
- **InSPACE**
  Study the fundamental behavior of a magnetic colloidal fluid under the influence of various magnetic fields. These materials are used on Earth for vibration dampening systems that can be turned on or off. This technology has promise to improve the development of new brake systems, robotics, airplane landing gears and bridge suspension systems.

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SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Black: Description; Green: Abbreviation/Acronym**

EXPANDING OUR UNDERSTANDING OF THE LAWS OF NATURE AND ENRICHING LIVES ON EARTH: Using a laboratory environment found nowhere else, the U.S. Laboratory on the ISS provides the only place to study long term physical effects in the absence of gravity.

- **CBOSS**
  Cells grown in microgravity grow and replicate into complex structures, unlike cells grown on Earth. To better understand the mechanisms that cause the differentiation of cells in microgravity seven cell lines of common human illnesses were grown on ISS. The cells were returned to Earth and were used in the studies of several human diseases. This study is important for understanding the mechanisms needed to fight common human diseases and future studies of basic cell growth.
- **CBOSS-FDI**
  Bubble formation in cellular cultures grown in microgravity is a serious problem. This investigation involves a series of experiments to optimize techniques used when mixing cell cultures in microgravity. Pictures are taken after each mixing activity and downlinked to the investigator for analysis. Elimination of bubbles in cell cultures is essential for continuing cellular research in microgravity.
- **CGBA**
  Commercial scientific hardware that can support many biological laboratory investigations adapted to operate in space and which require temperature controls from 4°C to +37°C. Experiments supported by this hardware will further the understanding of how gravity influences various biophysical and biochemical processes.

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SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description;**

EXPANDING OUR UNDERSTANDING OF THE LAWS OF NATURE AND ENRICHING LIVES ON EARTH: Using a laboratory environment found nowhere else, the U.S. Laboratory on the ISS provides the only place to study long term physical effects in the absence of gravity.

- **StelSYS**
  Tested human liver cell functionality in microgravity, then compared the results to the typical function of duplicate cells on Earth. The findings of this experiment provided unprecedented information about the effects of microgravity on the proper function of human liver cells, offering new insight into maintaining the health of humans living and working in space. Research in this area could lead to earlier and more reliable drug candidate screening for patients in need of liver transplants.
- **Yeast-Gap**
  Study the effects of genetic changes of yeast cells exposed to the space environment. Results will help scientists to understand how cells respond to radiation and microgravity, impact the determination of health remedies and increase the basic understanding of cell biology.
- **ADF**
  The avian (bird) experimental model offered opportunities to observe the changes in the cardiovascular, musculoskeletal, immunological and neurological development in microgravity. Avian eggs were incubated and preserved on orbit then returned to Earth for analysis. This study is important for understanding the role of gravity in living systems.

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SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

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

- **CBTM**
  Provided the capability to use the microgravity environment for evaluation of new pharmaceutical candidates in small mammals. May expedite the review of new pharmaceuticals for allowing immediate access to new disease treatments.
- **BPS/PESTO**
  Studied the photosynthetic response of plant tissues grown in microgravity. Results can lead to the development of regenerative life support systems on future missions to the moon or Mars.
- **ADVASC**
  Understanding the effects of gravity on plant life is essential in preparation for interplanetary exploration. Being able to produce high energy, low mass food sources during space flight will enable maintenance of crew health during long duration missions, while having a reduced impact on resources necessary for long distance travel. Applications of a plant growth chamber include using plants as components of regenerative life support systems for travel to the moon or Mars.
- **PGBA**
  Monitored and maintained light, temperature, humidity and oxygen levels to study lignin production changes in *Arabidopsis thaliana* (a fast growing plant) grown in microgravity. Results of this study revealed changes on a genetic level that will benefit the medical and commercial communities.

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SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

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

- **ARIS**
  Constant microgravity conditions are essential for many ISS experiments. Very small changes in acceleration (e.g., normal crew activity) can cause subtle vibrations to echo through the ISS. ARIS has protected these delicate experiments by absorbing the shock of motion before it can affect an experiment. This enables accommodation of future research that is very sensitive to vibration disturbances.
- **ISSI**
  Investigate solder flows and the quality and strength of solder connections formed in the absence of convection. This will lead to a better understanding of fabrication and repair methods for use in space.
- **MACE-II**
  Tested self-reliant, adaptive technologies that can detect problems with ISS hardware and correct those problems as needed. Decreased the effects of vibration in ISS; allowing engineers to design future spacecraft and facilities with lightweight, inexpensive materials without sacrificing the stability demanded by sensitive payloads.
- **MAMS and SAMS-II**
  An ongoing study of the small forces (vibrations and accelerations) on the ISS that result from the operation of hardware, crew activities, as well as dockings and maneuvering. It will be used to generalize the types of vibrations affecting vibration-sensitive experiments. We seek to better understand the vibration environment on the space station to enable future research.

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SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

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

- **MISSE**
  A test bed for materials and coatings attached to the outside of the ISS is being evaluated for the effects of atomic oxygen, direct sunlight, and extremes of heat and cold. This experiment allows the development and testing of new materials to better withstand the rigors of space environments. Results will provide a better understanding of the durability of various materials when they are exposed to the space environment. Many of the materials may have applications in the design of future spacecraft.
- **SPHERES**
  Revolutionary test bed for the development of formation flying control algorithms. Aids in the design of rendezvous and docking maneuvers for constellation and array spacecraft configurations.

OBSERVING THE EARTH:

- **CEO**
  Photography by crew: Provides a unique perspective of some phenomena such as volcanic eruptions, hurricane structures, urban crawl (based on nighttime light patterns) and many more. Also of general interest to a large number of citizens as indicated by the **20 million hits per month** on the NASA Earth Observation website. The database housing the photographs has a 40+ year history of Earth images. Long and short term dynamic Earth events can be studied through these sources.
- **ESTER**
  Test of a camera mount at a window that prevents blurring of images due to ISS motion over ground. Allows studies of faint or dark areas such as Auroras and urban areas at night.

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SYNOPSES OF ISS EXPERIMENTS (EXPEDITIONS 1- 8)

Key: Red: Objective; **Blue: Importance; Green: Abbreviation/Acronym; Black: Description**

EDUCATING AND INSPIRING THE NEXT GENERATION TO TAKE THE JOURNEY:

- **EarthKAM**
  Students remotely control a camera, mounted in the International Space Station, to photograph sites of interest on Earth. Enables the world wide educational community to learn about Earth from the unique perspective of space. The image collection is an extraordinary resource to support classes in multiple disciplines.
- **Education-Seeds**
  On-orbit videotape and photography of plant germination and early growth. Imagery was converted to educational videos used for the purpose of exciting and engaging students in science and technology. It was also used in motivating and providing professional development for teachers.
- **EPO**
  Crew demonstrations on the effects of microgravity on topics of interest to students. Topics such as how music sounds in space, how the laws of physics apply in space, and many others are answered and demonstrated by the crew.
- **Dreamtime**
  Supplied high definition television video cameras and obtained high quality video footage of activities on ISS for commercial, historical, training, educational, and public-interest use.

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ISS PRINCIPAL INVESTIGATORS

Assuring the survival of humans traveling far from Earth:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Advanced Diagnostic Ultrasound in Microgravity	ADUM	Scott A. Dulchavsky, M.D.	Henry Ford Health System Detroit, MI
Neutron Measurement Experiment Aboard the ISS	BBND	Tateo Goka, Ph.D.	Japan Aerospace Exploration Agency Tokyo, Japan
Effect of Prolonged Spaceflight on Human Skeletal Muscle	Biopsy	Robert Fitts, Ph.D.	Marquette University Milwaukee, WI
Chromosomal Aberrations in Blood Lymphocytes of Astronauts	Chromosome	Günter Obe, Ph.D.	University of Essen Essen, Germany
Dosimetric Mapping	DOSMAP	Gunther Reitz, Ph.D.	DLR Institute for Aerospace Medicine Cologne, Germany
Extravehicular Activity Radiation Monitoring	EVARM	Ian Thomson	Thomson & Nielsen Electronics, LTD Ontario, Canada
Space Flight-Induced Reactivation of Latent Epstein-Barr Virus	Epstein-Barr	Raymond Stowe, Ph.D.	The University of Texas Medical Branch at Galveston Galveston, TX
Foot/Ground Reaction Forces During Space Flight	FOOT	Peter R. Cavanagh, Ph.D.	The Cleveland Clinic Cleveland, OH
Hand Posture Analyzer	HPA	Vittorio Cotronei, Ph.D.	Italian Space Agency (ASI)
Effects of Altered Gravity on Spinal Cord Excitability	H-Reflex	Douglas Watt, M.D., Ph.D.	McGill University Montreal, Canada
Crewmember and Crew-ground Interactions During ISS Missions	Interactions	Nick A. Kanas, M.D.	University of California & Veterans Affairs Medical Center San Francisco, CA

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ISS PRINCIPAL INVESTIGATORS

Assuring the survival of humans traveling far from Earth:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Behavioral Issues Associated with Isolation and Confinement: Review and Analysis of Astronaut Journals	Journals	Jack Stuster, Ph.D.	Anacapa Sciences, Inc. Santa Barbara, CA
Test of Midodrine as a Countermeasure against Postflight Orthostatic Hypotension	Midodrine	Janice Meck, Ph.D.	NASA Johnson Space Center Houston, TX
Promoting Sensorimotor Response Generalizability: A Countermeasure to Mitigate Locomotor Dysfunction After Long-Duration Space Flight	Mobility	Jacob Bloomberg, Ph.D.	NASA Johnson Space Center Houston, TX
Effects of EVA and Long-Term Exposure to Microgravity on Pulmonary Function	PuFF	John B. West, M.D.	University of California San Diego, CA
Renal Stone Risk During Space Flight: Assessment and Countermeasure Validation	Renal Stone	Peggy Whitson, Ph.D.	NASA Johnson Space Center Houston, TX
Sub-regional Assessment of Bone Loss in the Axial Skeleton in Long-Term Space Flight	Subregional Bone	Thomas Lang, Ph.D.	University of California San Francisco, CA
Organ Dose Measurements Using a Phantom Torso	TORSO	Francis Cucinotta, Ph.D.	NASA Johnson Space Center Houston, TX
Effect of Microgravity on the Peripheral Subcutaneous Veno-arteriolar Reflex in Humans	Xenon-1	Anders Gabrielsen, M.D.	Karolinska Hospital Copenhagen, Germany

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ISS PRINCIPAL INVESTIGATORS

Expanding our understanding of the laws of nature and enriching lives on Earth:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Development and Function of the Avian Otolith System in Normal and Altered Gravity Environments	ADF	J. David Dickman, M.D.	Washington University St. Louis, MO
Skeletal Development in Embryonic Quail on the ISS	ADF	Stephen Doty, Ph.D.	Hospital for Special Surgery New York, NY
Crystallization of Human Low Density Lipoprotein (LDL) Subfractions in Microgravity	APCF	Manfred W. Baumstark M.D.	University of Frieburg Frieburg, Germany
Crystallization of Rhodopsin in Microgravity	APCF	Willem J. de Grip, Ph.D.	University of Nijmegen Nijmegen, The Neterlands
Effect of Different Growth Conditions on the Quality of Thaumatin and Aspartyl-tRNA Synthetase Crystals Grown in Microgravity	APCF	Richard Giegé, Ph.D.	Center National for Research Science Strasbourg, France
Crystallization of the Next Generation of Octarellins	APCF	Joseph Martial, Ph.D.	University of Liege Liege, Belgium
Testing New Trends in Microgravity Protein Crystallization	APCF	Fermin Otalora, Ph.D.	University of Granada Granada, Spain
Extraordinary Structural Features of Antibodies from Camelids	APCF	Lode Wyns, Ph.D.	Free University Brussels, Belgium
Solution Flows and Molecular Disorder of Protein Crystals: Growth of High Quality Crystals, Motions of Lumazin Crystals, and Growth of Ferritin Crystals	APCF	Sevil Weinkauf, Ph.D.	Technical University Munich, Germany

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ISS PRINCIPAL INVESTIGATORS

Expanding our understanding of the laws of nature and enriching lives on Earth:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Protein Crystallization in Microgravity, Collagen Model (X-Y- Gly) Polypeptides: the case of (Pro- Pro-Gly) 10	APCF	Adriana Zagari, Ph.D.	University of Naples Naples, Italy
Biomass Production System Technology Verification Test	BPS	Robert C.Morrow, Ph.D.	Orbital Technologies Corporation Space Center Madison, WI
Cellular Biotechnology Operations Support System	CBOSS	John E. Love	NASA Johnson Space Center Houston, TX
Evaluation of Ovarian Tumor Cell Growth and Gene Expression	CBOSS	Jeanne L. Becker, Ph.D.	University of South Florida Tampa, FL
PC12 Pheochromocytoma Cells: A Proven Model System for Optimizing 3-D Cell Culture Biotechnology in Space	CBOSS	Peter I. Lelkes, Ph.D.	Drexel University Philadelphia, PA
Human Renal Cortical Cell Differentiation and Hormone Production	CBOSS	Timothy G. Hammond, M.D.	Tulane University Medical Center New Orleans, LA
Use of NASA Bioreactor to Study Cell Cycle Regulation: Mechanisms of Colon Carcinoma Metastasis in Microgravity	CBOSS	John Milburn Jessup, M.D.	Georgetown University Medical Center Washington, D.C.

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ISS PRINCIPAL INVESTIGATORS

Expanding our understanding of the laws of nature and enriching lives on Earth:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Simulated Microgravity Applications Towards the Study of HIV: The Effect of Microgravity On The Immune Function of Human Lymphoid Tissue	CBOSS	Joshua Zimmerberg, Ph.D.	National Institutes of Health Bethesda, MD
Production of Recombinant Human Erythropoietin by Mammalian Cells	CBOSS	Arthur J. Sytkowski, M.D., Ph.D.	Beth Israel Deaconess Medical Center Boston, MA
Cellular Biotechnology Operations Support System - Fluid Dynamics Investigation	CBOSS-FDI	Joshua Zimmerberg, Ph.D.	National Institutes of Health Bethesda, MD
Effects of Osteoprotegerin (OPG) on Bone Maintenance in Microgravity	CBTM	Ted Bateman, Ph.D.	BioServe Space Technologies Boulder, CO
Commercial Generic Bioprocessing Apparatus	CGBA	Louis Stodieck, Ph.D.	BioServe Space Technologies Boulder, CO
Antibiotic Production in Space in the Commercial Generic Bioprocessing Apparatus	CGBA	David Klaus, Ph.D.	BioServe Space Technologies Boulder, CO
Commercial Protein Crystal Growth-High Density	CPCG-H	Larry DeLucas, OD- Ph.D.	University of Alabama Birmingham, AL
Coarsening in Solid Liquid Mixtures	CSLM-II	Peter Voorhees, Ph.D.	Northwestern University Evanston, IL
Dynamically Controlled Protein Crystal Growth	DCPCG	Larry DeLucas, Ph.D.	University of Alabama Birmingham, AL
Experiment Physics of Colloids in Space	EXPPCS	David Weitz, Ph.D.	Harvard University Cambridge, MA

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ISS PRINCIPAL INVESTIGATORS

Expanding our understanding of the laws of nature and enriching lives on Earth:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions	InSpace	Alice P. Gast, Ph.D.	Massachusetts Institute of Technology Cambridge, MA
Microencapsulation of Anti-Tumor Drugs	MEPS	Dennis Morrison, Ph.D.	NASA Johnson Space Center Houston, TX
Miscible Fluids in Microgravity	MFMG	John Pojman, Ph.D.	University of Southern Mississippi Hattiesburg, MS
Protein Crystal Growth-Enhanced Gaseous Nitrogen Dewar	PCG-EGN	Alexander McPherson, Ph.D.	University of California Irvine, CA
Improved Diffraction Quality of Crystals	PCG-STES	Craig Kundrot, Ph.D.	NASA Marshall Space Flight Center Huntsville, AL
Science and Applications of Facility-based Hardware for Protein Crystal Growth	PCG-STES	Dan Carter, Ph.D.	New Century Pharmaceuticals Huntsville, AL
Crystal Growth: Model System/Material Science	PCG-STES	Bill Thomas, Ph.D.	University of Alabama Huntsville, AL
Regulation of Gene Expression	PCG-STES	Gerald Bunick, Ph.D.	Oak Ridge National Laboratory Oak Ridge, TN
Searching for the Best Protein Crystals: Synchrotron Based Mosaicity Measurements of Crystal Quality and Theoretical Modeling	PCG-STES	Gloria Borgstahl, Ph.D.	University of Toledo Toledo, OH
Crystallization of Integral Membrane Proteins Using Microgravity	PCG-STES	Geoffrey Chang, Ph.D.	Scripps Research Institute La Jolla, CA

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ISS PRINCIPAL INVESTIGATORS

Expanding our understanding of the laws of nature and enriching lives on Earth:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Engineering a Ribozyme for Diffraction Properties	PCG-STES	Barbara Golden, Ph.D.	Purdue University West Lafayette, IN
Photosynthesis Experiment and System Testing Operations	PESTO	Gary Stutte, Ph.D.	Dynamac Corporation Orlando, FL
Toward Understanding Pore Formation and Mobility During Controlled Directional Solidification in a Microgravity Environment	PFMI	Richard Grugel, Ph.D.	NASA Marshall Space Flight Center Huntsville, AL
First Experiment with Human Liver Cells Studying Toxicity in Space	StelSys	Nancy Cowger, Ph.D.	Stelsys, Incorporated Baltimore, MD
Solidification Using a Baffle in Sealed Ampoules	SUBSA	Alexander Ostrogorsky, Ph.D.	Rensselaer Polytechnic Institute Troy, NY
Role of Specific Genes in the Response of Yeast to Spaceflight	Yeast GAP	Louis Stodieck, Ph.D.	BioServe Space Technologies Boulder, CO
Zeolite Crystal Growth Furnace	ZCG	Albert Sacco Jr., Ph.D.	Northeastern University Boston, MA
Creating technology to enable the next explorers to go beyond where we have been:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Microgravity Impact on Plant Seed-to-Seed Production	ADVASC	Weijia Zhou, Ph.D.	University of Wisconsin Madison, WI
Active Rack Isolation System	ARIS	Glenn Bushnell Ian Fialho, Ph.D.	The Boeing Company Houston, TX

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ISS PRINCIPAL INVESTIGATORS

Creating technology to enable the next explorers to go beyond where we have been:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Characterizing the Active Rack Isolation System	ARIS-ICE	Glenn Bushnell Ian Fialho, Ph.D.	The Boeing Company Houston, TX
In Space Soldering Experiment	ISSI	Richard Grugel, Ph.D.	Universities Space Research Association Huntsville, AL
Plant Generic Bioprocessing Apparatus	PGBA	Alex Hoehn, Ph.D.	Bioserve Space Technologies Boulder, CO
Middeck Active Control Experiment II	MACE-II	Rory Ninneman	Air Force Research Laboratory Kirtland Airforce Base, NM
Microgravity Acceleration Measurement System	MAMS	Richard DeLombard	NASA Glenn Research Center Cleveland, OH
Materials International Space Station Experiment	MISSE	William H. Kinard, Ph.D.	NASA Langley Research Center Hampton, VA
Space Acceleration Measurement System II	SAMS-II	Richard DeLombard	NASA Glenn Research Center Cleveland, OH
Synchronized Position Hold, Engage, Reorient, Experimental Satellites	SPHERES	David Miller, Ph.D.	Massachusetts Institute of Technology Cambridge, MA
Observing the Earth:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Crew Earth Observations	CEO	Kamlesh Lulla, Ph.D.	NASA Johnson Space Center Houston, TX
Earth Science Toward Exploration Research	ESTER	Greg Byrne, Ph.D.	NASA Johnson Space Center Houston, TX

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ISS PRINCIPAL INVESTIGATORS

Educating and inspiring the next generation to take the journey:			
Investigation	**Acronym**	**Principal Investigator**	**Institution**
Long Duration HDTV Camcorder Experiment Video	Dreamtime	Ben Mason	Dreamtime Holdings, Incorporated San Francisco, CA
Earth Knowledge Acquired by Middle School Students	EarthKAM	Sally Ride, Ph.D.	University of California San Diego, CA
Education Payload Operations	EPO	Cynthia McArthur	NASA Johnson Space Center Houston, TX
Education-Space Exposed Experiment Developed for Students	SEEDS	Howard Levine, Ph.D.	Dynamac Corporation Rockville, MD

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