Plan to Support Operations and Utilization
of the
International Space Station Beyond FY 2015

pursuant to

Section 601 of the NASA Authorization Act of 2008 (P.L. 110-422)

August 6, 2009

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1.0 BACKGROUND

This report outlines a plan to support operations and utilization of the International Space Station (ISS) beyond FY 2015 in response to direction in Section 601of the NASA Authorization Act of 2008 (P.L. 110-422). The specific requirements for this plan are outlined below.

> ***SEC. 601. PLAN TO SUPPORT OPERATION AND UTILIZATION OF THE ISS BEYOND FISCAL YEAR 2015.***
> *(a) IN GENERAL.—The Administrator shall take all necessary steps to ensure that the International Space Station remains a viable and productive facility capable of potential United States utilization through at least 2020 and shall take no steps that would preclude its continued operation and utilization by the United States after 2015.*
>
> *(b) PLAN TO SUPPORT OPERATIONS AND UTILIZATION OF THE INTERNATIONAL SPACE STATION BEYOND FISCAL YEAR 2015.—*
>
> *(1) IN GENERAL.—Not later than 9 months after the date of enactment of this Act, the Administrator shall submit to the Committee on Science and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate a plan to support the operations and utilization of the International Space Station beyond fiscal year 2015 for a period of not less than 5 years. The plan shall be an update and expansion of the operation plan of the International Space Station National Laboratory submitted to Congress in May 2007 under section 507 of the National Aeronautics and Space Administration Authorization Act of 2005 (42 U.S.C. 16767).*
>
> *(2) CONTENT.—*
> *(A) REQUIREMENTS TO SUPPORT OPERATION AND UTILIZATION OF THE ISS BEYOND FISCAL YEAR 2015.—As part of the plan required in paragraph (1), the Administrator shall provide each of the following:*
> *(i) A list of critical hardware necessary to support International Space Station operations through the year 2020.*
> *(ii) Specific known or anticipated maintenance actions that would need to be performed to support International Space Station operations and research through the year 2020.*
> *(iii) Annual upmass and downmass requirements, including potential vehicles that will deliver such upmass and downmass, to support the International Space Station after the retirement of the Space Shuttle and through the year 2020.*
>
> *(B) ISS NATIONAL LABORATORY RESEARCH MANAGEMENT PLAN.—As part of the plan required in paragraph (1), the Administrator shall develop a Research Management Plan for the International Space Station. Such Plan shall include a process for selecting and prioritizing research activities (including fundamental, applied, commercial, and other research) for flight on the International Space Station. Such Plan shall be used to prioritize resources such as crew time, racks and equipment, and United States access to international research facilities and equipment. Such Plan shall also identify the organization to be responsible for managing United States research on the International Space Station, including a description of the relationship of the management institution with NASA (e.g., internal NASA office, contract, cooperative agreement, or grant), the estimated length of time for the arrangement, and the budget required to support the management institution. Such Plan shall be developed in consultation with other Federal agencies, academia, industry, and other relevant stakeholders. The Administrator may request the support of the National Academy of Sciences or other appropriate independent entity, including an external consultant, in developing the Plan.*
>
> *(C) ESTABLISHMENT OF PROCESS FOR ACCESS TO NATIONAL LABORATORY.—As part of the plan required in paragraph (1), the Administrator shall—*

(i) establish a process by which to support International Space Station National Laboratory users in identifying their requirements for transportation of research supplies to and from the International Space Station, and for communicating those requirements to NASA and International Space Station transportation services providers; and

(ii) develop an estimate of the transportation requirements needed to support users of the International Space Station National Laboratory and develop a plan for satisfying those requirements by dedicating a portion of volume on NASA supply missions to the International Space Station.

(D) ASSESSMENT OF EQUIPMENT TO SUPPORT RESEARCH.—As part of the plan required in paragraph (1), the Administrator shall—

(i) provide a list of critical hardware that is anticipated to be necessary to support nonexploration-related and exploration-related research through the year 2020;

(ii) identify existing research equipment and racks and support equipment that are manifested for flight; and

(iii) provide a detailed description of the status of research equipment and facilities that were completed or in development prior to being cancelled, and provide the budget and milestones for completing and preparing the equipment for flight on the International Space Station.

(E) BUDGET PLAN.—As part of the plan required in paragraph (1), the Administrator shall provide a budget plan that reflects the anticipated use of such activities and the projected amounts to be required for fiscal years 2010 through 2020 to accomplish the objectives of the activities described in subparagraphs (A) through (D).

NASA's budget requests to Congress in recent years have assumed that the ISS program would conclude in the 1st quarter of FY 2016 when the U.S. laboratory reaches its 15-year design lifetime. While NASA has taken no steps to preclude extension of the ISS beyond this period, a formal decision by the Administration on whether or not to extend is pending consideration of the results of the ongoing Review of U.S. Human Space Flight Plans.

2.0 INTRODUCTION

The ISS constitutes a partnership among the nations of Canada, Europe, Japan, Russia and the United States (U.S.) to cooperate on the design, development, operation and utilization of a permanently occupied civil space station. Assembly began with the first element launched in November 1998, and the ISS has been permanently crewed since November 2000. In May 2009, the total permanent crew size was increased to six with the arrival of Soyuz mission 19S. On-orbit assembly, as of the STS-127 mission concluded July 2009, is approximately 85 percent complete. The remaining U.S. Operating Segment (USOS) assembly elements of ISS (Node 3 and Cupola) have completed development, test and evaluation, and are awaiting launch.

As the assembly of the ISS nears completion and the Space Shuttle fleet nears retirement, the ISS focus has changed from assembly and activation of the systems to maintenance and utilization. To augment the upmass capabilities of the cargo resupply vehicles provided by Russia, Europe and Japan, NASA has awarded two contracts for new U.S. Commercial Resupply Services (CRS). These commercial services are planned to help support U.S. maintenance and utilization of the ISS to meet NASA mission objectives in the post-assembly era after the Space Shuttle is retired from service.[1]

In parallel, the U.S. research mission for the ISS has been concentrated in two major areas, consistent with Presidential and Congressional direction. The first area is requirements-driven, exploration-oriented research for the development, demonstration, and delivery of technologies, biomedical countermeasures, and technical and operational knowledge that will enable humans to withstand the rigors of space and permit more ambitious long-duration exploration missions. The second area is the use of ISS as a National Laboratory by U.S. public and private entities for basic and applied research and applications that are not applicable to the NASA mission.

This report summarizes NASA's requirements to support operation and utilization of the ISS if it were decided to operate the ISS beyond FY 2015 and details the National Laboratory research management plan, the process for access to ISS, and equipment needed to support research.

3.0 REQUIREMENTS TO SUPPORT OPERATIONS AND UTILIZATION

3.1 Critical Hardware and Maintenance Actions to Support Operations

The hardware design specifications for the U.S. elements of ISS were 15 years. While some hardware was originally designed for a 30-year life, most was tested to the 15-year life requirement. This approach means there are unknowns that prevent providing an absolute definition of the lifetime capability of the ISS. To continue to operate the ISS past 2015, additional testing and analysis would be required. This work would allow a better understanding of the remaining capability of the systems. To determine what hardware is critical to support ISS operations for any time period, an analysis can be performed based on the various functions that are required to sustain ISS operations. These functions are organized into various ISS systems such as the electrical power system (EPS), environmental control and life support system (ECLSS), guidance, navigation and control (GN&C), and communications and data handling (C&DH) to name just a few. Hardware is built to provide the required functionality for the system and any hardware pieces which can be replaced during the life of the ISS are designed as Orbital Replacement Units (ORU). An ORU is usually a subassembly of a system that can be launched independently and serve as the replacement for a failed or consumed ORU. The failed ORU can then be processed for disposal, or returned for repair or refurbishment if it is an exceptionally high-value item that can be accommodated in the downmass capability available under the CRS contracts. Critical hardware and maintenance actions are divided into two main categories: planned or preventive hardware maintenance, and unplanned or corrective maintenance.

Preventative maintenance actions include cleaning or replacement of filters; replacement or recalibration of sensors or tools that have a limited calibration life; inspection of parts for wear; or change-out of expended consumables (much like the routine, scheduled maintenance on a car). The preventative maintenance intervals can be driven by calendar time, throughput, or cycle life. Due to the scheduled nature of preventative maintenance, planning to support longer-duration operation of ISS for these items is straightforward. Hardware requirements are known and

[1] In this case, NASA mission objectives include NASA-sponsored human research and engineering technology development and commitments to our International Partners but do not include the mission objectives of other U.S. Government agencies, private firms, or academic institutions with whom NASA holds agreements to use the ISS under the National Laboratory initiative.

procurements to purchase additional copies of existing designs can be placed with existing suppliers. Procurement decision dates have been identified to be six months prior to completion of the current work at each supplier. Depending on the supplier, these dates range from the beginning of FY 2010 to as late as 2015. A planning estimate has been included in the ISS budget to support these procurements assuming the currently scheduled change-out frequencies continue through 2020. A detailed database of maintenance requirements is managed by the ISS program and used in planning of the on-orbit tasks for the crew. Historical maintenance and failure data are also collected to allow for periodic evaluation of the maintenance intervals and to track the corrective maintenance actions required.

Corrective maintenance actions include unplanned replacement or repair of failed hardware. After a failure, an evaluation is performed to determine the impact to the functionality and redundancy of the on-board systems. Impact can range from no impact to functionality to requiring near immediate replacement. Initial projections of the operational lifetime of an ORU were based on an analytical technique that determined the Mean Time Between Failures (MTBF), which is derived from the known or predicted life of the various parts that make up the ORU, such as electrical parts, valves and mechanisms. These initial projections along with engineering judgment were used to define a quantity of spares required to keep the system operational. As hardware is operated on orbit, empirical data from the actual time between failures becomes available. Initial performance of the hardware was significantly better than was predicted by the MTBF so the actual failure data were used to adjust the original analytical predictions using Bayesian statistical methodologies. The original intent of this analysis was to determine if it was necessary to procure additional large, external ORUs or if existing quantities were sufficient. Over the past two years, this technique has been applied to all of the systems on the ISS. The empirically modified MTBF values are then used in a functional availability assessment to determine if more spare ORUs are required to continue to operate the ISS through a given time period. The analysis also assumes a certain level of degradation in some systems is acceptable near the end of life of the ISS.

In the past two years, this functional availability assessment has been performed for the scenario in which the ISS is operated through 2020. This analysis is updated annually to monitor and track the risks to ISS critical systems given updated system performance data. Results of this assessment by system are described below. Other options are being pursued that could preclude the need for procurement of additional ORUs and maintain the functionality of the ISS through 2020. These include evaluating systems for intermediate levels of maintenance and evaluating different operational scenarios. Intermediate level maintenance allows for replacement of failed parts within an ORU on orbit instead of requiring the replacement of the entire ORU. With this approach, significantly smaller parts can be procured, launched, and replaced, while still maintaining functionality of the system. Evaluating different operational scenarios allows risk to be mitigated by preventing wear and tear on the systems that can lead to failures. Operational changes that are evaluated run the spectrum from changing duty cycles to preserve life to operating at different conditions to allow for continued operation of a piece of hardware.

Timing of the decision on whether or not to continue ISS operations to 2020 is critical for the procurement of additional preventive and corrective maintenance hardware. Spares procurements are currently in place to maintain the system through 2015. As smaller vendors finish production of the required spares or subassemblies, contracts will be closed out and the vendors will not be retained. Major manufacturers will be retooling for other business. Once contracts with spares vendors are closed out, start up of new contracts will be required and will take months to initiate. Manufacturing production lead times are generally 2 or more years. Additionally, many older electronic parts may no longer be procurable due to the changes in the state-of-the-art in the industry. This would require newer parts to be certified as replacements. Specific decision dates have been defined for each ORU and the critical items are described below.

3.1.1 Electrical Power System (EPS)

The function of the EPS is to collect power from the solar arrays, store power in batteries, and distribute power throughout the ISS through a variety of control and switching units. Based on the updated functional availability analysis, the critical ORUs for the EPS are the batteries and the remote power control modules (RPCMs). The existing nickel-hydrogen batteries are aging and would have to be replaced to operate the ISS to 2020. New lithium ion batteries are being evaluated to replace the aging batteries as needed. Due to a known deficiency, the RPCMs have experienced a higher failure rate on orbit than predicted by the MTBF, so the updated analysis indicates the current spares quantities would not be sufficient. Additional RPCMs would need to be procured to maintain the EPS through 2020.

3.1.2 Structures and Mechanisms (S&M)

The S&M area provides the main pressurized and unpressurized structure of the ISS and the mechanisms to rotate the solar arrays and thermal radiators as well as to provide berthing, docking, and attachment mechanisms. The ISS structure is not an ORU; however a critical evaluation of this hardware is performed via life extension analysis. Events that are known to put a structural load into the system, like docking and re-boost, are measured as they occur. These data are then used in an analysis to determine how much of the structural life has been used. Based on this analysis, the remaining structural life of the vehicle can be calculated and along with a conservative prediction of future loading events, a determination of the new end of life is generated.

Critical areas that are evaluated are the pressure vessels, the attachment between the labs and truss structure, and the interfaces between pressurized labs. These areas are most sensitive to life degradation due to the fatigue induced by repeated pressure cycles or structural loading events. The critical mechanism ORUs for S&M are the Bearing Motor Ring Roll Module (BMRRM), the Utility Transfer Assembly, (UTA), the Trailing Umbilical System - Reel Assembly (TUS-RA), the Trundle Bearing Assembly (TBA), and the Drive Lock Assembly (DLA). Because of past on-orbit performance issues, the BRMMR, UTA, TBA, and DLA ORUs' performance will continue to be tracked and the availability analysis updated to determine if additional spares would be required post-2015 to maintain the system to 2020. Spares for the TBAs and DLAs are being procured to maintain the necessary inventory for operations through 2015. Various repair and refurbishment options are being evaluated to see if existing TBA and DLA hardware could be added back to the spares inventory for these ORUs to further mitigate the risk of needing additional spares for 2020. The on-orbit issue with the starboard Solar Array Rotary Joint (SARJ) lubrication has indicated another area where specific evaluation must be performed. While cleaning and lubrication of the SARJ on orbit appears to have solved the high friction problem that led to the anomalous behavior of the system, continued observation will be required.

As the system ages, additional remediation or hardware modifications may be required to continue to operate the ISS past 2015. Ground testing is being performed to characterize the remaining life of the degraded starboard SARJ system and to determine the lubrication maintenance intervals for both the port and starboard SARJ systems. The SARJ system is designed with two parallel race rings with the TBAs and DLAs attached to one ring and rolling on the other ring. This provides redundancy such that the TBAs and DLAs can all be switched to roll on either ring. However, power and data signals are limited in the redundant mode. To address this, full capability in the redundant mode is being incorporated with the design and development of a new ORU, the Rotary Joint Motor Controller (RJMC) Interface Unit. For the TUS-RA, the issue is not related to on-orbit performance, but to the risk of micrometeoroid/orbital debris (MM/OD) impacts. The approach to maintaining the system through 2020 would be to minimize exposure to MM/OD impacts and accept the risk of having only a single spare.

3.1.3 Guidance, Navigation, and Control (GN&C)

The GN&C system provides attitude determination, translation and control functions for the ISS through antennas and gyros. The functional availability analysis for 2020 indicates the Control Moment Gyro (CMG) Mechanical Assembly would be the highest risk to the system. This system is critical to operation of the ISS and requires very high confidence in maintaining redundant performance even at the end of ISS life. The current spares inventory is sufficient to maintain the systems through 2015. Functional availability analysis will continue to be updated with on-orbit performance data over the next few years. A decision date in the late 2010 timeframe has been identified to determine if more spares need to be ordered before the vendor is released.

3.1.4 Active Thermal Control System (ATCS)

The ATCS collects, transports, and rejects heat generated by the ISS systems. The pump module is the critical ORU for the ATCS. Spare ORUs have been procured and are being prepositioned on orbit in the event of a failure, as this ORU is critical to cooling equipment that provides power for the ISS. The radiators are also critically important for the performance of the system. Because of the large surface areas exposed to the space debris field, the radiators are continually at risk of impact from micrometeoroids and orbital debris. Additionally, one radiator panel has experienced a failure on orbit whose cause has not been definitively determined. Some of the possible causes could indicate a generic flaw with the design that would put all of the radiators at risk for repeated failure. To minimize the risk of a radiator failure impacting the life of the ISS, a spare radiator is being flown before Shuttle retirement. Prepositioning of the spare radiator will allow for near immediate replacement if a radiator fails completely, thus preserving the capability to continue ISS operations past 2015. Based on current on-orbit performance of the ORUs and planned spares procurements, no other ORUs are currently considered critical for the ATCS.

3.1.5 Environmental Control and Life Support System (ECLSS)

The ECLSS provides the key functions necessary to maintain a shirt-sleeve atmosphere for the crew. These functions include controlling temperature and humidity, providing smoke detection and fire suppression, maintaining the oxygen, nitrogen, and carbon dioxide concentrations for breathing, maintaining the total pressure equal to Earth’s, recycling urine and water for crew use and providing access to the space vacuum. The critical hardware for ECLSS is in three groups. The first group includes specific ORUs within major assemblies including the Carbon Dioxide Removal Assembly (CDRA), the Major Constituent Analyzer (MCA), the Oxygen Generation System (OGS), the Water Processing Assembly (WPA), and the Urine Processing Assembly (UPA). The second group includes the Temperature Control Check Valve (TCCV), the Pressure Control Panel (PCP), and the Vent Relief Valve (VRV) ORUs. The third group is hardware that is consumed during the operation of the system, for example, chemical adsorbent beds or filters that are used during the purification of the water or air, which after a collecting waste for a period of time are “full” and must be replaced.

The TCCV, PCP, and VRV as well as the critical ORUs within the CDRA and MCA have experienced a higher than predicted failure rate on orbit so the updated analysis indicates the current spares quantities may not be sufficient. Additional CDRA and MCA ORUs would be required to be procured to maintain the ECLSS through 2020. The on-orbit performance of the TCCV, PCP, and VRV will continue to be tracked and additional spares will be procured if required. For the other systems, including the OGS, WPA and UPA, very limited on-orbit operational time has occurred to allow for updates of the initial MTBF analysis with empirical performance data. For these systems, spares procurements to maintain the systems through 2015 are in progress, and the functional availability analysis will continue to be updated with on-orbit performance data over the next few years. Because spares production is ongoing over the next few years, additional quantities of ORUs can be procured from the current vendors if on-orbit performance indicates additional spares are required to maintain the system. The consumable items required to continually operate the system have been planned based on ground and on orbit testing and are being procured to support the system through 2015. Additional quantities can be procured from the existing vendors if the decision is made to operate through 2020.

3.1.6 Command and Data Handling (C&DH)

The C&DH system consists of the computers on which the ISS software runs. The system contains inherent redundancy in the Multiplexer/Demultiplexer (MDM) cards that are used throughout the system. Based on current failure rates, once Shuttle retires, the cards used for the Multi-Purpose Logistics Modules (MPLMs) can be added to the inventory of spare hardware which will provide sufficient quantities such that no other procurements would be required to operate through 2020.

3.1.7 Communications and Tracking (C&T)

The C&T system provides internal and external audio and video communications with ISS, provides the capability to command the ISS, sends the data to the ground, and tracks the position of the ISS through its orbit. Previous analysis of the spares required to maintain operation of the C&T system showed that it was more cost effective to upgrade the system than to continue to specially procure technology that had become obsolete. The Integrated Communications Unit will be incorporated on ISS by the end of 2011 and will allow additional high rate data communication both onboard between payloads (100 Megabytes per second [Mbps]) and with the ground (300 Mbps downlink, 25 Mbps uplink) which will be beneficial for utilization. The critical ORUs in the C&T system are the Audio Terminal Units (ATU) for the internal audio system and the Sync and Control Unit (SCU) for the video system. Very high functionality is required at the end of life for the ATU, as it is the system that sounds on board warnings to the crew in case of emergencies. Depending on performance of the existing ATUs on orbit, additional spares might be required to maintain the system through 2020. On-orbit performance will be tracked until mid-2011 at which point a decision on the number of additional spare ATUs will be made. Additional spare SCUs would be required to maintain the functionality of the video system through 2020.

3.1.8 Mobile Servicing System (MSS)

The MSS system provides the Space Station Remote Manipulator System (SSRMS), commonly referred to as the “station arm,” and a mobile platform that can traverse on rails on the ISS truss that is used to assemble station, support maintenance activities, and carry crewmembers and larger ORUs and pallets during Extravehicular Activities (EVAs). An attachment to the arm is the Special Purpose Dexterous Manipulator (SPDM) which is a 2-arm robot used to change out external ORUs without an EVA crewmember conducting an EVA. The system incorporates a telerobotic concept that can be operated in a computer-only manner with human oversight or in a cooperative, human-computer interface mode by either a ground controller or a crewmember on orbit. Spares assessments indicate there are sufficient spares to operate through 2015. Analysis for operation through 2020 is ongoing and will take into account the on orbit performance of the system. If additional spares are required, existing vendors are available for procurement of the added parts.

3.1.9 Extravehiclular Activity (EVA)

The EVA system consists of the EVA Suit, called the Extravehicular Mobility Unit (EMU), EVA tools, and ancillary hardware needed in order to be able to go on an EVA. The EMU is the most critical item and consists of a Life Support Subsystem (LSS) and a pressure garment (helmet, arms, legs, etc). The LSS life has been extended to 6 years to minimize requirements for the launch of additional hardware through 2015 and to allow the existing fleet to support ISS through 2020. The LSS will be utilized for its full life on ISS; the expired unit will be discarded and replaced with a ground spare as needed. The ground inventory will be maintained by performing preventive maintenance and replacing specific components within the LSS, as required. Life extension analysis is performed to extend the life of the components based on evaluation of the oldest and most utilized components within the fleet. The pressure garment will be procured as required when existing components reach the end of life, just as they are today in support of both ISS and Shuttle. EVA tools will continue to be analyzed for life extension and those that do not meet the extended life to 2020 would need to be procured. Vendors for the EMU, tools and ancillary hardware are retained for sustaining engineering of the system and are readily accessible for the procurement of additional spares at the time they are required.

3.1.10 Flight Crew Equipment (FCE)

The FCE area includes all of the crew personal hardware, household items, and tools to maintain the ISS. The majority of this hardware is purchased as commercial-off-the-shelf (COTS) hardware and minor modifications are made for space flight. Because of this, the FCE hardware items are not treated as ORUs, but are replaced as required with the latest COTS hardware. Sufficient quantities are available on board to maintain redundancy and thus, none of the FCE hardware is considered critical hardware. If additional equipment is required in the future, it would need to be procured from available COTS hardware.

3.2 Annual Upmass and Downmass Requirements

Annual upmass and downmass requirements for the ISS are documented in the 2008 Consolidated Operations and Utilization Plan (COUP) which covers the period from CYs 2008 through 2015. (See Tab A.) Internal and external cargo from 2010 to 2015 from the COUP is shown in Table 1 and Figures 1 and 2. Based on these requirements, upmass and downmass from 2016 to 2020 have been estimated. These requirements cover the critical hardware to support operations for maintenance, food, and crew supplies (System/Operations), as described in section 3.1, and utilization requirements for both the existing USOS utilization requirements (NASA utilization requirements plus International Partner utilization requirements) as well as the National Lab utilization capacity (National Lab Utilization). Each year, if the defined upmass is not required to support operations, it will be made available for utilization. Depending on the systems performance, upmass may be available one year but not another year.

Funding for the upmass for utilization requirements only covers the NASA sponsored utilization.

Table 1 – Upmass and Downmass Requirements for 2010 to 2020

Year	Cargo Launch/Recoverable Return Mass			
	Internal		External	
	Up (kg)	Down (kg)	Up (kg)	Down (kg)
2010	**17,160**	**3,047**	**5,599**	**1,352**
Systems/Operations	7,472	734	3,038	999
USOS research (funded)	8,250	1,798	2,018	353
National Lab Utilization (unfunded)	1,438	515	543	0
2011	**10,563**	**1,715**	**3,593**	**0**
Systems/Operations	7,003	585	995	0
USOS research (funded)	2,121	615	2,055	0
National Lab Utilization (unfunded)	1,438	515	543	0
2012	**11,358**	**1,725**	**2,954**	**0**
Systems/Operations	7,437	349	897	0
USOS research (funded)	2,453	851	1,502	0
National Lab Utilization (unfunded)	1,467	525	555	0
2013	**10,413**	**1,713**	**3,715**	**0**
Systems/Operations	7,070	394	2,028	0
USOS research (funded)	1,910	806	1,147	0
National Lab Utilization (unfunded)	1,432	513	540	0
2014	**11,641**	**1,706**	**3,175**	**0**
Systems/Operations	7,933	441	1,296	0
USOS research (funded)	2,293	759	1,344	0
National Lab Utilization (unfunded)	1,415	506	535	0
2015	**10,581**	**1,706**	**3,819**	**0**
Systems/Operations	7,576	389	1,381	0
USOS research (funded)	1,590	811	1,903	0
National Lab Utilization (unfunded)	1,415	506	535	0
2016 to 2020 per year*	**11,000**	**1,700**	**3,500**	**0**
Systems/Operations (unfunded)	7,600	400	1,350	0
USOS research (unfunded)	2,000	800	1,600	0
National Lab Utilization (unfunded)	1,400	500	550	0

*Detailed upmass and downmass requirements have not yet been defined for the 2016 to 2020 timeframe. However, based on the known requirements to support crew and systems operations and the crew time available for utilization, this table assumes that similar upmass and downmass will be required per year for 2016 to 2020 as are required for 2011 to 2015.

Figure 1 – Annual Upmass Requirements for Operation and Utilization of ISS

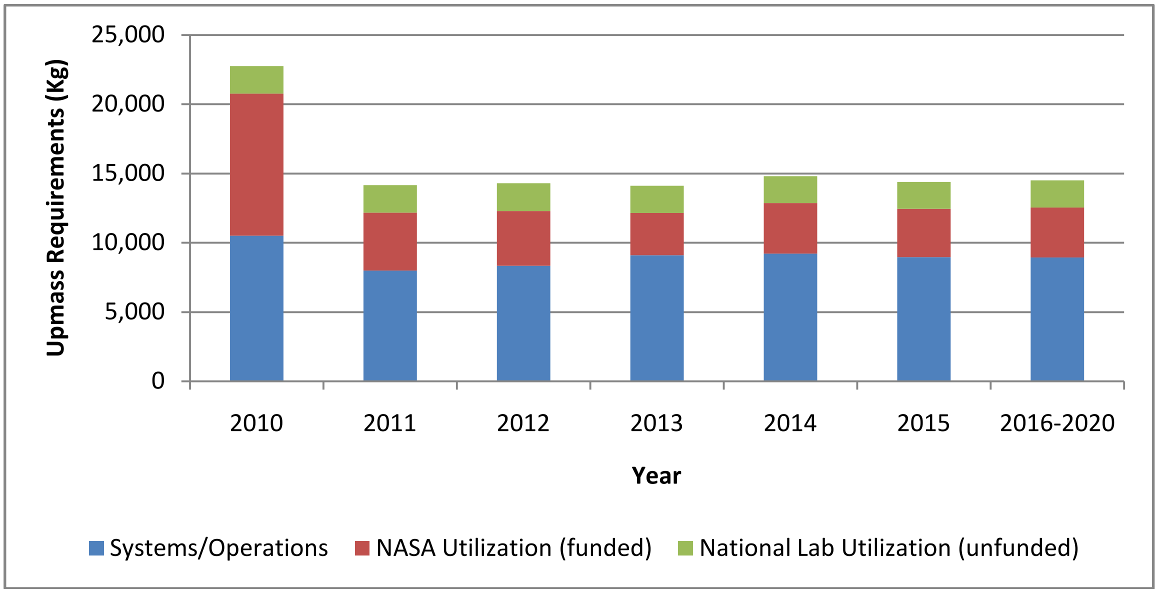
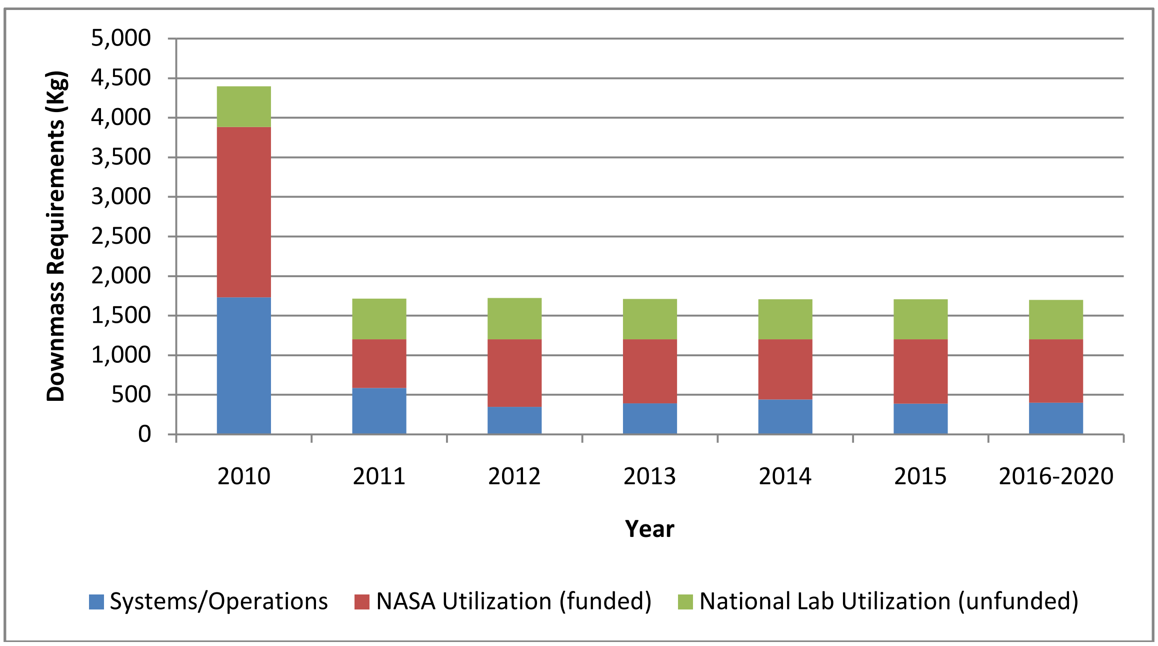


Figure 2 – Annual Downmass Requirements for Operation and Utilization of ISS



3.3 Cargo Transportation Strategy

Post-Shuttle retirement, cargo upmass capability is being procured from Space Exploration Technologies Corporation (SpaceX) and Orbital Sciences Corporation (OSC) through ISS Commercial Resupply Services (CRS) contracts, provided by the remaining Progress upmass procured from the Russian Space Agency through 2011, or from the agreements under negotiation with the European Space Agency and the Japanese Aerospace Exploration Agency for the use of Automated Transfer Vehicles (ATV), the proposed Advanced Re-entry Vehicle (ARV) and H-II Transfer Vehicles (HTV) respectively, as shown in Table 2. Of these, only the SpaceX and the proposed ARV vehicles are expected to be capable of providing downmass. To mitigate the downmass constraints, a number of different approaches are being used. Investigators are being encouraged to develop methods for digital data collection which can be downlinked to the ground instead of requiring samples to be returned. Additionally, experiments that focus on the cellular and molecular levels in research are becoming more prevalent and the samples required for return are very small. Based on availability of funds, techniques for on-orbit characterization of results, such as systems for gene array tests or DNA extractions, or for a rapid sample return system could be pursued.

Table 2 – Number of Flights/Upmass Planned/Purchased/Bartered per Year to 2015

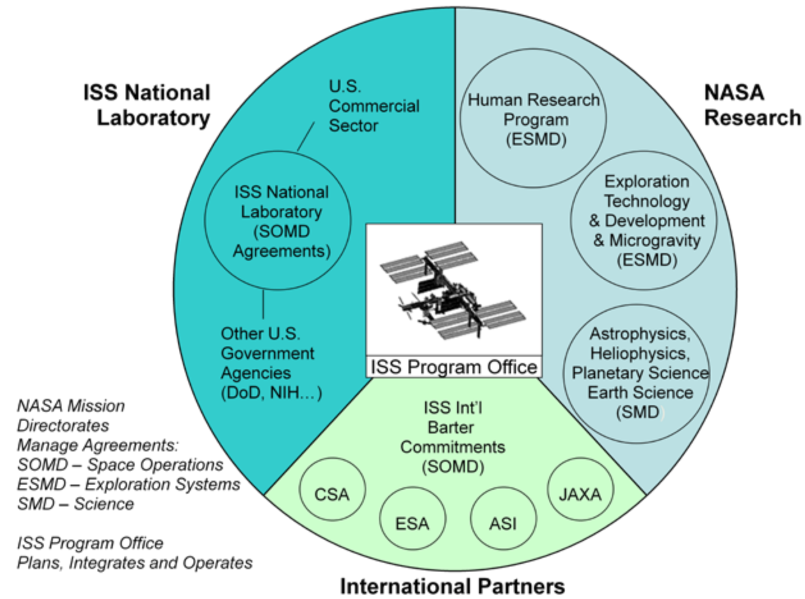
	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016-2020
Shuttle*	6						
Progress**	4.2 MT	1.4 MT					
ATV	1	1	1	1	0	0	TBD
HTV	1	1	1	1	1	1	TBD
Space X	0	2	1	3	3	3	TBD
OSC	0	0	1	2	2	3	TBD

*Includes Utilization and Logistics Flight (ULF) 6 **Values are in metric tons. Upmass will be split over multiple Progress vehicles and the Russian Mini Research Module (MRM).

4.0 NATIONAL LABORATORY RESEARCH MANAGEMENT PLAN

4.1 ISS Research Management Plan

ISS research is managed within NASA through the Space Station Payloads Office. This office is responsible for defining the available ISS interfaces and capabilities, meeting the requirements of National Laboratory and NASA investigators, meeting international commitments for partner utilization, and optimizing the overall research return from the ISS. Each utilization activity on ISS is either selected by NASA Headquarters (for NASA funded research), or selected by another organization that has an agreement with NASA for use of ISS. International Partner agreements and National Laboratory Agreements are managed by the Space Operations Mission Directorate, which then serves as the sponsor of the research implementation on ISS. NASA funded research is selected and sponsored by one of the NASA mission directorates. The sources of payloads on ISS and the directorate managing the agreements for access to ISS are shown in Figure 3. The organizations can be grouped into three categories: ISS National Lab, NASA, and International Partners. Prioritization is accomplished via the NASA ISS Science Prioritization Desk Instruction. (See Tab B.) Each sponsoring organization prioritizes the research they manage according to their programmatic objectives. The ISS program scientist then integrates the lists into a complete set of NASA priorities. The goal for the prioritization is to preserve the sponsoring organization's internal priorities while balancing the agency level objectives of exploration relevance, utilization impact, international commitments, scientific benefit, interagency commitments and relevance to other government agencies objectives, U.S. commercial commitments, and education and outreach impact. The International Partners who have a right to an allocation of the USOS resources provide their own priorities within their allocation. These priorities are separate from the NASA process, and integration is based on the allocations set in the ISS international agreements.



CSA – Canadian Space Agency
ESA – European Space Agency
ASI – Agenzia Spaziale Italiana
JAXA – Japan Aerospace Exploration Agency

Figure 3 – Sponsorship of Payloads to ISS

Once priority is established, the Payloads Office integrates and manages the upmass, downmass, and crew time resources to enable execution of those payloads through the Research Planning Working Group processes. Strategic planning is performed 18 months in advance of an ISS increment to define the baseline research plan. The entire research planning process is documented in SSP 50795 Research Planning Working Group Ops Plan (See Tab C.) After the baseline plan is defined, the tactical team takes over execution of the plan. As flight dates or manifest opportunities change due to the overall needs of the ISS Program, the tactical team iterates between the resources available and the priorities established in the research plan to enable execution of as much of the original research plan as possible. The execution process is documented in SSP 50471 International Space Station Payload Mission Integration Team Execution Plan (See Tab D.). Any items not accomplished in one increment are picked up in the next increment to ensure that the priorities are completed.

4.2 ISS National Laboratory Research Management Plan

ISS National Lab research is managed through the Assistant Associate Administrator for ISS in the Space Operations Mission Directorate at NASA Headquarters in cooperation with the ISS National Lab Office within the Space Station Payloads Office. Selection of research for use of

ISS as a National Laboratory is done through a number of methods. Agreements with other government agencies are made in those cases where the use of ISS would enhance the mission of the other government agency, such as the National Institutes of Health, the United States Department of Agriculture, or the Department of Defense. These agreements are normally documented in Memoranda of Understanding (MOU) between the parties. Identification of other government agencies that would benefit from such an agreement is made through formal and informal means, while agreements between agencies are typically executed at the Headquarters level. Private sector participants are selected through periodic NASA Announcements of Opportunity (AO) and awards are documented through Space Act Agreements (SAA). SAAs can also be written to enable early evaluation of an R&D concept in those cases where a private firm, or non-profit institution, may need access to NASA expertise to determine technical feasibility. Prioritization among the National Lab payloads is based on the scope of partner financial and technical commitments, and flight readiness. The goal for the prioritization is to meet the agency-level commitments made in the MOUs and SAAs, while also meeting the objectives for use of ISS as a National Lab. These objectives include mission benefit, interagency commitments and relevance to other government agencies objectives, commitments from U.S. private and non-profit entities, and education and outreach impact. The prioritized list of ISS National Lab payloads then feeds into the overall ISS research process described in section 4.1 along with the NASA-funded payloads and the International Partner payloads.

5.0 PROCESS FOR ACCESS TO NATIONAL LABORATORY

ISS National Laboratory users will be supported by the ISS National Lab Office in the Space Station Payloads Office. The ISS National Lab Office provides support to all National Lab payloads by providing an interface to the NASA payload processes to ensure requirements are identified, communicated, and secured. These requirements then flow into the existing NASA payload processes described in section 4.1 for implementation.

Transportation requirements to support the use of ISS as a National Lab will continue to be defined as the scope of what ISS can be used for is more clearly demonstrated to the public and private sector. Currently, National Lab users are offered a minimum upmass on the remaining Space Shuttle flights under a “pathfinder” initiative. National Lab Pathfinder agreements were put in place to demonstrate the benefits of space flight for non-NASA related research. As shown in Figures 1 and 2 in Section 3.2, an allocation of upmass capacity from 2011 to 2015 is being maintained for National Lab users in ISS strategic planning, although this upmass is not currently funded by NASA. Subject to availability of funding, this allocated upmass can be utilized to launch National Lab payloads to ISS.

6.0 EQUIPMENT TO SUPPORT RESEARCH

The research architecture is organized by facilities that provide specific research capabilities either internally or externally to the ISS. The facilities are available for either NASA-funded research or National Lab research. NASA also works with ISS International Partners to enable the cooperative use of facilities built by those partners. Internally, these facilities are rack-based and contain various lockers, drawers or inserts that can be changed out to accomplish varying R&D objectives. This provides flexibility for modifying facilities as research requirements change over time and technology developments enable new capabilities. Externally, these facilities are based on the Flight Releasable Attachment Mechanism (FRAM) that attaches to an external payload site. The passive half of the FRAM is attached to the facility while the active half is attached to the payload. This provides a common robotic interface for manipulation by the mobile servicing system. These payload sites are provided with a common set of utility interfaces that are required by most payloads. A short description of the key facilities is provided below. Details of these facilities, as well as the smaller handheld, locker-sized, and sub-rack hardware, can be found at http://www.nasa.gov/mission_pages/station/science/experiments/Discipline.html. Some of these items require refurbishment before they can be re-flown, since they have not been used recently. Demand for use of the hardware and funds availability will drive the refurbishment of these items. Periodic maintenance of the research hardware is dependent upon the usage rate and requirements are tracked in the same manner as they are for the operations hardware, as described in section 3.1.

6.1 Human Research Facility (HRF)

The HRF provides an on-orbit laboratory that enables human life science researchers to study and evaluate the physiological, behavioral, and chemical changes induced by space flight. Research performed with the HRF will provide data relevant to human adaptation to long-duration space flight. The two HRF racks include a clinical ultrasound, a device for measuring on-orbit crewmember mass, a refrigerated centrifuge, devices for measuring blood pressure and heart function, and the pulmonary function system for measuring lung function. The two HRF racks are both on orbit.

6.2 Expedite the Processing of Experiments to the Space Station (ExPrESS) Rack

The ExPrESS Rack (ER) is a multipurpose payload rack system that transports, stores and supports experiments aboard the ISS. With standardized hardware interfaces and streamlined approach, the ExPrESS Rack enables quick, simple integration of multiple payloads aboard the ISS. Experiments are exchanged in and out of the ER as needed, remaining on ISS for three months to several years, depending on the experiment's time requirements. Payloads within an ER can operate independently of each other. The ER provides stowage, power, data, command and control, video, water cooling, air cooling, vacuum exhaust, and nitrogen supply to payloads. ExPrESS racks 1 through 6 are on orbit. ER 7 launches on ISS assembly flight 19A (STS-131). ER 8 launch plans have not been finalized at this time.

6.3 Combustion Integrated Rack (CIR)

The CIR provides capabilities for sustained, systematic microgravity combustion research. The CIR is designed to be easily reconfigured on-orbit to accommodate a wide variety of combustion experiments. It consists of an optics bench, a combustion chamber, a fuel and oxidizer management system, environmental management systems, interfaces for science diagnostics and experiment specific equipment. For diagnostic purposes, there are five different cameras available for use by the investigator. The CIR is on orbit.

6.4 Fluids Integrated Rack (FIR)

The FIR features a large user-configurable volume that resembles a laboratory optics bench. The overall concept for FIR, in order to minimize upmass, is to utilize different modules that can support various types of experiments. The FIR provides data acquisition and control, sensor interfaces, laser and white light sources, advanced imaging capabilities, power, cooling, and other resources. The facility enables fluid physics research on complex fluids, interfacial phenomena, dynamics and instabilities, multiphase flows, and phase changes. The FIR will be delivered on ISS assembly flight 17A (STS-128).

6.5 Microgravity Science Glovebox (MSG)

The MSG provides containment of liquids and particles involved in experiments onboard the ISS, in order to prevent them from drifting around freely in the cabin. Crewmembers access the work area through ports equipped with rugged, sealed gloves that can be removed when contaminants are not present. A video system and data downlinks allow for control of the enclosed experiments from the ground, if desired. In addition to doing complete, laboratory-like experiments, the MSG allows scientists to test small parts of larger investigations in a microgravity environment and to try out new equipment in microgravity. The MSG can support all key areas of microgravity research as well as other scientific fields. The MSG is on orbit.

6.6 Materials Science Research Rack (MSRR)

The MSRR is used for basic materials research in the microgravity environment of the ISS. MSRR can accommodate and support diverse Experiment Modules (EMs). In this way many material types, such as metals, alloys, polymers, semiconductors, ceramics, crystals, and glasses can be studied to discover new applications for existing materials and new or improved materials. Materials science research benefits from the microgravity environment because a researcher can better isolate chemical and thermal properties of materials from the effects of gravity. This leads to improved crystal growth, longer polymer chains, and more structurally and chemically pure alloys. MSRR will enable this research by providing hardware to control the thermal, environmental, and vacuum conditions of experiments, monitor experiments with video, and supply power and data handling for specific experiment instrumentation. The MSRR will be delivered on ISS assembly flight 17A (STS-128).

6.7 Window Observational Research Facility (WORF)

The WORF provides a stable platform for Earth science remote sensing instruments using the Destiny science window, which contains the highest quality optics ever flown on a human-occupied spacecraft. The high quality optical window that WORF will support is located on the nadir (Earth facing) side of the U.S. Destiny Laboratory module. The window is made up of an assembly of four separate panes. The outermost pane is a replaceable debris pane. It is designed to protect the window from small orbital debris or micrometeoroids that might strike the station. If it is severely damaged, it can be replaced during an EVA. The two middle panes serve as the primary and secondary pressure windows, ensuring that the laboratory module stays pressurized. The innermost pane is a multi-layer scratch pane. The scratch pane has an integral heater element to prevent condensation from forming on the pressure panes, and has a special anti-scratch coating that protects against accidental bumps from camera lenses and other equipment during set-up work inside the WORF rack. WORF provides power, data, and thermal support for remote sensing instruments and allows the shirtsleeve environment of ISS to be used as a testbed for collecting data for new sensor technology development. The WORF will be delivered on ISS assembly flight 19A (STS-131).

6.8 Cold Stowage Capabilities

The Minus Eighty-degree Laboratory Freezer for ISS (MELFI) supports a wide range of life science experiments by preserving biological samples (such as blood, saliva, urine, microbial or plant samples) collected aboard ISS for later return and analysis back on Earth. Samples from the human research and life sciences investigations are stored in MELFI on ISS at temperatures as low as -80 degrees C (-112degrees F). The General Laboratory Active Cryogenic ISS

Experiment Refrigerator (GLACIER) provides an ExPrESS Rack compatible freezer/refrigerator for a variety of experiments that require temperatures ranging from + 4 degrees C (39 degrees F) to as low as -185 degrees C (-301 degrees F). The GLACIER is repeatedly launched and returned to ferry the MELFI samples to and from ISS. The Microgravity Experiment Research Locker Incubator (MERLIN) provides an ExPrESS Rack compatible freezer/refrigerator or incubator that can be used for a variety of experiments. Temperature range for MERLIN is -20 degrees C (-4 degrees F) to + 48.5 degrees C (+119 degrees F). In addition to the active refrigerators/freezers, there are a set of cold bags of varying sizes. These cold bags are highly insulated coolers that are ferried back and forth from the ground to ISS to allow sample launch and return at controlled temperatures. There are three MELFI racks: one is on orbit, one will be flown on ISS assembly flight 17A (STS-128), and one will be flown on ISS assembly flight 19A (STS-131). The GLACIERs and MERLINs rotate up and down and at any given time one or more of each may be on orbit and the remainder will be on the ground. The cold stowage plan is managed within the ISS Payloads Office to ensure all sample requirements can be met.

6.9 External Facilities

The Expedite the Processing of Experiments to the Space Station (ExPrESS) Logistics Carrier (ELC) is a platform designed to support external payloads. The ELC is mounted to the ISS and the Flight Releasable Attachment Mechanisms (FRAMs) with the payloads attached are mounted on the ELCs. By attaching to the starboard and port truss sites, a variety of views such as zenith (deep space) or nadir (Earthward) direction with a combination of ram (forward) or wake (aft) pointing allows for many possible viewing opportunities. Power and data connections are available at each payload location. ELC 1 and 2 launch on Utilization and Logistics Flight (ULF) 3, ELC 4 on ULF5, and ELC 3 on ULF6.

The U.S. also has rights to use external platforms on the Japanese Experiment Module - Exposed Facility (JEM-EF) and the Columbus - External Payloads Facility (Columbus-EPF). The Columbus-EPF is FRAM-based but the JEM-EF is not. Both facilities provide attachment capabilities (for power and data transfer) for external payloads. The JEM-EF also has robotic transfer capabilities and cooling.

6.10 *Previously Planned Facilities*

During the Spacelab era through the first years of ISS assembly, NASA's life and physical sciences program was guided by National Research Council reports and external advisory committee recommendations to accommodate a broad range of research disciplines, resulting in a highly diverse program with over 1,000 principal investigators, a wide range of disciplines, and hundreds of payloads in planning or development. As assembly of the ISS proceeded and the research program experienced both serious cost growth and ISS assembly delays, a review (the ISS Management and Cost Evaluation) directed by the Administration recommended that priorities be established for research on the ISS, so that the research return of the ISS program could be maximized within an executable program. This effort was undertaken by the Research Maximization and Prioritization (ReMaP) task force, which recommended in 2002 that biomedical research required for crew safety on long-duration missions be given highest priority, and biological and physical research that could contribute to exploration goals also be given priority over basic scientific research lacking clear relevance to exploration. Further budget-driven reviews of ISS research content, notably the Exploration Systems Architecture Study (ESAS) in 2005, further focused the scope of NASA-sponsored ISS research on content required to support defined exploration program requirements (as a result of Congressional direction in the

NASA Authorization Act of 2005 (P.L. 109-155), a small amount of non-exploration-focused ISS research remained in the NASA portfolio).

The focusing of ISS research on exploration requirements between 2002 and 2005 led to the termination of a number of research facilities during this period. NASA's animal (rodent) research facilities, including the Life Sciences Glovebox, Habitat Holding Racks 1 and 2, the 2.5-Meter Centrifuge Rotor, and the overall Centrifuge Accommodation Module (CAM) were cancelled. This equipment was determined to support fundamental research that would not yield results for many years, and therefore would not benefit lunar exploration. Additionally, major technical and budgetary risks to the completion and operation of the CAM remained unresolved. At the time of the negotiation with the Japan Aerospace Exploration Agency (JAXA) that bartered delivery of the CAM as part of JAXA's contribution to ISS common operating costs, internal budget estimates for the CAM had reached as high as $500 million and were continuing to increase.

Impacts to physical sciences included cancellation of the Commercial Materials Facility, Materials Science Research Racks 2 and 3, and the Low Temperature Microgravity Physics Facility.

Impacts to biotechnology research included cancellation of the X-Ray Diffraction facility, a proposed commercial facility that would have provided a capability to perform structural analysis on protein crystals grown aboard the ISS. Eventually the entire protein crystal growth effort was also terminated. The Biotechnology Facility was likewise cancelled. These actions followed a low priority assignment by the ReMaP task force and a National Research Council report in 2000 that expressed reservations regarding the inconclusive and often incremental progress made by space researchers to up to that time.

Finally, The Advanced Human Support Technology rack, though it was a component of the high-priority bioastronautics program, was cancelled in this era over concerns about the absence of clearly defined research objectives.

At this stage, it would cost several billions of dollars to re-instate the full scope of these research facilities. In the case of the suite of equipment planned for the CAM, the cost and technical challenges remain unresolved and only the Space Shuttle had the capability to deliver this very large pressurized laboratory element. In other cases, research priorities have continued to evolve – contemporary science objectives are increasingly focused on nano-scale inorganic systems and the molecular and cellular levels for organic systems. These pursuits are best accommodated through unique instruments designed for orbital research at the sub-rack level. The ExPrESS Rack architecture employed on the ISS was designed for these purposes, and the opportunity for continuous upgrade of experiment-specific research instruments remains available today and fits within the projected transportation capability.

While some research facilities were cancelled because they no longer supported NASA's exploration goals, several new facilities have entered the program since the ESAS study definitively established the content of the exploration-driven ISS research program. NASA is now planning to launch the second and third Minus Eighty Laboratory Freezers for the ISS (MELFI-2 and MELFI-3), and leave them on orbit as permanent ISS freezers to increase storage capabilities, rather than use them to transport frozen stowage back to Earth. The Muscle Atrophy Research System was developed cooperatively with ESA and is being targeted for launch on the Shuttle. Also additional ExPrESS multipurpose racks are planned for launch on Shuttle flight 19A (STS-131). Several externally mounted payloads are being planned either for launch on the

Shuttle, or for launch vehicles that will provide the next generation of transportation to the ISS. Among these payloads are the Materials International Space Station Experiment (MISSE), the Hyperspectral Imager for the Coastal Ocean (HICO), the Remote Atmospheric and Ionospheric Detection System (RAIDS), and the Communications Navigation and Networking Reconfigurable Testbed (CONNECT).

7.0 BUDGET PLAN

The President's FY 2010 budget request is based on the assumption that the ISS program would conclude in the 1st quarter of FY 2016 when the U.S. laboratory reaches its 15-year design lifetime. While NASA has taken no steps to preclude extension of the ISS beyond this period, a formal decision on whether or not to extend is pending consideration by the Administration of the results of the ongoing Review of U.S. Human Space Flight Plans. In the event of a decision to extend, NASA is prepared to develop a budget plan to meet the new objectives.