NASA Report

to

Committees on Appropriations

regarding

Alpha Magnetic Spectrometer (AMS)

February 2008

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I. Introduction

The following direction for NASA was included in the Explanatory Statement accompanying the FY 2008 Omnibus Appropriations Act (P.L. 110-161):

"The Administrator is directed to study the possibility of delivering the Alpha Magnetic Spectrometer (AMS) to the International Space Station. Not only will this mission enable researchers to prepare NASA and our international partners for future space exploration, it has widespread support in Congress. This study shall be submitted to the Appropriations Committees within 30 days of enactment of the Act and should include the steps necessary to prepare for such a mission."

In response to this direction, the enclosed study will address the technical and programmatic steps necessary to deliver the AMS to the International Space Station (ISS). Specifically, the study will address the completion of AMS experiment development, launch preparation activity (including integration onto a launch vehicle), delivery to the ISS, and integration with the Station. These steps and associated schedules will be summarized in section IV.

II. Background and current status

The AMS science experiment was selected by the U.S. Department of Energy (DOE) Office of Science in 1995. DOE is the sponsor of the 16-nation AMS International Collaboration that is responsible for AMS experiment development and testing. NASA signed a 10-year Implementing Arrangement (IA) with DOE in 1995, agreeing to integrate and launch AMS on the Space Shuttle twice: first, on a science and engineering test flight which was successfully accomplished on STS-91 in 1998, and second, to the International Space Station (ISS) to be installed as an externally attached payload. In the aftermath of Columbia and with the 2005 expiration of the AMS IA, DOE was notified that NASA would not be able to launch AMS on the Space Shuttle to the ISS due to technical and schedule constraints associated with the critical support of the ISS. NASA notified DOE subsequently that NASA AMS Shuttle/ISS integration activities would continue as long as these activities remained viable.

The AMS flight hardware (including the 2,500-liter superfluid helium tank, cryocoolers, and other associated hardware) was designed to support a baseline three-year science mission aboard ISS. AMS can also continue to support some minimal science operations once the helium supply is exhausted AMS in total weighs 15,100 lb (6,860 kg) including the experiment and NASA integration hardware, and has a volume of approximately 1,800 cubic ft (51 cubic m).

Figure 1 shows an artist's rendering of AMS deployed on the ISS. Figure 2 shows a cut-away view of AMS.

Completion of AMS Experiment Final Assembly

Final assembly of the AMS experiment began in August 2007, in a dedicated AMS clean room at the European Center for Nuclear Research (CERN). As part of this process, the AMS particle detector flight hardware and associated electronics and fluid piping were installed (see Figure 3). According to the current schedule, all of the detectors will be completely integrated by February 2008. The remaining major systems to be installed are the radiators and the flight magnet. These items are scheduled to arrive at CERN in May 2008. Once these items have been installed, along with their control electronics and fluid supplies, the payload will undergo a series of functional checkouts before being released for final experiment calibration.

Final Experiment Calibration

Current plans call for AMS to undergo high-energy particle beam testing at CERN in the October-November 2008 timeframe. This testing will ensure that data recorded by AMS are optimized. Use of CERN Accelerator Beam Facilities has already been coordinated with the CERN management by the AMS International Collaboration. During final assembly, functionality of the experiment's particle detectors will be checked out using cosmic rays. While this provides acceptable detector calibration, it does not provide the precise calibration required for AMS science because of the low incidence and unknown momentum of cosmic rays. The dedicated test beam available at CERN will address this by providing a beam of artificial particles of known composition and momentum over a wide range of entry angles into the AMS experiment. Based on the AMS team's long experience with particle beam tests, this calibration activity is estimated to require approximately one month.

Figure 1: AMS on ISS

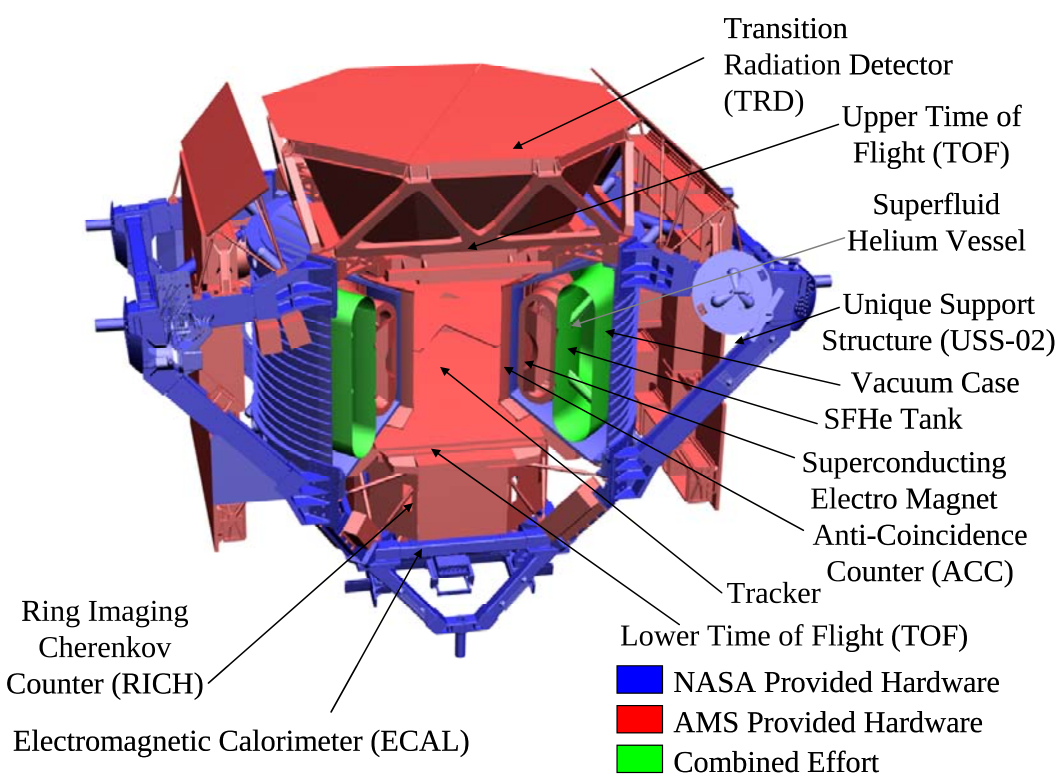

Figure 2: Cut-away View of AMS Showing Experiment Detectors

Figure 3: AMS Integration Status on November 23, 2007

Thermal/Vacuum Testing

The AMS payload will be tested for approximately 30 days in the European Space Agency (ESA) Large Space Simulator at Noordwijk, The Netherlands, in the December 2008 timeframe. Use and funding of the ESA facilities has already been coordinated with ESA by the AMS International Collaboration. The primary purpose of this test is to show that AMS can survive and operate under vacuum conditions. During three hot-cold cycles, the AMS thermal interfaces will be verified, thermal control systems thoroughly tested, and all electronics operated. A thermal balance test will be performed to help correlate the thermal model in order to better understand AMS on-orbit thermal behavior.

AMS Transport to the NASA Kennedy Space Center

Following successful thermal/vacuum testing, the AMS experiment is expected to be delivered to the NASA Kennedy Space Center (KSC), Florida, no earlier than 2009. The AMS International Collaboration will have the responsibility for shipment of AMS to KSC. In the interim, while awaiting delivery to KSC, AMS will undergo additional experiment calibration in Europe as time allows.

III. NASA AMS Integration Readiness

The FY 2008 NASA AMS Integration budget covers only the integration of the AMS onto the International Space Station (ISS) as an externally attached payload, and the option of integration onto the Space Shuttle, but not the launch of the payload.

III.A. Steps for NASA AMS Launch Integration

III.A.1. Hypothetical Shuttle Launch Integration

NASA AMS-Space Shuttle Integration Flight Hardware Delivery

The NASA AMS integration flight hardware, which has already been developed and delivered to CERN, has three primary functions. The NASA integration hardware would provide the structural, thermal, and avionics interfaces between both AMS and the Space Shuttle, and AMS and ISS. Combining ISS/Shuttle/AMS experiment interface functions, the NASA integration hardware is relatively lightweight (3,800 lbs./ 1,700 kg), increasing the ability to co-manifest the AMS in a Space Shuttle payload bay while displacing the minimum of critical ISS cargo items on the same flight. A similar lightweight NASA AMS integration hardware design approach enabled an earlier version of the experiment to be successfully co-manifested with space station Mir components on the STS-91 Space Shuttle flight in 1998. The relatively early delivery of the NASA integration flight hardware to CERN for incorporation into the overall AMS experiment final assembly process reflects the integral role of the NASA integration flight hardware in the AMS experiment design (see Figure 4).

The AMS cryogenic superconducting electromagnet system at the heart of the AMS experiment must operate in a vacuum. The required pressure control to support this is provided by the NASA-built cylindrical Vacuum Case. This Vacuum Case is, in turn, attached to the NASA-built Unique Support Structure (USS-02). Together, these two NASA flight hardware items provide attachment points for the entire AMS experiment as well as the Space Shuttle. At the bottom of the USS-02 is the NASA-built Payload Attachment System, a triangular structure which is the experiment's primary structural interface with the ISS. While AMS is in the Shuttle, power and data services from the Space Shuttle would come through the Remotely Operated Electrical Umbilical mounted on the front starboard side of the USS-02. The NASA-provided Flight Releasable Grapple Fixture would transfer AMS out of the Shuttle's payload bay. During the transfer from Shuttle to ISS, power and data services would be provided through a NASA-provided Power and Video Grapple Fixture mounted on the USS-02. Finally, on ISS, power and data for the AMS experiment would be provided through the NASA Umbilical Mechanism Assembly mounted on the lower part of the USS-02.

Safety Integration (Flight Safety/ Launch Site Safety)

In May 2007, the AMS project successfully completed the Phase II flight safety process. In the Phase II review, the NASA Flight Safety organization critically reviewed the design, operation and verification processes of the AMS and found it compliant with all documented requirements for safe flight aboard a Space Shuttle and delivery to the ISS. Also at this review, AMS compliance with ISS safety requirements was reviewed and approved. The final Phase III safety review (currently set for early FY 2009) is scheduled to report on the progress of any remaining safety verifications noted during Phase II. No major flight safety issues are anticipated for flying AMS on a Space Shuttle.

The AMS ground safety process Phase II review is scheduled to be completed in May 2008. During this review, the operations of the AMS and associated ground support equipment will be assessed for compliance with KSC safety requirements. This KSC review relies heavily on safety compliance documentation already provided to the NASA Johnson Space Center (JSC) flight safety review to resolve any issues directly associated with the AMS flight hardware. The Phase III Ground Safety Review for AMS (currently anticipated for early calendar year 2009) will document the final procedures for, and required verification of, safety compliance. No major ground safety issues are anticipated for AMS.

Analytical and Operations Integration

A preliminary AMS Mission Integration Plan has been developed. This plan documents all of the requirements of AMS and the Space Shuttle programs. The AMS and Shuttle programs are moving forward to develop, by early 2009, all required analytical and operations data to support an AMS launch on the Space Shuttle. This data will be coordinated with the ISS Program as required**.** No major analytical/operations integration issues are anticipated for AMS.

Potential for Manifesting AMS on a Currently-Planned Shuttle Flight

All remaining Space Shuttle flights to the ISS are fully manifested with critical items needed to complete assembly of the ISS and to preposition sufficient spares and associated stowage hardware onboard the Station for post-Shuttle operations. NASA has prioritized Space Shuttle payload space and the flight sequence to focus on delivering hardware and supplies to sustain the ISS; all available Space Shuttle capacity through program retirement in September 2010 will be needed to accomplish this task. The remaining Space Shuttle flights to ISS, 10 assembly and logistics flights plus up to 2 contingency flights that could be added to the manifest(if they can be safely flown before September 2010), are fully subscribed with these critical payloads. The recent issues with the alpha and beta solar array joints on the ISS demonstrate the criticality of maintaining the flexibility of manifesting additional spares and supplies on these last few Space Shuttle flights. Pre-positioning spares in 2009-10 will facilitate ISS operations after Shuttle retirement and before commercial cargo services are available to support the

Space Station. This helps reduce dependence on Russia and facilitate continued Space Station activities in support of exploration and science.

The AMS experiment would occupy roughly 43 percent of a Shuttle's payload capacity by weight, and roughly 25 percent by volume. While AMS would not necessarily require a dedicated Shuttle flight, manifesting AMS on a Shuttle flight would require bumping other selected, critical ISS hardware and/or supplies that were planned for that flight. If the decision were made to bump critical ISS hardware and spares in favor of AMS, then AMS would have to be manifested on a currently-planned Space Shuttle flight no later than February 2009.

Figure 4: NASA-Provided Integration Hardware

Potential for Manifesting AMS on an Additional Shuttle Flight

Adding another Space Shuttle flight to the manifest would be difficult, costly, and would have a significant negative impact on NASA's exploration program.

The high fixed costs of yearly Space Shuttle operations and the need to protect critical Space Shuttle capabilities in the event of a launch delay make it very difficult to extend the manifest part way into a new fiscal year without accruing nearly all the costs of the entire year. Flying the Space Shuttle safely requires multiple production and operations contractors whose unique capabilities must be maintained through the last flight of the program. Those contracts have been aligned to conclude with the end of the Space Shuttle program in FY 2010. The costs of re-opening those contracts to add an additional flight in FY 2010 would be substantial, with preliminary estimates on the order of $300 – 400 million. The costs of re-opening contracts and maintaining the capability of flying the Space Shuttle into FY 2011 (including the need to protect capabilities if a launch delay pushed the flight beyond the first quarter) would be even more substantial, with preliminary estimates on the order of approximately $2.7 – 4.0 billion. These costs would come directly at the expense of exploration development activities. Also, since exploration needs facilities and workforce that are currently dedicated to Space Shuttle operations, any delay in Space Shuttle retirement would have a significant negative impact on exploration development activities and further exacerbate the strategic gap in U.S. human spaceflight. In terms of schedule, mission-planning activities begin approximately 18 months prior to launch. This means that, if a major change needs to be made to the end of the Space Shuttle manifest prior to retirement in FY 2010, a decision to add an additional Space Shuttle flight would have to be made no later than February 2009.

In summary, the existing Space Shuttle flight schedule, and potentially up to two contingency logistics flights, may be achievable before FY 2010 retirement. However, the program does not have a significant amount of margin to accommodate an additional flight for AMS without significant impacts to future exploration goals, cost, and possibly safety.

III.A.2. Hypothetical ELV Launch Integration

Summary of Early Studies

In early 2006, NASA studied alternative launch options using ELVs to launch AMS to the ISS. Specifically, NASA reviewed a number of alternatives, including existing U.S. ELVs, European ELVs, Russian ELVs, potential Commercial Orbital Transportation Services (COTS)-derived vehicles, and the Japanese H-II Transfer Vehicle (HTV). One proposal even considered a combined Shuttle and ELV alternative that would reduce the cost of the spacecraft required to carry AMS to ISS because the approach would have used the Shuttle as a ferry between the AMS spacecraft and the ISS. At the time of these studies, the AMS development was still in the design phase, with much of the flight hardware not yet fabricated. Even at that point, it was determined that AMS could not fly on these alternative launch vehicles without major modifications to the NASA-built carrier/upper stage. Total cost for a U.S. ELV launch option was then estimated to range from $440-564 million, while the estimated cost for the Japanese HTV option ranged from $254 million (which included a rebate for a barter arrangement with the Japanese) to $380 million. Most of the ELV options resulted in estimated AMS schedule delays of at least two years to 2011, depending on launch vehicle availability (the ELV option involving a Shuttle rendezvous would have resulted in a launch delay to 2010).

Current Potential for AMS Manifesting on an ELV

Since the completion of the AMS alternative launch studies in 2006, the AMS development effort has completed design and flight hardware fabrication phases, subcomponent testing, and is now in the final assembly and testing phase. While some of the earlier ELV launch options are still theoretically available (for example, a non-standard Japanese HTV, or a non-standard COTS-derived vehicle), retrofitting the AMS for an ELV launch to the ISS at this point would likely involve the disassembly of the experiment, and subsequent retesting, redesign, modification and/or replacement of finished AMS flight hardware. This is because the NASA-provided AMS ISS/Shuttle integration hardware is also an integral part of the AMS experiment itself in terms of handling structural loads and thermal conductivity. To access the NASA integration flight hardware for ELV retrofitting would require, literally, taking the AMS experiment apart at over 900 physical interfaces to enable flight hardware modification and/or replacement. The early 2006 ELV studies' cost range of $254-564 million would likely now approach $1.0 billion or more if additional disassembly, retesting, redesign, modification, and/or replacement of much of the $1.5 billion AMS experiment flight hardware is required (see Figure 5). A recent United Launch Alliance proposal identified three different ELV architectures that might lift AMS to orbit without disassembly of AMS, ranging in price $200-290 million. When these costs are combined with the costs to develop a spacecraft bus able to meet both AMS power/communications requirements and ISS visiting vehicle requirements, and the costs to recertify AMS for launch on the new vehicle, overall mission costs would approach $570-600 million. The AMS launch schedule would likely be delayed to at least 2013 or 2014, two-three years or more beyond the 2011 estimate associated with those earlier options remaining theoretically available. Moreover, launching in that timeframe implies that the three-year minimum AMS science mission on ISS may not be completed by FY 2016, when current projections show ISS operations funding terminated.

In summary, the technical complexity of a hypothetical alternative AMS launch option to ISS involving ELVs has increased, making it much more difficult to retrofit the AMS experiment to an ELV. NASA has no funding to retrofit AMS for an ELV launch to ISS. If NASA were required to do so, the funding needed to accomplish such AMS ELV retrofitting would damage other established and agreed-upon NASA priorities.

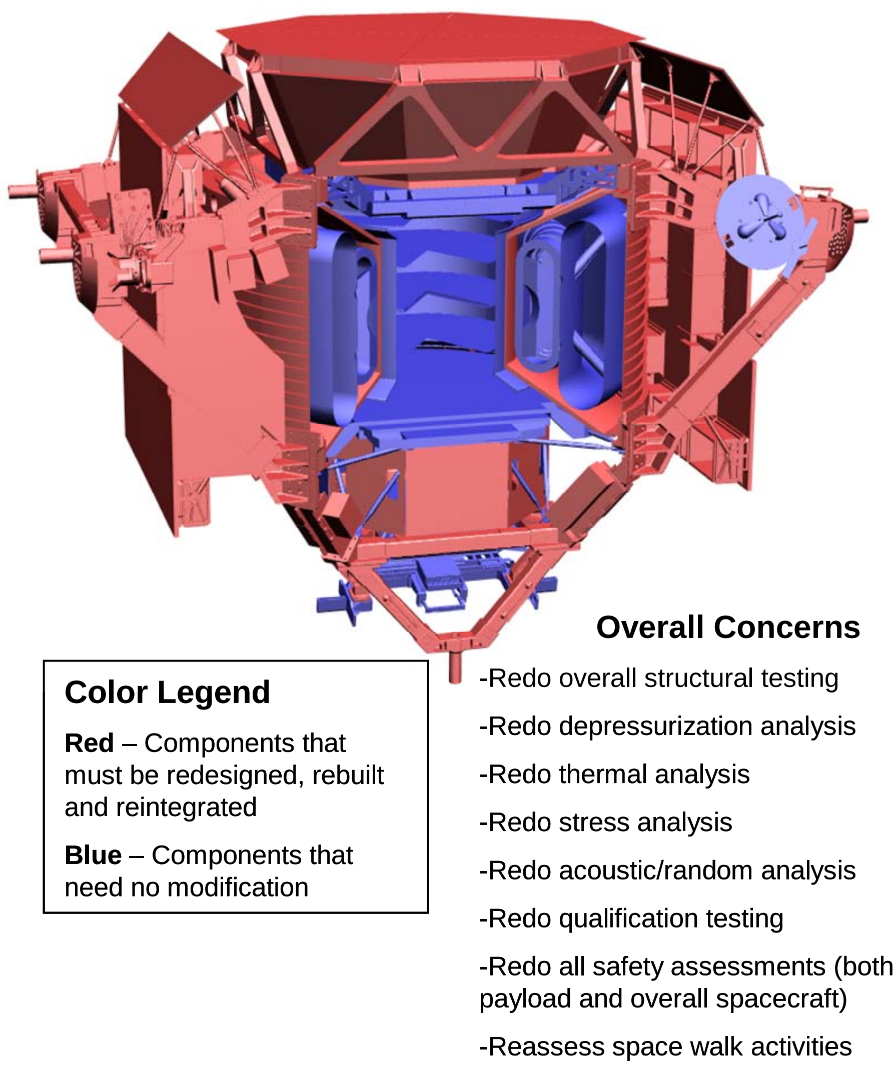

Figure 5: AMS Required Flight Hardware Changes for Hypothetical ELV Launch to ISS (updated since the early 2006 studies)

III.B. Steps for NASA AMS ISS Integration

ISS S3 Truss Installation

In June, 2007, the ISS S3 Truss segment was successfully added to the ISS during the STS-117 Shuttle flight. The S3 Truss has four external mounting locations; one of these locations could be the final mounting point for AMS. With the installation of the ISS S3 Truss segment, there is now sufficient ISS infrastructure in place to physically interface with the AMS experiment once launched. Figure 6 shows the S3 truss installed on-orbit.

AMS Safety Integration

As discussed in section III.A.1, the AMS flight safety process for operations aboard the ISS has successfully passed the most critical of the three required phases of safety review -- the Phase II review in May of 2007. The combined NASA Space Shuttle/ISS Flight Safety organization has critically reviewed the design, operation, and verification processes of the AMS and found them compliant with all documented requirements for safe operations aboard the ISS. The remaining safety review, known as the Phase III review (currently anticipated for early 2009), will report progress on open items from the Phase II review. No major flight safety issues are anticipated for AMS operation on the ISS.

The ISS has no unique requirements for ground processing safety; these are established by the launch vehicle and its host location.

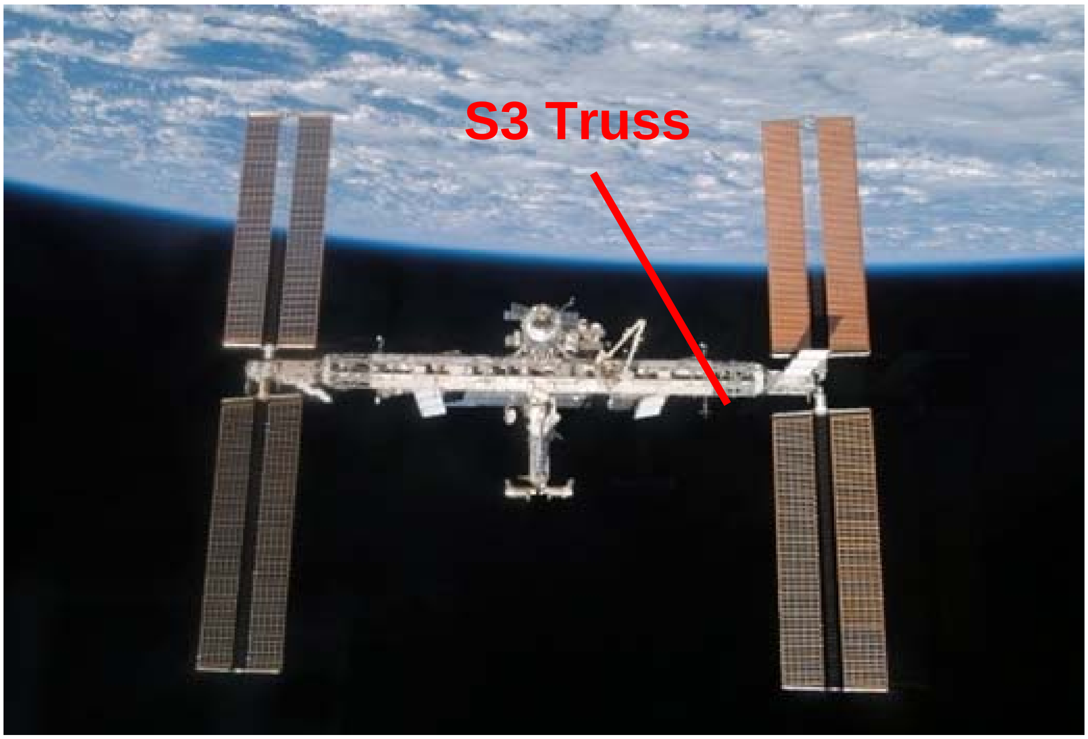

Figure 6: S3 Truss Installed on ISS

ISS/AMS Analytical/Operations Integration

The ISS Program and AMS Program have been working since 1999 to develop all necessary analytical and operations integration approaches and documentation. All AMS requirements are fully defined, and the AMS Program is working to verify that the requirements are being met. The ISS Program continues to support the AMS Program as needed to complete all necessary tasks to make AMS ready for its mission on ISS. In addition, the ISS Program will coordinate AMS analytical/operations integration planning with the Shuttle Program as required. No major ISS analytical/operations integration issues are anticipated for AMS operations on ISS.

ISS Power Availability

The ISS S3 Truss sites have adequate power interfaces to support AMS power needs once AMS is deployed on ISS. AMS requires 2,400 Watts of power on average and a peak of 2,800 Watts of power. Available ISS power resources would be sufficient for nominal AMS science operations.

ISS Data Availability

The ISS currently has adequate resources on-orbit to support AMS data needs. The AMS requires 2 Megabits per second of data on a continuous basis. The ISS can provide a data stream of 50 Megabits per second. In the event that AMS does not receive continuous data downlinks to Earth, AMS can store data on-orbit and burst the data down at rates as high as 40 Megabits per second.

ISS crew availability

Since AMS command and telemetry would be operated from the ground, only minimal crew interaction would be required for the initial robotic installation of the AMS on the ISS S3 Truss. As such, ISS crew resources would be sufficient for AMS.

In summary, there are no major ISS integration issues regarding AMS at this time.

IV. Summary of Steps Necessary to Deliver AMS to the ISS (see Table 1)

AMS continues to meet its internal project milestones for integration. Final payload integration is scheduled to be completed by early 2009.

However, the Space Shuttle manifest is fully subscribed with hardware and supplies needed to safely maintain the ISS in the post-Shuttle era. Manifesting AMS on one of the few remaining scheduled Space Shuttle flights would mean bumping other selected, critical ISS hardware and spares needed to maintain the ISS after September 2010. There are currently no Space Shuttle payload opportunities for AMS available before program retirement in September 2010. Adding an additional Space Shuttle flight to the manifest before September 2010, assuming contracts could be reworked, sufficient parts could be built and the schedule would allow such a change, would cost approximately $300-400 million and would mean accepting additional schedule and programmatic risk in the Shuttle program. Adding an additional Space Shuttle flight to the manifest after September 2010 and maintaining the infrastructure needed to safely fly the Space Shuttle into FY 2011 would cost approximately $3-4 billion, and have both a significant negative impact on NASA's exploration program and the potential of adding additional safety risks to the Space Shuttle program. In order to meet the 18-month mission planning lead time requirement, a decision to either manifest AMS on a currently-planned Space Shuttle flight or to add a new Space Shuttle flight for AMS would have to be made no later than February 2009.

Modifying the AMS hardware at this late stage to fly on an ELV would delay the launch until 2013 or 2014 and add at least an additional $0.57-1.0 billion to the cost of the project. No actions have been taken to modify the AMS hardware to launch on an ELV, and NASA has no budget to do so. Moreover, a 2013 or later ELV launch implies that the baseline AMS three-year science mission on ISS may not be completed by FY 2016 when current projections show ISS operations funding terminated. If NASA is required to retrofit AMS for an ELV launch to ISS, the funding needed to accomplish such an AMS ELV retrofit would damage other established and agreed-upon NASA science priorities.

NASA will continue to keep the Congress informed regarding AMS status.

Table 1 - Summary of Steps Necessary to Deliver AMS to the ISS

Steps Necessary	**Funding Responsibility**	**Timeframe (in calendar years)**
AMS Experiment Development Readiness for Launch		
- Completion of AMS Final Assembly	International/DOE	Late 2008
- Final Experiment Calibration	International/DOE	Late 2008
- Thermal Vacuum Testing	International/DOE	Late 2008
- AMS Transport to KSC	International/DOE	No earlier than 2009
NASA AMS Integration Readiness		
Shuttle Launch		
- NASA Integration Flight Hardware	NASA	Completed
- Safety Integration (Flight & Launch Site Safety)	NASA	Early 2009
- Analytical & Operations Integration	NASA	Early 2009
- Hypothetical AMS Manifesting Decision regarding a Currently-Planned Shuttle Flight	NASA	NLT February 2009
- Hypothetical AMS Manifesting Decision regarding a New Additional Shuttle Flight in FY 2010 or FY 2011	Unfunded	NLT February 2009
ELV Launch		
- Prior ELV Studies in early 2006	NASA	Completed
- Hypothetical AMS Manifesting Decision regarding an ELV (Updated since 2006 studies)	Unfunded	Launch 2013-2014 or later
ISS Integration		
- ISS S3 Truss Installation On-Orbit	NASA	Completed
- NASA AMS Integration Flight Hardware Delivery (Combined with Shuttle Hardware)	-	-
- Safety Integration (Combined with Shuttle Safety Integration)	-	-
- Analytical & Operations Integration (Combined with Shuttle Analytical Integration)	-	-
- ISS Power Availability	NASA	Completed
- ISS Data Availability	NASA	Completed
- ISS Crew Availability	NASA	Completed