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AUDIT REPORT

OFFICE OF AUDITS

A REVIEW OF NASA'S REPLACEMENT OF RADIATION MONITORING EQUIPMENT ON THE INTERNATIONAL SPACE STATION

OFFICE OF INSPECTOR GENERAL

National Aeronautics and
Space Administration

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Inspector General

Acronyms

ARI	Advanced Radiation Instrumentation
EV-CPDS	Extra-Vehicular Charged Particle Directional Spectrometer
EV-TEPC	Extra-Vehicular Tissue Equivalent Proportional Counter
EVA	Extra-Vehicular Activity
IRMA	Integrated Risk Management Application
ISS	International Space Station
IV-CPDS	Intra-Vehicular Charged Particle Directional Spectrometer
IV-TEPC	Intra-Vehicular Tissue Equivalent Proportional Counter
MORD	Medical Operations Requirements Document
MSL	Mars Science Laboratory
NPR	NASA Procedural Requirements
OIG	Office of Inspector General
RAD	Radiation Assessment Detector
REID	Risk of Exposure-Induced Death
REM	Roentgen Equivalent Man
ROM	Rough Order of Magnitude
TEPC	Tissue Equivalent Proportional Counter

OVERVIEW

A REVIEW OF NASA'S REPLACEMENT OF RADIATION MONITORING EQUIPMENT ON THE INTERNATIONAL SPACE STATION

The Issue

Space radiation, including gamma rays, protons, and neutrons, poses a danger to NASA's astronauts, increasing their risk of cataracts, cancer, damage to the central nervous system, and cardiovascular fatality.[1] Consequently, protecting astronauts from space radiation has been a fundamental requirement since space travel began.[2] To monitor astronauts' exposure to radiation while aboard the International Space Station (ISS) and to guard against overexposure, NASA installed a suite of monitoring instruments on the ISS between October 2000 and April 2002. However, these instruments have exceeded their design life; experienced varying degrees of failure, including in one case complete failure; and do not meet all ISS medical operations and radiation monitoring requirements. As a result, in 2008 NASA created the Advanced Radiation Instrumentation (ARI) Project to develop a new suite of instruments and ensure that NASA has the real-time information needed to protect its astronaut crews. Given the importance of radiation monitoring aboard the ISS and NASA's past challenges in the areas of acquisition and project management, the NASA Office of Inspector General (OIG) reviewed the ARI Project to assess its status and determine whether radiation monitoring and applicable project management requirements have been met. Details of the audit's scope and methodology are in Appendix A.

Results

NASA has poorly managed the development of replacement radiation monitoring instruments. As a result, the replacement instruments are costing more than expected, are behind schedule, and will not include all planned elements. More effective project management would have enabled the Agency to better use its resources to assess and protect astronaut health, ensure that astronaut radiation exposure is as low as reasonably

[1] Space radiation consists primarily of ionizing radiation in the form of high-energy, charged particles that can cause acute and long-term damage to living cells depending on the dose received. There are three naturally occurring and highly variable sources of this type of radiation: radiation trapped in the Earth's magnetic field, galactic cosmic radiation originating from outside the solar system, and radiation caused by solar events.

[2] Appendix B lists acceptable limits for astronaut radiation exposure, the health effects overexposure may cause, and a description of our review of astronaut exposure histories.

achievable, and collect data needed for planning long-range exploration missions during which astronauts' risk from radiation exposure will significantly increase.

In addition, until April 2010 NASA was developing an instrument that did not meet the radiation monitoring requirements identified in its ISS Medical Operations Requirements Document (MORD). The MORD specifies the monitoring and measuring requirements of charged particles outside the ISS, but NASA was developing an instrument that only would have measured radiation dosage.

Although we did not identify any instances of crewmembers exceeding defined radiation exposure limits, the instruments that provide real-time monitoring of the Space Station's radiation environment have reached the end of their design life and have partially or completely failed.

In addition, while reviewing NASA's management of the ARI Project and its development of new radiation monitoring instruments, we also found that the ISS Program has never monitored astronaut exposure to neutrons in accordance with MORD requirements.[3] Further, the Program had not adequately analyzed, planned, tracked, or controlled the risk created by this inability to monitor neutrons aboard the ISS. Research suggests that neutron radiation, which can deeply penetrate the body and damage blood-forming organs, may contribute as much as 10 to 30 percent of the total radiation dose received by astronauts inside spacecraft such as the ISS.

The ARI Project Is Costing More Than Planned, Is Behind Schedule, and Will Not Include All Planned Elements. The ARI Project experienced significant cost growth and schedule delays. Total estimated ARI Project costs increased approximately 62 percent, from $16 million to $26 million. Further, delivery of the new instruments has been delayed by almost 3 years. The cost growth and schedule delays occurred because the ISS Program approved the ARI Project based on cost estimates and schedule milestones that were not supported by accurate and complete data. For example, NASA did not have a firm proposal from the contractor responsible for building one of the replacement instruments when the ISS Program approved the ARI Project. When NASA received the proposal 7 months later, the cost of the instrument had nearly doubled from NASA's baseline projection.

Only after the ARI Project's Preliminary Design Review did ISS Program management completely understand the scope of work required to deliver the replacement suite of ISS radiation monitoring instruments, when the instruments realistically could be delivered, and how much they would cost. Baselining the ARI Project after the Preliminary Design Review, as described in NASA's project management policies, would have provided the Agency a better chance to deliver the Project within the planned cost, schedule, and scope.

[3] Section 7.5.3.2.1.3 of the ISS MORD requires that "[r]adiation monitoring instruments . . . provide the capability to characterize the neutron contribution to crew exposures."

We also found that the ARI Project included an instrument that did not meet existing external radiation monitoring requirements. Specifically, NASA did not review and, as necessary, formally initiate steps to revise radiation monitoring requirements during the early phases of the Project to ensure that the requirements, if met, would address the true radiation monitoring needs of the ISS Program. Johnson Space Center's Space Life Sciences Directorate should have established the current external radiation monitoring requirement and, if necessary, initiated steps to properly execute an official change to the MORD before beginning any development effort.[4]

As a result of these missteps, the ARI Project has been de-scoped, will not include all planned elements, and key radiation monitoring requirements for astronauts aboard the ISS continue to go unmet.

ISS Risk Management for Neutron Monitoring Was Inadequate. To accurately track astronaut radiation exposure and assess risks to crew health, the ISS Program is required to monitor the neutron portion of the radiation environment aboard ISS. However, the Program has never met the neutron-monitoring requirement and is not expected to do so before December 2014 when the instrument being developed to monitor neutrons will be available. In the interim, the Program did not adequately explain in its risk management system the context of the risk posed to astronaut crews. Further, the Program did not develop or document a plan to address the risk. NASA requires that risks be managed until they are mitigated or resolved. The failure to fully report the risk posed by the inability to monitor neutron radiation aboard the ISS meant that the issue did not receive the focused management attention required for timely resolution.

When we informed the Assistant Associate Administrator for ISS of this issue during the fieldwork for this audit, he acknowledged that the neutron risk had not been fully developed and directed the ISS Program to take immediate corrective action. Subsequently, the Program updated the ISS risk management system to more fully report the risk of not measuring astronaut exposure to neutrons while aboard the ISS. As a result, we are not making any formal recommendations related to this issue.

Management Action

To improve project management, we recommended that the ISS Program Manager ensure that all future ISS-related projects follow the tenets of NASA's project management policy and do not proceed to the implementation stage until managers demonstrate projects are properly anchored by firm requirements, realistic cost and schedule estimates, sufficient funding, and successful completion of a Preliminary Design Review.

We also recommended that Johnson Space Center's Director, Space Life Sciences, determine whether the current ISS medical operations requirement for external radiation

[4] The MORD must be updated in coordination with the Mission Integration and Operations Control Board, the Multilateral Medical Policy Board, and any affected international partners.

monitoring of the spectra of charged particles is appropriate and, if not, formally initiate steps to update the MORD in coordination with the Mission Integration and Operations Control Board, the Multilateral Medical Policy Board, and international partners.

In response to our draft report, the Assistant Associate Administrator for ISS concurred with our recommendations but took issue with some of our findings and conclusions. The full text of his comments are reprinted in Appendix C.

In response to our first recommendation, the Assistant Associate Administrator agreed to follow NASA's project management policy in the future. However, he stated that the ISS Program does not interpret NASA's policy to require that a project only proceed to implementation after completion of a Preliminary Design Review. He also took issue with our finding that the ARI Project has been poorly managed. Despite these disagreements, the Assistant Associate Administrator stated that as part of the lessons learned process the ISS Program will review how the ARI Project's cost and schedule estimates and assumptions concerning technology readiness levels were developed to determine what improvements can be made for future projects. The planned corrective action will be completed by December 15, 2011.

We consider the ISS Program's proposed actions to be responsive to the intent of our recommendation and will close the recommendation upon completion and verification of the proposed actions. We believe the planned review of the development of cost and schedule estimates and assessment of the technology readiness level for the ARI Project will help ensure future ISS-related projects are planned using more reliable estimates and more accurate information.

However, we disagree with the ISS Program's interpretation of NASA's project management policy. Section 2.3 of the policy establishes the project life cycle; describes the activities that occur in the formulation and implementation phases; and states that, although projects are initiated in the formulation phase, approval marks the transition from project formulation to implementation.[5] The Section further states that project plans – which include technical, schedule, and cost objectives – are baselined after the Preliminary Design Review and before approval to proceed to full implementation. After all, the purpose of the Preliminary Design Review is to establish the basis for proceeding with detailed design work by demonstrating that a project's preliminary design meets all requirements within an acceptable level of risk and existing cost and schedule constraints. Furthermore, Section 2.5 of the policy specifically lists the Preliminary Design Review as one of the internal reviews that leads to project approval and, therefore, implementation.

Although the ARI Project was given "full and final approval" in July 2008, managers did not gain a true understanding of the scope of work, cost, and schedule required until after the Project's Preliminary Design Review in April 2009. As a result, the Project's total estimated costs increased approximately 62 percent, from $16 million to $26 million; the

[5] NASA Procedural Requirements 7120.5D, "NASA Program and Project Management Processes and Requirements," March 2, 2007.

Project will not include one of the three planned instruments to reduce uncertainties in crew exposure and corresponding health risk; and delivery of one of the two remaining instruments has been delayed by almost 3 years. We believe these facts demonstrate that the Project was poorly managed and do not understand NASA's rationale for insisting otherwise.

In response to our second recommendation, the Assistant Associate Administrator stated that the Director of the Space Life Sciences Directorate will determine whether the current ISS medical operations requirement for external radiation monitoring of the spectra of charged particles is appropriate. Further, by October 15, 2011, the Director will provide the ISS Program with a plan to review and update the MORD. We consider the Space Life Sciences Directorate's proposed action to be responsive to our recommendation and will close the recommendation upon completion and verification of the proposed action.

CONTENTS

INTRODUCTION

Background

Exposure to space radiation, including gamma rays, protons, and neutrons, increases astronauts' risk of cataracts, cancer, central nervous system damage, and cardiovascular fatality.[6] NASA recognized this hazard and began monitoring astronaut exposure to radiation as early as Project Mercury in 1961 and has continued such monitoring during the Space Shuttle and International Space Stations (ISS) programs. Future long-duration expeditions outside Earth's protective magnetic field and into interplanetary space where space radiation is more intense will increase the risk of crew exposure. As NASA considers the feasibility of such future human space flight missions, radiation protection remains one of the key technological issues that must be resolved. Gathering accurate information on the effects of radiation aboard the ISS is an important step to understanding and resolving this issue.

Passive and Active Radiation Monitoring. To protect astronauts living and working aboard the ISS from the adverse effects of radiation, the ISS Medical Operations Requirement Document (MORD) establishes radiation health and exposure monitoring requirements.[7] Specifically, the MORD requires the monitoring and measurement of (1) radiation doses absorbed by human tissue, (2) charged particles and neutron radiation inside the ISS, and (3) charged particles outside the ISS during extra-vehicular activities (EVAs).[8] With regard to radiation, the Agency follows the "ALARA" philosophy, which means keeping astronaut radiation exposure As Low As Reasonably Achievable.

Because no single instrument is capable of measuring all energies, quantities, and types of radiation, NASA uses multiple passive and active monitoring devices to protect ISS crewmembers. Passive monitoring devices include personal dosimeters worn by each

[6] Space radiation consists primarily of ionizing radiation in the form of high-energy, charged particles that can cause acute and long-term damage to living cells depending on the dose received. There are three naturally occurring and highly variable sources of this type of radiation: radiation trapped in the Earth's magnetic field, galactic cosmic radiation originating from outside the solar system, and radiation caused by solar events.

[7] Space Station Program 50260, "International Space Station Medical Operations Requirements Document (ISS MORD)," Revision C, February 2006. Approval authority for the MORD is delegated to the Mission Integration and Operations Control Board, while the Multilateral Medical Operations Panel has control of all technical content of the MORD. Any changes or revisions to the MORD must be jointly agreed to and signed by NASA and the affected ISS international partners.

[8] Charged particles (protons and heavy ions) originating from solar flares and cosmic rays can cause acute and chronic health effects, depending on the dose received. The exterior of the ISS or fabric of a spacesuit can stop most charged particles; however, interactions of high-energy charged particles with spacecraft materials can produce neutron radiation (low-energy, uncharged particles). Neutron radiation, which also is generated by solar events, can deeply penetrate human tissue and damage blood-forming organs. Ten to thirty percent of the total radiation on the ISS is estimated to be neutron radiation.

crewmember that measure the dosage but not the type of radiation exposure. However, such passive devices do not provide real-time data and must be returned to Earth for analysis. In addition, they do not record the date and time an astronaut was exposed to particular doses of radiation. Accordingly, NASA supplements the data obtained from passive instruments with active instruments that provide the real-time measurements needed to allow crewmembers to take action in response to changes in the radiation environment in and around the ISS. For example, data from active instruments could alert NASA to a sudden or unexpected increase in radiation and allow crewmembers to take necessary action. In fact, after a large solar flare was detected the evening of December 12, 2006, crewmembers slept overnight in heavily shielded areas of the spacecraft as a precautionary measure.

A crewmember's cumulative radiation exposure history impacts his or her eligibility for future space flights. Therefore, radiation monitoring devices not only help NASA manage crew health and assess crew risk, they also are used to help make crew selection and assignment decisions. As described in Appendix B, each year a NASA radiation specialist uses the data from radiation monitoring devices to generate the Astronaut's Annual Radiation Exposure Report, which tracks each astronaut's career exposures and, thus, their eligibility for future missions. Career exposure limits, as specified in the MORD, cannot be 3 percent more than the general public's estimated risk of dying from cancer.

First Generation Active Monitoring Instruments: TEPC, IV-CPDS, and EV-CPDS. To characterize and quantify the radiation environment inside and outside the ISS, NASA installed three active monitoring instruments between October 2000 and April 2002:

1. The Tissue Equivalent Proportional Counter (TEPC) measures the real-time radiation dose human tissue receives inside the ISS. The TEPC became operational in October 2000 and continues to function, although it has a history of failures. The ISS has one operational TEPC and one spare unit on board. Both of these units have exceeded their design life by more than 3 years, and NASA has no other spares on the ground.

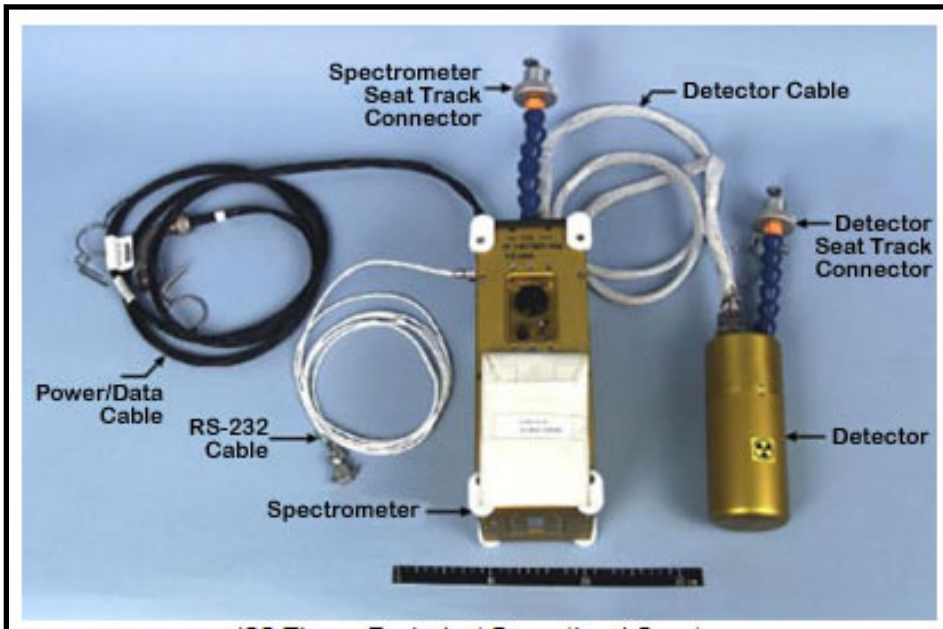
2. The Intra-Vehicular Charged Particle Directional Spectrometer (IV-CPDS) was deployed to the ISS in March 2001 to measure charged particles inside the ISS. The IV-CPDS failed in 2006 and has not been repaired or replaced. There are no spares. Intra-vehicular charged particle data is required to support crew risk estimation and recordkeeping as well as crew selection and assignment processes. According to NASA officials, data obtained from the instrument when it was operational along with ongoing research have led to the adoption of risk estimation procedures that help compensate for the loss of the instrument.

3. Flight controllers need information about radiation levels outside the ISS to evaluate the environment prior to and during spacewalks. To gather this information, NASA deployed the Extra-Vehicular Charged Particle Directional Spectrometer (EV-CPDS) to the ISS in April 2002. The instrument is essentially

three IV-CPDS units arranged at different angles on the outside of the ISS. However, only two of these units are operating – the third failed in May 2003 – and both have exceeded their design life by more than 5 years. In addition, NASA expects the units will fail before the ISS Program is scheduled to end in 2020.

Below are photographs of the first generation active radiation monitoring instruments (TEPC, IV-CPDS, and EV-CPDS).

Figure 1. TEPC, IV-CPDS, and EV-CPDS Photographs



ISS Tissue Equivalent Proportional Counter

IV-CPDS

EV-CPDS

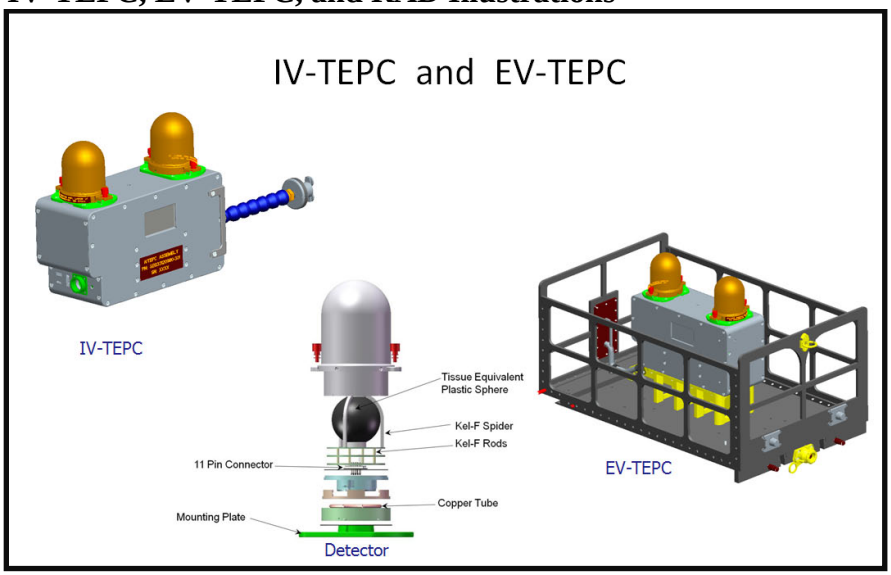
Source: Space Radiation Analysis Group, Johnson Space Center.

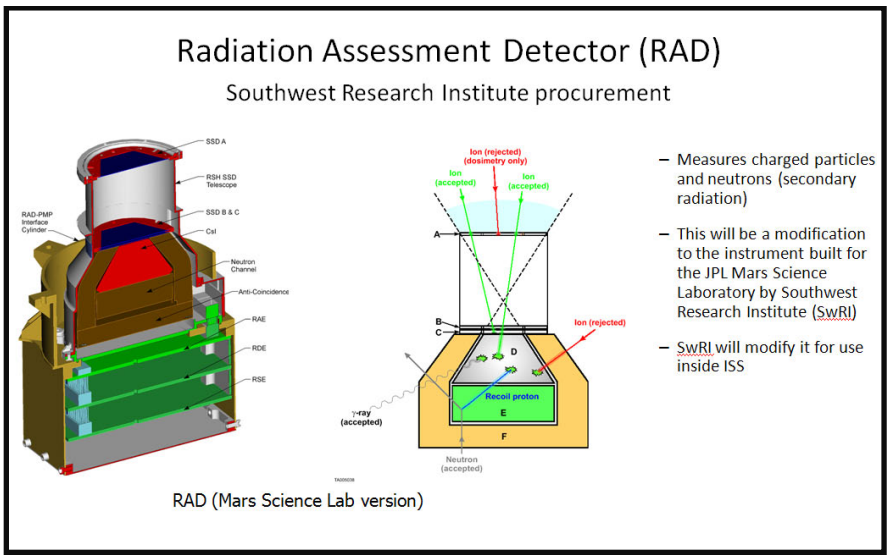
Replacement Suite of Active Monitoring Instruments: IV-TEPC, RAD, and EV-TEPC. In light of the repeated problems with the TEPC, the failure of the IV-CPDS

in 2006, and partial failure of the EV-CPDS in 2003, the ISS Program began developing a plan to replace the first generation hardware. In July 2008, the Program approved a replacement suite of active radiation monitoring instruments consisting of a new intra-vehicular TEPC (IV-TEPC); a Radiation Assessment Detector (RAD) to take the place of the IV-CPDS; and a second TEPC (EV-TEPC) to be deployed outside the ISS for monitoring radiation during EVAs. At the same time, the Advanced Radiation Instrumentation (ARI) Project was established at the Johnson Space Center (Johnson) to manage and develop the new instrument suite.

Below are illustrations of the three new instruments (IV-TEPC, EV-TEPC, and RAD) approved in the replacement suite.

Figure 2. IV-TEPC, EV-TEPC, and RAD Illustrations



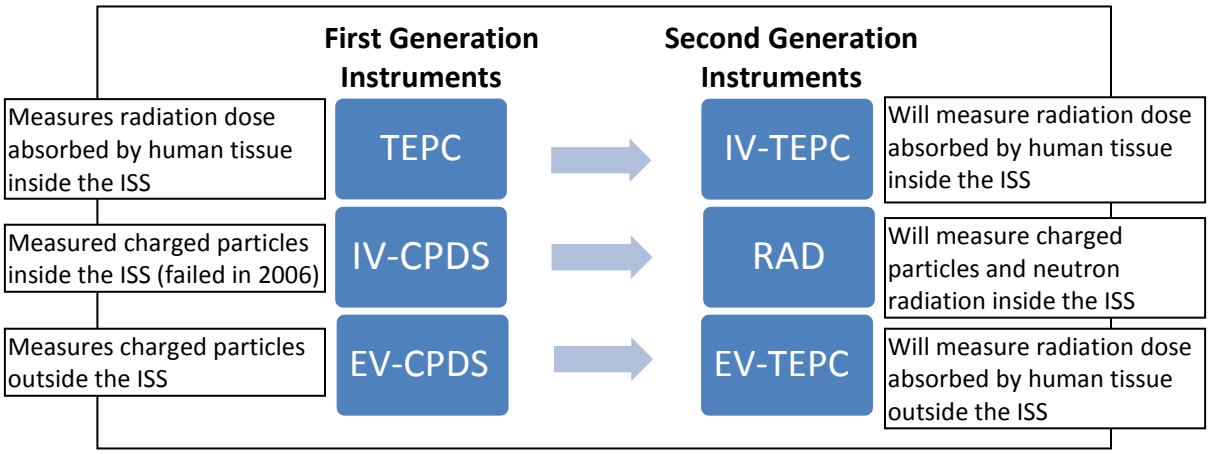


Source: Engineering Directorate's Avionic Systems Division, Johnson Space Center.

As shown in Figure 3 below, there are two fundamental differences between the proposed replacement instrument suite and the original hardware. First, the IV-CPDS will be replaced with a RAD that will measure charged particles inside the ISS. In addition, unlike the IV-CPDS, the RAD will also measure neutrons. At the time of proposal, a RAD had just passed Critical Design Review on the Mars Science Laboratory (MSL) payload complement, and the ISS Program hoped to develop an ISS RAD based on a modified design of the MSL model.[9] Southwest Research Institute designed both the MSL RAD and the ISS RAD.

Second, the instrument proposed to replace the EV-CPDS and measure radiation outside the Space Station would no longer monitor charged particles but instead would measure the radiation dose absorbed by human tissue. Specifically, Johnson's Space Life Sciences Directorate and ISS Program management told us that their experience with the EV-CPDS gave them a good understanding of the charged particle environment outside the ISS. Based on 10 years of using the EV-CPDS, they determined that the real need on the ISS was an EV-TEPC, which would measure the radiation dose absorbed by human tissue during EVAs. However, as discussed below, the current MORD requires measurement of charged particles.

Figure 3. Relationship between First and Second Generation ISS Active Radiation Monitoring Instruments and Corresponding Medical Operations Requirements



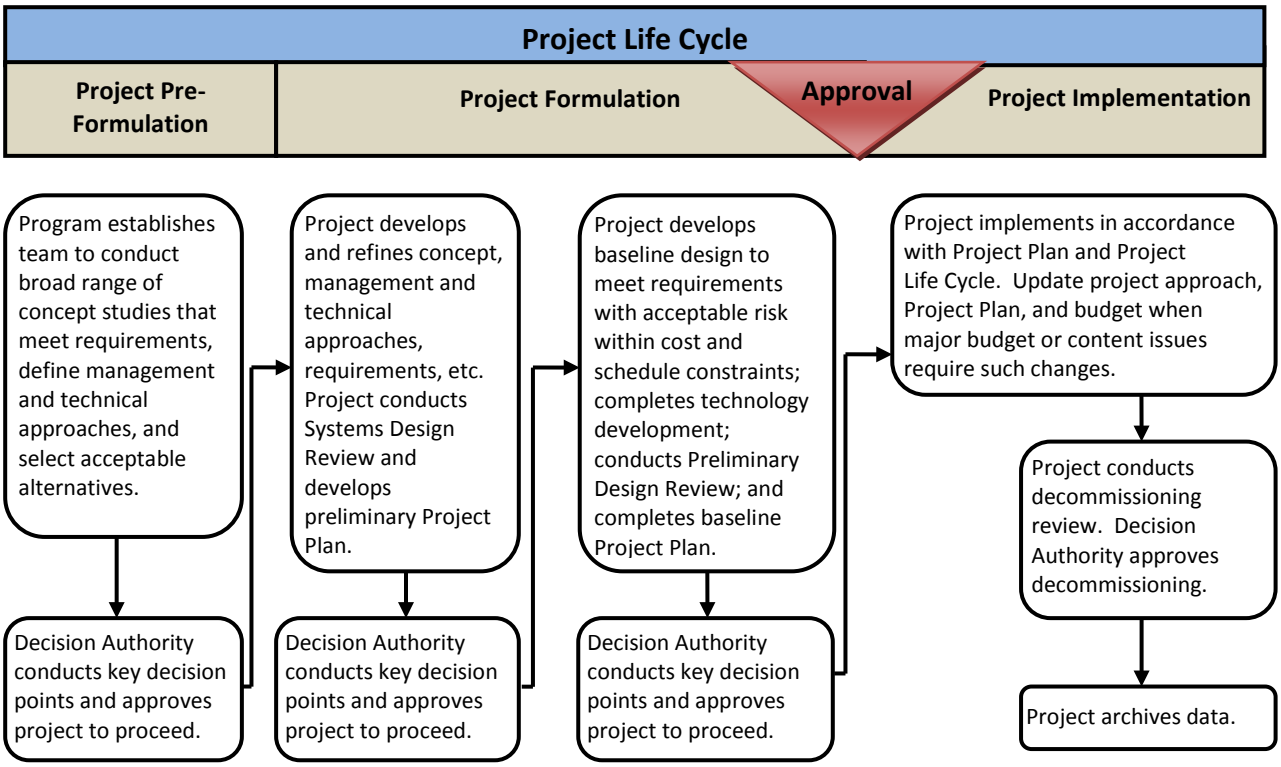
NASA Project Management Requirements. Agency-wide policies establish the requirements by which NASA should formulate and implement space flight programs and projects like the ARI Project.[10] Specifically, NPR 7120.5D and NM 7120-81 provide

[9] The Critical Design Review is a major milestone in program development, which demonstrates that a program's design is mature enough to proceed with full-scale fabrication, assembly, integration, and testing. Additionally, the Critical Design Review ensures that the technical effort will complete flight and ground system development and mission operations and meet overall performance requirements within the identified cost and schedule constraints.

[10] NASA Procedural Requirements (NPR) 7120.5D, "NASA Program and Project Management Processes and Requirements," March 2, 2007, and NM 7120-81, "NASA Space Flight Program and Project Management Requirements," NASA Interim Directive for 7120.5D.

that project planning should be based on realistic cost estimates. In addition, as shown in Figure 4, during a project's pre-formulation and formulation phases, project managers are to develop and define requirements and the basis for cost and schedule estimates to meet those requirements. Moreover, before the project is approved for implementation, a Preliminary Design Review is required to ensure that all requirements can be met with acceptable risk and within cost and schedule constraints. At completion of the Preliminary Design Review, NASA's project management principles require a baseline Project Plan to guide the project through the implementation phase. Baseline schedule estimates should be achievable in light of projected costs and available resources and based on realistic supplier cost and schedule proposals.[11]

Figure 4. Space Flight Project Management Process Overview



Source: Adapted from NM 7120-81, "NASA Space Flight Program and Project Management Requirements," NASA Interim Directive for NPR 7120.5D.

[11] Baselines are an agreed-upon set of requirements, cost, schedule, designs, and documents. Changes to baseline information are made through a formal approval and monitoring process.

Objectives

Our objective was to determine whether the ARI Project was meeting cost, schedule, and performance requirements. In addition, we examined whether NASA managers followed applicable project management requirements when developing radiation monitoring instruments and managing the Project. See Appendix A for details of the audit's scope and methodology, our review of internal controls, and a list of prior coverage.

THE ARI PROJECT IS COSTING MORE THAN PLANNED, IS BEHIND SCHEDULE, AND WILL NOT INCLUDE ALL PLANNED ELEMENTS

The ARI Project has experienced significant cost growth and schedule delays. Total estimated ARI Project costs increased approximately 62 percent from a baseline figure of $16 million in 2008 to $26 million in 2009, and delivery of one of the instruments has been delayed for almost 3 years. These conditions occurred, in part, because the ISS Program approved the ARI Project based on cost estimates and schedule milestones that were not supported by accurate and complete data. In addition, we found that the Program made a determination that the existing MORD requirements did not reflect the most current knowledge and needs concerning external radiation monitoring. Based on this assessment and without seeking to amend the MORD, the Program planned an instrument that would not have satisfied existing MORD requirements. As a result of NASA's poor management, the Project has been de-scoped and will not include all planned elements; the ISS Program has not been able to timely address known concerns about failed or failing radiation monitoring equipment; and key radiation monitoring requirements continue to go unmet.

ARI Project Experienced Significant Cost Growth and Schedule Delays

The ISS Program baselined the ARI Project in July 2008, approving $16 million to deliver three instruments: an IV-TEPC, RAD, and EV-TEPC (two flight units and one qualification unit for each instrument).[12] Approximately 7 months later, the Project obtained a firm proposal from Southwest Research Institute, the company that was building the MSL RAD, to build the RAD for the ISS. The contractor's proposal of $13.7 million nearly doubled the RAD's baseline cost. The cost for the TEPCs also increased from the baseline figures due to higher-than-expected manufacturing costs and problems Johnson's Avionic Systems Division encountered when developing the instruments' detectors.[13] As a result, total estimated ARI Project costs increased approximately 62 percent, from $16 million to $26 million; development of the IV-TEPC slipped 11 months; development of the RAD slipped almost 3 years; the planned deliverables for the RAD have been reduced from two flight units and a qualification unit to one flight unit with spare parts; and the EV-TEPC has been canceled outright. The

[12] A qualification unit, identical to a flight unit in form, fit, and function, is used to verify and certify the instrument's environmental and performance requirements.

[13] As depicted in Figure 2 (page 4), the IV-TEPC and EV-TEPC each consist of two detectors to measure radiation doses.

increases in Project cost and schedule estimates for development of the new radiation monitoring instruments are shown in Table 1.

Table 1. ARI Project Cost and Schedule Increases

	2008		2009		2010		2011	
	Cost (millions)	**Completion Date**	**Cost** (millions)	**Completion Date**	**Cost** (millions)	**Completion Date**	**Cost** (millions)	**Completion Date**
IV-TEPC	$6.3	September 2010	$9.0	March 2011	$10.0	July 2011	$14.0	August 2011[a]
RAD	$7.3	May 2011	$13.7	Contract Award plus 30 Months[b]	$12.4[c]	March 2014	$12.4	March 2014[d]
EV-TEPC	$2.1	September 2010	$3.0	March 2011	Canceled[e]			
Total	**$15.7**		**$25.7**		**$22.4**		**$26.4**	

[a] The IV-TEPC was completed (built) and certified in August 2011. In December 2011, NASA will ship the unit to the European Space Agency's French Guiana launch site for delivery to the ISS in March 2012 aboard a European Automated Transfer Vehicle.

[b] Per Southwest Research Institute's February 2009 proposal for the RAD.

[c] Quantity decreased from two flight units and one qualification unit to one flight unit and spare parts. As a result, the estimated cost from the previous year decreased by $1.3 million.

[d] The RAD is scheduled to be completed (built and certified) by March 2014 and is planned to be delivered to the ISS by December 2014. Because delivery of the RAD will not occur for 3 years, NASA has not yet added the instrument to a launch vehicle manifest.

[e] In April 2010, the ISS Program Office removed the EV-TEPC from the ARI Project.

ARI Project Cost Estimates and Schedule Milestones Not Supported by Reliable Data

Although NASA's project management principles provide that managers base project planning on realistic cost and schedule estimates, the ISS Program approved and baselined the ARI Project in July 2008 using only on a Rough Order of Magnitude (ROM) estimate. Specifically, from February to May 2008 Johnson's Avionic Systems Division determined the Project's feasibility and developed a ROM estimate for an engineering change request to replace the ISS radiation monitoring hardware.[14]

[14] NPR 7123.1A, "NASA Systems Engineering Processes and Requirements" ensures configuration control of NASA systems, such as those aboard the ISS, by requiring that requested engineering changes are evaluated prior to being implemented. Typically, a formal board is established to receive, review, and approve engineering change requests, such as the request that was made to replace the ISS radiation monitoring equipment.

However, the estimate was not based on reliable cost and schedule data. For example, the ROM assumed a Project start date of February 2008; however, the change request was not signed until June 2008. Accordingly, the Project was behind schedule from the start. Further, at change request submittal, the Avionic Systems Division was unsure whether Texas A&M University, with which the Division had partnered to design and develop the IV- and EV-TEPC detectors, could produce the hardware. As work on the detectors progressed, the Division discovered that the University's quality control and production capabilities were insufficient to produce flight hardware. After evaluating several vendors, the Division determined the best course of action was to do the work in-house. Finally, NASA's ROM estimate for the TEPCs did not account for:

- the spare detectors the Agency decided were needed due to having limited access to the ISS after retirement of the Space Shuttle;
- higher-than-expected subcontractor and manufacturing costs; or
- cost reserves.

In an internal document, the Project Manager acknowledged the shortcomings of the ROM: "The [TEPC] design prototyping effort has taken longer than initially planned, and the learning curve has been steeper than expected . . . . There were some big assumptions and unknowns that went along with our original ROM."[15]

The estimate for the RAD was equally unreliable. NASA formulated the estimate prior to receiving a firm proposal from Southwest Research Institute, and the verbal ROM the Agency received from the Institute was based on an assumption that developing the ISS RAD hardware would be similar to developing the RAD for the MSL. However, the Institute did not fully understand the changes necessary to convert its MSL RAD design and develop hardware for use on the ISS. Consequently, NASA's ROM for the RAD incorrectly estimated the instrument could be delivered for about $7.3 million in May 2011. As noted above, the Institute's formal proposal was almost double the amount of NASA's original cost projections and the instrument will not be completed until March 2014.

In addition, we found that the Program did not gain a true understanding of the scope of work required to deliver the replacement suite of instruments, when the instruments could be delivered, and how much they would cost until after the Preliminary Design Review in April 2009. However, contrary to NASA guidance, the Project was baselined before the Preliminary Design Review. Documentation shows that the Project asked for "partial implementation to PDR [Preliminary Design Review]" and to be allowed to come back at Preliminary Design Review with "firm cost and schedule to completion." Although the ISS Vehicle Control Board approved this approach, the Project was given "full and final approval" in July 2008 and the initial ROM "stuck." In retrospect – and in keeping with

[15] "ISS Advanced Radiation Instrumentation Project State of the Project" presentation, dated July 13, 2009.

NASA's project management guidance – baselining the Project after the Preliminary Design Review would have provided NASA with a better opportunity to deliver the Project within the planned cost, schedule, and scope.

According to a Program official, the ISS Program Manager authorized the initial Project baseline using the ROM estimate because it was the best cost estimate available at the time. However, a ROM estimate is generally considered reliable only when the cost of the desired item is well known and based on previous experience with the vendor and product. Although Program officials believed they sufficiently understood the level of effort required to develop new ISS radiation monitoring instruments and modify Southwest Research Institute's design for the MSL RAD to make it suitable for the ISS, the informal ROM estimate ultimately proved inaccurate.

When the Program received an updated estimate for the TEPCs and a firm cost proposal for the work required to deliver the RAD, NASA was not able to obtain the replacement suite of instruments for the $15.7 million allocated in the baseline projection and therefore had to de-scope the ARI Project. Program managers de-scoped the Project by ending development of the EV-TEPC after spending an estimated $2.3 million. In addition, as mentioned previously, the de-scoping included reducing the RAD deliverables from an initially planned two flight units and a qualification unit to one flight unit and spare parts.

The EV-TEPC Would Not Have Satisfied Current Program Requirements

The ISS Program approved development of an EV-TEPC as a replacement for the EV-CPDS, an instrument currently operational but not expected to perform through the end of the ISS's life. As discussed previously, Johnson's Avionic Systems Division was designing the EV-TEPC to measure the amount of radiation that would be absorbed by human tissue. However, the current MORD requires measurement of the spectra of charged particles outside the ISS. As a result, the EV-TEPC would not have met the Program's current requirements as expressed in the MORD.

According to Johnson's Space Life Sciences Directorate, ISS Program officials determined that the lessons learned through continuous operation of the Space Station and data obtained from 10 years of operating the EV-CPDS resulted in the decision to replace the EV-CPDS with an EV-TEPC. Specifically, Program officials said they determined that, despite the MORD requirements, it is no longer necessary to characterize charged particles outside the ISS. Instead, according to an ISS Program official, the Program determined that the ISS needs an instrument to monitor the spacecraft's EVA environment and a TEPC placed outside the vehicle (an EV-TEPC) would provide measurements of the real-time dose of radiation an astronaut conducting an EVA would receive.

As shown in Figure 4 (page 6), a fundamental first step in NASA's accepted project management principles is to develop and define requirements. Therefore, the Space Life Sciences Directorate should have established what type of external radiation monitoring was required and, if necessary, properly initiated an official change to the MORD before beginning development of any instrument. Because responsibility for the safety of astronauts aboard the ISS is shared among the United States and its international partners, and because the MORD is the primary compendium of all health-related requirements for the ISS, NASA should have initiated a revision to the MORD through the established amendment process before changing the type of radiation monitoring instruments on the ISS.

The ARI Project Has Been De-Scoped and Will Not Include All Planned Elements

As a result of NASA's poor management of the ARI Project, the Project has been de-scoped and will not include all elements originally planned. In addition, the ISS Program has not timely addressed known concerns about failed or failing radiation monitoring equipment and key radiation monitoring requirements continue to go unmet. Specifically, due to the significant cost growth and schedule delays caused by reliance on unsupported initial cost and schedule estimates, the ISS Program directed Johnson's Avionic Systems Division to stop work on the EV-TEPC and RAD instruments in April 2010. Thereafter, the EV-TEPC, for which NASA had already spent about $2.3 million, was permanently removed from the Project. While development of the RAD resumed 2 months later, delivery of the instrument, originally planned for May 2011, will be delayed until March 2014, almost 3 years behind schedule. This delay inhibits the ISS Program's ability to restore the capability to measure astronaut exposure to charged particles inside the ISS – a requirement that has gone unmet since the IV-CPDS failed in 2006 – and establish the capability to measure astronaut exposure to neutrons while aboard the ISS – a requirement that NASA has never met. Additionally, although NASA's original plans for this important RAD instrument included two flight units and a qualification unit, the revised Project plan will result in only one flight unit and spare parts.

During the course of our review, we did not identify any instances of crewmembers exceeding defined radiation exposure limits. However, improved project management would have enabled NASA to more effectively target its resources to protect astronaut health, ensure that astronaut radiation exposure is kept as low as reasonably achievable, and collect data needed for planning future long-duration exploration missions in which astronauts' risks from radiation exposure will significantly increase.

Recommendations, Management's Response, and Evaluation of Management's Response

Given the importance of radiation monitoring aboard the ISS and NASA's challenges in the areas of acquisition and project management, we recommended that the Agency take the following actions to ensure ISS projects follow the tenets of NASA's project management policy and that MORD requirements are kept current.

Recommendation 1. We recommend that the ISS Program Manager ensure that future ISS-related projects follow the tenets of NPR 7120.5D and do not proceed to the implementation stage until project managers demonstrate projects are properly anchored by firm requirements, realistic cost and schedule estimates, sufficient funding, and successful completion of a Preliminary Design Review.

Management's Response. The Assistant Associate Administrator for ISS concurred, stating that the ISS Program and JSC will follow NPR 7120.5 for future projects. Additionally, the ISS Program will initiate a lessons learned review of the ROM cost and schedule estimates and an assessment of the technology readiness level for the ARI Project to determine what improvements can be made for the benefit of future ISS and Johnson projects. A lessons learned review for the IV-TEPC will be completed by December 15, 2011.

Although the Assistant Associate Administrator agreed with our recommendation and proposed corrective action, he indicated that "the ISS Program does not interpret NPR 7120.5D to mean that a project must be initiated only to Preliminary Design Review and then a subsequent authorization processed for implementation." In addition, the Assistant Associate Administrator disagreed with our conclusion that the ARI Project was poorly managed. His full comments are reprinted in Appendix C.

Evaluation of Management's Response. We consider management's proposed actions to be responsive to the intent of our recommendation and will close the recommendation upon completion and verification of those actions. However, we reiterate our finding that the ISS Program did not comply with the requirements of NPR 7120.5D and our conclusion based on that finding that the Project was poorly managed.

Specifically, Section 2.3 of the policy establishes the project life cycle; describes the activities that occur in the formulation and implementation phases; and states that, although projects are initiated in the formulation phase, approval marks the transition from project formulation to implementation.[16] The Section further states that project plans – which include technical, schedule, and cost objectives – are baselined after the Preliminary Design Review and before approval to proceed to full implementation. After all, the purpose of the Preliminary Design Review is to establish the basis for proceeding

[16] NASA Procedural Requirements 7120.5D, "NASA Program and Project Management Processes and Requirements," March 2, 2007.

with detailed design work by demonstrating that a project's preliminary design meets all requirements within an acceptable level of risk and existing cost and schedule constraints. Furthermore, Section 2.5 of the policy specifically lists the Preliminary Design Review as one of the internal reviews that leads to project approval and, therefore, implementation.

Contrary to these requirements, the ARI Project was baselined and given "full and final approval" 9 months before Preliminary Design Review using unreliable ROM cost and schedule estimates. As a result, the Project's total estimated costs increased approximately 62 percent, from $16 million to $26 million; the Project will not include one of the three planned instruments intended to reduce uncertainties in crew exposure and corresponding health risk; and delivery of one of the two remaining instruments has been delayed by almost 3 years. We continue to believe that the assumptions and underestimations made by Project managers and now acknowledged by the Assistant Associate Administrator, along with the premature approval of the ARI Project based on inaccurate and incomplete data, constituted poor project management. Moreover, in light of these facts, we do not understand NASA's rationale for insisting otherwise.

Recommendation 2. We recommend that Johnson's Director of the Space Life Sciences Directorate determine whether the current ISS medical operations requirement for external radiation monitoring of the spectra of charged particles is appropriate and, if not, formally initiate steps to update the MORD in coordination with the Mission Integration and Operations Control Board, the Multilateral Medical Policy Board, and any affected international partners.

Management's Response. The Assistant Associate Administrator concurred, stating that the Director of the Space Life Sciences Directorate will provide the ISS Program with a plan to review and update the MORD by October 15, 2011. He noted that the Space Life Sciences Directorate's understanding of the ISS radiation environment has improved over the years of ISS operations and that this has reduced the complexity of requirements and design solutions needed to safely manage overall crew risk. He also noted that the delay in updating the MORD "has not impacted the implementation of the necessary requirements on the ARI Project."

Evaluation of Management's Response. The Assistant Associate Administrator's comments are responsive to our recommendation. Accordingly, we will close the recommendation upon completion and verification of the proposed corrective action. Although we understand that NASA's understanding of radiation monitoring requirements has evolved over the years of ISS operations, we believe it is imperative that NASA and its international partners update the MORD to reflect this understanding. The MORD is the primary compendium of all health-related requirements for the ISS. Therefore, the MORD should have driven the formulation of the ARI Project. If the Project believed that the MORD no longer reflected the most current knowledge, it should have initiated a revision to the document through the established amendment process.

ISS RISK MANAGEMENT FOR NEUTRON MONITORING WAS INADEQUATE

To accurately track astronaut exposure and assess risks to crew health, the MORD requires the ISS Program to monitor astronaut exposure to neutron radiation.[17] Monitoring such exposure is important because neutrons can affect blood-forming marrow in bones and may represent 10 to 30 percent of the total radiation dose an astronaut aboard the ISS receives. However, the ISS Program has never met this requirement and will not be able to do so until at least December 2014, when the RAD is scheduled to be delivered to the ISS. In the interim, the ISS Program had not adequately analyzed, planned, tracked, or controlled the risk posed by the Program's inability to measure neutrons.

The ISS Program uses the ISS Integrated Risk Management Application (IRMA) to manage risks related to the Program. Although we identified an entry in the database related, in part, to the lack of a neutron monitoring instrument on board the ISS, we found that the Program had not clearly and comprehensively explained the context of the risk posed to crews by this lack of monitoring.[18] Further, the Program had not developed or documented in IRMA a plan to address the risk.[19]

NASA requires that all project risks be managed until they are mitigated or resolved.[20] Risk management is an organized, systematic decision-making process that identifies, reduces, or controls risks to achieve program and project goals. Failure to fully report the risk posed by NASA's inability to measure crew exposure to neutrons while aboard the ISS meant that the issue did not receive the focused management attention required for timely resolution.

When we informed the Assistant Associate Administrator for ISS about this issue during fieldwork for this audit, he acknowledged that the Program had not fully developed the risk of its inability to monitor astronaut exposure to neutron radiation and directed the ISS Program to take immediate corrective action. Subsequently, the Program updated IRMA to reflect: (1) that the ISS is not equipped with an instrument designed to monitor neutrons; (2) that data provided by the TEPC instrument provides some insight into neutron radiation exposure, but not neutron-specific information; (3) that the Program accepts the risk of not having a neutron-specific monitoring device because the RAD will

[17] Section 7.5.3.2.1.3 of the ISS MORD requires that "[r]adiation monitoring instruments . . . provide the capability to characterize the neutron contribution to crew exposures."

[18] IRMA Watch Item 5686 "Tissue Equivalent Proportional Counter (TEPC) and Neutron Monitoring Devices Needed."

[19] The entry related to the neutron exposure issue reported an expected closure date of December 31, 2011 – clearly inaccurate in light of the expected December 2014 delivery date of the RAD to the ISS.

[20] NPR 8000.4A, "Agency Risk Management Procedural Requirements," December 16, 2008.

provide this capability; and (4) that the expected closure date for the neutron risk is December 31, 2014 – after the RAD is expected to have been successfully installed on board the ISS.

As a result of these corrective actions, we are not making any formal recommendations related to this issue.

Management's Comments on the Finding and Evaluation of Management's Comments

Management's Comments on the Finding. Although we did not make any recommendations based on this finding, the Assistant Associate Administrator noted in his response that NASA is currently controlling the radiation exposure risk to crewmembers to 95 percent confidence levels and that the current lack of neutron-specific monitoring does not prevent NASA from controlling the risk of the neutron component of radiation exposure. (See Appendix C for additional details.)

Evaluation of Management's Comments. As acknowledged in the Assistant Associate Administrator's response, the ISS Program currently lacks the capability to monitor the neutron portion of ionizing radiation as required by the MORD. Research suggests that neutron radiation, which can deeply penetrate the body and damage blood-forming organs, may contribute as much as 10 to 30 percent of the total radiation dose received by astronauts inside the ISS and other spacecraft. We believe installation of the ISS RAD in 2014 will enhance NASA's ability to track radiation exposure and risks to astronaut crews. In the interim, we support the actions NASA took during the course of our audit to more fully report the risk posed by NASA's current inability to measure crew exposure to neutrons.

APPENDIX A

Scope and Methodology

We performed this audit from December 2010 through August 2011 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objective. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objective.

Initially, we focused our review on processes used by the ARI Project to manage the development and implementation of Space Life Sciences radiation monitoring equipment needs. We interviewed key NASA Headquarters and Johnson Space Center personnel involved in the radiation monitoring program. We interviewed the Manager, ISS Vehicle Integration Office, to obtain background information on the ARI Project. We held multiple meetings with the ARI Project Manager to evaluate whether technical, cost, and schedule requirements were being met and to discuss the hardware content, cost, and schedule estimates.

Additionally, we compared the ARI Project's initial cost and schedule estimates with the current cost and schedule estimates. We also compared the Project's planned hardware content with the hardware content being built in 2011.

We identified and reviewed relevant Federal laws and regulations; NASA policies, procedures, plans, and guidance; and other criteria. We reviewed NASA and Johnson policies and procedures that prescribe the project management processes that should be followed to effectively meet a project's approved technical, cost, and schedule goals. Specifically, we reviewed:

- Johnson Space Center Engineering Directorate Work Instruction (EA-WI-023), "Project Management of Government Furnished Equipment (GFE) Flight Projects," Revision E, February 2006;
- NPR 7120.5D, "NASA Program and Project Management Processes and Requirements," March 2, 2007;
- NM 7120-81, "NASA Space Flight Program and Project Management Requirements," NASA Interim Directive for 7120.5D; and
- NPR 8000.4A, "Agency Risk Management Procedural Requirements," December 16, 2008.

We identified the ARI Project's baseline cost, schedule, and technical requirements and assessed the extent that Johnson's Avionic Systems Division and Space Life Sciences Directorate planned and took actions that would result in effectively developing and delivering a suite of replacement radiation monitoring instruments to the ISS.

We interviewed experts from Johnson's Space Radiation Analysis Group to identify and understand radiation monitoring requirements for the ISS, the extent these requirements are currently met, and how the proposed replacement suite of radiation monitoring instruments will meet the requirements. Also, we interviewed the Computer Resources Manager, Avionic Systems Division, to obtain an overview of the Avionics and Software Office responsibilities for the IV-TEPC development.

In addition to interviews, we obtained and reviewed documents to include:

- life-cycle documents;
- technical requirements, cost, and schedule data; Feasibility Assessment made by the Avionic Systems Division for the ARI Project, dated May 6, 2008, to obtain original hardware content, cost, and schedule estimates;
- Independent Government Cost Estimate made by Assessments, Cost Estimates and Schedules Office for ISS ARI Project dated May 12, 2008, to obtain independent cost and schedule estimates;
- ISS Change Directive 011073, dated July 3, 2008, and Revision 1, dated April 19, 2010, to obtain formal cost and schedule estimate and deliverables;
- internal task agreements between the ISS Vehicle Office and the Avionic Systems Division for fiscal years 2008, 2009, 2010, and 2011 to obtain formal cost and schedule estimate and deliverables; and
- financial data for work breakdown structure 401769.06.05.02.02.27 for ARI/IV-TEPC development from NASA's "Core Financial" system to compare with the Project Manager's current cost estimates.

From our interviews and analysis, we identified:

- the ISS radiation monitoring requirements contained in SSP 50260, "International Space Station Medical Operations Requirements Document (ISS MORD)," Revision C, February 2006;
- the extent that current instruments on board the ISS are satisfying the radiation monitoring requirements;
- whether NASA will have the replacement suite on board the ISS to prevent any gaps in continuously measuring and monitoring crew exposure to radiation;

- the capabilities of the TEPC currently on board the ISS, including its estimated useful life and whether the ISS Program has a backup plan should the TEPC fail; and

- the impact for a delayed development and delivery of the IV-TEPC.

Use of Computer-Processed Data. We did not use computer-processed data to perform this audit.

Review of Internal Controls

We reviewed internal controls that related to project management principles required by NPR 7120.5D and EA-WI-023; the ISS MORD requirements for measuring and monitoring astronaut radiation exposure; and NPR 8000.4A risk management requirements. We found instances where NASA's project and risk management requirements and internal controls were not followed. Specifically: (1) NASA's baseline cost estimate and schedule milestones for the ARI Project were not supported by reliable data; (2) the ISS Program expended funds developing a replacement radiation monitoring instrument that did not meet existing ISS medical operations requirements; (3) NASA has never met the requirement to monitor astronaut exposure to neutrons while aboard the ISS; and (4) NASA had not adequately reported the neutron risk in the ISS risk database. Our recommendations, if implemented, will correct the identified control weaknesses.

Prior Coverage

During the last 5 years, NASA and the NASA OIG have issued two reports of particular relevance to the subject of this report. Unrestricted NASA OIG reports can be accessed over the Internet at http://oig.nasa.gov/audits/reports/FY11.

NASA Office of Inspector General

"NASA's Management of the Mars Science Laboratory Project" (IG-11-019, June 8, 2011)

James Webb Space Telescope (JWST) - Independent Comprehensive Review Panel (ICRP)

JWST-ICRP Final Report (October 29, 2010), accessible at http://www.nasa.gov/pdf/499224main_JWST-ICRP_Report-FINAL.pdf

RADIATION EXPOSURE LIMITS AND HEALTH EFFECTS

Terrestrial radiation guidelines are considered too restrictive for space activities. For space flight activities, NASA has adopted the recommendations of the National Council on Radiation Protection. Based on the Council's recommendations, NASA has established career limits for ISS crewmembers' exposure to space radiation. Specifically, the Agency limits individual risk to 3 percent Risk of Exposure-Induced Death (REID) from cancer.[21] The acknowledged risk for the population at large of developing and dying of cancer is 20 out of every 100 people. NASA requires that astronauts' increased risks due to space radiation exposure will not be more than 3 percent above the estimate for the general population, or no more than 23 out of every 100 people. Each year, a NASA Radiation Specialist generates the Astronaut's Annual Radiation Exposure Report, which tracks astronauts' career exposures. Due to privacy issues, we did not review astronauts' medical records. However, at our request, the NASA Radiation Health Officer provided non-specific summary medical data that showed 12 astronauts have flown to the ISS in the last 2 years. All 12 astronauts were below 3 percent REID, with the maximum only at about 0.52 percent REID.[22] Therefore, all crewmembers who flew in the last 2 years were below the career risk limit stated in the NASA standard.

Table 2 shows NASA's astronaut radiation exposure limits by organ and exposure interval. These limits are considerably higher than those for terrestrial radiation workers, which are 5 rem per year.[23]

[21] REID is the lifetime risk that an individual in the population will die from cancer caused by his or her radiation exposure.

[22] The data does not include the 10 astronauts who flew on the final two Space Shuttle missions: STS-134 in May 2011 and STS-135 in July 2011.

[23] Rem (or Roentgen Equivalent Man) is a standard unit for measuring the effective radiation dose, which combines the amount of energy from any type of ionizing radiation that is deposited in human tissue along with the medical effects of the given type of radiation.

Table 2. Organ Specific Radiation Exposure Limits for Astronauts

Exposure Interval	Blood Forming Organs	Eye	Skin
30 Days	25 rem	100 rem	150 rem
Annual	50 rem	200 rem	300 rem
Career	150 – 400 rem [200 + 7.5(age - 30) for men] 100 – 300 rem [200 + 7.5(age - 38) for women]	400 rem	600 rem

Source: Space Radiation Analysis Group, Johnson Space Center website, accessed at http://srag.jsc.nasa.gov/SpaceRadiation/Why/Why.cfm, accessed April 25, 2011.

Exposure to a dose of 25 to 100 rem will produce mild weakness and changes in blood count. A dose of 100 to 650 rem will cause vomiting and changes to the blood but prognosis is still good at the upper range. Doses of 650 to 1,000 rem will completely destroy bone marrow and survival may depend on intense medical intervention. A dose of more than 1,000 rem is almost invariably fatal. Table 3 shows radiation doses that astronauts receive in space and exposure one might receive from terrestrial activities.

Table 3. Comparison of Radiation Exposure in Space and on Earth

Type of Exposure	Dose Equivalent*
ISS (Maximum Blood Forming Organ Dose in U.S. Segment)	16 rem/year
Space Shuttle (Maximum Skin Dose)	7.9 rem/mission
Apollo 14 (Maximum Skin Dose)	1.4 rem/mission
CT Scan (Chest)	.7 rem/event
Barium Enema	.4 rem/event
Airline Flight Crew	.2 rem/year
Houston Background	.1 rem/year

* The amount of biological damage caused by radiation varies with the amount of energy absorbed (dose). Radiation "dose equivalent" is a measurement that relates the amount of energy actually absorbed by human tissue to the effective biological damage of the radiation.

Source: Space Radiation Analysis Group, Johnson Space Center website, http://srag-nt.jsc.nasa.gov/SpaceRadiation/FAQ/FAQ.cfm, accessed July 6, 2011; and NASA Public Lessons Learned Database Entry 1071, "ISS Program/Radiation Exposure/Effects on Crew," February 1, 1998.

MANAGEMENT COMMENTS

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

SEP 26 2011

Reply to Attn of:

Human Exploration Operations Directorate

TO: Assistant Inspector General for Audits

FROM: Assistant Associate Administrator for ISS

SUBJECT: NASA Response to Draft Audit Report, "A Review of NASA's Replacement of Radiation Monitoring Equipment on the International Space Station" (Assignment No. A-11-004-00)

The International Space Station (ISS) Program and the Johnson Space Center (JSC) appreciate the opportunity to review your draft audit report entitled "A Review of NASA's Replacement of Radiation Monitoring Equipment on the International Space Station" (Assignment No. A-11-004-00). In the document, the Office of the Inspector General (OIG) describes several findings and provides two recommendations as a result. NASA's response, including planned corrective actions, follows:

Recommendation 1: We recommend that the ISS Program Manager ensure that all future ISS-related projects follow the tenets of NASA's project management policy and do not proceed to the implementation stage until project managers demonstrate projects are properly anchored by firm requirements, realistic cost and schedule estimates, sufficient funding, and successful completion of a Preliminary Design Review.

NASA Response: Concur. The ISS Program and JSC will follow Agency policy 7120.5 for further projects. However, the ISS Program does not interpret NPR 7120.5D to mean that a project must be approved to Preliminary Design Review and then a subsequent authorization processed for implementation.

The program authorized the project via a Space Station Change Directive. The cost and schedule estimate ROMs were the best available at project initiation and were supported by an independent Government estimate. These estimates were updated when firm cost proposals were received for the instruments. As a result, the discrepancy between the ROM estimates and the true implementation requirements for the RAD device were identified prior to entering PDR. The project, in cooperation with SLSD and the ISS Program, did conduct a PDR for the IV-TEPC and the EV-TEPC. As a result of the PDR and TEPC development unit results, the TEPC schedule and cost growth were identified and the program informed within two months following the PDR. In accordance with

NPR 7120.5D, upon identification of these issues, the project participated in the development of options to descope the project prior to entering the implementation phase.

The program then authorized only the IV-TEPC to proceed to implementation, gave direction to stop work on the EV-TEPC, and initiated a limited task to further understand the RAD project cost and schedule. The RAD project was not authorized to proceed to implementation until a program review of the results of that task was completed.

The ISS Program will initiate review of the development of the ROM cost and schedule and assessment of the TRL for the ARI project to determine what improvements can be made for the benefit of future ISS and JSC projects. These reviews will be conducted as part of the lessons learned review for each project. For the IV-TEPC the lessons learned review will be completed by December 15, 2011.

Recommendation 2: We recommend that Johnson Space Center's Director, Space Life Sciences, determine whether the current ISS medical operations requirement for external radiation monitoring of the spectra of charged particles is appropriate and, if not, formally initiate steps to update the MORD in coordination with the Mission Integration and Operations Control Board, the Multilateral Medical Policy Board, and any international partners.

NASA Response: Concur. We are currently meeting the external monitoring requirements as specified in the MORD, with the Extravehicular (EV)-Charged Particle Directional Spectrometer (CPDS). External exposures to the crew have been kept as low as reasonable achievable (ALARA). Our understanding of the ISS radiation environment has improved over the years of operations on ISS, reducing the complexity of requirements and design solutions needed to safely manage overall crew risk. The ability to safely control crew external exposures has also evolved, and current methods include monitoring satellite data for solar activity and for the Earth's environmental conditions, conservatively limiting egress times, and by estimating Extravehicular Activity (EVA) exposures for crew protection with passive detectors. It is expected that any future external monitoring requirements will be developed in conjunction with this concept of operations, ensuring lessons learned are carried forward in the ISS program. SLSD will provide a plan to review and update the MORD to the ISS program by October 15, 2011.

Other Matters

Statement of result: NASA has poorly managed the development of replacement radiation monitoring instruments. As a result, the replacement instruments are costing more than expected, are behind schedule, and will not include all planned elements.

NASA Response: NASA does not agree that the Advanced Radiation Instruments (ARI) project has been poorly managed. The ISS Program reviewed the cost and schedule growth as the project progressed from formulation to implementation in accordance with

NPR 7120.5D and will maintain oversight throughout the full performance of the project. As a result, the primary findings for this growth to date have been determined to be:

Design complexity and unexpected manufacturing challenges for the Intra-Vehicular Tissue Equivalent Proportional Counter (IV-TEPC): Based on early site visits, the project had assumed that Texas A&M would deliver a detector that required no modifications. The completion of the detector detailed design and build of the first flight-like prototype detector took one year longer than estimated at that time.

Underestimation of the maturity of the Southwest Research Institute (SwRI) design for the Radiation Assessment Detector (RAD): The estimates used to determine the ROM cost for the RAD were based on a similar instrument already in the implementation phase for the JPL Mars Science Laboratory. After the ROM cost was provided for the ISS RAD, the MSL RAD experienced cost growth. As a result of the MSL experience, the technology readiness level of the detector was understated for the ISS RAD and this actual experience was reflected in the firm proposal.

NASA's management of these projects resulted in identification and resolution of these technical issues as early as possible and did result in the revised scope described in the report. The ISS Program, with cooperation from the Space Life Sciences Directorate (SLSD) and the Engineering Directorate, will lead lessons learned reviews of both projects to determine how we can improve our assessment of technology readiness during the project formulation phase.

Statement of result: Specifically, NASA did not review and, as necessary, formally initiate steps to revise radiation monitoring requirements during the early phases of the Project to ensure that the requirements, if met, would address the true radiation monitoring needs of the ISS Program.

NASA Response: The ISS Program meets the current Medical Operations Requirements Document (MORD) requirements for extravehicular radiation monitoring today. We acknowledge that those instruments are aging, which was the driving need for the ARI project. However, our understanding of how to safely control EVA exposures has evolved with ISS operations over the past ten years with these instruments, satellite data, and other instruments in use on ISS. The functional requirements utilized for the project, and included in the instrument specifications, were developed primarily from the input of the SLSD based on the latest available knowledge in this area, first as the result of a Radiation Technical Interchange Meeting held in 2007 and approved at the ISS Vehicle Control Board. The formal project requirements were subsequently developed with SLSD participation in the System Requirements Review for the ARI project in 2008. Finally, SLSD was integral to all discussion of descope options as a result of the project cost growth to ensure that the ability to protect the crew onboard ISS would not be compromised. Thus, the requirements in place on this project are the best available to meet the needs of the program in the future and do not compromise the ability to protect the crew.

NASA concurs with the finding that the requirements in the MORD and the associated ISS Risk Management Application entries should be updated to better reflect the evolving state of ISS radiation monitoring plans and risks. This will be addressed in response to Recommendation #2, however the delay in updating the MORD has not impacted the implementation of the necessary requirements on the ARI project.

Statement of result: To accurately track astronaut radiation exposure and assess risks to crew health, the ISS Program is required to monitor the neutron portion of the radiation environment aboard ISS.

NASA Response: NASA is currently controlling the risk to crew to 95% confidence levels as specified in the MORD. The current lack of neutron specific monitoring does not prevent NASA from controlling the risk to crew of the neutron component of radiation exposure. The models that are used incorporate mission dosimetry and risk projection methodologies recommended by the National Council on Radiation Protection and Measurements (NCRP) and the National Research Council (NRC).

The mission dosimetry utilized during the period relevant to the investigation includes both area and crew personnel dosimetry and crew specific biodosimetry. The TEPC used as area monitor and biodosimetry, using pre- and post-flight blood samples from each ISS crew to measure increases in chromosomal aberrations, are well documented to have excellent responses to both neutrons and charged particles. Although TEPCs and biodosimetry cannot resolve specific contributions from protons, neutrons or other components in the space environment, the integral dose or dose equivalent values measured by the TEPC or biodosimetry contain the neutron contribution.

As we move forward with ISS RAD to meet the neutron specific requirement in the MORD, the information will potentially allow us to reduce the uncertainty of the neutron component of the calculated tissue dosimetry used in the risk model. Improved dosimetry reduces the overall uncertainty, expressed as a 95% confidence interval, of the estimated crew risk. More accurate risk estimates give NASA improved confidence in ALARA approaches not only for ISS but for future human exploration missions of the agency.

Thank you for the opportunity to review and comment on the draft audit report. If you have further questions or require additional information regarding the ARI project or the NASA response to the draft report please contact Mr. Michael Suffredini at 281-244-7085.

for Mark Uhran

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SEPTEMBER 29, 2011

REPORT No. IG-11-027

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