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Assurance
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for Space Science

**INDEPENDENT VERIFICATION AND VALIDATION
OF SOFTWARE**

March 28, 2003

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National Aeronautics and
Space Administration

OFFICE OF INSPECTOR GENERAL

Released by: [Original Signed By]

Alan J. Lamoreaux, Assistant Inspector General for Audits

Independent Verification and Validation of Software

Independent verification and validation (IV&V) is a critical management control for minimizing the risk of software-related, catastrophic mission failure. The audit focused on the effectiveness of NASA's procedures for ensuring that the appropriate level of IV&V is performed on its software development projects. Details regarding the audit objectives, background, scope, and methodology are in Appendix B.

We found that NASA had not effectively ensured that all applicable software development projects were assessed to determine their appropriate level of IV&V.

- NASA did not provide a complete list of all applicable software development projects to the IV&V Facility – the Agency's center of expertise for IV&V processes and technology. Such a list would have enabled Facility personnel to identify projects that had not yet been assessed to determine the need for IV&V.
- NASA did not include IV&V requirements in the current Jet Propulsion Laboratory (JPL) contract that will expire on September 30, 2003. NASA management agreed to incorporate the requirements into the follow-on contract effective October 1, 2003.

As a result of this condition, the safety, quality, and reliability of some of the Agency's programs and projects, including mission-critical programs and projects, could be compromised. For example, the Fluids and Combustion Facility (FCF) project, managed by Glenn Research Center, was a likely candidate for independent software reliability assurance. The FCF will be a permanent multi-rack research laboratory for conducting microgravity experiments onboard the International Space Station. The \$72 million project consists of hardware and related software that is expected to host more than 100 fluids and combustion experiments over its anticipated lifespan. After we brought our concerns about this project to management's attention, the NASA IV&V Facility told the project manager to assess the FCF project for IV&V; project management officials subsequently concluded that the FCF required IV&V. Without IV&V, the microgravity research program faced an unnecessary risk that the FCF project would not perform as intended.

Management Control Needed to Ensure Effective Application of IV&V Policy

NASA Policy Directive (NPD) 8730.4 requires that the IV&V Facility maintain "explicit involvement" with project managers in determining the appropriate level of IV&V for their software development projects. To ensure effective implementation of this requirement, the Agency should provide the IV&V Facility a complete list of all applicable software development projects. Facility personnel could then identify software projects for which IV&V assessment criteria should be applied and, in turn,

advise the cognizant project managers to apply the criteria to those projects. Details regarding NASA's IV&V policy for software are in Appendix C. Absent a complete list of applicable software development projects, IV&V Facility personnel initiated their own software project identification process by contacting Center personnel and searching the Agency's mission and project Web sites for information on software development activities. The Facility's efforts were commendable but did not result in a complete and accurate list of software development projects.

IV&V Requirements Not Included in Current JPL Contract

NPD 8730.4 states that the Agency's IV&V policy is applicable to JPL to the extent specified in the Agency's contract with the California Institute of Technology. In this regard, NASA had not incorporated the NPD requirement into the current contract, and JPL's internal policies did not require project managers to complete the Agency's IV&V assessment criteria. Further information regarding the Agency's IV&V policy relative to the California Institute of Technology contract is in Appendix D.

We discussed the Agency's IV&V policy with JPL procurement officials, NASA Office of Space Science officials, and officials in the NASA Offices of Safety and Mission Assurance and Chief Engineer. NASA management told us that it would not be prudent or cost-effective to incorporate software IV&V requirements into the current JPL contract; however, management agreed to incorporate the requirements into the follow-on contract effective October 1, 2003. The follow-on contract was awarded in November 2002 and requires JPL to comply with NPD 8730.4.

Conclusion

NASA should apply effective management controls, on a recurring basis, to ensure the IV&V policy is fully implemented. Until needed corrective actions are implemented, NASA's software management, engineering, and assurance processes will not be fully integrated with the Agency's program and project management processes. Further, NASA has not ensured that it has developed risk analyses and risk management strategies at each stage of the software development life-cycle.

Recommendations for Corrective Action

1. The NASA Chief Engineer, in coordination with the Associate Administrator for Safety and Mission Assurance, should establish a process that provides the NASA IV&V Facility, on a recurring basis, a complete and accurate list of the Agency's programs and projects governed by either NASA Procedures and Guidelines 7120.5A or NASA Technical Standard 8719.13A.
2. The NASA Chief Engineer should verify that the NASA IV&V Facility initiates appropriate actions to ensure that the programs and projects identified in

Recommendation 1 comply with the Agency's software IV&V policy.

Management's Response and our Evaluation of the Response

NASA concurred with the intent of the recommendations and has initiated corrective actions. Although we consider management's comments (Appendix F) to be responsive to the recommendations, the success of the alternative actions to be taken will depend on effective coordination between the Program Management Councils and the IV&V Facility. Effective coordination will help ensure that the Agency has adequately considered the need for IV&V and has performed IV&V where appropriate. Details related to disposition and closure of the recommendations are in Appendix A.

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Acronyms Used in the Report

FCF	Fluids and Combustion Facility
IV&V	Independent Verification and Validation
JPL	Jet Propulsion Laboratory
MCO	Mars Climate Orbiter
MPIAT	Mars Program Independent Assessment Team
MPL	Mars Polar Lander
NPD	NASA Policy Directive
NPG	NASA Procedures and Guidelines
OIG	Office of Inspector General

Appendix A. Status of Recommendations

Recommendation No.	Resolved	Unresolved	Open/ECD*	Closed
1	X		9/30/2003	
2	X		9/30/2003	

* Estimated Completion Date

Appendix B. Objective, Background, Scope, and Methodology

Objective

The overall objective of this audit was to determine whether NASA had established and implemented effective management controls over the Agency's software development process. Specifically, we determined whether effective controls existed to ensure the following:

- safety, quality, and reliability of software developed by or for NASA;
- integration of NASA software management, engineering, and assurance processes with the Agency's program/project management processes; and
- development of risk analyses and risk management strategies at each stage of the software development life-cycle.

Background

Independent verification and validation (IV&V) is a critical management control that helps ensure the safety, quality, and reliability of NASA's software. Software verification consists of assessing objective evidence at different phases of the development life cycle to ensure that the software product complies with specifications. Software validation takes place at the end of the software development process and consists of performing tests and assessing other objective evidence to determine whether a software system will accomplish its intended purpose. Validation ensures that a software system will perform as expected under operational conditions.

Independence is a key component to successful software verification and validation. Software developers and project managers may have vested interests and may not be objective in their self-assessments. Performing software verification and validation independently of the development and management functions helps to ensure that verification and validation activities are unbiased and based on objective evidence.

Congress established the IV&V Facility in Fairmont, West Virginia, in October 1991 to address recommendations made by the National Research Council and the Presidential Commission on the Space Shuttle Challenger Accident. The Facility is technically independent but is managed by the Goddard Space Flight Center (Goddard) and relies on Goddard for support functions such as personnel, training, and procurement.

The NASA IV&V Facility provides two levels of software assurance: independent assessment (IA) and full IV&V. An IA is a one-time review of existing products and plans, whereas IV&V is applied over the entire life cycle of a software system. Full IV&V provides more rigorous software assurance.

The importance of software testing is underscored by the failures of the Mars Climate Orbiter (MCO) and Mars Polar Lander (MPL) in 1999. NASA developed and launched

Appendix B

the two missions (both part of the JPL Mars '98 Development Project) at a total cost of more than \$327 million. To investigate the failures, NASA established the Mars Program Independent Assessment Team (MPIAT). The MPIAT summary report states:

. . . one mistake can be mission catastrophic. Mistakes are prevented by oversight, test, and independent analysis, which were deficient for MCO. Specifically, software testing was inadequate.

Regarding the MPL, the assessment team's report states:

As with MCO, the most probable failure of the Mars Polar Lander resulted from inadequate checks and balances that permitted an incomplete systems test and allowed a significant software design flaw to go undetected.

NASA has made progress toward establishing and implementing effective management controls over the Agency's software development process. For example, the Agency established policy (NPD 8730.4) to conduct IV&V of software based on the cost, size, complexity, life span, risk, and consequences of failure. In addition, the Agency established quantifiable criteria for assessing whether IV&V should be applied to a software development project and for performing the appropriate level of IV&V. However, as stated in this report, NASA had not ensured that needed IV&V was performed.

Scope and Methodology

NASA employs many processes, techniques, tools, and services to ensure the safety, quality, and reliability of its software. Because of the importance of IV&V as a management control in the software development process, our audit focused on the effectiveness of Agency procedures for ensuring that IV&V was performed. We did not assess the adequacy of detailed IV&V test procedures for ensuring that NASA software products will comply with specifications or that software systems will perform as expected under operational conditions.

To accomplish our objectives, we completed these steps:

- Reviewed NASA policies, procedures, and guidelines pertaining to the Agency's management of software development and use of the NASA IV&V Facility in Fairmont, West Virginia.
- Interviewed officials in the NASA Office of Safety and Mission Assurance and NASA Office of Chief Engineer regarding the Agency's IV&V policies and the applicability of IV&V policy to the Jet Propulsion Laboratory.

- Interviewed officials from the NASA IV&V Facility regarding procedures for assessing applicable software development projects for IV&V.
- Interviewed officials at selected Centers regarding procedures for complying with NASA's IV&V policy. Center officials included project managers, software quality assurance managers, personnel in systems management offices, and procurement personnel.
- Compared Center-provided lists of software development projects to IV&V Facility records of projects for which the Agency's IV&V assessment criteria had been adequately applied.

We did not assess the reliability of computer-processed data because we did not rely on such data to achieve our objectives.

Management Controls Reviewed

We interviewed officials at NASA Headquarters, the NASA IV&V Facility, and selected Centers to identify and assess management controls relating to the Agency's management of the software development process. We considered the management controls to be adequate except that NASA had not fully implemented effective controls to ensure that all applicable software development projects were adequately assessed to determine the appropriate level of IV&V.

Audit Field Work

We performed the audit field work from October 2001 through August 2002 at NASA Headquarters, the IV&V Facility, Glenn Research Center, the Jet Propulsion Laboratory, Johnson Space Center, Langley Research Center, and Marshall Space Flight Center. We conducted the audit in accordance with generally accepted government auditing standards.

Appendix C. NASA's IV&V Policy for Software

Memorandum Establishing Interim IV&V Policy. On July 21, 2000, the NASA Chief Engineer issued a memorandum on the Agency's policy for software IV&V. The Chief Engineer identified assessment criteria that Agency personnel should use in deciding whether IV&V is needed for a software development project. The criteria included steps for assessing the following consequences of software failure:

- loss of life,
- catastrophic mission failure,
- loss of equipment,
- waste of software resource investment,
- negative political and public image stemming from the failure of a system, and
- effect on routine operations.

The criteria also included steps for assessing the probability of software failure. Certain variables could affect the probability of failure:

- amount of contractor support,
- schedule pressure,
- degree of innovation, and
- number of software lines of code.

NASA Policy Directive (NPD) 8730.4, "Software Independent Verification and Validation (IV&V) Policy," August 1, 2001. The NPD establishes Agency policy to conduct IV&V based on the cost, size, complexity, life span, risk, and consequences of software failure. Section 1 of the Directive states that NASA will do the following:

- a. Establish and apply criteria, tools, and methodology to evaluate and assess software risk for the purpose of identifying the appropriate level of IV&V.
- b. For programs and projects governed by NPG [NASA Procedures and Guidelines] 7120.5A, task the NASA IV&V Facility in Fairmont, WV, to **manage the performance of all IV&V** [emphasis added] for software identified per the established criteria, and for any other safety critical software (as defined in NASA-STD-8719.13A). [NASA Technical Standard NASA-STD-8719.13A, "Software Safety," September 15, 1997, describes the activities necessary to ensure that safety is designed into software that is acquired or developed by NASA and that safety is maintained throughout the software life cycle.]
- c. Require programs and projects governed by NPG 7120.5A to determine the level of IV&V to be performed with the **explicit involvement** [emphasis added] of the NASA IV&V Facility.

Section 2 of the NPD states that the Agency's IV&V policy is applicable to "... NASA Headquarters and NASA Centers, ... and to the Jet Propulsion Laboratory to the extent specified in the contract." The NASA Office of Safety and Mission Assurance is responsible for NPD 8730.4 and the Agency's overall policy regarding software IV&V. The NASA Chief Engineer is responsible for ensuring that all programs and projects follow the Agency's IV&V policy.

Appendix D. IV&V Policy Relative to NASA's Contract With the California Institute of Technology

NASA issued contract NAS7-1407 to the California Institute of Technology to provide for operation of the Jet Propulsion Laboratory (JPL) from October 1998 through September 2003. Contract Section G-14, "NASA Issuance System," states:

The parties hereto agree that NASA Management Directives System publications ("NASA Issuances") are not in and of themselves applicable to the Contractor, and that the Contractor therefore is not obligated merely by virtue of their issuance to implement their intent or to observe the policies and procedures set forth therein, irrespective of the fact that certain NASA Issuances may state that they apply to JPL. NASA Issuances become contractually binding and obligatory upon the Contractor only when and to the extent made so by appropriate contractual means.

The NASA Office of Space Science has cognizance over the JPL contract.

During the audit, we found that JPL's internal policies did not require project managers to complete the Agency's IV&V assessment criteria. We brought this matter to the attention of cognizant JPL officials who subsequently established local procedures that required project managers to complete the Agency's IV&V assessment criteria for determining the need for IV&V. JPL issued the official requirement in Section 7.4 of "Flight Project Practices, Rev. 2" (Document Identification 58032), effective June 28, 2002. Although JPL officials did not issue the official requirement until June 2002, JPL's software development projects had been in compliance with the Agency's software IV&V policy since July 2000.

Appendix E. Summary of Prior Coverage

The NASA Office of Inspector General (OIG) issued one report on physical access controls at the NASA Independent Verification and Validation (IV&V) Facility and one report on the management of software development. The reports are summarized below, and copies are available at <http://www.hq.nasa.gov/office/oig/hq/reports.html>.

“NASA's Badging Program and Physical Access Controls at the Goddard Space Flight Center Independent Verification & Validation Facility,” Report Number G-01-026, September 25, 2001. The OIG completed an inspection of NASA's badging program and physical access controls at the Goddard Space Flight Center IV&V Facility. The objective was to focus on whether policies and procedures were in place to adequately control access to facilities including mission-critical locations and facilities containing sensitive or controlled information or materials. NASA concurred with the report's four recommendations for improving security controls and operational effectiveness.

“Software Assurance,” Report Number IG-00-059, September 28, 2000. NASA lacked adequate management controls for determining whether to use IV&V in its software development projects and for collecting, analyzing, and reporting software metrics designed to monitor these projects. This condition occurred because NASA had not issued guidelines to implement the controls. As a result, NASA had less assurance that the risks of potential software failures were adequately reduced through IV&V and the implementation of sound software assurance policies and procedures. NASA concurred with each of the report's two recommendations and issued interim IV&V criteria for use by program and project managers in determining whether new or existing projects should be subject to IV&V. Also, the Agency issued its IV&V policy in NASA Policy Directive (NPD) 8730.4, "Software Independent Verification and Validation (IV&V) Policy.”

Appendix F. Management's Response

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001



March 17, 2003

TO: W/Assistant Inspector General for Audits

FROM: AE/Chief Engineer

SUBJECT: Management Comments for the Draft Report Assignment
Number A-02-005-00, Independent Verification and Validation of Software,
February 20, 2003

Thank you for the opportunity to provide comments to the Office of Inspector General (OIG) draft audit report on the independent verification and validation (IV&V) of software. The following represents an integrated Agency response to the draft report. We appreciate the effort expended by the OIG to examine the effectiveness of NASA's procedures for ensuring that the appropriate level of IV&V is performed on its software development projects. The audit has resulted in specific recommendations concerning the establishment of a complete and accurate list of the Agency's programs and projects containing software that are governed by either NASA Procedures and Guidelines (NPG) 7120.5A or NASA Technical Standard (NTS) 8719.13A to ensure programs and projects comply with the Agency's software IV&V policy (NASA Policy Directive (NPD) 8730.4).

Below are comments that reflect actions which we have already begun in concert with your recommendations, or which we feel would improve the clarity, completeness, or context of your report. They are provided for your consideration.

Irrespective of these comments, I strongly believe that the kinds of improvements you have suggested, both specifically for the NASA Software IV&V Program, and more generally for IV&V throughout the NASA engineering community, are vital to NASA's future success in maintaining and improving its engineering programs. In particular, NASA needs a broader and more centrally coordinated application of IV&V principles, as well as improvement in the rigor with which engineering verification processes are conducted. I appreciate your effort in identifying and supporting these substantial improvements in our engineering processes.

Comments on Findings:

Finding 1: "NASA did not provide a complete list of all applicable software development projects to the IV&V Facility – the Agency's Center of expertise for IV&V processes and technology. Such a list would have enabled Facility personnel to identify projects that had not yet been assessed to determine the need for IV&V."

Comment: The Agency maintains a list of programs and projects governed by NPG 7120.5A which is updated annually. This is developed with inputs from the Enterprises through the Agency's Program Management Council (PMC) and maintained by the Office of Chief Engineer. It should be noted that the current list is not integrated with programs and projects governed by NTS 8719.13A, nor does the list indicate whether the projects listed contain mission critical software.

Finding 2. "NASA did not include IV&V requirements in the Jet Propulsion Laboratory (JPL) contract."

Comment: Although not bound by contract (at the time of this initial finding), JPL had established policy and procedures that required project managers to complete the assessment criteria for determining the need for IV&V. Since July 2000, when a memo was sent out by the Chief Engineer, JPL has been following the directives and policies concerning IV&V. Beginning with the new NASA contract with JPL (NAS7-3001, effective October 1, 2003), JPL will be formally required to comply with NPD 8730.4 under contract.

Comments on Recommendations:

Recommendation 1: "The NASA Chief Engineer, in coordination with the Associate Administrator for Safety and Mission Assurance, should establish a process that provides the NASA IV&V Facility, on a recurring basis, a complete and accurate list of the Agency's programs and projects governed by either NPG 7120.5A or NTS 8719.13A."

Comment: NASA concurs with the intent of this recommendation. However, the recommendation as stated implies inconsistency with the roles and responsibilities of the NASA IV&V Facility. Oversight of software development management (including programs and projects' use of IV&V) is the responsibility of the governing PMCs. NASA believes that the rewording below captures the intent of this recommendation without being inconsistent with NASA policy.

"The NASA Chief Engineer in coordination with the Associate Administrator for Safety and Mission Assurance should establish a process that provides, on a recurring basis, a reliable list of the Agency's programs and projects governed by either NPG 7120.5 or NASA-STD-8719.13. To support the oversight of software development management, this list should be provided to governing Program Management Councils."

Recommendation 2: "The NASA Chief Engineer should verify that the NASA IV&V Facility initiates appropriate actions to ensure that the programs and projects identified in Recommendation 1 comply with the Agency's software IV&V policy."

Comment: NASA concurs with the intent of this recommendation. However, the Agency should determine the process for compliance and the appropriate organizations to initiate

action. NASA believes that the rewording below captures the intent of this recommendation without committing the Agency to a specific solution.

“The NASA Chief Engineer should implement a reoccurring process for assuring that programs and projects governed by either NPG 7120.5 or NASA-STD-8719.13 comply with the Agency’s software IV&V policy.”

General Comments on Report Contents:

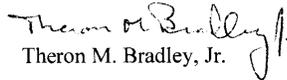
Comment concerning discussion of Mar Climate Orbiter (MCO) and Mars Polar Lander (MPL) in Appendix B: The MCO & MPL projects mentioned in the draft report as underscoring the need for IV&V involvement actually worked in a conscientious manner with the IV&V Facility and employed their services prior to the establishment of NASA's IV&V policy. It should be noted that the IV&V Facility provided direct “in-line” level of effort support in Denver, rather than IV&V and independent assessment activities, as currently defined and practiced by the Facility. The “in-line” activities consisted of the creation and maintenance of a requirements tracking and tracing database, review of design and code, test development support, anomaly analysis, and creation of databases and special tools. At that time the failure reports from these two unfortunate projects did not indicate that additional IV&V services would have prevented either failure.

Comment concerning discussion of the Fluids and Combustion Facility (FCF) project: The FCF project was called out in the draft report as a likely candidate for independent reliability assurance. The list provided with the Chief Engineer’s July 21, 2000, memo did not include the Glenn Research Center's (GRC) FCF project because it was a NASA “Generate Knowledge” project instead of a “Provide Aerospace Products and Capabilities” project (i.e., 7120.5A project). Additionally, FCF was not a 7120.5A project when NPD 8730.4 was approved. Credit should be given to the FCF project for a prior assessment for IV&V in 1999 before the fixed price contract for its development (called the Microgravity Research Development and Operations Contract) was initiated. This assessment was compliant with the existing GRC Center-level procedures on software development (GRC P-2.6.4). This assessment indicated FCF software was medium to high control level (i.e., not critical control level where software IV&V is mandatory). This assessment was revisited recently in September 2002, prior to the conversion of the \$72M FCF prime development contract from a Fixed Price Incentive Firm contract to a CPAF contract. The results of this second assessment yielded consistent results to the prior 1999 assessment. Within a limited funding profile the FCF project is currently pursuing the use of a software independent assessment by the NASA IV&V Facility. FCF is currently undergoing reconsideration of its’ classification as a non-7120.5A project. If this project is reclassified, its’ compliance will be verified by the Office of Chief Engineer.

Comment concerning the draft report’s statement “...some of the Agency’s programs and projects, including mission-critical programs and projects, could be compromised:” The October 5, 2001, letter from the OIG stated that the audit's "...overall objective is to determine

whether NASA has established and implemented effective management controls over the Agency's software development process." The draft report focuses on software IV&V and the use of the NASA IV&V Facility in Fairmont, West Virginia. IV&V is a supplemental approach employed, when appropriate, to mitigate software risks. There are many other processes, techniques, tools, and services that are employed by NASA to ensure the safety, quality, and reliability of software. The absence of IV&V on a program or project does not directly imply that these three attributes have been compromised.

Thank you again for the opportunity to comment on this draft audit report. We are available to discuss the draft report and our comments at your convenience. The points of contacts for this audit in the Office of the Chief Engineer are Dr. John C. Kelly ((202) 358-0682) and Gregory L. Robinson ((202) 358-2541).


Theron M. Bradley, Jr.

cc:

- | | |
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Branch Chief, Science and Space Programs Branch, Energy and Science Division, Office of Management and Budget

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Senior Professional Assistant, Senate Subcommittee on Science, Technology, and Space

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The Honorable Pete Sessions, U.S. House of Representatives

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Report Title: Independent Verification and Validation of Software

Report Number: _____ **Report Date:** _____

Circle the appropriate rating for the following statements.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A
1. The report was clear, readable, and logically organized.	5	4	3	2	1	N/A
2. The report was concise and to the point.	5	4	3	2	1	N/A
3. We effectively communicated the audit objectives, scope, and methodology.	5	4	3	2	1	N/A
4. The report contained sufficient information to support the finding(s) in a balanced and objective manner.	5	4	3	2	1	N/A

Overall, how would you rate the report?

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How did you use the report? _____

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How would you identify yourself? (Select one)

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