August 11, 2000

W

TO: M/Associate Administrator for Space Flight
Q/Associate Administrator for Safety and Mission Assurance

FROM: W/Assistant Inspector General for Inspections, Administrative Investigations and Assessments

SUBJECT: Assessment of the Portable Computer System and the Data Display Process, G-99-010A

While performing work related to our assessment of the International Space Station (ISS) Program Implementation of Communications Security and Automated Information Security Measures (G-99-010), we became aware of problems involving the Portable Computer System (PCS) and the accuracy of displays developed for the PCS. This report outlines our concerns about the ISS PCS and the process that is used to develop the displays for the PCS. We are bringing these concerns to the attention of ISS management for appropriate action.

I. BACKGROUND

The on-board PCS is the crew's primary interface for command and control[1] of the ISS and provides the crew with caution and warning (C&W)[2] information for the ISS. The PCS is a commercial laptop computer modified for flight use and loaded with commercial and custom software. There are two levels of PCS software. First, the Command and Data Software provides the PCS interface to the Multiplexer-Demultiplexer (MDM).[3] Second, the

[1] Command and control interfaces with other ISS systems such as environmental, power, and communications and tracking. Command and control of the ISS is also available through the ground facilities (which also serve as backup to the PCS) and the Space Shuttle's Multi-function Cathode Ray Tube Display System when the Shuttle is docked with the ISS.

[2] The caution and warning system is designed to warn the crew of conditions that may adversely affect ISS operations. It consists of hardware and electronics that provide the crew with both visual and aural cues when a system exceeds predefined operating limits.

[3] MDM's are the processing computers that control ISS systems.

Command and Data Handling Software provides the graphical user interface (GUI)[4] for the crew. The PCS displays consist of graphical and non-graphical (sometimes called tabular) formats.[5] The home page, as the top-level graphical display, provides the primary C&W information, including alarm type, alarm message, and graphical indication of affected subsystems and locations. The home page also provides navigational paths to more detailed displays of elements or subsystems.

Since early 1996, the Mission Operations Directorate (MOD) has managed the PCS project at the Johnson Space Center (Johnson) including the display development process.[6] The MOD Systems Division (Division code DF) provides display requirements and develops and tests non-graphical displays. Graphical displays are developed and tested by the PCS project (Division code DL). The Avionics Office of the ISS Program Office (which is responsible for the design, development, and testing of all ISS flight software as well as software/hardware systems integration) has primary responsibility for the PCS software.

The PCS and the display development process is a recognized area of concern for the ISS program since PCS displays are the primary crew interface or window into ISS systems. Multiple internal and independent reviews of the PCS and the display development process were conducted to address PCS concerns. In November 1996, an independent review team[7] identified several areas of concern. These concerns included no formal definition of display requirements, weak software engineering practices, an inadequately defined data delivery process, weak PCS software design, and poor communications between software providers (See Appendix B).

A 1998 internal Johnson display review team headed by Elric McHenry from the Engineering Directorate identified several similar problems. These problems included a lack of integrated program management[8] and lack of an overall software architect, missing and erroneous data, poor data flow, weak display development guidelines, technical problems in the display formulation and implementation process, weak configuration control, and the lack of integration of software tools and processes. This review recommended display requirements

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[4] The graphical user interface is the part of a program that uses pictures or graphics to help the user know what to do.

[5] Graphical displays incorporate mostly icons and other graphics to display user information. Non-graphical displays are used to display information that does not require graphics or may contain more detail than corresponding graphical displays. They typically display several items or records in rows and columns. See Appendix A for representative examples of graphical and non-graphical displays.

[6] The PCS Project has dual reporting responsibilities to MOD management and ISS Program management.

[7] The PCS Independent Review Team was a small team composed of individuals from academia and industry. This team was headed by Keith Bennett from the Washington University in St. Louis, Missouri.

[8] Specifically, the internal review team found that there was "[n]o integrated program management responsible for planning, scheduling, configuration control, resources management, [and] issue management." The review also found "[n]o single management review process to validate requirements, prioritize, and balance against implementation resources."

and display implementation changes to solve schedule and workload problems associated with PCS displays (See Appendix C).

A May 1999 Human Exploration and Development of Space (HEDS) Independent Assessment (IA) Review (JS-9026) also contained several recommendations for improving the PCS display development process. Process deficiencies listed in that report include a lack of prototyping, use of unbaselined program documentation, and lack of human factors engineering (See Appendix D).

II. FINDINGS

The following findings are the result of documentation reviews[9] and interviews of individuals involved with the PCS project and display development process. In some cases, these findings are repetitive of those highlighted from previous reviews. This duplication, however, indicates that the problems still exist because some recommendations made by these groups either were not fully implemented or were not implemented at all.[10] Although improvements in some areas have occurred, the improvements do not appear to be made in a systematic manner. Improvements typically are made on an ad-hoc basis, as problems occur. In addition, problems resolved in future releases of the PCS software might not solve problems with current, yet-to-be-flown releases of the software.

A. Need for an Integrated Product Team

An integrated product team (IPT)[11] is not being used in the PCS display development process. An IPT would enhance coordination between the various organizations responsible for display development. The lack of an integrated approach results in a communications breakdown between display development and procedure development. This breakdown in turn results in synchronization problems between the developers and a difficult procedure/display validation process. In some instances, the crewmembers were the first individuals to validate the procedures during training sessions. Procedures should already be validated as correct before the crew training sessions.

An IPT should consist of representatives from the crew office, the MOD Training Division, the MOD Operations Division, the MOD Systems Division, the MOD Flight Avionics Division, and Boeing, the prime contractor for ISS software. This team should report directly to ISS management because the display development process involves multiple organizations and directorates. In addition, the display development process should be accompanied by

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[9] Documentation reviewed includes MOD Systems Division and Flight Avionics Division ISO 9000 work instructions and safety hazard reports.

[10] Reasons for the not implementing some recommendations from previous reviews may include budget constraints, schedule pressures, and the reluctance to make organizational changes.

[11] An integrated product team is made up of one or more groups responsible for specific tasks related to the team's overall goal.

constant crew involvement to guarantee the best, most efficient human-computer interface possible in this critical system.

Recommendation 1: The ISS Program should create an Integrated Product Team, composed of all relevant organizational units, to direct the display development process.

B. Need for Independent Verification of Displays

There is no independent verification (evaluation and validation) of PCS displays or of the display development process, primarily due to schedule and personnel constraints. For example, the utility of graphics versus tabular displays with respect to the tasks performed by the ISS crew using the PCS is not independently evaluated. Several thousand tabular displays are being developed for missions through Flight 8A,[12] with one or two parameters being the critical values on each display. Since over 90 percent of the displays are tabular due to display implementation,[13] there is considerable risk that errors are not being detected during the current validation process. An independent verification process would help detect and correct errors and enhance utility at an earlier stage in the display development process.

Recommendation 2: The ISS Program should establish an independent verification function to assess the utility and form of the PCS displays and the overall display development process.

C. Usability of the PCS

There are numerous usability issues that affect the cost and schedule of the display development process and may have a safety impact. These issues affect cost and schedule because additional training and software releases could be required. The more serious usability issues include:

1. Static Display Indicators[14]
Currently, the crew has no consistent and reliable indication that the static data displayed on the PCS is no longer current. There are "heartbeat" indicators[15] that can show when a display

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[12] Flight 8A is scheduled for October 2001 and is the 25th ISS assembly flight based on the Interim Assembly Sequence, Revision E.

[13] Typically, when a display is developed, the developer decides whether the display should be graphical or tabular. This decision should be based on what type of data is being presented and the level of user interaction. However, since creating graphical displays for the PCS is time intensive (taking 7-10 days each thereby having a budget and schedule impact), the inclination may be to create tabular displays in lieu of graphical displays.

[14] Static data display indicators are used to show that the data on a display is no longer being updated. This could be the result of a hardware unit failure or a communications problem. Shuttle displays use an "M" displayed directly to the right of the affected parameter to indicate missing data.

[15] The software uses a "heartbeat" to determine if the communication channel between components is active. The indicator is usually a periodic pulse emitted to exhibit operating status.

is not working, but not every display has an indicator. Also, the indicator does not apply to all parameters being displayed. This means the crew must be trained to know to which data the indicator is applicable. With several thousand displays and numerous parameters on each display, this places a training burden on the crew and increases the possibility of human error. The crews' inability to determine which data is valid may have a safety impact.

2. Erroneous Information

Because the data used to develop the PCS displays (e.g., Standard Out[16]) contains erroneous and missing data, a significant amount of inaccurate information remains on the displays. Station Program Notes (SPN's) are used to document incorrect information contained on the PCS displays. Written procedures (contained in the operations data file) provide workarounds to account for some of this incorrect information. The crew is trained on these exceptions, and SPN's should be required to be flown on each mission. Although some incorrect information may be corrected in subsequent releases of the software, a risk still exists that errors will develop from erroneous display information on releases of PCS software with a high number of SPN's. There are currently over 500 SPN's (many attributable to PCS) and the number is increasing (See Appendix E). This may dramatically increases the training workload of the crew and may impact the usefulness of the displays because a large number of exceptions could be difficult for the crew to remember and maintain. A large number of SPN's may also impact the confidence the crew has with the associated PCS software release.

3. Inconsistent Application of Commands

Various users have reported the inconsistent application of C&W display and commanding approaches across systems. Different groups develop the displays for each system. One group may develop a "one click" procedure for critical commands whereas another may develop a "two click" procedure for a similar critical command.[17] Similarly, the same type of failure in different ISS systems could produce a different type of alarm indicator. A crewmember must be trained to a sophisticated level to understand how the different C&W's are displayed. Clearly written display standards could address this problem. This inconsistency increases training time and the potential of misinterpreting the different C&W indicators, particularly under conditions of stress.

4. Cumbersome Navigation

Navigating through windows and screens to perform a task is still cumbersome, particularly with time-critical commands. A one-page procedure may call upon the user to open ten display pages before the page with the appropriate information is located. This situation is alleviated somewhat by the use of task level displays which allow the user to "jump" to a display page. Task level displays are useful for repetitious, time critical, or complex commands.

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[16] Standard Out is the inclusive set of all software and data products delivered from the Mission Build Facility to ISS Program customers. It includes the flight software loads, flight data loads, and reconfiguration data files.

[17] A "one click" command requires the user to simply select the command and initiate it with no confirmation. A "two click" command requires the user to select and confirm that the command should be initiated.

5. Laptop Redundancy
A criticality level of 1R[18] for the PCS is achieved by using two redundant laptops during critical commands so that if one laptop is disabled, the procedure can continue to be executed on the second laptop. However, unless manually configured, two PCS's will not necessarily reflect the same information. For example, Limit Manager is an application that allows the crew to change preset limits for a given parameter such as motor temperature limits associated with the Space Station Remote Manipulation System. However, these manual inputs are specific to the laptop and are not mirrored by the redundant laptop. This poses a problem if a procedure is started on one PCS, the laptop freezes, and the procedure must be finished on a second PCS. The crewmember must configure the second PCS to mirror the first and navigate down to the appropriate display. In some cases, the entire process needs to be started again from the beginning. This process is logistically difficult, affects crew time, destroys necessary redundancy, and is of particular concern with time-critical commands. If problems such as the Limit Manager example exist for execution of critical operations, there could be a safety impact since the second laptop cannot immediately take over procedure execution.

Recommendation 3: The ISS Program should accurately implement static display indicators on all PCS displays to provide accurate display information to the ISS crew.

Recommendation 4: The ISS Program should improve the accuracy of data products, such as Standard Out, used to develop the displays.

Recommendation 5: The ISS Program should develop an ISS-wide method to identify and execute critical commands, regardless of the system involved.

Recommendation 6: The ISS Program and MOD should provide support for the more extensive use of task level displays to alleviate the cumbersome navigation methods used in the PCS.

Recommendation 7: The ISS Program should address the requirement for redundant laptops and ensure that the process is accurate and efficient and consistently meets a criticality level of 1R.

D. Software Engineering

The ISS Program does not have a coordinated, well-defined process for software engineering and software management. The lack of such a process results in numerous problems with requirements control, configuration management, cost and schedule estimates, and defect prevention.

While issues exist for the entire software development process, our review identified several areas specific to PCS and displays development. For example, there is inadequate communication between software users, software developers, and project managers. A formal

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[18] A criticality category of 1R indicates redundant items, all of which if failed, could result in loss of the ISS or the loss of flight or ground personnel.

communications process should include display requirements providers, systems experts, display developers, and test personnel such as Multi-Element Integrated Test personnel.[19] A coordinated communications process would improve the application of requirements across organizational lines and reduce costs and schedule slippage on software projects.

Additionally, based on a review of the development tools currently being used, NASA is not using the best tools in its display development process. Tools such as GUI builders, Computer-Aided Software Engineering (CASE) tools, and test tools should be used to improve the display development process and the quality of the displays. Also, the use of rapid prototyping tools to quickly develop a display or the use of a prototyping lab to preview displays before they are released would significantly improve the process. The current method of hand coding graphical displays in the C++ programming language is not an efficient process for software development or long-term software management. It currently takes 7-10 days to develop a graphical display. A less time and labor intensive method would allow more use of graphical displays that provide a more user-friendly interface. An astronaut who recognized the need in this area developed one of the very few automated tools currently used by the program to build displays.[20] The use of more automated tools would give the program more flexibility in the types of displays developed and would shorten the time required to develop the display, thereby reducing display development costs.

NASA should better coordinate the software and display development process. The Program currently lacks an effective process for ensuring the consistent use of techniques and tools across organizational lines. An effective, coordinated process would also bring cohesion to the current display development processes. Additionally, an overall software architect,[21] not a program manager, should be designated to help resolve the problem of poor data products (such as inaccurate Standard Out files) being used in the display development process.

<u>Recommendation 8</u>: The ISS Program should develop a formalized process for the communication of system requirements between users, software developers, and project managers. This process should cover all activities involved in the development of system software including system displays.

<u>Recommendation 9</u>: The ISS Program and MOD should identify and procure or develop GUI builders, CASE tools, and testing and rapid prototyping tools to aid in the software and display development process.

<u>Recommendation 10</u>: The ISS Program should develop an overall software and displays development methodology to coordinate the work done by the different organizational units.

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[19] The Multi-Integrated Test, or MEIT, is the final stage of testing flight-qualified hardware and software. MEIT tests the operational compatibility of interrelated ISS systems.

[20] The Command Page Authoring Tool (CPAT) is a software tool used to build non-graphical displays.

[21] A software architect should have technical and budget authorities to focus solely on and control the end to end ISS software development process.

<u>Recommendation 11:</u> The ISS Program should designate an overall software architect, with appropriate management and budget authority, for the entire software development process.

III. SUMMARY AND EVALUATION OF NASA MANAGEMENT RESPONSE

Management's reply to our draft report appears in Appendix F. The reply was not responsive. For instance, responding to recommendation 3, the ISS Program "determined that it is not practical to place frame counter-indicators next to every piece of data because that would soon clutter the display. Currently, the frame counter-indicators are strategically placed at locations around the displays." Further, the response contended that "the ground telemetry stream contains all data and frame counters for the entire C&DH, where stringent monitoring and analysis can be made on a continuous basis." Our recommendation that the program "accurately implement static display indicators on all PCS displays to provide accurate display information to the crew," did not prescribe frame counters. The purpose of the recommendation was to increase the accuracy of information supplied to the crew. The management response chose only to address frame counters, but not other possible design options such as color highlighting or blinking (neither of which would use more screen space). Further, the response did not address the possible safety issues attendant to inactive data in the PCS.

Our recommendation 11 stated that the ISS Program "should designate an overall software architect, with appropriate management and budget authority, for the entire software development process." The Agency responded by stating that "the ISS program designated the Avionics and Software Office Manager as directly reporting to the ISS Program Manager with 'Program wide Software Architecture and Budget authority.' The ISS Software Architect reports directly to the Avionics Office Manager, and all software development budget issues are routinely addressed at the ASCB." It is unclear from the response who fulfills the role of software architect, and whether the official has the appropriate management and budget authority to effectively lead the process. Neither the current organization chart nor our interviews with program personnel indicate that the software architect function is being performed.

Given such responses, it is difficult to determine if NASA management is concurring or nonconcurring with our recommendations. NASA guidelines[22] require that a management response contain a position of concurrence, nonconcurrence, or partial concurrence for each recommendation. The reply does not comply with this guidance.

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[22] NASA Procedures and Guidelines (NPG 1200.1), Management Accountability and Control, Audit Liaison, and Audit Followup, Chapter 4, Section 4.3.4.2, states that for "each audit recommendation and estimated monetary benefit, the audited organization will include a declaration of concurrence, partial concurrence, or nonconcurrence." The Agency's pending revision to NPG 1200.1 (NPG 1290.1, Audit Liaison and Followup), also establishes the requirement that management respond with a position of concurrence, partial concurrence, or nonconcurrence.

IV. CONCLUSION

The PCS display quality and navigation has improved measurably since the beginning of the project and the efforts of the ISS Program to address some of the issues are apparent. However, the display development process still has significant weaknesses that impact usability and reliability of the PCS. These weaknesses must be addressed to ensure that the PCS is a dependable crew interface. Prudent software engineering would allow future hardware and software upgrades and changes to be as efficient as possible. We believe the recommendations made in this report will improve the overall display development process and will increase the usability and reliability of the PCS. We request that NASA management reconsider its response to our recommendations and submit a reply consistent with Agency guidelines not later than August 30, 2000.

David M. Cushing

8 Enclosures
Appendix A: ISS PCS Display Examples
Appendix B: PCS Independent Review Team Report
Appendix C: JSC Display Review Team Report
Appendix D: HEDS IA PCS Display Development Process Report
Appendix E: SPN Statistics
Appendix F: NASA Management Response
Appendix G: Summary of Report Recommendations
Appendix H: Report Distribution
NASA Office of Inspector General Reader Survey

MAJOR CONTRIBUTORS TO THIS REPORT

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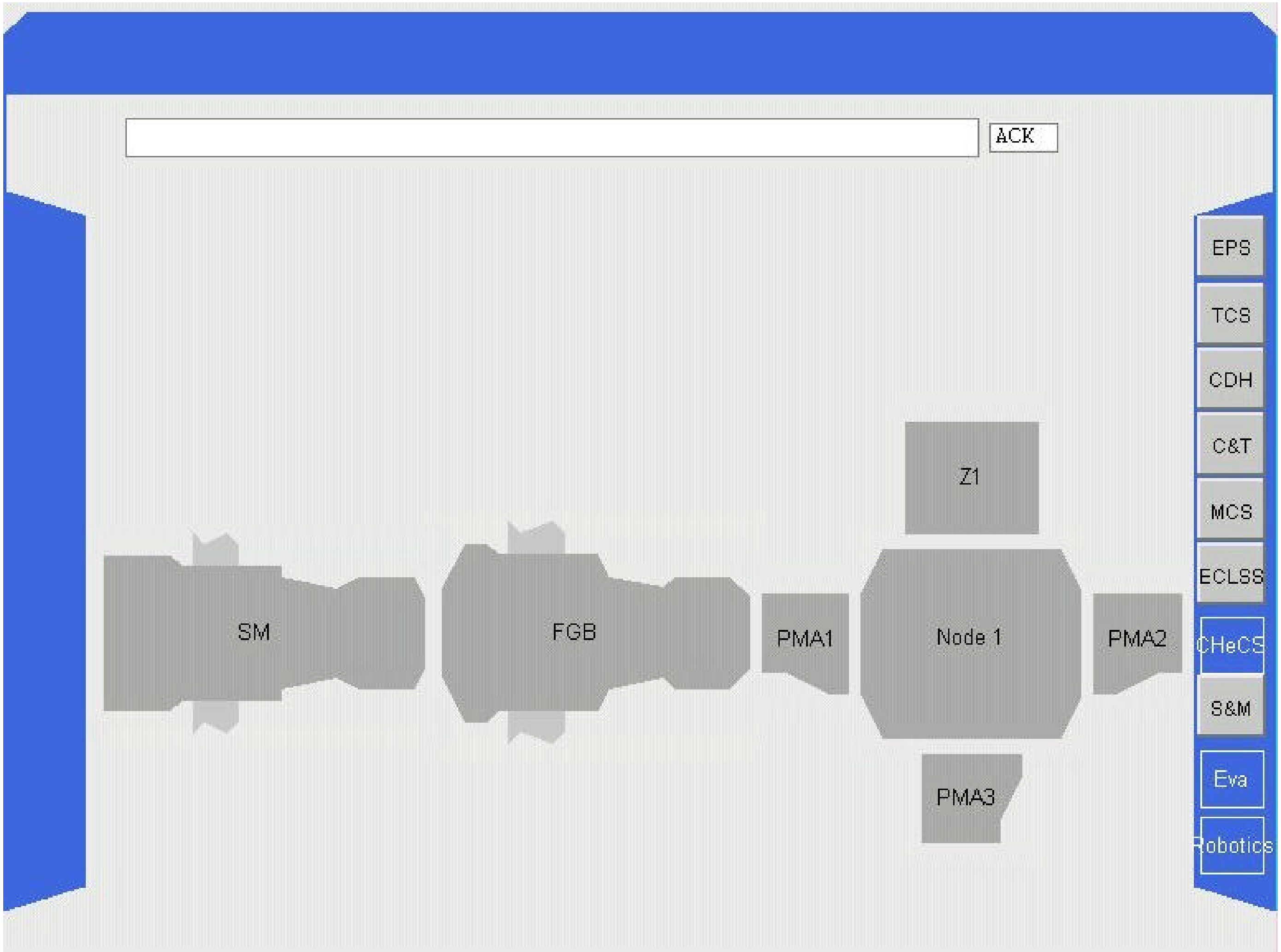
Appendix A

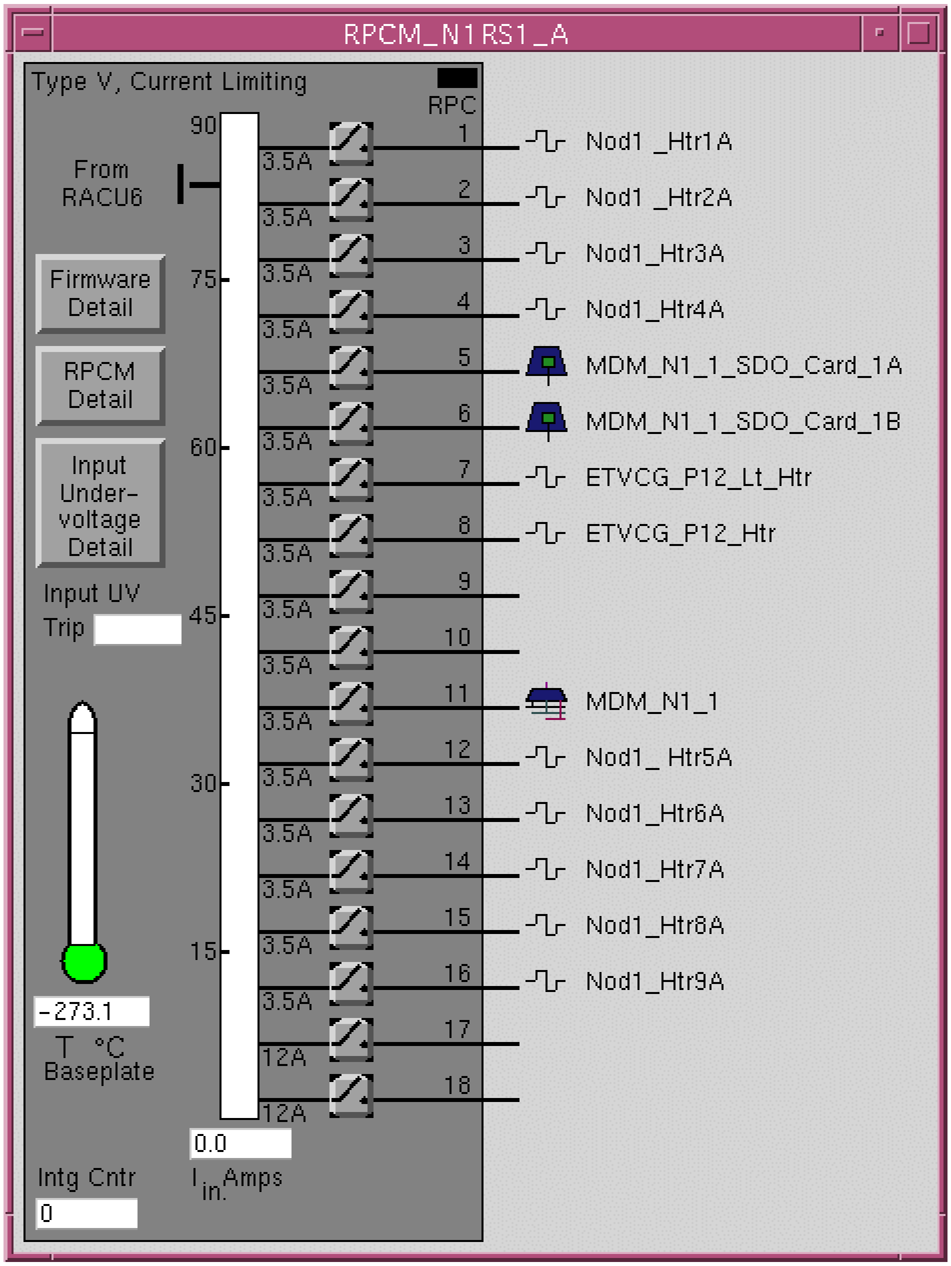
ISS PCS Display Examples



GRAPHICAL DISPLAY EXAMPLE

Flight 3A ISS Homepage

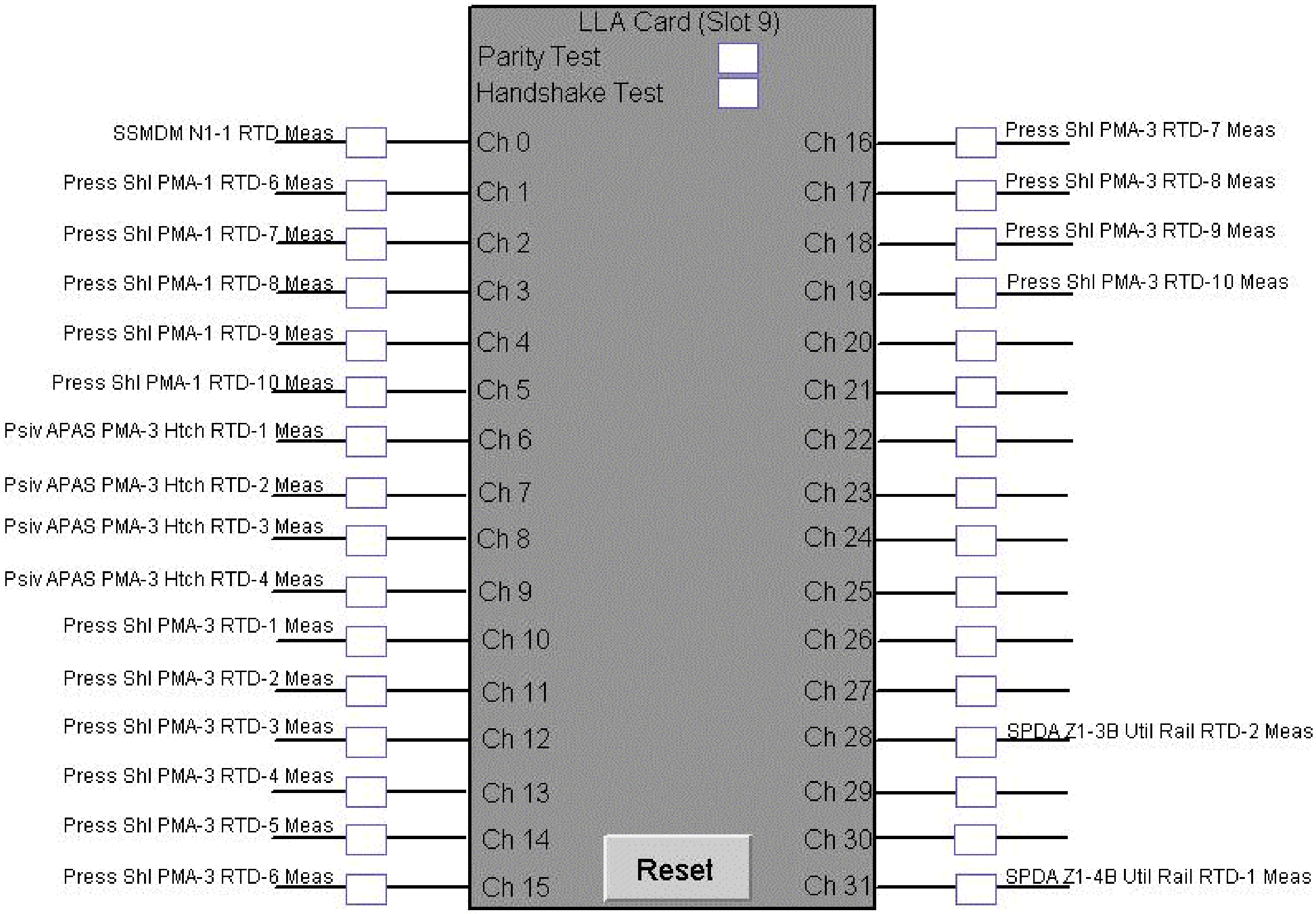
(Source: http://flight.jsc.nasa.gov/IDAGS/3a_gen.html)



NON-GRAPHICAL DISPLAY EXAMPLE

Flight 3A Remote Power Control Mechanism

(Source: http://klaatu.jsc.nasa.gov/rst/AST/PCS_Displays/PCS_displays_node1/)



NON-GRAPHICAL DISPLAY EXAMPLE

Flight 6A Node Control Software Low Level Analog

(Source: http://flight.jsc.nasa.gov/IDAGS/6a_cdh.html)

Appendix B

PCS Independent Review Team Report

[Not Available at This Time]

Appendix C

JSC Display Review Team Report

[Not Available at This Time]

Appendix D

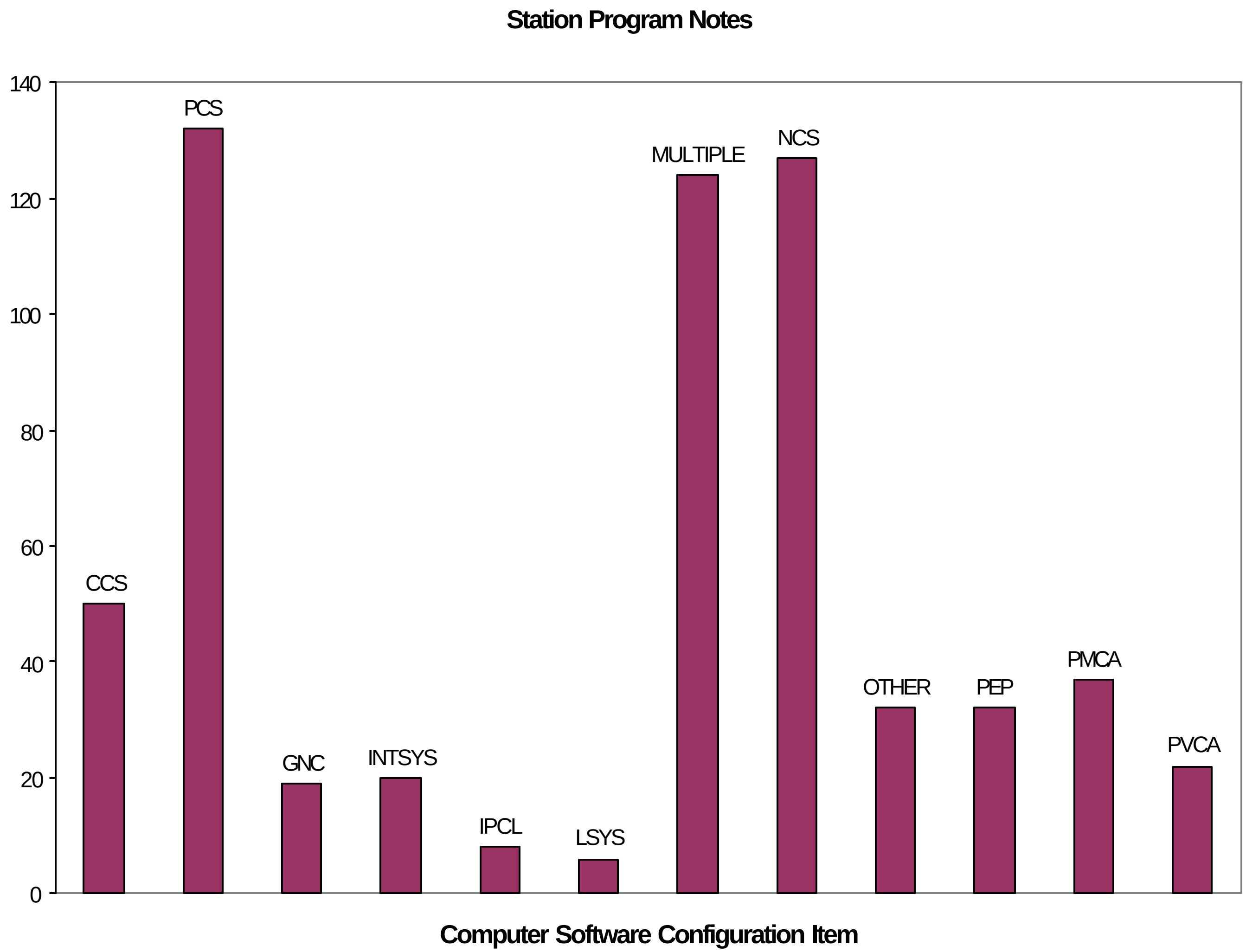
HEDS IA PCS Display Development Process Report

[Not Available at This Time]

Appendix E

SPN Statistics

[Aggregate Statistics Chart Not Available at This Time]



- CCS — Command and Control Software
- PCS — Portable Computer System
- GNC — Guidance, Navigation & Control
- INTSYS — Internal System
- IPCL — Instrumentation Program and Command List
- LSYS — Laboratory System
- NCS — Node Control Software
- PEP — Payload Executive Processor
- PMCA — Power Management and Control Application
- PVCA — Photovoltaic Controller Application

Appendix F

NASA Management Response

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

-1 3:15

Reply to Attn of: MI.

TO: W/Assistant Inspector General for Inspections, Administrative Investigations, and Assessments

FROM: M/Associate Administrator for Space Flight

SUBJECT: Assessment of the Portable Computer System (PCS) and the Data Display Process, G-99-010A, Draft Report

Thank you for providing the Office of Space Flight (OSF) with an opportunity to comment on your draft report on the Assessment of the Portable Computer and Data Display Process, G-99-010A, for the International Space Station (ISS).

In general we find that the report addresses issues and management practices that have been the subject of continued and proactive management and technical attention over the past several years. This is evident in your attachments, which date our attention to the issues raised in the report as early as 1996. The ISS program office has been very diligent in resolving problems and addressing the PCS issues throughout that period. This has led to development of a culture of continuous improvement; such improvements are made as they are identified. In addition to that, the fact that Early PCS displays have performed successfully on actual ISS space flight missions has demonstrated the basic soundness of the overall approach.

Your findings and recommendations do not appear to recognize much of the focused attention already provided to the PCS and data display process. As such, we would suggest reconsideration of the draft report recommendations. Enclosed are specific comments to each recommendation, which NASA considers relevant to this reconsideration. Please contact Mr. Dan Hedin at (202) 358-1691, if further assistance is required.

Joseph H. Rothenberg

Enclosure

cc:
M-4/Mr. Hawes
MX/Ms. Gabourel
AE/Mr. Hudkins
AO/Mr. Holcomb
J/Mr. Sutton
JM/Ms. Tynan
Q/Mr. Gregory
JSC/AA/Mr. Abbey
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    NQ/Mr. Kelly
    OA/Mr. Holloway
    OA/Mr. Greene

Assessment of the Portable Computer System (PCS) and the Data Display Process, G-99-010A, Draft Report

SPECIFIC RESPONSE TO FINDINGS AND RECOMMENDATIONS

A. Need for Integrated Product Team

Recommendation 1: *The ISS Program should create an Integrated Product Team, composed of all relevant organizational units, to direct the display development process.*

Since at least 1997, as we have implemented and used a team approach in the PCS display development process. In addition, we have clearly stated our approach in ISO Work Instruction DF-08, PCS Display Requirements Development, which effectively defines an Integrated Product Team (IPT). We are continuing to develop and refine the IPT function to include all necessary parties and disciplines on the team, including, Mission Operations Directorate (MOD), Engineering Directorate, Astronaut Crew Office, Avionics Software Office, Contractor Avionics Software Office (Boeing), Safety Reliability and Maintenance and Quality Assurance (SRM&QA), Vehicle Integrated Product Team (VIPT), and others.

B. Need for Independent Verification of Displays

Recommendation 2: *The ISS Program should establish an independent verification function to assess the utility and form of the PCS displays and the overall display development process.*

The independent verification of the PCS activities is already functionally in place as a part of the normal development process. Two verification functions are associated with PCS displays: one is to verify whether the display is appropriately a graphical or command detail page, and the second is to review the process by which displays are developed. In addition, a Crew Comments Database is used to register comments about the displays as they are being used, and we routinely use this data to improve our product. From a formal standpoint, the Independent Verification and Validation contractor as well as NASA Safety, Reliability and Mission Assurance personnel regularly provide independent reviews of the process from a software development viewpoint.

C. Usability of PCS

Recommendation 3: *The ISS Program should accurately implement static display indicators on all PCS displays to provide accurate display information to the ISS crew.*

The ISS program has determined that it is not practical to place frame counter-indicators next to every piece of data because that would soon clutter the display. Currently, the frame counter-indicators are strategically placed at locations around the displays. However, the ground telemetry stream contains all data and frame counters for the entire Command and Data Handling System, where stringent monitoring and analysis can be made on a continuous basis. Operational experiences over the initial crew expeditions will certainly influence future use of frame counters.

Recommendation 4: *The ISS Program should improve the accuracy of data products, such as Standard Out, used to develop the displays. (2. Erroneous Information)*

The ISS Program Office has been striving to improve the accuracy and timeliness of the Standard Out data from the beginning. As a result, significant improvements and upgrades have been made to the Standard Out build process, as verified by our Software Quality Assurance Team. Validation tools for the Mission Build Facility (MBF) where Standard Out software files are built and stored, have also been enhanced. Changes have been made outside the MBF as well, including use of Stage Data engineers at Boeing and NASA to focus on operational needs for data issue resolution.

Due to the parallel efforts of simultaneous software development and operation, the PCS display development can lag behind the Standard Out releases, thus creating the need for Station Program Notes (SPNs). The majority of SPNs are incorporated into operations procedures, thereby eliminating any need for a crewmember to rely on their memory.

Recommendation 5: *The ISS Program should develop an ISS-wide method to identify and execute critical commands, regardless of the system involved.*

A method to identify critical commands is already in place. The criteria for determining the criticality of commands are established by the Safety community and documented. The criticality for each command is established through a cooperative effort by the mission operations, safety, and the ISS Program Office. In addition, the ISS Program Office has established a Caution and Warning System Integration Team. This team is chartered to address any command and display inconsistencies with regard to caution and warning.

Recommendation 6: *The ISS Program and MOD should provide support for the more extensive use of task level displays to alleviate the cumbersome navigation methods used in the PCS.*

We believe that task level displays, those dedicated to a specific task, are very useful and are inherently supported by our existing architecture. However, the application of task displays, as a tool, is strictly an operational decision. The ISS Program Office believes that the current PCS capabilities provide significant support for extensive use of task level displays. Task level displays supplement rather than replace the more general and widely used hierarchical display navigation methods. It is anticipated that as more experience is gained in operating the actual ISS spacecraft, additional task level displays will, in fact be created. Moreover, the PCS development team and the MOD Systems Division are working with the JSC Engineering Directorate to jointly prototype a new display building tool that will allow the creation of 'procedures displays.' Nonetheless, hierarchical navigation is a widely accepted, straightforward and reliable method of navigating through several levels of computer displays. It is one of the approved navigation methods in the ISS Display and Graphics Commonality Standard, SSP 50313. Additionally, the crew and OSP communities both participate in the display definition process. This concurrent participation serves to optimize these task displays.

Recommendation 7: *The ISS Program should address the requirement for redundant laptops and ensure that the process is accurate and efficient and consistently meets a criticality level of 1R.*

The ISS program fully understands the implementation of redundancy for computer systems and made a decision to utilize a standby computer. The choice to use a standby backup computer rather than a fully synchronized hot backup one was fully coordinated with all relevant parties and disciplines, including the Crew Office. The Safety Review Panel assessed this approach and found it to be acceptable in meeting the intent of the requirement for Crit 1R. The hazard analysis also documents that any critical system safety functions can be accomplished either autonomously, on-board, or by ground intervention. The redundant laptop computer requirement is under close control of the Space Station Control Board (SSCB) and the Integrated Display and Graphics Standards Panel (IDAGSP) is the utilization watchdog for implementation of this requirement.

D. Software Engineering

<u>Recommendation 8:</u> *The ISS Program should develop a formalized process for the communication of system requirements between users, software developers, and project managers. This process should cover all activities involved in the development of system software including system displays.*

The PCS Displays Development project indeed, does have a formalized process that covers end-to-end activities dealing with system requirements, software and displays development. As pointed out in our response to the Recommendation 1, we have a formal Work Instruction DF-08, <u>PCS Display Requirements Development</u>, which covers requirements development. Graphical and non-graphical display designs are developed using this Work Instruction and the full software life cycle requirements process, which includes strict review of all display designs to assure compliance with adopted standards. Although both graphical and non-graphical display designs are subject to the same requirements and design process, it is possible that the current version of the Work Instruction could be interpreted such that non-graphical displays may not be consistently held to the same standards as the graphical displays. In order to assure that all display designs are developed in full accordance with established software standards and procedures, the PCS Display Requirements Development Work Instruction, DF-08 has already begun the process of revision, as required, to clarify its application to the development of both graphical and non-graphical display requirements and their subsequent implementation. This revision will be coordinated with full representation and knowledge of the PCS Project Management, and will be reviewed by the display users, software developers, and the Joint Software Assurance Panel (JSAP) of the Avionics Software Control Board. The JSAP has representation from the entire software design community, including the software Independent Verification and Validation Facility, in Fairmont, West Virginia, which now reports to the Agencywide Software Assurance Office at Goddard Space Flight Center.

<u>Recommendation 9:</u> *The ISS Program and MOD should identify and procure or develop GUI builders, CASE tools, and testing and rapid prototyping tools to aid in the software and display development process.*

The ISS Program already uses a variety of tools as appropriate to build Graphical User Interfaces (GUI) and the associated graphical displays. Experience has shown us that constantly utilizing different software tools is not usually a cost-effective method to develop displays. Accordingly, we have made steady and incremental improvements over time, employing a generally used suite of display development tools. Even so, we are actively in the process of developing additional tools consistent with improving our processes and shortening our display development time. Test tools have also been developed in this way, and new test tool developments are now in process to improve our efficiency and performance.

Recommendation 10: *The ISS Program should develop an overall software and displays development methodology to coordinate the work done by the different organizational units.*

The PCS development process has a documented methodology in place for display development. For example, for the International Partner (IP) segments, a Software Management Plan has been under negotiations for the past several months and now it is in the final stages of the approval process. Each IP's development process meets or exceeds the Mil Standard 2167A, the basic ISS software development standard.

Recommendation 11: *The ISS Program should designate an overall software architect, with appropriate management and budget authority, for the entire software development process.*

Last year the ISS program designated the Avionics and Software Office Manager as directly reporting to the ISS Program Manager with "Program wide Software Architecture and Budget authority." The ISS Software Architect reports directly to the Avionics Office Manager, and all software development budget issues are routinely addressed at the Avionics Software Control Board.

Appendix G

Summary of Report Recommendations

SUMMARY OF REPORT RECOMMENDATIONS

Recommendation 1: The ISS Program should create an Integrated Product Team, composed of all relevant organizational units, to direct the display development process.

Recommendation 2: The ISS Program should establish an independent verification function to assess the utility and form of the PCS displays and the overall display development process.

Recommendation 3: The ISS Program should implement accurate static display indicators on all PCS displays to provide accurate display information to the ISS crew.

Recommendation 4: The ISS Program should improve the accuracy of data products, such as Standard Out, used to develop the displays.

Recommendation 5: The ISS Program should develop an ISS-wide method to identify and execute critical commands, regardless of the system involved.

Recommendation 6: The ISS Program and MOD should provide support for the more extensive use of task level displays to alleviate the cumbersome navigation methods used in the PCS.

Recommendation 7: The ISS Program should address the requirement for redundant laptops and ensure that the process is accurate and efficient and consistently meets a criticality level of 1R.

Recommendation 8: The ISS Program should develop a formalized process for the communication of system requirements between users, software developers, and project managers. This process should cover all activities involved in the development of system software including system displays.

Recommendation 9: The ISS Program and MOD should identify and procure or develop GUI builders, CASE tools, and testing and rapid prototyping tools to aid in the software and display development process.

Recommendation 10: The ISS Program should develop an overall software and displays development methodology to coordinate the work done by the different organizational units.

Recommendation 11: The ISS Program should designate an overall software architect, with appropriate management and budget authority, for the entire software development process.

Appendix H

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