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**REPORT OF
THE
SHUTTLE PROCESSING REVIEW TEAM**

JUNE 30, 1993

REQUESTED BY THE

NASA ADMINISTRATOR

(NASA-TM-109728) REPORT OF THE
SHUTTLE PROCESSING REVIEW TEAM
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INDEX

I.	Executive Summary	1
II.	Detailed Report	7
A.	Introduction	7
	1. Objective	
	2. Approach	
B.	Background	9
	1. John Young Report	
	2. Gene Thomas Report	
C.	Follow-up/Verification of Corrective Actions	10
	1. John Young Report	
	2. Gene Thomas Report	
D.	Incidents Reviewed for Adequacy of Corrective Action Implementation	22
	1. STS-56 Lost/Found Pliers Incident	
	2. Fuel Cell Incident	
	3. O ₂ Meter Left in Intertank on STS-56	
	4. VAB Crane Incident	
E.	Specific Subjects Reviewed	28
	1. Safety	
	2. Tool Control	
	3. Structured Surveillance	
	4. Problem Reports	
	5. Mishap Reports	
	6. Training and Certification	
	7. Quality Assurance	
F.	Voluntary Interview Results	36
G.	Conclusions	37
H.	Overall Recommendations	39
III.	Appendix	
	A. Dan Goldin Letter	
	B. Robert Crippen Letter	

SHUTTLE PROCESSING REVIEW TEAM

I. Executive Summary

The intent of this report is to summarize the assessment of the Shuttle processing operations at the Kennedy Space Center (KSC) as requested by the NASA Administrator. He requested a team re-affirm that safety is our number one priority and review operations to ensure confidence in the Shuttle processing procedures at KSC.

It is the opinion of this Review Team that the Space Shuttle Processing is the best that it has ever been and is continually being evaluated for improvements. Launch rates have improved, processing times have decreased dramatically, and in-flight anomalies have decreased. These factors are indicative of a mature and excellent program. It is the consensus of this Team that safety continues to be the number one priority in Shuttle processing at KSC.

This Review Team also believes that confidence in the Shuttle processing operations procedures and personnel is well placed. Management, technicians, Quality Control and Safety personnel all take tremendous pride in their work and perform their tasks in an excellent manner. They are creative and constantly think of ways to perform their job better. The success of the Shuttle Program is a result of the efforts of thousands of dedicated people. The work is extremely complex and involves hundreds of thousands of operations that must be done correctly. By design, the hardware is tolerant of some mistakes, and a degree of risk is accepted in space flight that something remaining undetected can always occur.

Some perceptions were expressed to the Team by the work force of fear concerning job security. There is a perception that reporting incidents and mistakes may result in punitive action and possible loss of employment. This perception may be the result of recent reductions in force dictated by budget cuts as well as the sometimes exaggerated reporting of incidents by the media. There is also a perception that controls effected as the result of problems and incidents are excessive and have resulted in a slowdown in processing. While the Team found no evidence to substantiate these perceptions, the fact that they exist should be addressed. The perceptions do not reflect upper management policies in the area of reporting incidents and mistakes.

The Shuttle Processing Review Team was appointed by Robert Crippen, Director, KSC, at the request of the Associate Administrator for Space Flight and charged with the responsibility to review the circumstances, underlying causes, and corrective actions taken as a result of recent incidents and close calls during Shuttle processing at KSC. The Team was further tasked to determine if actions taken are considered sufficient to prevent problems from recurring.

To establish a baseline and point of reference for this review, the Team examined the actions taken as the result of the recommendations from a report, entitled "Assessment of Human Error Incidents at Kennedy Space Center", June 6, 1991. This report was generated as a result of the findings of a team headed by John W. Young and is referred to as the "John Young Report". The John Young Report strongly endorsed the recommendations from a report by J. A. (Gene) Thomas entitled "Report of the NASA/SPC Committee to Study Incidents", dated July 1990. It is referred to as "the Gene Thomas Report". The Shuttle Processing Review Team conducted on-site visits and personal interviews to determine if the recommendations contained in these two reports had been properly implemented and closed-out.

In addition, the Team reviewed summaries of all mishaps, incidents and close calls that occurred subsequent to October 1990. The Young Team had addressed those prior to that date. Specific mishaps were reviewed in detail to identify causes and corrective actions taken to preclude recurrence. Documentation review, on-site visits and personal interviews were conducted to determine if corrective actions were appropriate and had, in fact, been implemented.

The team of technicians, inspectors and engineers at KSC, who are responsible for our success, were asked to meet with the Team members at their respective work area without their supervisors being present. The Team asked them to volunteer their opinions and feelings as to why NASA has been so successful yet incidents continue to occur. The focus of these sessions was to solicit honest, no-holds-barred opinions as to why the Shuttle Program has been so highly successful, yet the people who are responsible for this success also seem to receive disproportionate criticism whenever a minor incident occurs. The underlying causes for these incidents and the actions taken as a result of them were also subjects of discussion. Many of our observations are reflective of the perceptions at the technician level and are intended to assist the Shuttle Processing Team to further enhance their enviable record. It was not the intent of this Review Team to cast doubt on the efficiency and the safe accomplishments of the Shuttle Operations Team.

CONCLUSIONS:

The following are the overall conclusions reached by the Team:

1. Safety continues to be the number one priority in Shuttle processing operations and confidence in processing operations procedures and personnel is well placed.
2. The Shuttle Operations Team has developed a comprehensive methodology to continuously improve quality while reducing labor costs. Some areas observed seemed to excel in continuous improvement more than others and are models to emulate. The Orbiter tile shop, the tire shop, the Hypergolic Maintenance Facility (HMF) and the Space Shuttle Main Engine (SSME) processing areas are considered examples. Teamwork, new efficiencies in operations, facility improvements and automation techniques have been combined to result in record processing quantities with continuing improvement in quality and a low incidence of mishaps.
3. The underlying causes for recent incidents and close calls during Shuttle processing at KSC as determined through a review of documentation is attributable to human factors, equipment failures and procedures. The predominant causes (66%) of all mishaps is human factors. For flight hardware incidents human factors were responsible for 32% of the mishaps and procedures caused 26% of the mishaps. The actions taken as result of these incidents were reviewed in detail. The corrective actions in most cases were determined to be adequate and had, in fact, been implemented. However, in some cases, implementation was still in process or budget restrictions and revised methods of operation were stated to be the reason for not implementing the recommendations.
4. The recommendations of the John Young Report and the Gene Thomas Report have not been fully implemented in all areas. These were recommendations and not directives. The degree of implementation is subject to management judgement and recognized is the fact that NASA policies, budgets, and management systems have changed since these recommendations were made.
5. The Team concluded that multi-discipline team building has improved; however, there is a need to expand it to all areas. The task team leader concept, including the training and assignment of dedicated technicians and quality control personnel is not yet complete. Engineering support to the work site needs to be readdressed. Efficiencies achieved in non-critical operations have placed even more responsibility for the quality of the work on the technicians performing the task. Systems are in place to reward special performance and accomplishments. However, because of reductions in force and recent disciplinary actions associated with incidents that received disproportionate media attention, there is a perception that has developed

among the work force that making mistakes results in punitive action. There is a fear that noted mistakes will lead to loss of employment. Therefore, there is a tendency to not report problems, close calls and incidents because of the of the fear of reprisal. The Review Team found no evidence that disciplinary action was taken inappropriately.

6. Some NASA and SPC technicians and Quality Control personnel desire more detailed knowledge of systems and subsystems to which they are assigned to verify procedural compliance. Some Quality Control personnel interviewed expressed concern that their areas of responsibility are too broad. Concerns were also expressed relative to lack of involvement by quality inspectors in generating processing paper and planning tasks to be accomplished. The pilot Structured Surveillance Program is complete and full implementation is in process. However, some inconsistencies and misinterpretations were expressed by the technicians and quality control personnel. Corrosion inspection requirements in the OMRSD are being met; however, deficiencies were noted in the adequacy of the process used to detect corrosion on the Orbiter.

7. Not all Design Center(s), CIL and Hazard acceptance criteria involved in KSC processing are "linked" to the OMRS creating the potential for an oversight during selection of inspection requirements in work authorization documents. A change request approved by the Program Manager allowed deletion of CIL and Hazard related inspection requirements in the OMRSD if defined by released engineering.

8. The category "A" mishap on the fuel cell resulted in an Investigation Board Report with 26 recommendations. The Team found the documentation for closeout of the recommendations reflected satisfactory rationale, but the corrective action implementation requires reevaluation and documentation update to reflect management decisions.

9. Some personnel feel their concerns about hazards are not being addressed. Workers in Orbiter aft compartment indicated concerns with lighting and noise levels. SCAPE suit problems continue to occur. Although significant management attention has been placed on SCAPE suits, some of the work force feel that known design deficiencies have not been adequately corrected. Close calls were stated to have occurred which have not been reported.

RECOMMENDATIONS:

The Team assessed the results of their review and developed the overall recommendations summarized below:

1. Management should continue to be a positive influence on safety improvements and continue to respond to the constant challenge of communicating with the work force to ensure perceptions accurately reflect management policies. Top management, mid-level managers and first-line supervisors need to continue to communicate with their subordinates to allay their fears that reporting problems, close calls and mistakes leads to reprisals and disciplinary action.
2. KSC and SPC management should study closely the areas of excellence that have evidenced themselves and capture the lessons learned and successes achieved in order to apply these successful techniques to all processing operations.
3. KSC and SPC should establish additional continuous improvement teams to investigate root causes for incidents and problems attributable to human factors. Feedback should be solicited from the work force as to solutions for problems.
4. The SPC closures for the recommendations of both the John Young Report and the Gene Thomas Report need to be reassessed by NASA to see if they are still applicable and reflect the current Agency directions. If they are found to be applicable, they should continue to be implemented and regular audits should be performed to assure compliance. If found to be not applicable, the closeout reports should be amended to reflect the current policies of operation.
5. Multi-discipline team building needs to continue to be implemented, especially in the VAB and at the launch pads. The task team leader concept, the on-site engineering support and the dedicated technician and inspector approach need to be integrated into an overall strategy for critical operations. KSC management, both NASA and contractor, should continue to do as much as possible to provide an environment that encourages integrated teamwork and cooperation between the various organizations on-site.
6. NASA and SPC should continue to review and update their training and certification programs for technicians and quality control personnel. Quality personnel should have adequate involvement in generating the processing paper and planning the tasks to be accomplished. KSC should assure that quality inspectors have appropriate training in critical systems. Emphasis must be placed on each individual stamp as a warranty that the work was performed correctly. The system used to identify areas in need of in-depth quality audits or increased surveillance could be improved. Improved trend analysis, in addition to trend reporting, would be beneficial to help identify recurring problem areas requiring corrective action. The requirements for in-depth corrosion inspection criteria need to be reviewed by the Design Center. Training and certification should be improved appropriately.

7. To preserve the integrity of risk assessment and risk management activities, Space Shuttle program management must ensure that KSC Operations and Maintenance Requirements Specifications Document (OMRSD) derived from CIL or Hazard Report acceptance rationale are properly identified to ensure independent inspection, closed-loop accounting of work completion, and proper application. NASA JSC, KSC and Space Shuttle program management should determine the validity of the KSC situation. If similar situations exist at Design Center contractors' plants, they should initiate corrective action as soon as possible. The Shuttle Program Manager (JSC) should reassess the impact of the Change Request that deleted OMRSD requirements that are defined by released engineering.

8. The process for verifying implementation of recommendations in mishap investigation reports needs to be reviewed to assure corrective actions documented in the closeouts are effected.

9. NASA and SPC should continue to address concerns about hazards held by personnel working in the Orbiter aft compartment to assure they are given proper visibility and are aggressively pursued. The Design Center should assist in these efforts by considering design changes that would reduce the noise level from the purge air system. NASA and SPC need to continue to address the cause for the incidents on SCAPE suits. Communication between SCAPE Operations and Life Support personnel need to be improved. A means should be established to flag trends and resolve issues such as the number of SCAPE problems. Management needs to evaluate the system for reporting close calls to assure employee participation is not discouraged and safety concerns are properly addressed.

**SHUTTLE PROCESSING REVIEW TEAM
DETAILED REPORT**

A. INTRODUCTION

The NASA Administrator requested the Associate Administrator, Office of Space Flight (OSF), re-affirm that safety is our number one priority. He recommended Robert Crippen establish a team to ensure continuing confidence in the Shuttle processing procedures at Kennedy Space Center (KSC). (Enclosure 1)

Robert Crippen appointed Richard U. Perry, NASA Headquarters, Director, Space Flight Safety and Mission Assurance Division, to chair a team to conduct this review. (Enclosure 2) Team members included:

Roger Mielec
Manager, Systems Effectiveness, Headquarters Safety Division
NASA Headquarters

Ken Colley
Headquarters Manager, Space Shuttle Operations Integration
Kennedy Space Center

Hector Delgado
Systems Assurance Office
Kennedy Space Center

Major Andrew Allen, USMC
Astronaut Office
Johnson Space Center

John Starnes
Aviation Safety Office
Johnson Space Center

George Jarrell
Shuttle Safety and Mission Assurance Division
Johnson Space Center

Ken Jones
RSRM Chief Engineer
Marshall Space Flight Center

Paul Teehan
Safety and Mission Assurance Representative
Marshall Space Flight Center Resident Office,
Kennedy Space Center

Linder Metts
Project Assurance Office
Marshall Space Flight Center

Lon Miller
Manager, ASRM Project Office
Stennis Space Center

SUPPORT TEAM MEMBERS:

Syd England
Loral Corporation
SSP SR&QA Resident Office/
Kennedy Space Center

Janet Cipolletti
Loral Corporation
SSP SR&QA Resident Office/
Kennedy Space Center

Ben Weil
Loral Corporation
SR&QA Support Office/
Johnson Space Center

Mary Ann Turner
Recording Secretary
Kennedy Space Center

Ettie Karpman
Recording Secretary
Space Flight S&MA Division
NASA Headquarters

1. OBJECTIVE

The Charter for the Team stated the objective as: "Review the circumstances, underlying causes and corrective actions taken as the result of recent incidents and close calls during Shuttle processing at the KSC to determine if actions taken are considered sufficient to prevent problems from reoccurring."

2. APPROACH

The Team was to review Shuttle processing incidents, close calls, surveys, audits and significant problem reports to ascertain if previously recommended corrective measures were appropriate and effectively implemented. They were to review selected current Shuttle processing procedures and determine if they are appropriate to prevent similar problems. Finally, the Team was asked to develop conclusions and provide recommendations for system or procedural improvements.

B. BACKGROUND

On June 6, 1991, a report entitled "Assessment of Human Error Incidents at Kennedy Space Center" was issued by the Associate Administrator, Office of Space Flight. The report summarized an assessment of human error incidents at KSC which was conducted by a team headed by John W. Young. The assessment team was requested to categorize and summarize the incidents and determine if there appeared to be a pattern to their occurrences. The team was also requested to recommend standards and criteria that should be used to assess whether the number of incidents was excessive. Using these standards, they were to assess whether KSC was doing as well as they should and determine what could be done to lower the frequency of such incidents.

The assessment team focused on human error incidents in Shuttle processing operations which occurred between July 1, 1989, and October 5, 1990. A total of 216 reported mishaps/incidents and 69 close calls were documented during this period. The assessment team did not observe any condition or concerns that were materially different from findings of earlier investigation boards. They did not find an available set of indices from which to judge quality performance and trends on a macro scale, but the team made a recommendation that the KSC/Shuttle Processing Contractor (SPC) processing team establish a methodology/process for "bench marking" this experience base and measuring improvements against this "bench mark". The report provided six specific recommendations. The Shuttle Processing Review team was asked by the Chairman to review the actions taken as a result of the John Young Report and determine if those actions had been implemented. The SPC response, dated July 19, 1991, summarized the actions that were taken or were in the process of being implemented.

The John Young Report also referred to a report of the NASA SPC Committee to study incidents, chaired by J. A. (Gene) Thomas, KSC Deputy Center Director, in July 1990. The John Young assessment team found the "Thomas Study" to represent a comprehensive, thorough effort and recommended that KSC and the SPC provide a plan of action and specific initiatives to address those recommendations. On June 4, 1991, the SPC reported closure of all the actions.

C. FOLLOW-UP VERIFICATION OF CORRECTIVE ACTIONS

1. John Young Report

Recommendation #1

During the period October 1, 1989, to September 30, 1990, the John Young Report indicated 216 mishap/incidents and 69 close calls were reported. The report recommended increased emphasis be placed on reporting close calls.

Analysis of mishaps in the MR/CAS database for the period October 5, 1990 to April 30, 1993, shows that 612 mishaps occurred. Of this total, 177 were classified as close call mishaps. The proportion of close calls to total mishaps on a monthly basis has become more random, but is generally 29% of total mishaps for this time period.

The SPC has a separate reporting system for mishaps, incidents and close calls. A Preliminary Evaluation Report (PER) is prepared for unplanned events or conditions that qualify or are suspected of qualifying as a mishap, incident or close call. The PER's are submitted to the Incident/Error Review Board (IERB) for review, evaluation, tracking and determining appropriate corrective actions and dispositioning. NASA mishap reports are initiated when appropriate.

Although increased emphasis has been placed on reporting close calls, the Team found there was a hesitancy and genuine unwillingness at the technician level to report mistakes and close calls for fear of disciplinary action. They sincerely believe that reporting an incident may, and probably will, result in disciplinary action including dismissal. No evidence was found by the Review Team where disciplinary action was taken inappropriately. Management needs to continue to communicate with their subordinates to allay their fears that reporting incidents and close calls leads to reprisals and disciplinary action.

Recommendation #2

The report recommended an engineering, manufacturing, quality, and safety team be formed to analyze the causes and handling of human errors.

An Incident Error Review Board (IERB) was formed by the SPC. The IERB, which is chaired by SPC SRM&QA analyzes all incident (PER) causes. There have been 135 occurrences that qualified as requiring submittal to the IERB since April 1991. Of these, 105 or 78% were attributed to human factors such as "human error", "failure to follow procedure", or "inattention".

Some analysis of the causes of human errors have been accomplished. However, the Team concluded more work is required before this recommendation is fully implemented. The percentage of Preliminary Evaluation Reports (PER's) attributable to human factors still requires an in-depth analysis by NASA and the contractors to determine underlying causes. A continuous improvement team should focus on determining root causes for human errors.

Recommendation #3

The Young Report recommended NASA KSC and the SPC form a team to develop a comprehensive methodology including standards, criteria and measurement indices which will allow KSC/SPC to measure overall quality improvement achievements and trends with a goal of seeking continuous improvement.

The team found that NASA KSC and the SPC had initiated an active Total Quality Management/Continuous Improvement Process Program with a series of measurement indices that are used to indicate quality. The number of problems per 1000 direct labor hours are portrayed by department. The number of NASA Quality Surveillance Reports (QSR's) are also tracked as a measure of SPC performance. The SPC performance evaluation takes into account some of these indices in determining the award fee.

Overall performance is indicated by the success of the operations team. In the last year, May 1992 through April 1993, the KSC team successfully launched nine Shuttle missions (STS-46, STS-47, STS-49, STS-50, STS-52, STS-53, STS-54, STS-56 and STS-55). STS-55 was delayed due to engine pump problems at the factory, a hydraulic hose rupture and range conflicts. The March 22 launch attempt of STS-55 was scrubbed at T-3 seconds due to an engine valve problem. A second scrub on April 6 at T-11 seconds occurred on STS-56 because of a faulty MPS sensor, but STS-56 was successfully launched 2 days later on April 8, and STS-55 was successfully launched on April 22. The KSC launch team successfully safed the vehicle after the March 22 abort and evacuated the crew after the engine shutdown at the launch pad. This was an outstanding demonstration on the part of the crew, the launch team and the systems. The Shuttle Program Manager and the OSF Associate Administrator commended the team for their superb handling of the shutdown. The total number of in-flight anomalies for each mission by vehicle has declined. During the last three missions, a total of 41 in-flight anomalies were

recorded. This is an average of 1.76 anomalies per flight day, well below the previous average. None of these anomalies were attributed to ground processing. Both LSOC and Thiokol were awarded the prestigious NASA Excellence Award for Quality in 1992. This award is based on demonstrated excellence and outstanding quality.

In an effort to help the Program and the Agency meet projected budget reductions of 15 percent by 1998, KSC analyzed current processing requirements, and over the last 2 years has made significant reductions in processing times. Reductions in the direct labor work force have been achieved while process improvements and new innovations such as the structured surveillance quality assurance program have improved process efficiency. Recent problems with the SSME configuration at Canoga Park have necessitated pulling engines from all vehicles and recycling them through the KSC engine shop for component replacement, retest and reinstallation. The speed and efficiency of these changeouts was due in part to the process improvements. The Team concluded that KSC and the SPC have developed a comprehensive methodology to continuously improve quality while reducing labor costs and processing time to comply with budget reductions.

Recommendation #4

The Young Report recommended the KSC/Shuttle Processing Team increase the management emphasis on communicating the importance of quality and safety as job elements and on improving management worker awareness of quality trends. The Shuttle Operations Review Team found strong involvement of management in promoting quality and safety. The SPC contractor was awarded the NASA Safety Award of Distinction in 1992.

The Young Committee also recommended that multi-discipline team building efforts be increased to improve quality personnel ownership of their work. The launch site directorate established a task team concept that identifies a task leader for flight element work tasks. The task leader was to be the recognized expert for the task to be performed and members of the team were to be assigned specific responsibilities; i.e., quality, safety, etc. (SPC, SPI SP-006(2)K). Discussions with Vehicle Assembly Building (VAB) and launch pad personnel resulted in the conclusion that the team leader concept is not being fully implemented in all areas.

Under the team leader concept, Quality Control (QC) is required to "provide appropriately trained (and certified as required) personnel to support scheduled work tasks". Launch pad and VAB personnel stated that the SPC QC personnel understand the system and work to be performed but the NASA QC's are not as familiar with operations and are not as well trained in the systems. However, the

ratio of NASA inspectors to contractor inspectors requires a more general knowledge of a broad area of the operations they must cover.

The Shuttle Operations Review Team recommends the training/certification program continue to be reviewed to assure that it provides adequate systems knowledge and skills required to perform QC and Safety tasks. This training should culminate in a stand-board where candidates would be required to demonstrate their expertise.

The SPC contractor response to Recommendation #4 also stated that technicians and Quality Control personnel have been identified and assigned for dedicated support on specific Space Shuttle systems. This is being applied on a limited basis.

This Team reiterates the Young Committee recommendation that multi-discipline team building efforts be increased in the VAB and at the launch pad and continue to be implemented. It is recognized that increased efficiencies and costs saving measures have been achieved throughout the Space Shuttle processing operations. Also recognized is the fact that this was achieved, in large part, by having the ability to assign skillful technicians to perform a wide variety of tasks within a broad technical field. Without question, the NASA KSC management approach to dealing with risk has been most successful. The complexity of the work and the number of critical operations performed mandate the assignment of well-trained technicians and inspectors. With the possibility of further cost reductions, the number of people who perform Shuttle processing will have to be further reduced. NASA KSC management must continue to analyze the impact of reductions and determine when resources reach a critical limit.

Recommendation #5

The John Young Team recommended the KSC/SPC processing team undertake a series of reviews, assessments and procedure changes to improve a number of aspects of the work process. These involved reviewing work authorization documents to assure appropriate caution and safety notes were clearly communicated to the users.

The Young Report also recommended the signatures for work documents be limited to those who actually participated in the activity or were directly responsible for their accuracy/integrity. The SPC response stated that KSC had adopted a signature philosophy for work documents limiting approvals to those who are responsible for their accuracy/integrity. The implementation of this philosophy was outlined in a three phased approach that has reduced KSC, LSS and SPC signatures and resulted in significantly reduced approval times.

The Launch Site Support (LSS) review is limited to verification of proper implementation of design requirements. LSS personnel stated that on several occasions after the fact review resulted in their conclusion that the paper should have been signed by the design center representative because the problems appeared to involve the design.

The Review Team recommends NASA KSC, MSFC and JSC reassess the current procedures for distributing copies of processing paper to allow timely and appropriate review by LSS personnel.

The Thomas Committee also recommended SPC expedite the use of bar coding and computerized scheduling systems to facilitate productivity in documentation, work flow and test team activity.

The SPC has developed the SPDMS-II system which permits the bar codes of equipment that facilitates tracking by location and user. The system also permits tracking of parts scheduled for preventive maintenance, calibration and proof loading. Work Authorization Documents have also been successfully coded. The system is operational in the HMF, in the tile shop and is being expanded to many other areas as well. The system is being tried out on a pilot basis in other areas; however, to assure accountability, the manual system of logging this equipment on Temporary Installation Records (TIR's) is also being maintained.

Recommendation #6

The Young Report recommendation said, work assignment for quality control personnel should be reviewed to ensure that the quality oversight function for complex tasks is performed by specifically qualified personnel who fully understand the activity being performed. The report stated that NASA and contractor personnel needed to be qualified specifically for the activity being monitored. The report reiterated a finding from the Atlantis Fuel Cell Mishap Investigation Board Report: "Quality inspectors are not given inspection work based upon their knowledge or previous inspection assignments. They respond to a call board that lists tasks calling for an inspector, consequently, an inspector appears in somewhat indiscriminate fashion to perform the inspection task."

The Shuttle Processing Team reviewed the documentation for closeout and found the fuel cell investigation report closeouts reflected satisfactory rationale. However, through on-site visits and personal interviews it was determined the call board system continues to be used and that the recommendation was in fact not implemented as stated.

This Team recommends that NASA revisit the Young recommendation and continue to assess the training of quality control personnel to assure Quality inspectors have appropriate training in critical system. Specialized people should be assigned to the multi-discipline teams to assure teamwork approach.

2. Gene Thomas Report

In July 1990, the Thomas Committee was formed to conduct a study of incident causes and make recommendations to alleviate potential deficient conditions. The Shuttle Processing Review Team reviewed the letter from the Lockheed Space Operations Company (LSOC) to NASA KSC, dated June 4, 1991. The enclosure to the letter listed all corrective actions taken on each of the recommendations of the Thomas Committee. The Review Team conducted investigations of operations to verify implementation of the LSOC responses.

Recommendation #1

The Thomas Committee recommended a responsible task leader be clearly defined for every work task. LSOC responded that a task team leader implementation plan had been completed and 1800 LSOC and NASA technicians/engineers had completed training.

The Review Team found that implementation of the task team leader concept varies depending on the hardware system involved and the Shuttle processing area. In the OPF, the task team leader concept has been implemented. However, in the VAB and at the launch pad they have not been fully implemented. The Shuttle Processing Instruction lends itself to interpretation.

The Team concluded that multi-discipline team building has improved; however, the task team leader implementation is not yet complete in all Shuttle processing areas.

It is recommended that NASA and SPC identify areas where the plan has been implemented successfully and evaluate each for the most effective means of implementation. The SPI should be reviewed and revised to eliminate areas of ambiguity. Engineering, Quality Control, technicians and the task team leader should review the floor paper together and contribute to the rewrite of the procedures to improve understanding and assure better communication. A performance training program similar to those conducted in other areas should be conducted and geared to specific areas of responsibility. Certifications should be conducted on a periodic basis and should be included in system level training on critical system where appropriate.

Recommendation #2

The Thomas Committee recommended first and second level supervisors share responsibility/discipline for "lack of discipline" or "failure to perform" incidents.

The LSOC response states that incidents had been examined and results show an equitable distribution of responsibility/discipline were being administered.

Interviews with technicians on all three shifts clearly indicated it is their perception that mistakes/incidents/close calls result in punitive action to them alone. They stated they are usually all alone to "face the music". Therefore, they have a hesitancy to report mistakes and close calls. They stated that these incidents may go unreported unless they feel it could impair the safety of the vehicle/crew or it cannot be hidden. Punitive action is perceived as management reaction and results in disciplinary action and isolation of the individuals concerned. This is followed by overreaction when new procedures and verification programs are introduced.

The Team recommends NASA and the SPC continue to communicate the current policies and procedures for discipline with all employees. Improved communications between management and workers should encourage the reporting of close calls and voluntary admission of simple errors/mistakes. Workers should be positively recognized when they come forward and report an incident. For example, the technician who dropped a pair of duck-billed pliers in the Orbiter aft compartment (just after all the notoriety over the pliers that were found on the booster) immediately reported the incident even though his pliers were recovered. He should be commended for reporting this incident and assuring all flight hardware was inspected.

Recommendation #3

This recommendation stated, SPC should promote a higher standard of teamwork at all working levels.

The SPC and NASA have conducted senior led "all hands" meetings to convey the benefits of teamwork. Continuous improvement teams have been established in numerous disciplines. The task team leader concept was initiated. However, after hearing presentations from the various organizations at KSC (NASA, LSOC, LSS, Thiokol, Rocketdyne, etc.), the Team concluded that some organizations and contractors view themselves as separate entities.

The Team recommends that KSC management (NASA and contractors) continue to do as much as possible to provide an environment that encourages integrated

teamwork and cooperation among the various NASA, contractor, and SPC organizations on-site.

Recommendation #4

KSC was asked by the Thomas Committee to institute quality improvement teams which were representative of the work areas and that focus on incident susceptibility, accident prevention and job quality. The Shuttle Processing Team verified that KSC and the SPC have in place an excellent continuous improvement plan and focused teams have been chartered. Obvious results have been achieved in process improvement and cost reduction.

NASA KSC and SPC have made significant progress in implementing a continuous improvement program. The Launch Site Operations contractor has over 400 active teams. All team activity is connected to the overall goals and objectives. Regular status reviews are held to measure progress. Demonstrated results are measured in terms of cost and time savings. Charts are posted in the areas depicting process improvement team progress. Significant cost and time savings have been achieved.

Recommendation #5

The Thomas Committee recommended additional engineering personnel support the work site on a more frequent basis. They suggested a general listing of work tasks be generated to be covered continuously by engineering personnel (SPC and NASA) at the work site.

The task team leader concept was to be employed to further enhance engineering availability at the work site. A detailed listing of engineering tasks to support the critical flow in the Orbiter Processing Facility (OPF) was published and an increased number of engineers were identified to support OPF processing. However, the recommendation was not carried out in all areas, especially the VAB and launch pads. Throughout our interviews, the technicians expressed a desire for more engineering support on the floor.

The effects of reduced budgets and subsequent personnel reductions first affected support organizations such as engineering. Shop labor was preserved during the first rounds until efficiencies could be identified.

KSC conducted an extensive review of the number of personnel reviewing and signing paperwork. A Memorandum of Understanding (MOU) was signed between KSC, the design center and prime contractor launch site support organizations. The number of approvals by LSS engineers was greatly reduced. Thus, continuous coverage by LSS engineering at the work site has been reduced in some areas.

The Team recommends NASA KSC, NASA JSC, NASA MSFC and the SPC contractors reassess the total engineering support provided to the work site.

Recommendation #6

The Thomas Report recommended that specific hardware systems be selected and dedicated, trained technicians and inspectors be assigned to these systems.

The SPC response stated that technicians and quality control personnel have been identified and assigned for dedicated support on specific Space Shuttle systems. After being cross-trained and on-the-job trained, they will also become backup specialists on additional systems.

The Team found that technicians are dedicated to a specific area of the Orbiter on a specific shift and are usually assigned to a specific Orbiter Processing Facility (OPF) bay. Certain technicians in each crew are further specialized by mechanical and electrical skills. There are approximately 12 Orbiter systems and each system has six to eight technicians assigned. An individual may be assigned to as few as three, but not more than five, specific areas. The supervisor and the task team leader are given latitude to assign technicians and should be knowledgeable of their certifications and monitor and evaluate their performance.

While the SPC had made progress in implementing this recommendation, they have been faced with reducing costs and therefore reducing the number of people who perform Shuttle processing. With over 3000 people who execute over one million procedure steps per mission flow or otherwise interface with the hardware, the recommendation is extremely difficult to achieve. Such an approach for all systems and operations may be impractical from an efficiency/cost point of view. However, critical systems and operations require consistent and accurate execution of the tasks to maintain safety and reliability. Therefore, NASA and contractor management need to be assertive during proposed reductions and maintain the dedicated technicians and quality control personnel they have in place on critical systems. Efficiencies achieved in non-critical applications such as the reevaluation of inspection requirements and the structured surveillance program have in essence placed even more responsibility for the quality of work on technicians performing the task.

The Team recommends NASA KSC reevaluate this Thomas recommendation and revise the direction to the Shuttle operations team to reflect the current policies in effect under reduced budgets and new efficiencies in operations that have been implemented. The task team leader reevaluation (Recommendation #1), the on-site engineering support (Recommendation #5) and the dedicated technician and inspector approach (Recommendation #6) need to be integrated into an overall

management approach for Shuttle processing operations. The top down operation plan should map out the strategies for critical and non-critical operations and establish measures of effectiveness for each in terms of reduced incidents, time required for accomplishment, cost avoidance, job satisfaction, and team effectiveness. More emphasis on operations is especially needed in the VAB and at the launch pads.

Recommendation #7

The Thomas Report recommended that SPC investigate means of further rewarding special performances.

The SPC initiated several systems of rewards for accomplishment which are presented at the work site, in the company of fellow employees and as close as possible to the completion of task.

The Team concluded the intent of this recommendation is being met. Continued emphasis must be placed on this area in spite of current and future budgetary restrictions.

Recommendation #8

The Thomas Committee said "management must continually re-affirm the importance of task performance in compliance with the written procedure". They recommended the KSC Center Director and the SPC Program Manager issue a letter to all Shuttle employees affirming the commitment "in no case will schedule prevent taking adequate time to safely do a quality job".

The reaffirmation is accomplished through all-hands briefings and tailgate meetings, Shuttle status bulletins, quarterly meetings, supervisor meetings and in training courses. SPC senior management further reinforces this need through personal contact and taped video messages.

The KSC Center Director, General Forrest McCartney, issued the recommended letter on November 27, 1990, and SPC management issued a memo signed by D. Sargent, President of Lockheed Space Operations Company, on November 30, 1990.

The Team concluded this recommendation was implemented and continues to be affirmed by the current KSC Center Director, SPC Program Manager and senior management.

Recommendation #9

This Thomas recommendation simply stated "every effort should be made to enhance scheduling".

The closeout cited an intensive number of reorganizations, critical resource loading analysis, working groups, schedule development improvements and work control measures that had been developed and were ongoing.

The launch rates achieved and record flow times that reflect significant reductions, combined with the decline in mission in-flight anomalies and good safety performance, speak for themselves. To accomplish this record of management of the most complex operations in the world, while reducing costs to comply with budgetary reductions, reflects the spirit and dedication of KSC, NASA and the contractor team.

This Team did not evaluate this recommendation in detail regarding scheduling. Interviews resulted in the overall conclusion that operations employees attempt to achieve schedules and are innovative in identifying ways to more efficiently perform the work. They are not, however, reluctant to stop the work whenever they are unsure or feel the situation may jeopardize flight safety.

Recommendation #10

This recommendation by the Thomas Committee was that the SPC should establish a weekly newsletter to be distributed to every Shuttle employee.

The SPC established a biweekly newsletter that is published by the Office of the Launch Site Director and is titled, "Shuttle Team News". This communication is designed to create a better informed work force.

D. INCIDENTS REVIEWED FOR ADEQUACY OF CORRECTIVE ACTION

The following specific problems, mishaps, incidents and close calls were reviewed to identify causes and corrective actions taken to preclude recurrence. Documentation review, on-site visits and personal interviews were conducted to determine if corrective measures were appropriate and had been effectively implemented. Conclusions and recommendations are summarized.

1. STS-56 LOST/FOUND PLIERS INCIDENT

During STS-56 post flight Solid Rocket Booster (SRB) disassembly operations on April 10, 1993, at Hangar AF on the Cape Canaveral Air Force Station, a pair of

diagonal cutting pliers fell to the ground as the right SRB was being rotated. The pliers were in the vicinity of the number four hold-down post area of the aft skirt. On closer investigation, rust stains indicated the pliers had been wedged between the booster blast retainer and the aft skirt. They remained there during launch and subsequent booster recovery operations. The area is difficult to see and inspect prior to launch.

A NASA Mishap Report (Number 93-022) was initiated by Thiokol Corporation and reported to NASA Safety. Launch pad B supervision immediately began an investigation when notified by the SRB disassembly team. Documentation showed that cutting pliers were last used on April 1, 1993, when the blast container fasteners were lockwired. A tool box inventory at the end of the shift on April 1 did not disclose the missing pliers. An inspection of the area around the blast containers had been conducted per OMI B5306 task 10-008 on April 2, 1993, on second shift, and the lost pliers had not been noted. The pliers were discovered missing during an inventory at 3:30 p.m., April 2, 1993, by a Thiokol supervisor. The SPI requires the supervisor to initiate a Lost Tool Report; however, as specified in SPI QA-001(3)K, the supervisor failed to initiate a report. He also failed to report the lost tool to his management. Although a closeout inspection had been conducted prior to flight, the inspection failed to find anything out of configuration.

Witness statements by the second shift technician and second shift inspector that performed the closeout stated that access was very limited and it was also dark at the time of inspection. A flashlight was used to perform the inspection. The inspector verified the lockwire on hold-down post #4 on April 1, second shift, but stated he did not see a pair of pliers behind or around the hold-down post. He returned on April 2 and inspected around all blast containers on the left and right boosters and did not see a pair of pliers. The inspector stated the area in question around hold-down post number 4 has very limited access. Pick boards and purge lights had been removed and blast shields had been installed. The inspection was done at night with a mirror and flashlights. They had not been informed of the missing pliers.

Corrective actions taken as a result of discovering the lost pliers and finding no documentation had been initiated as required and included:

1. A complete physical inventory of all Shuttle work area tool boxes was performed with only minor discrepancies noted and no flight concerns.
2. STS-55 aft skirt area was totally reinspected using improved access and lighting enhancement.

3. The ET/SRB physical inspection areas were reviewed for accessibility/visibility and areas requiring improvement were modified.

4. A bulletin was issued and management sessions were held with all Operations and Quality personnel to review tethering requirements, lost tool reporting criteria and tool box inventories.

5. Disciplinary action was imposed on the supervisor for his lack of reporting the lost tool.

Corrective actions were deemed appropriate by the Team and ongoing improvements in tool control should preclude recurrence. However, because tool control problems had been noted for the preceding year by NASA Quality Control, additional measures are required.

On January 6, 1993, the midpoint evaluation (October-December 1992) report for the Award fee for the Shuttle Processing Contractor, the Director, Safety, Reliability and Quality Assurance stated, "Quality surveillances at the pad indicate Thiokol is not in compliance with tool control requirements. Although progress is being made, similar surveillances in the VAB indicate the same violations. In both areas, improvement methods should receive the utmost attention."

However, the April 5, 1993, Evaluation Report stated, "In OPF Bay 3, there were seven instances documented for tool accountability problems and four for tool out-of-calibration. During this reporting period, there have been three Quality Deficiency Notices (QDN's) issued addressing problems with tool control. Continued Management attention is required to assure tool boxes are in compliance with the tool control program." "Thiokol tool control continues to be a problem in the VAB. Examples of non-conformances are: (1) tools not identified, (2) tools improperly stored, and (3) lack of periodic tool box audits. Previous reports failed to resolve this problem; thus resulting in the issuance of a QDN."

The Team recommends contractor management be more responsive in taking action as a result of NASA evaluations that cite repeated deficiencies.

This incident, although it caused no damage to flight hardware or injury to operations personnel, received disproportionate media attention. During testimony to the House Subcommittee on Space, Committee on Science, Space and Technology on April 27, 1993, Chairman Hall (D-TX) presented a list of problem areas as he saw them which included "recent minor but bothersome quality control problems in the Space Shuttle program". Major General Pearson detailed the teams he had put in place to solve specific problems and noted appropriate action had been taken regarding the pliers left in the aft skirt.

Although unfortunate that the pliers incident became the object of much criticism of the Agency, it is considered fortunate that they were discovered and the systems in place to discover missing tools and report them were reassessed and strengthened. This Review Team examined the tool control program in all Shuttle processing areas, and section E summarizes the results.

2. FUEL CELL INCIDENT

On April 4, 1990, one of the three fuel cells (#3) in Atlantis was damaged during an attempt to vent the fuel cell prior to its removal. The Orbiter hydrogen (H₂) purge vent port was erroneously capped. This allowed the H₂ pressure to exceed the oxygen (O₂) pressure in the fuel cell causing migration of corrosive potassium hydroxide (KOH) water solution throughout the O₂ side of the fuel cell. No one was injured and repair costs were estimated to be approximately \$3.1M.

Capping the purge vent port was a result of good shop practice to prevent contamination and test personnel were not aware that the cap was on the purge vent port. There was no related instruction that authorized the capping procedure.

A NASA Headquarters investigation team produced a mishap investigation report on April 27, 1990, with findings, observations and recommendations. The NASA KSC Industrial Safety Office tracked the progress and documents that were used to close out the recommendations in association with the mishap report. All recommendations for implementation or closeout were assigned to the KSC Shuttle Operations Directorate. Several recommendations on training and validation of OMI procedures were delegated to JSC Engineering and the JSC Subsystem Manager via a KSC Director's letter dated August 10, 1990. Seven findings with recommendations and 12 observations with recommendations were addressed in the investigation team's report. There was a total of 26 recommendations which were considered "closed".

A detailed review of the recommendations by the Shuttle Processing Review Team concluded the documentation reflected satisfactory closeout rationale but require reevaluation of the effectiveness of the corrective action implementation.

For example, the investigation report recommended "System training and knowledge should be made a part of certification requirements for all technicians and quality inspectors and should be one of the primary considerations to pay increases and promotions. System training should be made available during off-shift hours."

Familiarization training (200-level course) on the fuel cell by the contractor is provided to technicians and QC's. This is a 2.5 hour course. Based on discussions

with system engineers, technicians, the trainer and QC's, the familiarization course is not equivalent to "system training." System training is taught (8 hours, 300-level course). There are no plans to provide the 300-level fuel cell system training course to QC's. There is an on the job training (OJT) fuel cell task list for technicians to complete under the instructions of an experienced person, this typically takes 1-2 years to become fully competent. Technicians and QC's are certified for critical tasks, but there are no plans to certify or dedicate technicians or QC personnel on the fuel cell system.

The investigation report also recommended "When new control rooms are provided, they should be located within the Orbiter Processing Facilities (OPF)."

There are no control rooms in the OPF, they are still in the Launch Control Center (LCC). A Processing Control Center building was built to house control rooms, but a joint NASA/contractor decision was made to not move the control rooms to the OPF.

The report recommended "Training should be designated as a separate and major functional entity at the same level as the engineering, operations, logistics, and quality groups within the Lockheed organization." Lockheed training is under logistics and there is no plan to implement the recommendation. The joint NASA/contractor decision was made to not move training out of logistics.

It is recognized that these were recommendations and not directions, and NASA/contractor decisions were made to implement them to the degree agreed on. However, this Review Team recommends the closeout reports be updated to reflect those decisions and agreements so that audit and review teams understand the basis for closeout.

A second Orbiter fuel cell mishap occurred on August 12, 1991. A KSC investigation board published a mishap investigation report on December 4, 1991. The mishap occurred on the Orbiter Atlantis, OV-104, when increased helium pressure was inadvertently ingested into the fuel cell O₂ supply causing a sudden performance loss by fuel cells 2 and 3 subsequently resulting in the loss of power to the Orbiter buses B and C. Loss of fuel cell power necessitated the implementation of the Emergency Power Down Procedure. The emergency procedure did not address the loss of multiple fuel cells with no vehicle ground power and, therefore, did not accomplish the required isolation of Fuel Cells 2 and 3 from the Orbiter main buses. Therefore, there was no power available to drive the fuel cell 2 and 3 main bus motor switches to the open (isolate) position. No one was injured. OMI's have been revised to power down the more powerful fuel

cell bus last. Interface procedures with payload power requirements were reviewed and appear to be adequate. Closeout of the associated recommendations from the fuel cell power down investigation report do not present a concern and are considered adequate to preclude recurrence. However, improved systems training would be beneficial.

3. OXYGEN ANALYZER IN EXTERNAL TANK INTER TANK

An O₂ analyzer was found inside the inter tank cavity of the ET on STS-57. The analyzer had been installed per OMI T5048, step 03-005, when the stack was in the VAB. The analyzer should have been removed before closeout in the VAB and routed to SPC Safety per step 03-009. Removal was stamped off by the technician. The temporary door was closed, lead integrity seals applied and the stack was rolled to the pad with O₂ analyzer still inside.

The OMI states under "special Instructions": "Ingress/Egress logs are not required for items controlled by this OMI." However, this procedure for safety equipment provides a single point failure. Management stated that the meter would have been found during the prelaunch walk down.

The corrective action taken as a result of this incident stated this was a discipline problem and management should stress strict adherence to procedures. The OMI has been rewritten to separate the tasks. A plan is being generated to control all safety equipment. This Team recommends that requirements be revised to list all safety equipment on the Temporary Installation Record (TIR) or use the bar code systems to provide a check and balance to assure non-flight hardware is removed from the vehicle.

4. VAB CRANE INCIDENTS

Preliminary Evaluation Reports 019-92 and 038-92 written on March 18, 1992, and August 11, 1992, respectively, documented unexpected movements of the 250 ton cranes in the VAB. Preliminary evaluation of the March 18 incident attributed it to an unknown cause. Several precautionary actions were taken. These included procedure changes, a potentiometer was changed, different springs were installed in the joy sticks, test team discipline was emphasized, a checklist was added to the planning and a sneak circuit analysis of drive systems was performed.

When the second crane incident occurred on August 11, 1992, a formal Mishap Investigation Board was formed to investigate and determine proper corrective action. The primary cause was determined to be erratic output from the Metadyne controller. Corrective action was to design and install solid state control systems in the 250 and 175 ton VAB cranes and to provide different cleaning procedures

for the Metadyne equipment that was not modified. The primary cause corrective action also remedied the first contributing cause.

A contributing cause to the mishap was repeated "funnies" that had previously occurred during crane operations and were not communicated properly. Procedure changes have been made to correct this. The technician felt the actions were proper and would remedy the problems.

All corrective actions were found to be implemented except for the hoist controller on the 250 ton crane number 2. These will be completed immediately following STS-51 stacking in mid June. On-site discussions with the crane electronic technicians and observation of the cranes themselves showed action were complete as documented.

E. SPECIFIC SUBJECTS REVIEWED

1. SAFETY

It is the unanimous consensus of this Team that safety continues to be the number one priority in Shuttle processing operations at KSC. No major safety concerns were surfaced during the review. However, there were some concerns identified that warrant further investigation by KSC to preclude the possibility of a mishap. These are summarized as follows:

a. Workers in the Orbiter Aft Compartment

The technicians, engineers and quality control personnel voiced similar complaints that purge air being piped into the Orbiter aft compartment makes it extremely difficult to hear required communications. The problem appears to be exacerbated by the length of time a person is in the aft. Personnel stated they have difficulty hearing communications and the loud speakers that sound warnings. Additional concerns were expressed over the lighting conditions in the aft compartment. Portable lights have been provided but electric cords strung into the compartment create a potential for accident. Noise and lighting problems in the aft have been a concern since STS-1. Although studies have been done on noise and lighting, and some changes have been made, no effective method for solving the concerns has been found. Bullhorn/warbler systems have been added as a result of employee concerns and oxygen deficiency monitors are in place to mitigate hazards.

Rocketdyne engineers, technicians and quality personnel stated that close calls have occurred while working in the aft compartment. Though it was not possible to fully substantiate these claims, it is apparent from discussions with personnel that they believe these types of incidents have occurred. However, no mishap reports for these types of incidents were found. Procedures are in place to prevent these types of occurrences, but the difficulty personnel have hearing warnings while in the aft may be the primary problem.

NASA and SPC must continue to address the concerns held by personnel working in the aft compartment to assure they are given additional visibility. Rocketdyne and SPC should continue to encourage all personnel working in the aft compartment to report any safety concerns and close calls. These concerns need to be surfaced and aggressively pursued. The Design Center should evaluate engineering changes that will reduce the noise level from the purge air system in the aft compartment. In the interim, SPC should continue its efforts to improve conditions. Visual means of warning personnel should be considered. The engineer conducting the task must ensure all personnel understand the task and the implication of all deviations. During critical operations, all personnel in the aft compartment should be on the OIS headset. The type of headset being used should be evaluated to determine if a different type/make could provide greater confidence in the quality of communications. Before movement, purges or other hazardous operations are performed, all personnel must be advised and verification that they heard the warnings must be received.

b. Orbiter Processing Facility

A technician in the OPF stated he has tried for over a year to obtain a four foot high work platform for the chin panel area. The team noticed he had a two foot high platform with a four gallon milk crate on top of it in order to reach. He stated that an individual fell off the top of the crate and an Engineering Support Request (ESR) had been submitted for a new work stand. He understood there was some delay due to the need to generate drawings for the platform.

Another technician indicated safety ropes that had "Danger" or "Hazard" signs on them had been taken down with the signs in place and hung to the side. Safety installs and removes the signs. Operations personnel had been delegated the responsibility to put up

the ropes. The technicians stated they were not clear as to who removes the ropes.

Safety should be totally responsible for putting up and taking down barriers and signs for hazardous operations. Signs should indicate who in safety is responsible for the sign and how they can be reached.

c. Engine Shop

The number of main engines (16) in process in the VAB engine shop area represent National resources valued at almost one billion dollars. A major mishap during SRB stacking could destroy these resources. SRB stacking normally occurs on second shift, and personnel not involved with stacking are kept out of hazardous areas. However, because of extensive engine activity recently, engine operations have been impacted by stacking operations. Funds have been approved to build a new engine facility outside the VAB.

d. SCAPE Suits

Interviews with SCAPE operations personnel revealed that many technicians and QC's are not comfortable with the existing Category 1,4 and 6 SCAPE suits. Several instances of torn suits and opened zippers/closure seals were cited which were detected on completion of an operation.

While most of the SCAPE suit incidents are reported, at least three unreported incidents were discussed where hazardous materials were actually introduced into the suit. One of these occurred when a technician twisted suddenly causing the relief valve to allow N_2O_4 into the suit. Although training classes and procedures recognize this condition and train personnel on proper use of the suits, SCAPE operations personnel feel there are instances where this type of action is unavoidable and a design change to the relief valves is required.

Interviews with Life Support personnel revealed that they are concerned about unreported SCAPE suit problems. Life Support personnel have recognized zipper flap closure problems in the Category 6 suits and joined with KSC Safety to limit the use of these suits to special operations under interim controlled procedures while they investigated possible solutions with the manufacturer.

There appears to be general lack of communication between personnel performing SCAPE operations and Life Support personnel. Personnel performing the operations feel that they are not consulted or informed of changes being made in suit manufacture and design. Life Support personnel were unaware of any legitimate problems with Category 1 and 4 suits and are genuinely concerned with incidents going unreported.

Additionally, the original SAA's on all SCAPE suits need to be redone with new ground rules that emphasize the particular importance of these suits and specify that this Ground Support Equipment (GSE) is unique and should have a unique analysis. Also, the Systems Assurance Analysis (SAA's) should reflect recent design modifications to make the suits safer. Safety should review the hazard analysis to assure that they meet the current requirements. In addition, existing procedures need to be reviewed or new procedures need to be established to ensure that issues that are identified by all users are presented to Life Support personnel and that the disposition of these items is conveyed to the originator.

2. Tool Control

The KSC Space Shuttle Tool Control Program and SPC Tool Control Program have been dramatically improved. Tool boxes with "shadow box" inserts for each tool have been purchased for all areas of the OPF. Contents are serialized to the box and are inventoried at the beginning and end of each shift. Damaged or missing items are reported to the supervisor. General tools, gauges and disposable items have been collected from the floor and can be checked out from the tool crib.

SPC is incrementally supplying all areas with new tools and boxes. The OPF is complete and boxes at the pad are being modified and furnished. Some workers expressed their concern that the OPF had new tools and the VAB and pad did not. Technicians and quality personnel in some areas voiced their frustration with the difficulty they have in obtaining good quality tools and hand held instruments. Management should continue to survey operations personnel to determine what tools and equipment are necessary to accomplish the work and optimize efficiency and accountability for tools. Management needs to assure everyone that new tools will be supplied according to a master plan.

One area requires review and definition of the tool control program. The Payload Changeout Room (PCR) at the pad has three different disciplines

and various contractors or experiment principle investigators that require access to the Orbiter. It is not apparent that there is a common material/tool control program for PCR operations. KSC should develop a memorandum of understanding for PCR material and tool control and implement procedures rapidly. Payload personnel have been extremely conscientious about tool control in the PCR.

The tool control program does not apply to safety equipment such as the oxygen analyzer that was found in the inter tank of the external tank on STS-57. The Team recommends the procedures be revised to require all safety equipment to be listed on the Temporary Installation Record (TIR) or use the bar code system to provide a check and balance to assure non-flight hardware is removed from the vehicle.

3. Structured Surveillance

Due to the STS-51L incident and the subsequent requirements for return to flight, quality assurance inspections were greatly increased. Since the initial return to flight missions, NASA KSC has looked for ways to improve efficiency and effectiveness by reducing quality assurance's reliance on inspection.

Significant increases in productivity and efficiency can be achieved by reducing reliance on hands-on inspection, placing more responsibility with individuals who are actually performing the task and implementing statistically based work sampling to determining areas needing improvement. The primary objective of the Structured Surveillance Pilot Program is to demonstrate the gains in efficiency that can be realized by reducing dependence on inspection and more effectively utilizing the expertise and judgment of the highly skilled technician work force. The approach to be used in achieving that objective involves a combination of traditional inspection activities and statistical sampling strategies.

Structured Surveillance is a concept which provides for implementing a NASA-wide initiative to improve the product and process quality of all NASA KSC operations. Under the program, quality assurance of both the Criticality 1 Hardware and functional Criticality Requirements 1 (1, 1R, and 1S for contractors) and Criticality 2 and 2R is supposed to continue to be accomplished by an independent inspection. Verification of Criticality 3 and non-critical OMRS requirements will be accomplished by the technician performing the actual work. Inspection by the quality assurance organization will also be used to provide additional confidence when warranted.

The primary goal is to accomplish an increase in efficiency while ensuring that safety, reliability, and the quality of the hardware and software is maintained. This will be accomplished by empowering the technicians who perform the work with the tools to attain "First Time Quality", thus reducing the (1) time to perform the work, (2) waste and (3) total man-hours.

The change in the quality assurance program is a shift away from inspection of an individual's work and focuses on monitoring and measuring the processes. Techniques, such as qualitative and quantitative surveillance methods will be used to establish a closed loop continuous quality assurance process for monitoring assurance and process improvement and corrective action implementation.

Opinion of the shop personnel in the OPF, VAB and pad seem to be split. Most felt that placing more responsibility on the person doing the work is a move in the right direction, however, the personnel did not fully understand the program. Management should provide shop level personnel with more details about the program and help them understand the concept of first time quality.

Even though some inconsistencies were identified, Phase I of the Structured Surveillance Pilot Program was a success. All organizations learned from their participation and made improvements which simplified Phase II of the pilot program. Therefore, the benefits derived from full implementation of the Structured Surveillance Program can be substantial.

The potential exists for an oversight during placement or deletion of critical inspection points in OMI's because not all design center CIL retention rationale and hazard controls are "linked" to OMRSD's. On January 17, 1991, a Change Request was approved by the Shuttle Program Manager deleting inspection requirements from the OMRSD when they are defined by released engineering. A review of the process being used by Quality Engineers to place or delete OMI inspections shows the CIL retention rationale and hazards are not required to be reviewed to identify critical inspections in KSC work authorization documents (WADS). For critical inspections, where the CIL and hazard controls are contained in Level III Orbiter installation drawings rather than in the OMRSD, the Quality Engineers do not have a means of identifying which inspections are critical and must closed-loop accounting. These are considered minor (criticality 3) inspections by Quality Engineering subject to deletion under the guidelines of Structured Surveillance. In addition, for integrated OMI's,

changes are being made by other than the responsible organization (i.e., LSOC changed SSME inspections without Rocketdyne input). The engineers doing these reviews consider determining the criticality of inspection to be the Quality Assurance organization's responsibility and do not intentionally verify retention of critical WADS were in compliance with the requirement to maintain independent inspection.

NASA KSC and SPC Quality Assurance must continue to ensure that OMRSD requirements derived from CIL or Hazard Report acceptance rationale are maintained and closed or accountability is achieved. In order for KSC to do this, the Design Centers must provide these requirements. This must include use of the CIL retention rationale and Hazard Analyses to identify critical inspection requirements. NASA SR&QA management should take immediate action to assure that no adverse effects on safety and mission success resulted from the deletion of inspections in the WADS as a result of OMRSD changes. As an interim measure, the cognizant Engineers at the Design Centers should review all inspection points for KSC WADS to assure no omission of critical requirements. The Shuttle Program Manager (JSC) should reassess the impact of the Change Request that deleted OMRSD requirements that are defined by released engineering.

4. Problem Reports

For the period October 5, 1990, to April 30, 1993, 49,013 KSC problem reports (PR's) were analyzed for trends. More specifically, those problem reports that listed workmanship as the cause were reviewed. Since the beginning of 1992, the trend in total PR's has been decreasing from about 2200 per month to the current 1200 per month. Likewise, workmanship PR's have decreased from about 390 to 170 per month for the same period. The previous year, 1991, showed an increasing monthly trend in total and workmanship PR's. Some examples of improper use of the workmanship cause codes were noted.

It is recommended that a program of continuous improvement for the rate of workmanship PR's for subsystems and components be established. Standard repair procedures and Statistical Process Control should be investigated as methods to reduce the level and variability of workmanship errors and to track workmanship as different initiatives and programs are instituted. Additional efforts should be looked at that approach human error from a scientific and engineering aspect to determine root causes. Contract award fees should contain additional emphasis on the accuracy and efficiency in reporting problem reports.

5. Mishap Reports

NASA and SPC need to emphasize the requirements and procedures for reporting all safety incidents and concerns, especially close calls. For those reports that do not qualify as a PER, feedback to the originator should be provided as to exactly why the report was not forwarded to the IERB.

Discussions with working level personnel revealed that they are either unfamiliar or uncertain about the criteria and procedures for reporting safety incidents (PERS). Additionally, many personnel expressed the view that reporting safety concerns will either be viewed negatively or will not result in any meaningful response.

SPC uses a PER as the reporting mechanism for safety incidents. The IERB/SOAG has the role of reviewing PER's for appropriate action. However, working level people have stated that they have initiated a PER only to indirectly discover that it had been rejected and never sent to the IERB. No feedback has been provided to these personnel about their concern resulting in a negative perception of the entire safety reporting system. Software and console incidents/concerns are not reported as PER's but are usually documented and dispositioned as Interim Problem Reports (IPR's).

For the above period, 612 mishaps were reviewed for trends, 177 were classified as close call mishaps. Only 78 mishaps were associated with flight hardware. Overall, the trend in mishaps shows variability from month to month, but the level remains relatively constant, about 20 per month. Close call mishaps average 6 per month. Mishaps fall largely into the "C" category - \$25K to \$250K damage or lost time/restricted duty. The fuel cell emergency power down was the only significant mishap, category A, for the time period addressed. Data indicates the following causes for all mishaps:

Human factors	66%
Equipment failure	8%
Procedures	5%
Other	21%

For flight hardware associated mishaps, the causes are:

Human factors	32%
Procedures	26%

Equipment failure	12%
Communication	11%
Handling	6%
Other	13%

As with problem reports, structured root cause analysis of human errors should be investigated to implement a continuous improvement program.

6. Training and Certification

The SPC Training and Certification Department is doing an excellent job. An automated scheduling system and better training aids would improve their efficiency. The critical skills training and certification program is well managed. Course material is considered to be current and is tailored to specific student needs. Technical training statistics through May 1993 show that approximately 80% of the training requested is approved and scheduled. Student to instructor ratios are proper. The year-to-date "no-show" rate is about 26% which is considered to be excessive. This rate represents an estimated loss of over 2,000 student hours per month.

The need for improved skills training and expertise has been highlighted by several mishap investigation teams as the contributing cause to processing incidents. A review of the SPC IERB findings confirmed this need. Technicians and QC personnel, both SPC and NASA, expressed a desire for increased systems knowledge and proficiency. Their concern is that a specific task may be understood, but how it relates to the overall function of the system is not clear. Training relative to their areas of responsibility should be evaluated to consider expanding their systems knowledge.

Training and certification is provided to the OMRSD requirements, but the OMRSD inspection requirements are not definitive enough for corrosion inspection. A special working group is addressing this issue. Improved NDE techniques are being investigated. A review of as-run structural inspection OMI's indicates the inspectors using approved techniques were not able to detect active corrosion on the orbiter wing and vertical tail. Subsequent reviews of hardware by structural engineers using more in-depth techniques detected the corrosion and provided appropriate disposition and repair. Corrosion detection and control is a critical skill that requires better definition. The Training and Certification Board should continue to consult with industry experts, NASA's Langley Research Center, the Navy Safety Center and Naval Air Systems Command to develop an improved training and certification program. The OMRSD requirements should be revised to specify in-depth corrosion inspection criteria.

The Training Department currently has the Naval Education Service Center assisting in the development of a Distributive Computer Based Training System. This is believed to be of great benefit. Expansion of this system is strongly encouraged.

7. Quality Assurance

SPC and NASA Quality Assurance organizations are required to cover a wide variety of complex tasks and operations. The ratio of SPC inspectors to technicians is approximately one to four. NASA QC has approximately one inspector for every four SPC inspectors. This Team's findings in a few areas indicate a need for increased emphasis in some aspects of the quality assurance function. These include training and certification, structured surveillance, QA inputs to processing paper, QA stamp integrity, audits, trending and corrective action. Training and structured surveillance are addressed elsewhere in this report.

The QA inspectors are concerned about having little or no input to the preparation of the processing paper. Quality Engineers have some input. In many cases, the same "paper problems" keep recurring in spite of numerous deviations being generated to correct deficiencies. Procedures that are unclear detract from the ability to control quality and prevent "escapes" in flight hardware.

Historically, there have been several occurrences of work being bought-off or stamped as complete although it was not actually performed. This has raised concerns relative to the stamp as warranty. There is a difference between "verify" and "witness" inspection buy-offs. The use of both quality and technicians stamps must be carefully reviewed. Administrative usage of stamps (i.e., paper review) should be minimized. Emphasis must be placed on each individual stamp as warranty that work was performed and was performed correctly. Stamps must be a personal certification.

The system used to highlight areas in need of in-depth quality audits or increased surveillance should be improved. Recurring problems with the scape suits, VAB cranes, hardware impact by access platforms could have benefitted from identification by audits. The audit system could be improved by focusing on areas where data shows a need for increased attention.

Use of trending appears to be trend reporting rather than trend analysis to help detect root cause problems and to identify areas to effect corrective

actions. Certain work areas are trending by collecting, tabulating, and reporting data. There is need to improve the system to collect and analyze trending information related to processes which have been identified as needing improvement. Additionally, incorrect or inaccurate problem descriptions in the PRACA system inhibits the trending utility of the data base for analyzing, resolving and preventing recurrence of non-conformances. Trend analysis needs should be identified by the user community including floor level personnel, the design center engineers, management and vendors.

F. VOLUNTARY INTERVIEW RESULTS:

The Space Shuttle Program has continuously improved since the Challenger accident. Great strides in efficiency, costs, and schedule have evolved in recent years. We are flying the cleanest and most reliable vehicles ever.

The Space Shuttle is a unique and extremely complex vehicle, and the uniqueness and complexity is carried over into the management and processing for each flight. It was not the intent of this Review Team to cast doubt on the efficiency in the safe accomplishment of our Space Flight goals. It is the opinion of this Review Team that the overall performance and success of the Space Shuttle Program is exemplary. Our observations and recommendations are intended to allow the Shuttle Processing Team to further enhance their enviable record. Many of our observations are reflective of the perceptions at the technician levels. The perceptions that were expressed to the Team do not reflect upper management policies in the area of reporting mistakes.

There is a perception in some work areas, among the technicians, that reporting mistakes results in punitive action. Punitive actions are reflected in individual performance records and the fear is that noted mistakes will lead to loss of employment. Corrective action is also viewed as an overreaction from management and it usually results in additional procedures and verifications.

Communication is felt to be limited to/from the technician level to the upper level management. The technicians are a competent and motivated group with regard to "getting the job done". However, they do not feel as though their concerns are heard by upper management. It is the conclusion of this Review Team that these perceptions need to be addressed. This conclusion was drawn on the basis of personal as well as group interviews of hundreds of personnel and documentation obtained that indicate the following:

1. In some work areas there is a tendency to not report problems, close calls and incidents because there is fear of reprisal.

2. Problems that are discovered, such as the lost pliers, result in criticism directed at the hands-on technicians who are the people responsible for the Agency's success. This is not common to all areas nor is it an isolated issue.

3. Controls effected as a result of these problems are considered excessive by the work force and in their opinion have resulted in a slowdown in processing in some areas.

4. Technicians and engineers have developed an in-depth knowledge of their work and understand the hardware systems they are responsible for; however, in their opinion, the quality control and safety people do not have an appropriate degree of systems knowledge in many cases. The Quality personnel interviewed indicated they desire more systems training.

5. Technicians have discovered or devised efficient ways to perform work. They improve procedures in order to do the job more efficiently or correctly. They stated that the same problems exist in the paper for each flow. The number of deviations, changes documents and engineering orders attached to documents make the work extremely complicated. They follow the paper to the best of their ability; however, some procedural errors occur.

6. It became apparent to the Team that each organization, be it NASA, LSOC, Thiokol, SPS, LSS, etc., exhibit corporate pride and competitiveness; however they tend to sometimes view themselves as separate entities. In no way is this to say the work force is not dedicated and performing at a high level to achieve the overall goals. Within each area high quality work is generally the norm, but there is room for more cooperation between work area organizations.

The Review Team found that for many incidents investigated, someone was aware of the problem or of the potential for a problem but either felt powerless to remedy the situation, reported it but it didn't get worked, or it was simply let go without being pursued. Generally, this was the input from the floor level personnel. Feedback to the originator of PER's that do not qualify as IERB items should be provided so personnel understand why their report was not accepted.

G. CONCLUSIONS:

The following are the overall conclusions reached by the Team:

1. Safety continues to be the number one priority in Shuttle processing operations and confidence in processing operations procedures and personnel is well placed.

2. The Shuttle Operations Team has developed a comprehensive methodology to continuously improve quality while reducing labor costs. Some areas observed seemed to excel in continuous improvement more than others and are models to emulate. The Orbiter tile shop, the tire shop, the Hypergolic Maintenance Facility (HMF) and the Space Shuttle Main Engine (SSME) processing areas are considered examples. Teamwork, new efficiencies in operations, facility improvements and automation techniques have been combined to result in record processing quantities with continuing improvement in quality and a low incidence of mishaps.

3. The underlying causes for recent incidents and close calls during Shuttle processing at KSC as determined through a review of documentation is attributable to human factors, equipment failures and procedures. The predominant causes (66%) of all mishaps is human factors. For flight hardware incidents human factors were responsible for 32% of the mishaps and procedures caused 26% of the mishaps. The actions taken as result of these incidents were reviewed in detail. The corrective actions in most cases were determined to be adequate and had, in fact, been implemented. However, in some cases, implementation was still in process or budget restrictions and revised methods of operation were stated to be the reason for not implementing the recommendations.

4. The recommendations of the John Young Report and the Gene Thomas Report have not been fully implemented. These were recommendations and not directives. The degree of implementation is subject to management judgement and recognized is the fact that NASA policies, budgets, and management systems have changed since these recommendations were made.

5. The Team concluded that multi-discipline team building has improved; however, there is a need to expand it to all areas. The task team leader concept, including the training and assignment of dedicated technicians and quality control personnel is not yet complete. Engineering support to the work site needs to be readdressed. Efficiencies achieved in non-critical operations have placed even more responsibility for the quality of the work on the technicians performing the task. Systems are in place to reward special performance and accomplishments. However, because of reductions in force and recent disciplinary actions associated with incidents that received disproportionate media attention, there is a perception that has developed among the work force that making mistakes results in punitive action. There is a fear that noted mistakes will lead to loss of employment. Therefore, there is a tendency to not report problems, close calls and incidents because of the of the fear of reprisal. The Review Team found no evidence that disciplinary action was taken inappropriately.

6. Some NASA and SPC technicians and Quality Control personnel desire more detailed knowledge of systems and subsystems to which they are assigned to

verify procedural compliance. Some Quality Control personnel interviewed expressed concern that their areas of responsibility are too broad. Concerns were also expressed relative to lack of involvement by quality inspectors in generating processing paper and planning tasks to be accomplished. The pilot Structured Surveillance Program is complete and full implementation is in process. However, some inconsistencies and misinterpretations were expressed by the technicians and quality control personnel. Corrosion inspection requirements in the OMRSD are being met; however, deficiencies were noted in the adequacy of the process used to detect corrosion on the Orbiter.

7. Not all Design Center(s), CIL and Hazard acceptance criteria involved in KSC processing are "linked" to the OMRS creating the potential for an oversight during selection of inspection requirements in work authorization documents. A change request approved by the Program Manager allowed deletion of CIL and Hazard related inspection requirements in the OMRSD if defined by released engineering.

8. The category "A" mishap on the fuel cell resulted in an Investigation Board Report with 26 recommendations. The Team found the documentation for close out of the recommendations reflected satisfactory rationale but the corrective action implementation requires reevaluation and documentation update to reflect management decisions.

9. Some personnel feel their concerns about hazards are not being addressed. Workers in Orbiter aft compartment indicated concerns with lighting and noise levels. SCAPE suit problems continue to occur. Although significant management attention has been placed on SCAPE suits, some of the work force feel that known design deficiencies have not been adequately corrected. Close calls were stated to have occurred which have not been reported.

H. OVERALL RECOMMENDATIONS:

The Team assessed the results of their review and developed the overall recommendations summarized below:

1. Management should continue to be a positive influence on safety improvements and continue to respond to the constant challenge of communicating with the work force to ensure perceptions accurately reflect management policies. Top management, mid-level managers and first-line supervisors need to continue to communicate with their subordinates to allay their fears that reporting problems, close calls and mistakes leads to reprisals and disciplinary action.

2. KSC and SPC management should study closely the areas of excellence that have evidenced themselves and capture the lessons learned and successes achieved in order to apply these successful techniques to all processing operations.

3. KSC and SPC should establish additional continuous improvement teams to investigate root causes for incidents and problems attributable to human factors. Feedback should be solicited from the work force as to solutions for problems.

4. The SPC closures for the recommendations of both the John Young Report and the Gene Thomas Report need to be reassessed by NASA to see if they are still applicable and reflect the current Agency directions. If they are found to be applicable, they should continue to be implemented and regular audits should be performed to assure compliance. If found to be not applicable, the closeout reports should be amended to reflect the current policies of operation.

5. Multi-discipline team building needs to continue to be implemented, especially in the VAB and at the launch pads. The task team leader concept, the on-site engineering support and the dedicated technician and inspector approach need to be integrated into an overall strategy for critical operations. KSC management, both NASA and contractor, should continue to do as much as possible to provide an environment that encourages integrated teamwork and cooperation between the various organizations on-site.

6. NASA and SPC should continue to review and update their training and certification programs for technicians and quality control personnel. Quality Control personnel should have adequate involvement in generating the processing paper and planning the tasks to be accomplished. KSC should assure that Quality inspectors have appropriate training in critical systems. Emphasis must be placed on each individual stamp as a warranty that the work was performed correctly. The system used to identify areas in need of in-depth quality audits or increased surveillance could be improved. Improved trend analysis, in addition to trend reporting, would be beneficial to help identify recurring problem areas requiring corrective action. The requirements for in-depth corrosion inspection criteria need to be reviewed by the Design Center. Training and certification should be improved appropriately.

7. To preserve the integrity of risk assessment and risk management activities, Space Shuttle program management must ensure that KSC Operations and Maintenance Requirements Specifications Document (OMRSD) derived from CIL or Hazard Report acceptance rationale are properly identified to ensure independent inspection, closed-loop accounting of work completion, and proper application. NASA JSC, KSC and Space Shuttle program management should determine the validity of the KSC situation and if similar situations exist at Design Center

contractors' plants and initiate corrective action as soon as possible. The Space Shuttle Program Manager (JSC) should reassess the impact of the Change Request that deleted OMRSD requirements that are defined by released engineering.

8. The process for verifying implementation of recommendations in mishap investigation reports needs to be reviewed to assure corrective actions documented in the closeouts are effected.

9. NASA and SPC should continue to address concerns about hazards held by personnel working in the Orbiter aft compartment to assure they are given proper visibility and are aggressively pursued. The Design Center should assist in these efforts by considering design changes that would reduce the noise level from the purge air system. NASA and SPC need to continue to address the cause for the incidents on SCAPE suits. Communication between SCAPE Operations and Life Support personnel need to be improved. A means should be established to flag trends and resolve issues such as the number of scape problems. Management needs to evaluate the system for reporting close calls to assure employee participation is not discouraged and safety concerns are properly addressed.