NASA ACCIDENT INVESTIGATION TEAM

FINAL REPORT

DRAFT

AUGUST 4, 2003

EXECUTIVE SUMMARY

This NASA Accident Investigation Team (NAIT) Final Report documents how NASA conducted the accident investigation associated with the Columbia mishap. This report covers how 14 teams and working groups (each with a section in this report) were organized and staffed for the investigation; their responsibilities; aid they required and their interfaces; processes and procedures used; problems faced and lessons learned; and findings, observations, and recommendations. The lessons learned and associated findings, observations, and recommendations relate only to performance of the accident investigation. Lessons learned involving the cause of the Columbia accident are contained in other technical reports.

Nearly all the 14 entities reported rapid initial organization that went well in accordance with various in-place contingency plans. Most then experienced some wheel-spinning in the early days of the investigation due to unforeseen problems: reorganizations for more efficient interfacing; lack of trust and fear of the appearance of compromising the CAIB's independence from NASA; personnel with inadequate security clearances; inadequate staffing; fuzzy chains of command; immediate funding problems and procurement problems regarding needed equipment and facilities; high-tech communications problems due to the many Government agencies, companies, and NASA organizations involved; conflicting, unclear, or overlapping duties; data required but not available immediately; and overwhelming numbers of requests for information from the public, Congress, and other investigative groups. Due to the high caliber of personnel, some innovative ideas, willing volunteers, and extremely hard work and long hours, the problems were overcome or abated so that the teams and groups could do their jobs.

Reported as specifically facilitating the work were: briefing sessions for the CAIB about their precise mission and the Space Shuttle Program and NASA in general; dual leadership of groups in some cases; daily tagup meetings; the President's declaration of a disaster; coordination with outside agencies previous to the accident; decision-making at the field level; effective electronic tools, web sites, and databases; previous contingency training simulations; and individuals with expertise in several areas. Even simple cell phones were invaluable.

This report contains about 130 recommendations, some basically the same but from different teams or groups, with some recommendations far more detailed than others. The basic theme throughout is that NASA needs to be better prepared for contingencies. Highlights of the more important recommendations follow.

NASA needs to have more detailed contingency plans for contingencies at liftoff, on orbit, and during landing and conduct simulations for each. There should be plans should an accident happen over foreign soil and should the President not declare a disaster. Plans need to be reviewed before each mission and updated annually or as needed. Current plans need to be revised (perhaps appendixes added) to address things like the chain of command and interfaces between investigative groups; transition from contingency working groups to investigative working groups; an actual contingency budget and accounting guidelines; procurement procedures; specific electronic tools to be used; interfaces with other Government agencies such as the Federal Emergency Management Agency (FEMA), Department of Justice (DOJ), Forest Service, Department of

Defense (DOD), and National Transportation Safety Board (NTSB) prior to a contingency; uniform procedures for impoundment and release of records (including at non-NASA sites); and archiving of investigation records.

NASA should not delay in establishing staffing support for the task force and teams; personnel with specific expertise in databases, accident investigations, procurement, travel, documentation libraries and archiving, configuration management, information technology security, and many other functions should be identified ahead of time. Anticipate investigators' needs (including facilities) so they do not have to process requests for everything. Standard investigator kits could be issued. Locate related investigative groups and teams near each other. The same goes for public affairs representatives. The majority of investigative team and group members should be from organizations independent from the subject or organization the team or group is investigating.

Institute a NASA-wide, clear, and consistent information technology security policy for management of sensitive information relative to the International Traffic in Arms Regulations (ITAR), export control, and any accident investigation. Provide uniform guidelines regarding the Freedom of Information Act (FOIA).

Allow use of existing Governmental resources when they can be provided more quickly and cheaply than from an outside contractor. Do not use outside contractors automatically on the basis of the appearance of investigative independence from NASA.

Streamline paper processes, perhaps by standard forms modeled on existing ones and compatible with electronic tools being used. Volunteers need training, and it would be beneficial if those taking calls could enter information on forms directly into computers.

Develop survivable part markings to help in orbiter reconstruction. Include in reconstruction safety plans provisions for their change if actual circumstances are not the worst-case scenario as written in the plans. Invest in computer modeling of the orbiter. Develop a secure server setup between centers and contractors for use in transferring data to and from other NASA centers and contractors outside the Johnson Space Center (JSC) firewall. Define and streamline the approach for getting flight data out of secured areas in a crisis.

To prevent budget and flight schedule from forcing NASA into a reactive mode regarding contingencies, form an organization to seek out and define preemptive actions against, and advocate resources to correct, the so-called "Unknown Unknowns" that threaten mission success. To control Thermal Protection System (TPS) materials, systems, and processes over time, form a TPS senior expert advisory board available to Space Shuttle Program elements as a resource to assess future changes, provide continuity, and assess credibility of verifications.

A format for weekly status reports to Level II and a limit to the length of each report should be established. At the beginning of the investigation, Level II should establish and define a preferred set of credibility classification designators such as "Improbable," "Likely," "Unlikely," and "Probable," with agreement by all investigation teams.

CONTENTS

ABBREVIATIONS AND ACRONYMS

Acronym	Explanation
AFB	Air Force Base
AFRL	Air Force Research Laboratory
AI	Office of Chief Information Officer
AMOS	Air Force Maui Optical and Supercomputing
ARC	Ames Research Center
ASAP	Aerospace Safety Advisory Panel
BNS	Boring NASA Systems
BOSS	Base Operations Support Services (Contractor)
CAA	Controlled Area Access
CAAR	Corrective Action Assistance Request
CAC	Columbia Action Center
CAI	Columbia Accident Investigation
CAIB	Columbia Accident Investigation Team
CAP	Contingency Action Plan
CARRT	Columbia Accident Rapid Response Team
CBO	Central Budget Office (NASA Headquarters)
CD	Compact Disk
CFR	Code of Federal Regulations
CIL	Critical Items List
CIO	Chief Information Officer
CM	Configuration Management
COFR	Certification of Flight Readiness
COFTA	Certificate of Fault Tree Acceptance
CONUS	Continental United States
COTS	Commercial Off-the-Shelf
CRDS	Columbia Reconstruction Data System
CRO	Columbia Recovery Office
CSR	Columbia Source Repository
CST	Central Standard Time
CTF	Columbia Task Force
D&RH	Data and Records Handling
DAWG	Debris Assessment Working Group
DA9	Management Services Office
DB	Database
DBA	Database Administrator
DCIST	DOD Columbia Investigation Support Team
DCMA	Defense Contract Management Agency
DDMS	Data and Documentation Management System
DFO	Disaster Field Office
DOD	Department of Defense
DOE	Department of Energy
DOJ	Department of Justice
DPAT	Debris Photo Analysis Team

DVD	Digital Video Disk
EDS	Energy Dispersive X-Ray Spectroscopy
EOC	Emergency Operations Center
EP	Equivalent Person
EPA	Environmental Protection Agency
ESAT	Early Sightings Assessment Team
ESCA	Electron Spectroscopy for Chemical Analysis
EST	Eastern Standard Time
ET	External Tank
EVA	Extravehicular Activity
FAA	Federal Aviation Administration
FBI	Federal Bureau of Investigation
FCS	Flight Crew Systems
FCOD	Flight Crew Operations Directorate
FEMA	Federal Emergency Management Agency
FMEA	Failure Modes and Effects Analysis
FOIA	Freedom of Information Act
FT	Fault Tree
FTIR	Fourier Transform Infrared Spectroscopy
FTP	___ ___ Protocol ???????????????????????
FW	Firewall
GIS	Geographic Information System
GMT	Greenwich Mean Time
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning System
GRC	Glenn Research Center
GSA	General Services Administration
GSFC	Goddard Space Flight Center
HCAT	Headquarters Contingency Action Team
HFT	Hardware Forensics Team
HMIS	??????????
HQ	Headquarters
HRR	Hardware Release Request
HTML	Hypertext Markup Language
IO	Investigations Organizer
I/T	Information Technology
ICD	Interface Control Document
IFMP	Integrated Financial Management Planning
IML	Inner Mold Line
IO	Investigation Organizer
IP	Internet Protocol
IPRA	In-Process Rework Authorization
IRIS	Incident Reporting Information System
ISD	Information Systems Directorate
ISS	International Space Station
ITAR	International Traffic in Arms Regulations

DVD	Digital Video Disk
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I/T	Information Technology
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IFMP	Integrated Financial Management Planning
IML	Inner Mold Line
IO	Investigation Organizer
IP	Internet Protocol
IPRA	In-Process Rework Authorization
IRIS	Incident Reporting Information System
ISD	Information Systems Directorate
ISS	International Space Station
ITAR	International Traffic in Arms Regulations

JSC	Johnson Space Center
JSCRO	Johnson Space Center Resident Office
KSC	Kennedy Space Center
LACB	Landing Aids Control Building
LaRC	Langley Research Center
LESS	Leading Edge Subsystem
LM	Lockheed Martin (Corporation)
LOCV	Loss of Crew and Vehicle
LOE	Level of Effort
M&P	Materials and Processes
MAF	Michoud Assembly Facility
MCC	Mission Control Center
MEICT	Multi-Element Integration Closure Team
MER	Mission Evaluation Room
MG	Management Integration Office???????
MIT	Mishap Investigation Team
MLG	Main Landing Gear
MLP	Mobile Launcher Platform
MMH	Monomethylhydrazine
MMT	Mission Management Team
MMVF	???????
MOD	Mission Operations Directorate
MPP	Manufacturing Process Plan
MRT	Mishap Response Teleconference or Mishap Response Team
MSFC	Marshall Space Flight Center
N_2O_4	Nitrogen Tetroxide
NAIT	NASA Accident Investigation Team
NARA	National Archives and Records Administration
NASA	National Aeronautics and Space Administration
NCD	Non-Conformance Document
NDE	Non-Destructive Evaluation
NISN	NASA Integrated Services Network
NOAA	National Oceanic and Atmospheric Administration
NSRS	NASA Safety Reporting System
NTSB	National Transportation Safety Board
OCR	Optical Character Recognition
ODIN	Outsourcing Desktop Initiative for NASA
ODRC	Orbiter Data Reduction Complex
OEX	Orbiter Experiments
OFK	Official Flight Kit
OI	Operational Instruction
OMDP	Orbiter Maintenance Down Period
OML	Outer Mold Line
OMRS	Operations and Maintenance Requirements and Specifications
OMS	Orbital Maneuvering System
OPS	Orbiter Positioning System

Ops-ftp	???????????????????? (See Section 6)
OSF	Office of Space Flight
OVE	Orbiter Vehicle Engineering
PAO	Public Affairs Office
PBMA	Process Based Mission Assurance
PC	Personal Computer
PDF	Portable Document Format
PDRR	Payload Data Release Request
PKI	Public Key Infrastructure
PLMD	Palmdale
POC	Point-of-Contact
PPE	Personal Protective Equipment
PRACA	Problem Reporting and Corrective Action System
PRCB	Program Requirements Control Board
PRT	Problem Resolution Team
QC	Quality Control
RADES	Radar Evaluation Squadron
RCC	Reinforced Carbon-Carbon
RCS	Reaction Control System
RDM	Responsible Data Manager
RDS	Reconstruction Documentation Sheet
Rep	Representative
RFI	Request for Information
RLV	Reusable Launch Vehicle
RPIII	Regents Park III Offsite Security Building
RRT	Rapid Response Team
RSRM	Reusable Solid Rocket Motor
RTFPT	????????????????? (See bottom of Table 2-1)
RTQ	Response to Query/Question????????????????
S&MA	Safety and Mission Assurance
SAM	Subsystem Area Manager
SDS	Shuttle Drawing System
SEB	Source Evaluation Board
SEM	Scanning Electron Microscopy
SFO	Space Flight Office
SGS	Space Gateway Services
SI	Systems Integration
SIDD	Shuttle Interagency Debris Database (or Shuttle Investigation Debris Database??????)
SIP	Strain Isolation Pad
SLF	Shuttle Landing Facility
SMA	Safety and Mission Assurance?????
SR	Service Request
SRIL	Significant Recovered Items List
SQL	Structures Query Language
SRB	Solid Rocket Booster

SRM	Solid Rocket Motor
SR&QA	Safety, Reliability, and Quality Assurance
SSC	Stennis Space Center
SSL	Single Socket Layer
SSME	Space Shuttle Main Engine
SSP	Space Shuttle Program
STI	Scientific-Technical Information (Center)
STM	Standard Material specification
STP	Standard Process Specification
TAL	Transoceanic Abort Landing
TAR	Test Approval Request
TCS	Thermal Control System
TEF	Technical Exchange Forum
TF	?????????????????????????
TPS	Thermal Protection System
TVC	Thrust Vector Control
UA	Unexplained Anomaly
USA	United Space Alliance
USB	Universal Serial Bus
USGS	United States Geological Survey
VCR	Video Cassette Recorder
VITT	Vehicle Integration Test Team
WG	Working Group
WLE	Wing Leading Edge
WSTF	White Sands Test Facility
XPS	X-Ray Photoelectron Spectroscopy
XRD	X-Ray Diffraction
2-D	Two Dimensional
24/7	Twenty-Four Hours per Day, Seven Days per Week
3-D	Three Dimensional

1. COLUMBIA TASK FORCE

1.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

1.1.1 Background and Charter

On February 1, 2003, the Columbia Task Force (CTF) was activated in response to the Columbia accident. As required by the NASA Contingency Action Plan (CAP), dated January 2003, the NASA Administrator determined that this constituted a Type A Mishap and, among his immediate actions, he created a Space Shuttle Interagency Investigation Board, now named the Columbia Accident Investigation Board (CAIB). In addition to the prescribed membership of the CAIB, the Associate Administrator for Space Flight, acting on behalf of the Administrator, activated the CTF, a Task Force Team.

The CAP required that the Associate Administrators for Space Flight and Safety and Mission Assurance and Johnson Space Center (JSC) Center Director, within 72 hours, meet to select and recommend task force members to the CAIB Chairperson. The task force members then were to convene and meet with the appropriate NASA working group and team leads to:

1. Be the formal interface between the CAIB and the activated NASA Mishap Response Teleconference (MRT; called "Mishap Response Team")
2. Monitor, collect, document, and file the reports of the MRT working groups activated to support the accident investigation
3. Provide CAIB members with the requested information and reports from the working groups
4. Assist the CAIB in preparation of interim and final reports, as required

The above actions were completed within the time prescribed by the CAP. Mr. Frank T. Buzzard was appointed Director of the CTF on February 2, 2003, and immediately initiated activities to organize and staff the CTF. Through several revisions of the CAIB charter, each improving the description of CAIB independence from NASA, the charter of the CTF remained the same.

1.1.2 Startup Activities

No activation plan, critical functions required, or list of personnel existed at the formation of the CTF. The CTF Director developed a draft organization chart and list of candidates for the key functions within 48 hours of CTF activation based on his experience in supporting the 1986 Challenger Accident Investigation and leading the Russian Proton Launch Failure Investigations for NASA in 1999. Since the CTF interface function with the CAIB would involve technical, integration, and administrative support, including support relating to prelaunch, launch, mission operations, engineering, flight crew, Space Shuttle Program (SSP) Office, Configuration Management (CM), legal matters, Information Technology (I/T), safety, public affairs, MRT, and multiple NASA centers, these key functions were included in the CTF organization chart. (See Figure 1-1.) The CTF Director immediately conducted a videoconference with the affected center Directors to present his requirements and organizational structure. All NASA centers immediately responded with complete support—material and requested personnel—without reservation.

Following the initial coordination meeting with the CAIB, the CTF organizational structure was revised, to match the CAIB division of responsibility, into three Technical Teams:

1. Prelaunch History and Program Management Team
2. Flight Preparation and Operations Team
3. Engineering and Technical Analysis Team

CTF Group Leads were identified and selected to provide direct coordination and support to CAIB Leads. This organizational structure turned out to be functionally correct and efficient for the remainder of the investigation. CTF issue identification and rapid redirection of priorities was facilitated by a daily 30-minute teleconference that included all members of the CTF. These daily tagups preceded the daily CAIB tagup and allowed the CTF Director to provide the CAIB timely and accurate information on the status of CTF actions. Even though typical startup transients affected the efficiency of the CTF for the first 2 weeks, the quality and dedication of personnel provided by the NASA centers were the key to the success of the CTF and its support of the CAIB. An important lesson learned is to add the key functions in the CTF organization chart to the CAP and preselect a CM tool approach. (See Lessons Learned Nos. 10 and 11.)

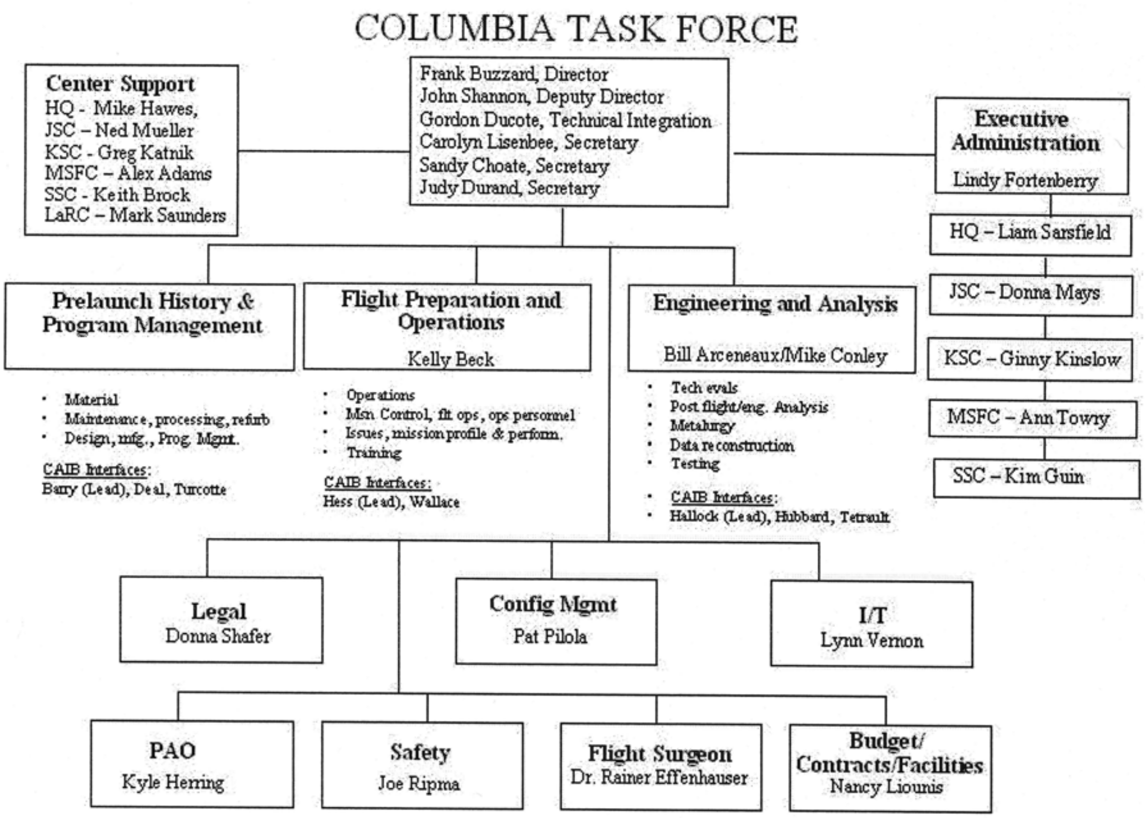

Figure 1-1. CTF Organization

1.1.3 Evolution and Transition Activities

When the CTF was formed initially, NASA reviewed the organizational structure used during the Challenger investigation. Unfortunately, the makeup and operating principles of the CAIB were significantly different from the Rogers Commission, so a new task force structure had to be developed.

There were three initial functions of the CTF: to provide data to the CAIB quickly, verify that data were accurate and complete, and place all Requests for Information (RFIs) and associated responses under CM. The last two functions were at direct odds with the first. NASA Space Shuttle Managers were very concerned that any data released to the CAIB be vetted fully by the MRT and fully documented. This, however, left the CAIB with virtually no information for the first 2 weeks. This delay resulted in CAIB frustration and an adversarial relationship with NASA at a critical time. The CTF effectively mitigated this problem by imbedding NASA personnel in the CAIB subgroups to work as proponents to provide data as quickly as possible and convincing the MRT to allow release of preliminary information to the CAIB, to be followed by official, final releases of information.

Another early concern was with the ad hoc method in which requests were received initially (e.g., post-it notes). It was determined quickly that an official form with required signoffs was needed for accuracy in framing the questions and information required by the CAIB. The STS-107 Columbia Accident Investigation Board (CAIB) Action/Request for Information (RFI; JSC Form 564) was developed in March 2003, and proved extremely useful. The embedded CTF member would help write details on the information/data desired and determine an appropriate due date. A CAIB member would sign the form and release it to the CTF. NASA then would track the request and response and sign for the official release of information. Then, the CAIB member would sign the RFI when the requested data were provided. While cumbersome, this provided a very good method for tracking the status of requests and ensuring that the CAIB received information in a timely manner.

Two other problems in the early RFI process were redundant requests for the same information and that staffers for the CAIB were requesting information not related to the root cause of the accident. To solve these problems, the CAIB Chairperson released a memo authorizing only CAIB members to sign official RFIs and also regular daily tagups between the embedded CTF members.

After a period of about 3 weeks, the process was in place and significant data began flowing from NASA to the CAIB. A regular status on open actions and tracking of overdue actions was provided to the MRT and CAIB.

The disparity between the way NASA had set up its investigation working groups and the way the CAIB was organized also created management problems. About 2 months into the investigation, NASA restructured the MRT into the NASA Accident Investigation Team (NAIT), with a similar architecture to the CAIB's. This further facilitated the flow of planning, discussion, actions, and data between comparable and knowledgeable NASA and CAIB points-of-contact (POCs). (See Lessons Learned Nos. 1 and 6.)

1.2 PROCESSES/PROCEDURES USED

1.2.1 Technical Teams

Logic dictated that CTF support to the CAIB's Technical Teams be aligned identically for consistent, efficient technical interchange. CAIB members arrived in Houston with little or no significant understanding of the Space Shuttle Vehicle (SSV) or the organization and processes of the SSP. CTF Technical Teams were required to provide a range of information and data services, from tutorials to historical documentation. The Team Leads for CTF Technical Teams were selected by the CTF Director for strong affiliations with the NASA processes, as well as the knowledge and management skill to provide CAIB members with the most effective, positive learning curve. While this report provides distinctly different organizational structure and interfaces and significant process descriptions for the three CTF Technical Teams, it should be noted that they operated very similarly as parts of the CTF.

1.2.1.1 Prelaunch History and Program Management Team (CTF Team 1)

1. **Organization and Interfaces**

Unique to CTF Team 1 was the presence of two Team Leads. Initially, it was set up so that each lead would have separate responsibilities; however, it worked best when both leads were involved in all activities. This excellent "tag-team" approach allowed for the unexpected to be handled (and the unexpected occurred more than once). Assuming this effort was typical of other similar efforts, a co-leader approach minimizes stress and maximizes response in the environment of heavy traffic in requests and extensively traveled investigators that existed for CAIB Group 1.

The Team Leads found that, by becoming part of the CAIB Group 1 processes, meetings, and activities, they were able to ensure effective and efficient teamwork, coordination, and overall CAIB support. They became embedded Group 1 team members.

Occasionally, the CTF Lead was not in the best position to ascertain if the response was appropriate and so the requester had to be asked, "Is this what you need?" While this is easy to do, it then set in motion the go-between syndrome where the Team Lead became a negotiator between requester and responder. Simply having the requester and provider meet and/or talk directly with each other wherever possible negated the weakness of such an arrangement. An approach of connecting the CAIB with specific POCs on the NASA side eventually was used to address CAIB questions and resolve issues. This approach should be used from startup, along with a previously established set of CM tools and processes, to ensure quick and effective understanding and coordination of issues between board investigator and NASA. This would require a definite set of previously established rules, processes, and procedures for the POC and the necessary management agreements and structure to resolve conflicts and establish priorities.

2. **Significant Processes**

CTF Team 1 essentially followed the same processes and procedures that were established for all of the CTF activities regarding the generation, concurrence, and closure of CAIB requests via the RFI form. Due to the overlap in questions being generated within the groups of the CAIB, it was necessary to establish internal coordination on a daily basis with the other Group Leads and Teams Leads in an attempt to minimize duplicate CAIB requests and benefit from the synergy.

1.2.1.2 Flight Preparation and Operations Team (CTF Team 2)

1. **Organization and Interfaces**

The Team Lead for CTF Team 2, interacting with the individual CAIB groups, was able to effectively draw on the expertise of the other support leads (for Legal, CM, the Public Affairs Office (PAO), etc.) and Center Leads. It was important for the CAIB groups to have a single POC to work through; however, since one person cannot be an expert in all areas, close coordination with the support leads was essential.

The Team Lead of CTF Team 2 used the Team 2 CM Lead, who logged and tracked RFIs, distributed RFIs to actionees, coordinated with actionees on estimated completion dates, coordinated reproduction requests, and ensured that CTF Team 2's portion of the database was maintained. The individual team CM Leads were invaluable in keeping track of the large number of RFIs. It is recommended that each team be assigned one or more CM personnel at the same time the Team Leads are assigned.

The CTF Crew Representative (Rep) and the Safety Rep interacted significantly with CAIB Group 2, assisting in their understanding of operations and safety. Bringing in reps from areas of key interest to the CAIB worked much better than the Team Lead's attempting to be a go-between. There were many other areas where it was helpful to bring in someone from outside the CTF to help provide general information and assist the CAIB in understanding the area they were investigating. This was scheduled in a more reactive fashion in the early stages of the investigation. It is recommended that such educational sessions be identified and scheduled as soon as a CAIB group's areas of interest are identified.

The CTF Legal Rep performed the interview scheduling with input from the Team Leads, who coordinated interview requirements. Implementing an electronic calendar improved this process significantly, since it eliminated scheduling conflicts with the interview room and was used to show the interviewers' scheduling constraints.

2. **Significant Processes**

   a. **RFI Process.** The RFI process evolved with time into an effective, but sometimes cumbersome, process. The startup process requires significant improvement. Before the CTF was created and engaged, requests from CAIB members simply were logged into a spreadsheet with little supporting information. A name for the requester was not listed, so it was not clear whom to approach for clarification. This caused a significant workload for CTF personnel early in the investigation and delayed getting the CAIB the desired information. Since the CAIB required a few weeks for orientation and to organize themselves, many of these early requests were deemed unnecessary after CAIB members had a better understanding of their task. It is recommended that the task force be assigned as quickly as possible so that the RFI process can be used at the start of the investigation. Assigning Team Leads and having them travel with the board during their orientation phase also should be considered. This would ensure that board members have a NASA person to work with to assist them in formulating their questions and requests and ensure that RFIs will be understandable to the groups or organizations required to respond.

Once the CTF and the RFI process was established, the Team Leads assisted the CAIB members and their staff in drafting RFIs. This process worked best when staff members would discuss their requests with the Team Lead, since members of the CAIB, their staff, and NASA did not always "speak the same language." The Team Lead assisted them in drafting RFIs so they would receive the information they were expecting and the RFIs were understandable to the organization responding. The Team Lead then gave the RFIs to one of the CAIB members for signature, usually the Group Lead. As this process matured, new RFIs were signed at the Group 2 tagup to make sure these RFIs were relevant to the investigation. Although an electronic "workflow" type RFI system would have reduced paperwork, the face-to-face discussions forced by the paper signature were instrumental in making sure the RFIs were written clearly.

The Team Lead of CTF Team 2 had limited knowledge of Group 2's "work plan" or specific questions and areas they were pursuing in the investigation. This may have been attributed to the fact that this Team Lead was on the STS-107 Team, making CAIB members and staff hesitant to share information. An open exchange would have been beneficial so that the CTF Team 2 Lead could assist CAIB members and staff in identifying information they should request to facilitate their investigation. It is recommended that individuals not directly associated with the accident being investigated be assigned as Team Leads to maximize the trust between board members and their staff and the Team Lead.

b. **MRT/NAIT and CTF Interaction.** Early in the RFI process, before the MRT transitioned into the NAIT, signed RFIs were given to the CTF Deputy Director to be taken to the MRT Chairperson daily for identifying the responding organization. RFIs would be classified as "MRT," meaning the response needed to come back through the MRT before being provided to the CAIB, or "Other," meaning that the CTF would distribute the RFI to the organizational POCs directly. Later, when the NAIT was established, this daily tagup was replaced with a regularly scheduled meeting between the NAIT leaders and CTF Team Leads. This direct contact assisted in providing clarification on RFIs, when needed, and eliminated two single POCs in the process. To facilitate this screening of RFIs, the CTF Team Leads met prior to each NAIT/CTF tagup to screen for duplicate requests. This could have been facilitated further if an improved Search feature had been implemented and used in the Process Based Mission Assurance (PBMA) System.

The MRT/NAIT/CTF tagups were very beneficial in ensuring that the appropriate organizations received RFIs, but they did add an extra management layer for easily answered requests. It is recommended that guidelines be established for which types of RFIs can be distributed directly by the task force so that all RFIs do not have to be screened by the MRT. For example, any requests for STS-107 information, even for information published prior to the accident, had to be funneled through the MRT (and then later the NAIT). This added 1 or 2 days' delay before an RFI was distributed to the actionee. For information already published prior to the accident, it is recommended that the task force distribute these RFIs directly to the responding organizational POCs.

Consideration should be given to merging some task force functions into the MRT. During this investigation, when the MRT was still in existence, there was benefit in having a neutral body between the CAIB and MRT; however, after the NAIT was established, this no longer was an important factor. Because the NAIT took over a few weeks into the investigation and did not want to disrupt the process and initiate another "startup transient" (their goal was a seamless transition), no significant changes in the interface to the CTF were made. If the NAIT had been established at the same time as the CTF, it may have been beneficial to absorb the CTF into the NAIT. The roles within the CTF would have been unchanged, but would have allowed the CTF and NAIT to work more closely together and eliminate duplication of effort. For example, all RFIs ("MRT/NAIT" and "Other") were tracked by the CTF using the PBMA System, but the MRT/NAIT used a different mechanism to track "MRT/NAIT" RFIs. Joining the NAIT and CTF into one organization would have eliminated this duplication and resulted in fewer layers through which to get RFIs to and from actionees. It was also observed that in some cases "NAIT" RFIs were given more attention than "Other" RFIs, independent of the priority established by the CAIB. Absorbing the CTF into the NAIT, would have given additional weight to "Other" RFIs. (See Lessons Learned No. 7.)

1.2.1.3 Engineering and Technical Analysis Team (CTF Team 3)

1. Organization and Interfaces

CTF Team 3 provided the interface between the CAIB Group 3 and NASA working groups in the investigation to determine the specific failure that caused the final catastrophic breakup of Columbia. CTF Team 3 ensured that the engineering and analysis that NASA was conducting would be provided to the CAIB Group 3 members and data requests from the CAIB to other NASA centers were honored. CTF Team 3 was composed of personnel from the JSC Engineering and Mission Operations directorates, SSP Office, and International Space Station (ISS) Program Office. All the members had both the breadth and depth of human space flight experience, as well as the integration skills, needed to support the CAIB Group 3 investigations.

With a staff of six, CTF Team 3 was the largest team, due to the diverse work content. Each member was assigned an area of responsibility based on the member's background. The team was fortunate that the CM members also were outstanding engineers with good integration skills, which were extremely helpful in working and closing issues. Members supported MRT/NAIT, Orbiter Vehicle Engineering Working Group (OVE WG), and special investigation meetings. The CTF Team 3 also accompanied the CAIB and NAIT members to Kennedy Space Center (KSC) and debris collection centers, as required, to ensure that actions were taken and documented.

Following the transition from MRT to NAIT, a standing meeting was established with the NAIT Group 3 Lead (Mr. Benz) and the CAIB Group 3 members. CTF Team 3 generated formal agendas and tracked actions. This worked very effectively to resolve problems (real and perceived). This meeting served well as an integration forum.

CAIB Group 3 never established a single-point leader to focus the overall work and actions for the investigations, and the strong personalities of CAIB members proved to be difficult. The CTF quickly became a "management integration" staff not only for the CAIB Group 3 members but also between CAIB Group 3 and CAIB Groups 1 and 2. This caused procedural difficulties in the early weeks of the investigation before clear responsibilities brought about more responsive, repeatable patterns. CTF Team 3 facilitated a morning meeting with the CAIB Group 3 to compare notes, review work completed, and forward activity. (See Lessons Learned No. 2.)

The plethora of meetings requiring attendance from CTF Team 3 necessitated a strong, delegated staff. A deputy was assigned to speak for the team in the absence of the Team Lead; however, each team member had the authority to represent the team and make commitments. CTF Team 3 met as required and used e-mail to communicate parallel activities. Also, the RFIs were opened and closed more efficiently. Near the end of the investigation, the Team Lead rescinded delegation for opening RFIs to slow the generation of unnecessary work.

CTF Team 3 continued to operate though the closure of all RFI and testing activities. The staff was reduced in mid-May to four. Due to the reduced workload, the staff was able to return to their normal duties on a part-time basis, but their CTF duties remained their priority until the CAIB activity was concluded.

2. **Significant Processes**

   a. **Scenario Development.** The specific event timeline (into which the instrumentation, videographic analyses, and forensic analyses were integrated) was developed to determine the chain of events, from pre-liftoff through launch, ascent, on orbit, and entry. The CAIB and NASA conducted independent scenario development through the first half of the investigation. The NASA analysis activity (e.g., aerodynamic and aerodynamic/thermodynamic) supported both efforts. Due to the duplication of effort, the activity was combined into a single "Working Scenario." The CTF ensured that the data flow between NASA and the CAIB remained free and open.

b. **Testing to Validate Scenarios.** Many hypotheses required special tests to establish if the hypothesis was credible. NASA conducted most of these tests with CAIB insight (awareness of the testing with receipt of a final report) and oversight (CAIB approval of the test plan required and CAIB representation at the test).

c. **Debris Collection.** NASA, in collaboration with the Department of Defense (DOD), Forest Service, and many other Government entities, led the field collection of the Columbia debris. The CTF ensured that the CAIB was aware of the debris collection status and approved any special debris handling, analysis, or testing requests. (See Lessons Learned No. 8.)

d. **Forensic Analysis.** Both NASA and the CAIB had investigators evaluating and analyzing the Columbia debris. The CAIB, therefore, required NASA to strictly control and maintain the debris for investigation reliability and held final approval authority for any destructive testing. The CTF ensured that the CAIB special requests for analysis, debris layout, and any other direction were transmitted accurately to NASA.

e. **Fault Tree.** NASA was responsible for the fault tree development and closure. The CAIB maintained strong oversight and final approval of fault tree closure. The CTF ensured that any issues the CAIB raised would be transmitted to NASA for resolution.

1.2.2 Legal

1.2.2.1 Organization and Interfaces

The CTF Legal Rep established POCs with each NASA center, NASA Headquarters (HQ), designated NASA contractors, and the CAIB Counsel.

1.2.2.2 Significant Processes

1. **Witness Interviews.** The process for setting up witness interviews worked well. The CTF Legal Rep established POCs with each NASA center, NASA HQ, and NASA contractors. Each company had slightly different processes in place to schedule interviews, and having a single POC was beneficial. Early on, the CAIB requests for interviews consisted only of names, which were sometimes misspelled. This created a delay in the scheduling process, because it took time to identify the individual and where he or she worked within NASA or the NASA contractor community. (See Lessons Learned Nos. 27 and 29.)

2. **Transcripts.** The CAIB decided to tape-record interviews with witnesses and have the tapes transcribed following the interview. The method selected (against the advice of Counsel) to conduct interviews turned out to be the most resource intensive and least accurate method to complete the interviews. The poor recording quality resulted in a considerable amount of erroneous information in the actual transcripts that, in turn, resulted in a highly labor intensive review process for inter-

viewees who attempted to reconstruct the interview. If transcripts are intended to be official records to be relied upon later as accurate, court reporters should be used. (See Lessons Learned No. 26.)

3. **Freedom of Information Act (FOIA) Requests.** The existing NASA FOIA process was used; however, early on, appointed NASA Legal Counsel for JSC (in addition to the dedicated CTF Legal Rep) and NASA FOIA Officers began a daily tagup to discuss the incoming FOIA requests and the most expeditious manner to handle the large volume of requests. The FOIA team worked with the CTF Legal Rep and CAIB Counsel to facilitate responses to any CAIB or NASA requests. This team approach assisted with well-coordinated FOIA responses.

4. **Control of Sensitive Data.** An early goal for this investigation was to get as much information out to the public as soon as possible. With this in mind, a separate tracking system was established to track RFIs that would be exempt from release (e.g., medical information or requests for formal witness interviews) under FOIA in order to facilitate the timely release of nonexempt information.

5. **Document Retention and Archival.** The Department of Justice (DOJ) was retained by the CAIB to facilitate document retention and archival. It is recommended that a document retention and archival process be put in place as soon as possible. (See Lessons Learned No. 25.)

6. **Release of Impounded Data.** The STS-107 CAIB Impounded Hardware and Debris [and Data] Test Approval Request (TAR) was used for both internal and external releases. TARs required approval from NASA and the CAIB. This process worked well and ensured that no releases were made that would, in any way, compromise the investigation. Additional coordination was necessary for external releases (e.g., to payload customers), resulting in a longer period of time for release approval.

7. **Export Control.** The existing export control process was used to facilitate releases of information to the public by the CAIB. The SSP Office Export Rep reviewed data turned over to the CAIB and made a written recommendation concerning the release of that information. It is important to sensitize individuals unfamiliar with NASA data to the fact that many types of Space Shuttle data are controlled by International Traffic in Arms Regulations (ITAR), Code of Federal Regulations (CFR) Title 22, Parts 120 to 130.

8. **Avoiding Conflict of Interest Issues.** CAIB members who were hired as NASA employees need to complete the appropriate financial disclosure reports (e.g., Public – OGE 278 and/or Confidential – OGE 450). The ethics review of those completed reports needs timely completion to avoid conflict of interest issues.

9. **External-to-CTF Legal Support.** An important note is made that, in addition to supporting the investigation via a dedicated CTF Rep, the following legal support was provided:

   a. **Recovery and Mishap Investigation Team (MIT) Support.** Legal advisors were sent to Barksdale Air Force Base (AFB), Louisiana, immediately after the accident and later to the Disaster Field Office in Lufkin, Texas, to support the

MIT to help develop procedures and respond to issues quickly in the process of collecting debris and transporting it to KSC for reconstruction. Issues addressed included acquiring death certificates and working with medical personnel from NASA and the DOD on other matters dealing with the loss of the crew, creating procedures for effective interagency cooperation (i.e., data collection and archiving, reimbursement for agency support, and handling and shipping of debris), and maintaining appropriate interfaces with the various Federal, state, and local agencies assisting in the recovery effort. The CTF recommends using legal advisors from the Lead Center for investigation and recovery response, if possible, to ensure adequate coordination with investigation efforts.

b. **Claims.** Claims were divided into two categories upon receipt: 1) personal injury and property damage or 2) reimbursement for services and/or supplies. Using the procedures in the CFR as a guide, procedures were developed for the review, validation, and settlement of these claims by the JSC Legal Office. Early on, the public was given telephone numbers for the legal offices at JSC, Stennis Space Center (SSC), and NASA HQ to file a claim, but in the end, it was much easier to have one Lead Center act as the receipt and administration point for all claims and requests for reimbursement received by NASA and to coordinate with NASA HQ as necessary.

1.2.3 Safety

1.2.3.1 Organization and Interfaces

The duties of the Safety Rep to the CTF were to provide an interface between the CTF Team Leads and the safety community. Upon occasion, there was direct interface between the CAIB staff and the Safety Rep.

1.2.3.2 Safety-Related Processes

Frequent, almost continuous, communication between the CTF Team 1 and 2 Team Leads and the Safety Rep, and occasionally CAIB staff, was extremely beneficial to successfully acquiring the information desired by the CAIB. The Safety Rep held daily tagups with the SSP Safety and Mission Assurance (S&MA) Manager. The tagups kept the SSP S&MA Manager informed and able to respond to the myriad of data requests received. Open communications between the CTF Chairperson and CTF members clearly contributed to the successful closure of safety-related actions. The use of Blackberries for mobile e-mail access contributed to keeping the information flowing.

Another factor contributing to success was that the Safety Rep had a working knowledge of the safety and SSP organizations and the people in both communities. This knowledge facilitated getting RFIs to the proper organizations and individuals.

Although communication overall was excellent, there were areas that could be improved. The CTF Safety Rep should have held regular tagups with the safety community to keep them informed about CAIB activities and for the CTF Safety Rep to keep up with what S&MA organizations were doing in support of the investigation. Regular tagups could have expedited more consistent responses from the S&MA community. Another improvement would have been for the Safety Rep to have direct communication with the CAIB staff early in the investigation on safety-related matters. This direct contact might have helped focus the scope of some of the early RFIs.

NASA Safety Reporting System (NSRS) reports should have been processed at NASA HQ so as not to waste time processing reports irrelevant to the accident investigation.

For each key position, there should be a primary individual and a trainee. The accident investigation is a complex task, and the best way to learn it is through experience. It could be the trainee's assignment to document the activities of the key position. If the documentation already exists, the trainee should be responsible for updating it.

1.2.4 CM

1.2.4.1 Organization and Interfaces

At CAIB and CTF startup, there were no CM assets in place, including staff, tools, requirements, or procedures. Significant amounts of time were spent establishing basic agreements, processes, and procedures. As a result, the CTF CM Team adapted or modified processes and procedures, when possible, to expedite CAIB requests and still be able to support CTF data capture for archiving and retrieval. (See Lessons Learned Nos. 9 and 19 for specific recommendations.)

1.2.4.2 CM Processes

1. **Responsibilities.** The CTF CM Team was responsible for establishing appropriate processes and procedures to ensure that requests for actions and/or RFIs from the CAIB were tracked, monitored, controlled, maintained, electronically accessible, and archived for future reference. Specifically, CTF CM responsibilities included:
   a. Developing and maintaining the official data repository for NASA data provided to the CAIB
   b. Recording and capturing CAIB investigation meeting minutes
   c. Capturing and monitoring CAIB data requests and actions
   d. Tracking and maintaining STS-107 Hardware Release Requests (HRRs) and TARs
   e. Establishing and maintaining a document management system for official sensitive and nonsensitive investigation data, as well as unsolicited data from the public and international communities
   f. Establishing metrics for tracking actions
2. **Minutes and Recordings.** Civil servant skills and expertise for recording and transcribing meeting minutes no longer exist at NASA and could be provided only through contract mechanisms. A contractor with no direct ties to NASA was used to support this function. Tape recordings were created to assist with the creation of the final CAIB record (i.e., minutes) of the meetings and were not maintained once the minutes were finalized. The process for generating and finalizing minutes is shown in Figure 1-2.

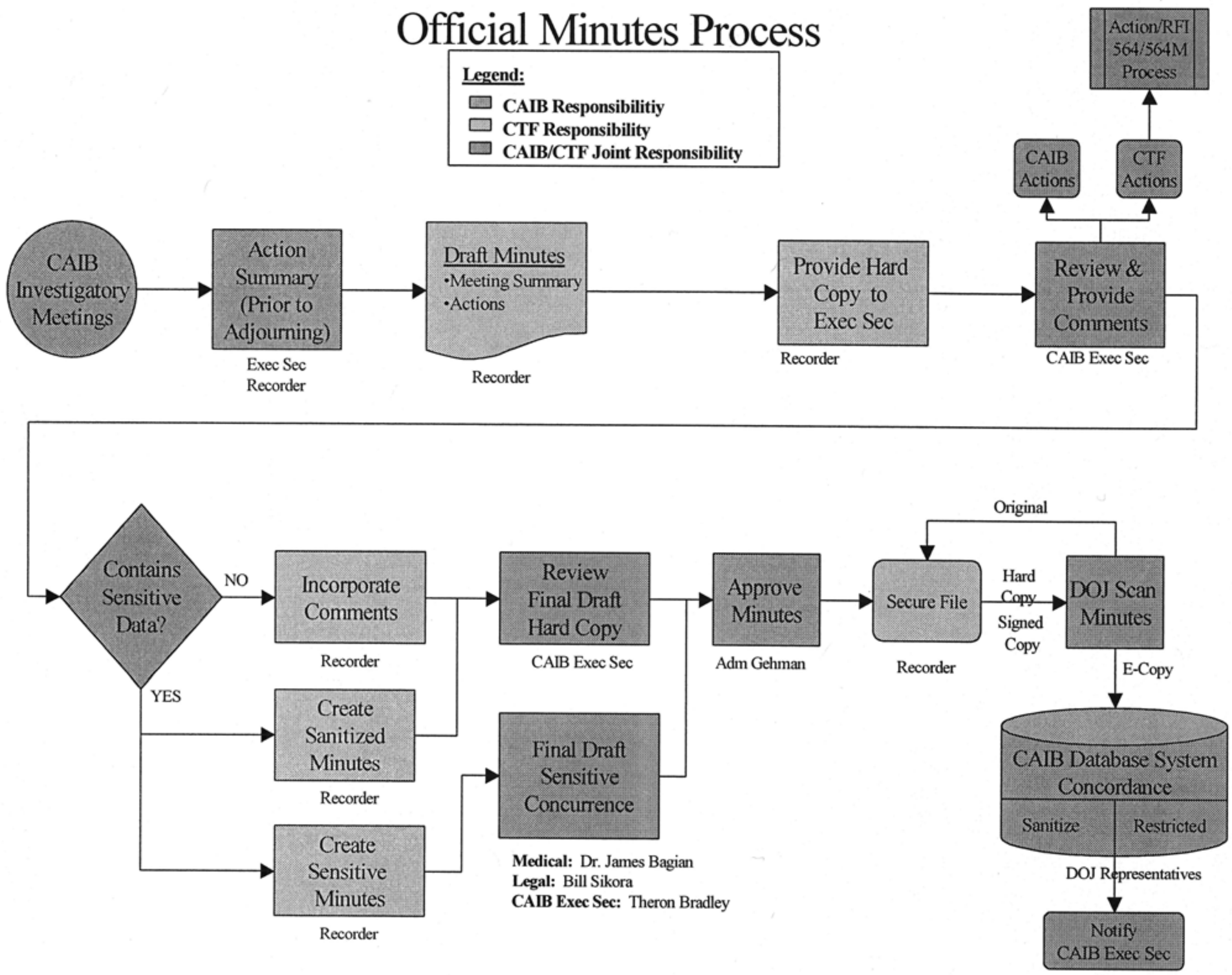

Figure 1-2. Official Minutes Process

3. **Action Request and RFI Tracking.** More than 650 action requests and RFIs were processed by completion of CAIB activities. The action tracking process used by the CTF and CAIB is depicted in Figure 1-3. JSC Forms 564 (nonsensitive) and 564M (sensitive) were used to document CAIB actions.

   Nonsensitive actions were tracked in the secure (two-factor user authenticated) PBMA System. Sensitive data such as medical information, personnel records, and witness statements were tracked in a separate log maintained on a secure JSC server. The sensitive data were maintained in a secured file.

4. **HRR and TAR Process.** Figure 1-4 depicts the approval process for releasing STS-107 impounded hardware and conducting tests on these assets. Over 100 HRRs and 80 TARs were released during the investigation.

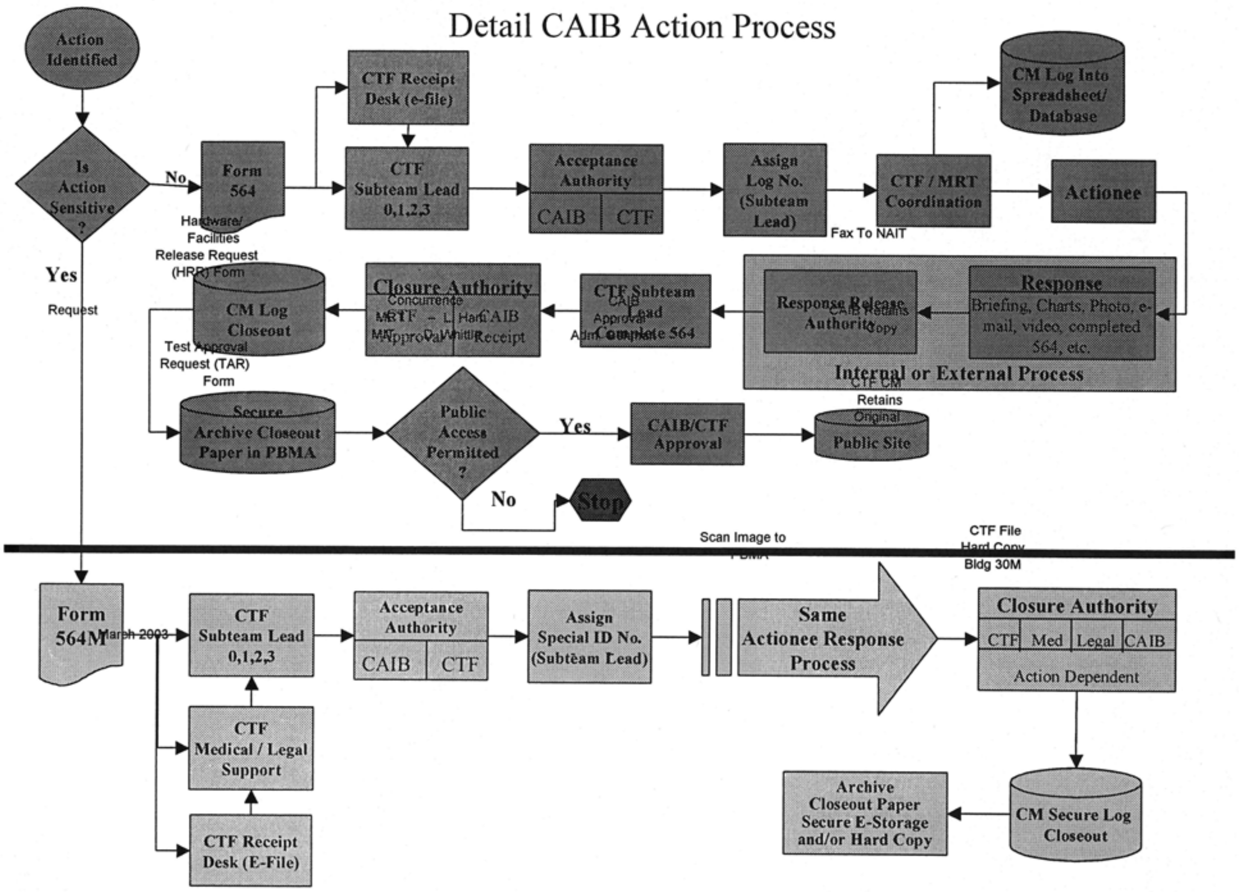

Figure 1-3. Sensitive and Nonsensitive Action Tracking Processes

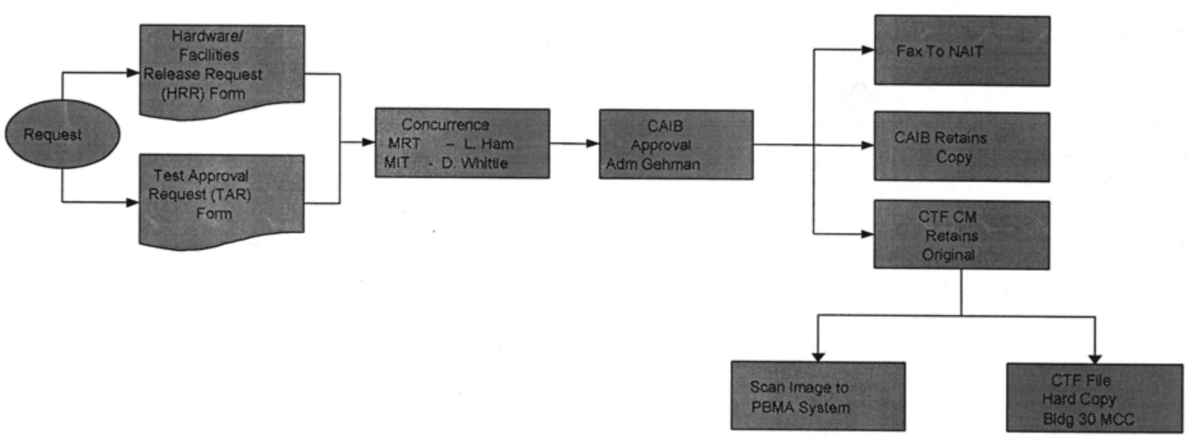

Figure 1-4. Hardware Release Process

5. **Documentation Management.** The CAIB established the initial electronic documentation structure used to store presentations, reference material, action closure data, and other data required for the investigation. A librarian and two support contractors were added later to the CTF CM Team to restructure the electronic documents and help populate and maintain the database. Metadata also were added to the files to assist in identifying, searching, and retrieving files. Initial estimates for conducting the library function were under-scoped, resulting in a significant backlog. In the end, more then 8,000 documents and more than 15 gigabytes of data were maintained. Other JSC institutional organizations provided support for scanning documents and duplicating video and audiotapes, Compact Disks (CDs), and Digital Video Disks (DVDs).

   A CAIB Export Control Process document was developed by the CTF and CAIB Legal Reps and coordinated with SSP and JSC Export Control personnel. In addition, a warning label was added to the electronic database stating, "This database contains technical data subject to the International Traffic in Arms Regulations (ITAR), 22 CFR 120-130. Before public release, consult CAIB Counsel."

   The DOJ was used by the CAIB as an independent source to manage and maintain CAIB data. As a result, an Interface Control Document (ICD) was established between the CTF and DOJ to capture the interface requirements, processes, and procedures. The ICD process for transferring documents between the CTF and DOJ is depicted in Figure 1-5. (See Lessons Learned No. 5.)

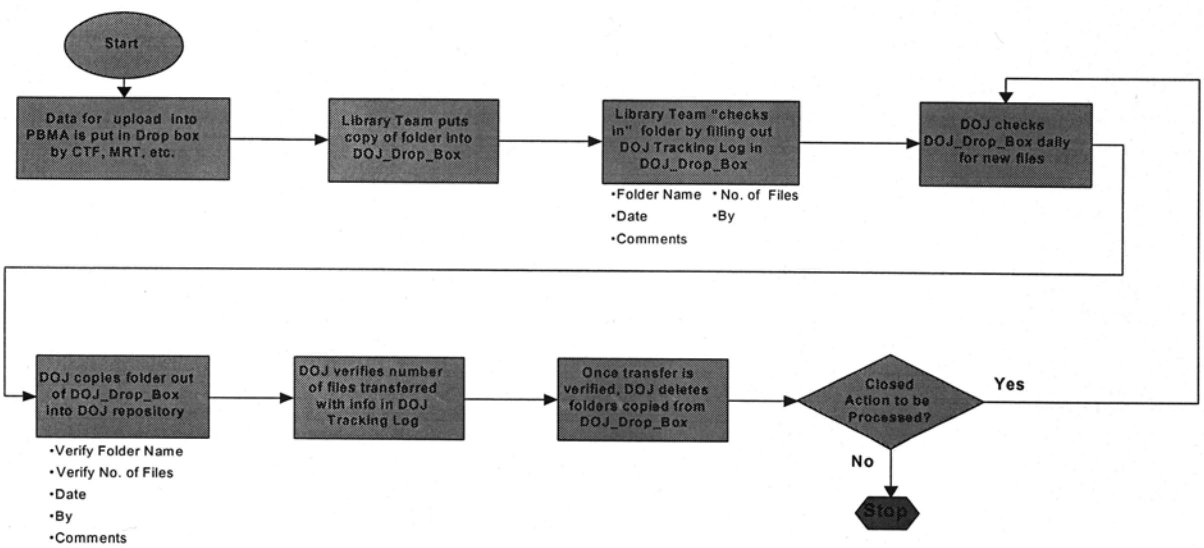

Figure 1-5. CTF to DOJ File Transfer Process

6. **Archives.** The SSP Data and Records Handling Working Group provided guidance for archiving and managing CTF data. Upon completion of the investigation, all CTF data became the property of the SSP Office. The CTF coordinated with NASA HQ, SSP Office, JSC Information Systems Directorate (ISD), and National Archives and Records Administration (NARA) to ensure the integrity of the data during the archiving process. (See Lessons Learned No. 25.)

   CTF CM trained SSP and ISD personnel to access the CAIB and CTF database or provide data retrieval for external inquiries from NASA-approved Governmental and public interest groups.

7. **Other Processes Developed for the CAIB**

   a. JSC Library document access and checkout (Figure 1-6)

   b. Building access and badging security procedures (Figure 1-7)

      To ensure independence and data integrity, the CAIB used an offsite facility, but were given NASA badges that allowed access to all NASA facilities required. Secure access also was established at the CAIB offsite facility, and all NASA and contractor personnel supporting the investigation required additional badges to access the facility. Badging procedures are depicted in Figure 1-7.

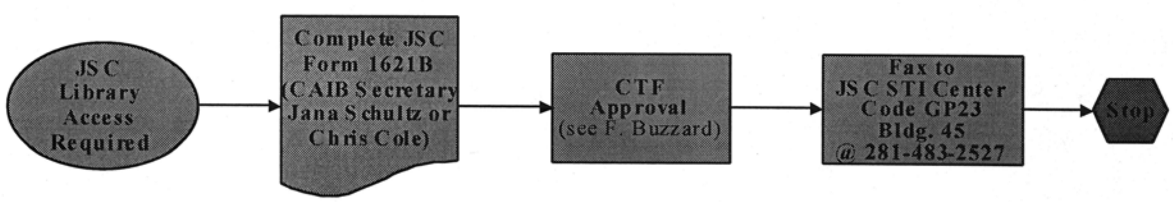

Figure 1-6. JSC Library Access Process

3/17/2003 - PSP

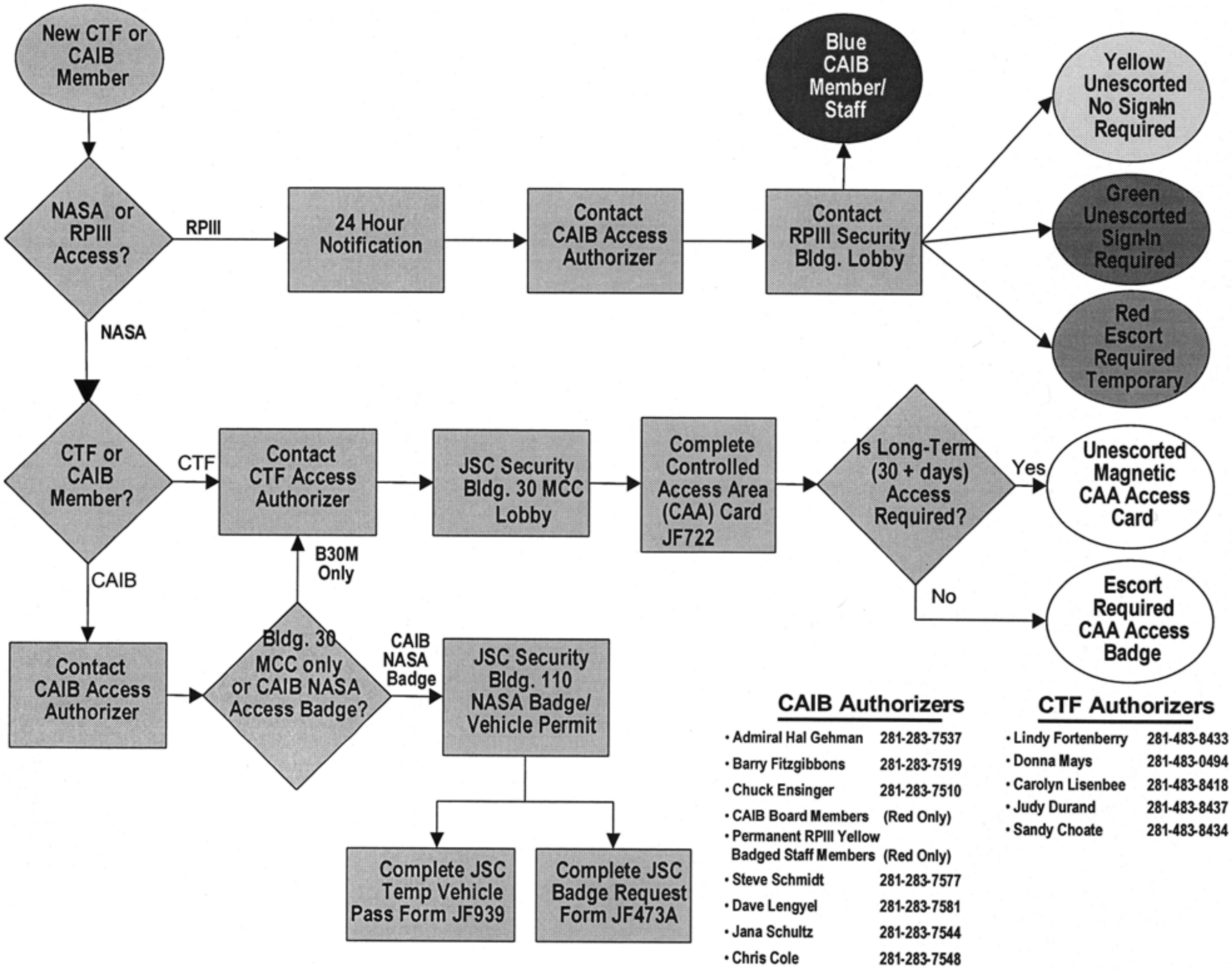

Figure 1-7. CAIB and CTF Process for Regents Park III and JSC Building 30 Mission Control Center (MCC) Security Access

1.2.5 Flight Surgeon

Organization and Interfaces

The CTF Flight Surgeon acted as the senior medical interface between the CAIB and NAIT (formerly MRT). This responsibility included supporting the CTF teleconferences, acting as the rep for sensitive medical data requests, acting as POC for medical and medico-legal issues that arose during the investigation, and ensuring that the STS-107 medical records were reviewed and secured appropriately. In addition, the CTF Flight Surgeon coordinated information flow to the Director of Space and Life Sciences and directly supported the CAIB Medical Rep (Dr. James Bagian). During the CTF process, working closely with NASA Legal Reps for various medico-legal issues was required. Early during the investigation, the need to, in a secure manner, enter sensitive medical data in a database and store it was identified and procedures were implemented.

1.2.6 I/T

1.2.6.1 Organization and Interfaces

The CTF structure was set up with a primary CTF I/T Lead, who was responsible for working with the CAIB and CTF to establish the I/T architecture required for support of the CAIB and CTF and to ensure proper security of information. This function was the primary interface between the CAIB and NASA I/T resources owned by JSC, SSP, and other centers. The CTF I/T Lead also provided the function of primary interface between the CAIB contractors and NASA systems organizations. A list of primary POCs for the various systems organizations and centers was established quickly.

Initial establishment of the CAIB and the constant influx of new members resulted in a significant and continual flow of requests and requirements for various tools, services, and access. The initial flood of requests and requirements resulted in duplicate actions being worked in different ways. Establishment of the CTF I/T Lead as the primary focus for both the CAIB and CTF greatly reduced this, but the lack of a CAIB I/T Lead constrained the definition of CAIB requirements and policy. An example was the agreement to use JSC e-mail as the mail system to support the CAIB during the investigation. This was the agreed-to system; however, many individual CAIB members and staffers chose to continue to use their home e-mail systems as their primary system for CAIB activities. This resulted in several issues such as connectivity to the home systems and backup and archive of the data. (See Lessons Learned Nos. 12 through 17.)

1.2.6.2 I/T Process and Tool Requirements

To support the full scope of the investigation, a wide variety of I/T tools, services, and access was required. A significant amount of data related to the investigation was in electronic form; therefore, communication of or access to this information required different tools. The travel of the CAIB and the CTF members required that their I/T tools be accessible remotely. To facilitate communications, cell phones, Blackberries, and text pagers were provided to select members.

The following are the tools used by the CTF and CAIB to complete the investigation.

1. **CM Data Repository**

   a. **PBMA System.** The PBMA System is a secure (two-factor user authenticated) system located at Glenn Research Center (GRC). This system was used to maintain the CAIB calendar and action lists and was the CM repository for the information/data provided to the CAIB from NASA and other sources.

      Located behind the GRC firewall, the PBMA System provided proven, verified security and support for the CAIB. The system's security was analyzed thoroughly and tested to ensure that the system was not vulnerable and could ensure the privacy and protection of the data it contained. Access to the CAIB's working group was limited to CAIB and CTF members and support, one System Administrator, and one Application Manager (who maintained the system and the system security), although only CAIB and CTF members authorized by the CAIB and CTF Chairpersons had access to the core data.

b. **E-mail, Calendar, and Schedules.** The JSC e-mail system, using Microsoft Outlook, was provided to the CAIB. All CAIB and support staff were given JSC e-mail addresses. Outlook provided individual calendar and schedule capabilities in addition to the PBMA System.

c. **Investigations Organizer (IO).** The IO tool is located at Ames Research Center (ARC) and was used primarily by CAIB Group 3. Located behind the ARC firewall, the system's security was analyzed thoroughly and tested to ensure that the system was not vulnerable and could ensure the privacy and protection of the data it contained.

   Access to IO was highly restricted and controlled by the CAIB Group 3 Lead. All user accounts and their passwords were reviewed and tested regularly. The physical system and its daily backup tapes were housed in a restricted-access facility. Each group or team using the IO system had its own restricted space, with specific permissions, and was not aware of the existence of other users. The developers of the system only had access to the CAIB area when requested to support a needed "bug fix" and test code updates.

d. **GroupSystems.** GroupSystems was installed in the CAIB conference room to support investigation analysis and coordination among CAIB members. GroupSystems provided:

   1) A decision-making tool
   2) Real-time agenda management
   3) Electronic brainstorming
   4) Categorizing of common group activities
   5) Online voting

   Although JSC Management had begun to use the tool, there was not a significant knowledge base at JSC on how to configure and use the system. The CAIB chose to contract out GroupSystems for better support, as well as to maintain independence from NASA.

e. **Data-Gathering and Recording Tools.** The CAIB required the capability to gather information using media such as digital photos and audio recordings during interviews. The tools used were:

   1) Micro and standard cassette recorders
   2) Micro and standard cassette transcription devices
   3) Digital cameras with additional memory sticks and personal computer (PC) upload capability

f. **Office Automation Tools.** The United Space Alliance (USA) contractor configured the Regents Park III facility and the I/T infrastructure to support the CAIB. This was done in a very short period of time and with constantly evolving requirements. The USA contractor provided:

   1) PCs
   2) Laptop computers

3) Network connectivity
4) Universal Serial Bus (USB) drives
5) Printers

The CAIB grew significantly larger than originally predicted. Although this growth was supported successfully, it did put a significant strain on the facility resources that were available. A lesson learned is to consider board and staff size in the CAP to accommodate sufficient I/T resources.

2. **I/T Architecture.** Figure 1-8 shows an architecture diagram for the I/T systems that supported the investigation.

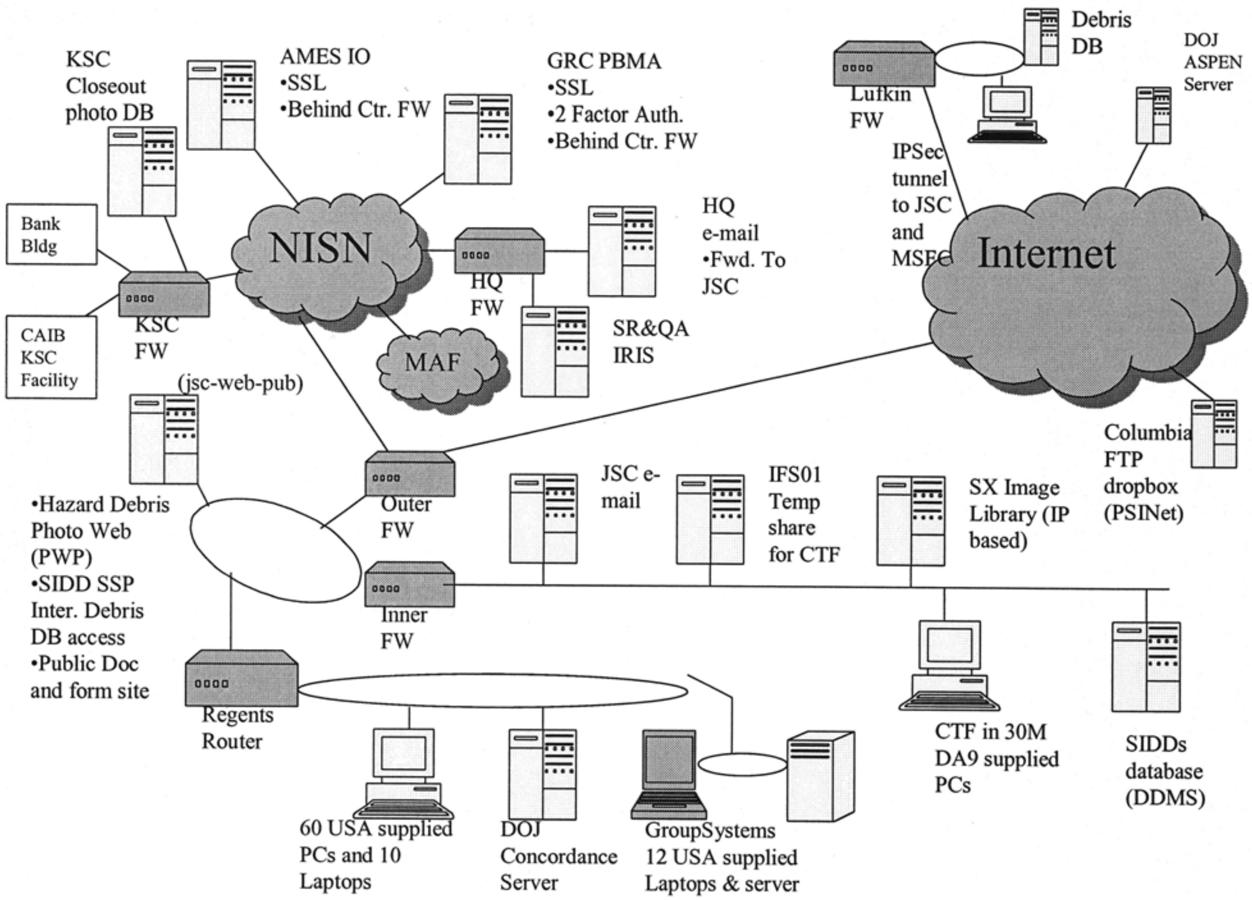

Figure 1-8. CAIB and CTF I/T Architecture

3. **I/T CM.** The following Figures 1-9, 1-10, and 1-11 show the I/T CM process for support to the CAIB. The STS-107 Columbia Accident Investigation Board (CAIB) IT Support Request form was used.

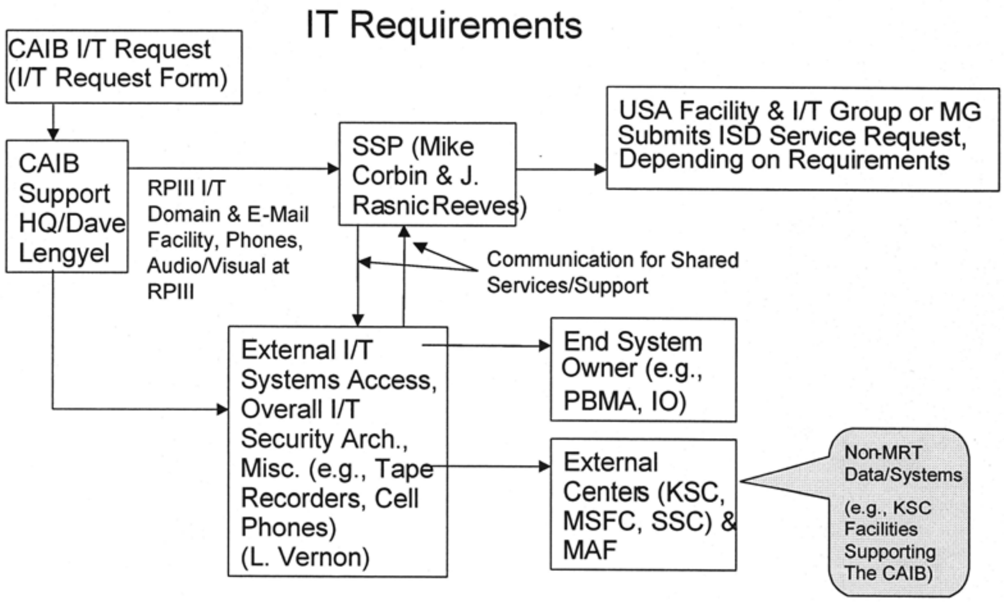

Figure 1-9. I/T CM Process

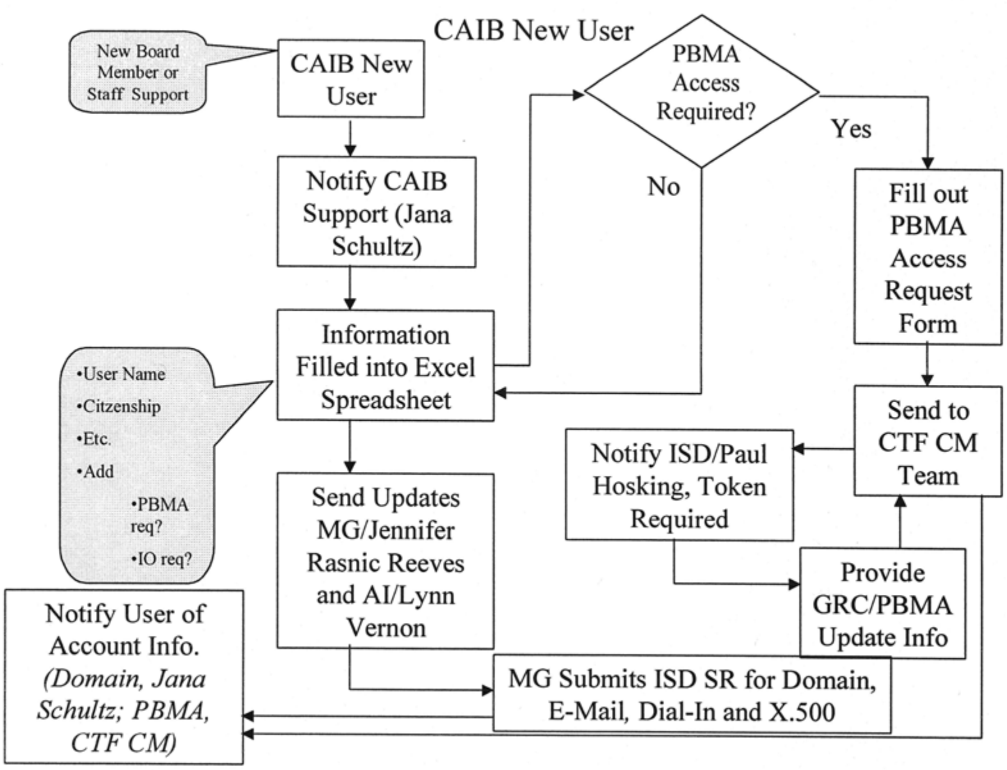

Figure 1-10. CAIB New User

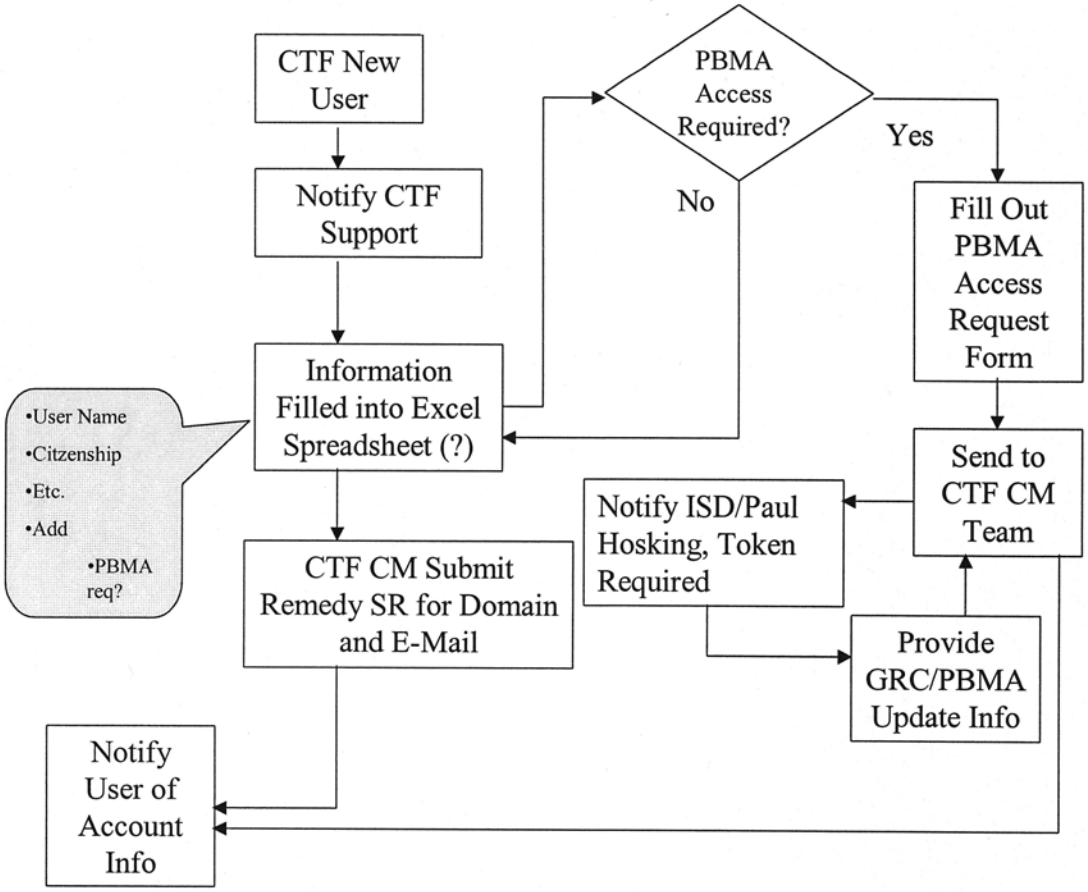

Figure 1-11. CTF New User

1.2.7 Budgets, Contracts, and Facilities

1.2.7.1 Organization and Interfaces

A Budget/Contracts/Facilities Specialist was brought in at the startup of CTF activities. It is absolutely essential that this person be experienced in the initiation of a major ad hoc organization at the Lead Center and be highly skilled in the official procurement and contract processes.

1.2.7.2 Significant Processes

1. **Facilities.** The Facilities Lead role was the most challenging at startup, when adequate facilities and support equipment had to be located and provided on very short notice. In general, this effort flowed reasonably well. It is noted that the office building designated to house the CAIB (Regents Park III) was a large meeting facility already under lease to a local JSC contractor and was not used continually; therefore, it was readily available (with last-minute modifications) to turn over for CAIB use. Had this building not been already under lease and available, the JSC operations and procurement directorates had people and processes available and could have had alternative facilities leased and outfitted within a few days. A major

consideration to note is that the number of CAIB members and staff initially was estimated at 25 and grew rapidly to over 100. (See Lessons Learned Nos. 23 and 24.)

2. **Budgets.** The CTF Budget Lead role was not a significant one, inasmuch as actual expenditures for investigation-related activities generally were incurred by other organizations. This is consistent with the philosophy that required CTF support and activities would be accomplished using existing budget and contract processes and arrangements already in place. Within 2 days of the accident, NASA HQ had established "flash" fund codes to be used for charging of civil service labor and travel and contract costs related to accident investigation. Actual funds in those fund codes were not received at the center until several weeks later, which created consternation on the part of contractors. Additionally, the methodology for allocating costs to the appropriate charge codes had to be worked out for specific contractors and situations. This is not particularly unexpected and is not a new circumstance for JSC resource managers. Budget and funding activities for the NASA civil service workforce and the support and program contractors were performed without the creation of special offices or new processes (other than the use of the new charge codes) by the center financial management offices. The CTF itself expended little or no funds outside the existing center program and support contracts, drawing on those contracts (such as Outsourcing Desktop Initiative for NASA (ODIN) for I/T; Base Operations Support Services (BOSS) Contractor for moves and logistics, etc.) for support it needed.

   The CAIB, however, suffered from lack of a previously established budget process and a designated official to manage and track its expenditures. By not having an established budget process with designated approval authorities for expenditures, some confusion and disagreement arose at times when relatively high-dollar-value requests or action items were assigned by the CAIB. By not having a budget manager appointed from the outset, the CAIB was unable to identify the estimated costs associated with its RFIs, action items, and other expenditures. It is strongly recommended that any future similar board have a Budget (or Budget and Contracting) Manager named from the outset, so that the board can have an understanding of the costs it is incurring (or causing to be incurred) by its requests and establish a reasonable budget control mechanism. (See Lessons Learned No. 3.) It is also noted that the CAIB had a support contract, awarded by Langley Research Center (LaRC) at NASA HQ direction, and cost estimates for that contract grew unexpectedly. Having a CAIB Budget Manager would have enabled the CAIB to make better predictions for and track expenditures.

3. **Contracts.** The CTF Contracts Lead role consisted of two parts:

   a. The first part was to sort out how best to acquire the support services and items needed by the CTF (and by the CAIB, to the extent that it used JSC and the CTF as a source, rather than its own support contractor). Normally, these procurement requirements were fairly small in dollar value but required a very quick turnaround. All procurement requirements were accomplished in line; i.e., by the normally assigned procurement office's following standard procurement procedures, with the CTF Contracts Lead acting as a facilitator, information or management POC, etc. Having a reasonable working knowledge of the range of contracting alternatives and the scope of the various JSC procurement organizations is, therefore, an asset to performing the Contracts Lead role. One recommendation is that the board appoint a member who is issued a Government purchasing card to make small required purchases so the board would not be forced to turn to the task force for that support.

b. The second part of the CTF Contracts Lead role, which could be called a "program procurement expert," was not anticipated originally but ended up being very helpful in working with the CTF Team Leads in facilitating development and closure of RFIs relating to all contractual and business aspects of the SSP. While most of the RFIs and briefings related, naturally, to technical aspects of the SSP, many of the later ones focused on contractual aspects, and the CTF Contracts Lead was able to play a key role in helping the CTF and CAIB counterparts define RFIs, focus requests, suggest the content of informational briefings, etc. Because of this, it is recommended that the task force Contracts Lead be an individual with background or experience in the SSP contract.

1.2.8 Center Support Reps

Organization and Interfaces

Once the CTF was fully staffed and functional, Center Support Reps generally responded promptly and effectively to CAIB and CTF requirements. The type and level of support varied widely among the centers. For instance, KSC was heavily involved with CAIB activities and visits, while SSC played a more minor role. The level of support required from Marshall Space Flight Center (MSFC) and LaRC ranged between KSC's and SSC's responsibilities. Due to the fact that the CAIB, CTF, SSP Office, and MRT and NAIT all were headquartered in Houston, Texas, JSC Reps provided a relatively low level of support because key CAIB, CTF, SSP Office, and MRT and NAIT members were able to communicate directly and had ample support in place. Additionally, NASA HQ Reps provided uniquely critical support and interfaces.

Most of the challenges faced by Center Support Reps arose from the rapid establishment of CTF organization and procedures subsequent to the Columbia mishap. Many of these challenges also resulted from CTF's imperative to interface effectively with the CAIB, which also required several weeks to establish its own form and function. While it is difficult to contemplate the possibility and virtually impossible to anticipate the exact nature of any future tragedy, the establishment of a better CAP addressing the full range of activities, as well as the issues listed below with corresponding recommendations, would greatly increase Center Support Reps' effectiveness. This new CAP should be reviewed regularly at a specified interval by reps of each organization and functional area and updated as appropriate.

Due to the rapid establishment of so many entities across NASA, initially, it was difficult to ascertain the relationship among team members, who was giving direction, and how individual centers should respond. This, in turn, occasionally hampered the ability to respond effectively and quickly. It is recommended that a strawman organization chart be included in the CAP with a description of responsibilities, delineation of communication paths, and a listing of key individuals.

At times, it was difficult to identify funding sources accurately, along with commensurate reporting responsibilities and metrics. Some of this difficulty was associated with funding paths between and within the SSP Office and individual NASA centers. Additional challenges associated with identifying "Additive Costs" as directed by HQ's Central Budget Office (CBO) continue to be problematic. "Additive Costs" include such line items as: contractor overtime expended on accident debris recovery and investigation; additional contractors retained solely for accident debris recovery and/or investigation; equipment and materials purchased specifically for accident debris recovery and/or investigation; additional travel costs incurred by contractor personnel; and civil servants' overtime expended on accident debris recovery and investigation. Although accounting for these line items was, and remains, a significant effort, determining "Additive Costs" and their impact on funding for normal center and SSP activities is even more daunting. The issue most likely will be aggravated by potentially increasing Congressional, public, and media interest in the aftermath of release of the CAIB Report. It is recommended that NASA HQ identify a centralized funding source and establish cost accounting procedures to be included as an appendix or annex to the CAP. NASA's movement to total cost accounting and implementation of Integrated Financial Management Planning (IFMP) should increase the ability to capture costs rapidly and accurately, as well as improve response to auditing agencies.

Once again, the imperative to effectively respond to CAIB requirements while the CAIB was experiencing dynamic and rapidly evolving growth and organizational change frequently produced miscues in a wide array of areas. Some of these areas included, but were not limited to: response to RFIs, visit coordination, procurement, leasing of office space and facilities, and providing pertinent feedback from CAIB communications to appropriate CTF personnel. Periodic training of key individuals listed in the CAP is recommended to ensure that the leadership cadre is familiar with past challenges and able to advise any future board quickly and effectively on how to avoid prior missteps and gear up more rapidly.

1.2.9 Administrative Support

1.2.9.1 Organization and Interfaces

A CTF Executive Administrator was appointed at startup to lead the administrative functions and provide an interface with management and administrative personnel at all NASA centers and the CAIB. CTF Administrative Officers were appointed at each NASA center to facilitate coordination of any administrative functions inherent in CTF support at that center. Every effort was made to maximize the use of existing NASA administrative and institutional processes, services, and personnel to avoid duplication of readily available resources and minimize startup issues for the Columbia accident investigation.

JSC did not choose to assign a mail code to the CTF; nevertheless, workable procedures were established to help compensate for this situation. Assignment of mail codes to both the CTF and CAIB would have eliminated several occurrences of misplaced mail and facilitated the efficient conduct of business.

Administrative support to the CTF and CAIB was provided by NASA administrative professional and secretarial personnel whenever possible. This ensured administrative support by staff already knowledgeable of Government policies and procedures, thus minimizing training issues and startup time.

The web-based volunteer signup database instituted by JSC Human Resources did not indicate the numbers of hours per week that individuals were available to support the CTF. It was not difficult to locate persons who could donate a few hours per week, but most could not obtain approval to work full time on the investigation. Designation of part-time or full-time availability, as well as supervisory approval, would have been a very useful and timesaving tool.

Due to the lack of JSC Travel Specialists who could be dedicated to full-time support of the investigation, the CAIB travel coordinators' positions were filled with knowledgeable NASA retirees, hired through the CAIB's contractor, Valador, Inc. Other staffing needs within the CTF were facilitated by coordination between the CTF Executive Administrator and JSC Human Resources, aided by the screening and selection of possible candidates using a JSC-developed web-based list of volunteers.

1.2.9.2 Significant Processes

1. **Travel.** The CTF Executive Administrator and CAIB Travel Coordinator worked extensively with the JSC Travel Office to develop the specific travel processes and procedures used to govern the processing of CAIB travel documentation, CAIB use of Government aircraft and Flex Jets, and CAIB's interaction with the JSC travel contractor (CI Travel). The CTF and CAIB each were assigned dedicated accounting codes for tracking travel costs. The CAIB travel coordination staff, as well as CAIB and CTF secretaries, provided processing of travel reservations, orders, and vouchers for their respective organizations using specifically assigned accounting codes.

2. **Ground Transportation.** CTF administrative personnel coordinated ground transportation with JSC for CAIB members in the local area, particularly in the early weeks of the investigation. Assignment of additional Government vehicles to JSC by the General Services Administration (GSA) allowed issuance of dedicated vehicles to the CAIB. CAIB members also made use of rental vehicles and continued to request JSC-provided buses when transporting large groups. CTF administrative personnel at each NASA center coordinated ground transportation, providing vans and drivers for CAIB and CTF members visiting their centers.

3. **Badging.** CTF and CAIB administrative staff coordinated the badging for access to JSC (site access), JSC Building 30 MCC (Controlled Area Access (CAA)), and Regents Park III CAIB facility. CTF administrative personnel at the field centers handled badging of CAIB and CTF visitors at the field centers.

4. **Distribution and Contact Lists.** CTF and CAIB administrative personnel created and maintained electronic (e-mail) global distribution lists and telephone contact lists for the CTF and CAIB.

5. **Recognition and Awards.** The CTF Executive Administrator coordinated the recognition and awards activity at the close of the CTF's activities, including identification of candidates, authoring award narratives, and development of appropriate award materials and presentation items.

1.2.10 PAO

1.2.10.1 PAO Role

The role of the CTF PAO Rep was crucial during the startup days. The CTF Public Affairs Officer also served as the PAO Rep to the MRT, which later transitioned duties to the NAIT. Hundreds of news media crews and dozens of broadcast media crews were clamoring for any information possible regarding the accident. Press conferences were being conducted daily. Many media inquiries were coming in regarding the investigation and the independent board that was being set up to run it. An experienced Public Affairs Officer was an absolute requirement.

At startup and for several weeks, the CAIB did not have its own Public Affairs Officer, so the NASA PAO Rep filled that role. The NASA JSC PAO, for example, organized all of the early CAIB press releases, press conferences, and public hearings. As the ability of the CAIB to operate more independently became established, a CAIB public affairs person arrived (an individual having experience with the National Transportation Safety Board (NTSB)) and the NASA PAO role transitioned from direct support to the CAIB to support primarily of the NASA working groups and the CTF. About a month into the investigation, this function transitioned to the CAIB.

The PAO Rep was responsible for interfacing with the CAIB PAO and NASA PAO agencywide (including the Columbia Accident Rapid Response Team) on all issues relative to news media and general public inquiries, while serving as the primary POC on issues relating to newsworthy events, including press conferences, interviews, or potential news-making activities associated with the investigation. (See Lessons Learned No. 28.)

The CTF PAO also provided a compilation of related news stories to CTF, CAIB, and NASA personnel, which typically provided a "weather vane" for follow-on RFIs.

1.2.10.2 Public Inquiries

Inputs from the general public deluged the NASA and CAIB resources, especially in the early days after the accident. The initial inputs and inquiries were directed to the JSC Emergency Operations Center (EOC), where the immediate focus was to take the calls and e-mails regarding the debris recovery and handling. Other inquiries also poured in: eyewitness reports; radar, photographic, and videographic imagery; and theories of what caused the accident. Other NASA centers, including the Headquarters Contingency Action Team, also received numerous inputs and inquiries. Eventually, the CAIB set up a mechanism to receive, record, and distribute public inquiries intended for CAIB members.

The CTF created a Public Inquiries function to assist the various NASA and CAIB entities in determining the proper response to each public inquiry and input. Since the CTF was a NASA organization, it was deemed appropriate that the CTF originate as many responses as possible to ensure the public of proper treatment and consideration of their input or inquiries. Volunteers from the JSC volunteer pool were recruited and assigned as many as 200+ e-mails to answer. These responses tended to be simple Thank You's, but included, as required, some level of technical response commensurate with the complexity of the public input. (See Lessons Learned No. 31.)

In general, the guidelines were: if a letter was received, respond with a letter; if an e-mail was received, respond with an e-mail. The following Table 1-1 summarizes CTF responses (e-mails and letters) to public input and inquiries.

Table 1-1. Summary of CTF Responses to the Public

Original Recipient	Media	Approximate Volume to CTF for Response
JSC EOC or other JSC Office	E-mail, fax, letter, and telephone	3,000
Other NASA centers	E-mail, fax, and letter	100
CAIB web site	E-mail, letter, telephone	110

1.3 LESSONS LEARNED AND RECOMMENDATIONS

1.3.1 Lessons Learned No. 1

Description of the Driving Event:

NASA took the initial strong lead in organizing the investigation, only to be required to allow the independent CAIB to take the lead, causing team leadership and public image concerns.

Lesson(s) Learned:

NASA should recognize from the beginning that NASA will not be the lead public investigative entity of a manned spaceflight mishap.

Recommendation(s):

The charters of the NASA Accident Investigation Team, NASA Task Force, and Independent Investigation Board should be expanded more clearly in the CAP. While it probably is unavoidable that NASA managers who were responsible for vehicle and mission operations should lead the initial phases of the investigation and analysis, these managers should be replaced by senior managers who were not directly involved in day-to-day decision processes as soon as the board is organized. Who will release which reports (including interim and final reports), video imagery, public releases, etc., to the public should be defined clearly in the CAP and then managed closely by Public Affairs Reps from both the board and NASA. NASA should identify a standing accident investigation entity on at least an annual basis. This standing team could participate, as needed, in the training simulations at least annually.

1.3.2 Lessons Learned No. 2

Description of the Driving Event:

The CTF was required to be the major integration function between the CAIB group and subgroup investigation teams.

Lesson(s) Learned:

An independent accident investigation board is composed of many diverse members and is not, at least initially, capable of integrating itself without help from NASA.

Recommendation(s):

While it may be impossible to predict the board's structural organization because of a Chairperson's personal style, as well as in which flight or ground phase the accident occurs, a future board must establish an internal integration function to ensure that all groups and teams integrate their goals, responsibilities, data requests, etc. Each group and team within the board's organization should select a leader to regulate group discussion. Each group and subgroup member should have a defined role and/or area of investigative responsibility and, where overlap occurs, document it for the entire board. Group members also should be assigned administrative functions such as press conference organization, travel planning, etc.

1.3.3 Lessons Learned No. 3

Description of the Driving Event:

There was concern over the CAIB services contractor's conflict with NASA and other Government agencies, which could provide services much cheaper. Decisions often were based on the perception of independence from NASA rather than cost efficiency or effectiveness.

Lesson(s) Learned:

In general, outside contractors should not be used automatically on the basis of "independence" if a service can be provided more effectively by the NASA center or another Government agency.

Recommendation(s):

Put enabling language in the CAP that allows full use of existing Governmental (e.g., Federal Emergency Management Agency (FEMA), NTSB, DOD, DOJ, etc.) resources to prevent rushed contracting efforts for capabilities not needed in the technical aspects of the investigation. Obtain buy-in for this from Congress. Services provided to the investigation groups will require support 24 hours per day, 7 days per week (24/7) at startup, with the appropriate organizational functions in place, as required. Where possible, if products need to be purchased (e.g., high-resolution camera, recording devices, and software system), consult with previously identified onsite experts so that (1) the users of the product can be trained or a professional can be provided and (2) the hardware and software can be used by that provider at the end of the project.

1.3.4 Lessons Learned No. 4

Description of the Driving Event:

The role of the Aerospace Safety Advisory Panel (ASAP) in accident investigation is not established clearly.

Lesson(s) Learned:

Organizations typically giving advice to NASA need to be given an appropriate role in the CAP.

Recommendation(s):

All anticipated participants' roles should be established clearly in the CAP, including the ASAP and NTSB. Have a Letter of Agreement with each agency ahead of need. Establish the role of the ASAP as a potential data source, but not an active player from an investigative standpoint.

1.3.5 Lessons Learned No. 5

Description of the Driving Event:

The role of the DOJ was not established until well into the second month of investigation.

Lesson(s) Learned:

Recognize that the DOJ can, if the Chairperson agrees, play an important role in documentation processes and archiving, unrelated to technical investigation.

Recommendation(s):

Whether or not they will be used to staff the board, bring in the DOJ Rep (identified in the CAP) early to consult on DOJ's prospective role. Then, ensure that the role is articulated clearly to the technical groups. Consider the DOJ to manage such areas as FOIA requests and archiving requirements (but not interview transcriptions, because it caused concern among interviewees that the DOJ person was from the FBI).

1.3.6 Lessons Learned No. 6

Description of the Driving Event:

The MRT/NAIT was forced to reorganize its structure to be more compatible organizationally with the CAIB.

Lesson(s) Learned:

Reorganization of the board or NASA investigation structures midstream is inherently destabilizing and should be avoided as much as possible.

Recommendation(s):

As soon as the board's organization is established firmly, usually within 10 days of startup, reorganize the NASA teams into an interface structure consistent with the board's.

1.3.7 Lessons Learned No. 7

Description of the Driving Event:

Roles and responsibilities of the CAIB and CTF support staff occasionally overlapped.

Lesson(s) Learned:

One of the board Chairperson's and task force Director's earliest duties is to establish clear areas of responsibility, for the specific event's investigation, between the board, NASA working groups, and NASA task force. The better the description of roles and responsibilities in the CAP, the better equipped the board and task force support staff will be to understand and support each other.

Recommendation(s):

Expand the CAP to be as clear as possible. Do not permit vague lines of responsibility between the board and NASA support organizations. Given this recent experience, consider using the board's Executive Secretary to enforce the rules. Although NASA teams should not be allowed to create board processes, they can assist in having certain functions implemented most efficiently without compromising the appearance of independence (e.g., by conducting press conferences and public hearings, for which NASA had the resources in place, even off site).

1.3.8 Lessons Learned No. 8

Description of the Driving Event:

NASA mishap personnel were surprised at the number of organizations that managed and participated in the field debris collection effort.

Lesson(s) Learned:

A manned spaceflight accident will involve many national, state, regional, and local emergency organizations in many phases of the investigation, especially debris recovery.

Recommendation(s):

National, state, and local (and possibly international) organizations and agencies likely to take part in the debris collection effort should be identified in the CAP, with roles, responsibilities, and POCs identified. Where possible, the interagency processes and interfaces that will be needed to organize the efforts and what the authority hierarchy will be (who is in charge over what and when) should be established ahead of time. Establish the likely kinds of equipment, personnel, and facility support needed. Do not, however, allow these plans to be so detailed or accident-specific as to be administratively burdensome to maintain.

1.3.9 Lessons Learned No. 9

Description of the Driving Event:

Board members arrived with little knowledge of Space Shuttle systems and quickly flooded the system with informational and data requests to come up to speed, slowing down the NASA technical investigation and analysis.

Lesson(s) Learned:

NASA needs to be better prepared to handle the independent investigators in terms of technical and procedural materials that will enhance the learning curve of board members.

Recommendation(s):

Incoming board members should be briefed that the board's charter function is Causal Determination, not Corrective Actions. Accordingly, NASA should take the initiative in delivering information/data that supports the board's charter, without having to be asked for every little thing (e.g., a startup kit). To assist the board startup activities, NASA should consider maintaining an updated list of personnel with investigator experience to reduce the learning curve, recognizing the need to balance experienced personnel with people who have no previous knowledge (for fresh ideas). NASA contingency planning should maintain basic documentation procedures, which always will be scrutinized in a major investigation (e.g., for maintenance, facilities, safety programs, contracts, and training). NASA should improve its archival system to provide the most rapid possible recovery and delivery of documentation that shows vehicle histories, problems, etc. Consider assigning this background function to NASA's onsite library system or to the flight program offices. Readily available data such as drawing databases and existing web sites to which board members can have immediate access should be kept up to date and be more user friendly. Create a directory or "cheat sheet" with pointers to existing databases, web sites, etc.

1.3.10 Lessons Learned No. 10

Description of the Driving Event:

Personnel requirements for the NASA task force were unknown until the accident occurred. For the CTF, the "application/volunteer process" worked well to identify potential candidates after the fact.

Lesson(s) Learned:

Basic personnel requirements for support to the task force should be identified ahead of time at each NASA center.

Recommendation(s):

Basic personnel requirements for support to the task force should be identified and updated at least annually in each center's emergency action plan. The task force Director should have immediate access to this personnel database. It is recommended that the task force Director select both technical and professional personnel who are:

1. Process-oriented
2. Self-initiators requiring little or no direction to accomplish tasks
3. "Big picture" individuals who pay attention to detail, but don't get stuck there
4. Able to commit 24/7 time and energy through the startup phase (1 to 2 months)
5. Problem solvers who may not know all the answers, but know how to get them

6. Have a "whatever-it-takes" attitude
7. Not personnel (civil service or contractor) who were involved in day-to-day Space Shuttle operations or management of the activity in progress when the accident happened

Do not delay staffing up. Part of the stress early on was based on an overwhelming amount of work and not enough people to do it. People should be identified ahead of time and known to be on call. An understanding of the numbers of people (at different phases in the task) and types of expertise required can be determined in early planning. Consider that all operational NASA centers should have a contingency response team of technical, operational, and administrative personnel with staggered assigned duties to respond to major and minor incidents. Team building and training should be part of this permanent team. NASA should provide the board with a business manager at startup.

1.3.11 Lessons Learned No. 11

Description of the Driving Event:

Organizational requirements for the NASA task force were unknown until the accident occurred.

Lesson(s) Learned:

Basic organizational support requirements for the task force should be identified ahead of time at each NASA center.

Recommendation(s):

At a minimum, assume that any accident investigation task force will require the following:

1. Technical Leads for each phase of flight and ground operations being investigated
2. Technical Leads at each NASA center involved in the investigation
3. Legal Office Lead (to address witness statements, FOIA, and export control)
4. CM Lead and support
5. I/T Lead and support
6. Safety Lead
7. Astronaut and Flight Surgeon Leads
8. Budget Support/Contracting Officer
9. Facility Coordinator
10. Administrative Lead and support
11. Public Affairs Lead

1.3.12 Lessons Learned No. 12

Description of the Driving Event:

CAIB and CTF database and documentation management requirements were not well defined or understood at decisionmaking time for the kinds of internal database tools needed. The CAIB, CTF, or PBMA System management could not anticipate or identify all of the functional and interface requirements needed to support the investigation. Inconsistent application of I/T security policies exacerbated the requirements change process. Finally, the degree and complexity of library management requirements, as driven by DOJ, did not emerge until a month after implementation of the PBMA System.

Lesson(s) Learned:

Real-time, crisis-mode systems engineering cannot capture all potential requirements. Rapid development for some enhanced functions and/or new capabilities likely will be required, and the I/T tools must be flexible enough to incorporate the changes at a minimum cost and schedule. A functional requirements analysis should be performed and clear I/T security requirements identified in advance of software tool selection.

Recommendation(s):

Establish an agency-wide hardware and software requirements baseline in the SSP CAP for mishap response and investigations, to be reviewed on a yearly basis. The requirements should include the following:

1. I/T security (e.g., single- vs. two-factor user authentication) consistent with the level of safeguarding required and the investigation's need for simplicity and rapid startup
2. Easy storage and retrieval of very large data files that are an order of magnitude larger than normal daily files (e.g., 100- to 300-megabyte files)
3. Secure remote access consistent with board travel needs
4. Strong keyword Search capability, preferably full-text Search
5. Secure hyperlink access to other data for action closures or reference material (Hyperlinks may be embedded in action closure documentation and may point to data in remote locations.)
6. Advanced capability to adapt to new functional requirements "on the fly" without requiring customized software engineering, yet easy to learn and use and compatible with other software applications
7. Proven commercial, off-the-shelf (COTS) software, when possible
8. The functional capability to store, read, and manipulate detailed three-dimensional (3-D) engineering models and drawings in use at NASA
9. Implementation of the application software on a server separate from the database server (to allow routine large-file backup to take place on the database server without slowing down the web server)
10. Adequate pretest by experienced investigators for full buy-in by the board and support staff

1.3.13 Lessons Learned No. 13

Description of the Driving Event:

While JSC Mission Operations Directorate provided an I/T support person for CTF hardware, that person was not located with the CTF. It was often difficult to contact this person and, therefore, sometimes difficult to get I/T issues resolved.

Lesson(s) Learned:

At least during startup, the resident I/T Specialists need to be in situ with the board and task force, with support available 24/7.

Recommendation(s):

These I/T Specialists should be responsible for generating all NASA Service Requests (SRs) and working PC configuration issues. Do not make the task force submit SRs for everything they need; consider blanket SRs. For contractor support, have a Level of Effort (LOE) task put in the current I/T contract to support this type of function ahead of time. This I/T Specialist should not be the person responsible for administering the action tracking and documentation management system.

1.3.14 Lessons Learned No. 14

Description of the Driving Event:

A criteria-based software tool selection process was not used. As a result, the primary CAIB and CTF users procured software tools without understanding fully the capabilities and limitations of the software. In addition, investigation personnel were required to learn new software tools (e.g., databases), adding inefficiencies in CAIB and CTF startup time. Some investigators insisted on using systems that they had used before and with which they were familiar.

Lesson(s) Learned:

A criteria-based tool selection process should occur prior to an accident and should emphasize software tools with which most people are familiar. New tools, such as databases, cause delays in initiating an investigation. Further, the use of multiple software tools implemented to satisfy specific needs causes additional startup delays and taxes the I/T support staff.

Widespread, long-term buy-in and use by the investigation and support teams of a single online software solution for CM, electronic library capability, action tracking database, and document search and retrieval may not be attainable.

Recommendation(s):

Identify required functions and incorporate an I/T tool set in an appendix or annex to the CAP. The tool set should be reviewed and updated annually, based on established criteria. This tool set should be vetted and available prior to the start of an investigation. Plan ahead to avoid tools that likely would be unfamiliar to investigation staff or tools that would be overly complex and require steep learning curves. The tools should be easy to learn and use. By vetting the I/T tool set in advance, problems with I/T availability, access control, and security issues can be avoided. Consider the following when developing the CAP appendix or annex:

1. Establish clear functional requirements for use in a criteria-based tool selection. In particular, consider early on that all investigation data will have to be archived.

2. Identify in advance software tools for data management that can be implemented and used quickly, considering software system availability, data security, firewall requirements, data capacity, and onsite and offsite access requirements.
3. When possible, implement software solutions that are proven and with which local center I/T and CM personnel are familiar to minimize coordination, expedite implementation, and reduce potential system and transmission interface issues.
4. When necessary, develop specific software system requirements so that support contractors have clear guidance and can implement requirements appropriately. Significant modification or customized software development should be avoided.
5. Separate the database administration and general task force I/T support functions (e.g., SRs, user configuration, setup, etc.).
6. Avoid multiple software solutions and multiple data repositories, because data will diverge, making CM difficult.
7. Provide a startup kit and appropriate training for the board Chairperson and members upon their arrival.
8. Discourage investigation board and support staff recommendations to implement new software solutions that have to be "force-fit" with systems defined in the CAP that have been approved, tested, and accepted by NASA's I/T administration.

1.3.15 Lessons Learned No. 15

Description of the Driving Event:

On February 1, 2003, there was no consistent NASA policy concerning I/T security requirements for web-based systems hosting ITAR and export controlled data. Each NASA center maintained its own, sometimes unclear, policy (in apparent contradiction of the "One NASA" vision), creating an inconsistent and confusing rule-set regarding application of the need for two-factor user authentication. Applications held to the higher standard of two-factor user authentication requirements resulted in administrative burdens, hardware and software complications, cost, and delay.

Lesson(s) Learned:

NASA must have in place clear and consistent I/T security policies across all NASA centers as they relate to the management of ITAR, export control, and investigation sensitive information.

Recommendation(s):

Implement clear and consistent I/T security policies across all NASA centers as they relate to the management of ITAR, export control, and investigation sensitive information.

Baseline a NASA system host-center firewall, secure socket layer encryption, and a secure but usable single-factor user authentication policy. A generic, but tailorable, I/T security plan should be in place for the hot standby system.

1.3.16 Lessons Learned No. 16

Description of the Driving Event:

The STS-107 Columbia Accident Investigation Board (CAIB) Action/Request for Information form (JSC Form 564) format took a long time to establish, causing many investigators to use obsolete and discontinued formats. A significant amount of time was spent backtracking and cataloging actions, responses, and data that were created prior to selection of a specific format.

Lesson(s) Learned:

Complex forms will take endless iterations to implement evenly across all organizations and may cause the action authorization process to break down.

Recommendation(s):

The action-request and RFI process should be established within the first days of board arrival. Upon startup, the board and task force CM Leads immediately should create an action tracking form (JSC Form 564 is recommended) that captures actions and closure response processes tailored to the accident specifics. All action requests and RFIs should be screened by task force Technical Leads to ensure that the requests are germane to the investigation and detailed enough to be interpreted accurately during initial review by NASA data providers. Forms, tracking logs, files, and databases must accommodate sensitive and proprietary (legal, medical, contractual, national security, and export control) data and generic or public data required by the board, as well as unsolicited data provided by the public, private industry, and/or political sector. Establish an authoritative Sensitive/Secure Data Lead who should determine early which data should be evaluated and marked (export controlled, sensitive, proprietary, etc.) or if all documentation should be protected with a global generic statement. Inform the board early about known sensitive data process requirements. Ensure that this authority reviews any data to be released to the public. Regularly audit the system process.

1.3.17 Lessons Learned No. 17

Description of the Driving Event:

Submissions of data in response to action requests and RFIs were in forms incompatible with I/T CM tools (e.g., web sites requiring access and Hypertext Markup Language (HTML)) and caused unnecessary administrative effort to archive.

Lesson(s) Learned:

Strive for well-known, commonly used formats in all data deliveries.

Recommendation(s):

Whenever possible, all data responses should be provided electronically, along with keywords and other search aids. Electronic signatures using Public Key Infrastructure (PKI) or other accepted electronic authorizations also would improve the process, eliminating multiple forms by date and/or authority.

1.3.18 Lessons Learned No. 18

Description of the Driving Event:

The end-to-end CM process for actions took significantly longer than expected to be established and begin running smoothly. A manual, paper-based signoff process further hampered it.

Lesson(s) Learned:

Recognize that the full end-to-end processing of requests and response cataloging will take several weeks. Ensure strong support to the CM organization because until it is working, the investigation cannot really begin.

Recommendation(s):

The startup phase for the full end-to-end CM process may take 4 to 6 weeks. Additional CM personnel probably would speed up that startup inefficiency. After the startup phase, the end-to-end CM process for a single action still may take, on average, around 3 weeks. Designate CM Specialists to analyze and tune the various CM processes and subprocesses for improvements and efficiencies. A board support person also should be designated to ensure that board members understand the CM processes so they do not create CM issues. The CM process should use electronic or manual concurrence (not both), but the one chosen must avoid multiple entries and differing status.

1.3.19 Lessons Learned No. 19

Description of the Driving Event:

Personnel and processes were not in place to assist in startup. Although heroic efforts on the part of key CM personnel minimized the number of individual problems, better planning might have improved startup efficiency.

Lesson(s) Learned:

Have a set of draft processes ready to implement for data management and CM.

Recommendation(s):

Include CM processes defined for the task force as an initial reference in the NASA CAP. Revising a previous or previously established process will be easier than starting from scratch, and the board will run more smoothly as well. Ensure that adequate CM personnel resources are available at startup.

CM personnel requirements (Equivalent Persons (EPs)) should be in accordance with these guidelines:

1. Action Trackers: at startup, four; at peak activity, eight; and for standard operations, four
2. Data Entry and Librarian/Archivist: five (The library function requires expertise in scanning and archiving. Bring in someone familiar with library science to assist with the document management function. Create a library group.)

3. For I/T support and processes: at startup, three Database Administrators, two primary and one backup (These individuals should have knowledge of existing NASA action tracking and document management databases.)
4. Meeting Coordinator/Minutes Recorder: three

1.3.20 Lessons Learned No. 20

Description of the Driving Event:

A hastily arranged contract for copiers (and support) and other devices caused contractual nightmares.

Lesson(s) Learned:

Do not wait for the board or task force to ask for standard office electronics (black-and-white and color printers and copiers, fax machines, televisions with Video Cassette Recorder (VCR)/DVD/CD, CD burners, etc.).

Recommendation(s):

Equipment and/or sources for equipment should be available for immediate installation the day work begins. If it is readily apparent that the investigation will be lengthy, add such things as refrigerators, microwaves, etc.

1.3.21 Lessons Learned No. 21

Description of the Driving Event:

Creation of new forms for the CAIB was inefficient and time consuming.

Lesson(s) Learned:

New forms (e.g., travel requests, SRs, witness statements, etc.) are difficult to develop and get approved in real time.

Recommendation(s):

The driving requirement is that forms need to be compatible with the databases or I/T systems they feed. Since NTSB has established an example set of the necessary tools for this kind of investigation, consider using and adapting their forms, or at least use them as a checklist for the types of forms that may be required.

1.3.22 Lessons Learned No. 22

Description of the Driving Event:

Personnel on the CAIB and CTF were not cleared for much of the information and data from DOD resources, creating investigation inefficiencies, lost data, and inadequate use of national assets. This was similar to what happened during the mission when classified photography was requested and then the request was rescinded, partly because it would not get to the right people.

Lesson(s) Learned:

Proper security clearances are necessary for key personnel conducting investigations.

Recommendation(s):

NASA must reevaluate its clearance requirements. It should establish a senior designee to be responsible for the annual review of these requirements. Center-level organizations, as well as the SSP Office and ISS Program Office personnel, should be included. Board members and staff designated ahead of time should be cleared to appropriate levels for the period of their designation.

1.3.23 Lessons Learned No. 23

Description of the Driving Event:

Facility space requirements were determined after the Columbia accident, creating a rushed search for office space.

Lesson(s) Learned:

A list of available facilities should be maintained by all NASA centers to facilitate board and task force startup.

Recommendation(s):

Determine ahead of time which facilities potentially are available for this type of activity and develop a checklist on how to outfit the facilities to support staff, conferencing, audio and video, etc., requirements. Such a facility could be used for contract Source Evaluation Board (SEB)/bunker-type activities as well as investigator-type operations. When deciding on facility space, consider the following:

1. An offsite facility, which may be required for the perception of independence from NASA
2. Secure facility access, with badging and escorts
3. At least two interview rooms, both to be soundproofed and windowless
4. A facility secure for both walk-in or drive-through events (The address should not be published, nor photographs of the building exterior permitted.)

1.3.24 Lessons Learned No. 24

Description of the Driving Event:

Conferencing capability was critical and worked fairly well, but could have been organized more efficiently.

Lesson(s) Learned:

A Conferencing Specialist should be included as part of the I/T startup team.

Recommendation(s):

Ensure that the conferencing facility has a sound system that can project a presenter's voice to the back of the conference room. Also ensure that an adequate tape and/or video projection and recording system exists that allows the minutes recorder to document the meeting results correctly. Create a table seating chart and table tents for board members and others at the table to help improve the accuracy of the meeting minutes. Required meeting minutes turnaround time should be 24 to 36 hours.

1.3.25 Lessons Learned No. 25

Description of the Driving Event:

Handling, destination, and formats of archival documentation were not given enough consideration in initial startup of library functions.

Lesson(s) Learned:

All data and documentation should be handled with the understanding that eventually they will be archived officially.

Recommendation(s):

Consider that all data collected and archived eventually will be sent to NARA and will be considered public information unless directed otherwise. All export controlled, sensitive, and proprietary data must be segregated and marked accordingly prior to sending of data to NARA. Establish a POC at NARA. Brief all investigators and staff on handling of proprietary and privileged information, specifically in the context of what can and cannot be put in the final report (public domain) and also in the context of archives and how they are handled. Do not permit various I/T formats to be delivered. Have the NASA Archivist recommend formats for delivering data (to include formats for photographs). Native format (not Portable Document Format (PDF)) may be best, because it allows easy cutting and pasting. If in PDF, documents must be text-searchable (i.e., Optical Character Recognition (OCR) or other). Establish an e-mail archiving policy ahead of time.

1.3.26 Lessons Learned No. 26

Description of the Driving Event:

The CAIB experimented with different methods to record interviews, creating problems with transcriptions.

Lesson(s) Learned:

Ground rules, processes, and equipment necessary for review and revision of transcribed interviews should be established prior to the first interview.

Recommendation(s):

Assign a support staff member to test recording equipment prior to need under a variety of circumstances (e.g., where interviews actually will take place) to make certain it will accomplish the task it is intended to accomplish. Room logistics should be addressed, including room size, access control, and documentation control. Electronic recorders should use analog tape (not digital), because it is easier to copy and duplicate and the files are in a standard format (unlike with some digital devices). Laptop-computer-based recording does not work.

1.3.27 Lessons Learned No. 27

Description of the Driving Event:

CAIB representatives were concerned that court reporters would add a level of potential discomfort to interviewees. The CAIB determined, against the advice of Counsel, to use tape-recorded interviews. This turned out to be the most labor-intensive and least accurate method of capturing the information shared by interviewees. Many, if not all, of the interviewees complained about the terrible quality of the transcripts and the amount of time required of them to attempt to make them more accurate.

Lesson(s) Learned:

Recognize that, while using a court reporter is the most efficient, accurate, and timely method, witness intimidation and transcript accuracy are issues for the investigation team to consider.

Recommendation(s):

Tape recording of witness interviews should be considered only as a last resort and only if there are measures put in place to provide assured quality and accuracy. Interviewees should be required to review the transcripts for accuracy, and only professional transcribers should be hired to complete the transcriptions. Witness intimidation may be outweighed by the need to rely on witness transcripts. Consider giving the interviewee the option of either a court reporter or electronic recording. Also, the names of interviewees should not be made public either before or after their interviews, and results of their interviews cannot be put in any released documentation.

1.3.28 Lessons Learned No. 28

Description of the Driving Event:

The CAIB and NASA sometimes caught each other off guard with public releases and responses to Congressional inquiries.

Lesson(s) Learned:

Roles of respective Public Affairs Reps would run smoother if their respective charters were agreed to in the CAP and the reps either were located together or in closer contact.

Recommendation(s):

The board Public Affairs Rep should be identified as early as possible, because he or she becomes the official spokesperson for the entire board. The board and NASA Public Affairs Reps should agree on who can release which kinds of information to the public and whose concurrences should be required. Violations of that agreement (leaks) should be followed back to the source and appropriate action taken to enforce the rules. Congressional inquiries sent to the board should be handled by a single interface on the board and coordinated with (not approved by) NASA. Similarly, NASA should respond to Congressional inquiries sent to NASA with board coordination. Consider locating the board and NASA Public Affairs Reps together.

1.3.29 Lessons Learned No. 29

Description of the Driving Event:

The CAIB was slow to identify witnesses for public hearings, causing extensive complications in ensuring that witness scheduling and prehearing preparations were accomplished.

Lesson(s) Learned:

The board should assign a specific individual on the board staff to propose and coordinate witnesses for the public hearings.

Recommendation(s):

The board should be instructed to assign the board's Legal Counsel or other board staff member to initiate witness identification as early as possible. The witness identification and notification process should include a Public Affairs Officer and NASA task force Legal Counsel. Information provided in a formal interview setting where an individual has been advised that his or her interview will be protected from disclosure should not be presented or implied in public hearings. The board Chairperson should establish the ground rule that formal interviewees will not be called as public witnesses at public hearings.

1.3.30 Lessons Learned No. 30

Description of the Driving Event:

A large number of unsolicited public inquiries and inputs created an unexpected workload on both administrative and technical personnel in NASA and on the CAIB.

Lesson(s) Learned:

Any major NASA accident will draw a large number of public inputs ranging from eyewitness reports, accident-cause theories, and people offering their services.

Recommendation(s):

Establish the public access and input web site early in the investigation and equip those who manage it with the knowledge of the system being investigated and the technical areas of responsibility of the NASA and board investigators. Establish a policy with regard to how to answer public inquiries, be they simple Thank You's or more complex answers to questions and referrals to investigators. Have all the entities involved in answering public inquiries coordinate their response methodology; i.e., EOC, program office, task force, board, and PAO, etc.

1.3.31 Lessons Learned No. 31

Description of the Driving Event:

The issue of whether to use digital or film cameras was never settled. Digital cameras used by the CAIB were an expensive purchase item, especially in the procurement of SmartMedia Cards, Memory Stix, etc. On the other hand, waiting for photography laboratory services was inefficient.

Lesson(s) Learned:

An initial supply of both digital and film cameras should be made available to the board immediately by the NASA center's photography laboratory or imagery department.

Recommendation(s):

To minimize film-processing delays, set up an agreement with the center photography labortory to provide and process cameras (including disposables), batteries, and film (with overnight processing). At JSC, assign overall responsibility to the JSC Imagery Working Group. Also, have a limited number of digital cameras available at startup for checkout by the board.

1.3.32 Lessons Learned No. 32

Description of the Driving Event:

At startup, investigators had to purchase their own tape recorders.

Lesson(s) Learned:

An initial supply of both digital and tape recorders should be made available to the board immediately by the NASA center's contingency operations department.

Recommendation(s):

Create a recommended investigator's toolkit to identify the tools that will be required regardless of the depth of the investigation (mandatory tools). Anticipate a board's needs.

2. HEADQUARTERS CONTINGENCY ACTION TEAM

2.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

2.1.1 Background

On February 1, 2003, Mr. William Hill was monitoring the STS-107 mission loops from the NASA Headquarters Action Center (called "Action Center") for the re-entry of STS-107. As the events leading to loss of signal from Columbia unfolded, Mr. Hill contacted the Headquarters Contingency Action Team (HCAT) members, some of whom, having heard the radio reports, had arrived already. The HCAT, chaired by the NASA Deputy Administrator, Mr. Fred Gregory, convened about noon on February 1, 2003. (The NASA Administrator and Associate Administrator for Space Flight were on travel status for the Columbia landing.) As part of their meeting, they participated in a telephone briefing to the members of the Space Shuttle Mishap Interagency Investigation Board, NASA's standing independent board. All the board members, identified in NASA's Agency Contingency Action Plan for Space Flight Operations, participated in the teleconference, as well as Admiral Harold Gehman (U.S. Navy, Retired), the board Chairperson selected by Administrator O'Keefe earlier in the day. Admiral Gehman changed the name of the board to the Columbia Accident Investigation Board (CAIB).

The full complement of HCAT members continued to meet daily through the first week following the Columbia accident, helping to set the course for providing NASA technical expertise to the CAIB, ensuring the CAIB's independence from NASA and openness with the public on details of the accident investigation. While the HCAT members continued to meet periodically, Action Center Controllers and staff coordinated all phases of the accident investigation and answered public inquiries. Organizational structure and HCAT responsibilities are described in the following sections.

2.1.2 Organization

The initial organization of the HCAT is shown in Figure 2-1. The HCAT was established to ensure coordination, consistency, and accuracy of accident-related information used internally (to keep HCAT members advised of the latest status of the investigation) and disseminated externally (to the press, public, Congress, and U.S. Administration). To accomplish this, the Action Center carried out the day-to-day HCAT activities. The Action Center was intended to be a clearing house, in the sense that the HCAT would have final review and approval authority for all information released and also would archive the version of products released (in the case of analysis information continually being updated).

In the days immediately following the accident, it was envisioned that the Mishap Investigation Team (MIT) would provide search and debris status reports to the Mishap Response Teleconference (MRT; called "Mishap Response Team"). These reports, along with the analyses being performed by the Space Shuttle Project Offices, then would be reviewed and catalogued by the HCAT prior to release (to the CRT, CAIB, Congress, and public). In fact, this worked fairly well, given the small Action Center staff.

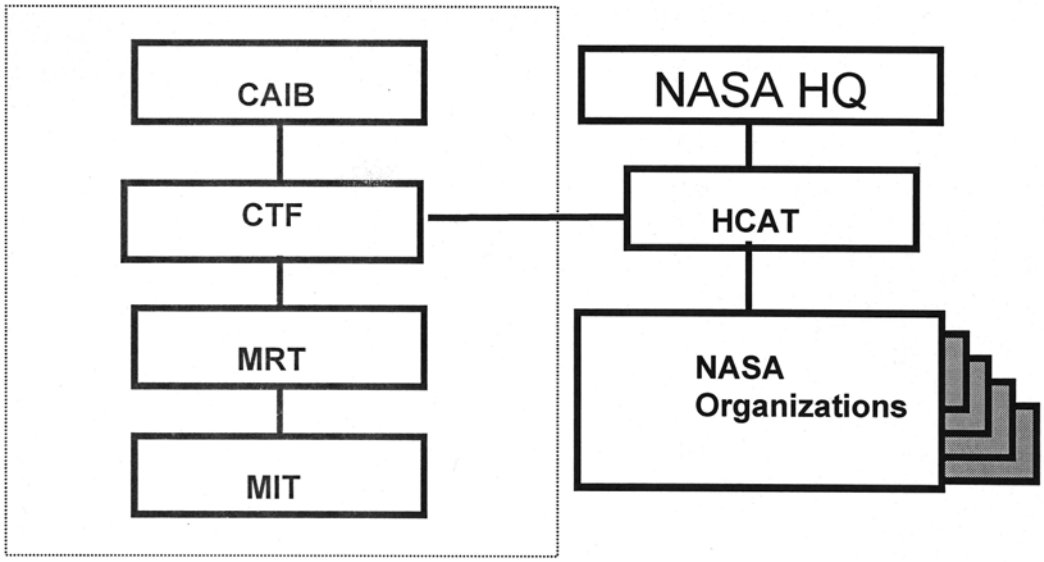

Figure 2-1. Initial Organization

As the NASA Task Force evolved into the Columbia Task Force (CTF), a staff interface, Mr. Mike Hawes (not from the Action Center), was selected as the Headquarters CTF interface. As the MRT transitioned to the NASA Accident Investigation Team (NAIT), Mr. Hawes also became the primary interface for that team. The Action Center interface with the Space Shuttle Program (SSP) was through Mr. Randall Adams in the SSP Office (JSC MA2). Mr. Hawes and Mr. Hill worked closely to ensure that information-sharing took place quickly and efficiently. (See Figure 2-2.)

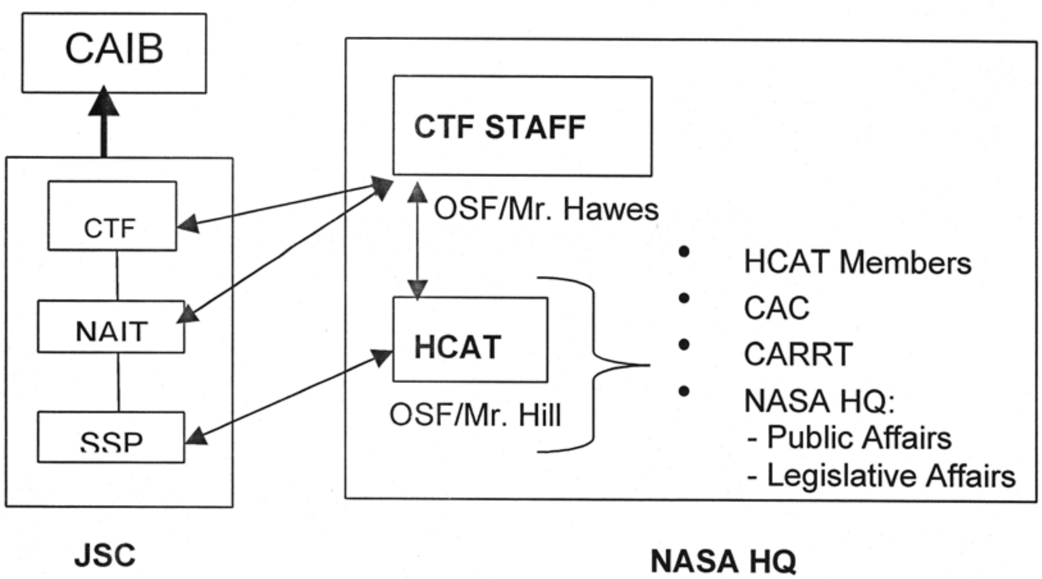

Figure 2-2. Evolved HCAT Working Relationships

The Action Center Controllers pulled together the Office of Space Flight (OSF) Space Shuttle and International Space Station staffs to support the development and coordination of a number of accident-related and SSP impact-related status reports. A representative listing of the types of products and customers is provided in Table 2-1.

Table 2-1. Action Center Customers and Products

Accident-Related Responsibilities	Product(s)	Customer(s)
Status of the investigation	Briefing charts and status reports	HCAT members, White House staff, and Congressional staff
Press inquiries	RTQs	NASA Public Affairs Offices (PAOs)
Public offers to help	Transmittal document	CAIB through the CTF
Teleconferences	Memos for record	HCAT members
Analyses reviews	Status of reviews	HCAT members
Freedom of Information Act (FOIA) requests	Review	FOIA Office and Columbia Accident Rapid Response Team (CARRT)
Columbia Action Center (CAC)	Databases	NASA HQ
CARRT	Review and coordination	CARRT member
Congressional inquiries	Testimony review and hearing preparation (questions and answers, visuals, etc.)	Congressional members and staff
Teleconferences: CTF, NAIT, SSP Program Requirements Control Board (PRCB), Orbiter Vehicle Engineering Working Group (OVE WG), etc.)	Not applicable	Participant
RTFPT	Not applicable	Team member

2.2 PROCESSES/PROCEDURES USED

The Action Center started as a 24/7 operation. By mid-February, activity on the night shift did not warrant having staff on site at night; therefore, staffing hours were reduced to an 18-hour shift from 6:00 a.m. to midnight. By early March, the hours were cut back again to, basically, a single 12-hour shift (6:00 a.m. to 6:00 p.m.), with many days exceeding the published shift schedule to handle short-notice requests.

The primary role of the Action Center remained that of being a source for credible and up-to-the-minute information on the status of the accident investigation (including, but not limited to, status of CAIB activities, re-entry timeline analyses, fault tree closeouts, etc.). The Action Center strove to have a good working knowledge of accident-related activities going on at Headquarters, as well as at the OSF field centers. After the Action Center had been formed, two new Headquarters organizations were established to help ensure NASA's continued rapid response to inquiries. The CAC was formed and chaired by the Associate Deputy Administrator for Technical Programs to create a database of official accident-related information and coordinate responses to external inquiries. It was staffed by Headquarters offices' volunteer representatives who had SSP experience and experience working with the public. Following the activation of the CARRT; also called "RRT"), the CAC was disbanded. The NASA Deputy Chief of Staff chaired the CARRT. It was staffed by the applicable NASA Deputy Associate Administrators and other invited personnel. For example, Mr. Hill was a member of the CARRT representing the Action Center. In late May, the chair duties for the CARRT transitioned to the Office of the General Counsel.

2.3 LESSONS LEARNED AND RECOMMENDATIONS

HCAT observations fall into two general categories: contingency planning and Action Center operations.

2.3.1 Contingency Planning

The HCAT functioned as well as it did due to periodic simulations and meetings with the independent board. The latter meetings, used to keep board members advised of NASA programs and procedures, proved to be a critical element in getting the CAIB up and running in a very short period of time.

2.3.2 Action Center Operations

The system of having two experienced controllers handling day-to-day activities helped ensure consistency, accuracy, and timeliness in product delivery. Although the quality of Action Center staff was very high, the continuing turnover of personnel forced some staff orientation on each shift. A dedicated support staff may have worked more efficiently. Also, in retrospect, there was no need for 24-hour operations. Since, in great part, the HCAT workload came from the press, the Action Center should have become a joint PAO and Technical Staff operation that operated on the same shift schedule. In total, these were minor items to correct and the overall operation of the Action Center fully met customer and management expectations.

3. MISHAP RESPONSE TELECONFERENCE/NASA ACCIDENT INVESTIGATION TEAM

3.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

In accordance with NSTS 07700, Volume VIII, Appendix R, Space Shuttle Program Contingency Action Plan (SSP CAP), "The Manager, Space Shuttle Program (SSP) Integration, is responsible for chairing the Mission Management Team (MMT) during on-orbit activities. If a suspected mission contingency occurs, it is the responsibility of the Manager, SSP Integration, to coordinate and chair the MRT from JSC and to inform the MMT." The SSP CAP also states, "The purpose of the teleconference is to enumerate the facts regarding the contingency, present the situation as it currently stands, and indicate the direction of the investigation activities."

Mishap Response Teleconference (MRT; called "Mishap Response Team") membership included the following:

1. Manager, SSP Integration, Johnson Space Center (JSC) (Chairperson)
2. MMT
    a. Manager, SSP Integration (Chairperson, Flight MMT)
    b. Manager, Space Shuttle Safety, Reliability, and Quality Assurance
    c. Manager, SSP Vehicle Engineering Office
    d. Manager, SSP Space Shuttle Systems Integration Office
    e. Manager, Shuttle Processing, Kennedy Space Center (KSC)
    f. Director, Flight Crew Operations
    g. Director, Mission Operations
    h. SSP Flight Manager
    i. Director, Space and Life Sciences
    j. Manager, Marshall Space Flight Center (MSFC) Projects
    k. Commander, Department of Defense Manned Space
    l. SSP Deputy Manager, Space Flight Operations Contract
    m. Manager, Extravehicular Activity (EVA) Project
3. Mishap Investigation Team (MIT) Chairperson
4. Early Sightings Assessment Team (ESAT) Chairperson
5. Manager, Emergency Operations Center (EOC)
6. Data and Record Handling Team Chairperson
7. External Tank Working Group (ET WG) Chairperson
8. Space Shuttle Main Engine Working Group (SSME WG) Chairperson
9. Reusable Solid Rocket Motor Working Group (RSRM) Chairperson
10. Solid Rocket Booster Working Group (SRB WG) Chairperson
11. Systems Integration Working Group (SI WG) Chairperson
12. Orbiter Vehicle Engineering Working Group (OVE WG) Chairperson
13. Public Affairs Office representative

The NASA Accident Investigation Team (NAIT) was established by authority of the NASA Administrator on March 6, 2003. NAIT membership included all of the above, with the exception of changing the Chairperson to three NASA senior agency officials (Deputy Director, JSC; Deputy Director, KSC; and Director, JSC Engineering) to support the Columbia Accident Investigation Board (CAIB) structure. The Manager, SSP Integration, was appointed as an advisor to the NAIT.

3.2 PROCESSES/PROCEDURES USED

3.2.1 Declaration of Contingency, February 1, 2003

STS-107 was scheduled to land at KSC on February 1, 2003, at 14:16 Greenwich Mean Time (GMT). The seven-member crew successfully had completed a 16-day research mission. Telemetry from the orbiter was nominal until approximately 13:50 GMT, when flight controllers noted off-nominal indications in several orbiter systems. All communications with Columbia were lost just prior to breakup over Texas at 14:00 GMT. At approximately 14:15 GMT, the Entry Flight Director declared a contingency.

Upon declaration of the contingency, the Manager, SSP Integration (MRT Chairperson), called the MIT Chairperson to inform him of the contingency and requested that he notify his team that the MRT would convene at 9:30 a.m. Central Standard Time (CST). The MRT Chairperson then contacted SSP personnel resident in the Mission Control Center (MCC) Customer Support Room and requested that all members of the MMT be called and informed of the accident and told to convene at JSC. All members were contacted and present either in person or via teleconference, and a joint MIT and MRT meeting was conducted at 9:30 a.m. CST on February 1, 2003. Immediately upon declaration of the contingency in accordance with the SSP CAP, all data potentially related to the accident were impounded. The MIT was deployed on February 1, 2003, to begin recovery efforts, and the SSP Manager activated several working groups to begin the accident investigation. SSP personnel were identified as points-of-contact (POCs) to coordinate actions and responses with external and internal organizations. Specifically, POCs were identified to interface with the Headquarters Contingency Action Team (HCAT), EOC, and payload customers. The MRT command center was housed in the Customer Support Room, and activities were managed via the Customer Support Room Desk. SSP personnel provided technical and administrative support to the MRT and MIT, as needed.

3.2.2 CAIB Introduced, February 2, 2003

By authority of the NASA Administrator, the CAIB was activated on February 1, 2003, and Admiral Harold Gehman was appointed Chairperson. Notification was given to the MRT on February 2, 2003.

3.2.3 MRT Organization and Initial Processes Defined, February 3, 2003

An MRT organizational chart that included interfaces with the CAIB and Columbia Task Force (CTF) (configuration management function and interface between the CAIB and MRT) was issued. Several processes and procedures not identified in the SSP CAP were developed early on for the following:

1. Meeting and teleconference requirements
2. Release of impounded hardware and data
3. Freedom of Information Act (FOIA) guidance
4. External interfaces guidance
5. Data requests from NASA Headquarters

6. Press interview request approval

A document was drafted to capture all newly developed processes and procedures.

The teleconference was set up via a meet-me telephone line and recorded by the conference coordinator. The meetings were conducted according to a standard agenda, actions were tracked, and minutes were documented. All presentation charts were coordinated via the Customer Support Room Desk. Release of impounded hardware and data was conducted using the following processes and forms:

1. Hardware Release Request (HRR)
2. Test Approval Request (TAR)
3. Payload Data Release Request (PDRR)

The HRR and TAR forms required concurrence by the MIT and MRT/NAIT Chairpersons and approval by the CAIB Chairperson. The initiator presented the requests, with rationale, to the MRT/NAIT for concurrence prior to submittal to the CAIB for final approval.

3.2.4 MRT Transitioned to SSP Standard Meeting Infrastructure, February 10, 2003

The MRT command center was transitioned from the MCC to JSC, Building 1, to use standard SSP Management Integration personnel and processes. The same processes and procedures identified above were used; however, because of suspected breaches in security, the teleconferences were conducted via dial-out according to a controlled telephone list, versus the meet-me line that had been used for the first several teleconferences. NASA Headquarters Office of General Counsel also requested that all data presented to the MRT be identified as preliminary and not be forwarded to any organization or personnel outside the MRT/NAIT. NASA Headquarters provided updated FOIA guidance.

3.2.5 CAIB Request for Information (RFI) Process, February 13, 2003

The CTF and MRT representatives met on February 13, 2003, to establish the process for coordinating CAIB data requests. The requests were submitted via an RFI form that was screened by the MRT Chairperson to determine if the action should be tracked by the MRT (if STS-107 accident related) or by the CTF (if generic in nature and/or non-STS-107 accident related). Note: This philosophy changed later such that only RFIs requesting data from one of the working groups were tracked by the MRT. The MRT Chairperson concurred on all of the RFIs to authorize implementation of the request. The MRT distributed the RFIs electronically and tracked closure via a database. The process and procedures were briefed to the MRT as it evolved, starting on February 15, 2003, and a formal presentation was provided to the MRT February 20, 2003. A status of the closure of RFIs was presented at an MRT meeting once a week.

3.2.6 Web Site on Line, February 18, 2003

The SSP Management Integration Office released the MRT web site, accessible via the SSP web site. The site housed the MRT organizational chart, policies, procedures, and processes, as well as minutes of meetings and status of MRT actions, HRRs, and

TARs. As processes and procedures were developed or revised, they were made available to the MRT via the web site.

3.2.7 Transition to NAIT, March 24, 2003

By direction of the NASA Administrator, the MRT was reorganized to support the CAIB structure and became the NAIT. Three senior agency officials were named to act as cochairpersons. All policies, processes, and procedures developed for the MRT were transitioned for use by the NAIT, including the administrative functions. When the frequency of the NAIT meetings decreased, some of the processes were modified, such as the process for HRRs and TARs. The requests were reviewed at the OVE WG when waiting for a scheduled NAIT meeting would have impacted work. Once concurrence was received by the OVE WG, however, one of the NAIT Chairpersons would concur "outside the board" prior to submittal of the form to the CAIB for final approval. The NAIT met formally until June 4, 2003. Due to the decrease in CAIB activity, the NAIT members were advised that meetings would be called, if warranted; otherwise, actions would be conducted in an outside-the-board manner.

3.3 LESSONS LEARNED AND RECOMMENDATIONS

3.3.1 Lessons Learned

3.3.1.1 Lessons Learned No. 1

The SSP CAP outlines the organizational structure, processes, and procedures for the MRT. While the document is an excellent resource, it should be updated to incorporate the lessons learned during the STS-107 accident investigation.

Recommendation:

The SSP should update the SSP CAP. The following are items for consideration:

1. Review the SSP CAP for applicability to all mission phases; it currently focuses on a contingency during ascent.
2. Identify SSP Management Integration Office as a standard member of the MRT.
3. Add the EOC function to the SSP CAP, as appropriate. A specific requirement is to add a blank EOC call form, with an accompanying paragraph, explaining why the various data are requested from the caller.
4. Identify requirements for handling sensitive material.
5. Add the Customer Support Room Desk (SSP management command center) function.
6. Specify that all charts presented to the MRT should be labeled as preliminary in nature and should not be forwarded beyond the approved distribution without consent of the MRT.
7. Document in the SSP CAP the requirement at remote MIT command centers for a liaison between the MIT Chairperson and MRT administrative support personnel. Liaison function should be SSP personnel knowledgeable of the organization and management POCs.

8. Reference the MRT web site for standard policies, processes, procedures, and forms (RFIs, HRRs, TARs, and PDRRs).
9. Review the suggested list of working groups and determine if it should be updated.
10. Add a suggested standard agenda and define the requirement for transcripts and minutes of the meetings for the MRT.

3.3.1.2 Lessons Learned No. 2

While all members were contacted within 1 hour (in accordance with the SSP CAP), several members were not immediately reachable at the contact number provided. Not all members provided a cell phone as a contact number. The use of electronic pagers did not allow confirmation that the member received the message and would be available.

Recommendation:

All members should be reachable immediately during the mission at all times. NASA should provide cell phones for all MMT/MIT members.

3.3.1.3 Lessons Learned No. 3

Launch contingency simulations are required every 18 months according to the SSP CAP. Prelaunch MMT simulations also are conducted periodically. Currently, there is no requirement for on-orbit or entry contingency simulations.

Recommendation:

Simulate contingency operations for all mission phases: ascent, on orbit, and entry.

3.3.1.4 Lessons Learned No. 4

Providing information to the MRT/NAIT initially was conducted only by e-mail, which resulted in several limitations in capability, was very labor intensive, and was vulnerable to security breaches. The development of the MRT/NAIT web site allowed policies, processes, and procedures to be posted in a central location for accessibility by all users.

Recommendation:

Develop a permanent web site for contingency operations and provide the address to NASA Office of Space Flight (OSF), MMT/MIT members, center Directors, and other key personnel. The web site should contain the following:

1. Standard policies, processes, and procedures (including forms)
2. Key POCs and titles, with office telephone numbers
3. Standard agenda and format for tracking logs and minutes
4. Presentation format and restrictions (if applicable)

3.3.1.5 Lessons Learned No. 5

The CAPs for all NASA centers define the requirement to impound data in support of an accident investigation; however, several of the STS-107 payload customers were resident at non-NASA centers (e.g., European Space Agency personnel resident at a university) and were unclear about the impoundment requirement. To facilitate impoundment of all data related to the accident, the payload customers were given guidance and they complied with the requirement.

Recommendation:

The SSP should provide a policy that defines the impoundment requirement to all payload customers who provide mission support at non-NASA centers.

3.3.1.6 Lessons Learned No. 6

The initial MRT and MIT teleconferences were conducted via dial-in or meet-me numbers to expedite the setup of the teleconference. After the initial teleconferences, the numbers continued to be used as a matter of convenience. Concerns arose, however, that use of the dial-in numbers was not secure, and the MRT did not have conclusive knowledge of who was participating in the teleconferences. Records were obtained from the company that set up the teleconferences to determine who was participating, but the records were inadequate. It was clear that use of dial-in numbers was not a secure method to set up the teleconferences and, thus, was discontinued.

Recommendation:

Document that dial-in numbers are to be used only as necessary. Establish a meet-me number prior to each mission and distribute to MMT and MIT members, and others as directed by SSP Management, for initial meetings in support of contingency operations. As soon as practical, conduct all teleconferences using the standard secure method of dial-out by the conference coordinator so that participants are traceable.

3.3.1.7 Lessons Learned No. 7

As a result of SSP personnel (at all centers) receiving numerous requests from several organizations at NASA Headquarters, a process was developed to coordinate all requests and responses between the SSP and Headquarters. An HCAT POC (and backup) and MRT POC (and backup) were identified. All requests for data in support of Congressional inquiries and press and/or investigation material were coordinated via the POCs.

Recommendation:

Immediately establish an interface and assign POCs between Headquarters and the MRT for action coordination. Implement the following:

1. Define authority and responsibilities.
2. Define and communicate processes and procedures.
3. Assign the MRT POC the responsibility of screening impounded and/or sensitive data. This removes the burden from the actionees so that they can focus on completing the action, not determining whether the data should be released.
4. Enforce the process at all management levels.
5. Require who, why, priority, and due date for each action request.
6. Identify SSP internal organizational POCs.
7. Maintain a tracking log.

3.3.2 Observations

3.3.2.1 Observation No. 1

The SSP CAP was instrumental in guiding the SSP investigation of the Columbia accident. It was noted that there is no CAP for joint International Space Station (ISS) Program/SSP operations.

Recommendation:

The ISS Program and SSP should develop a CAP to address contingency operations during the joint phase of Space Shuttle/ISS missions.

3.3.2.2 Observation No. 2

The status of CAIB actions routinely was provided at the MRT/NAIT meetings. The visibility that the actions received at the meeting was an incentive for actionees to meet due dates.

Recommendation:

Implement routine statusing of actions levied by an investigation board on the MRT/NAIT.

3.3.2.3 Observation No. 3

The MRT command center was housed in the Customer Support Room during the initial phase of the investigation, because SSP management operates from this facility during real-time operations. SSP personnel resident in the Customer Support Room are responsible for implementing callup of the MIT/MRT. Due to the enormity of the administrative tasks associated with coordinating the MRT, however, the use of standard administrative infrastructure is required.

Recommendation:

Transition the administrative and programmatic tasks of the MRT to standard SSP infrastructure as soon as practical.

3.3.2.4 Observation No. 4

Guidance concerning the FOIA policy was discussed at several MRT meetings, the policy was issued and revised, and finally the MRT was told to use NASA's standard FOIA policy and processes.

Recommendation:

NASA Headquarters OSF should document in the CAP the FOIA policy and processes to be used.

4. MISHAP INVESTIGATION TEAM

4.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

In accordance with NSTS 07700, Volume VIII, Appendix R, Space Shuttle Program Contingency Action Plan (SSP CAP), outlining Mishap Investigation Team (MIT) membership, processes, and procedures, the Space Shuttle Program (SSP) Office activated the MIT on February 1, 2003. The MIT is composed of 10 members from various disciplines. The specific MIT membership is published via memo 6 weeks before each flight. The MIT assumes the responsibility for debris recovery, protection, and impoundment. Once the accident investigation board is activated, the board may choose to alter the debris collection responsibilities, as they deem necessary. In the case of the Columbia accident, the Columbia Accident Investigation Board (CAIB) chose to keep the MIT in the debris recovery role.

The initial organizational structure, responsibilities, and procedures for the MIT are specified in the SSP CAP. There was no "Columbia Recovery Organizational Chart" beyond that shown in the SSP CAP. The SSP CAP clearly says that the Chairperson of the MIT is responsible for debris recovery. All activities, philosophy, and decisions regarding debris recovery were coordinated through the MIT Chairperson.

4.1.1 Deployment

The MIT initially deployed to Barksdale Air Force Base (AFB), Louisiana. Barksdale AFB was chosen because it provided the facilities to handle large aircraft, had capabilities to accommodate a large contingent of people, had the appropriate facilities to accommodate human resources processing and transportation, and provided the security needed. As distribution of the Columbia debris became better understood, additional recovery centers were established in Lufkin, Texas, and at Carswell Field in Fort Worth, Texas.

The Carswell Field MIT subgroup was responsible for responding to debris reports between Corsicana, Texas, and areas west of Fort Worth, Texas. Based on recovered debris items, small self-initiated searches were performed by the Carswell Field operation, but none to the extent performed by the Forest Service between Corsicana and the Toledo Bend Reservoir. The Lufkin MIT subgroup worked debris recovery in the area from Corsicana, Texas, to Fort Polk, Louisiana. They identified the initial search corridor and coordinated with the Federal Emergency Management Agency (FEMA) and Forest Service for resources to search these areas. The SSP CAP did not take into consideration the magnitude of the accident and the number of state, Federal, and local agencies involved. All MIT search activity was coordinated with daily teleconferences involving all locations. After about 3 weeks, the Carswell Field activity was closed and all MIT activity moved to the Lufkin Disaster Field Office (DFO). A daily coordination meeting between NASA, FEMA, and other agencies provided the interagency coordination necessary to ensure a unified understanding of progress and issues. The daily MIT meeting addressed search activities, search philosophy, progress, and plans as they affected ground, air, water, and strategic search activities.

There were a great many people across NASA who volunteered to assist. NASA centers developed a list of volunteers, and coordination for rotating in of new people was worked through points-of-contact (POCs) at the task level. In most cases, there was a time overlap between volunteers to ensure that the task and philosophy were understood before the new volunteer was left alone. In some instances, there was a rotation between a fixed set of people, thus requiring minimal overlap. Those volunteering in the search areas received briefings and directions in the same manner as the Forest Service searchers. The Forest Service rotated crews on a 14-, 21-, or 30-day basis, which required a continuous indoctrination program for the new searchers.

The declaration of Texas and Louisiana as Federal disaster areas brought FEMA and all their resources into the recovery picture. For the first 3 weeks, there were two parallel recovery activities in place. One activity was for the recovery of human remains and the second for recovery of Columbia debris. NASA had the lead responsibility for each activity, with supporting roles held by other state, Federal, and local agencies. NASA, FEMA, the Environmental Protection Agency (EPA), and the Forest Service were the primary players in debris recovery activity. NASA identified the areas to be searched. The Forest Service provided the people and equipment to search the identified areas. EPA provided experts in decontamination of the debris; tagged, photographed, and identified locations of debris; and picked up the debris for transport. FEMA provided the money for most of the activity and, of equal importance, had the authority and agreements to activate assistance from Federal and state agencies.

4.1.2 Debris Distribution

The distribution of Space Shuttle debris greatly influenced the resources and techniques applied to recovery. Video from a variety of sources, as well as telemetry, indicated that the Space Shuttle vehicle was losing pieces significantly west of Texas. It appeared that the vehicle was dropping debris even west of the California coast. Using video, radar analysis, telemetry analysis, and public reports, the debris trail was identified. The greatest density of debris began south of Fort Worth, Texas, and ended in Fort Polk, Louisiana. Although there is significant evidence that debris fell in Nevada, Utah, and New Mexico, the most westerly piece found to date was located in Littlefield, Texas. The heaviest concentration of debris was along a line from Corsicana, Texas, to Fort Polk, Louisiana. As expected, heavier pieces, with their higher ballistic coefficients, were found toward the end of the debris trail, closer to Louisiana, while light objects were found more toward the beginning, in north central and west Texas.

There were 1,459 debris reports from 40 states other than Texas and Louisiana. Teams representing the MIT addressed all reports. There also were reports from Canada, Jamaica, and the Bahamas. No Space Shuttle debris has been confirmed outside of Texas and Louisiana.

4.2 PROCESSES/PROCEDURES USED

The processes and procedures for debris recovery were different, depending on the debris location. Searches in the states of Louisiana and Texas were handled differently than in the rest of the United States. Texas had the largest concentrations of debris well identified and spread along a well-defined line. Louisiana had several large engine pieces and a small scattering of smaller items in several parishes. Along the Columbia flight path from Texas to the California coast, there was radar and visual evidence of debris leaving the Space Shuttle vehicle and perhaps hitting the ground. Radar, video analysis, and trajectory analysis were used to define high-probability areas for ground search in New Mexico, Utah, and Nevada. Working through FEMA, local resources were activated to search these high-probability areas for debris. Notices were published and broadcast asking that any debris or sighting information be forwarded to the NASA toll-free number. Public notices via flyers and news media pieces were used several times during the recovery process.

The debris in Texas and Louisiana was along a well-defined path. Radar analysis and call-in reports provided sufficient information to identify a search area. The area was centered on a line drawn through 100 large pieces, which were recovered early in the search. A +/-2-mile-wide corridor was defined around the centerline and was felt to contain a 1-sigma distribution of the debris. A +/-5-mile-wide corridor was defined around the centerline and was felt to contain a 2-sigma debris distribution.

At the Lufkin DFO, search responsibilities were divided into the following five areas of responsibility, each with a designated leader:

1. All states outside Texas and Louisiana
2. Ground search within Texas and Louisiana
3. Air search within Texas and Louisiana
4. Water search
5. Strategic search activities

The area leader coordinated search activities in each of the identified areas. Overall coordination occurred at daily planning and coordination meetings with the MIT.

4.2.1 Search

The search efforts required a variety of assets and techniques. In Texas alone, debris was spread over an area exceeding 2,000 square miles. Such a large area required a combination of ground and airborne search techniques. The heaviest debris corridor between Corsicana and Fort Polk, Texas, was the initial focus of attention. Most of the ground search was conducted by firefighters from the Forest Service, assisted by representatives from EPA and NASA. For the ground search, a Probability of Detection (POD) of 75 percent for a 6- by 6-inch object was selected. The 75-percent POD determined the search techniques to be used by the field searchers.

For the air search, the POD was 50 percent for a 12- by 12-inch piece of debris. More than 3,000 Forest Service firefighters were used in search activities. These searchers were staged out of four Forest Service managed camps located in Corsicana, Palestine, Nacogdoches, and Hemphill, Texas. The area along the corridor from Granbury, Texas, to Fort Polk, Louisiana, was divided into 2- by 2-nautical-mile grids. Grids were assigned to the Forest Service for search by the firefighters. More than 35 helicopters and 7 fixed-wing aircraft were assigned to search areas outside of the center 4-mile-wide corridor.

If the initial breakup occurred over the Pacific Ocean, it is quite likely that some Columbia debris fell into the ocean. Oceanographic data indicated three counties along the California coast that had the highest probability of debris washing up on the beach. An organized search of the beach area was conducted using local law enforcement and volunteer organizations. No debris was found along the California coast.

A number of remote sensing resources were used and considered during the search process. Many of these were from agencies volunteering their assets as potentially useful in the search. Everything was considered and evaluated by the MIT. Considerable remote sensing skill was available to the MIT to help identify potential devices and platforms and to assist in evaluation of the results. In several instances, sensors were assigned areas as test cases to ascertain their capability to identify debris. Some of these were optical sensors, and several were electronic sensors employing various techniques to identify debris.

4.2.2 Debris Handling

Debris from Columbia was decontaminated, if necessary, and then tagged with information concerning its location. Pictures were taken of the debris in its found location. Collection centers were opened at Corsicana, Palestine, Nacogdoches, and Hemphill, Texas. All collection sites shipped debris to Barksdale AFB, Louisiana. Barksdale AFB was the location of most debris packaging and shipping to Kennedy Space Center (KSC). Debris going to Barksdale AFB was entered into the database, photographed, packaged for protection, and shipped to the KSC Shuttle Landing Facility (SLF) hangar.

Twenty to thirty items were identified as "hot items" and shipped to other locations. These, too, were entered into the database. Examples of these items are general-purpose computers, film, cameras, Miniature Airborne GPS Receiver (MAGER; GPS = Global Positioning System), Orbiter Experiments (OEX) recorder, and Orbiter Positioning System (OPS) recorders. All these items had information that could potentially impact the search and investigation. In some cases, battery lifetimes could limit access to potentially important information.

4.3 LESSONS LEARNED AND RECOMMENDATIONS

4.3.1 Observations

1. It is important to get a good database as early as possible. A good database administrator should be named immediately. Database functionality, hosting, changes, etc., should be coordinated through a single point. NASA should consider developing a database that could serve as a starting point for similar activities.

2. Significant administrative support should be identified early in the process. Large amounts of data need to be organized and accessed throughout the field activity. There is also the need for records retention and archiving. Planning for records retention and archival needs to start early.

3. Leaving decision-making at the field level made for a more efficient operation. This activity was a perfect example of letting the field operations be managed in the field.

4. The mapping capability provided by the Geographic Information System (GIS) was a significant asset. It provided a good communications tool between the field and management and between the DFO and remote locations.

5. Having dual NASA representatives was confusing to many people, including the other agencies working with us.
6. Having the leadership operate from a central location significantly helps inter-agency and team communications.
7. FEMA provided access to significant human resources. The declaration of a disaster by the President made this possible. NASA should consider how to accomplish debris retrieval if a disaster were not declared or if a similar accident were to happen outside the United States.
8. Remote sensing provided little assistance in identifying debris locations.
9. Communications support is a must. Portable and land-line telephones and computers are absolute requirements. These resources were provided by FEMA. NASA should have a plan to provide similar capabilities in cases where FEMA is not involved.
10. Mobility of management is important for a search area of this magnitude. Face-to-face meeting with leaders at the remote locations is very important. FEMA provided fixed-wing aircraft and helicopter support for management visits to remote locations.
11. The contingency plans published by SSP and NASA centers worked very well. They provided directions for the initial notification and coordination. The program has conducted contingency simulations at least every 18 months. These simulations play a key part in making the process familiar to the players. As is often the case, the Columbia accident was not exactly the scenario simulated or expected. The Columbia scenario did not impact the contingency declaration, MIT activation, or management process. The impoundment of evidence and key documentation began immediately, and there were few problems throughout the entire search process. The SSP CAP did not take into consideration the disaster declaration made by the President. This made significant additional resources available to the MIT, which were easily incorporated into the recovery plan and were important in the success of the effort.

4.3.2 Recommendation

Planning for a major Space Shuttle event on foreign soil needs attention. The fact that NASA and the National Transportation Safety Board (NTSB) previously had coordinated responsibilities was significant in determining lines of responsibility. Similar coordination needs to take place with host countries of Transoceanic Abort Landing (TAL) sites.

5. RECONSTRUCTION TEAM

5.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

5.1.1 Accident Background

On February 1, 2003, at approximately 0800 Central Standard Time (CST), the Orbiter Columbia broke up over east central Texas during re-entry into the Earth's atmosphere. The orbiter was returning to Kennedy Space Center (KSC) at the completion of Mission STS-107. At the time of breakup, the orbiter was traveling at about Mach 18 at an altitude of approximately 208,000 feet. The debris field was scattered over an area of eastern Texas and western Louisiana and measured approximately 645 miles long by 10 miles wide. The debris was recovered and shipped to KSC for examination in the Columbia hangar. It is estimated that approximately 38 percent (composed of over 83,900 individual items) of the orbiter, by weight, has been recovered to date.

5.1.2 Reconstruction and Purpose

Aircraft accident investigators typically perform a partial or total vehicle reconstruction to trace damage patterns and failure clues to aid in determining the accident's probable cause. This is especially useful when the recorded vehicle data does not provide significant insight into the causes and contributing factors or when an in-flight structural breakup occurs, scattering parts over a large geographical area.

Reconstruction may take on many forms, but essentially involves placing the recovered debris into its original position prior to the occurrence of the structural failure. In some cases, the reconstruction is performed in a two-dimensional (2-D) representation, and in other cases, the debris is reconstructed in a three-dimensional (3-D) representation in custom-designed fixtures.

In virtually all aircraft accident investigations, a 2-D layout of at least a section of the vehicle is performed, and only when enough information cannot be obtained through this method is a more costly 3-D reconstruction performed. Thus, the 2-D reconstruction planning must begin before the debris arrives at the reconstruction site. Planning for the 3-D reconstruction can be done months or even years later, if required.

An essential decision to make before performing a 2-D layout is how best to use the available reconstruction space and intelligently represent a 3-D vehicle on a 2-D layout grid. Usually, the initial accident reports and preliminary data dictate the reconstruction scheme.

In most aircraft reconstructions, the fuselage layout is split at either the upper or lower centerline, then opened up to show either the internal or external surface. The 2-D layout grid has an expansion factor, usually set at 10 percent to 25 percent, allowing sufficient room for investigators to examine each piece of debris from all angles.

Damage patterns can be discerned as the reconstruction grid is populated. It becomes possible to study the damage's continuity or lack of continuity on associated pieces. As an example, if a wrinkle in one skin panel section continues across a break or tear, it is possible to conclude that the forces necessary to cause the wrinkle were applied prior to the break or tear. The continuity of smears and score marks across breaks provides additional evidence and aids in differentiating between inflight, postbreakup, and ground impact damage. Overall, relating the damage between individual debris pieces determines failure patterns, including directional indications of force application (for example, the manner and direction in which rivets, screws, and bolts were sheared).

Often, differences between adjacent or symmetric (i.e., left vs. right) debris pieces provide valuable clues that lead to determining the initiating event. All significant debris pieces are documented, and the most relevant are analyzed further by various sampling and forensic techniques. Because the failure modes and signatures of typical aerospace construction materials are known, an accurate assessment of the overall failure scenario can be made based upon the debris and material assessment results.

5.1.3 Organizational Structure

The NASA Deputy Administrator gave direction to perform the reconstruction at KSC. This was the triggering decision for the creation of the Reconstruction Team and activation of the Reusable Launch Vehicle (RLV) Hangar at the Shuttle Landing Facility (SLF) as the Columbia reconstruction site. Based on plans contained in SFOC-GO0014, KSC, Space Shuttle Program, Salvage Operations Plan, the Reconstruction Team structure was adapted for the Columbia contingency and debris reconstruction effort. NASA maintained primary responsibility for the Columbia reconstruction effort, with support from United Space Alliance (USA), Boeing, the National Transportation Safety Board (NTSB), and various other support contractors. An organization chart is shown in Figure 5-1.

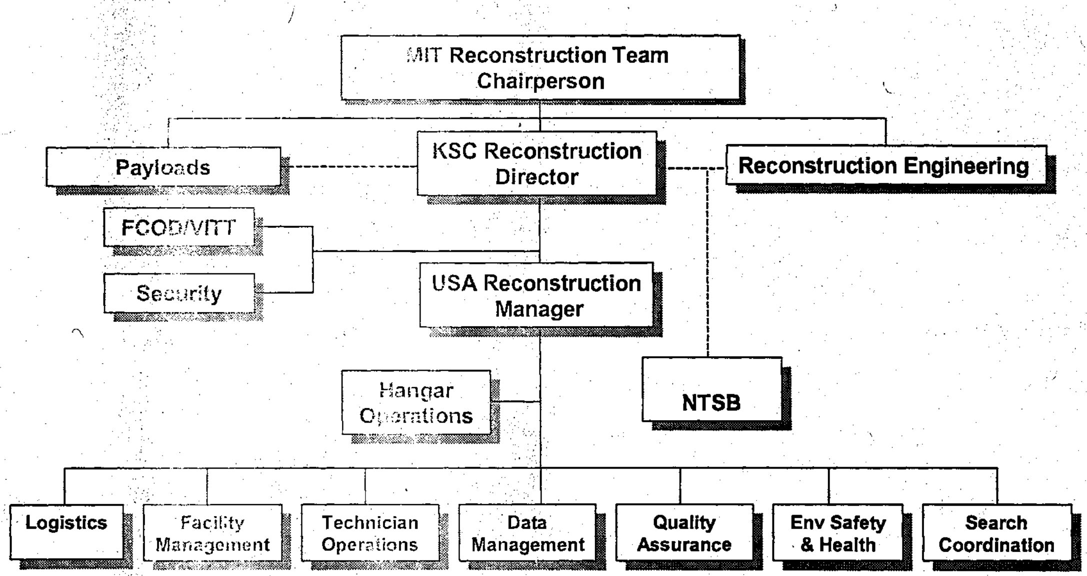

Figure 5-1. Mishap Investigation Team (MIT) Reconstruction Team Organization

5.1.3.1 Staffing of the Reconstruction Effort

For the majority of the reconstruction period, approximately 75 personnel supported operations on each of two 8-hour shifts, 6 days a week. Technical experts from KSC and Johnson Space Center (JSC) were deployed to the Columbia hangar and assigned to staff the Floor Support, Technical Disciplines, Crew Module Support, Payload Support, Materials and Processes (M&P) Engineering, or Data Management processes.

1. **Floor Support**

   Floor Support consisted of NASA and USA environmental safety and health personnel, Logistics Specialists, receiving technician functionaries, Quality Inspectors, Material Handling Technicians, and Industrial Engineers. All were employees from USA Integrated Logistics, Orbiter Operations, and Launch Operations directorates and safety operations organizations. These personnel constituted approximately 60 percent of the daily workforce.

   Environmental safety and health personnel were responsible for determining if detectible levels of hazardous propellant residue were present on the debris. This group verified that each truck and box was safe for handling before it entered the Columbia hangar. NASA, USA Safety and Health Florida, and Space Gateway Support (SGS)/Comprehensive Health Services' Environmental Health Services employed these personnel.

   Logistics Specialists, under the supervision of a first-line manager, controlled the truck off-loading and uncrating of all materials received at the Columbia hangar. Orbiter Technicians were used in the receiving areas as receiving technicians to unpack and clean debris. Quality Inspectors verified debris-associated field notes, separated multiple items under one tracking number into individual tracking-numbered items, and photographed each item.

   Material Handling Technicians facilitated the movement of all material from one location to another. All items moved to the reconstruction grid, or material storage bins and shelves, were inventoried and recorded by Material Handling Technicians.

   Periodic audits of debris location within the Columbia hangar were performed to verify process integrity and accuracy. Industrial Engineers performed these independent assessments of debris handling and storage. In addition, a Grid Manager was used to control all movement of items to and from the reconstruction grid.

2. **Technical Disciplines**

   USA, Boeing, Rocketdyne, and NASA supplied the engineering support for the Columbia reconstruction effort. The Reconstruction Engineering Team leadership was composed of the NASA JSC Resident Office (JSCRO), USA Ground Operations, and JSC Orbiter Element. The JSCRO Manager and USA orbiter Subsystem Area Managers (SAMs) provided technical and processing leadership, including 3-D laser imaging and debris assessment, respectively. USA Ground Operations provided administrative leadership. Engineering personnel made up approximately 30 percent of the total Reconstruction Team and consisted of the following:

a. **Structural Engineer** - responsible for vehicle airframe debris

b. **Mechanisms Engineer** - responsible for landing gear hatches and mechanisms

c. **Thermal Protection System (TPS) and Thermal Control System (TCS) Engineer** - responsible for orbiter thermal protection debris such as tile, thermal blankets, gap fillers, etc.

d. **Hypergols Engineer** - responsible for orbiter Orbital Maneuvering System and Reaction Control System (OMS/RCS) components and safing of hypergol-contaminated debris

e. **Fluids Engineer** - responsible for evaluation of nonhypergolic fluid system debris such as main fuel cells, engines, radiators, etc.

f. **Electrical Engineer** - responsible for evaluation of electrical power and distribution, instrumentation, and avionics debris such as black boxes and wiring

g. **Auxiliary Power Unit (APU) and Hydraulics Engineer** - responsible for orbiter APUs and hydraulic systems

h. **Flight Crew Systems (FCS) Engineer** - responsible for processing and identification of items with which the crew interfaced directly

i. **SpaceHab/Payload Engineer** - responsible for SpaceHab and STS-107 payload-related debris

After the bulk of debris was processed into the Columbia hangar, the Debris Assessment Working Group (DAWG) was established. The DAWG began a system-wide engineering analysis of the debris to determine how the major structure and TPS elements failed. The DAWG was composed of Boeing Subsystem Engineers, USA SAMs and System Specialists, senior NASA System Engineers, and NTSB investigators.

3. **Crew Module Support**

The crew module workforce organizational structure was dictated by a combination of the workforce available at the Columbia hangar, the need for privacy for crew sensitive items, and the engineering experience needed for assessment.

The Flight Crew Operations Directorate (FCOD) at JSC assigned astronauts to the reconstruction effort, to be responsible for overall management of the crew module workforce. They provided a continuous onsite astronaut presence at the Columbia hangar. Other astronauts rotated to KSC to help in debris identification and determining stowage locations.

4. **Payloads Support**

KSC, Goddard Space Flight Center (GSFC), Boeing, and SpaceHab personnel supported payload recovery efforts. The core group consisted of two NASA Payload Management representatives, one NASA Operations Engineer, and NASA and Boeing engineers with extensive payload experience backgrounds. This core group coordinated activities with the NASA Accident Investigation Team (NAIT), contact (POC) and responsible for all the interfaces with external databases such as the Shuttle Interagency Debris Database (SIDD).

The Documentum Support Team was responsible for storage and retrieval of all photographs and supporting debris documentation. User interfaces were developed by this team to load photographs and documents easily into the proper folder structure. In addition, web pages were developed by this team to retrieve the photographs and documents quickly and easily.

5.1.3.2 External Interfaces

1. **Mishap Response Teleconference (MRT; called "Mishap Response Team")**

The initial NASA response to the loss of Columbia was the establishment of the MRT chaired by the Mission Management Team. The MRT managed and coordinated all activities for the first 24 hours. Representatives from all program elements, as well as other Federal agencies, departments, and military units, participated in assisting with the recovery efforts and supported the MRT.

The KSC Rapid Response Team (RRT), consisting of 40 people under the auspices of the MRT, arrived at Barksdale Air Force Base (AFB), Louisiana, within 12 hours of the accident. KSC's initial support was two-fold: first, the senior leadership in Texas and Louisiana presented plans for the debris recovery in the field and second, KSC leadership presented their status on supplying personnel for that effort. The RRT evolved into two distinct teams: one to continue the planning for and recovery of the orbiter debris, and one to begin orbiter reconstruction from the debris. Planning for the formation of the Reconstruction Team began at this point. The Reconstruction Team at KSC was formed less than 1 week after the Columbia accident, upon the decision of the NASA Deputy Administrator.

The chain of command that initially had the Reconstruction Team reporting to the MIT evolved over time, given the geographic separation of the Recovery Team in Texas and the Reconstruction Team at the KSC Columbia hangar. The Reconstruction Team was recognized as a distinct and separate entity and began reporting directly to the MRT. This was necessary also because the ground search ended and the MIT was phased out 2 months before the reconstruction effort concluded. The Reconstruction Team provided its status to and received direction from the MRT for the remainder of the reconstruction and investigation.

2. **Columbia Accident Investigation Board (CAIB)**

Concurrent with the above, the NASA Administrator activated the CAIB, an independent investigative body. By policy, the CAIB controlled the debris and began to assemble the members and support staff required to conduct an investigation into the accident. The MRT received direction from the CAIB and continued the NASA investigation into the accident, using all of the functional elements and organizations normally reporting to the Space Shuttle Program (SSP).

3. **Columbia Task Force (CTF)**

Recognizing the need for a formal interface, the CTF was established shortly after the CAIB and became the forum for resolving all matters between the CAIB and MRT. The CTF had no specific investigative responsibilities, but was an administrative body that controlled a number of work tasks and ensured that appropriate managers were aware of their tasks and priorities.

4. **NAIT**

After approximately 7 weeks, the MRT was reformulated into the NAIT to reflect the same three-team structure and responsibilities the CAIB had adopted. The NAIT Team 1 (Materials) Team Lead was the Deputy Center Director of KSC. The NAIT Team 2 (Operations) Team Lead was the Deputy Center Director of JSC, who also acted as the overall NASA Lead. The NAIT Team 3 (Engineering) Team Lead was the Director of Engineering at JSC.

Representatives of the CAIB, NAIT, OVE WG, NTSB, and Astronaut Office were located with the Reconstruction Team to facilitate communication and expedite all necessary paperwork.

5. **Technical Support**

Many companies and Government organizations were called upon to provide special expertise to the Reconstruction Team. These included:

a. Michelin: tire identification
b. Goodrich: landing gear identification
c. Aerospace Corporation: re-entry science
d. NASA Glenn Research Center (GRC): wiring identification
e. NASA Langley Research Center (LaRC): high-temperature-resistant materials
f. Federal Bureau of Investigation (FBI): tile identification
g. Honeywell: avionics identification
h. SpaceHab: SpaceHab item identification

Other teams active in the investigation called upon the Reconstruction Team for their knowledge of the debris and what it showed. These included the OVE WG, Failure Scenario Teams, and STS-107 Unexplained Anomaly Closure Team.

5.2 PROCESSES/PROCEDURES USED

5.2.1 Tools and Techniques

5.2.1.1 CRDS

Within 4 days of the accident, the official CRDS Development Team was established. This team was given the monumental task of having a fully operational database system designed, developed, tested, and deployed within 1 week of being chartered formally. When the debris began arriving at the Columbia hangar 1 week later, the CRDS was on line and ready to support. The CRDS architecture consisted of an SQL Server database with a Cold Fusion web page user interface.

The CRDS web pages (user interface) were designed to provide all users with a common look and feel. This provided users changing from one job to another an easy transition with a minimum of training. All users' screens provided access to common information such as engineering assessments and current item locations. In addition, all screens provided a complete history of where an item had been, who performed various functions on the item, and date/time stamps of when the function was completed.

Read access to the CRDS was made available generally to the NASA centers and contractors involved in the Columbia investigation, provided they were within trusted domains. The CRDS had controls to assign data entry permissions to authorized personnel.

5.2.1.2 2-D Grid

With guidance from the NTSB, a grid layout was chosen that maximized the amount of orbiter Outer Mold Line (OML) that could be reassembled in the space available in the Columbia hangar. A 2-D layout was chosen over a 3-D layout for reconstruction. This was due to the limitations a 3-D layout would place on accessing each of the items after placement on the grid, as well as the supposition that only a very small percentage of the orbiter would be recovered.

5.2.1.3 Crew Module Reconstruction

The crew module was set up as a 3-D grid upon recommendations from the NTSB. The 3-D aspect was provided by the use of "bread racks" to store items in bins. One area of the crew module reconstruction was set up as the flight deck and another as the middeck. Racks were labeled both with the parts' physical location on the orbiter and also a simple rack identification.

Crew personal and sensitive items were kept segregated, even within the crew module area, because of their potential emotional impact and also their potential financial value. Personal items and agency Official Flight Kit (OFK) items were kept in a locked cabinet in the segregated area as an extra measure of security.

5.2.1.4 M&P Sampling and Analysis

1. **Sampling**

   A sampling plan was developed to ensure that samples obtained from the orbiter debris yielded the most data possible while maintaining the integrity of the debris. This plan defined sampling type by criticality, destructive and nondestructive debris sampling, and preservation of samples.

   Sampling criticality was divided into two classifications. Type II sampling was defined as sampling conducted on a critical surface, such as a fracture surface, a uniquely damaged area, or a single-point source of contamination. By default, Type I sampling was defined as those that did not meet the Type II criteria. The level of approval required for sampling depended upon the classification.

   Several destructive and nondestructive sampling techniques were developed. These included coring for debris that either was on or embedded in tile, removal of metal deposits from the structure or Reinforced Carbon-Carbon (RCC) surface by a clean laboratory scalpel or forceps, and removal of a small portion of the debris item by cutting with a diamond blade.

Preservation of debris samples was an important aspect of sampling. Photographs of the debris item were taken prior to taking of a sample. The sample orientation relative to the original item was maintained and documented. Also, work instructions defined packaging requirements to prevent sample contamination.

Debris items sampled included RCC, tile, and metallic components. As the investigation progressed, the majority of the sampling was done in support of analysis for left Wing Leading Edge (WLE) items.

2. **Analysis**

The M&P Team employed standard forensic analysis techniques in both the Columbia hangar and laboratories. Some nondestructive testing was conducted within the hangar using stereomicroscopic, x-ray, and eddy current examination. Analytical techniques developed and evolved throughout the investigation as results from previous analyses gave the team insight into the types of information that could be gleaned from the debris. Initial analyses consisted of the following:

a. Optical macroscopic and microscopic examination

b. Polarized light microscopy-crystalline characterization

c. Scanning Electron Microscopy (SEM) (including low-vacuum) with Energy Dispersive X-Ray Spectroscopy (EDS) (including semi-quantification and dot mapping)

d. X-Ray Photoelectron Spectroscopy (XPS) or Electron Spectroscopy for Chemical Analysis (ESCA)

e. Metallographic sectioning, mounting, and polishing

f. X-Ray Diffraction (XRD)

g. Fourier Transform Infrared Spectroscopy (FTIR)

As the investigation progressed, the following techniques were included:

1) Exemplar technique
2) Neutron activation
3) Microprobe with Wavelength Dispersive Spectroscopy (WDS)
4) Auger spectroscopy

Forensic analysis techniques played a significant role in the analysis of left Main Landing Gear (MLG) components, WLE structure, and selected left wing tiles.

5.2.1.5 3-D Physical Reconstruction

1. **Left WLE**

The evaluation of the left WLE hardware, as it was laid out on the grid, quickly reached a point where no further useful information could be ascertained. It was decided to reconstruct this region in 3-D, and a local prototype lab was tasked with fabrication of 3-D support fixtures for the left WLE hardware. These fixtures consisted of a transparent Lexan sheet that was shaped to the contour of the RCC panel and Tee OML. Metal braces supported the Lexan and connected it to a support subframe. This connection was made with quick-disconnection pins, allowing the Lexan and bracing portion of the fixture to be rotated for access to the interior of the RCC panel. The subframe was attached to a heavy metal stand through a pivoting arm that allowed the RCC items to be viewed either right side up or inverted like the grid orientation. The stand was mounted on castors to make the fixtures as mobile as possible. Each fixture contained two or three adjacent RCC panels.

2. **Right WLE**

To support the comparison of the right WLE to the left, the right side was also reconstructed in 3-D; however, due to the same limitations noted above, no right WLE panels were placed in fixtures. The same materials and techniques used on the left WLE panels 14 through 22 were used for all the panels on the right side.

3. **Left Wing Lower Tile**

Initially, when a tile was identified positively or identified to an approximate orbiter location, the tile was placed in a tote box on the grid at the corresponding X_0 and Y_0 location. This method, however, failed to provide a visual trend of the overall wing TPS. Additional tools were required to assist TPS Engineers with the debris assessment process and allow investigators to visualize the entire lower surface. Thus, 22 movable tables, sized to allow for easy access and handling, were built to replicate the lower left wing surface.

The tables were covered with a full-scale tile map that displayed the part number and cavity size for each tile. The tables were covered with Lexan to prevent degradation of the maps. Troughs were added to the WLE reconstruction to hold the lower Leading Edge Subsystem (LESS) carrier panels. Structural seams were added to the table to establish visual indicators for screed and rivet patterns.

These tools allowed each positively identified tile to be placed correctly on the table and provided visual data to help with the evaluation of scenarios. Placing the positively identified tiles on the table also assisted in the identification of other tiles by matching their damage characteristics to the characteristics of the previously identified tiles.

5.2.1.6 Virtual Reconstruction

At the time of the Columbia accident, NASA was engaged in the Digital Shuttle Project to document the as-built configuration of the orbiter using scanning devices. After a demonstration of the Digital Shuttle Project's capabilities, scanning was adopted as a Reconstruction Team technique. The initial purpose was to provide a 3-D virtual reconstruction visualizing Columbia debris items in their proper location on the orbiter. Later, it also was used for debris identification.

5.2.2 Debris Handling and Management

A receiving and processing flow was developed prior to arrival of the first debris truck at the Columbia hangar. An overview of the receipt and processing flow activities is depicted by Figure 5-2.

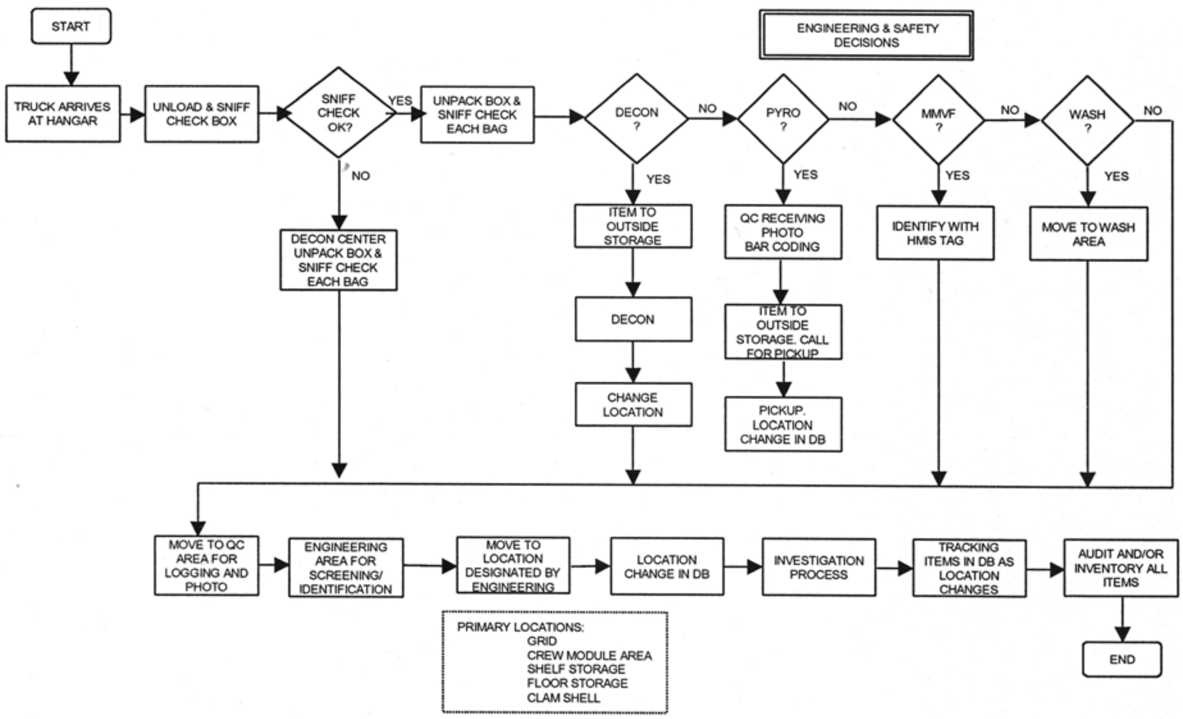

Figure 5-2. Debris Receipt and Processing

The process involved all aspects of shipping and transportation, weighing of debris, uncrating, receiving, quality inspection, database entry, bar-coding, photography, movement of debris, grid management, and release of debris.

In addition, there were several debris categories that required special receiving and handling. These were crew module debris, biological debris, and pyrotechnic devices.

After the debris receiving process was completed, items were routed to the Reconstruction Engineering Team identification area of the hangar, where cleaning occurred as required. Tiles went through a tile identification process. Possible crew module debris was routed to the crew module reconstruction area of the hangar, and potential payload debris was routed to the Payloads Identification Team.

The accurate and prompt relay of engineering assessments of the significant recovered items from KSC back to the recovery command center at Lufkin, Texas, was crucial to the debris search effort. Items identified as potentially on the Significant Recovered Items List (SRIL) were placed in the fast-track process to expedite identification.

5.2.3 Supporting Processes

5.2.3.1 Environmental Safety and Health

NASA and USA Environmental Safety and Health reviewed the Columbia reconstruction process and assessed the hazards associated with the orbiter and handling of its components. Plans were put in place to mitigate both physical and health hazards to an acceptable level. Where applicable, engineering controls were incorporated into the process and the appropriate Personal Protective Equipment (PPE) was identified and required for use.

The health hazards identified included, but were not limited to, the handling of hypergol-contaminated items, contacting liquid chemicals, and handling friable materials. Hypergolic propellants are fuels and oxidizers that ignite on contact with each other and need no ignition source. For orbiter systems, the fuel is Monomethylhydrazine (MMH) and the oxidizer is Nitrogen Tetroxide (N_2O_4). Friable materials are those that are broken easily into small fragments or reduced to powder.

The physical hazards identified included, but were not limited to, handling of noncontaminated debris, ordnance, and high-pressure systems. Special procedures were established for each of these hazards.

The NASA Environmental Program Branch and USA Environmental Management Florida reviewed all processes and walked down the reconstruction impoundment areas to identify potential environmental compliance concerns in an effort to limit liability with regard to state and Federal regulations.

The USA Environmental Safety and Health organizations supplied the Reconstruction Engineering Team with a checklist to review when writing debris-handling work steps so that all potential safety or environmental issues could be addressed prior to implementation of a process.

5.2.3.2 Security

1. **Area Security**

   The designated debris impound areas included the Columbia hangar, north facility apron area adjacent to the hangar, debris-recovery- and salvage-related temporary storage buildings, and containers required to support the reconstruction effort. Additional controlled areas included the SLF Midfield Park Site Decontamination Area, Landing Aids Control Building (LACB), and the clam shell (an auxiliary storage hangar). Many aspects of both physical and personnel controls were used.

2. **Security Procedures**

   Designated debris areas were established as NASA Limited Areas and were controlled as such. “Limited Area” signs were posted conspicuously around facility perimeters and on fences in accordance with KHB 1610.1 (as revised), KSC Security Handbook.

Introduction and removal of material or packages into or out of the NASA Limited Areas, or subcomponent areas, of this operation were controlled by a system that identified the individual(s) moving the item(s) and accountability and tracking of the item(s) moved. This system was determined and managed by the designated authority specified in SFOC-GO0014, KSC, Space Shuttle Program, Salvage Operations Plan.

Unless approved by the Reconstruction Director, the following items were prohibited inside the Columbia hangar:

a. Briefcases, backpacks, lunchboxes, or other such containers
b. Cameras and laptop computers
c. Food and drink items
d. Flammable devices

Media events inside the Columbia hangar were supported with one SGS Security Officer and/or a NASA Special Agent. Mutually agreed upon media areas were cordoned off with ropes and stanchions. These areas provided the media access to the debris without compromising security and safety requirements.

5.2.3.3 Public Affairs and Media Support

As the Columbia debris began arriving at KSC, KSC's Public Affairs Office (PAO) was asked to coordinate with the Reconstruction Team concerning all media queries about the reconstruction effort.

5.2.3.4 Photography and Video Imaging Operations

Aside from the photography documentation done for the PAO, the reconstruction personnel needed their own photographic support to complete their work. The photographs were used to provide visual documentation of hardware at check-in to the CRDS, to support the hangar status briefing to the NAIT and OVE WG, for engineering identification of hardware through electronic transmission to system experts, onsite and offsite engineering routine uses, unique initiatives such as virtual scanning or spectral imaging, and the CAIB's investigations.

5.2.3.5 Document Control

As additional documentation requirements evolved during the reconstruction process, it became apparent that there was a need to establish some form of paperwork storage and control in the hangar. A library was set up to house all paperwork that was not attached directly to the debris.

5.3 LESSONS LEARNED AND RECOMMENDATIONS

5.3.1 Organization and Communication

Recommendation No. 1

Clearly define and empower the chain of command.

By necessity, NASA is a very process-oriented organization in order to accomplish the complex mission of human spaceflight. This procedural hierarchy actually hindered the investigation in some instances. A prime example encountered during the early phases of debris receiving was when onsite personnel made a recommendation to wash mud off of or disassemble a part to aid in identification. There were multiple management forums that had to render a decision before work could proceed. This slowed the pace of debris processing. More autonomy and approval authority should be given to the on-site team, which specifically was staffed with appropriate expertise to make these types of onsite decisions.

The Reconstruction Team reported to both the MIT and OVE WG Chairpersons. Both recognized the need for the preservation of evidence and both took leadership roles in reconstruction; however, the relationship between these two entities was not well defined. The impact of this to the Reconstruction Team was conflicting requirements and priorities. It remained unclear to some as to who ultimately was in charge of the reconstruction activity at the SSP level; therefore, the role of Reconstruction Engineering Team and the chain of command remained fuzzy for the duration of the effort.

Recommendation No. 2

Promote trust and a free flow of information.

There is a lesson to learn in the evolution of the team from independent elements to a synergistic unit. The initial charge to the CAIB was for an independent investigation; however, a teaming approach from the start would have been more effective. Though the reconstruction participants eventually melded into a team, early on in the investigation, the information flow to and from the CAIB was very slow. The duality of the investigation by the CAIB and NASA during the first few weeks caused some tension and competition for resources.

There appeared to be a fear of giving raw data to onsite CAIB personnel before NASA had a chance to review and validate it. Part of NASA's reservation was due to the legitimate fear that data would be released prematurely or misinterpreted by the CAIB. Communications improved when CAIB personnel were permitted to share any factual reports with NASA. Once the teams began two-way sharing of data and analyses, real investigation and technical exchange of ideas could occur.

5.3.2 Facilities and Infrastructure

Recommendation

Overestimate Information Technology (I/T) requirements.

Satisfying the I/T requirements necessary for the reconstruction effort proved to be more difficult than originally anticipated, because computers were used extensively in all areas of the effort. The entire process of tracking, identification, assessment, and analysis of debris was performed and documented electronically. Based on the multitude of tasks being performed electronically and the volume of data being developed and exchanged, it quickly became apparent that the initial set of requirements would not be sufficient. Upgraded computer systems and increased network bandwidth resolved the issues. Computer resources essentially were tripled to support the investigation.

With a team as broad and diverse as the Reconstruction Team, the I/T Team faced challenges associated with connecting users from various contractors, agencies, and geographic locations, while maintaining security. To overcome this issue, trust agreements were negotiated between centers to allow users to access any computer, regardless of their domain; however, one integrated network for information exchange that all teams and subteams could have accessed would have eased communications.

5.3.3 Tools and Techniques

Recommendation No. 1

Provide high-fidelity identification tools in a timely manner.

Reference material to aid in debris identification was essential to successful reconstruction. The dependency on these reference tools was apparent when the initial effort to identify flight crew equipment debris was delayed by the unavailability of a library of quality digital photographs. Bench review and other photographs tended to show items all together in their packed and stowed configuration, as opposed to individual photographs of equipment. Eventually, a library of Compact Disks (CDs) and hard-copy drawings of these items was built up; but in many cases, no photographs existed at all. The effort to identify orbiter structure was much easier, because the Shuttle Data System (SDS) and KSC closeout photographs were readily available.

Recommendation No. 2

Create a powerful, yet flexible, database.

As helpful as the database was, it was only as good as the data being entered into it. A standard vocabulary list and structured description fields could have been created and applied to every debris item. These key words and descriptions would have aided in database searches. In addition, the initial field identifications were valuable only until a more exact identification could be made. Once the more exact identification was made, the initial field identification should have been overwritten with the correct assessment.

Recommendation No. 3

Address the medium for technical information exchange.

As hardware began to arrive at KSC and identification was underway, a process was developed to assess debris items and provide some level of documentation (fact sheet) on their condition. Fact sheets are a fairly standard tool in aircraft accident investigations and, normally, are quick notes and sketches of individual items. Investigators use the fact sheets as the basis for their final reports; however, for this accident, fact sheets very quickly mushroomed into an unmanageable task when the Technical Integration Team and OVE WG required briefings and top-quality, exacting reports, complete with color photographs on every item that was of interest. This left no time for individual evaluation of the mass majority of items. As a result, the investigation began to outpace the team's ability to prepare fact sheets; therefore, the technique was suspended in lieu of broader subsystem or zonal reports. The final report had to be generated without the benefit of a large number of fact sheets as backup material. Fact sheets would have continued to serve their purpose if an appropriate status tool had been made available to facilitate technical information exchange among teams.

Recommendation No. 4

Develop survivable part markings.

Most of the system components on the orbiter were identified per drawing with decals, metal tags, or ink stamp over coated surfaces. This made identification very difficult, unless the appropriate area on the item was shielded from aerodynamic and thermal effects. Items that had etched part numbers usually required only minimal cleaning to raise the number and were, therefore, much easier to identify. With respect to the TPS, today's convention is to print part numbers on the OML only. Most tile part numbers on the OML were ablated and unreadable; however, many recovered Columbia tiles were identified by the stamped part numbers on the Inner Mold Line (IML)--a technique used in the past for bonding array Strain Isolation Pad (SIP) bonds. This duplicate part-marking of tile was useful in the identification process.

5.3.4 Search and Recovery Coordination

Recommendation

Prioritize recovered debris carefully.

The process of labeling items in the field as "Fast Track" to raise their priority and speed identification because of their suspected criticality was useful in assisting grid search priorities. It was only useful, however, when it was used for a limited number of items. Fast track was to be an exception process. It lost its significance when the majority of parts received were labeled as such, overwhelming the identification pipeline. The recovery forces must have clear guidelines on what to identify for the fast-track process.

5.3.5 Supporting Processes

Recommendation

Generate a realistic safety plan.

One safety issue that never was resolved adequately was the monitoring of personnel and air within the hangar for hazardous particulates generated from the collection and handling of debris. Safety and health representatives imposed requirements for daily personnel and area-air monitoring for operations inside the Columbia hangar. The original plan was designed around the potential for worst-case friable materials and by-products, because of the unknown condition of the debris arriving from the field collection sites.

The Reconstruction Team established an air-monitoring program to gain baseline data on air quality in the hangar. Once some baseline monitoring was performed and the results of the samples showed that particulate counts remained at ambient levels, the Reconstruction Team requested that the safety and health organizations revisit the plan to see if some of the more stringent requirements for personnel monitoring could be lifted.

Although a revised sampling plan eventually was put in place, there was a great deal of debate within the safety and health community, with no clear ruling authority among parties involved to make the appropriate revisions. There remained some confusion over the requirements, and there never was consensus on the plan. It is recommended that any future safety plan geared to address the worst-case scenario also have provisions to allow for modification of the requirements, as warranted, to fit the needs of the operations.

5.3.6 Debris Handling and Management

Recommendation

Streamline the paper process.

No paper process is without flaws or limitations. The Columbia investigation and reconstruction effort in particular generated large volumes of paperwork to ensure proper tracking and investigation integrity. The reconstruction documentation process was established with the best intentions, but did not result in as streamlined a process as planned or desired. The process turned out to be burdensome, requiring a Reconstruction Documentation Sheet (RDS) for analysis of each component. Each RDS required multiple reviews and signatures before implementation. Generically grouped RDSs, or "bucket RDSs," could have been used for nondestructive, generic failure analyses.

The overarching investigation documentation process involving Test Approval Requests (TARs) and Hardware Release Requests (HRRs) usually was the cause of delays in accomplishing tasks that had some urgency. Delays of several days were not uncommon throughout the investigation. The Reconstruction Team acknowledges the responsibility of the CAIB to oversee the reconstruction and suggests that more local authority by CAIB resident members would have increased greatly the speed of many test and analysis efforts.

6. ORBITER VEHICLE ENGINEERING WORKING GROUP

6.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

On February 1, 2003, the STS-107 Loss of Crew and Vehicle (LOCV) during return to Earth initiated a series of actions supported by a large number of individuals covering a wide range of disciplines and facilities. Immediately following the loss of tracking and communication with the vehicle, the reality of what had happened over Texas became more apparent; and the Mission Evaluation Room (MER), along with other NASA and contractor support facilities, began preparing for postaccident activities. These activities were to address the immediate, near-term, and long-term needs of the Space Shuttle Program (SSP) comprising a wide range of activities, facilities, and personnel from within and external to the normal Space Shuttle/orbiter community.

Several documents define the process and procedures to be used in a contingency. NPD 8621.1H, NASA Mishap and Close-Call Reporting, Investigating, and Recordkeeping Policy, requires contingency plans within NASA to respond effectively to NASA mishaps, life-threatening emergencies, or natural or human-made disasters to mitigate further injury to personnel or additional damage to, or loss of, equipment or property. It also requires that situations having the potential to cause any of the preceding adverse occurrences and/or generate political or media attention be reported as well.

Johnson Space Center (JSC) developed JPG 8621.1, JSC Contingency Action Plan. This plan includes only the immediate actions that would be performed within the first hours of an Office of Space Flight (OSF) operations contingency. It does not describe the Mishap Investigation Team (MIT) process in detail, except to sketch the options for convening a team and the process for naming the team Chairperson.

NSTS 07700 Volume VIII, Appendix R, Space Shuttle Program Contingency Action Plan (SSP CAP), serves as an integrated plan to predetermine program response in the event of a Space Shuttle contingency. This plan is implemented in concert with the OSF CAP and associated JSC CAP.

Once the CAPs were implemented, the Orbiter Vehicle Manager established the Orbiter Vehicle Engineering Working Group (OVE WG). This forum provided for an open exchange of information and a mechanism to manage the investigation activities. These meetings were conducted on a regular basis, with the initial schedule being 7 days a week, gradually changing to 5 days a week for the majority of the investigation, and then on an as-needed basis to support team closeout briefings and test support. In support of the OVE WG technical activities, the Orbiter Vehicle Manager established the Technical Integration Team with support from a variety of engineering and operational disciplines.

The purpose of the OVE WG was to provide management and technical direction to all activities associated with the determination of the root cause for the LOCV. Immediately following the accident, the team structure shown in Figure 6-1 was established. This included technical management and direction for all personnel, facilities, and activities supporting the accident investigation while under the supervision of the Orbiter Vehicle Manager.

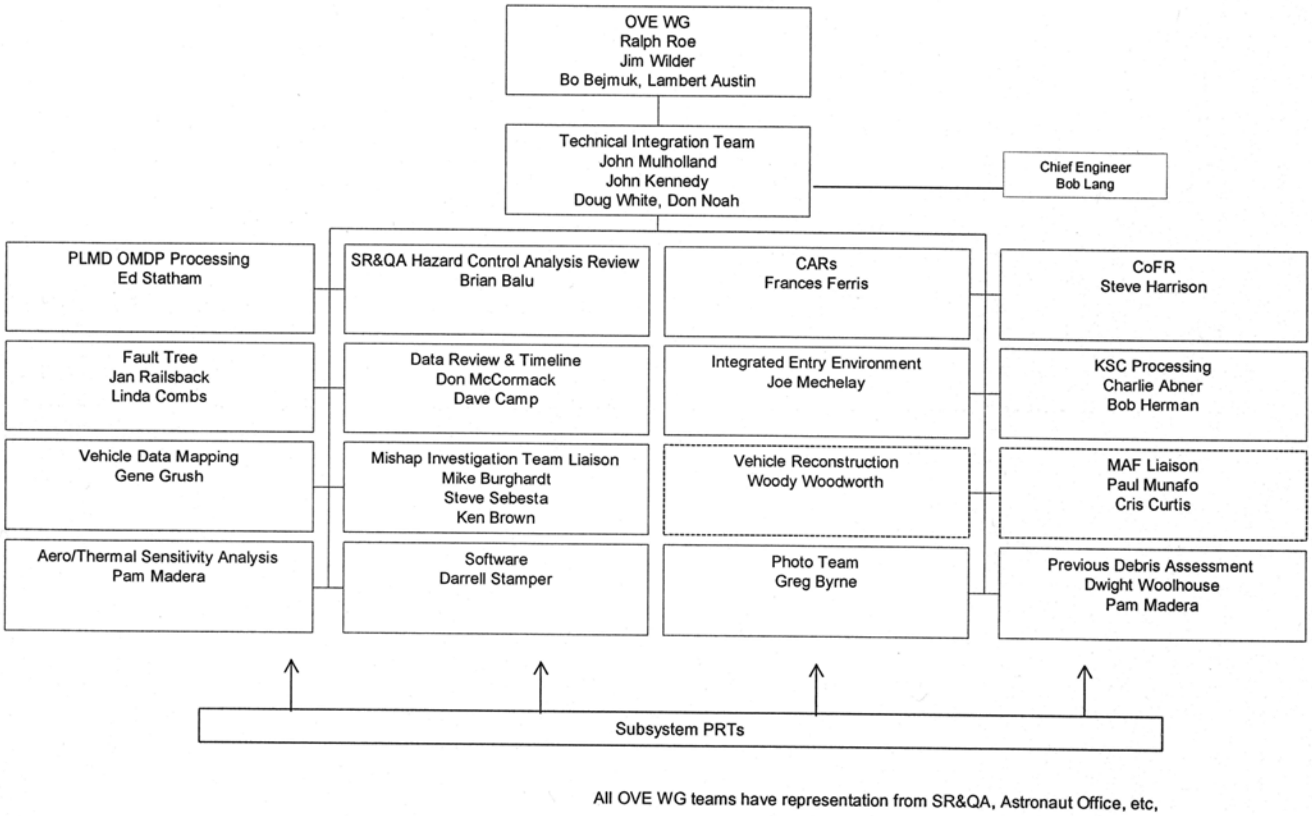

Figure 6-1. Initial OVE WG Organization

As the investigation matured, the team support structure was adjusted to better reflect the division of work and responsibilities as shown in Figure 6-2.

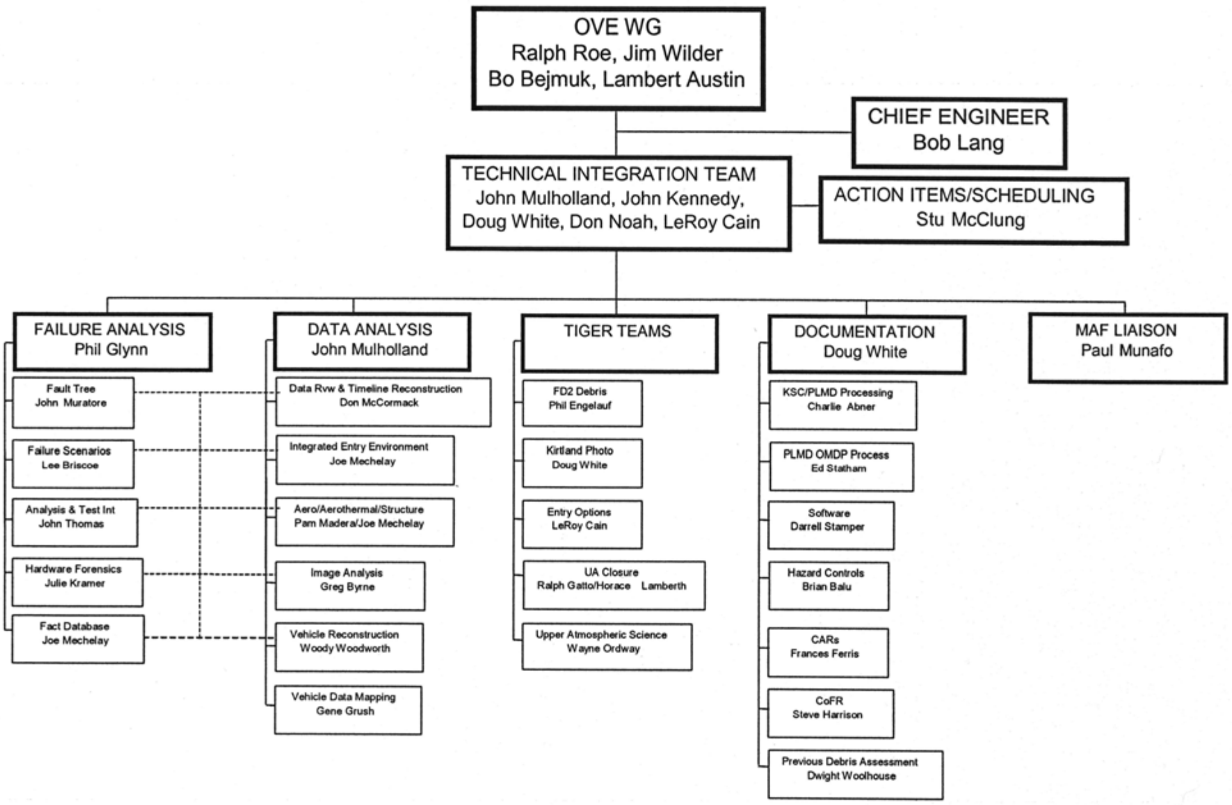

Figure 6-2. Enhanced OVE WG Organization

6.2 PROCESSES/PROCEDURES USED

By direction of the Orbiter Vehicle Manager, this investigation was to be "*Managed from the fault tree.*" In accordance with this direction, a detailed fault tree was developed, with actions tracked and mapped to each block of the fault tree. The exceptions to this were those actions administrative in nature and those associated with the initial capture and securing of data immediately following the accident. The fault tree was expanded from the initial orbiter-related scope to assess potential root causes from other program elements such as the External Tank (ET) and Solid Rocket Booster (SRB). In concert with managing the investigation to the fault tree, a scenarios team was developed to define credible scenarios to match the investigation information. This team generated 10 scenarios that were matched against the fault tree supporting analysis, debris forensics, event timeline, and photographic documentation. Based on these comparisons, the family of scenarios was narrowed down to a single option that focused on a wing leading edge penetration (Reinforced Carbon Carbon (RCC) or T-seal) in the panel 5-10 region of the left wing. The actions associated with these activities were managed and tracked on the Columbia Secure Repository (CSR) web site (https://rs2.usa-extra.com/csr/). In addition to those actions developed by the OVE WG, orbiter-related actions assigned by the Columbia Accident Investigation Board (CAIB) also were tracked on the CSR action-tracking database.

6.3 LESSONS LEARNED AND RECOMMENDATIONS

6.3.1 Observation No. 1

Because server access between all centers and contractors was not available, investigation teams relied on the use of nonsecure e-mail. Note that existing "secure server" availability is not very efficient, and transfer of data and information was difficult and slow.

Recommendation:

Develop a secure server setup between centers and contractors for use in transferring data to and from other NASA centers and contractors outside the JSC firewall. It also should be available to other NASA centers and contractors without requiring special hardware or software tools that most organizations lack.

6.3.2 Observation No. 2

The investigation teams had difficulty retrieving flight data and then transporting the data to other investigation locations (problems with turnaround time, consistency between retrievals, content and format of electronic files, etc.).

Recommendation:

Define and streamline the approach for getting flight data out of secured areas in a crisis. Other possible improvements: set up a secure, read-only server for the Orbiter Data Reduction Complex (ODRC) data; add more people to the access list; and have user terminals in strategic locations for self-service data pulls.

6.3.3 Observation No. 3

Little of the orbiter today is captured in some type of electronic modeling. All the investigation modeling was created after the accident and required considerable resources to support but was extremely useful in scenario development and instrumentation failure analysis.

Recommendation:

Invest in modeling of the entire orbiter using the results of the extensive investigation effort. It is not recommended to be to the detail of the investigation, but start with a framework of primary and secondary structure in addition to key components.

6.3.4 Observation No. 4

Photographic documentation of many of the orbiter areas and hardware needs to be updated. Photographs were extremely useful in identifying hardware in the field and for the investigation of orbiter internal condition and configuration. Also, electronic photographs need to have an accurate naming process to allow easier identification of relevant pictures.

Recommendation:

Invest in complete photo documentation and categorization of the interior of the orbiter and orbiter hardware. Maintain this information on a server that provides access to all relevant NASA centers and contractors.

6.3.5 Observation No. 5

Local contractors (specifically, Boeing Houston facilities) could not access ODRC in their facility until 12 days after the accident. Due to limited capacity in the MER, many of the Boeing orbiter personnel supporting the investigation were located in their facility. Many of the flight data processing tools reside only on the Boeing workstations off site, and very few reside on the MER workstations.

Recommendation:

Improve the time to gain access to the ODRC data from local contractor facilities to support contingency situations.

6.3.6 Observation No. 6

Prior to gaining access to ODRC data, the OVE WG personnel supporting the investigation from off site had to rely on the ops-ftp server. The ops-ftp server allows users to transfer files from the MER workstations to a server outside the MER/Mission Operations Directorate network.

Recommendation:

Provide additional MER personnel accounts on the ops-ftp server.

6.3.7 Observation No. 7

The initial investigation progress was slowed during the time the ODRC and Shuttle Drawing System (SDS) servers were impounded.

Recommendation:

There needs to be a precoordinated plan for impounding electronic data. The plan should define which data to back up and a process for releasing the data in the most expedient manner possible. These systems should be among the first to be made available.

6.3.8 Observation No. 8

The contingency plans do a good job of identifying what needs to be done. Unfortunately, they don't cover the detail of how to do it. At Boeing, for example, it was at least a week before they had a plan and instructions to employees on how to impound the electronic files, e-mail, and hard-copy data.

Recommendation:

The SSP should develop implementation plans to support the CAPs. In these plans, protocols between teams (e.g., the NASA Accident Investigation Team (NAIT), OVE WG, etc.) need to be established early on. This should include the process for notification of meetings and requests for data and actions. Plans for a central web site should be defined, along with the process for storing data and additional information such as meeting schedules, investigation organization charts, key personnel telephone lists that include their support staff, and web links to other important sites.

6.3.9 Observation No. 9

For the contractors, development of accounting guidelines from NASA was slow.

Recommendation:

SSP business personnel quickly need to organize and establish (even define prior to an accident) accounting guidelines for the NASA and contractor personnel supporting the investigation.

6.3.10 Observation No. 10

The Challenger contingency happened during ascent and over water versus the Columbia contingency that occurred during entry and over land.

Recommendation:

The SSP and element team structure should not be set rigidly when planning for a contingency. Each contingency will have its unique features, and flexibility needs to be provided to allow the team organizational structure to mold around the event.

6.3.11 Observation No. 11

The SSP was slow in developing the plans and direction for data management and configuration control of the investigation.

Recommendation:

An implementation plan in support of the SSP CAP should be developed to define configuration control and data management requirements.

6.3.12 Observation No. 12

The definition of who has authority to approve release of copies of impounded data from the MER was confusing. Initially, it was identified that the Management Integration Office had the authority to release this information, but that was later delegated to the elements.

Recommendation:

For the implementation plans of the SSP CAP, identify the delegated responsibility for data release in each of the elements.

7. EMERGENCY OPERATIONS CENTER

7.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

Soon after the Columbia Mishap Response Teleconference (MRT; called "Mishap Response Team") was activated, Johnson Space Center (JSC) Center Operations Directorate's Emergency Operations was tasked by the MRT to be the lead in coordinating receipt of information on debris and sightings provided by the public to JSC and coordinating dissemination of this information to the various teams involved in recovery and analysis. Emergency Operations activated the Emergency Operations Center (EOC), which was designated to be the initial hub for receiving all the public-provided information. One of the EOC's telephone numbers was released to the news media by the Office of Public Affairs as the number for the public to call regarding any information pertaining to the mishap. Safety, Reliability, and Quality Assurance Office's Safety and Test Operations Division; Information Systems Directorate's Customer Support Office and Information Technology Division, Communications Branch; and Space Shuttle Program's Customer and Flight Integration Office personnel joined with Emergency Operations to establish communication protocols, configure hardware, organize volunteer support, develop processes and procedures for handling the different media information, and coordinate support for the Mishap Investigation Team (MIT).

The Manager of Emergency Operations was designated the Manager of this EOC effort. Since this effort would involve support 24 hours a day, 7 days a week (24/7), two Emergency Operations personnel were designated to be alternate EOC Managers. The supporting organizations reported to the EOC Manager, and the support staff reported to their designated operational leads. The EOC support team members (leads), their organization codes, and their assignments are shown below.

William Roeh	JA17	EOC Manager; primary contact for the MIT and MRT. Ensure distribution of call reports and data to the appropriate investigation teams.
Bob Gaffney	JA17	Alternate EOC Manager
Dennis Perrin	JA17	Alternate EOC Manager
Sandy Griffin	NS	Coordinate and schedule telephone bank volunteers, develop call response forms, train call takers, and log in telephone responses.
Michele Brekke and Anne Sweet	MT	Review, sort, and distribute call reports and coordinate, schedule, and train volunteers to perform these duties.
Dave Kelldorf	GT2	Configure telephone bank.
Lynn Buquo	GC	Establish and maintain e-mail address and review and distribute e-mails. Establish and maintain web site for receipt of video and picture files. Establish web site for storage of electronic pictures. Provide staff of personnel to sort e-mails.
Carrie McCaslin	GP	Develop a database for all call reports and perform data entry into this database.

To ensure that debris information was being processed expeditiously, Emergency Operations participated in the daily teleconferences with the MIT and Federal Emergency Management Agency (FEMA) and was in constant communication with persons coordinating debris-logging at Barksdale Air Force Base (AFB), Louisiana. The database for debris call reports was provided to the MIT daily until the Shuttle Interagency Debris Database (SIDD) was activated.

The EOC also was responsible for bringing any information that described illegal activities or contained threatening information to the attention of the Federal Bureau of Investigation (FBI) and NASA Office of Inspector General.

In addition to the initial assignment of receiving information from the public, the EOC also supported the MRT with the following responsibilities:

1. Establishing a database of debris and nondebris call records
2. Creating an initial tracking map of debris reports
3. Investigating and recovering potential Columbia debris from the Houston area
4. Establishing a process for handling debris brought to JSC either from Lufkin, Texas, or by individuals
5. Initially coordinating pickup and transportation of biohazards from the field recovery centers to JSC

Emergency Operations continues to support the Columbia Recovery Office (CRO) since the closure of the Lufkin Disaster Field Office (DFO). The debris hot line (1-866-) has transferred to the EOC and is being answered by the EOC dispatchers 24/7. The CRO currently is operating in the EOC Community Support Room.

7.2 PROCESSES/PROCEDURES USED

There were no preexisting guidelines or processes for the EOC to implement in response to the Columbia mishap. The guidelines and processes developed were the result of the experience and combined efforts of the Emergency Operations staff and the team leads supporting the EOC. The overall activities and processes for handling incoming information were improved throughout the activation as staff experience and assessment team requirements matured. The following sections provide more detail on the individual activities and processes.

7.2.1 Telephone Call Center Setup

The first immediate concern was the establishment of a telephone bank to receive the incoming calls. The EOC Community Partners area served as an excellent facility to handle this requirement, because cubicles with existing telephones already were in place. Information Systems configured 16 telephones into a telephone bank to answer incoming calls. When one telephone was busy, subsequent calls automatically rolled over to the next telephone in the telephone bank.

7.2.2 Caller Information Processing

A caller information form and an instruction sheet for call takers were developed and revised as needed. On the caller information form, the call taker indicated if the call was computers and personnel from their office and the IMPASS contract to enter the data. Copies of all of the incoming telephone call reports were provided to Information and Imaging Science every 2 hours (8:00 am until 10:00 pm) for input into the database. At the end of each day, the data from the laptop computers were consolidated into one spreadsheet, which the EOC Manager e-mailed to Barksdale AFB MIT, Lufkin MIT, FEMA Region 6, and other designated recipients. Once the SIDD was activated, the JSC EOC database was merged into the SIDD, and all future entries were made directly into the SIDD at Lufkin from the faxed caller information sheets provided by the EOC. Personal Computers (PCs) permanently located in the EOC Situation Room allowed the EOC easy access to the database as needed.

7.2.5 Debris Tracking

An additional EOC activity initiated almost immediately was to establish mapping of the debris field. The Flight Director's Office organized this effort using EOC volunteers co-ordinated by Customer and Flight Integration. Copies of all debris reports were given to the mapping group, and they marked the location on wall-sized maps created by Information Systems. The mapping information then was relayed to the MIT. Other organizations such as FEMA, Stennis Space Center (SSC), Steven F. Austin University, and the Forest Service began setting up more sophisticated tracking programs that included data from field units not reporting to JSC, and by February 5, 2003, the EOC no longer was required to perform any tracking functions.

7.2.6 Receipt of Mail and Debris

The EOC was tasked with being the clearinghouse for all of the incoming mail (a specific mail address was established for Columbia-related information) and to coordinate the receipt of debris at JSC either from Lufkin or the public. Because there was concern as to what some individuals might send in the mail given the status of world tensions, Emergency Operations coordinated with Safety, Reliability, and Quality Assurance; the Occupational Health Office; and Logistics to develop a procedure for processing incoming mail and debris so that it would be inspected properly prior to its receipt in the EOC or to bonded storage at Logistics. Each piece of mail was handled in the same manner as videos. When received at the EOC, each piece of mail was logged in and assigned a tracking number (2-1-xxxx), with some exceptions. Credible theories and redesign concepts were forwarded to the MER for evaluation. Other theories and redesign concepts (wild speculations, repeat of newspaper reports, etc.) only were logged and filed. Items that were for astronaut families, Public Affairs, or the Columbia Accident Investigation Board (CAIB) were not logged but were forwarded to those organizations. Pictures/videos received by mail were assigned a different series of tracking numbers (2-4-xxxx). Protocols and routing for all Columbia-related materials received by JSC Logistics were established.

7.2.7 Houston Area Debris Recovery

The MIT asked that the EOC set up a team to evaluate and recover any debris that was reported in the Houston area. The Houston team used the same guidelines used by the Lufkin MIT established by Safety, Reliability, and Quality Assurance for handling of debris. The debris was collected and processed as described above.

7.2.8 Followup Telephone Calls

Telephone bank personnel also made a significant number of followup telephone calls to obtain more information from the original caller, follow up on insufficient information provided by e-mails, or support DPAT requests. The DPAT asked the EOC to verify that specific items identified in debris photos had indeed been retrieved by the field teams.

7.2.9 Transportation of Biohazard Materials

The EOC was asked by the MIT to coordinate pickup of biohazard materials from the field centers. The EOC provided the initial coordination with Logistics' Transportation Branch and the Lufkin DFO to provide for the orderly movement and process for pickup and delivery of these biohazards to Building 37 at JSC. After the first shipment on February 26, 2003, coordination of these activities was transferred to Transportation. U.S. Department of Transportation standards were evaluated and used for transportation of this material.

7.2.10 Data Control

The EOC maintained records of calls to the JSC hot line (281-483-3388), which provided information on debris sightings, human remains sightings, visual sightings of Columbia's return, offers of services and help, suggestions for design changes, theories, and pictures/videos taken. These call records were stored in locked file cabinets in the EOC, a controlled access area (i.e., card reader access required). The data from the caller information forms were entered into a database maintained by Information and Imaging Science on a secure password-protected web site (http://ddms0.jsc.nasa.gov/eoc). Users had to be granted access permission by the EOC Manager to access this database. The EOC Manager also maintained the data on compact discs.

A log and record of pictures/videos mailed to JSC also was maintained and kept in a locked file cabinet in the EOC as well as an electronic database. All pictures/videos were distributed to the ESAT and a signed receipt log maintained. After review of the videos and tapes by the ESAT, they were sent to the depository at Building 8 where they again were cataloged and permanently filed. These pictures/videos, if possible, were cross-referenced to other receiving logs (i.e., call reports). The videos also could be cross-referenced to another database for e-mails received. That database was maintained by Information and Imaging Science but was available to the EOC. Information and Imaging Science was responsible for maintaining all the original received materials and approving and distributing any copies.

Another source of data for which the EOC was responsible was a web site (https://issimagery.jsc.nasa.gov/collections/Photos/Columbia/) created by Information and Imaging Science. Two curators were assigned, and the web site was password-protected with only specified individuals granting access approval. This site contained a combination of all the public pictures/videos sent to JSC either by e-mail or via the controlled web site where data could be entered but not reviewed by the sender. Information and Imaging Science maintained these data and e-mail data, but the EOC authorized use of this web site.

Call reports for debris sightings were faxed to the appropriate DFO (Lufkin or Carswell Field in Forth Worth, Texas) and the MIT Operations Center at Barksdale AFB. The EOC Manager approved distribution of copies of call reports and the databases.

7.3 LESSONS LEARNED AND RECOMMENDATIONS

1. Establish and maintain control of EOC operations.

   The EOC is in an area with access control using the Computerized Security Control System (i.e., card readers). Access was limited to prevent distractions and unneeded interruptions. Leaders for each team of volunteers were established, thus providing firm yet flexible control of the persons working in the area.

   a. Remove nonteam players immediately.

   b. Identify alternates for anyone experiencing emotional trauma or inability to handle the work or tactfully remove him or her from the work area. Involve the Employee Assistance Office early.

2. Install multiple dry erase boards.

   Keep process flows diagramed and key contacts listed on the dry erase boards for viewing by team members. As processes or names and telephone numbers change, they can be updated immediately and all parties using the processes are made aware of the changes.

3. Improve telephone call reception.

   a. Establish a toll-free number quickly. This did not happen until approximately 1 week after the mishap.

   b. Preestablish a process and procedure for creating a multiple-line telephone bank.

   c. Ensure that calls coming in that exceed the capacity of the telephone bank hear a prerecorded message and are put into a queued system.

4. Improve caller information forms.

   a. Use a multiple-page form to avoid making copies.

   b. Write legibly.

   c. Never write on the back of forms.

   d. Green ink does not fax well; always use blue or black ink when filling out forms. Blue is recommended over black to distinguish between the original and copies.

5. Add power receptacles in the EOC for fax and copy machines.

6. Use of designated multicolored folders for sorting copies and original caller information forms facilitated distribution of information to the different teams.

7. Consider establishing a shared electronic database system or network for entering caller information by PC as it is received rather than handwriting on forms (similar to the SIDD).

The efficiency of entering and retrieving caller information greatly would have been enhanced if each call receiving station were equipped with a PC for entering the information on an electronic form. The forms or database then could have been sent electronically to the field centers rather than by fax. This would have provided better quality and quicker distribution of the information provided to the field centers. Flags could be preset that would not allow the form to be saved until all necessary fields were filled out, thus ensuring that adequate data were provided.

8. E-mail and Internet worked well for receiving citizen observer reports.
9. Training of volunteers is critical for achieving proper call handling, sorting of information, and distribution of data.
10. Managers routinely need to step away from the process to ensure that all of the requirements are being satisfied.

8. DATA AND RECORDS HANDLING WORKING GROUP

8.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

8.1.1 Introduction

The Data and Records Handling Working Group (D&RH WG) was established on February 2, 2003, with a verbal charter to identify, inventory, and preserve all STS-107 mission-related data; control access to the data; and maintain records of data provided in support of the investigation.

There were no preexisting guidelines regarding D&RH WG structure or membership. Membership was established via a Mishap Response Teleconference (MRT; called "Mishap Response Team") request that each organization with impounded data provide a representative. The response was immediate, with additional members added over time as the need was identified. D&RH WG members, their organization codes, and their respective organizations are shown below. This arrangement remained unchanged for the duration of the effort.

Bob Heselmeyer	MG	D&RH WG Chairperson; Johnson Space Center (JSC) Space Shuttle Program (SSP) Management Integration
Mike Corbin	MG	SSP Management Integration
Rick Mastracchio	CA	JSC Flight Crew Operations
Jim Brandenburg	DA	JSC Mission Operations
Betty Brown	MT	SSP Customer and Flight Integration
Rich Schmidgall	MS	SSP Space Shuttle Systems Integration
Ramona Aleman	MV	SSP Vehicle Engineering
Mark Liberty	NA	JSC Safety, Reliability, and Quality Assurance (SR&QA)
Charlie Crews	EA	JSC Engineering
Bert Jackson	USA	Program Integration
Keith Burleson	MP3	Marshall Space Flight Center (MSFC) External Tank (ET) Project
Steve Wofford	MP2	MSFC Space Shuttle Main Engine (SSME) Project
Kate Matus	MP4	MSFC Solid Rocket Booster (SRB) Project
David Beaman	MP5	MSFC Reusable Solid Rocket Motor (RSRM) Project
Yolanda Harris	MP	MSFC Systems
Pete Nickolenko	PH	Kennedy Space Center (KSC) Shuttle Processing
Bill Dowdell	UB	KSC International Space Station/Payloads Processing
Wanda Hobley	GA	JSC Information Systems
John Cools	AI	JSC Office of Chief Information Officer (CIO)
Mel Buderer	SA	JSC Space and Life Sciences
Henry Kunkel	Boeing	Program Integration
Ted Sobchak	451	Goddard Space Flight Center (GSFC)
John Stealey	VA	Stennis Space Center
Robert Cort	RD	White Sands Test Facility (WSTF)

Details of the various subjects addressed in this report are documented in the D&RH WG minutes, which are posted at http://sspweb/webdata/drmwg/.

8.1.2 Background

8.1.2.1 Impounded Data

The impounded data consisted of large quantities of various types of data located at seven NASA centers; several NASA and Air Force tracking stations; numerous contractor and subcontractor facilities; and a large number of universities, laboratories, and commercial facilities used by payload investigators. The data media included paper, photos, audio and video tapes, compact and floppy disks, laptop computers, computer tapes and memory devices, and medical and experiment samples of various kinds. Computer systems, some of which were required to support other ongoing NASA operations (i.e., Space Station operations and network support of other satellites), were configuration-frozen and shut down. In many cases, the initial impound activity was not very selective; data even remotely related to the flight were impounded, and, in some cases, whole facilities were locked down.

NASA organizations had individual contingency plans addressing the impoundment of data, although the authorization to impound was not defined clearly when it affected non-Government facilities, as in the case of some payload data. In these cases, a "trust factor" was introduced to allow cognizant individuals at these locations the authority to secure any STS-107 information.

The impounding of flight preparation and mission data was accomplished by all organizations. This activity already had been completed before the first D&RH WG meeting. The role of the D&RH WG, therefore, was to establish a consistent scope and processes for managing the already impounded data, provide guidance on unique data-handling situations, and assist other investigation working groups and organizations with data-related questions.

8.1.2.2 Database Access and Connectivity

Although not a D&RH WG responsibility per se, an ancillary responsibility associated with the D&RH WG was the authorizing of access and enabling of connectivity to the debris and imaging databases supporting the orbiter recovery activities. Questions arose regarding who needed access, how it would be granted, and how system and center firewall and other security considerations could be dealt with rapidly. The formation of a "data" working group provided an obvious focal point for this activity, with the Chairperson and Management Integration representative established as the authorizing officials. This activity expanded to include CIO involvement with database connectivity issues. These responsibilities, however, were handled apart from the D&RH WG activities.

8.2 PROCESSES/PROCEDURES USED

8.2.1 Data Impound and Release Policies

Although data had been impounded by the responsible organizations according to their individual contingency plans, there was no guidance in place that addressed how to manage the data. There were urgent questions regarding which data could be released, to whom, and by which authority; should the data be considered sensitive and, if so, how should it be transmitted; and what were the criteria for releasing computer systems and facilities required for ongoing operations?

The D&RH WG Chairperson and Management Integration representative immediately began to draft a formal D&RH WG policy. The initial draft was briefed at the February 8, 2003, MRT meeting, subsequently rewritten by the MRT Chairperson, and initially released to the D&RH WG members on February 18, 2003. The latest version of the policy is posted to the MRT and D&RH WG web sites.

As early as February 5, 2003, and in subsequent D&RH WG meetings during this period prior to the release of the policies, direction on urgent subjects was provided to the group members based on policy reviews and offline discussions with the MRT Chairperson. This was necessary because of the pressing need to deal with data and system requests. For the most part, consistent guidance was provided; however, there were several instances of significant changes:

1. Initial direction from the D&RH WG Chairperson was that computer systems could be released for operations if a backup tape was generated and impounded. This requirement subsequently was changed to a backup tape plus one copy. (In some cases where very large numbers of tapes were required (i.e., 1,700 for the Software Production Facility), it was proposed, and the D&RH WG Chairperson concurred, that the copy could be made for requested data at the time of the request.)
2. Original direction contained data sensitivity categories and suggestions for how the data should be transmitted, which subsequently was deleted.
3. Based on a request from Mission Operations (with detailed justification), the D&RH WG Chairperson approved the release of the Mission Control Center (MCC) and Integrated Planning System data prior to these types of releases being approved via Facility Release Request at the MRT.

An uncertainty associated with the data impound and release policies was the fact that they were never signed. Early on, as the policies developed, there was uncertainty about whether or not the policy was official and which was the latest version. The situation was made more complicated because of the need to communicate these data to a large number of people in many different organizations. The D&RH WG member organizations accepted the policies as communicated via the working group, although the Department of Defense (DOD) submitted a Facility Release Request for Columbia Accident Investigation Board (CAIB) approval to verify the validity of the system release criteria. Overall, communication of the data impound and release policies was effective, but the process would have been much crisper if the policies had been signed.

The D&RH WG met a vital need in determining and disseminating policies regarding the management of impounded data. In general, the D&RH WG was effective in providing timely and consistent guidance. The above cases of early changes in direction and policy uncertainty are indicative of the initial absence of any guidance and the difficulty in generating procedures during the hectic days after the mishap.

8.2.2 Data-Gathering

A major responsibility of the D&RH WG was to assemble information pertaining to the vast collection of impounded data. For their respective organizations, the D&RH WG members assembled and submitted the applicable procedures and names of individuals authorized to release data; the locations and inventories of impounded data; specific organizations responsible; and, in response to an MRT action, the databases or applications actively being populated with new investigation-related data. The MRT specified that the database include information about location, specific organizations responsible, purpose, access controls, and typical user.

The D&RH WG members were very responsive to all of these requests, and the working group format was an effective way to accomplish these tasks. Collecting these data was extremely important in terms of understanding the extent and types of data and how well the data were being protected. Particularly helpful was early insight into the fact that most of the data are electronic, which enabled early coordination with the NASA Records Officers and National Archives and Records Administration (NARA) regarding long-term storage of such data.

8.2.3 Impounded-Data-Related Issues and Questions

The D&RH WG served as a common forum for the various organizations to raise issues and ask specific questions not addressed by the general policy. For example, how far back in their build and modification history was considered “mission preparation” for reusable vehicles? For KSC payload processing, the NASA Safety and Mission Assurance organization was responsible for impounding the data, which raised custody and liability concerns by the contractors. Contractor-to-contractor data release was discussed on several occasions, as were the evolving procedures for data release based on the source of the request (i.e., CAIB, Freedom of Information Act (FOIA), and Headquarters Contingency Action Team (HCAT)) or within the Government but not investigation related. Experimenter laptop computers with proprietary data or software as well as what to do about Principle Investigator payload data scattered in laboratories and offices throughout the world also were addressed.

The resolution of these and other questions was determined at the working group level or with the advice or concurrence of the MRT Chairperson at the discretion of the D&RH WG Chairperson. Because of the lack of any documented guidance, the D&RH WG was the logical and necessary forum to deal with these kinds of subjects

8.2.4 Long-Term Data Repository

Contingency plans are very clear that all data potentially useful to a mishap investigation must be impounded to preserve it for use in the investigation. There are, however, no requirements that address what to do with the data at the conclusion of the investigation. Similarly, there are no requirements that address the retention of data generated in support of the investigation.

Based on the Challenger model, the D&RH WG is working to establish a data repository at JSC for the long-term preservation of STS-107 and accident investigation data. The purpose of such a repository is to continue to preserve accident-related data in a protected environment so that the agency can support any future investigations. Without in reference to debris, human remains, volunteer services, visual sightings, theories, or pictures/videos taken. The staff of call takers consisted of all volunteers who initially were scheduled in shifts by Safety and Test Operations so that the telephones would be answered 24/7. As each shift came on board, the personnel were given the current instruction sheet and an orientation briefing by the Safety and Test Operations lead.

After the telephone calls were received, the annotated caller information forms were forwarded to the EOC Situation Room where a designated individual logged them in numerical sequence. All caller information forms were assigned a unique tracking number (2-1-xxxx) and sorted for proper distribution. The forms initially were sorted by the categories of debris and information only. The debris reports then were sorted into human remains and Columbia debris. The information-only reports were sorted by the categories of sightings, condolences, theories, services, illegal activities (for example, sale of debris on eBay), and legal claims. Copies then were made of all reports. The human remains reports were faxed to the FBI at Lufkin and a copy made for the Space Medicine Office. Initially, all debris reports also were faxed to FEMA Region 6 Headquarters and then to Barksdale AFB and Lufkin as soon as those MIT field offices were established. All the information-only reports were copied and supplied to the Early Sightings Assessment Team (ESAT) at JSC. The information-only call reports offering services that could be used by the field teams initially were faxed to Lufkin and Barksdale AFB. Later, all offers of services were faxed to FEMA, once that responsibility was transferred to them. All theories on the cause of the disaster and suggestions for Space Shuttle redesign were provided to the Mission Evaluation Room (MER) at JSC for assessment. Calls that possibly might indicate potentially illegal activities were distributed to the FBI and NASA Office of Inspector General. The EOC maintained and filed the original telephone caller information forms.

7.2.3 Receipt of E-Mails and Electronic Photos/Imagery and Videos

Three actions were initiated to receive and process e-mails and electronic photos/imagery and videos voluntarily provided by the public:

1. Establish an e-mail address (Columbiaimages@nasa.gov) to receive any digital images and e-mail from the public.
2. Establish a web site (http://www.jsc.nasa.gov/instructions) to receive large files that might not be able to be transmitted by e-mail.
3. Establish a web site (https://issimagery.jsc.nasa.gov/collections/Photos/Columbia/) for processing and storage of the imagery. All photos and imagery eventually were transferred to this web site for viewing by the ESAT, Debris Photo Analysis Team (DPAT), and MIT. Access to this site was by approval only, either by the EOC or Customer Support Office Manager.

7.2.4 Call Database Setup and Maintenance

It immediately became apparent that a database should be established to allow for researching and tracking of all incoming calls. By the end of the first day, Information and Imaging Science Division developed a spreadsheet database that captured all of the data in the caller information sheets to date and entered the debris data. To ensure that a daily report was provided to the MIT, Information and Imaging Science used 15 laptop such a repository, the data would remain with the myriad of organizations that generated or used it, and its retention would be based on the various requirements in NPG 1441.1D, NASA Records Retention Schedules, and each organization's compliance with those requirements.

At the conclusion of this investigation, the CAIB data will be sent directly to the NARA. All of the other data generated during the debris recovery and accident investigation and all impounded data are subject to inclusion in the JSC repository. A "Columbia Mishap Permanent Repository Data Acquisition Requirements" document is being written that addresses how data should be prepared and shipped as well as guidelines for which data can be excluded from the repository. The SSP Manager and NASA Records Officer are the anticipated approving officials.

8.3 LESSONS LEARNED AND RECOMMENDATIONS

8.3.1 Observation No. 1

The D&RH WG as chartered provided a necessary function for impounded data management and issue resolution. The timely formation and broad support were important factors in its effectiveness. The current NSTS 07700, Volume VIII, Appendix R, Space Shuttle Program Contingency Action Plan (SSP CAP), however, defines two separate working groups to deal with data issues, neither of which covers all data and records issues that need to be addressed.

Recommendation:

Update the SSP CAP to establish one data handling working group chartered to address all data-related subjects.

8.3.2 Observation No. 2

Although the SSP CAP refers to impounded data, there are no guidelines addressing which data, when and how it should be protected, how access should be controlled, or any conditions on data or system release. Development and approval of a policy on these subjects after the mishap was protracted, resulting in some confusion.

Recommendation:

Update the SSP CAP to include guidelines addressing the above impound data subjects. Also, develop standard impound procedures for all payload customers and notify them prior to flight.

8.3.3 Observation No. 3

There was uncertainty at the D&RH WG level regarding the level of approval required for policy direction issued by the group. Further confusion resulted, because the data impound and release policies never were signed.

Recommendation:

Update the SSP CAP to define the approval level for working-group-generated policies and require that the policies be signed at that level.

8.3.4 Observation No. 4

Access authorization to new databases created to support the Mishap Investigation Team (MIT) became the responsibility of the D&RH WG. This was a significant additional workload, which detracted from the primary responsibility of the D&RH WG.

Recommendation:

Update the SSP CAP to add an Information Technology member responsible for the development, operations, and connectivity of databases created to support the MIT investigation.

8.3.5 Observation No. 5

The Integrated Network includes White Sands Complex (WSC), NASA Integrated Services Network (NISN), Flight Dynamics Facility (FDF), Air Force Satellite Control Network (AFSCN), Remote Tracking Stations (RTSs), Dryden Flight Research Center (DFRC), Western Area Test Range (WATR), Wallops Flight Facility (WFF), Merritt Island Launch Area (MILA) and Ponce de Leon (PDL) Tracking Stations, and Network Integration Center (NIC). These sites and elements were represented by the GSFC Network Director. Each had varying roles and levels of involvement regarding mishap data, which created some initial confusion regarding the impounding of data.

Recommendation:

Update the SSP CAP to address the Integrated Network's roles and responsibilities in mishap investigation.

8.3.6 Observation No. 6

Agency requirements for mishap data long-term preservation and guidelines pertaining to which data should be included do not exist. Because most data are generated and stored on computers, the long-term storage media are disks and tapes of various kinds, which are dependent on current software to be read.

Recommendation:

Coordinate with NASA Records Officer and Chief Counsel to establish guidelines for mishap repositories and data storage.

9. EARLY SIGHTINGS ASSESSMENT TEAM

9.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

The Early Sightings Assessment Team (ESAT) was formed 2 days after the Space Shuttle Columbia accident on February 1, 2003. The ESAT had two primary goals:

1. Sift through and characterize the reports of witnesses who saw Columbia during entry.
2. Obtain and analyze all available data to better characterize the prebreakup debris and ground impact areas, to include providing the NASA interface to the Department of Defense (DOD) through the DOD Columbia Investigation Support Team (DCIST).

9.2 PROCESSES/PROCEDURES USED

Of the 17,400 public telephone, e-mail, and mail reports received from February 1 through April 4, 2003, more than 2,900 were witness reports of Columbia during entry and prior to vehicle breakup. Over 700 of the reports included photographs or video of Columbia during entry. It quickly was discovered that public imagery provided a near-complete record of Columbia's entry over the United States, and the video showed debris being shed from the orbiter. Final analysis showed 20 distinct debris-shedding events and three flashes/flares during entry over the Continental United State (CONUS). To facilitate the trajectory analysis, these witness reports first were prioritized to process entry imagery with precise observer location and time calibration, with an emphasis on video.

The ESAT set up a process to time-synchronize all video, determine the exact debris-shedding time, measure relative motion, determine ballistic properties of the debris, and perform trajectory analysis to predict the potential ground impact areas or footprints. Key videos were hand-carried through the Johnson Space Center (JSC) system, expedited through the Photo Assessment Team, and put into ballistic and trajectory analysis as quickly as possible. The Aerospace Corporation independently performed the ballistic and trajectory analysis for Debris 1, 2, 6, and 14 for process verification.

Exact debris-shedding times were calculated based on detailed relative motion analysis. Figure 9-1 shows the predicted ground impact areas for each debris-shedding event. Similar footprints were generated for 35,000- and 80,000-foot altitude for use in searching recorded Federal Aviation Administration (FAA) and DOD air traffic control radar in close partnership with the National Transportation Safety Board (NTSB) and FAA. The Radar Analysis Team searched through more than 2 million individual radar returns generated between 1330 and 1500 Zulu on February 1, 2003. Footprints for all debris observed in video were searched by analysts at JSC and the NTSB for indications of any uncorrelated radar threads falling through the airspace. A generic debris swath extending from California through breakup in Texas also was searched for radar threads in long-range radar.

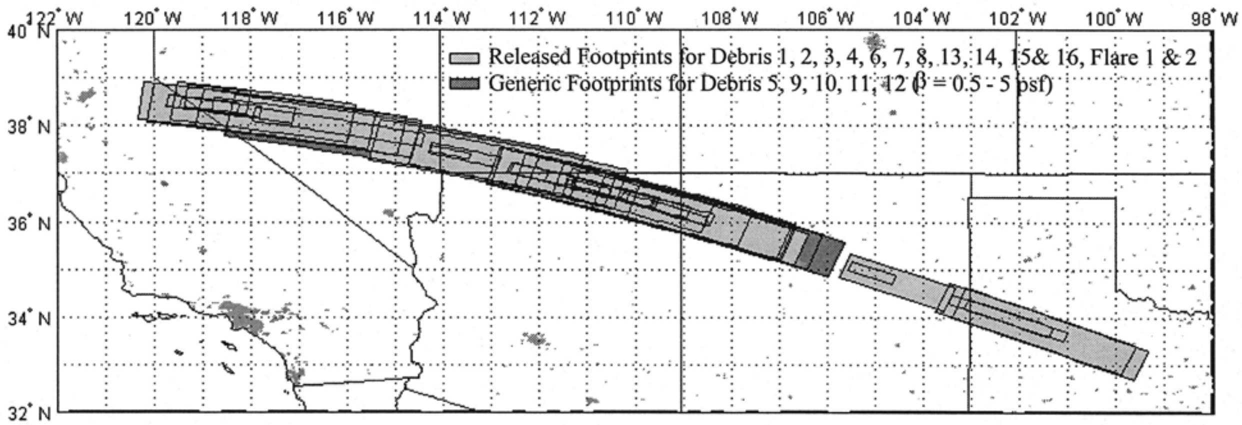

Figure 9-1. Combined Ground Impact Footprints of Observed Debris 1 Through 16 and Assumed Debris at Flare 1 and 2 Constant Ballistic Coefficients, 0-0.15 L/D, C_d 1.0

The combination of trajectory analysis and radar searches led to 20 prebreakup search areas extending from the California-Nevada border through west Texas. The search areas were prioritized by overall confidence based on the trajectory analysis, radar data quality, and, in one case, a supporting witness account. The search areas ranged in size from as small as 1 to 11 square miles, for the radar-based areas, to 300 to 1,700 square miles, for trajectory-only-based areas. All areas typically were in high desert or mountainous terrain. Although ground searches of several of the smaller areas did not produce any Columbia debris, the "Littlefield Tile" (Kennedy Space Center (KSC) database object no.14768) was determined to have shed from the orbiter in the approximate time of Flare 1 through Flare 2 seen in public video.

Results from a series of radar tests by the Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base (AFB), Ohio, show that the various orbiter external materials have low maximum detection ranges for the air traffic control radars. Although the larger, leading-edge components have much higher radar detection ranges, ballistic and telemetry analyses suggest that the long stream of debris observed in video is composed of smaller objects, not a series of large, near-intact, leading-edge components. Thus, confidence was reduced that the radar threads used as the basis for search boxes are Columbia debris. This leaves the much larger trajectory-based areas as best predictions for prebreakup debris.

Emphasis then was given to the areas in which the highest probability regions of multiple early debris-shedding footprints overlap as shown in Figure 9-2. The darkest regions in the plot indicate the most overlap.

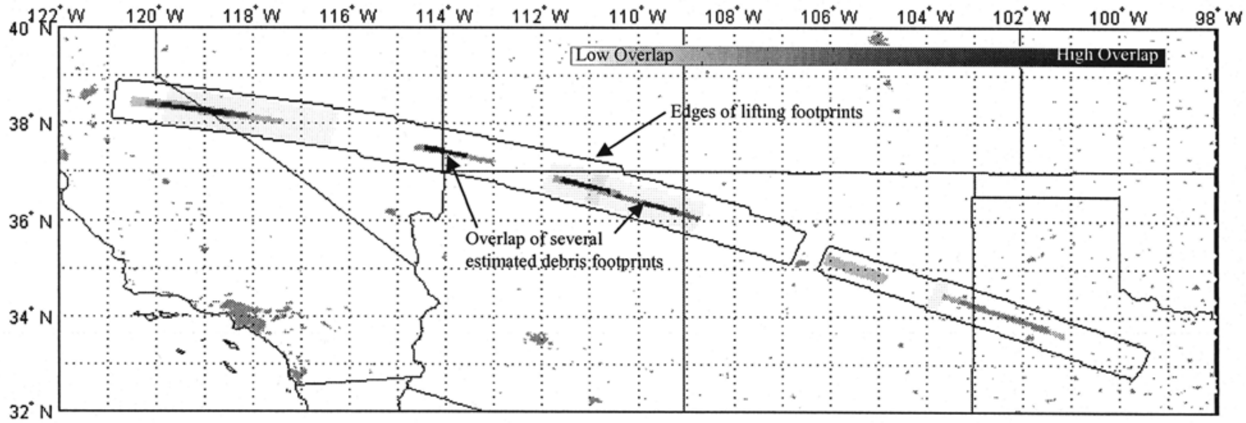

Figure 9-2. Combined Overlapping Ground Impact Footprints of Observed Debris 1 Through 16

AFRL performed additional radar tests on materials and components inside the payload bay and on the exterior of the orbiter to fully characterize the radar cross-sections for correlation with the C-band radars that track during ascent and two deep-space tracking radars. The C-band radar tests were added to investigate the ability to track debris during ascent, with a primary goal of quantifying the likelihood of discriminating Space Shuttle debris in the ascent plume, and the ability to track the most likely Space Shuttle debris with the C-bands in general. The deep-space tracking radar tests were used to evaluate radar data from an object tracked by Air Force Space Command during the mission that was shown to have originated at the orbiter on flight day 2. Detailed discussion of the evaluations of the flight day 2 object is deferred to the tiger team formed under the Orbiter Vehicle Engineering Working Group (OVE WG) to study these data.

In the first 2 weeks of the investigation, there were preliminary indications in various unclassified and classified sensors of some anomalous events during entry. There were similar preliminary indications of anomalous events during ascent. After additional analysis, however, there are no reliable indications in any DOD remote sensor data of anomalous events during ascent or prebreakup during entry, including debris shedding.

Images of Columbia were captured during 3 days of STS-107 orbit operations by the Air Force Maui Optical and Supercomputing (AMOS) site and during entry by employees of the Starfire Optical Range at Kirtland AFB, New Mexico. The AMOS site and Kirtland AFB images are the only DOD images taken of Columbia during STS-107 from any source, unclassified or classified. The AMOS site images are predominantly of the upper surfaces with payload bay doors open, obscuring a significant portion of the wings and showing no discernible damage. Detailed discussion of the Kirtland AFB images is deferred to the tiger team formed under the OVE WG to study them.

DOD, Department of Energy (DOE), and National Oceanic and Atmospheric Administration (NOAA) infrasound researchers collaborated to study infrasonic signals recorded during STS-107 entry. Similarly, the United States Geological Survey (USGS) studied seismic data recorded throughout the southwest CONUS during entry. Although signals associated with the orbiter are found in both sets of data, analysis to date does not provide any data that positively can be identified as off nominal, such as debris shedding, high-energy release, and ground impact.

Analysis of luminosity data, embedded in public imagery, was initiated in an effort to extract an estimate of the size and mass of specific debris material. Ames Research Center (ARC) has developed a series of tests to explore this possibility, but at the time of this writing, these tests had not yet begun, but the confidence that this will yield significant data is considered low. Also investigated early on was the use of spectral data for constituent determination, but this is not expected to be pursued, based on the relatively poor-quality video data.

The top-level interfaces and data paths within the JSC team are shown in Figure 9-3. The interfaces to the various non-NASA groups are not depicted.

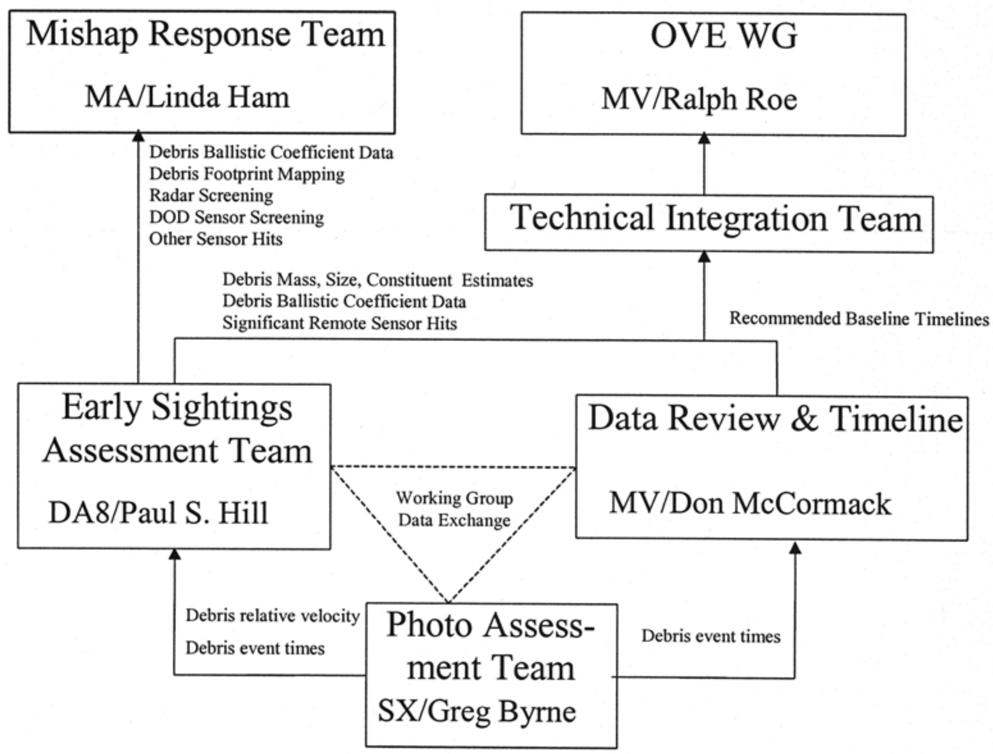

Figure 9-3. ESAT Interfaces

9.3 LESSONS LEARNED AND RECOMMENDATIONS

9.3.1 Debris Sighting Report Evaluation

1. The public report form should be standardized and ready for use in any future incident to maintain uniformity of collected information. This form should include key interview questions, detailed locations, contact information, and zip codes.
2. All telephone interviews (and any public reports) should be entered directly into a database as the interview takes place to facilitate immediate accessibility by all investigation teams, and fields should be included to distinguish between reports of

human remains, debris, and visual sightings. Additionally, the database should have a search function for the various types of input fields.

3. Eyewitness reports should be treated as a "case file" rather than as separate reports. This would allow the team to add to an existing report and note when video or other media were received without logging repeated calls from the same witness as separate reports.
4. A single point-of-contact (POC) should be used for responding to Emergency Operations Center (EOC) reports whenever possible due to sensitivity among some of the public to being contacted repeatedly for the same EOC report.
5. Various products referencing EOC reports should be built using the EOC reference number, not the public caller's name.
6. On a daily basis, record exact location, weight, dimensions, and a digital still of all debris as it is recovered and input it into a single database. This would allow the use of some back-propagation techniques to better define the debris field, identify debris separation times, and confirm validity of objects as debris. Additionally, it should be noted how the location was determined (Global Positioning System (GPS) coordinates, map location, street address, etc.).

9.3.2 Debris Trajectory Analysis

1. Observer-provided information on location, camera specifications, zoom settings, and time synchronization was invaluable as the debris analysis progressed.
2. The combination of automation and parallel processes for calculating a relative range for each time step in video ensured both a quick and accurate answer and is highly recommended to anyone performing a similar analysis in the future.
3. The Debris Footprint Team generated the method to shape a debris footprint between the heel and toe specifically for this accident to aid the Search and Recovery Team in avoiding unnecessary search areas and will be used in all future debris footprint predictions.
4. In this incident, the first debris footprint predictions were not available until 4 hours after the accident. To improve the possibility of crew rescue, perform one of the following:
   a. Design a "running" debris footprint for future Space Shuttle missions such that as soon as telemetry is lost, a debris footprint and estimated crew module impact point would be available.
   b. Ensure that a footprint prediction team is available during entry.
5. An upper bound on ballistic coefficient was not known for an orbiter on entry; the Debris Footprint Team now has a maximum ballistic coefficient to use in any future orbiter-only debris field analysis, based on the Columbia observed value of 220 pounds per square foot (psf).

9.3.3 Radar Search Areas

1. Focus energy looking for localized "blob" tracks versus linear radar tracks.

2. Focus the search for tracks closer to the ground track within the nonlifting footprint.
3. Integrate eye-witness reports into radar search as early as possible.
4. Station a NASA Radar Analysis Team representative at the field operations center for debris searches to help coordinate search box data and act as primary liaison between the Radar Analysis Team, Mishap Investigation Team (MIT), and search coordinators.
5. Conduct daily teleconferences with NTSB, FAA, and Radar Evaluation Squadron (RADES) to discuss radar tracks, search boxes, etc.

9.3.4 Witness Reports

NASA should consider developing a method of educating the public on how best to record future re-entries so that, if such a mishap ever occurs again, the video would more easily facilitate postflight analysis. This would include all important imagery characteristics and supporting data that are key to the analysis.

9.3.5 DOD Data

1. A single DOD POC, located at the NASA center conducting the investigation, is essential to effectively exchanging data and requesting additional support.
2. Generic DOD tracking capability and the resulting routine tasks on Space Shuttle flights should be reviewed and updated as required for all phases of flight.
3. Generic DOD imaging/sensor capability and the resulting routine and contingency tasks on Space Shuttle flights should be reviewed and updated as required for all phases of flight.
4. NASA and the Air Force should study the use of orbiter-specific material maps to facilitate AMOS site's thermal mapping of all orbiters during orbit operations.

9.3.6 Other Sensor Data

1. The state-of-the-art for infrasonic and seismic data does not support their use for monitoring orbiter entry.
2. The state-of-the-art for infrasonic and seismic data does not provide significant engineering value for Columbia's postincident investigation.

10. SYSTEMS INTEGRATION WORKING GROUP

10.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

The Systems Integration Working Group (SI WG) was established based on NSTS 07700, Volume VIII, Appendix R, Space Shuttle Program Contingency Action Plan (SSP CAP). The SI WG was structured to focus on a complete review of the Certification of Flight Readiness (COFR) for STS-107 and the technical disciplines required to analyze system reconstruction and flight data of the STS-107 mission. The participants formally supporting the SI WG represented various SSP, integration, and engineering disciplines among NASA's Johnson Space Center (JSC), Kennedy Space Center (KSC), and Marshall Space Flight Center (MSFC) and contractors United Space Alliance (USA) and Boeing NASA Systems (BNS).

SI WG members, their organization code, and their respective organization are shown below.

Lambert D. Austin	MS	SI WG Chairperson; JSC SSP Space Shuttle Systems Integration
Donald S. Noah	MS	JSC SSP Space Shuttle Systems Integration
Richard A. Schmidgall	MS	JSC SSP Space Shuttle Systems Integration
Rodney O. Wallace	MS2	JSC SSP Engineering Integration
David L. Ladrach	MS3	JSC SSP Project Integration
LaDonna J. Miller	MT	JSC SSP Customer and Flight Integration
Randall L. Segert	MK-SIO	KSC Space Shuttle KSC Integration
Jolene J. Martin	MP71	MSFC Propulsion Systems Integration
H. Neal Hammond	USA	Program Integration
Scott M. Nagle	USA	Program Integration
Pat A. Pryor	USA	Program Integration
Henry J. Kunkel	BNS	Engineering
James A. Kaminsky	BNS	Engineering
Ed J. Klein	BNS	Engineering

A critical element of the SI WG was the development of fault trees for both system- and project-level hazards. Elements of the overall SI WG scope that were complementary to the fault tree development included a complete verification of the COFR process and products, a review of KSC processing, day-of-launch activities, and flight reconstruction.

The following are summaries of the COFR, flight integration, and Space Shuttle system integration activities for the SI WG:

1. COFR review
    a. Reconfiguration
        1) Installation products
        2) Operations and Maintenance Requirements and Specifications (OMRS)
    b. System safety--integrated hazards
    c. Cargo safety
        1) Cargo integration risk assessment report

        2) Payload Interface Control Documents (ICDs)
        3) Integrated payload hazards

    d. Space Shuttle element interfaces

        1) System ICDs
        2) Test verification OMRS

    e. Environment verification

2. Flight reconstruction

    a. Integrated vehicle thermal
    b. Guidance, Navigation, and Control (GN&C) and Thrust Vector Control (TVC) response characterization
    c. Integrated vehicle loads and dynamics
    d. Natural environments
    e. Aerodynamics and debris transport analyses
    f. Propulsion system performance
    g. Photographic and video analyses
    h. Separation clearances
    i. Payload interface structures and mechanics
    j. Element avionics integration and electromagnetic effects
    k. System performance
    l. Support analyses and products for other elements

3. Space Shuttle system integration

    a. Day-of-launch I-loads and wind analyses

    b. Fault-tree development

        1) System hazard verification
        2) Project element hazard verification

    c. Payload system verification

Detailed documentation of the previously summarized STS-107 SI WG activities is included in document NSTS 37399, Program Integration Final Report. This report provides the results of the investigation activities conducted by JSC SSP Space Shuttle Systems Integration, JSC SSP Customer and Flight Integration, KSC Space Shuttle KSC Integration, and MSFC Propulsion Systems Integration.

10.2 PROCESSES/PROCEDURES USED

The first activity of the SI WG involved the survey and impoundment of data relevant to the STS-107 mission. These records are maintained in accordance with JPG 1440.3, JSC Files and Records Management Procedures. All records for controlled access were documented on the STS-107 Investigation Data/System Access Request Form and retained in the Space Shuttle Systems Integration files.

An SSP-wide compilation of all STS-107 investigation activities immediately was begun by Space Shuttle Systems Integration. This effort reflected the activities of all SSP elements in support of the STS-107 accident investigation and was baselined by the SSP

Mishap Response Teleconference (MRT; called “Mishap Response Team”) on February 20, 2003, as the STS-107 MRT Integration Plan.

Product review was accomplished using the existing structure of the SSP technical panels that represented the appropriate system integration functions as baselined in NSTS 07700, Program Definition and Requirements, Volumes II and IV. Assessments and the status of tracked tasks were provided to the NASA Accident Investigation Team (NAIT), chaired by the JSC Deputy Director.

The SI WG initiated the development of a standalone integration fault tree with the intent of providing a mechanism to link the orbiter/Columbia Accident Investigation (CAI) fault tree with the MSFC hardware projects and payload fault trees. The integration fault tree was built to provide additional detail and root causes if CAI-level faults could not be closed. Additionally, the integration fault tree was designed to identify multielement faults that would require integrated analysis, rationale development, and review by multiple SSP elements to close the fault.

The Multi-Element Integration Closure Team (MEICT) was established to review integrated closure rationale for faults across the physical and functional interfaces of the Space Shuttle elements. The MEICT included membership from the SSP Element Chief Engineers; SSP Vehicle Engineering; Safety, Reliability, and Quality Assurance; Mission Operations; Flight Crew Operations; and SSP Space Shuttle Systems Integration and was chaired by the Manager of Space Shuttle Systems Integration. The MEICT reviewed and dispositioned all multielement faults designated on the integration fault tree.

10.3 LESSONS LEARNED AND RECOMMENDATIONS

10.3.1 Observations

1. There are inadequate process definition, tools, and skills to efficiently execute integrated fault-tree development and closeout reporting for incidents involving multiple SSP elements.
2. While the contractor skills available are sufficient to support the reconstruction requirements for “normal” Space Shuttle missions, they are inadequate to support the timeline and number of products required for an investigation of the magnitude of STS-107.

10.3.2 Recommendations

1. Update the SSP CAP to reflect multiorganization and multicenter support requirements.
2. Improve understanding of organizational communication and coordination requirements by expanding the Mission Management Team (MMT) contingency training simulations to include all flight phase scenarios.

11. EXTERNAL TANK WORKING GROUP

11.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

Following the loss of Space Shuttle Columbia (OV-102) on February 1, 2003, the Marshall Space Flight Center (MSFC) External Tank (ET) Contingency Working Group was activated in accordance with MSFC-SSCP-5-77, MSFC Space Shuttle Contingency Plan. Prior to every launch, contingency working group membership for the Space Shuttle Projects managed at MSFC is established and documented by the MSFC Shuttle Integration Office (MP71). For STS-107, the MSFC Space Shuttle Contingency Working Group List was released on January 9, 2003.

Upon activation of the ET Contingency Working Group on February 1, 2003, two members were not immediately available to support the investigation, so their parent organizations identified alternates to replace them. Approximately 1 week after its formation, the ET Contingency Working Group was transitioned into the ET Working Group (ET WG) in order to support the activities of the Multi-Element Integrated Closure Team (MEICT), NASA Mishap Response Teleconference (MRT; called "Mishap Response Team"), Columbia Accident Investigation Board (CAIB), and, upon its later formation, the NASA Accident Investigation Team (NAIT).

The STS-107 ET WG members, their organization codes, and their technical areas of expertise are shown below. This list includes members who were added during the first weeks of the investigation to fill needs for specific disciplines that were not available in the original working group.

Paul M. Munafo	ED30	Chairperson
Neil E. Otte	MP31	Alternate Chairperson
Joanne M. Terek	ED02	Executive Secretary
Larry Nemecek	QS20	Safety and Mission Assurance (S&MA)
Steven J. Gentz	ED35	Materials/Debris
J. Scotty Sparks	ED34	Materials/Thermal Protection System (TPS) Debris
Patrick Rogers	ED22	Structures/Non-TPS Debris
Rob Wingate	ED22	Structures/Non-TPS Debris
John H. Honeycutt	TD52	Propulsion/Interfaces
Lee D. Foster	TD50	Induced Environments/Test Lead
Steven G. Holmes	MP31	ET Project/TPS
Jay K. Sambamurthi	MP51	Reusable Solid Rocket Motor (RSRM) Project/TPS
Eugene K. Ungar	EC2	Thermodynamics-Johnson Space Center (JSC)/Testing
Robert W. Bobo	TD52	Testing
Ricky L. Wilbanks	ED27	Testing
Preston B. McGill	ED33	Testing
Douglas N. Wells	ED33	Testing
Mark D'Agostino	TD63	Testing
Darrell DeWeese	ED34	Testing

The tests, analyses, paper reviews, and other activities required to support the investigation demanded contractor counterparts for each major discipline, plus a very large number of additional support personnel from Lockheed Martin (LM) Corporation, MSFC, other NASA centers, and other Government agencies. A total of approximately 150 personnel supported the ET WG investigation.

The responsibility of the ET WG was to generate and evaluate data to determine if the ET was either a root cause or a contributor to the STS-107 Loss of Crew and Vehicle (LOCV). The ET WG was organized into 14 subteams to focus on the elements of the investigation that became evident early during its formulation. The organization of the ET WG is shown in Figure 11-1.

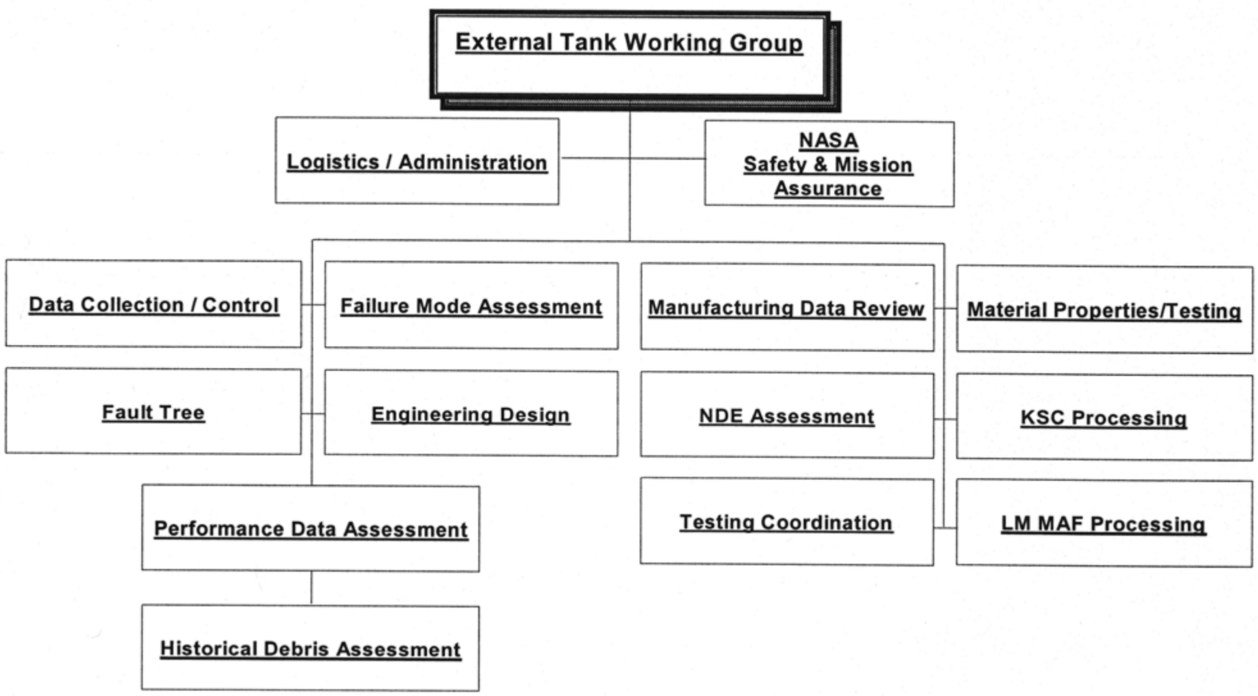

Figure 11-1. Organization of the ET WG

11.2 PROCESSES/PROCEDURES USED

The ET WG conducted its investigation in accordance with MWI 8621.1A, Close Call and Mishap Reporting and Investigation Program; NPG 8621.1, NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping; and NPD 8621.1H, NASA Mishap and Close-Call Reporting, Investigating, and Recordkeeping Policy. The ET WG first convened at 11:30 a.m. Eastern Standard Time (EST) on February 1, 2003, in response to the declared contingency for STS-107.

The first activity of the ET WG was to ensure impoundment of all data relevant to STS-107 (ET-93). This included processing and build paperwork, performance data, flight hardware (in all stages of manufacture), and postflight assessment data at MSFC, Kennedy Space Center (KSC), and LM Michoud Assembly Facility (MAF). As the investigation progressed, flight hardware was released (to permit an orderly return to normal production activities and evaluation of STS-107-similar hardware to support the investigation) and restrictions on data and paperwork were relaxed. All release of data, paperwork, and hardware was done with the approval of the ET WG, MRT, NAIT, and CAIB.

The ET WG process involved the following complementary elements:

1. Scenarios formulated to guide thinking and development of a fault tree and testing
2. Fault tree, including Cut Sets, to ensure that synergistic effects were considered

   Note: A Cut Set is a set of fault tree events from different branches that are related by "and" gates; they are used to ensure that synergistic effects are investigated.
3. Testing, performed on coupons, bench-top parametric specimens, full-scale bipod simulations, and as-built flight hardware
4. Analysis, to support full-scale testing and interpolate and extrapolate test data for disposition of fault tree events
5. Consultation with outside experts
6. Independent S&MA assessments

11.2.1 Fault Tree

The fault tree was the primary process driver. A top-down approach, the fault tree displayed logical fault paths in the typical branch style format. Scenarios of possible events were developed separately and then checked against the fault tree to ensure completeness. The Cut Set methodology was used to define chains of events, or fault paths, that were not linear on the fault tree. The top event on the fault tree was "ET Caused Damage to Orbiter," and the two events below the top event were "Debris Caused Damage to Orbiter" and "ET Interface Performance Compromised Orbiter Reentry Systems."

While system performance data were available to support disposition of the interface branch, there was very little physical evidence to support disposition of the debris branch. The ascent imagery up to the time of Solid Rocket Booster (SRB) separation provided the major piece of physical evidence by showing the event, 82 seconds into flight, wherein debris from the forward bipod area struck the orbiter left wing. The performance data during orbiter descent indicated that a compromised orbiter left wing was the principal cause of the STS-107 accident. The lack of any recovered ET flight hardware necessitated a risk assessment approach for the sake of completeness. If a postulated debris source could not be disproved, then it had to be assumed as possible, and testing and/or analysis had to be performed to assess the probability of an associated debris event.

The initial fault tree was very large; it contained more than 5,000 events. A Diamond Deferral methodology was developed to disposition events in locations from which Level 2 transport analysis showed that debris could not strike the left wing.

Note: A Diamond Deferral permits closure of an event to be deferred indefinitely, with the implication that it was noncontributory, pending disclosure of additional data that would necessitate revisiting the deferral rationale.

Some events were not deferred, including TPS foam break-off in areas from which it could not strike the left wing but might strike another area on the orbiter. Other events not in the Level 2 defined Left Wing Debris Origin Zone also were evaluated fully (as opposed to Diamond Deferral) at the discretion of the fault tree Branch Leads. After the Diamond Deferral process was exercised, a total of 3,470 events (blocks) remained for formal disposition by the ET WG. The fault tree process flow is shown in Figure 11-2.

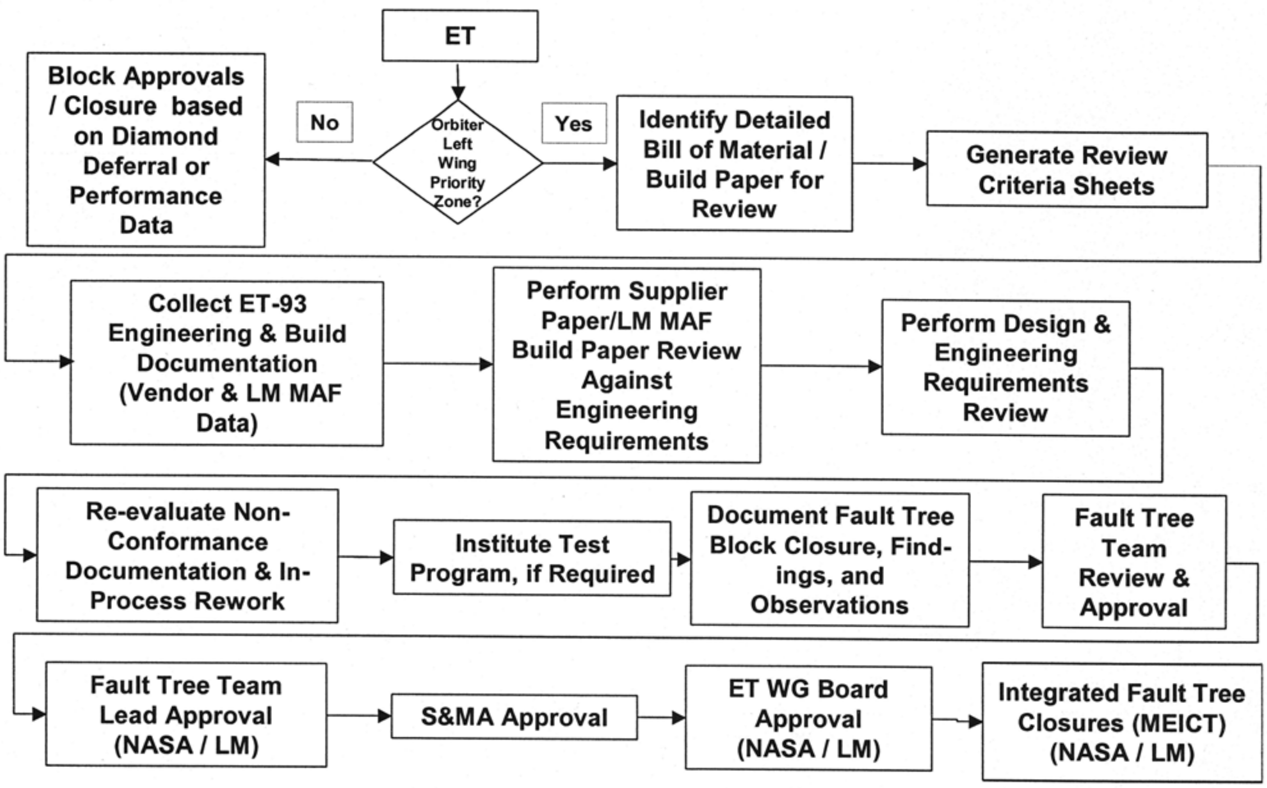

Figure 11-2. Fault Tree Process Flow

The data evaluated during the fault tree closure process varied for the particular branch under assessment, but the total database consisted of:

1. System requirements
2. Design assessments, including structural materials and analysis and verification

3. STS-107 loads and environments, including best estimated trajectory loads and flex body loads
4. ET-93 build records (supplier, LM MAF, and KSC processing records), including:
    a. Standard Material Specifications (STMs)
    b. Standard Process Specifications (STPs)
    c. Manufacturing Process Plans (MPPs)
    d. Acceptance testing records
    e. Non-Conformance Documents (NCDs)
    f. In-Process Reworks Authorizations (IPRAs)
    g. KSC Problem Reporting and Corrective Action (PRACA) System items and Corrective Action Assistance Requests (CAARs)
    h. Practitioner interviews
    i. Previous ET build histories
5. Flight performance data, including:
    a. Video and postflight inspections
    b. All available electrical and propulsion measurements
    c. STS-107 reconstructions
    d. Evidence of nominal performance and anomalies (postflight assessment data from other elements)
    e. Interface and structure functional performance
    f. Any direct or indirect effects on the TPS and orbiter re-entry system
    g. Previous ET flight histories:
        1) Space Shuttle flight experience, preflight predictions and expectations, and postflight performance reconstructions
        2) Propulsion performance
        3) Electrical performance
6. Personnel training records

An electronic database using Relex Fault Tree software was developed to manage the closure process for this extremely large fault tree. A secure web site was established to allow access from both local and remote locations. All data were stored in a single location, with backup performed every 2 hours. Electronic routing and approval were provided, with automatic prompting to the individual next in line for approval of a particular event and closure status provided and updated on a real-time basis. Large data files could be shared and transmitted securely via the web. The entire database, including closure forms and attachments, could be word-searched. Multiple sites were available and were updated automatically, as appropriate, when data were recorded on the fault tree closure forms. This interactive feature linked the following tools and related data tables:

1. Fault tree Data Manager
2. Fault tree block closure
3. Possible scenarios
4. Hardware build review findings
5. Documentation and Information Release Request
6. Integration fault tree block closures

11.2.2 Testing

An extensive testing program was conducted to help understand the sensitivities of the various possible debris sources. The tests fell into six general categories:

1. Support to the full-scale orbiter TPS impact testing being conducted by the Orbiter Vehicle Engineering Working Group (OVE WG) (This included determination of credible debris configurations from the forward bipod area, measurement of the dynamic mechanical properties of foam, and preparation of simulated foam debris samples that were compatible with the testing apparatus at the test sites.)
2. Dissection of as-built hand-sprayed foam on flight hardware (specifically, forward bipod ramps, hydrogen tank/intertank flange joints, and a protuberance air load ramp), to understand the hardware's propensity for containing defects
3. Testing of "neat" (single material) specimens, to augment the database of mechanical and physical properties of the foam and ablator TPS materials
4. Special bench-top tests in simple foam/ablator configurations, to gain a general understanding of physical phenomena such as water absorption and cryoingestion
5. Empirical, parametric testing of specific thickness combinations of ablator under foam, to attempt to determine an envelope under which high-energy foam-release mechanisms might occur
6. Full-scale simulations of the forward bipod and tank/intertank joints under simulated thermal and mechanical loading conditions, to attempt to reproduce the observed TPS loss at 82 seconds into flight

Note: Hundreds of specimens were tested in support of the ET WG investigation, as will be described in the formal written report to the CAIB.

11.2.3 Analysis

Two NASTRAN computer models of the bipod region were developed: a highly detailed plates-and-beams model and a solid element model. The results were used to assess effects of the various flight loading conditions, including substrate motion, to support the full-scale tests as well as for direct use in fault tree block closure.

11.2.4 Consultation With Outside Experts

Two groups of experts provided advice to the ET WG. The Emeritus Panel, a group of retired senior managers with experience on the ET Project, reviewed progress approximately every 2 weeks and critiqued each major presentation. The Technical Exchange

Panel met on March 3 and 4, 2003. Consisting of 23 discipline specialists from outside the Space Shuttle Program (SSP), including industry, academia, and other Government institutions, the Technical Exchange Panel participated in an organized "brain-storming" session directed at potential TPS debris mechanisms. The intent of this Technical Exchange Forum (TEF) was to obtain insight from a broader spectrum of the technical community, which was not available through normal SSP channels. The TEF resulted in dozens of recommendations for consideration by the ET WG, and approximately one-third of the Technical Exchange Panel was retained by SSP to provide consultation and perform specialized testing in support of the investigation. The briefings and recommendations of the TEF are documented in the formal written report to the CAIB.

11.2.5 Independent S&MA Assessment

A team of independent S&MA reviewers, separate from the S&MA support to the fault tree closure process, conducted an independent review of critical documentation. As a sampling check against the contractor process for treating manufacturing discrepancies, the 662 NCDs written against ET-93 were reviewed, along with the 571 IPRAs. A total of 43 observations, primarily paperwork documentation issues, were identified; none was judged to be serious enough to justify a safety-of-flight concern, neither generic to the contractor's system nor specific to ET-93. The team also assessed all hazards and Failure Modes and Effects Analysis and Critical Items List (FMEA/CIL) items that pertain to the ET. With respect to the ET risk documentation, it was determined that no credible STS-107 LOCV causes had been left out of the fault tree.

The fault tree analysis is now complete; all of the 3,470 blocks have been dispositioned. A total of 142 blocks (basic events) have been determined to be possible contributors to damage to the orbiter left wing. Of the basic events, 135 were associated with release of TPS debris, and the remaining 7 events reflected the possibility of release of non-TPS debris from the interface regions. Of the 135 possible TPS debris sources, 6 of them were judged to be likely contributors to the debris that emanated from the forward bipod area at 82 seconds into flight.

The ET WG presented the results of the fault tree development, relevant to multiele-Ment closure, to the MEICT Board on May 21, 2003. Seven multielement block closures, capturing 39 integrated fault tree blocks, were discussed in detail. The MEICT approved five of the seven closures and requested further evaluation of the two remaining multielement blocks: G521, ET Debris Induced by External Sources, and G506, Operational Anomalies. The required data subsequently were provided, and the MEICT approved closure of the ET multielement blocks on June 4, 2003.

The ET WG presented the results of the entire fault tree analysis to a joint session of the OVE WG and NAIT on June 4, 2003, and to the CAIB on June 5, 2003. One action item was assigned by the CAIB and is being worked through the NAIT action log, to be completed on or before June 30, 2003.

11.3 LESSONS LEARNED AND RECOMMENDATIONS

The ET WG investigation yielded 142 fault tree findings, several areas for improvement in the ET Project, and some observations and associated recommendations relative to the investigative process.

11.3.1 Findings

A total of 142 basic events on the fault tree were determined to be possible contributors to damage to the STS-107 orbiter left wing. Six of these events, all related to TPS, were judged to be likely contributors to the debris that emanated from the forward bipod area at 82 seconds into flight. These findings are described completely in the final report to the CAIB.

Note: The observations and recommendations for improvements in the ET Project will be provided in a separate report to the ET Project Office.

11.3.2 Observations and Recommendations

During the course of the investigation, the following observations with respect to process were noted.

11.3.2.1 Observation No. 1

There was a certain amount of confusion over the focus of the fault tree. Strictly speaking, it should have been directed specifically toward events that could have led to the loss of STS-107; however, good engineering judgment dictated that the scope should be broader and that the SSP could gain a large benefit with a small additional expenditure of resources by expanding the fault tree investigation to identify other events that could cause a similar result in the future.

Recommendation:

As a minimum, state in the documentation guiding incident investigations that the working groups should determine factors or events that could have been causal to the incident and also any other factors or events that might be similar, but, for one reason or another, did not cause this particular incident.

11.3.2.2 Observation No. 2

While initial completion schedules for the investigation were aggressive and did ensure no less than “full throttle” effort by the working groups, these schedules caused compromises to be made in testing and analysis options.

Recommendation:

Initial schedules should be reassessed and revised at the earliest opportunity during an investigation based on assessments of the magnitude of technical efforts that will be required during the investigation. This will ensure that severe shortcuts will not be required to meet schedules, which could possibly adversely affect the quality of the investigation.

11.3.2.3 Observation No. 3

The urgencies of flight schedule and budget too often force NASA into a reactive mode when dealing with contingencies. There seems to be neither time nor resources available to proactively seek out and solve problems before they occur.

Recommendation:

Create a functional organization, either within SSP or accountable to it, that would proactively seek out, define preemptive actions against, and advocate resources to correct the so-called "Unknown Unknowns" that threaten mission success.

11.3.2.4 Observation No. 4

Changes in precursors, materials, requirements, and vendors create a turbulent environment that makes control of TPS materials, systems, and processes difficult for all elements of SSP.

Recommendation:

Form a TPS senior expert advisory board to be made available to all SSP elements as a resource to assess future changes, provide continuity, and assess credibility of verification.

11.3.2.5 Observation No. 5

The current SSP management scheme at MSFC has the Chief Engineer reporting to the Project Manager, which tends to inhibit proper checks and balances on technical issues.

Recommendation:

Re-institute at MSFC an organizational separation of the Project Manager and Chief Engineer functions.

11.3.2.6 Observation No. 6

S&MA is expected to take a leadership role in incident investigations; however, S&MA investigative procedures and required forms are not in place. Furthermore, S&MA does not have its own funding for investigations, having to rely on the Project Manager, for example, to provide travel funding.

Recommendation:

S&MA should develop an Operational Instruction (OI) for incident investigations. Early in the process, discretionary funding should be provided to S&MA.

Note: Other observations noted during the course of the investigation were technical in nature rather than organizational and/or process-oriented and will be included in the formal written report; they have already been made available to SSP for consideration in the return-to-flight activity, currently under way.

12. SPACE SHUTTLE MAIN ENGINE WORKING GROUP

12.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

Following the loss of Space Shuttle Columbia (OV-102) on February 1, 2003, the Marshall Space Flight Center (MSFC) Space Shuttle Main Engine (SSME) Contingency Working Group was activated in accordance with MSFC-SSCP-5-77, MSFC Space Shuttle Contingency Plan (called "Contingency Plan"). Prior to every launch, contingency working group membership is established and documented by the MSFC Shuttle Integration Office (MP71). For STS-107, the MSFC Space Shuttle Contingency Working Group List was released on January 9, 2003. On February 1, after activation of the SSME Contingency Working Group, one member was added, to incorporate a needed technical discipline, and one was replaced, due to unavailability, to make up the final SSME Working Group (WG).

The STS-107 SSME WG members, their organization codes, and their technical areas of expertise are shown below.

Helen McConnaughey, Ph.D.	TD50	Chairperson
Ron Tepool	MP21	Alternate Chairperson
Pravin Aggarwal	ED22	Stress Analysis
Martin Carson	QS20	Safety and Mission Assurance (S&MA)
Tony Fiorucci	TD63	Dynamics Analysis
Brian Goode	ED25	Thermal Analysis
Charles Horne	ED14	Software and Controls
Rob Lambdin	ED35	Materials and Processes
Lewis Maddux	TD51	Engine Systems
Tom Rieckhoff	TD53	Photographic Engineering Analysis

The responsibility of the SSME WG was to determine if the SSME was the primary contributor to the STS-107 Loss of Crew and Vehicle (LOCV). The organization of the SSME WG was structured to focus MSFC propulsion system expertise and SSME experience on the investigation. The SSME WG Chairperson was the Manager of the Vehicle and Systems Development Department in the MSFC Space Transportation Directorate. The Alternate Chairperson was the SSME Project Office Chief Engineer. The SSME WG was supported by the broad array of engineering resources from MSFC, Space Shuttle contractors, and other NASA centers, as required.

12.2 PROCESSES/PROCEDURES USED

The SSME WG conducted its investigation in accordance with MWI 8621.1A, Close Call and Mishap Reporting and Investigation Program; NPG 8621.1, NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping; and NPD 8621.1H, NASA Mishap and Close-Call Reporting, Investigating, and Recordkeeping Policy.

The first activity of the SSME WG involved the survey and impoundment of data relevant to the investigation. STS-107 SSME performance data, all SSME hardware, and all SSME processing paperwork were impounded at NASA centers (MSFC, Kennedy Space Center (KSC), and Stennis Space Center) and at all contractor sites. Later, as the investigation progressed, the initially imposed data access restrictions were modified, with the approval of the SSME WG and NASA Accident Investigation Team (NAIT).

The SSME WG coordinated the combined efforts of its members, the MSFC support team, and support teams from Rocketdyne and Pratt & Whitney. Throughout the investigation, senior independent reviewers were consulted relative to the investigation approach, results, and conclusions. Three primary methods of investigation were employed:

1. SSME hardware pedigree, software pedigree, and operational processes were evaluated.
2. All SSME and SSME-pertinent data from STS-107 were analyzed for all mission phases.
3. A fault tree analysis was conducted considering the SSME as the primary contributor to the STS-107 LOCV.

The evaluation of the SSME hardware pedigree included an examination of all configuration discrepancies and a review of contractor records, with special attention given to off-nominal processing and engineering changes flown for the first time on STS-107. The evaluation of the software pedigree included an examination of software history, verification, and certification. Further, the STS-107-specific software generation from build requirements through verification was reviewed. Results of the SSME avionics checkouts using the STS-107 software also were reviewed. The evaluation of SSME operational processes included an examination of work authorizing documents, closeout photos, and flash reports for SSME ground-related processing activities. All of these evaluations of hardware, software, and processing repeated examinations previously conducted as part of normal support of the Space Shuttle Program (SSP) flights.

The analysis of STS-107 SSME performance data and SSME-related data through all mission phases constituted an extension of and a more stringent and detailed approach to processes already accomplished in support of SSP flights. Data sources for the analysis included digital performance data from both the SSME and orbiter, high-speed digital data retrieved from the Orbiter Experiments (OEX) recorder, and photographic data. The data review effort also included development of an events timeline.

The development of a fault tree and subsequent examination of proposed failure scenarios represented the most significant focus of the SSME WG investigation effort. Generation and organization of reasonable scenarios were accomplished through iterative deliberations by the SSME WG. Senior independent reviewers were consulted and concurred with the fault tree content and approach. The events timeline and data analysis results were considered for impact to the scenario list. All SSME-to-orbiter interfaces were analyzed to ensure that interactions between the SSME and orbiter were captured within the fault tree. Hazard reports and the SSME Failure Modes and Effects Analysis and Critical Items List (FMEA/CIL) were reviewed to ensure that the proposed fault tree represented a comprehensive collection of potential mishap scenarios. Extensive data analyses and mathematical modeling were undertaken to determine if any of the scenarios indicted the SSME as the primary contributor to the STS-107 LOCV.

The SSME WG presented the results of the fault tree development and the scenario closure analysis portion of the investigation to the Multi-Element Integration Closure Team (MEICT) on April 3, 2003. This same information was presented to the NASA Accident Investigation Team (NAIT) and the Orbiter Vehicle Engineering Working Group (OVE WG) on April 4, 2003, and then to the Columbia Accident Investigation Board (CAIB) on April 5, 2003. The NAIT recommended closeout of the SSME fault tree, and on April 15, 2003, the CAIB concurred, with comments on the NAIT recommendation for closeout.

Following the fault tree presentations, the SSME WG compiled its final report in accordance with NPG 8621.1, NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping, which covered all aspects of the investigation and included a list of findings, observations, and recommendations. The final report was submitted to the NAIT on April 25, 2003.

12.3 LESSONS LEARNED AND RECOMMENDATIONS

The SSME WG investigation yielded one finding and two investigative process observations and associated recommendations as listed below.

12.3.1 Finding

The SSME WG found no credible evidence that the SSME was the primary contributor to the STS-107 LOCV.

12.3.2 Observations and Recommendations

12.3.2.1 Observation No. 1

During the investigation, there was confusion regarding the details and intent of pertinent contingency plans and the SSME WG's relationship with various managerial layers and other investigative groups. This confusion seemed to stem from differences between NASA centers in terms of approaches to mishap investigation and in terms of roles and responsibilities. It resulted in cumbersome communications, inefficiencies, and delays.

Recommendation:

SSP should review and modify, as necessary, all related contingency plans to increase effectiveness and consistency in a number of areas, including:

1. Roles and responsibilities of investigative groups; program and project, institutional, and safety, quality, and mission assurance managers; and integration groups (The need for independence of an investigative group relative to the Project Office of the element or system being investigated also should be addressed.)
2. Necessary reporting channels
3. Data and hardware impoundment requirements, including:
    a. Which data and hardware are subject to impoundment
    b. Purpose for impoundment (preservation of data, sensitivity of information, etc.)
    c. Backup requirements for data subject to impoundment
    d. Who is to be responsible for impoundment

   e. Release procedures for impounded data and hardware
   f. When impounded data or hardware should be released
   g. Who should have access to data and/or hardware, etc.

   Care should be taken to allow timely access to hardware and release of flight data to appropriate parties who legitimately need it.

4. Contingency working group processes, to provide for more efficient communication with management and other working groups (minimizing layers, middlemen, and unnecessary reporting) and facilitate accomplishment of the investigation (minimizing bureaucratic baggage)

It is recommended that all resultant contingency plans be reviewed by SSP and Project Offices prior to each launch to ensure uniform preparedness and familiarity with all related plans and associated processes.

12.3.2.2 Observation No. 2

During the investigation, difficulty was encountered by SSME WG members and supporting engineers in accessing and using vehicle data for mission phases following ascent.

Recommendation:

SSP should pursue improvements in accessibility and usability of all previous flight and historical data across all Space Shuttle elements.

13. REUSABLE SOLID ROCKET MOTOR WORKING GROUP

13.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

Following the loss of Space Shuttle Columbia (OV-102) on February 1, 2003, the Marshall Space Flight Center (MSFC) Reusable Solid Rocket Motor (RSRM) Contingency Working Group was activated in accordance with MSFC-SSCP-5-77, MSFC Space Shuttle Contingency Plan (called "Contingency Plan"). Prior to every launch, contingency working group membership is established and documented by the MSFC Shuttle Integration Office (MP71). For STS-107, the MSFC Space Shuttle Contingency Working Group List was released on January 9, 2003.

Upon activation of the RSRM Contingency Working Group on February 1, 2003, two members were not immediately available to support the investigation, so their previously identified alternates replaced them. The RSRM Contingency Working Group soon was transitioned to the RSRM Working Group (WG) to support the activities of the Multl-Element Integrated Closure Team (MEICT), NASA Mishap Response Teleconference (MRT; called "Mishap Response Team"), Columbia Accident Investigation Board (CAIB), and, upon its later formation, the NASA Accident Investigation Team (NAIT).

The STS-107 RSRM WG members, their organization codes, and their technical areas of expertise are shown below.

Paul McConnaughey, Ph.D.	ED20	Chairperson
Andrew Schorr	MP51	Alternate Chairperson
Chris Cianciola	QS20	Safety and Mission Assurance (S&MA)
J. Louie Clayton	ED25	Thermodynamics and Heat Transfer
James R. Hawkins	ED22	Strength Analysis
Pat Lampton	TD51	Propulsion
Tomas E. Nesman	TD63	Fluid Physics and Dynamics
Marie Louise Semmel	ED34	Manufacturing and Processes
Scott Tillery	ED34	Manufacturing and Processes

The responsibility of the RSRM WG was to determine if the RSRMs were either a root cause or a contributing root cause of the STS-107 Loss of Crew and Vehicle (LOCV). The organization of the RSRM WG was structured to focus MSFC's experience and expertise in propulsion systems and a range of other disciplines to assess RSRM performance and any potential links to the loss of Columbia. The RSRM WG Chairperson was the Manager of the Structures, Mechanics, and Thermal Department within the Engineering Directorate at MSFC, and the Alternate Chairperson was the Lead for RSRM Engineering Design within the RSRM Project Office. The RSRM WG was independent of the RSRM Project Office and used a broad array of support from MSFC engineering resources, other NASA centers, Space Shuttle contractors, and independent support contractors and consultants.

13.2 PROCESSES/PROCEDURES USED

The RSRM WG conducted its investigation in accordance with MWI 8621.1A, Close Call and Mishap Reporting and Investigation Program; NPG 8621.1, NASA Procedures and

Guidelines for Mishap Reporting, Investigating, and Recordkeeping; and NPD 8621.1H, NASA Mishap and Close-Call Reporting, Investigating, and Recordkeeping Policy. The RSRM WG first convened at 1:00 p.m. Eastern Standard Time (EST) on February 1, 2003, in response to the declared contingency for STS-107.

The first activity of the RSRM WG was to ensure impoundment of all STS-107 RSRM hardware and data. This included processing and build paperwork, performance data, flight hardware, and postflight assessment data at MSFC, Kennedy Space Center (KSC), and Alliant Tech Systems (ATK) Thiokol. Later, as the investigation progressed, the initially imposed restrictions on data, paperwork, and hardware were relaxed, as appropriate, with approval of the RSRM WG, MRT, NAIT, and CAIB.

The RSRM WG coordinated the combined efforts of its members, the MSFC support team, and support teams from ATK Thiokol and United Space Alliance (USA). Throughout the investigation, several independent senior review teams were consulted relative to the investigation approach, results, and conclusions. Three primary methods of investigation were employed:

1. A detailed review of the STS-107 motor set integrity, with an emphasis on looking for out-of-family anomalies and potential links to the loss of Columbia
2. A top-down (fault tree) analysis, based on physical mechanisms and the assumption that the RSRMs were responsible for the loss of Columbia
3. A cross-linking and correlation of the two preceding approaches, to determine if the RSRMs were a cause of or contribution to the loss of Columbia upon reentry

The motor set integrity assessment focused specifically on the motor manufacturing process and the subsequent in-flight performance. The objectives of this assessment were to: 1) review all planned and unplanned changes throughout all phases of the RSRM's life (see Figure 13-1) to identify and investigate any out-of-family conditions, and 2) determine if a credible link to the STS-107 Columbia LOCV could be established. The RSRM WG collected and analyzed data and records related to RSRM build, transportation, stacking history, prelaunch, launch, flight conditions, performance, recovery, and postflight operations hardware assessment in search of any discrepancies or anomalies. All potentially plausible scenarios that might link the RSRMs to the STS-107 LOCV were identified and incorporated into the fault tree analysis. Subsequently, all available pertinent data, records, and hardware were studied and the necessary analyses conducted to determine if each scenario was credible.

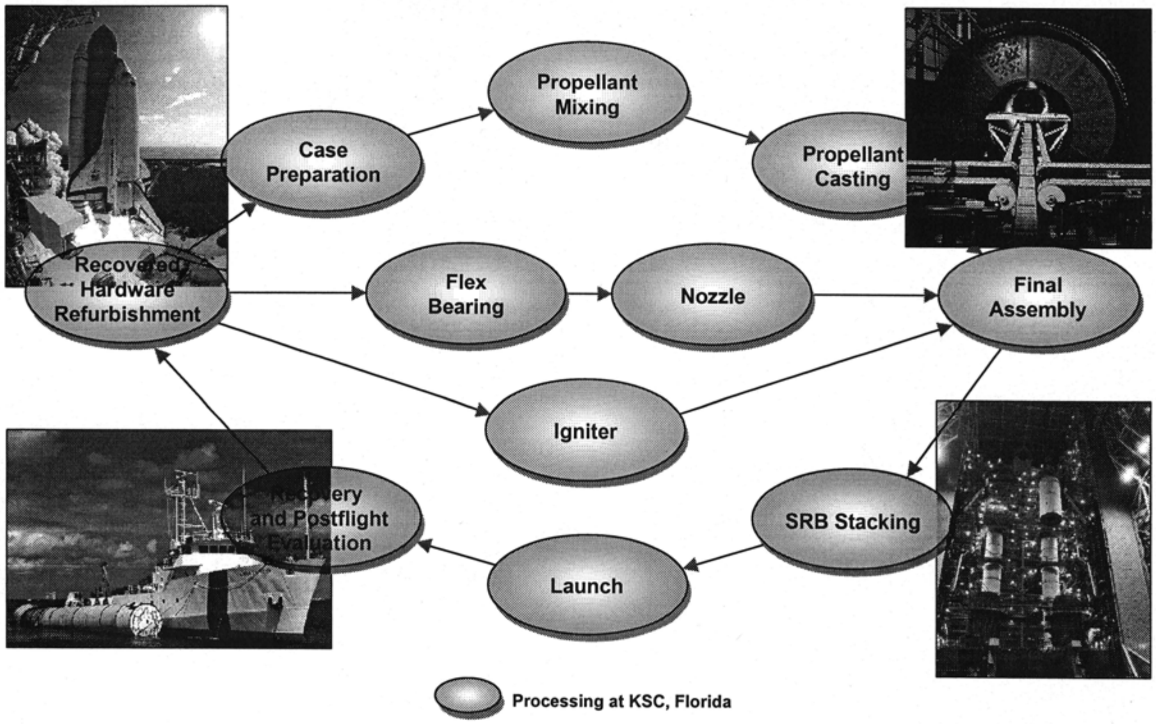

Figure 13-1. RSRM Process Flow

The RSRM WG also used a top-down approach, known as fault tree analysis, to identify and organize the sequences and combinations of physical events. The RSRM WG assumed that the top undesired event on the fault tree was "Loss of Orbiter on Reentry Due to Anomalous RSRM Behavior." The RSRM WG began with the assumption that the RSRMs were responsible for the LOCV and attempted to identify every credible scenario or combination of events that could lead to the accident. The resulting fault tree was based on physical mechanisms at the system level, with an emphasis on identifying out-of-family anomalies. The result of this analysis was mapped directly into the Columbia Accident Investigation Fault Tree for the overall program. All of the RSRM fault tree blocks were part of the MEICT-identified multielement closure process.

In developing the potential fault events, the RSRM WG used existing baseline program risk documentation to ensure that all potential failure causes were identified and considered. Documentation considered included: RSRM Hazard Reports, RSRM Failure Modes and Effects Analysis, Critical Items List, and Program-Level Integrated Hazard Analysis. Each hazard cause was evaluated to determine potential impact on each bottom-level event on the RSRM fault tree. These hazard causes then were considered in closure of the subject events. A matrix map linking the fault tree blocks to RSRM-related program risk documentation was created from this evaluation.

Four independent reviews of the RSRM WG fault tree were conducted: one review by a team of senior S&MA personnel, a second review by the MSFC Systems Working Group, and two different reviews by an MSFC meritorious team.

The closure guidelines established by the RSRM WG required consideration of all available data: all Space Shuttle system elements, the Mobile Launch Platform (MLP), past flights and flight history, ground test, and (where appropriate) ascent performance reconstruction. The RSRM WG emphasis was on postflight hardware assessment and ballistics. Multiple pieces of evidence for closure rationale were used, when available, including primary and secondary (and sometimes tertiary) evidence. Typically, four to ten pieces of supporting data for each closure were cited.

The closure process required the RSRM WG members and ATK Thiokol counterparts to jointly formulate closure rationale. Actions were assigned to MSFC or ATK Thiokol personnel for generation or collation of data to support the closure rationale. Data analysis for closure was significantly more broad and in-depth than typical RSRM postflight analysis. For example, flight data from the orbiter, solid rocket boosters, and Space Shuttle Main Engines (SSMEs) were analyzed in addition to RSRM data for fault tree closure. Internal documentation at ATK Thiokol was reviewed to support the build integrity assessment, and personal hardware inspections by the RSRM WG members verified some closure rationale. Completed rationale and supporting data were brought to the RSRM WG and ATK Thiokol for review and approval.

The data were scrutinized for quality, rigor, consistency, depth, and accuracy. During the review, all closure rationale forms were modified to some degree. Approximately half were sent back for updates and further review, and several underwent multiple reviews by the RSRM WG. Final closure acceptance required complete consensus by the RSRM WG members and their ATK Thiokol counterparts. Each approved closure then was signed by MSFC and ATK Thiokol counterparts, the fault tree Block Lead, S&MA, and the RSRM WG Chairperson.

Thirty-five potentially credible failure scenarios were developed and assessed in detail by the RSRM WG, which found no credible evidence that the RSRMs were either a root cause or a contributing root cause of the STS-107 LOCV.

The RSRM WG presented results of the fault tree development and the scenario closure analysis portion of the investigation to the MEICT on April 7, 2003. This same information was presented to the NAIT and the Orbiter Vehicle Engineering Working Group (OVE WG) on April 8, 2003. The NAIT recommended closeout of the RSRM fault tree, and on April 9, 2003, the CAIB concurred, with comments on the NAIT recommendation for closure.

Following the fault tree presentations, the RSRM WG compiled its final report in accordance with NPG 8621.1, NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping, which covered all aspects of the investigation and included a list of findings relative to the loss of Columbia. The final report was signed on May 21, 2003, and subsequently submitted to the NAIT.

13.3 LESSONS LEARNED AND RECOMMENDATIONS

The RSRM WG investigation yielded one finding and one investigative process observation and associated recommendations, as follows.

13.3.1 Finding

The RSRM WG found no credible evidence that the RSRMs were either a root cause or a contributing root cause of the STS-107 LOCV.

13.3.2 Observation and Recommendation

The appropriate documentation (NPG 8621.1, NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping, and the Contingency Plan) was in place to define the actions required in the event of a contingency; however, during the course of the investigation, the following was noted.

Observation:

The defined contingency plans clearly delineate appropriate roles and responsibilities for both Government and contractor personnel to follow in the event of a contingency; however, once the initial hardware and data lockdown and impoundment actions were accomplished, the transition from contingency working group to investigation working group and associated interfaces (intergroup communication and reporting channels) were not as well defined.

Recommendation:

It is recommended that the Space Shuttle Program (SSP) and MSFC Contingency Plans be updated to more clearly define the transition between the contingency working group and working group phases of the investigation, including specific roles and responsibilities of the individual working groups. This additional clarification would significantly enhance the flow and communication of necessary data and analyses, and, in turn, facilitate the investigative process.

Note: Other observations made during the course of the investigation were technical in nature rather than organizational and/or process-oriented and were passed on to the SSP Office at the Program Resources Control Board on May 29, 2003, for appropriate disposition.

14. SOLID ROCKET BOOSTER WORKING GROUP

14.1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

Following the loss of Space Shuttle Columbia (OV-102) on February 1, 2003, the Marshall Space Flight Center (MSFC) Solid Rocket Booster (SRB) Contingency Working Group was activated in accordance with MSFC-SSCP-5-77, MSFC Space Shuttle Contingency Plan (called "Contingency Plan"). Prior to every launch, contingency working group membership is established and documented by the MSFC Shuttle Integration Office (MP71). For STS-107, the MSFC Space Shuttle Contingency Working Group List was released on January 9, 2003.

The SRB Contingency Working Group met for the first time the afternoon of February 1, 2003, with all members in attendance. Soon after the initial meeting, the SRB Contingency Working Group transitioned into the SRB Working Group (SRB WG) to support the activities of the Multi-Element Integrated Closure Team (MEICT), NASA Mishap Response Teleconference (MRT; called "Mishap Response Team"), Columbia Accident Investigation Board (CAIB), and, upon its later formation, NASA Accident Investigation Team (NAIT). During the first week of the investigation, one member was replaced due to involvement in another contingency working group. Approximately 3 weeks after the initial meeting, a member was added to provide additional support in the flight structures area, and another member was added approximately 5 weeks into the investigation to support system-level integration of fault tree elements.

The STS-107 SRB WG members, their organization codes, and their technical areas of expertise are shown below.

Pete Rodriguez	ED20	Chairperson
Joe Lusk	MP41	Alternate Chairperson
Darrell Davis	ED25	Thermodynamics and Heat Transfer
Joe B. Davis	MP41	Pyrotechnics
Jeff Dilg	ED23	Flight Structures
Don Ford	UP30	Systems Engineering
Joe Gentry	ED23	Flight Structures
Rusty Jones	TD51	Propulsion
Tina Malone	ED33	Materials and Manufacturing Processes
Malissa Meadows	ED15	Electrical and Instrumentation
Boris Pagan	TD55	Thrust Vector Control System
Tom Rieckhoff	TD53	Photographic Analysis
George Story	TD51	Booster Separation Motors
Randall Tucker	QS20	Safety and Mission Assurance (S&MA)
Renee Wilson	ED22	Management Support Assistant

The responsibility of the SRB WG was to determine if the SRBs were a contributor to the STS-107 Loss of Crew and Vehicle (LOCV). The organization of the SRB WG was structured to focus MSFC's experience and expertise in structures and propulsion systems and specific SRB critical components (specifically the Booster Separation Motors and Thrust Vector Control System). The SRB WG Chairperson is the Deputy Manager of the Structures, Mechanics, and Thermal Department within the Engineering Directorate at MSFC, and the Alternate Chairperson is the Assistant Project Manager for the SRB Project Office. The leadership and majority of the members of the SRB WG were selected from organizations different from the SRB Project Office to provide an independent investigation. The SRB WG used a broad array of support from MSFC engineering resources, other NASA centers, Space Shuttle contractors, and independent support contractors and consultants. The SRB WG established a Senior Advisory Group with members consisting of retired experts in Solid Rocket Motor (SRM) and SRB structural and propulsion systems. The Senior Advisory Group provided expert assistance in fault tree development, closure rationale evaluation, and return-to-flight recommendations.

14.2 PROCESSES/PROCEDURES USED

The SRB WG conducted its investigation in accordance with MWI 8621.1A, Close Call and Mishap Reporting and Investigation Program; NPG 8621.1, NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping; and NPD 8621.1H, NASA Mishap and Close-Call Reporting, Investigating, and Recordkeeping Policy. The SRB WG first convened at 2:00 p.m. Eastern Standard Time (EST) on February 1, 2003, in response to the declared contingency for STS-107.

On February 2, 2003, all the SRB hardware and related documentation associated with STS-107 were impounded and placed under 24-hour surveillance. This included processing and build paperwork, performance data, flight hardware, and postflight assessment data at MSFC, Kennedy Space Center (KSC), and United Space Alliance (USA) at KSC. As the investigation progressed and hardware components were assessed, selected hardware components were released for continued processing. Many hardware components made from non-corrosion-resistant steel were released temporarily for application of corrosion-preventive grease and then returned as accident investigation evidence. Any investigation-related processing of the impounded hardware was meticulously documented with photographs, written procedures, and signed hardware release authorization sheets.

USA, the SRB prime contractor, formed investigation subteams that paralleled the areas of discipline of the SRB WG. With this format established, the SRB WG members became active members in the following USA investigation subteams:

1. Electronics and Instrumentation
2. S&MA
3. External Materials and Thermal Protection Systems
4. Loads and Environments
5. Parachutes
6. Pyrotechnics and Booster Separation Motors
7. Structures
8. Thrust Vector Control System

Each subteam initially developed team-focused fault trees that later were integrated into the final SRB WG fault tree. The integration process involved multiple fault tree development meetings, Senior Advisory Group reviews, and an independent review from the MSFC STS-107 Systems Working Group. Figure 14-1 shows the process followed.

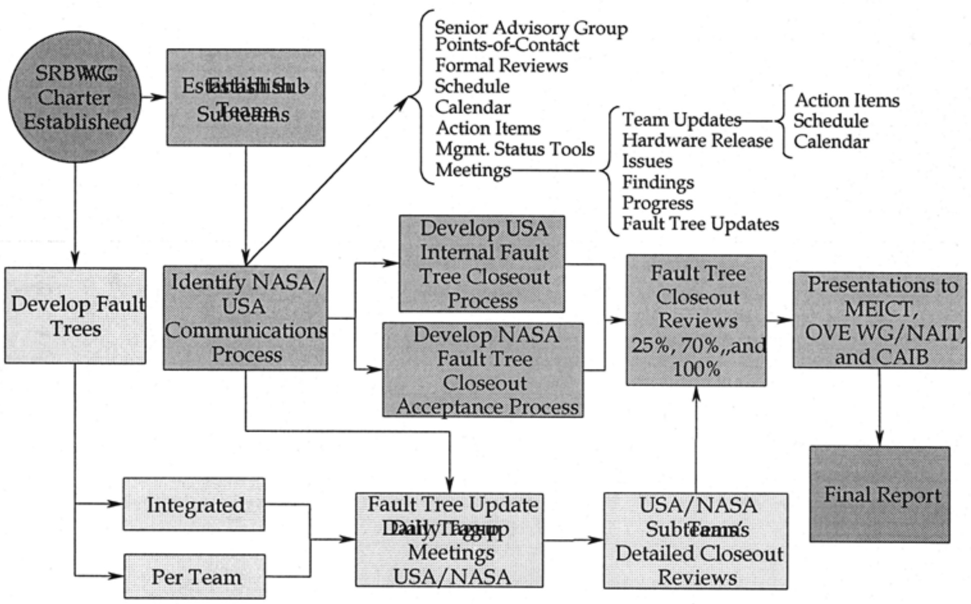

Figure 14-1. SRB WG Process Flow

The SRB WG and USA subteams developed a fault tree that contained 509 blocks. After many meetings and discussions, the Investigation Team (composed of SRB WG and USA/NASA subteams) decided on a total of 88 blocks that would encompass all the necessary data to close out the entire fault tree. These 88 blocks are discussed in detail in the SRB WG final report to the CAIB. In order to identify the appropriate level of rationale needed to close out the 88 blocks, the SRB WG and USA agreed to classify hardware into two groups: 1) retrieved and 2) not retrieved. For hardware that was not retrieved, the evidence of how it performed was not readily available, so it was critical that a significant level of detail from all available documentation be used to assure understanding of the condition of the hardware prior to flight. Table 14-1 shows a comparison of the primary and secondary data sources used to develop the closure rationale for hardware retrieved and not retrieved.

Table 14-1. SRB WG Data Used for Closure Rationale Development

Data Used for Closure Rationale	Hardware Retrieved	Hardware Not Retrieved
Postflight Assessment	P	N/A
SRB WG Reassessment	P	N/A
Video and Photography	P	P
Flight Loads Analysis	P	P
Flight Data	P	P
10MNL-0035 Requirements Document	P	P
Comparison to Retrieved Hardware With Equal Processing	S	P
As-Designed Documentation	S	P
As-Built Documentation	S	P
Engineering Changes Affecting STS-107	S	P
Problem Reports	S	P
Squawks	S	P
Nonconformance Reports	S	P
SRB Buildup Documentation	S	P
Consumables Usage	S	P
Ground Operations Buildup Documentation	S	P
NASA ALERTS	S	P
Hazard Analysis Correlation to Fault Tree	S	P
Critical Items List (CIL) Review	S	P
SRB Waiver List Review	S	P

P = Data used as primary source for closure rationale development
S = Data used as secondary source for closure rationale development
N/A = Not applicable

The acceptance of each fault tree block closure rationale was a multistep, sequential process that started with the subteams' developing an initial rationale and ended with the signing of a Certificate of Fault Tree Acceptance (COFTA) by the SRB WG. This sequential process is summarized as follows:

1. The subteams, including input from the SRB WG members and the Defense Contract Management Agency (DCMA) representative, developed initial closure rationale and identified the documentation used for rationale development.

2. The USA SRB Chief Engineer's Office performed an initial assessment of the closure rationale to ensure completeness of data, format, system flow-engineering accuracy, and relevance to the identified failure scenario.

3. The SRB WG Chairperson, along with the MSFC S&MA representative, performed individual one-on-one reviews with the NASA/USA subteam members on the closure rationale for each fault tree block to be closed out. Areas assessed during these reviews were adequacy of photographic and/or engineering evidence to answer the failure scenario, completeness of rationale statement, relevance of data used, and uniformity of agreed-upon standard statements.

4. The SRB WG, USA, and the SRB Project Office held combined meetings for specific groups of fault tree blocks. During these meetings, the USA responsible team member presented to the entire group the rationale for each fault tree block closure. After all discussions pertaining to an individual fault tree block closure were answered, the SRB WG Chairperson obtained verbal concurrence from all members of the SRB WG. If any member of the SRB WG did not concur, actions were assigned to respond to the concerns and the fault tree block was reassessed at the next meeting. Additionally, after each fault tree block closure was reviewed, the SRB WG Chairperson solicited verbal approval from the DCMA representative. Once the verbal approvals were obtained, the fault tree blocks were deemed ready for incorporation into a COFTA.

The SRB WG performed three major reviews for all 88 closure blocks: 25%, 70%, and 100% completion of the fault tree. These review meetings were held at the USA facilities at KSC, Florida, and occurred at the end of the weeklong series of one-on-one meetings and SRB WG/USA/SRB Project Office combined meetings. At the conclusion of the reviews, the SRB WG members signed a COFTA.

The development of the fault tree was a top-down approach wherein the primary block was identified as the *"Solid Rocket Booster Causes the Loss of Mission, Vehicle, and Crew."* The fault tree was organized into three major branches:

1. Anomalous Loads and Environments on SRB Adversely Affect Mission, Vehicle, and Crew

   All natural and induced environments were addressed within this branch. Additionally, all loads on the SRB and those transmitted through the structural interfaces with the External Tank (ET) and Mobile Launcher Platform (MLP) were assessed, including prelaunch, launch, liftoff, ascent, and booster separation.

2. Anomalous Performance of Active Subsystems

   The SRB WG identified two major subsystems as providing the "intelligence" to the SRBs: Electrical and Instrumentation Subsystem and Thrust Vector Control System.

3. SRB Debris Impacts the ET and Orbiter

   This branch contained the majority of blocks of the SRB WG fault tree. It was arranged by major SRB hardware component from the top of the SRB (nose cap) to the interface with the MLP (aft skirt). Every component that generated debris, regardless of the size of the debris, was identified.

To ensure that the SRB WG fault tree was integrated with the overall fault tree from the MEICT, the SRB WG Chairperson assigned two individuals, the systems engineer and S&MA representative, to serve as the interface to the MEICT. They jointly identified the fault tree blocks that required data exchange between other vehicle elements (ET, SRM, orbiter, and Space Shuttle Main Engine (SSME)) and the SRB for closure. These blocks were identified as multielement blocks. The SRB WG fault tree had 39 multielement blocks, all of which were addressed at the system level in the MEICT fault tree.

The SRB WG adopted the philosophy of "All Hardware Is Guilty Until Proven Innocent" and used this as a guiding theme for many discussions and decisions for accepting closure rationale and data. The investigation produced a total of 122 references or attachments that were used throughout the investigation as evidence-providing material for the closure rationale of each fault tree block.

The SRB WG presented the results of the fault tree development and scenario closure analysis portion of the investigation to the MEICT on May 22, 2003. A slightly modified version was presented to the NAIT and Orbiter Vehicle Engineering Working Group (OVE WG) on May 28, 2003. The NAIT recommended that two of the blocks related to the Booster Separation Motor debris generation remain open due to the uncertainty, albeit very small, in the closure rationale. The SRB WG presented the fault tree and closeout data to the CAIB on May 29, 2003, and all closeout rationale was accepted with the exception of four fault tree blocks related to the SRB forward bolt catchers. These blocks are still open at the time of this writing and will be completed after a series of structural, dynamic, and thermal tests have been completed.

Following the fault tree presentations, the SRB WG began compiling its final report in accordance with NPG 8621.1, NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping, which covered all aspects of the investigation and included a list of findings relative to the loss of Columbia.

14.3 LESSONS LEARNED AND RECOMMENDATIONS

14.3.1 General

During the course of the investigation, the various activities and ensuing discussions produced observations (recorded herein with a corresponding recommendation) that potentially could improve the efficiency of the investigation and provide for better availability of data should an investigation of this magnitude be required again. These investigation process-related observations deal with lessons learned for improvement of the organization, process, data reporting, and overall performance of the investigation.

The appropriate documentation (NPG 8621.1H and MSFC-SSCP-5-77) was in place to define the actions required in the event of a contingency. During the course of the investigation, however, the following observations were noted.

14.3.2 Observations and Recommendations

14.3.2.1 Observation No. 1

During the second week of the investigation, cell phones were requisitioned and obtained for all team members. This proved to be an invaluable communications tool. There often was a need to hold discussions after hours or when members were in different parts of the country during the investigation. Instant access to the team members was critical to effective transmittal of data.

Recommendation:

It should be an investigation requirement that all teams use cell phones during the investigation.

14.3.2.2 Observation No. 2

Shortly after the investigation began, all investigation teams established Senior Advisory Groups to help in the review of the fault trees. The SRB WG used this emeritus group of professionals as regular consultants that not only reviewed the fault tree development but also participated in reviewing closure rationale, developing recommendations for return to flight, and reviewing final presentations.

Recommendation:

Establish a focused set of requirements for Senior Advisory Groups so that effective use of the skills and knowledge can be made throughout the entire investigation process.

14.3.2.3 Observation No. 3

During the investigation, there were several instances wherein the SRB WG chairperson felt that the SRB Project Office wanted to influence the process of the investigation. Recommendations from the SRB Project Office are needed and on many occasions were exceptional; however, it was not clear what the true role of the SRB Project Office was in the investigation. The SRB Project Office Chief Engineer provided exceptional support from the technical perspective and knowledge of the hardware. The decision of who was needed at certain places was influenced by the travel budget that was managed by the SRB Project Office. On several occasions, travel plans had to be changed or even canceled due to lack of available funding from the SRB Project Office.

Recommendation:

The majority of the team membership should be from organizations that are independent of the SRB Project Office; however, it is important that the SRB Project Office Chief Engineer be included on the team. The team must be solely responsible for the investigation, and the SRB Project Office always must be in a supporting role. Travel funds for the investigation team should not reside within the SRB Project Office. As soon as the investigation team is established, a separate travel budget should be allocated and managed by the team chairperson. An Operational Instruction should be established that explains roles and responsibilities such that the independence of the investigation is not jeopardized.

14.3.2.4 Observation No. 4

Weekly status reports to Level II were essential in maintaining the appropriate communications to the entire team; however, there was no official format for the presentations, so some were very long. This took valuable time away from the other participants in the investigation.

Recommendation:

Establish a format for weekly status reports to ensure that short presentations will occur first on the agenda. Also establish a limit to the length of time of each weekly status report.

14.3.2.5 Observation No. 5

During the investigation, each team worked independently in the development of the individual team fault trees. Although this gave the teams freedom to select the categories and branches within the fault tree that they deemed appropriate, it made integration with the Level II fault tree more complicated.

Recommendation:

As soon as practical, the system team must be responsible for developing an appropriate fault tree format to be used by all teams. The selection of this format must be done in conjunction with the investigation teams.

14.3.2.6 Observation No. 6

Each investigation team used different versions of the credibility classification for the closure of fault tree blocks.

Recommendation:

At the outset of the investigation, Level II should establish a preferred set of credibility classification designators such as “Improbable,” “Likely,” “Unlikely,” and “Probable.” The definition of each classification designator should be agreed upon by all investigation teams.