Section 6 - Safety Assurance

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6.1 Introduction

In 1994, an agreement between NASA and Russian Space Agency management (WG-0/RSC-E/NASA/0001) created a number of joint working groups for the real-time resolution of issues across all major disciplines. As one of these groups, the Joint Safety Assurance Working Group (JSAWG) was created whose objective was the evaluation of safety requirements for the Shuttle-*Mir* Program.

In accordance with the agreements made, this was an integrated, multifaceted program and was responsible for three primary objectives:

1st objective: Flights of Russian cosmonauts on STS-60 and STS-63. During these flights, the Russian cosmonauts participated as crew members and took part in operations, research and experiments connected with meeting the objective of independent flight of the Shuttle.

2nd objective: Flight of an American astronaut on the Russian Soyuz TM vehicle; docking of the vehicle to the *Mir* station; and extended work of the American astronaut as a crew member on board *Mir*. During this flight the American astronaut participated in operations, research and experiments connected with fulfilling the flight objectives. The American astronaut was returned to earth on board STS-71 after completion of a joint flight under the Shuttle-*Mir* Program.

3rd objective: Joint flight of the STS-71 Shuttle and the *Mir* orbital station during which the Shuttle would dock with the station and Russian and U.S. cosmonauts would conduct joint research, experiments, and other operations. Each of these objectives had its own safety assurance features.

During the course of this program it became clear that expansion of the functions of the JSAWG was essential. The JSAWG became responsible for analysis of off-nominal situations on board the *Mir* and the Shuttle, for the safety review of cargo delivered to the station, for the safe functioning of scientific hardware, and for safe conduct of operations, etc.

The work of the JSAWG began with the development of the joint principles for ensuring safety, the development of the structure and content of safety documentation and the determination of scope and status for the JSAWG.

6.2 Documentation Structure

A joint basic document WG-2/NASA/RSC E/003/2000 was developed entitled “Joint Safety, Reliability, and Quality Assurance Policies for the Shuttle/*Mir* and NASA/*Mir* Programs” (document 3-1 in Figure 6.1).

This document set forth:

- general provisions for evaluation and verification of safety during implementation of the programs;
- main technical requirements which have to be fulfilled in order to ensure mission safety;
- structure of joint documentation release and exchange of safety program documentation.

The structure of all safety documentation developed by the JSAWG is presented in Figure 6.1.

The set of documents developed by the JSAWG reflected the joint work and effort of both sides for implementation of an integrated and effective safety assurance program for *Mir* and Shuttle.

6.3 Policies and Ground Rules

As a basis for confident resolution of the objectives presented with minimum accepted risk for both sides, the following were taken into account:

- Russian and U.S. experience and knowledge accumulated during space exploration;
- Russian experience accumulated during the assurance of the safety of Salyut and *Mir* orbital stations, and Soyuz and Progress vehicles;
- U.S. experience accumulated during the assurance of the safety of Space Shuttle, payloads, and Skylab missions;
- analyses and reviews performed to assess the safety of systems, Space Shuttle and *Mir* interfaces, and operations, both nominal and off-nominal. These analyses and reviews will also ensure that documentation developed for these missions implement jointly and individually identified safety measures.

Also, as a basis of each side’s responsibility, the following principles were assumed:

- During the joint program, both sides are governed by the basic desire and intent not to inflict damage to each other's crew or hardware;
- The side installing hardware in the other side's spacecraft is responsible for impact of such hardware on safety of the mission within the scope of established requirements;
- The Russian side is responsible for ensuring the flight safety of the U.S. astronaut on the Soyuz TM and the *Mir* (including the long-term presence of the U.S. astronauts aboard the *Mir* station). The criteria, process, and requirements for the continued presence of the U.S. astronauts on board the *Mir* are delineated in the International Space Station (ISS) Phase 1 - Program Directive;
- The U.S. side is responsible for ensuring the flight safety of the Russian cosmonaut on the Shuttle;

- The U.S. side is responsible for safety during Shuttle proximity and docking operations until the initiation of the mechanical interface of the two vehicles is achieved. During operations, the Russian side shall maintain required and agreed-upon conditions for docking.
- Both sides are responsible for the safety of the joint mission. However, the Russian side is responsible for the safety of the mixed crew on *Mir*, whereas the U.S. side is responsible for the safety of the mixed crew on Space Shuttle. In the event an off-nominal situation arose, the U.S. astronauts would return to the Shuttle, and the Russian cosmonauts would return to *Mir*.
- The supplying side is responsible for the safety certification of the experiments, hardware and logistics which are to be transported or operated on U.S. and Russian spacecraft. If these experiments, hardware, or logistics have hazard potential, their safety must be certified by both sides.

The JSAWG developed the main provisions for safety assurance procedures which, in particular, provided for:

1. Safety assurance procedures, in accordance with which the safety requirements that were developed for earlier design phases of both space vehicles (Shuttle and *Mir*), were used to develop hardware as well as methods for quality control and testing. The effectiveness of safety procedures developed has been confirmed by extended use of both vehicles.

2. Joint analysis of joint flight operations and possible off-nominal situations and the development of real-time measures to control or to reduce the degree of risk.

3. The development by each side of off-nominal situations and hazardous factors (harmful effect to the habitable environment, hazardous radiation levels, external effects of space events, etc.) for the vehicle and for equipment located in the other side's vehicle. The hazard criteria were the effects of reviewed factors on crew safety, vehicle functionality, and completion of the main flight objectives.

4. Joint analysis of off-nominal situations for each side and development of a joint document that contains a listing of off-nominal situations that require joint actions to prevent them.

As the Program was expanded to multiple Shuttle/*Mir* missions, the JSAWG developed a separate set of documents for each mission, which addressed the above provisions, ending with the Joint Certificate of Flight Readiness (COFR).

Following management's decision about transferring the safety issues for payloads delivered to *Mir* and the safe functioning of scientific hardware on board *Mir* to the JSAWG, main provisions were developed for payload safety (including scientific hardware) and were documented in the "Safety Certification Agreement for Transport of Logistics and Hardware in a Pressurized Volume to and From the *Mir*" and the "Safety Certification Agreement for Experiment Hardware Operations On Board the *Mir* and Shuttle." Basic requirements were also developed for the documentation for hardware safety (document WG-2/RSC-E/NASA/2100), including the format of the safety certificates, their content, and the requirements for the hazard reports.

Based on these documents, the JSAWG performed a safety analysis of all payloads including scientific hardware transported both on Russian vehicles and the Shuttle and also conducted a safety analysis for operating and stowing these payloads on *Mir*. Each side published summary documents containing a complete list of payload safety certificates.

Based on a Directive from Team Zero, the JSAWG conducted safety assessments for the U.S. astronauts' long-duration missions on *Mir*, taking into consideration activities on board the *Mir* Station.

All of the above came together as an effective, integrated safety program for Phase 1. From initial evaluation of safety requirements to the certification of flight readiness for each mission phase, safety was assured through this comprehensive safety program.

6.4 Top Safety Joint Accomplishments

6.4.1 Preface

A significant number of design changes and operational modifications were implemented as a result of joint participation between the Russian and American partners in the JSAWG. One of the Lessons Learned engendered most of these changes, i.e. "When multiple spacecraft are on orbit, new families of requirements are created and require assessment - each orbiting spacecraft imposes specific added requirements on the other." For ease of discussion, the accomplishments have been grouped into four categories: Hardware Changes, Integrated Analyses, Joint Flight Rule Changes and Safety Operational Contributions.

6.4.2 Hardware Changes

This category summarizes those risks that were identified in the joint safety process which resulted in modifications and/or changes to flight hardware. The majority of these changes were implemented on the American side. The primary focus was not to redesign existing hardware on either side but to make modifications as necessary to enhance the safety of Shuttle/*Mir* operations.

<u>1. Modification of Criticality 1 ODS Connectors</u>
Due to the existing design of Russian avionics boxes, the primary and redundant capabilities (i.e. main power buses, logic buses, etc.) are routed through the same Russian docking mechanism connector, which violates NSTS 8080-1, Standard 20, Redundant Electrical Circuits. The JSAWG recommended, and action was taken, to separate the primary and redundant capabilities on the American

connector side of Russian-American wire harnesses. This implementation mitigated potential single-point failures (i.e. inadvertent demate of connectors) which could cause risk to the crew or vehicle during on-orbit phases.

2. Hatch Installed for STS-74, -76, -79, and -81 to Protect for Separation Redundancy

The hazard analysis for STS-71 identified that loss of pressurization in the ODS/tunnel adapter could compromise the operations of the avionics associated with the ODS structural hook opening, as well as the ability to perform the 96-bolt contingency extravehicular activity (EVA). The JSAWG recommended the addition of a hatch between the internal airlock/tunnel adapter and the ODS external airlock to isolate the two compartments and maintain redundancy for Shuttle/*Mir* undocking. This change was implemented for STS-74 through STS-81, thereby eliminating the risk of a single failure that could cause loss of both primary and contingency undocking capabilities.

3. Tool Developed to Manually Release Capture Latches

During Safety evaluation of contingency operations for Shuttle/*Mir*, a new contingency was identified wherein the capture latches would not release and the guide ring could not be retracted. An internal EVA was evaluated in the Weightless Environment Training Facility (WETF) and it was determined that a special tool to release the capture latches was required. The tool was developed and has been flown on all missions since it became available.

4. Wrenches Added to Allow Disassembly of Hatches From Either Side

To protect for the situation where the *Mir* hatch could not be opened after docking, a Russian hatch tool was flown on board the Shuttle and the crew was trained for *Mir* hatch opening. In light of the STS-80 hatch failure and the potential impact to the resupply of the *Mir* by the Shuttle, as well as the inability to perform an astronaut exchange, a joint off-nominal situation (ONS) assessment was performed to determine if appropriate tools and procedures are available for the U.S. astronaut on *Mir* to open the Orbiter hatch from the *Mir* side if necessary. It was determined that existing tools which had been delivered to *Mir* for a NASA payload were available to open the Orbiter hatch from the *Mir* side. It was verified that the U.S. astronaut on *Mir* was trained to open the hatch using existing procedures documented in the Johnson Space Center (JSC) EVA checklist.

5. Elimination of Single-Point Failures on Payload Equipment

Safety discovered and required the elimination of single-point failures from the thermoelectric holding facility fans, the Thermoelectric Freezer (TEF), and the Shuttle Orbiter inflight food warmer.

6.4.3 Integrated Analyses

The Russian and American partners performed safety analyses to identify risk components associated with Shuttle-*Mir* operations. By the completion of the Program, a total of 27 hazard reports containing 100 hazard causes were developed for the Shuttle while 16 hazard reports covering 57 causes were prepared for the *Mir*. One of the most significant benefits of these analyses was to identify aspects of the risk components which required the participation of both the Russian and American sides for resolution.

1. Identification/Resolution of Items for Joint Consideration

Through the hazard analysis process performed by the U.S. and Russian specialists, a methodology was developed to identify and resolve safety items requiring joint consideration. This effort led to the identification of additional required integration analyses, as well as the definition of requirements for joint operational and contingency procedures. This process also included a methodology to perform a closed-loop joint verification of each hazard control.

2. Exceedance of Mated Shuttle/*Mir* Load Constraints

During the evaluation of the *Mir* Structural Dynamics Experiment (MiSDE), an issue was identified that the *Mir* structural loads constraints would be exceeded in the event of a primary thruster failed "on" in a continuous firing mode. The JSAWG then identified the need for specific loads analysis of failed-on primary reaction control system (PRCS) jets. Analysis results indicated the potential for exceedance of interface load constraints within the response time capability for manual crew power-down of the failed jet. This led to the development of a flight rule defining priorities for mated attitude control and a requirement for PRCS reaction jet drivers to be powered off except when needed, and the definition of safety rationale for performance of the MiSDE.

3. Use of Iodine-Based Water on the *Mir*

During the STS-71 review of Shuttle-*Mir* safety, the Russians expressed a concern about mixing the iodine-treated water with the silver-treated water on *Mir*. Procedures were developed by which the transferred water was filtered through an iodine removal cartridge.

4. Halon Fire Suppression Toxicity Issues

During development of the STS-71 Shuttle/*Mir* integrated hazard analysis, a joint hazard was identified due to the potential release of halon into the mated spacecraft. Accidental discharge and leakage of halon is controlled by design and preflight checkout of the fire suppression system. Several analyses were performed concerning the release of halon into the habitable volume, including that of thermal decomposition of Halon 1301 and the effects on humans. Joint operational rules and procedures were developed concerning fire on board Shuttle/*Mir*. It was determined that, in the event of a fire, hatches will be closed before executing firefighting procedures.

5. Bounce-Off and Other Collision-Related Issues

Contingency situations such as bounce-off during docking- and collision-related issues such as clearance were documented and carried as open issues in the integrated hazard analysis until action was taken to eliminate those operational hazards or they were identified to management as risk issues. The JSAWG has worked closely with the dynamics personnel both at Boeing North American and NASA to evaluate the contingency situations and ensure that operational controls have been implemented to reduce the hazard potential and that crew training for these contingency situations has been accomplished. In situations where the requirements of the Orbiter specification have not been met, waiver action was submitted to management for approval.

6.4.4 Joint Flight Rules

1. Safe Jettison of Hardware

The hazard analysis for the STS-74 docking module (DM) mission highlighted the need to establish operational constraints on hardware jettison while in the same orbit as *Mir*. This led to the development of an NSTS 18308 flight rule, X20.4.0-8, and although eliminated during the operational documentation update for a later mission cycle, the closed-loop verification of the JSAWG safety process drove the reinstatement of the rule as a hazard control for potential collision with jettisoned hardware.

2. Constraints on Viewing of Lasers

The JSAWG hazard analysis which assessed crew injury during Shuttle/*Mir* missions identified a hazard concerning potential laser injury to the crew. Subsequent analysis determined that for trajectory control sensor (TCS) operations in the pulse mode, there is no potential for eye damage due to adequate distance between the TCS laser unit and the *Mir* crew view port. Failure modes for TCS continuous wave operations were also analyzed, and were considered to be precluded by design because they required three failures. The handheld lidar is not hazardous to the unaided eye when in use. Finally, the *Mir* crew identified operational constraints for use of optical hardware when the Shuttle is within 10 meters. All of the operational constraints are documented in NSTS 18308, X20.4.2-5.

6.4.5 Safety Operational Contributions

1. Established Criteria for Restow Versus Jettison of DM in the Event Rapid Safing is Required

STS-74 was a delivery and assembly flight of the DM to the *Mir*. The DM was launched in the Shuttle payload bay, removed by the remote manipulator system (RMS), installed onto the Shuttle ODS, and finally docked to the *Mir*. The JSAWG developed time lines for rapid safing to determine at what point the DM could be restowed, or needed to be jettisoned in order to ensure a safe emergency return of the Shuttle. These data were presented to the Payload Safety Review Panel which concurred with and approved the JSAWG criteria for “DM Rapid Safing.”

2. Established Risk of Bailout to Long-Duration Crew Members

Prior to the STS-71 mission, several concerns were expressed regarding the ability of deconditioned crew members to egress the vehicle in a bailout situation and the likelihood of bailout with deconditioned crew on board. An analysis was conducted to determine the probability of a scenario where the Shuttle could not safely land but could be kept stable for a bailout. The study showed the likelihood to be 1 in 60,000. The recumbent seating and the bailout options were considered appropriate measures due to the remote likelihood of these being used.

3. Identified Shuttle as a Critical Component of *Mir* Resupply System

The basic elements of the *Mir*/NASA Program included cosmonaut flights on board Shuttle, Shuttle docking with the *Mir* to exchange NASA astronauts, conduct of long-term scientific research and experiments aboard *Mir*, and development of coordinated operations between Russian and U.S. flight control systems while performing joint flights. In this regard, the Shuttle was initially not an integral part of the *Mir* resupply plan. However, as the *Mir*/NASA Program progressed, and Shuttle flights were interleaved with Soyuz and Progress resupply missions, Shuttle flight readiness and mission success became critical to crew and station safety.

4. Established Requirement for 96-Bolt EVA for Contingency Separation

Early in the Shuttle-*Mir* Program and prior to the initial docking flight to *Mir*, hazard analysis of the ODS determined that the separation function for the vehicle stack was only single-fault tolerant by means of primary electromechanical and backup pyrotechnic mechanisms. The JSAWG investigated proposed options and was instrumental in initiating actions to develop a third means of separation by EVA removal of 96 bolts at the docking mechanism / docking base interface. This resulted in a two-fault tolerant system that complies with program requirements and mitigates the risk of failure to separate.

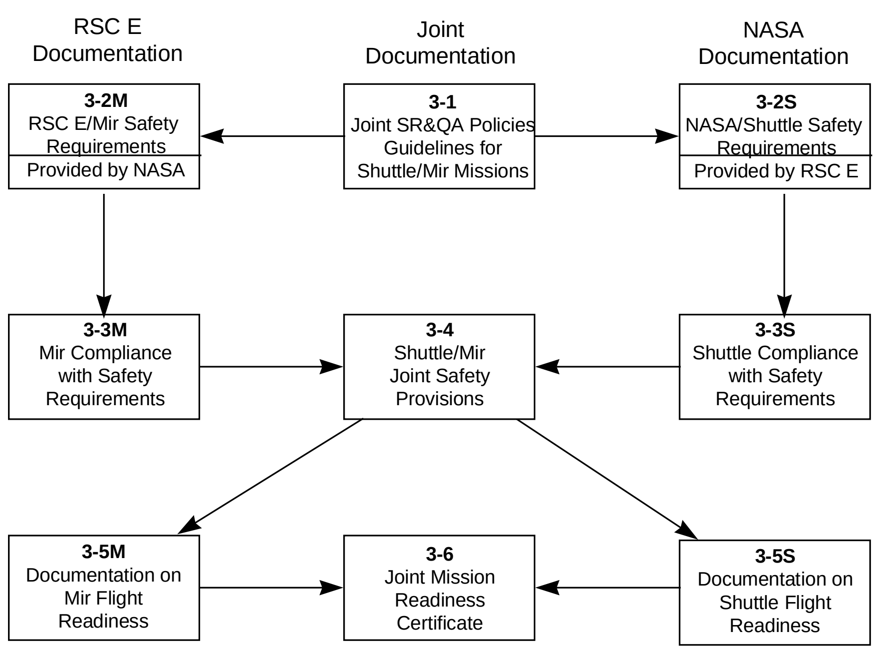

Figure 6.1: Joint Safety Assurance Working Group Documentation Structure

6.5 Top Safety Lessons Learned

The success of the Shuttle-*Mir* Integration Safety Program resulted from the joint efforts of both the Shuttle and *Mir* specialists working together from the Program's inception through its completion. In this regard, the safety criteria and requirements for each program were identified and exchanged so that a single program safety operating policy could be jointly developed to fulfill the needs and concerns for each side. This policy outlined the process and structure (see Figure 6.1) which delineated that vehicle specialists independently perform analyses to identify hazardous conditions and necessary control measures. Subsequent joint review and evaluation of hazard control measures were performed to identify items requiring joint action. These included joint verification analyses and, in particular, analyses and definition of joint operational measures required for real-time response to in-flight off-nominal situations. Based upon these efforts, individual and joint conclusions were developed to support joint safety certification of flight readiness.

The Shuttle-*Mir* Safety Program has demonstrated that the early involvement of safety specialists for each program element, and the active exchange of information by all concerned parties throughout the program duration, is essential for the identification and resolution of integrated hazards between programs and program elements.

1. Station to Shuttle Integrated Safety Analyses Performed by Both Parties

One of the significant analytical legacies for ISS application was the development and execution of a unique integrated hazard analysis process. A primary lesson learned during Phase 1 was the inability of a single side to identify, characterize and resolve those risks associated with multiple programs. This process involved participation by both Shuttle and *Mir* Station specialists to identify and resolve risks involved with the joint on-orbit operations. Individual programs initiated these analyses, and each party identified issues affecting their respective areas of responsibilities, as well as items requiring joint resolution. The team then worked together to identify the optimum solution(s) for the total program.

2. Operation and Transportation Safety Analysis of Payloads

A simplified safety certification process was developed for experimental equipment and logistics hardware for operation or transportation. Safety Certificates were developed which were signed by the developer, the co-chairmen of the Joint Safety Assurance Working Group and the Phase 1 Program Managers. The user and the transporter utilized this process for safety certifications for safe hardware transfer, delivery, and operations. This process provided the flexibility to use either country's launch vehicles for delivery of logistics, scientific experiments, etc., to the station. A unified certificate database was created to allow certification of reflight cargoes.

3. Joint Safety Assurance Working Group

The organizational cooperation plan (WG-0/NPO E/NASA 0001) signed by the program managers of NASA and RSC-E was developed at the beginning of joint activities of the Shuttle-*Mir* Program. This document officially established the joint working groups, defined their tasks and responsibilities, and appointed the chairmen. Consequently, a JSAWG was established to provide a day-to-day forum for assessing and resolving risks between the two programs. The formal (4 to 5 times per year) face-to-face meetings, augmented by weekly teleconferences, ensured maximum involvement by both sides. An international partnership was formed which successfully worked through differences in cultural and engineering processes. This cooperative effort involved a methodical joint review and evaluation of each step of the integration process, from policy development through requirements definition and analysis of each aspect of the joint mission. The JSAWGenabled risk identification and resolution in an open and cooperative work environment that engendered joint teamwork, which resulted in a total risk management process.

4. Integrated Safety Documentation Structure

The Phase 1 Safety Program was guided by six facets of documentation (see Figure 6.1) providing safety policy, requirements, analyses, assessments of hardware and Certificate of Flight Readiness for all parties. Provisions existed for the Phase 1 Joint Management Working Group's approval of each of the six components on a mission-by-mission basis. The major contribution of this structure was the visibility into requirements implementation for all program participants.

The ownership of the structure by both partners engendered a climate of cooperation for the safety participants instead of a climate of defense which commonly is characteristic of review boards and panels.

5. Preplanned Contingency Operations Developed for Each Mission by Both Parties

Hazards and hazard causes that required the participation of both the U.S and Russian parties to mitigate or eliminate the risk were identified as items for joint consideration. These items were reviewed, in a joint forum, and specific real-time actions were defined and agreed to by both safety organizations. This resulted in the development of joint contingency procedures and requirements for flight rules and joint crew operations. These were a catalyst to drive operational measures to resolve or mitigate the ONS.

6. Creation of an Agreed-To Set of Critical Life Support Criteria

The JSAWG identified life support requirements for continuation of the American astronaut on the *Mir* including atmospheric pressure and composition, thermal conditions, food and water reserves, oxygen generation capability, and quantity/functionality of fire extinguishers, breathing masks. This criteria tool provided a method for all parties to evaluate the safety of the station for continued operations.

7. Joint Policy for Out-of-Scope Activities

As the Shuttle-*Mir* Program progressed, the necessity to define minimum safety parameters became evident for several issues including EVA, test of new hardware such as the Inspektor, and other "ad hoc" tests. The JSAWG created a Phase 1 Joint Management Working Group's (Team "0") Safety Directive to provide consistent safety policy and directions. This allowed the JSAWG to accommodate new issues and perform safety assessment of changes in the evolving program activities.

8. Real-Time Responses to Safety-Related In-Flight Anomalies
The hazard analyses performed by the JSAWG considered safety-related failures that had been experienced during flight for both the Shuttle and *Mir*. During Phase 1, the cooperative effort by both parties to deal with the experienced ONS of fire, failures of computers, chemical exposure, depressurization, loss of power, etc., further served as a basis for formulating emergency scenarios for the ISS. Contingency approaches and joint procedures developed for Phase 1 of the ISS can be used to establish station-wide policy for specific emergencies on Phases 2 and 3 of the ISS.

9. Development of Readiness Requirements for *Mir* EVA
Preparation for use of the Russian Orlan space suit by American astronauts and Russian cosmonauts resulted in NASA's development of methodology to identify the station-unique risks and certify EVA readiness for joint missions with joint program hardware. The process developed for Phase 1 EVA facilitates transition to similar operation on the ISS.

10. Multiple Orbiting Vehicles Impose Specific Added Requirements on Each Other
The concept of a system integration effort consisting of predefined requirements coupled with evaluation of only interfaces was recognized as being totally inadequate for on-orbit space operations. The value of this lesson is that the ISS requirements will vary on a mission-by-mission basis in three key areas; configuration (system interactions), interface, and operational protocols. Each of these areas is dynamic and changes on a mission-by-mission basis as well as within phases of a given mission. The provisions for identifying and considering items for joint consideration allowed the Shuttle/*Mir* Safety Program to maximize its value to the Phase 1 effort.

11. Safety Assurance of U.S. Astronaut During EVA
NASA learned very early that the Russian JSAWG membership did not include an EVA expert. The Russian Safety experts, while focused on safety concerns, could not address detailed EVA issues. Similarly, the Russian EVA experts are not safety engineers, and while focused on EVA concerns, the Russian EVA experts could not expend the resources requested by the Americans for a detailed safety analysis. This lesson learned has been addressed in a new joint working group for ISS.

From the Phase 1 Program, the American Safety EVA Team learned about Russian EVA hardware, how to work with limited engineering data, and to work within the EVA community to resolve issues. (The Joint EVA Working Group was an extremely useful and effective resource, and continues to be for ISS issues.) Prior to the Phase 1 Program, the experience of the American Safety EVA Team dealt with short-term Shuttle-based EVAs. With *Mir*, the EVA Team learned the issues associated with operating a long-duration space station, to work with aging equipment, and to "making do" with a given situation to complete unexpected tasks. Additionally, Russian and American EVA experts from Phase 1 are also working ISS, therefore the knowledge and relationships gained early on in Phase 1 are already in use.

12. The Joint Safety Analyses of the STS-74 DM Assembly Mission.
The STS-74 mission required transport of the DM to the *Mir* in the Shuttle. The integrated hazards to the Shuttle and *Mir* were evaluated as the DM was transformed from a Shuttle payload to an extension of the ODS. Later in the assembly process the DM became a permanent part of the *Mir* Station. Attendant joint activities of the DM called for an integrated assessment by both the Shuttle and *Mir* programs. Since an operation performed by one spacecraft might have an adverse effect on the other, both programs needed to analyze the DM as an entity, address systems interaction and operations and resolve the unique assembly issues in terms of the safety of their respective vehicles. This mission and the attendant analyses were the first of this kind, representing the initial Shuttle/Station assembly mission. Specific hazards identified and the joint process developed to resolve them provide lessons learned which are directly applicable to Shuttle assembly missions which are planned for Phase 2 of the ISS Program.

6.6 Conclusions

The unparalleled successful experience in implementing the Shuttle/*Mir* program (ISS, Phase 1) has taught us how to assure the safety of complex operations in space in spite of intergovernmental boundaries. These operations included delivery and return of astronauts and scientific hardware to and from orbit, conducting rendezvous, docking, maintenance and repair on orbit, joint EVAs in open space, delivering consumables and scientific hardware from Earth, and other preparatory steps necessary for the future assembly and operation of ISS. The main objective of the ISS Program Phase 1 was the safety and well-being of the astronauts and cosmonauts during the successful performance of joint American-Russian experiments by the partners and the integration of the laboratory and habitable modules with the *Mir* space station.

The jointly developed safety and risk management programs have been effective in identifying and controlling risks, which will provide valuable lessons for the ISS Phase 2 Program. These lessons include the joint preparation of Station to Shuttle integrated safety analysis by both parties, payload operation and transportation safety analysis, and a pro-active JSAWG with a unique integrated safety documentation structure.

In spite of the fact that not only the joint work, but also the independent work, of Russian and American managers who were responsible for safety and their working groups allowed them to effectively identify and control risks, the most valuable experience from the Phase 1 Program was received as a result of the joint safety assurance efforts while executing these two independent crewed spaceflight programs. This experience includes station operations by a joint American-Russian crew taking into consideration the recommendations developed by the safety group, performing integrated joint safety analyses, safety analysis of payload operation and transportation, the activities of the JSAWG with its uniquely developed documentation structure, and includes among other things, preplanned actions for off-nominal situations jointly developed for each mission.

NASA 6 astronaut David Wolf during an EVA training session