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U.S./Russian EVA Interoperability Status

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ABSTRACT

Guidance for the goals of U.S. and Russian cooperation in the International Space Station (ISS) was provided in an addendum to the Program Implementation Plan, dated November 1, 1993, which was jointly signed by the NASA Administrator and the RSA General Director. Subsequent working level agreements for Extravehicular Activity (EVA) have resulted in joint projects which are building confidence and capabilities for commonality of hardware and operations. Parallel EVA planning and implementation of the Shuttle missions to Mir and the assembly of ISS are proving beneficial to both programs. Experience in each program is being fed back into the other program. This paper describes the joint EVA efforts related to the Mir docking missions which are leading to the assembly of ISS. On-orbit EVA plans, external experiments, tools, suit components and training facilities which support specific missions as well as ISS preparations are discussed. Lessons learned to date show that a considerable similarity exists in the fundamentals of EVA physiology, hardware design, and task performance techniques between the systems of both countries. While technical differences do exist, they have not been significant obstacles and have more often led to joint opportunities. Recent successes illustrate the possibilities for mutual assistance and show that the opportunities and challenges of ISS EVA are achievable.

INTRODUCTION

In 1993, the ISS gained another partner in its development and operation. Russia and its space flight program have joined with the United States, Canada, the European nations and Japan to create a truly global platform for scientific investigations. At present, NASA and the Russian Space Agency (RSA) are cooperating in early missions to the Mir space station as preparation for ISS joint activities and to accomplish early scientific and technology development objectives. Many of these Mir investigations are described as risk mitigation experiments since they are specifically intended to validate new ISS technologies before they become operational.

In terms of EVA, there are numerous joint projects underway involving a wide array of technical subjects.

Since Mir is in the same orbit as is planned for ISS, several experiments are being deployed and retrieved to learn about the effects of the external environment on spacecraft materials. Mir provides small experiments with opportunities for long duration exposures that would not be otherwise available. The combination of U.S. and Russian EVA crewmembers provides a variety of options for external experiment support.

Because the same type of dual EVA capability will exist on ISS, work is underway to provide equipment that will allow both nations to assist each other with ISS assembly and maintenance. Current efforts are focusing upon common tethers and foot restraints that will work with both U.S. and Russian space suits. It is essential that each can safely translate, transport equipment and perform work on both U.S. and Russian components of ISS.

Though present capabilities are adequate for infrequent joint EVA, each suit design is being studied for possible future enhancements that could reduce joint logistics costs and improve joint operations. Radio communication is a typical example. Because current suit and vehicle radio frequencies and modulation do not match, voice communication is only possible via **a** relay method. This relay method is subject to timing delays and strict procedural discipline since limited radio frequencies preclude everyone from talking at once. Other examples of possible enhancement include common boots, gloves, C02 scrubbing canisters, batteries and thermal improvements.

Successful examples of joint assistance with unplanned contingencies can be cited. One in particular involved the deployment of a solar array on Mir's new Spectr module. This array did not release automatically as planned. The Mir-19 crew cut a launch restraint using a special cutter designed by NASA and delivered by STS-71.

To prepare for future on-orbit ISS EVA, neutral buoyancy training facilities in Houston and in Moscow are also being studied to determine how to best operate both types of suits in each water tank. To avoid the difficult and expensive duplication of all U.S. and Russian mockups in both locations, it is believed that it will be more efficient for crews to train for external tasks in the home country where the hardware is designed, developed and managed. When supplemented with a set of each other's tools, having Russian suits in Houston and U.S. suits in Moscow should provide considerable training flexibility with relatively minor integration costs. Other technologies applicable to joint training are also being investigated. Virtual reality computer simulation shows great potential as an easily adaptable training medium.

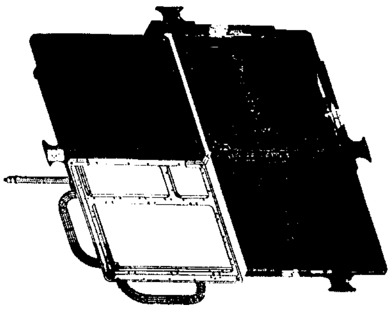
While considerable effort is ongoing with new projects, attention is also being paid to current and historical EVA capabilities. By learning each other's design philosophies, technical requirements, task techniques, physiological constraints and existing equipment, we are finding common ground for future efforts.

One means of accomplishing this learning process and validating future operations concepts is through the development and performance of specific on-orbit tasks and ground tests. A Russian crewmember operated the Shuttle robotic arm in direct support of Shuttle based EVA during STS-63. STS-74 delivered a docking module to Mir in late 1995. U.S. crew will conduct an EVA on a portion of the Mir exterior during STS-76 in March 1996. In early 1997 during Mir-23, an American astronaut will participate in a Russian EVA wearing a Russian spacesuit. In late 1997, current plans call for a joint EVA as part of the STS-86 mission to Mir. External experiments will be transferred between the Shuttle and Mir and may involve 4 crewmembers in Russian and U.S. suits simultaneously. Future Shuttle flights will deliver other major Russian built payloads. Each mission is leading the way for joint EVA operations on ISS.

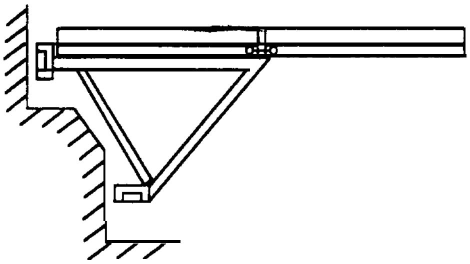
MIR EXTERNAL EXPERIMENTS

Russia has considerable experience with the deployment and retrieval of scientific experiments on their space stations. Similar U.S. EVA experience has been limited since Skylab. To take advantage of Mir as an orbiting platform, the following experiments are being developed using a combination of U.S. and Russian scientific instruments and EVA interfaces :

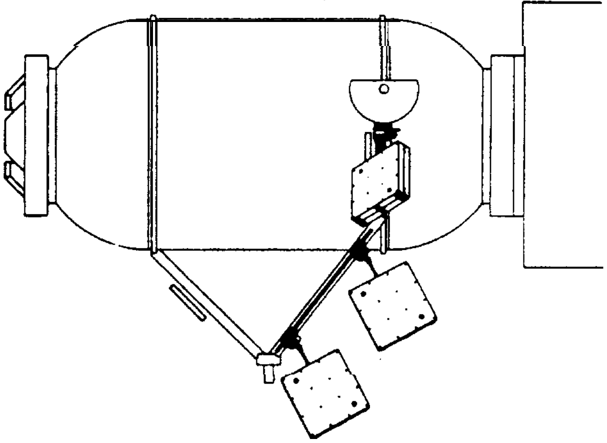
Particle Impact Experiment (PIE) - The container for this passive material exposure device is derived from the French Aragatz experiment which was conducted earlier in the life of Mir. After launch by Russia inside Priroda, the Mir-21 crew will deploy PIE in early 1996 outside Kvant-2, and the Mir-23 crew will retrieve it in early 1997 for return to earth by the Shuttle. A Russian magnetic clamp serves as the mechanical attachment to Mir.



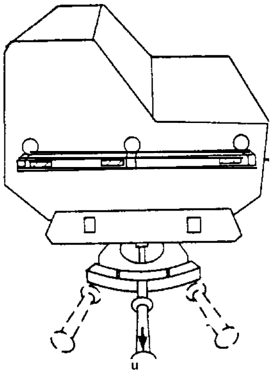
Mir Sample Return Experiment (MSRE) - The platform for this passive micrometeroid/debris collection device will reuse the stand and support panels already onboard Mir for the completed TREK experiment. A similar experiment flew on the top exterior of the Shuttle's Spacehab module. New sample trays to be delivered by Priroda will be attached to the panels while inside Mir. The Mir crew will deploy and retrieve MSRE outside Kvant-2 during the same EVA's as for PIE. Return to earth will be via the Shuttle.



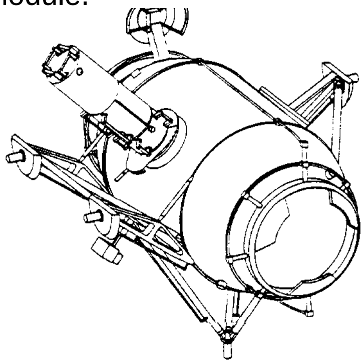
Mir Environmental Effects Payload (MEEP) - This is a set of 4 containers for passive material exposure, offgas sampling and debris collection. Each MEEP container will be deployed and retrieved by Shuttle EVA crew during STS-76 and STS-86 respectively. These containers were specially designed for launch in the Shuttle payload bay and were sized for EVA crew handling and installation. They attach to Russian handrails on the Mir docking module by NASA designed clamps.



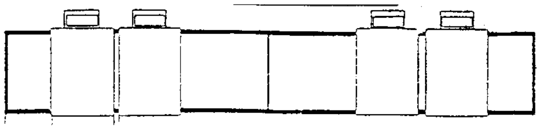
Optical Properties Monitor (OPM) - This active materials sampling experiment was originally intended for the EURECA satellite and has been repackaged for transfer to Mir and EVA handling. After launch by STS-81, the Mir-23 crew will deploy OPM in early 1997 outside the docking module. The STS-86 crew will retrieve it in late 1997 for return to earth by the Shuttle. A Russian clamp and electrical connector serves as the external interfaces with Mir.



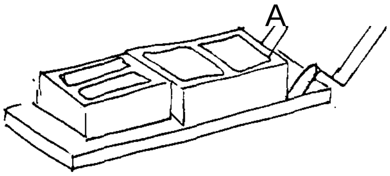
Hydrogen Maser Clock (HMC) - This large active time measurement experiment will be deployed by the STS-86 EVA crew. No return is planned. It uses the same Russian mechanical and electrical interfaces as the OPM for mating with the Mir docking module.



Mir Solar Array Evaluation Experiment (MSAEE) - Russian EVA crew will retrieve several samples of solar cells from old arrays. These old arrays are being replaced by new ones which were delivered by STS-74. Russia will develop the EVA support equipment. The samples will be returned to earth via STS-81 in late 1996.



External Radiation Dosimeters - The container for this passive radiation recording device is based upon a similar Russian experiment which was conducted earlier in the life of Mir. After launch by STS-79, the Mir-22 crew will deploy this equipment outside Kvant-2 and retrieve it after roughly one month's exposure for return to earth by STS-81.



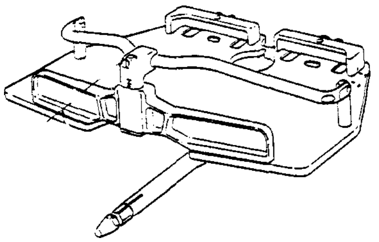
Insuit Radiation Dosimeters - Currently the data from crewmember's personal dosimeters can only be recovered after the mission, upon return to earth. A new pen sized dosimeter, developed in Hungary and used inside the Shuttle and Mir previously, can be analyzed on-orbit. It may prove beneficial for use inside an EVA space suit.

COMMON EVA HARDWARE

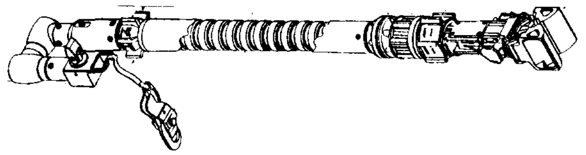
Since the EVA systems of the U.S. and Russia have evolved independently in the past, there are some fundamental differences in suit and tool design. Even so, there are many similarities because of the universal nature of the laws of physics and human physiology. Previous joint EVA studies have largely focused upon the different space suit designs and recommended changes for suit commonality. While the different suits may not be optimal in all aspects of use and logistics support, each is functional and serves its assigned tasks adequately. While some enhancements to each suit are independently being implemented, each suit is anticipated to essentially be used as is for ISS. Limited budgets and the extensive infrastructures which already exist to support each suit type make it unlikely that there will be any dramatic design changes for suit commonality in the near future.

Some EVA support equipment commonality is actively being pursued for near term implementation. To ensure that crew in different suits can work on either the U.S. or Russian portions of ISS, common safety tethers, tool/equipment transport and body restraint at worksites are being developed. Much of this equipment will first be demonstrated on-orbit during STS-76 by U.S. crew. The Mir-23 crew will also demonstrate some of the tethers at a later date. If the results are positive, a basic level of EVA hardware interoperability will be implemented on ISS.

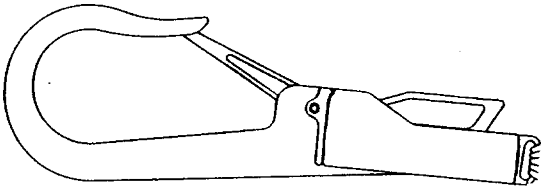
The common foot restraint was derived from U.S. and Russian designs. Each boot heel has a different foot plate engagement interface and changes to the boots were not desired due to the high costs of altering existing boot inventories. Though other alternatives are being investigated, the current common foot plate design uses the Russian toe bar and a special new heel clip that grips both boot types. A front toe stop was added to maintain heel clip engagement. With one exception, no moving parts are necessary for high reliability and safety assurance. Though rarely used, the U.S. small boot did drive the design to make the heel clip adjustable on-orbit. When implemented in appropriate locations on ISS, this will allow crew in any suit to perform tasks involving high reaction forces for extended periods.



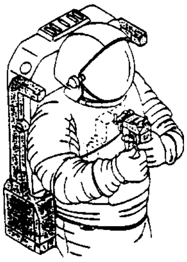
A new multiple use tether for equipment transport and body restraint is being developed that can be attached to either suit. Both countries studied this type of tether independently for years. The new tether will grip both U.S. and Russian handrail cross-sections and has optional end effecters for other equipment. It is a useful third hand for low force tasks.

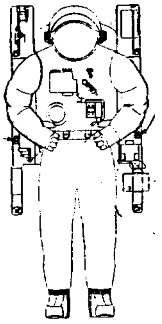


Tether hooks are essential for crew safety and are one of the most frequently used items during external operations. Improved designs have been desired for some time to reduce actuating time and fatigue. The large common size fits both U.S. and Russian handrails and is easy for either gloved hand to actuate. When combined with the new small hook and the U.S. retractable tether reel, the options for crew safety tethering and equipment restraint are numerous.



Suit component commonality is also being pursued on several levels. Safety is not only being addressed through tethers and hooks, but a self rescue device is being considered for both suits. The Simplified Aid for EVA Rescue (SAFER) was demonstrated successfully during STS-64 in 1994. Improvements will be incorporated for the U.S. EVA's performed while docked to Mir on STS-76 and STS-86. A new effort is now being considered to repackage components from the U.S. design for attachment to the Russian suit. This would give any ISS crewmember in any suit the capability to fly back to the vehicle after accidental detachment. These devices have been proven to be the most reliable, effective and easiest to operate of all other self rescue design solutions (deployable poles, grappling ropes, handheld thrusters, etc.) and avoid the overhead time expended upon multiple tethering.

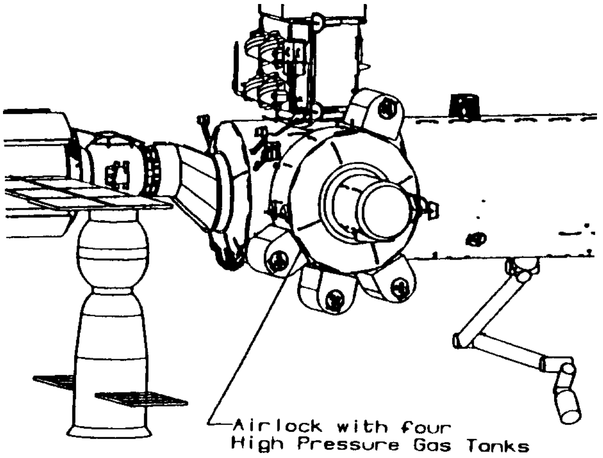




Though the need for a mixture of suits to be outside simultaneously will be rare, one fundamental capability needed for this scenario is good voice communication. While direct radio links between suits on compatible frequencies are preferred, it is difficult to implement since the impact to vehicle antennas, wiring and electronics is extensive. Relay options will be demonstrated during Mir missions starting with STS-76, though it is anticipated that special relay electronics will be needed to eliminate transmission delays and allow true duplex exchanges.

In support of a common EVA airlock for ISS, an Orlan DMA is being returned to earth on STS-79. Old Orlan suits are normally jettisoned when their safe on-orbit life has expired. Because a new Orlan-M takes up to 2 years to manufacture and could not be readied in time for ISS airlock certification testing in 1997, the old suit will be refurbished and modified for ground testing. Studies of the suit materials and hardware life will also be conducted to aid future designs. This information will be shared with both U.S. and Russian suit designers.

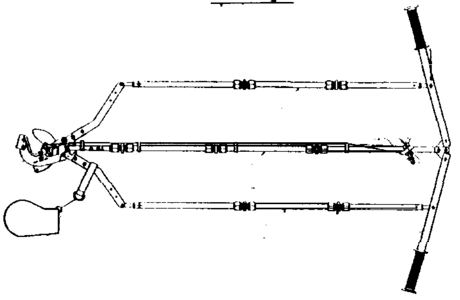
The common ISS airlock can be used by either U.S. or Russian designed suits. Prior to the launch of this airlock, Russian suited crew will use the service module airlock. When the Russian docking compartment is delivered, it becomes another alternative for Russian suited EVA (and a contingency ingress location for the U.S. suited crew).



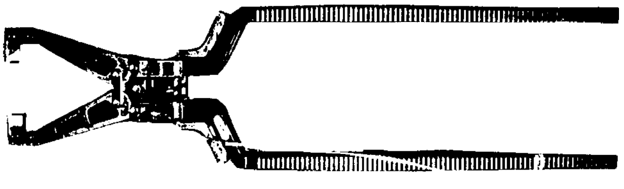
CONTINGENCY EVA SUPPORT

EVA is an extremely capable resource for solving unforeseen problems. The U.S. and Russia have each demonstrated this capability repeatedly in the past. With joint cooperation, additional possibilities for mutual aid now exist which will be extremely beneficial to the long term success of ISS.

A new NASA developed long handled cutting tool was successfully used by the Mir-19 EVA crew to complete deployment of a solar array. This task and tool are reminiscent of a previous experience during Skylab. Due to the difficult location, size and strength of the failed solar array restraint, neither country had a tool on the shelf that would do the job. Using commercial components as a starting point, this tool was conceived, designed, manufactured, certified and launched to Mir in less than two weeks. The Mir-19 crew was trained in its use while in Houston for unrelated training prior to their own launch to Mir by Soyuz. A smaller version of this tool will now be flown on all Shuttle flights and the original unit will remain on Mir (just in case it is needed later).

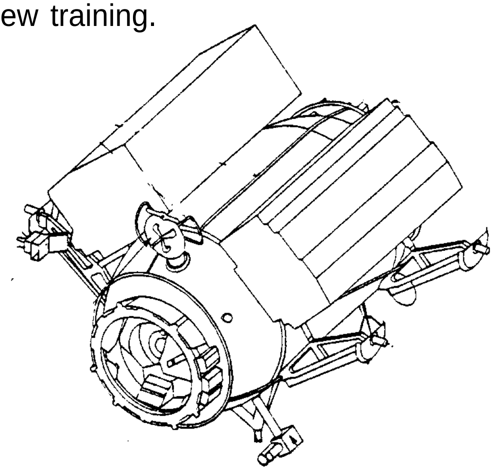


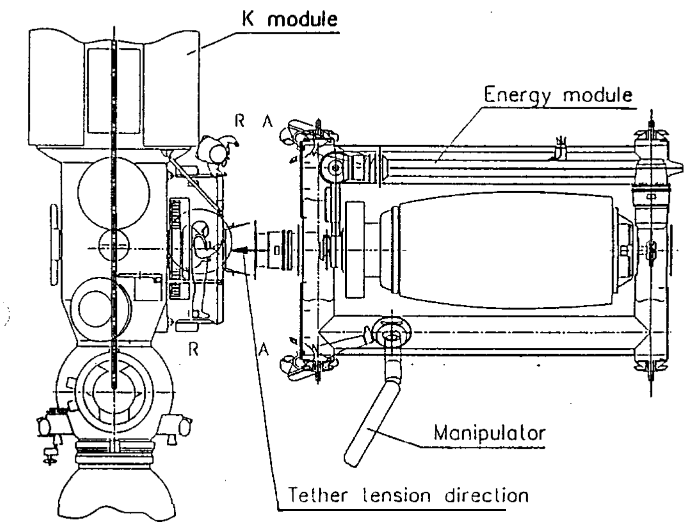
Russia has provided a latch release tool to NASA which can be used in response to a specific contingency scenario where the Shuttle and Mir do not separate properly. This tool is now flown on all Shuttle missions to Mir and will also be carried on future ISS missions.



STS LAUNCHED RUSSIAN PAYLOADS

Much of the real experience with U.S. and Russian EVA integration has come from work with major Russian payloads launched by the Shuttle. The docking module was delivered to Mir by STS-74 in November 1995. Only contingency support was needed for this mission, but EVA techniques developed as a backup to robotic arm docking will benefit future ISS assembly missions. The Energy Module has been developed for Shuttle launch, robotic arm transport and joint U.S. and Russian EVA crew attachment. Work has now started for the delivery and assembly of a Russian solar array and thruster assembly on ISS. Development of the associated flight and training hardware has exercised our joint processes for requirements definition, design verification and crew training.





EVA TRAINING FACILITY OUTFITTING

Because on-orbit EVA is only possible with properly trained crewmembers, a review of the EVA training infrastructure in Houston and Moscow is being performed. Since only three crewmembers will be onboard ISS for the years before assembly completion, they will have to cover all U.S. and Russian EVA except during transient visits by Shuttle EVA crew. To reduce the training demand of crews who have many other tasks, it will be the goal for the crew of any single mission to primarily be trained in one type of suit and one airlock for normal operations. Selection of the suit and airlock is easy for the early flights since there are no U.S. suits onboard. When the joint airlock and the U.S. suits arrive, either system could be used. Selection may be based upon the specific EVA planned for each crew increment. However, it is clear that the engineering expertise of the U.S. and Russian segments resides in each respective country. It is also clear that it is impractical to only train in one single location by duplicating each other's facilities and full scale vehicle mockups. The use of a single airlock and suit design would reduce training complexity and crew time, but would not resolve where to go for hands on task training. Virtual reality training is promising as a supplement, but cannot yet replace suited training with real hardware. The dynamic interaction of the body inside the pressurized suit is too unique. Even so, common computer simulation of EVA translation paths, worksites and self rescue for both the U.S. and Russia is being pursued to aid training efficiency. For the foreseeable future, Russia will train crews in Moscow to operate Russian suits, airlocks, robotics and external tasks. The U.S. will train crews in Houston to operate U.S. suits, the joint airlock, robotics and external tasks.

The best option for maximizing joint EVA training capability appears be in the integration of Russian suits in Houston's water tank and U.S. suits in Moscow's water tank. One Orlan suit is soon to be functioning in the Houston facility. This has primarily been a job of adapting the air and water plumbing lines between the Orlan suit and the Houston umbilicals. Existing facility control consoles and life support systems have been used. Efforts are now in progress to achieve a similar system for the U.S. suit in Moscow. Ultimately it is desired to have two suits of each type operating in each location.

In a few cases, it will be prudent to exchange mockups for EVA training. For the Mir missions, a docking module mockup built by RSC Energia is being used in Houston for science experiment deployment and retrieval training. For ISS, since both have specific shared interfaces that are frequently used, the areas between the FGB and the joint airlock may be represented in each water tank facility.

Since suits and mockups alone are not much use without tools, tethers and other aids, a subset of these items will be exchanged as well. This minimal duplication of mockups and tools for generic training provides crewmembers with a head start and allows them to concentrate upon unique assembly and maintenance tasks during overseas visits.

ISS EVA OPERATIONS

The U.S. and Russia will each be largely responsible for the EVA conducted on their respective components of ISS. As noted earlier, the capability will exist for mutual assistance when needed. The joint airlock can be used by either U.S. or Russian suits. A set of common support equipment can be used to allow productive and safe work by either suit type on any external area. Because ISS vehicle hardware is funded, designed, built and launched by each nation using unique engineering expertise and manufacturing processes, it will be inherently difficult and cost prohibitive for any single location or group to thoroughly prepare the flight crew for each mission. With only 3 crewmembers onboard ISS through much of the assembly phase and separate training facilities, it will necessary to travel between countries to receive training. The EVA training facilities, suits and tools of each nation will be maintained and EVA mockups of vehicle interfaces will be primarily located in their home locations. Several guidelines have been proposed for U.S. and Russian EVA responsibilities which recognize the constraints described above while considering STS-Mir experience and allowing for exceptions to accommodate contingencies.

a. Any task requiring assistance from the other side must be jointly developed, verified and accepted as feasible and safe.
b. While the Shuttle is docked, all U.S. segment EVA tasks will be conducted by crew trained in the U.S. to use U.S. suits and either the Shuttle airlock or the joint airlock.
c. While the Shuttle is docked, all Russian segment tasks should be conducted by Russian trained crew. The Shuttle crew may assist if U.S. suits are used.
d. When the Shuttle is not present and prior to installation of the joint airlock, all ISS EVA will utilize a Russian airlock and Russian suits.
e. When the Shuttle is not present and after installation of the joint airlock, selection of the airlock and suits to be used by the ISS crew will be based upon the quantity, location and complexity of scheduled U.S. and Russian tasks. The joint airlock and U.S. suits will be used if tasks are prevalent on the U.S. segment. Russian suits and the joint airlock or a Russian airlock may be used if planned Russian segment tasks are in the majority.
f. Crew rotation schedules and the selection of nominal EVA tasks should be synchronized. Each on-orbit crew should only be scheduled to work on either the U.S. or Russian segment (not both).

CONCLUSIONS

There are many advantages to the development of joint EVA capabilities. Any reduction in EVA demand increases useful crew time for other applications. Efficient selection and utilization of both U.S. and Russian EVA resources may minimize crew time spent on nominal EVA. It may also lead to reduced total EVA logistics costs through shared hardware. In specific applications, the selective use of the best designs from each country can reduce the time and risks associated with standalone EVA. Though all nominal ISS EVA will still be designed around the work of two persons outside at one time, for certain missions it may be possible to increase the frequency and quantity of EVA through the rotation of two pairs of crewmembers (as exemplified by STS-61). The redundancy provided by each EVA system increases the options to preserve mission success and supply contingency support.

ACRONYMS

EVA	Extravehicular Activity
FGB	Functional Cargo Block
HMC	Hydrogen Maser Clock
JSC	Johnson Space Center
ISS	International Space Station
MEEP	Mir Environmental Effects Payload
MSAEE	Mir Solar Array Evaluation Experiment
MSRE	Mir Sample Return Experiment
PIE	Particle Impact Experiment
NASA	National Aeronautics and Space Administration
OPM	Optical Properties Monitor
RSA	Russian Space Agency
SAFER	Simplified Aid For EVA Rescue
STS	Space Transportation System
WETF	Weightless Environment Training Facility

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