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Report to the Chairman, Subcommittee on Government Activities and Transportation, Committee on Government Operations, House of Representatives

June 1992

SPACE STATION

Delays in Dealing With Space Debris May Reduce Safety and Increase Costs

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Information Management and
Technology Division

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June 2, 1992

The Honorable Barbara Boxer
Chairman, Subcommittee on Government
Activities and Transportation
Committee on Government Operations
House of Representatives

Dear Madam Chair:

Space debris—orbiting remnants from past space missions—presents a relatively new and long-lasting danger to future space endeavors.[1] On two recent missions, the space shuttle had to maneuver to avoid oncoming debris; collision with these objects would have destroyed the shuttle. The National Aeronautics and Space Administration's (NASA) planned Space Station Freedom will be even more vulnerable to space debris than the shuttle because of its large size, its altitude in a relatively debris-laden orbit, and the long duration of its mission. Building the station to withstand or avoid potentially catastrophic collisions with space debris is essential for its viability.

Given the importance of the space station to NASA's manned space program, you asked that we provide information on NASA's progress in incorporating the latest estimate of the debris environment into space station design requirements. You also asked us to determine if NASA had an overall strategy for protecting the station from small, medium, and large space debris, and to report on its efforts to keep the debris environment model current. Details of our objectives, scope, and methodology are provided in appendix I.

Results in Brief

The majority of NASA's current designs for protecting the space station and crew from debris are outdated and its overall debris protection strategy is insufficient. NASA's contractors have designed the station using a 1984 model of the space environment that is obsolete, significantly underestimating the increasing amount of debris that the station will encounter during its 30-year lifetime. In February 1992 NASA directed its space centers to incorporate an updated 1991 model into their designs. However, the agency has not yet made critical decisions on how to

[1]Space debris, orbiting man-made objects, can range in size from microscopic paint flecks to rocket bodies and defunct satellites the size of a van or larger.

implement this change. Preliminary evaluations show that incorporating the 1991 model using currently established safety criteria could entail a major redesign of some components, with significant cost impact and schedule delays.

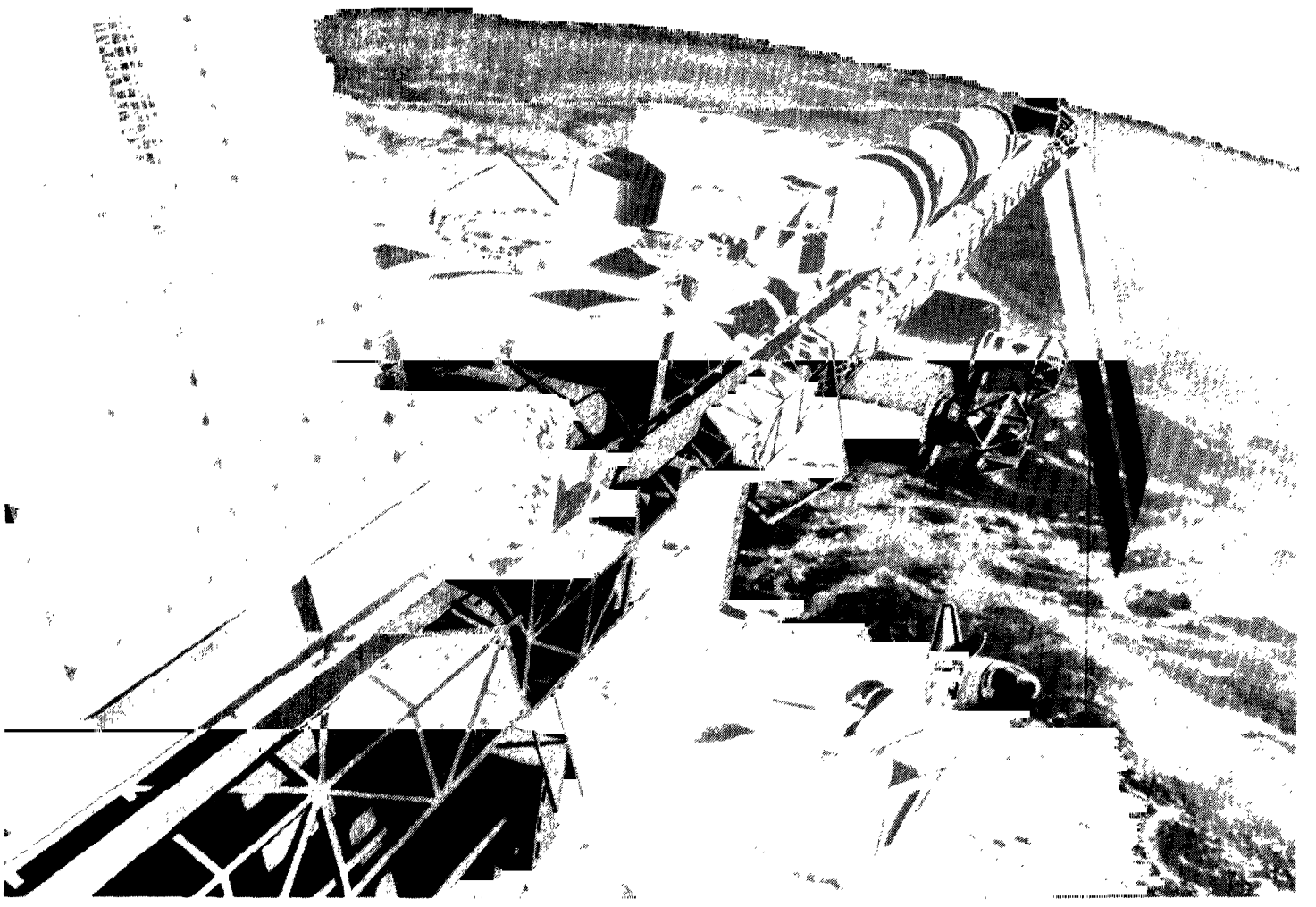
NASA's overall protection strategy for space debris is insufficient. While NASA has concentrated its protection efforts on shielding the station from small debris and plans to augment this initial shielding in orbit, it has not yet developed designs or studied the cost and operational impact of augmenting its protection with additional shielding. Further, current designs do not provide the capability of warning or protecting the crew from imminent collision with mid-size debris. Finally, although some capabilities exist for maneuvering the station away from large debris, the agency lacks collision-avoidance plans and debris-tracking requirements.

In developing a comprehensive strategy to protect the station from the more severe debris environment, NASA cannot avoid some difficult decisions. These decisions involve tradeoffs between how much the agency is willing to pay to protect the station, the schedule delays it may incur, and the risk to station safety it is willing to accept. It is important that these decisions be made before NASA completes its critical design reviews in early 1993. At that time key designs will be made final and manufacturing will begin. Without a comprehensive strategy, NASA will have decided to build the station, knowing it is less protected than currently required, but without knowing the consequences of this decision on station and crew safety, and on life-cycle station costs.

Background

Called the critical next step in all our space endeavors, NASA's Space Station Freedom Program is a multibillion-dollar international project. The station will primarily act as an in-orbit laboratory. It is expected to remain in service for 30 years and, fully deployed, cover an area roughly the size of a football field. In early 1993 NASA plans to complete critical design reviews, a time when key designs are made final and manufacturing begun. Assembly of the station in space is planned to begin in December 1995. Although the agency faces many engineering challenges, a particularly troublesome one is how NASA will protect the station from a steadily worsening debris environment.

Figure 1: Artist's Conception of the Planned Space Station



Source: NASA

The environment around the earth is littered with millions of whole and fragmentary objects resulting from years of space exploration. Known as space debris, these objects are extremely dangerous because they pass each other at a relative velocity of about 22,000 mph. At this speed, a 1-centimeter aluminum particle (roughly the size of an aspirin tablet) hits

surfaces with the impact of a 400-pound safe going 60 mph. At least 140,000 objects 1 centimeter or larger are believed to be in orbit around the earth; any one can cause catastrophic damage upon impact. Even the smallest debris particles, those about .01 centimeter in size (the size of a printed period), are of concern because they cause surface pitting and erosion by chipping away at protective paints and surfaces. The space environment is expected to become increasingly polluted as worldwide spacecraft launches increase and as fragmentations in space create even more debris.[2]

In 1984 NASA developed a model of the debris environment that used actual data on very large and very small objects and estimated the environment for debris roughly between 1 and 10 centimeters in size. NASA obtained data on large debris through radar observations, and on very small debris through the study of objects returned from space. This 1984 model was incorporated in the space station's design requirements. Since then, NASA's estimate of the debris environment has changed dramatically, as the agency has refined its understanding of the environment.

As we reported in April 1990, the space debris environment was significantly worse than the 1984 model NASA was using to guide its space station designs.[3] As we testified in May 1991, NASA still had not updated the debris environment in its space station design requirements.[4] During 1991 NASA revised its model of the debris environment through optical telescope and radar measurements. The agency also confirmed the new 1991 model through preliminary analysis of the recently returned Long Duration Exposure Facility, an unmanned laboratory sent to space to sample the environment.

[2]Fragmentations are break-ups of orbiting payloads, rocket bodies, and other large debris that result from explosions or collisions. These break-ups produce additional particles, causing the total debris population to grow.

[3]Space Program: Space Debris a Potential Threat to Space Station and Shuttle (GAO/IMTEC-90-18, Apr. 6, 1990).

[4]Questions Remain on the Costs, Uses, and Risks of the Redesigned Space Station (GAO/T-NSIAD-91-26, May 1, 1991).

Station Components Designed to Outdated Debris Environment

Two program documents determine the designs for protecting the space station from debris. One specifies the design requirements for dealing with debris,[5] and another defines the debris environment.[6] Station design requirements for critical components[7] specify a .9955 probability of experiencing no failure from a meteoroid[8] or debris impact that would endanger the crew or space station survivability for 10 years. Space station contractors have been using the environment model established in 1984, now sorely out-of-date. It significantly underestimates the increasing amount of debris that the station will encounter during its lifetime. For example, a NASA debris expert stated that the 1991 model is on average four to eight times more severe than that shown by the 1984 model.

The effect of not changing the station's shielding designs to protect against the more severe debris environment was illustrated to senior space station management in January 1992 by NASA engineers and debris experts. With safety requirements remaining constant, there would be an overall 11 percent risk that the shielding on one of the station's critical components would be penetrated during the first 10 years in orbit if shielding is redesigned to accommodate the new debris model. However, this risk increases to 36 percent if the program continues with current shielding designs, based on the old model. This 36-percent risk would increase to 88 percent over the station's 30 years in orbit. (See fig. 2.)

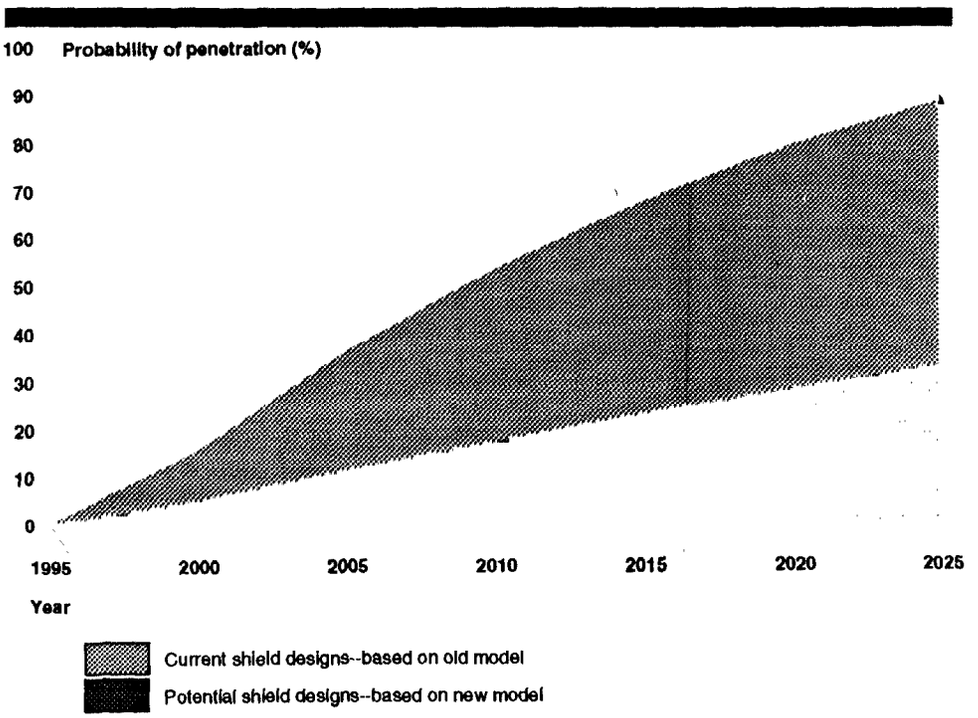
[5]SSP 30000, Space Station Program Definition and Requirements Section 3: Space Station Systems Requirements, Space Station Program Office, October 31, 1988.

[6]SSP 30425, Space Station Program Natural Environment Definition for Design, Space Station Program Office, January 15, 1987.

[7]Space station core equipment is divided into two categories—critical and functional items. Critical items are those whose failure—or the effect of that failure—endanger crew or station survivability. The failure of functional items may degrade the station's performance, but does not endanger crew or station survivability.

[8]Meteoroids are naturally-occurring particles that average .01 centimeter in size. NASA has historically shielded its spacecraft from the meteoroid environment. The debris environment poses a much more likely and more severe source of spacecraft damage.

Figure 2: Probability of Penetration for Different Shield Designs



In recent months NASA has made progress toward using the 1991 debris model for space station design. On February 19, 1992, space station program headquarters directed the three space centers building the station (Johnson, Marshall, and Lewis) to incorporate the 1991 debris model in their designs. The centers are now issuing contract change directives and instructing the contractors to submit their proposed implementation methods and costs. According to NASA headquarters officials, responses from the contractors are due in the next several months. NASA has already authorized some additional shielding for the station's propulsion modules. However, actual design changes for a majority of the station's critical components cannot be implemented until after NASA reviews and approves the technical and cost proposals. In the meantime, designs remain based on the old environment.

Using the New Environment May Increase Costs and Delay Program

Implementing the 1991 debris model could have a significant impact on cost and schedule. For example, according to a senior engineer at one NASA center, if safety criteria were not lowered, major portions of the station would have to be totally redesigned. He noted that such changes would significantly increase costs as well as delay the program. In September

1991 a contractor at another NASA center informed the agency that further delays in incorporating the new debris environment would greatly multiply the cost of changing its designs, and could delay the program to the point where it might not be able to meet its milestones.

NASA Could Decide to Reduce Its Debris Safety Criteria

As discussed, NASA has not yet obtained estimates from station contractors on the effect of incorporating the more severe debris model in their hardware designs. If faced with prohibitive cost, weight, and schedule impact, NASA managers could decide to relax safety criteria. One approach being considered would waive safety criteria for one or more components. In fact, one center instructed its contractor to submit waivers for components that cannot meet the safety criteria.

NASA headquarters officials stated that no waivers of their safety requirements have been granted or are under consideration. However, we believe that NASA will not determine the need for waivers until the potentially significant design and cost implications of using the new environment become known. Waivers may then become a reality for some critical components.

Another approach that is being strongly considered will delay requirements to meet the safety criteria. That is, NASA would accept from contractors designs that do not meet the safety criteria at the time the critical component is launched, but that could be incrementally improved over a 10-year period. This approach would, however, increase the vulnerability of some components in the early years, and would rely on augmented shielding to be applied in orbit, a potentially risky and costly task. Both of these approaches increase the risk to station safety and cost and should be evaluated thoroughly and formally before being adopted.

NASA's Overall Strategy for Dealing With Debris Is Insufficient

The debris environment is made up of three classifications of debris: small debris (less than 1 centimeter), mid-size debris (between 1 and 10 centimeters), and large debris (greater than 10 centimeters). A NASA debris expert estimated that in 1991 there were about 3.5 million small objects, 126,000 mid-size objects, and roughly 14,000 large objects in orbit around the earth. Consistent with the most likely threat, NASA has concentrated its protection on shielding the station from small debris. However, the risk remains that the station will be hit by mid- or large-size debris. The program has not developed a comprehensive strategy for all three size classifications.

Strategy for Shield Augmentation Not Developed

To deal with small debris, NASA is considering increasing the shields on some critical items and incrementally augmenting the initial shields once the components are in orbit. NASA engineers have made considerable progress in developing light-weight shielding technology; they have also developed concepts for increasing the initial shielding on some of the station's critical components. However, increasing initial shielding may not be feasible for all critical components because of a variety of factors including added cost, weight, size, and potential schedule delays caused by redesign. According to several space station engineers, augmentation in orbit may be the only conceivable protection mechanism for these components, two of which are the habitation and laboratory modules.

Augmentation in orbit is complicated. It requires extensive early planning of the initial and augmented shield design, and assessment of the additional costs and operational impact of in-flight modifications. Augmented shielding may require changes to the station's heating and cooling systems, and may increase extravehicular activity in order to physically add the augmented shielding.

NASA's requirements currently call for scars on the station's exterior surfaces to allow for shielding augmentation, but no specific augmentation strategy exists.[9] A comprehensive augmentation plan would include a thorough analysis of all engineering and safety issues related to augmentation. Without such a plan, NASA would be placing the station in orbit before understanding all its safety vulnerabilities and cost uncertainties.

NASA Has No Plans to Protect the Station From Mid-Size Debris

Current station designs do not provide a way to warn or protect the crew of an imminent collision with mid-size debris. Although NASA engineers are considering on-board sensors to detect and track objects in the mid-size range, and a combination of active and passive techniques to protect the crew and station, all of these strategies require further research and development.[10] Because NASA has not developed even preliminary plans for protecting the station and crew from mid-size debris, both are left vulnerable to particles of this size.

[9]Scars are provisions made on hardware to allow for future changes or additions.

[10]Active techniques may involve some sort of laser that would hit and deflect oncoming debris. Passive techniques could include providing a "storm cellar" for the crew to move to in case of an imminent debris hit, or deploying movable shields to block oncoming debris.

NASA Lacks Collision-Avoidance Plans and Debris-Tracking Requirements

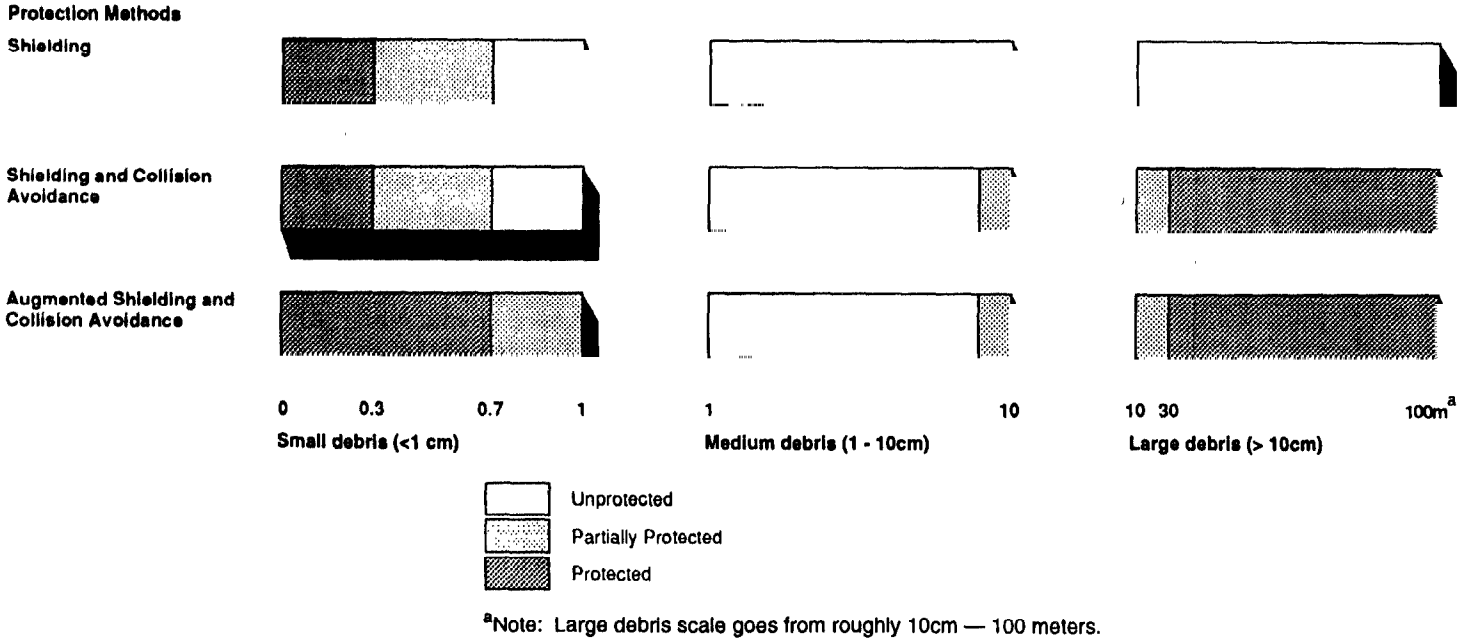
Department of Defense ground-based radars routinely track large debris. NASA engineers believe that with sufficient warning, the space station could maneuver away from potential collisions. However, at this time NASA lacks collision-avoidance plans and detailed tracking requirements. Any collision-avoidance plans NASA develops will have to address such technical complexities as propulsion requirements, the need to accurately pinpoint the exact position of the station and of approaching debris, and the effect a maneuver will have on operations. Unnecessary or frequent maneuvers could have a serious impact on the station's planned mission. For example, planned microgravity experiments will require that the station not move for six 30-day periods per year (180 days per year). A NASA debris expert estimated that the station may need to maneuver 40 times per year at the station's proposed 400 kilometer altitude to avoid collisions with currently known and tracked objects larger than 10 centimeters.[11]

Finally, unresolved questions remain about the U.S. Space Command's ability to continually track all large debris objects with enough accuracy to allow collision-avoidance maneuvering. According to NASA headquarters officials, these technical issues are now being discussed by a joint NASA-DOD collision-avoidance working group.

Figure 3 shows that NASA's selection of protection options will greatly affect the station's vulnerability to different debris sizes. For example, if the station relies on initial shielding alone, it will be totally vulnerable to mid- and large-size debris. As additional protection methods are added, the station's vulnerability decreases. However, protection from mid-size debris is the most difficult to achieve. NASA determined that it cannot practically shield against mid-size debris, and existing radars are not capable of tracking debris of this size from the ground, making collision-avoidance impossible.

[11]This estimate is based on the shuttle's flight rules for maneuvering; it has not been determined if these rules would change for the station.

Figure 3: Space Station Vulnerability Given Different Protection Methods



[a]Note: Large debris scale goes from roughly 10cm — 100 meters.

Planned Studies May Not Provide Critical Data

In February 1992 space station engineers developed a draft action plan for identifying those station components most at risk from debris and recommending alternative ways to protect them. Among other things, the plan called for a test and analysis program to identify which critical station components fail to comply with the safety requirements, and to recommend which noncomplying items should be given enhanced orbital debris protection. The plan also called for a risk assessment to determine the necessity for and essential components of a collision-avoidance plan.

If the plan had been implemented this past March, NASA officials estimated that it could have been completed by March 1993, in time for the station's critical design reviews. This plan, however, had not been approved by senior program management as of May 14, 1992. Hence, results of the plan may be too late to have any effect on the station's final designs. Further, managers and engineers throughout the program expressed concern that the plan would not provide adequate resources for testing the effects of debris penetration on critical components.

Increasing Debris Environment Requires Continuous Monitoring and International Effort to Slow Debris Growth

NASA has made great strides in understanding and updating its model of the debris environment, and in working with other countries to help mitigate the debris threat. However, continued monitoring of the debris environment and further dialogue with other space-faring nations are essential to protecting the station and other spacecraft from this growing threat.

Any plans for protecting the space station from debris hinge on having an up-to-date, reliable estimate of the amount of debris likely to be encountered over the next 30 years. The 1991 debris-environment model is widely considered to best represent the actual and potential debris environment for the mid-1990s and beyond.

In spite of the improvements in NASA's 1991 debris model, however, a high degree of uncertainty in estimating the growth rate of the debris environment remains. For example, the 1991 model assumes that only one fragmentation will occur each year. However, ten fragmentations occurred in the 18 months between October 1990 and April 1992. According to a NASA debris expert, the occurrence of nine unpredicted fragmentations—seven in orbits that will not affect the station—is probably an anomaly. Whether or not this is true, or whether the fragmentations indicate a more severe debris growth rate, can only be determined through continued study of the debris environment.

NASA plans to continue obtaining data on the debris environment from the U.S. Space Command's Haystack radar, located at Millstone Hill, Massachusetts and the Haystack Auxiliary Radar, which is under development. The Haystack radar provides information on the quantity of mid- and large-size debris. NASA has a memorandum of agreement with U.S. Space Command for the Command to continue collecting debris data through 1997. This information, and continued debris information-collection throughout its 30-year life cycle, is essential if the space station is to be adequately protected from the debris threat.

In addition to its considerable effort over the years to understand the debris environment and its trends, NASA realized that it could not combat the debris environment alone. The agency initiated discussions with research and technical institutions in other major space-faring nations, to apprise them of the U.S. understanding of the debris environment, debris population growth projections, and alternatives to mitigate debris creation. From this, NASA and the European Space Agency developed an agreement

on the need to control the number of intentional and accidental explosions in space. Dialogue with other countries is continuing.

Conclusions

NASA has been wrestling with the space debris issue for many years, and it is clear that there are no easy answers. The agency is actively working with other space-faring nations to avoid creating unnecessary debris and has made progress in estimating the current and future seriousness of the problem. By issuing a directive to its space centers, NASA has initiated the process of incorporating the latest estimate of the environment in its space station designs. The agency has not, however, made critical decisions on how it will implement this directive. That is, NASA does not know how it will protect the space station and crew from this potentially catastrophic danger to space flight. Until all cost and design issues are known and resolved, space station designs will continue to be based on an outdated and significantly understated debris environment.

NASA has been studying the potential effects of debris on space station components and is considering alternatives that could affect safety and shielding. However, the agency lacks a comprehensive strategy for dealing with debris, including detailed designs for initial shielding, subsequent augmentation, and mitigation techniques for medium and large debris. As station design and time move forward, NASA may be left with no feasible way to protect the station adequately while keeping the program on schedule and within allowable costs. Changing designs now to protect all critical components against debris could result in major redesigns, causing serious slippages in cost and schedule. Keeping designs based on the 1984 debris model would increase risks to station and crew until the agency is able to augment the station's shielding—which could be costly and may not be feasible.

NASA will have to make some difficult decisions involving tradeoffs between the cost of protecting the station from debris and the risks it is willing to accept. These decisions could influence the long-term hardware designs. Therefore, they must be made before completing the 1993 critical design review.

Recommendations

In order to provide the best protection possible for the Space Station Freedom and its crew, we recommend that the Administrator, National Aeronautics and Space Administration, delay the completion of critical design review until (1) the 1991 model of the debris environment is fully implemented, (2) any changes to NASA's debris safety criteria are thoroughly assessed, and (3) NASA develops a comprehensive strategy for dealing with debris, including:

- shielding and augmentation plans for small debris (including an assessment of the costs and operational impact of proposed augmentation designs); and
- protection concepts for medium and large debris.

Agency Comments

As requested, we did not provide a draft of this report to NASA for its review and comment. However, we discussed the report's contents with NASA officials, including the special assistant to the director of the space station program, the manager of the program engineering office, the manager of the utilization and operations office, and senior engineers and program representatives at the Johnson Space Center and Marshall Space Flight Center. Their comments have been incorporated as appropriate. In general, NASA officials believe that they are now designing the station in accordance with the 1991 debris environment, and are unaware of any approved or pending requests to waive safety requirements. We commend NASA for taking the first in a series of steps toward incorporating the 1991 debris environment in space station designs. However, we believe that until the potentially significant design and cost implications of using the new environment are resolved, the 1991 debris environment cannot be implemented. While we modified our report to reflect NASA's comments regarding safety requirements, we believe that waivers could become a reality for some critical components if the engineering and cost impact of implementing the new environment prove to be insurmountable.

We conducted our review in accordance with generally accepted government auditing standards, between October 1991 and May 1992. As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of this letter. We will then give copies to appropriate congressional committees; the Administrator, NASA; and other interested parties. Copies will also be made available to others upon request.

This work was performed under the direction of Samuel W. Bowlin, Director, Defense and Security Information Systems, who can be reached at (202) 512-6240. Other major contributors are listed in appendix II.

Sincerely yours,

Ralph V. Carlone

Ralph V. Carlone
Assistant Comptroller General

Contents

Abbreviations

GAO	General Accounting Office
IMTEC	Information Management and Technology Division
NASA	National Aeronautics and Space Administration

Objectives, Scope, and Methodology

On June 18, 1991, the House Committee on Government Operations, Subcommittee on Government Activities and Transportation, requested that we examine several issues related to the Space Station Freedom Program, one being space debris. In subsequent discussions with the Committee, we agreed to provide information on (1) NASA's progress in incorporating the latest estimate of the debris environment into space station design requirements, (2) whether NASA had an overall strategy for protecting the station from small, medium, and large space debris, and (3) NASA's efforts to maintain current information about the debris environment.

To meet our objectives, we:

- analyzed documentation on Space Station Freedom program requirements for protection from space debris and proposals for changes to these requirements;
- discussed station design changes and the impact of potential changes with senior engineers and space station managers at the space station program office in Reston, Virginia; the Johnson Space Center in Houston, Texas; and the Marshall Space Flight Center in Huntsville, Alabama;
- analyzed documentation on the latest protection concepts for small, medium, and large debris;
- met with space environment experts at Johnson and Marshall to determine the status of the environment definition, future trends, and concerns with changes in the environment; and
- observed simulations of debris impact at Johnson's hypervelocity impact laboratory to better understand the effect of debris collisions.

We discussed the contents of this report with program officials and engineers from each of the locations visited, and have incorporated their comments where appropriate.

Major Contributors to This Report

Information Management and Technology Division, Washington, D.C.

Ronald W. Beers, Assistant Director
Colleen M. Phillips, Evaluator-in-Charge

Related GAO Products

Questions Remain on the Costs, Uses, and Risks of the Redesigned Space Station (GAO/T-NSIAD-91-26, May 1, 1991).

Space Program: Space Debris a Potential Threat to Space Station and Shuttle (GAO/IMTEC-90-18, Apr. 6, 1990).

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