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Annual Report
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NATIONAL RESEARCH COUNCIL



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The Space Studies Board is a unit of the National Research Council, which serves as an independent advisor to the federal government on scientific and technical questions of national importance. The Research Council, jointly administered by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, brings the resources of the entire scientific and technical community to bear through its volunteer advisory committees.

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From the Chair



This 1993 annual report of the Space Studies Board of the National Research Council chronicles the activities of the Board during a year filled with questioning and change in the country's civil space program. The brief accounts contained herein of the activities of the Board and of its committees, together with summaries of two major reports and the complete texts of three letter reports, sketch out major space research issues that faced the nation's space scientists and engineers during the year.

In addition to uncertainties facing space scientists involved in robotic missions to explore the Earth, the solar system, and the farthest reaches of the universe, instability persisted in the human flight program. In the spring of 1993, the Clinton administration convened a blue ribbon panel to critically evaluate several redesign options for the international space station. By the end of the year, the station had assumed an even stronger international cast, as Russia was brought into the program based on both technical and foreign policy considerations. The evolution of the space station, with yet another redesign on its curriculum vitae, continued into the year 1994.

There continues to be an underlying questioning of the purposes of federally funded research in all fields, particularly "basic" research. For space research, these uncertainties are increased by the confusion about its purpose, or purposes, in a post-Cold War world where the United States no longer needs to express its technological sophistication through a very visible and very open civil space program. Indeed, it has been a most successful program in that the country has sent humans and robotic probes to targets never before visited by any human individual or device. Yes, the space program has had many "spinoffs," but demonstration of national technical prowess was a central driver for the program.

At the same time that an intense questioning of the purposes of federal funding of research is in progress, a similar questioning, driven by issues of profitability and survivability, exists in U.S. industry. All in all, it is not a comforting time for most Americans in R&D, who have been accustomed to feeling like the elite of the work force, of the intelligentsia, and of the technical base of the country. Where is the nation going from here with R&D in the universities, in the national laboratories, in industry? How will the nation apply the talents of its most highly educated and trained?

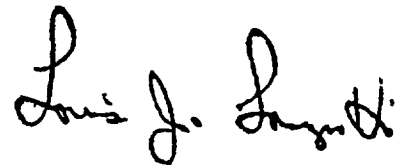
As a start to addressing these and other issues in R&D policy, the Office of Science and Technology Policy (OSTP) organized, together with the principal federal R&D agencies and the national academies, a "Forum for Science in the National Interest: World Leadership in Basic Science, Mathematics and Engineering Research." The forum, which took place at the beginning of 1994, provided opportunities for members of the research community to hear the views of political leaders on the future of R&D and to confer with them and with other attendees from

academia, the national laboratories, and industry. OSTP's intent is to use the resulting discussion session reports and individual position papers to help formulate a long-range vision for federal R&D.

Principles and goals for federal R&D funding following the forum are yet to be publicly articulated and disseminated by the OSTP. With the assumption of the responsibilities of the National Space Council by the executive branch's new National Science and Technology Council, however, it is clear that space endeavors, and space science, do not have as high a visibility and budget priority as they previously enjoyed. Adaptation to this changing environment will present major challenges and opportunities for the space research community and the Space Studies Board in the years ahead.

As I write these thoughts, my second term as chair of the Space Studies Board is drawing to a close. The last six years of new results in space research have been phenomenal; at the same time, national and international space policy has evolved in ways that I could not have imagined when I began my service on the Board. As I have written previously, the nation needs a new space policy, a policy that can provide guidance and a vision for the future, a policy that can be agreed upon across the political spectrum and by the public at large. If this could be achieved, the space program would flourish. A will to define such a policy is sorely needed.

If asked now to state one impression that will remain with me as I leave the Board, I would answer that it is the incredible collective talent of U.S. scientists and engineers that I have encountered during these years. My hope is that the political and industrial leadership of the country will lead in a manner that will encourage and harness this collective talent for the commonweal.



Louis J. Lanzerotti
Chair
Space Studies Board

June 1994

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I

History and Charter of the Board

ORIGIN OF THE SPACE SCIENCE BOARD

The National Academy of Sciences was chartered by the Congress, under the leadership of President Abraham Lincoln, to provide scientific and technical advice to the government of the United States. Over the years, the advisory program of the institution expanded, leading to the establishment of the National Academy of Engineering and the Institute of Medicine, and of the National Research Council, today's operational arm of the Academies of Sciences and Engineering.

After the launch of Sputnik in 1957, the pace and scope of U.S. space activity grew dramatically. Congress created the National Aeronautics and Space Administration (NASA) to conduct the nation's ambitious space agenda, and the Academy-Research Council created the Space Science Board. The original charter of the Board was established in June 1958, three months before final enactment of the legislation creating NASA. The Space Science Board has provided independent scientific and programmatic advice to NASA on a continuous basis from its inception until the present.

REORGANIZATION OF THE BOARD— CREATION OF THE SPACE STUDIES BOARD

In 1988, the Space Science Board undertook a series of retreats to review its structure, scope, and goals. These retreats were motivated by the Board's desire to more closely align its structure and activities with evolving government advisory needs, and by its assumption of a major portion of the responsibilities of the disestablished Space Applications Board. As a result of these retreats, a number of new task groups and committees were formed, and several committees were disbanded and their portfolios distributed to other committees. The Committee on Data Management and Computation and its activities were terminated. The Committee on Planetary Biology and Chemical Evolution was also dismantled, but its responsibilities were distributed to other discipline committees and task groups. The charters of the remaining committees were revised, and an executive council of the Board was created to assist the chair of the Board in managing Board activities.

Recognizing that civilian space research now involves federal agencies other than NASA (for example, the National Oceanic and Atmospheric Administration (NOAA), the Departments of Energy (DOE) and Defense (DOD), and the National Science Foundation (NSF)), it was decided to place greater emphasis on broadening the Board's advisory outreach. This broadening is fully consistent with the Board's founding charter in 1958.

CHARTER OF THE BOARD

The basic elements of the charter of the Board remain those expressed by National Academy of Sciences President Detlev Bronk to Dr. Lloyd Berkner, first chair of the Space Science Board, in a letter of June 26, 1958:

We have talked of the main task of the Board in three parts—the immediate program, the long-range program, and the international aspects of both. In all three we shall look to the Board to be the focus of the interests and responsibilities of the Academy-Research Council in space science; to establish necessary relationships with civilian science and with governmental science activities, particularly the proposed new space agency, the National Science Foundation, and the Advanced Research Projects Agency; to represent the Academy-Research Council complex in our international relations in this field on behalf of American science and scientists; to seek ways to stimulate needed research; to promote necessary coordination of scientific effort; and to provide such advice and recommendations to appropriate individuals and agencies with regard to space science as may in the Board's judgment be desirable.

As we have already agreed, the Board is intended to be an advisory, consultative, correlating, evaluating body and not an operating agency in the field of space science. It should avoid responsibility as a Board for the conduct of any programs of space research and for the formulation of budgets relative thereto. Advice to agencies properly responsible for these matters, on the other hand, would be within its purview to provide.

Thus, the Board exists to provide advice to the federal government on space research and to assist in coordination of the nation's space research undertakings. Since its restructuring in 1988 and 1989, the Board has assumed similar responsibilities with respect to space applications. The Board also addresses scientific aspects of the nation's program of human spaceflight.

Recommendations may be prepared either in response to a government request or on the Board's own initiative, and are released after review and approval by the National Research Council (NRC). In general, the Board develops and documents its views based on findings of its discipline committees or interdisciplinary task groups that conduct studies of varying duration and extent. These committees and task groups are composed of prominent researchers and recognized experts whose appointments are reviewed and approved according to a formal procedure of the NRC. On occasion, the Board itself considers major issues in plenary session and develops its own statements. The Board also provides guidance, based on its publicly established opinions, in testimony to Congress.

The Board's overall scope of activity has several components: discipline oversight, interdisciplinary studies, international activities, and advisory outreach.

OVERSIGHT OF SPACE RESEARCH DISCIPLINES

The Board has responsibility for strategic planning and oversight in the numerous subdisciplines of space research, including space astronomy, Earth studies from space, microgravity science, solar and space physics, space biology and medicine, and planetary and lunar exploration. This responsibility is discharged through an organization of separate discipline committees, and includes preparation of strategic research plans as well as assessments of progress in these disciplines. The standard vehicle for providing long-term research guidance is the research strategy report, which has been used successfully by the Board for many years. Committees also prepare formal assessment reports that examine progress in a discipline in comparison with published Board advice. From time to time, in response to a sponsor or Board request, or to circumstances requiring prompt and focused comment, a committee may prepare and submit a brief report in letter format. All committee reports undergo Board and NRC review and approval prior to publication. Board and committee reports are formally issued as reports of the Board and of the National Research Council.

Individual discipline committees may be called upon by the Board, from time to time, to prepare specialized supporting material for use by either the Board or its interdisciplinary committees or task groups.

INTERDISCIPLINARY STUDIES

While the emphasis over the years has been on discipline research planning and evaluation, the reorganization of the Board recognized a need for crosscutting technical and policy studies in several important areas. To address these needs, the Board creates internal committees of the Board and ad hoc task groups. Internal committees, constituted exclusively of Board members, are formed to carry out short-period study activities or to serve as initial planning bodies for topics that may require subsequent formation of a regular committee or task group. Task groups

resemble discipline committees in composition and operation, except that they have predetermined lifetimes, typically two to three years, and clearly delimited tasks.

INTERNATIONAL REPRESENTATION

The Board continues to serve as the U.S. National Committee for the International Council of Scientific Unions (ICSU) Committee on Space Research (COSPAR). The U.S. vice president of COSPAR serves as a member of the Board, and a member of the Board's staff serves as Executive Secretary for this office. In this capacity, the Board participates in a broad variety of COSPAR panels and committees.

As the economic and political integration of Europe has progressed, so also has the integration of Europe's space activities. The Board has collaborated successfully with the European space research community on a number of ad hoc joint studies in the past and is now seeking in a measured way to deepen its advisory relationship with this community. To date, the Board's approach has been regular exchange of observers at meetings of the Board and of the European Space Science Committee (ESSC), under the European Science Foundation.

In the future, the Board hopes to initiate cooperative advisory exchanges with the space research programs of Russia and Japan.

ADVISORY OUTREACH

The Space Science Board was conceived to provide space research guidance across the federal government. Over the years, the Board's agenda has focused on NASA's space science program. Since the Board's reorganization, however, several influences have acted to expand the breadth of the Board's purview, both within NASA and outside it.

First, it is recognized that the incorporation in a major way of scientific objectives into human flight programs such as the shuttle and space station programs, and possibly a human exploration initiative, necessitates additional interfaces with responsible offices in NASA. The Board is attempting to strengthen its links to the space technology office in NASA through collaborative activities, such as joint workshops, with the NRC's Aeronautics and Space Engineering Board. Stronger links to NASA's space operations, international affairs, and commercial programs offices may also be needed in the future.

Second, the Board's assumption of space applications responsibilities from the dissolved Space Applications Board has implied a broadening of its advisory audience to other agencies; an example is NOAA, which is responsible for operational weather satellites. In response, NOAA has become a cosponsor of the Board's Committee on Earth Studies.

Third, the maturation of some of the physical sciences may lead to progressive integration of space and nonspace elements, suggesting a more highly integrated advisory structure within the NRC. One example is the solar-terrestrial community, where the Board's Committee on Solar and Space Physics has operated for several years in a "federated" structure with the NRC's ground-based Committee on Solar-Terrestrial Research. Another example is astronomy, where the 1991 report of the NRC's Astronomy and Astrophysics Survey Committee¹ suggested a close relationship between space astronomy and ground-based astronomy, the latter primarily supported by the NSF. The Board therefore established, in 1992, a new Committee on Astronomy and Astrophysics. This committee operates as a joint committee of the Space Studies Board and the Board on Physics and Astronomy. Another area of possible future disciplinary association is the biomedical research community, including elements supported by the National Institutes of Health (NIH) and NASA's space biology research program.

Fourth, it has become apparent that new participants may become involved in space exploration, for example, the Ballistic Missile Defense Organization (BMDO). Their involvement originates partly from an interest in development of space technology, and partly as a result of declassification of some defense technologies in response to the changing geopolitical environment. The BMDO has expressed the intention of conducting several space missions of potential scientific interest; the Board has performed an initial assessment of one of these (the Clementine mission to the Moon and an asteroid) and is contemplating establishing a sponsorship relationship with the BMDO. The Board expects to continue to reach out beyond NASA to other federal agencies, seeking to establish advisory and corresponding sponsorship relationships, where appropriate.

¹*The Decade of Discovery in Astronomy and Astrophysics*, Astronomy and Astrophysics Survey Committee, National Academy Press, Washington, D.C., 1991.

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Activities and Membership

During 1993, the Space Studies Board and its committees and task groups gathered for a total of 31 meetings. Two full-length reports were issued, one on the human exploration of the solar system and one on NASA's technology programs. Three letter reports were released, dealing with space station utilization in anticipation of human exploration (Section 4.1), several scientific and programmatic issues in the space life sciences (4.2), and a scientific review of the rescoped Advanced X-ray Astrophysics Facility (AXAF) (4.3). Three committees, the Committee on Microgravity Research (CMGR), the Committee on Planetary and Lunar Exploration (COMPLEX), and the Committee on Solar and Space Physics (CSSP), were heavily engaged in developing or updating research strategies. The Committee on Earth Studies (CES) devoted most of its energy to development of a sweeping status assessment of fields within its scope, to include operational environmental systems as well as some aspects of the national security space infrastructure.

The following sections present highlights of the meetings of the Board and its committees during 1993. Formal reports and letter reports developed and approved during these meetings are referenced by the section number of this annual report where their summaries are reprinted (in the case of full-length reports) or where they are reproduced in full (in the case of letter reports).

SPACE STUDIES BOARD

The year 1993 began with the nation on the cusp of a new era in science and technology. During the year, space scientists would watch with anxious fascination as the Superconducting Supercollider slipped into oblivion, and many wondered about the fate of Cassini, AXAF, and the Hubble Space Telescope. Unmistakable signs of change were apparent even before the last year of twelve of Republican administrations had fully ebbed away. Shortly before the beginning of the new year, Office of Science and Technology Policy (OSTP) Director D. Allan Bromley released the report of the President's Council of Advisors on Science and Technology on the research university system,¹ which spelled out an end to across-the-board research growth. At the same time, the NSF took the first steps in shifting operating budgets to "strategic research."

In the closing days of 1992, President Clinton announced the selection of Office of Technology Assessment Director John Gibbons as the new science advisor and director of OSTP. Within two months, the new president had announced his intention to emphasize technology in its relation to national growth, including the roles of technology transfer and government-industry partnership. In spite of statements in favor of the space station program, the role

¹*Renewing the Promise: Research-Intensive Universities and the Nation*, report of the President's Council of Advisors on Science and Technology, U.S. Government Printing Office, Washington, D.C., December 1992.

of space and space science in the new administration remained murky; in a reorganization of the White House, the National Space Council was absorbed into OSTP, which shared the president's across-the-board 25% staffing cuts. In a presidential statement issued on February 22, entitled *Technology for America's Growth—A New Direction to Build Economic Strength*, the word "technology" is pervasive, but "space" is nearly absent.

The Board held its 109th meeting on February 24-25 at the National Academy of Sciences in Washington, D.C. The meeting was chaired by member Dr. William Merrell, of Texas A&M University, in the absence due to illness of Board Chair Louis Lanzerotti. The space policy backdrop for this meeting was particularly turbulent, with new consequences of the change in national administration emerging on almost a daily basis. Dr. Gibbons took the helm as director of OSTP in early February. NASA Administrator Daniel Goldin, who had initiated a series of sweeping management changes at the agency on October 15, was awaiting word on his continued service before finalizing them. Concurrently, ominous rumors of major over-runs on the space station program, some as high as \$1 billion, were emanating from the Johnson Space Center. This was followed by a period of conflicting reports as to whether the administration would seek to cancel or maintain the space station program, in the context of President Clinton's deficit reduction program presented to the American people in his first State of the Union Address on February 17. President Clinton subsequently directed NASA to prepare a less expensive space station plan for White House action by June 1. NASA Administrator Goldin responded by establishing a 90-day redesign team to prepare a series of downscaled options for assessment by a blue ribbon panel, the Advisory Committee on the Redesign of the Space Station, chaired by MIT President Charles Vest. The redesign team was to prepare three alternatives, costing over a three-year period \$5 billion, \$7 billion, and \$9 billion, respectively, compared to the baseline \$14.6 billion program planned by the Bush administration over the same period.

As is customary at its February meeting, the Board had briefings on the budget outlook for space science. Because of the government transition, no formal budget had yet been transmitted to the Congress. Since President Clinton had made a number of aspects of his plans public, however, officials of the Office of Management and Budget and of the Congressional Budget Office were able to sketch the outlines of the new administration's program and its prospects. Associate Administrator for Space Science and Applications and Chief Scientist Lennard A. Fisk presented science program status and his expectations for the organizational and programmatic changes in progress. The Board also heard an account of the status of major Russian space research programs from the Russian Counselor for Science and Technology, Dr. Lev Mukkin.

Principal items of internal business that the Board took up at the meeting included action on several proposed letter reports from committees. The Board discussed, and remanded for revisions, letters from the Committee on Space Biology and Medicine (4.2) and from the Committee on Astronomy and Astrophysics (4.3), the latter operated jointly with the NRC's Board on Physics and Astronomy. Board members also discussed tentative findings of the research strategy development effort of the Committee on Microgravity Research, study plans of the Committee on Planetary and Lunar Exploration on MESUR/Pathfinder, and recommendations by the Committee on Solar and Space Physics on the reflight of the Tethered Satellite System. Members of the Board nominated absent Chair Louis Lanzerotti to assume the role of U.S. national representative to COSPAR on completion of his term as Board chair in mid-1994. A major activity at the meeting was to conduct a trial of the research prioritization procedure developed by the Board's Task Group on Priorities in Space Research. Members applied the task group-developed evaluation instrument to a set of fictitious space research initiatives and analyzed the results of the trial. The task group planned to document these results, with recommendations, in a report to the June meeting of the Board.

On March 9, the Executive Committee of the Board held a teleconference to follow up on a number of items from the Board meeting. Final approval was given for a transmittal letter (reprinted in Section 4.1) to NASA Administrator Goldin intended to accompany the new report of the Committee on Human Exploration. Potential major Board-level projects were discussed, and options for the June meeting agenda were considered. It was decided to hold a face-to-face meeting of the Executive Committee in April to meet the newly appointed Associate Administrator of Life and Microgravity Sciences and Applications Harry Holloway and to discuss issues in the NASA life sciences programs.

Two months later than a returning administration, the Clinton team presented its first budget to Congress. To the relief of space scientists, the necessary big increases for AXAF, Cassini, and EOS were included in this FY94 budget, which provided for an 8.7% increase for NASA R&D and a 6.5% increase for NASA overall. On the other hand, the Bush/Quayle Space Exploration Initiative was abandoned, and its program office at NASA headquarters was disbanded.

Shortly thereafter, Mr. Goldin finalized his reorganization of NASA, announced the previous October, dividing the Office of Space Science and Applications into three new science offices. Former OSSA Director Lennard Fisk announced his departure from NASA.

As planned in March, the Executive Committee met in Washington, D.C., on April 7. Committee on Space Biology and Medicine member Drew Gaffney was also invited to join the dialogue with Holloway, and a tentative plan for the June Board meeting, to be held at the Johnson Space Center in Houston, Texas, was developed.

The Executive Committee held one more planning teleconference before the Houston meeting on May 5; the members and staff blocked out the agenda for the meeting and defined the major issues to be addressed.

On June 7, the space station redesign team presented its three options to the Vest committee. One option (A) was essentially a downscoped version of the old *Freedom* design, organized around an integrated flight control module called Bus-1, developed by Lockheed for robotic spacecraft. The second option (B), closest to the previous design, depended on an altered assembly sequence and reduced capabilities in a number of areas to achieve savings. The final option (C) was a radically new concept that came to be known as "man in a can"; it was a large pressurized volume to be launched intact, and featured no external truss. This option, whose costing was regarded with suspicion because of its radical departure from *Freedom* heritage, presented problems for integration of international partner elements as well as a number of serious operational drawbacks. House Committee on Science, Space, and Technology Chair George Brown promptly announced that none of the designs presented would be politically acceptable in the Congress. On June 10, the Vest committee reported to the White House: after reviewing the designs presented, the committee reached the overall conclusion that "Option A has an advantage in capability and lends itself to modular build-up. Option C is the lowest risk and potentially lower in cost."²

In the middle of these dramatic developments, the Board held its 110th meeting on June 9-11 at the Johnson Space Center in Houston. Major activities of the meeting included action on three reports: a research strategy by the Committee on Microgravity Research, a final report of the Task Group on Priorities in Space Research, and a report on science management by the Committee on Human Exploration. One day was spent in presentations and tours of Center facilities involved with life sciences research and astronaut and crew training activities. Dr. David Black, director of the Lunar and Planetary Institute, discussed the work of his institute with members. The Board also heard status reports from the Committees on Planetary and Lunar Exploration, Astronomy and Astrophysics, and the Joint Committee on Technology. After vigorous discussion, it was decided that the final report of the Task Group on Priorities in Space Research should be recast as an internal report to the Board, including an account of Board discussion of the prioritizing methodology and its trial at the February Board meeting.

Shortly after this meeting, on June 17, President Clinton announced his selection of a modified version of option A and asked Congress for \$1.85 billion for the station for FY94 and an additional \$250 million for scientific payloads. On top of the \$9 billion already spent on the program, the president's proposal called for an additional investment of \$10.5 billion over the next five years to complete the station.

The rapid evolution of the space station program continued in the third quarter, which was marked, however, by the dismaying loss of the Mars Orbiter spacecraft. On the evening of August 21, following pressurization of the spacecraft's fuel tanks to enter Mars orbit, the spacecraft failed to respond to ground control commands. Since the Observer had already received full instructions for Mars orbit insertion, the possibility existed that it was in orbit around the planet. But all safe-mode contingencies failed to return any signal from the spacecraft, and its location and trajectory remain unknown. With the total loss of the billion-dollar mission and its expected data return, NASA convened a study team at the Jet Propulsion Laboratory to review options for an expedited return to Mars with a replacement mission that might meet scientific objectives for Mars enunciated by the Board's Committee on Planetary and Lunar Exploration and the affected research community.

The Space Studies Board did not meet during the third quarter of 1993. Its Executive Committee and Committee on International Programs met jointly on July 28-30 in Woods Hole, Massachusetts, to complete approval action on several items carried over from the June Board meeting and to discuss long-range activities of the Board. Acting on behalf of the Board, the committees approved the revised Committee on Human Exploration and Committee on Microgravity Research reports for submission to NRC review and accepted the Board's 1994 program plan. In addition, new or revised project statements of task were approved for the Committees on International Programs, Planetary and Lunar Exploration, and Space Biology and Medicine and the Joint Commit-

²*Final Report to the President, Advisory Committee on the Redesign of the Space Station*, U.S. Government Printing Office, Washington, D.C., June 1993, p. 49.

tee on Technology. Plans for a workshop by the Committee on Earth Studies and a joint study on the space station program by the Committees on Space Biology and Medicine and Microgravity Research were also approved.

In the meantime, there were hopeful developments in the space station program. Vice President Al Gore and Russian Prime Minister Victor Chernomyrdin met and announced a number of space-related agreements, including a ground-breaking accord on joint development of a further redesigned international space station. The resulting plan called for the previous international partners, ESA, Japan, and Canada, to be integrated in a later stage of station buildup. In spite of some reservations about the U.S.-Russian concept and widespread concerns about the stability of the Russian space program, the station's prospects in the FY94 appropriations process seemed strengthened.

In a wider arena, the administration released its National Performance Review report on September 7. It recommended major changes in many areas of government operations, not the least of which was a proposed net reduction of a quarter-million federal employees over a period of five years. How the space program might be affected by this and other proposed changes remained uncertain.

The Executive Committee met by teleconference on October 1 to discuss the agenda for the next Board meeting.

The Board held this final meeting of 1993 (its 111th) on November 15-17 at the Beckman Center in Irvine, California. The Board took advantage of the presence of the NRC's Board on Physics and Astronomy there to hold a rare joint session. After introductory presentations on the current activities of the two boards, Dr. Jeremiah Ostriker, member of both the Board and of the boards' joint Committee on Astronomy and Astrophysics, presented ongoing activities and plans of the committee. NSF Assistant Director William Harris briefed the boards on NSF plans and programs, and Dr. Robert Mewaldt concluded the joint meeting with an interesting account of the SAMPEX mission, a small but highly productive science mission. Members of the Board considered and approved, subject to minor revisions, the new integrated strategy of the Committee on Planetary and Lunar Exploration.

On the second day of the meeting, the Board considered a second draft of the final report of its Task Group on Priorities in Space Research. It was decided that the report should be reformatted and published as a discussion paper rather than as a report presenting formal recommendations. The Board also considered and approved, with a number of revisions, a report on space station science management recently prepared by the Committees on Space Biology and Medicine and on Microgravity Research. The remainder of the day was devoted to a number of subjects: Prof. François Becker, the new chair of the European Space Science Committee, gave a summary of planned organizational changes and new and ongoing projects. Dr. Charles Elachi of JPL described options under consideration for recovering the science lost with Mars Observer. The last item for the day was a videoconference with Drs. France Cordova and Wesley Huntress featuring discussion of the role of NASA's chief scientist and the status of space science within the agency.

On the last day of the meeting, a planned videoconference with NOAA Administrator D. James Baker had to be canceled due to a last-minute conflict. The status of the Committee on Earth Studies survey project was reviewed, and the Board adjourned after a general discussion of the previous day's videoconference with NASA science executives.

Overall, 1993 was a year of mixed results for space research. At NASA, Mars Observer was lost, but two Discovery-class missions (MESUR/Pathfinder and NEAR) got new starts in the FY94 budget. AXAF-S was canceled, but the Hubble repair mission went without a flaw. Space station planning advanced as a major Clinton international initiative, promising early access for U.S. science to the Russian Mir, but possibly at the cost of some canceled Spacelab missions.

The space research community looked ahead with apprehension to the FY95 budget and subsequent congressional action. Space science did not appear high among the administration's priorities, and two large missions, AXAF-I and Cassini, were reaching their spending peaks. The space station, newly invigorated by its enhanced foreign policy importance, seemed likely to be preserved, together with the shuttle; aeronautics and Mission to Planet Earth were expected to increase. At the same time, the prevailing high priority of deficit reduction meant that NASA and other discretionary elements of the federal budget could be expected to remain flat or actually decline.

In this environment, NASA Administrator Daniel Goldin was moving to address a long-perceived need by unveiling a strategic plan for the agency in early 1994. With NASA's new Chief Scientist, Dr. France Cordova, installed and representing the agency's science programs within the administrator's office, the hoped-for agency-wide strategic plan could be the mechanism by which space science and applications would be clearly oriented within the president's R&D policy structure.

NOAA, too, experienced both failure and success during 1993. NOAA/NESDIS worked to develop a long-range strategy for remote sensing for meteorology, oceanography, terrestrial measurements, and the space environment. NOAA-13 was launched in August and suffered a power system failure two weeks later, apparently due to a failure in the battery charge controller unit. But an agreement for a long-term mutual geostationary satellite backup was signed by NOAA and EUMETSAT, and the tri-agency (NOAA/NASA/DOD) plan for convergence of the polar-orbiting platforms DMSP/POES/EOS-PM was completed and submitted to the Office of Science and Technology Policy. Landsat-6 was launched in October but did not achieve orbit. Discussions with NASA on the future of Landsat continued, as did discussions about the trade-offs between national security interests and commercialization of remote sensing.

Membership of the Space Studies Board

Louis J. Lanzerotti, § AT&T Bell Laboratories (chair)
 Joseph A. Burns, Cornell University
 John A. Dutton, Pennsylvania State University
 Anthony W. England, University of Michigan
 James P. Ferris, Rensselaer Polytechnic Institute
 Herbert Friedman, Naval Research Laboratory
 Riccardo Giacconi, * European Southern Observatory
 Harold J. Guy, § University of California at San Diego
 Noel W. Hinners, § Martin Marietta Astronautics Company
 David A. Landgrebe, * Purdue University
 Robert A. Laudise, AT&T Bell Laboratories
 Richard S. Lindzen, § Massachusetts Institute of Technology
 John H. McElroy, University of Texas at Arlington
 William J. Merrell, Jr., Texas A&M University
 Robert H. Moser, * University of New Mexico
 Norman F. Ness, § University of Delaware
 Marcia Neugebauer, Jet Propulsion Laboratory
 Simon Ostrach, Case Western Reserve University
 Jeremiah P. Ostriker, § Princeton University
 Carle M. Pieters, § Brown University
 Judith Pipher, University of Rochester
 Mark Settle, * ARCO Oil and Gas Company
 William A. Sirignano, University of California at Irvine
 John W. Townsend, Jr., NASA (retired)
 Fred Turek, Northwestern University
 Arthur B.C. Walker, Jr., Stanford University

Marvin A. Geller, State University of New York at Stony Brook (ex officio)
 Duane T. McRuer, Systems Technology, Inc. (ex officio)
 Vincent Vitto, Massachusetts Institute of Technology (ex officio)
 Donald J. Williams, * Johns Hopkins University (ex officio)

Marc S. Allen, Director
 Richard C. Hart, Deputy Director
 Betty C. Guyot, Administrative Officer

*term expired during 1993

§member of the Executive Committee

COMMITTEE ON INTERNATIONAL PROGRAMS

The Committee on International Programs (CIP) met jointly with the Executive Committee of the Board on July 28-30 in Woods Hole, Massachusetts, to discuss long-range activities of the Board, as described above.

On November 11-12 the committee sent a delegation of CIP Chair William Merrell, member Arthur Walker, and Board Director Marc Allen to the fall meeting of the European Space Science Committee (ESSC) at ESA, in Paris. Augmented by several discipline-specialist guests, the ESSC reviewed an Italian x-ray astronomy mission, the X-ray Astronomy Satellite (SAX), at the request of the Italian Space Agency (ASI). Attendees also heard briefings by Drs. Roger Bonnet and L. Emiliani on the ESA space science and Earth observations programs, respectively. An anticipated Russian presentation was canceled when the delegation was unable to attend.

The committee discussed the meeting at a teleconference on December 1, focusing on prospects and a process for possible joint studies.

CIP Membership

William J. Merrell, Jr., Texas A&M University (chair)
Herbert Friedman, Naval Research Laboratory
Norman F. Ness, University of Delaware
Arthur B.C. Walker, Jr., Stanford University

Richard C. Hart, Executive Secretary

JOINT COMMITTEE ON TECHNOLOGY FOR SPACE SCIENCE AND APPLICATIONS

The Joint Committee on Technology (JCT), a collaborative activity with the NRC's Aeronautics and Space Engineering Board, released its first report, *Improving NASA's Technology for Space Science* (National Academy Press, Washington, D.C., 1993), and met in Washington, D.C., on March 4 to discuss its next task. Briefings at this meeting by NASA's Office of Advanced Concepts and Technology (OACT) and Office of Space Science and Applications (OSSA) dealt primarily with the agency's reorganization. OSSA representatives pointed out a strong parallelism between the committee's new report and current directions of OSSA thinking. NASA briefers offered some suggestions for the committee's next task. In subsequent discussion on future activities, the committee considered three possibilities: doing nothing, assessing a specific technology (for example, robotics and automation), or analyzing process (i.e., creation or transfer of technology). The committee chose the last option, feeling that it would be a logical extension of the first study and would permit exploration of areas such as technology transfer, the relationship between science needs and technological opportunities, and the role of universities. Committee members were tasked to flesh out the proposal, which Co-chairs David Landgrebe and John Hedgepeth planned to present to the committee's parent boards and to NASA officials. A study period in late summer or early fall was tentatively envisioned.

Dr. Anthony England assumed the chair of the Space Studies Board component of the joint committee in midyear.

Subsequently, the joint committee met again in Washington, D.C., on November 9 to review NASA's progress in implementing the recommendations of its earlier report. The committee co-chairs noted that the committee had not yet settled on its next task. The study proposal drafted at its previous meeting was felt to be too broad by its two parent boards and by its NASA sponsors. A proposed charge from the Space Studies Board Executive Committee asking the joint committee to formally review NASA's responses to the recommendations of previous reports was considered.

Several briefings followed. Office of Advanced Concepts and Technology representative Dr. Robert Norwood noted that NASA's Integrated Technology Plan was still in preparation and that the White House had issued a new national technology policy aimed at encouraging economic growth, more productive and responsive technology programs, and world leadership in basic science. Representatives of the agency's science offices discussed the effects of NASA's reorganization and described their individual responses to the report. They identified several areas for committee assistance, such as suggesting membership for internal technology advisory panels, advocating budget stability, suggesting mechanisms for identifying private-sector technology interests, encouraging broader involvement of the academic community, and suggesting ways to coordinate technology development across federal agencies. The committee decided to continue to monitor NASA's plans and strategies for implementing its published recommendations and to defer initiation of a new study.

JCT Membership

Anthony W. England, University of Michigan (co-chair)
 David A. Landgrebe,* Purdue University (former co-chair)
 John M. Hedgepeth,§ Digisim, Inc. (co-chair)
 Joseph P. Allen,§ Space Industries Intl.
 John M. Logsdon,§ George Washington University
 Duane T. McRuer,§ Systems Technology, Inc.
 Simon Ostrach, Case Western Reserve University
 Judith Pipher, University of Rochester
 Alfred Schock,§ Fairchild Industries
 John W. Townsend, NASA (retired)

Richard C. Hart, Executive Secretary (Space Studies Board)
 Noel E. Eldridge, Executive Secretary (Aeronautics and Space Engineering Board)

*term expired during 1993

§member, Aeronautics and Space Engineering Board

COMMITTEE ON ASTRONOMY AND ASTROPHYSICS AND TASK GROUP ON AXAF

The Committee on Astronomy and Astrophysics (CAA), chaired by Prof. Marc Davis of the University of California at Berkeley and operated jointly with the NRC's Board on Physics and Astronomy, met for the first time on January 13-14. The committee heard program status presentations from the NSF, NASA, and the Department of Energy (DOE). NSF briefers spoke about reductions facing the Astronomy Division, but assured the committee that funding for the Laser Interferometer Gravity-wave Observatory (LIGO) would not be taken from this division's budget. NASA Astrophysics Division presenters described the tight funding foreseen by NASA over the coming five years and discussed the status of AXAF, SIRTf, SOFIA, COSTAR, and international cooperation on missions. NASA's astrophysics mission operations and data analysis (MO&DA) program was also discussed. A representative of the DOE Physics Division described their non-accelerator physics program. The CAA discussed the possibility of developing recommendations for NASA and the NSF on how to implement the Astronomy and Astrophysics Survey Committee recommendations, especially the high-priority recommendations on maintaining the astronomy infrastructure (as defined by peer-reviewed projects), ongoing maintenance, and existing cutting-edge facilities in the new fiscal environment.

Prof. Arthur Davidsen, chair of the Task Group on the Advanced X-ray Astrophysics Facility (AXAF), or TGA, presented the findings of the task group to the CAA. The TGA was chartered in late 1992 to perform a scientific assessment of the rescoped AXAF program (AXAF-I and AXAF-S) and completed its deliberations at its meeting on December 10-11, 1992. The TGA's letter report was forwarded by the CAA to the Board for action at the February Board meeting. The letter (4.3), which found that the restructured mission was capable of meeting the scientific goals of the original mission, was approved by the Board and by the NRC and was released on April 28.

The committee met again on April 27-28 and began with a detailed presentation on the Gemini Telescope project. House Space Subcommittee Science Consultant Richard Obermann discussed NASA and NSF issues before Congress and described the problem of funding NASA programs under a constrained federal budget. NSF Assistant Director William Harris introduced Dr. Hugh Van Horn as the director-designate of the Astronomical Sciences Division. Mr. Arthur Fuchs, chief of the NASA Observatories Development Branch, discussed reorganization in the Office of Space Science, budget figures, and a timetable for future missions. Dr. Guenter Riegler, chief scientist for Science Operations, discussed the pressures on the MO&DA program. The committee also heard progress reports on three new activities of the Board on Physics and Astronomy: the Cosmology Panel, the Neutrino Astrophysics Panel, and the Committee on Cosmic-Ray Physics.

The committee met a third time on November 12-13 at the Beckman Center. Incoming NASA Astrophysics Division Director Daniel Weedman gave his perspective on the status of the NASA astrophysics program. The committee was requested in a letter from NASA Associate Administrator Wesley Huntress to advise on NASA's infrared astronomy program, particularly on whether the rescoping of SIRTf and SOFIA within current budgetary

constraints satisfied the Bahcall report's scientific objectives for infrared astronomy. In response, a task group was formed on SIRTf and SOFIA and charged to submit a report in March 1994.

Col. Thomas Humpherys, USAF, described possible dual use of a Ballistic Missile Defense Organization (BMDO) 4-meter thin-mirror, active-optics orbital telescope for national security tests and astronomy. Mr. Sam Williams of Lockheed and Mr. Roland Plante of Itek described the technical details of the 4-m system and of a future 10-m design. Committee member Doyal Harper described the advantages—low water-vapor content, atmospheric stability—for astronomy from the South Pole, and the projects proposed to take advantage of them. NSF Astronomy Division Director Hugh Van Horn charged the committee with advising NSF on its ground-based optical and infrared astronomy program, leading to formation by the CAA of a second separate task group to address these issues. Van Horn also discussed the Gemini telescopes; Acting Gemini Director Sydney Wolff discussed the latest technical developments on the project.

CAA Membership

Marc Davis, University of California at Berkeley (chair)
 Arthur F. Davidsen, Johns Hopkins University
 Sandra M. Faber, Lick Observatory
 Holland C. Ford, Space Telescope Science Institute
 Jonathan E. Grindlay, Harvard University
 Doyal A. Harper, Jr., Yerkes Observatory
 Kenneth I. Kellermann, National Radio Astronomy Observatory
 Richard A. McCray, Joint Institute Laboratory for Astrophysics
 Jeremiah P. Ostriker, Princeton University Observatory
 Bernard Sadoulet, University of California at Berkeley
 Anneila I. Sargent, California Institute of Technology

Robert L. Riemer, Executive Secretary

TGA Membership*

Arthur F. Davidsen, Johns Hopkins University (chair)
 David W. Arnett, University of Arizona
 Hale Bradt, Massachusetts Institute of Technology
 Anne P. Cowley, Arizona State University
 Paul Gorenstein, Smithsonian Institution
 Steven M. Kahn, University of California at Berkeley
 James D. Kurfess, Naval Research Laboratory

Robert L. Riemer, Executive Secretary

*task group disbanded in 1993

COMMITTEE ON EARTH STUDIES

The Committee on Earth Studies (CES) met on June 14-15. Objectives of the meeting were to plan for a September workshop, hear status reports on NOAA and NASA programs, and obtain information on various small satellite initiatives. Mr. Anthony Durham of NOAA/NESDIS briefed the committee on the status and plans of the agency's polar and geostationary environmental satellites. Mr. Durham discussed with the committee the possibility of conducting an assessment of NOAA's polar environmental satellite program. These discussions were to continue as the committee seeks to identify the agency's specific advisory needs.

The committee heard briefings from JPL and Goddard Space Flight Center about programs and activities under their respective jurisdictions. A representative from the Advanced Research Projects Agency made a presentation on the proposed Collaboration on Advanced Multispectral Earth Observation (CAMEO) program. Dr. Arturo Silvestrini, president of EOSAT, provided an overview of the company's current efforts and discussed issues associated with the sale of Landsat data in the future. The committee considered plans for a workshop to be held in

September at the Beckman Center. The workshop would focus on scientific and policy developments that had occurred since publication of the committee's report, *Assessment of Satellite Earth Observation Programs—1991* (National Academy Press, Washington, D.C., 1991). In addition to committee members, participants would include NASA and NOAA managers as well as invited cross-disciplinary experts from the space-related earth science and applications community.

The committee subsequently hosted this week-long workshop at the Beckman Center on September 13-17. The specific purpose of the meeting was to begin a study surveying programs and plans for civil Earth observations for the next two decades. The study will encompass NASA's Mission to Planet Earth program, NOAA's polar and geostationary operational satellites, and civilian uses of DOD's meteorological satellites and associated information systems. It was planned to present the study to the Board for review at its winter meeting in 1993 and to complete NRC review and publication by April 1994.

In addition to status updates from NASA and NOAA, the September meeting featured briefings from several other NRC chairs on related completed or ongoing studies, an overview of recently published and planned Office of Technology Assessment reports on remote sensing, an update from the U.S. Geological Survey about its Earth observation activities, and a presentation on future passive sensor systems.

CES Membership

John H. McElroy, University of Texas at Arlington (chair)
 William Bonner, University Center for Atmospheric Research
 George Born, University of Colorado
 Janet Campbell, Institute for the Study of Earth, Oceans, and Space
 Dudley Chelton, Jr., Oregon State University
 John Evans, COMSAT Laboratories
 Diana Freckman, Colorado State University
 Elaine Hansen, University of Colorado
 Roy Jenne, National Center for Atmospheric Research
 Kenneth Jezek, Ohio State University
 Edward Kanemasu, University of Georgia
 Richard Kott, consultant, Fort Washington, Maryland
 Conway Leovy, University of Washington
 John MacDonald, MacDonald-Dettwiler Associates
 Pamela Mack, Clemson University
 Stanley Morain, University of New Mexico
 Clark Wilson, University of Texas at Austin

Joyce M. Purcell, Executive Secretary

COMMITTEE ON HUMAN EXPLORATION

The Committee on Human Exploration (CHEX) released its first report, *Scientific Prerequisites for the Human Exploration of Space* (National Academy Press, Washington, D.C., 1993).

The committee met in Washington on April 5-6 to undertake two tasks: to respond to comments by external reviewers on its second report, *Scientific Opportunities in the Human Exploration of Space*, and to finalize the text of its third report, *Science Management Principles for the Human Exploration of Space*. The committee was briefed about recent organizational changes at NASA, particularly the breakup of the Office of Space Science and Applications into three parts and the dissolution of the Office of Exploration. Following a general review of the comments made by the external reviewers of the *Opportunities* report, the committee drafted responses to specific criticisms and suggestions. The remainder of the meeting was devoted to drafting final recommendations for the *Management Principles* report for forwarding to the Board for approval at its June 1993 meeting.

CHEX Membership

Noel W. Hinners, Martin Marietta Astronautics Company (chair)
 Louis J. Lanzerotti, AT&T Bell Laboratories

Elliott C. Levinthal,* Stanford University
William J. Merrell, Jr., Texas A&M University
Robert H. Moser,* University of New Mexico
John E. Naugle, consultant, North Falmouth, Massachusetts
Marcia S. Smith, Congressional Research Service
Gerald J. Wasserburg, California Institute of Technology

David H. Smith, Executive Secretary

*term expired during 1993

COMMITTEE ON MICROGRAVITY RESEARCH

The Committee on Microgravity Research (CMGR) met at the Beckman Center on January 21-22 to revise its draft strategy report and to discuss input for the planned prioritization exercise of the Board's Task Group on Priorities in Space Research. Other issues discussed included the Aeronautics and Space Engineering Board's committee on the space station, the place of international microgravity science activities in the committee's strategy report, and schedule and reviewers for the report. The committee decided to plan for presentation of the strategy report to the Board at its June 1993 meeting and scheduled an extra meeting for March 10-11 in Washington, D.C.

At this March meeting the committee continued revision of its draft strategy report. The meeting began on the evening of the 10th with a working dinner and report review session. The committee spent the next day on redrafting and confirmed its plans to have the completed report ready for Board review at its June meeting.

The committee met again at the Beckman Center on April 26-27 to revise the draft strategy report. After a presentation by NASA officials on program status, the remainder of the meeting was spent drafting and editing the report. The committee discussed whether NASA should keep biotechnology within the Microgravity Science and Applications Division rather than moving it to the Life and Biomedical Sciences Division. Potential future tasks for the committee that were discussed included review of commercial programs, review of international activities, analysis of NASA field center and headquarters interactions for flight experiments, review of NASA's response to the strategy report, and continued review of past and future science programs.

The committee met at Woods Hole on August 26-27 to assess the status of its strategy report and to consider future plans. The report was approved by the Board at the end of July and was sent out for external review. The possibility of delaying the report to include the results of recent dedicated microgravity shuttle flights was rejected in favor of proceeding as rapidly as possible to press and including new results in an appendix if they became available in time. Dr. Harry Holloway, NASA associate administrator for the Office of Life and Microgravity Sciences and Applications (OLMSA), accompanied by Dr. Bonnie Dunbar and Mr. Robert Rhome, director of the NASA Microgravity Sciences and Applications Division, met with the committee to describe the organization of the office, its goals and objectives, the outlook for the FY94 budget, an overview of the microgravity program, the flight and space station programs, the status of the planned cooperative program with the Russians, and plans for a new internal advisory organization. Other subjects discussed with the NASA officials included interference by commercial microgravity programs with the microgravity science program because similar activities were being conducted without adequate scientific review; the relative usefulness of the committee's proposed future activities; and the question of whether basic physics experiments (particularly Gravity Probe-B) should be managed by the OLMSA. The committee also discussed potential future tasks, including those aired at the April meeting and a study on NASA's needs for space-enabling technology development.

The committee met on November 4 in joint session with the Committee on Space Biology and Medicine (described in detail below). The CMGR continued its meeting on November 5 to prepare responses to reviews of its research strategy report and to plan future activities. The committee also reviewed the scientific results of shuttle missions USML-1 (flown for 14 days in July 1992) and USMP-1 (flown in September 1992), presented by Director Robert Rhome and Chief Scientist Roger Crouch of the Microgravity Science and Applications Division. The committee also discussed NASA's plans for the Shuttle/Mir program. Rhome noted that the committee's strategy report would be useful input for a series of upcoming NASA Research Announcements if it became available in time. It was agreed that several committee members would prepare brief descriptions of the scientific results of USML-1 and USMP-1 to include in the report.

CMGR Membership

William A. Sirignano, University of California at Irvine (chair)
 Rosalia N. Andrews, University of Alabama at Birmingham
 Howard M. Einspahr, The Upjohn Company
 Martin E. Glicksman, Rensselaer Polytechnic Institute
 L. Gary Leal, University of California at Santa Barbara
 Franklin D. Lemkey, United Technologies Research Center
 Ronald E. Loehman, Sandia National Laboratories
 Alexander McPherson, University of California at Riverside
 Simon Ostrach, Case Western Reserve University
 Morton B. Panish, AT&T Bell Laboratories
 Ronald F. Probst, Massachusetts Institute of Technology
 John D. Reppy, Cornell University
 Warren C. Strahle, Georgia Institute of Technology
 Julia R. Weertman, Northwestern University

Richard C. Hart, Executive Secretary

COMMITTEE ON PLANETARY AND LUNAR EXPLORATION

The Committee on Planetary and Lunar Exploration (COMPLEX) met at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, on January 11-13 to continue work on an integrated strategy for the planetary sciences for the next 15 years. The committee continued a series of presentations, begun at the previous NASA Goddard meeting, on possible future space missions to solar system objects that have so far received only cursory examination by robotic probes. The subject chosen for the JPL meeting was initial reconnaissance of Pluto. In addition to revising draft sections of the strategy report, the committee composed a list of key outstanding questions for each major solar system object and developed text on the philosophy of priority setting and on the search for planetary systems of other stars. Presentations were also heard on the current status and prospects for MESUR, Galileo, and a proposed flight test of the Russian Topaz-2 nuclear reactor. ESA Cornerstone projects and post-Voyager missions to Jupiter, Uranus, and Neptune were discussed. In the course of these presentations, COMPLEX was asked by NASA's Solar System Exploration Division to assess the MESUR/Pathfinder mission at its next meeting. Motivated by technological developments that might be used on future space missions, the committee toured JPL's microrover and microdevices laboratories, which were particularly relevant in the context of the forthcoming Russian Mars 94/96 missions and the MESUR program.

An important facet of COMPLEX's integrated strategy effort is outreach to the planetary science community, both U.S. and international. Committee Chair Joseph Burns made a public presentation to JPL personnel on what COMPLEX is, what it is doing, and why and how it is doing it. JPL meeting participants included Prof. Jacques Blamont, member of the European Space Science Committee. The general aim of this presentation and others held at Goddard and at major international scientific gatherings (including the meetings of the American Astronomical Society's Division of Planetary Sciences in Munich, Germany, and the American Geophysical Union in San Francisco) was to solicit ideas from the community for the committee's research strategy project. The committee also enlarged its sponsorship base by obtaining contributing support from the SDIO/BMDO for issues relating to the Clementine program and technology transfer into the civil space program.

The committee met on April 19-21 at the University of Arizona's Lunar and Planetary Laboratory in Tucson to continue work on its integrated strategy for the planetary sciences. The committee reviewed the format and contents of Board strategies and heard briefings by Board member Noel Hinners, chair of the Board's Committee on Human Exploration, on that committee's three reports, from Dr. Jonathan Lunine on NASA's Solar System Exploration Subcommittee, including the results of a recent prioritization study, and from Dr. Nick Woolf (Steward Observatory) on the Steward Observatory Mirror Laboratory, and in particular the controversy surrounding the choice of mirror for the 8-meter Gemini telescopes. Woolf conducted a guided tour of the Mirror Laboratory and showed the committee the recently cast 6.5-m blank for the Multiple Mirror Telescope upgrade.

Once again, committee Chair Joseph Burns made a public presentation to over 60 local planetary researchers on the research strategy study. Following this briefing, the committee and guests broke up into five working groups to discuss individual areas in depth.

COMPLEX discussed topics for future studies, including NASA's planetary data system and instrumentation and technology issues, but no final decision was made. The remainder of the meeting was devoted to the process of prioritization and to redrafting sections of the integrated strategy and preparing new material (in particular, "what objects answer which questions" for each of the subject areas). A particular issue discussed was how the prioritization of objectives should be represented in the final report.

The committee met at Woods Hole on July 19-23 to finalize the text for the strategy report, now entitled *An Integrated Strategy for the Planetary Sciences: 1995-2010*. The committee also discussed future studies. Following this discussion, the committee drafted a charge for a study on the ability of small missions to achieve priority objectives in the planetary sciences. This was forwarded to the Board's Executive Committee for approval at a meeting later in the month. The committee agreed to begin the study at its next scheduled meeting, to be held in Washington, D.C., on December 13-15, and to complete it at a later workshop.

A small group met in Ithaca, New York, in September to add final touches to the strategy report for presentation to the Board at its November meeting.

The committee subsequently met at the NRC's Georgetown facility on December 13-15 to begin its study of the ability of small planetary missions to achieve priority objectives in the planetary sciences. Following a brief discussion of the status of the integrated strategy report and presentations on the current status of NASA's Solar System Exploration Division and Office of Space Science, the committee devoted most of the first day to presentations on various small planetary missions. These included in-depth briefings on NASA's Discovery program and a status report on BMDO's Clementine mission. In addition to gaining basic background information on current plans for small space missions, the committee was particularly interested in comparing and contrasting programmatic aspects of current missions with sources of problems in previous attempts to establish small planetary mission lines at NASA.

The second day continued with a briefing on NASA's Small Explorer mission line and on one of the two funded Discovery missions, the Near Earth Asteroid Rendezvous (NEAR). The committee also heard two perspectives on the Discovery program from outside NASA: those of the academic and industrial communities. Part of the second day was devoted to a tour of the Clementine control center in Alexandria.

The final morning of the meeting was devoted to an additional briefing on the Small Explorer program and a presentation on BMDO's plans to deploy a 4-m space telescope. The committee also discussed future activities that might be undertaken following the completion of the study of small missions. Two topics were suggested: a review of the planetary science data system and an assessment of plans to recover from the loss of Mars Observer. The committee decided that, given the nature of its current study, its February 1994 meeting should be held at NASA's Ames Research Center.

COMPLEX Membership

Joseph A. Burns, Cornell University (chair)
 Reta F. Beebe, New Mexico State University
 Alan P. Boss,* Carnegie Institution of Washington
 Geoffrey A. Briggs, NASA Ames Research Center
 Michael H. Carr, U.S. Geological Survey
 Anita L. Cochran,* University of Texas at Austin
 Thomas M. Donahue,* University of Michigan
 James L. Elliot, Massachusetts Institute of Technology
 Peter J. Gierasch,* Cornell University
 John F. Kerridge, University of California at San Diego
 William S. Kurth, University of Iowa
 Barry H. Mauk, Applied Physics Laboratory
 William B. McKinnon, Washington University
 Norman R. Pace, Indiana University
 Graham Ryder,* Lunar and Planetary Institute
 Darrell F. Strobel, Johns Hopkins University
 George W. Wetherill, Carnegie Institution of Washington

David H. Smith, Executive Secretary

*term expired during 1993

COMMITTEE ON SPACE BIOLOGY AND MEDICINE

The Committee on Space Biology and Medicine (CSBM) met on January 27-29 in Washington, D.C. The meeting was devoted primarily to presentations and discussion on the subjects of several verbal requests from NASA for committee advice. These subjects included information derived from the Russian space station Mir and Cosmos biosatellites and future plans for both programs, NASA life sciences research review and management procedures, the current status of NASA/NIH cooperative activities, the Neurolab shuttle mission (SLS-4), and plans for use of animals on the SLS-2 mission. In response to these presentations and related requests, the committee drafted a set of short statements on the topics and a cover letter summarizing these views and recommendations. The letter and attachments were presented to the Board at its February 24-25 meeting. The Board referred the package back to the committee for revision and resubmission to the Board's Executive Committee, which subsequently approved it (text reprinted in full in Section 4.2). A major portion of the recommendations provided in the letter was later incorporated nearly verbatim in the FY94 Senate appropriations report.

In addition to the four subjects treated in this letter, NASA requested that the committee revisit its research strategy, *A Strategy for Space Biology and Medicine for the 1980s and 1990s* (National Academy Press, Washington, D.C., 1987), to determine whether it accurately reflects the committee's current views and recommendations for NASA's space biology and medicine research program, or needs revision. The committee discussed this request and decided to devote a substantial portion of its April meeting to the task. The committee also prepared draft responses to the Task Group on Priorities in Space Research's advocacy template for a hypothetical research initiative. This material was used in a realistic trial of the task group's prioritization procedure at the February Board meeting.

The committee met in Washington, D.C., on April 29-30. Key tasks were to prepare recommendations to the Space Studies Board for its June meeting at Johnson Space Center and to be introduced to the new NASA life sciences organization's management and plans and policies for the future. Dr. Harry Holloway, recently named associate administrator for the Office of Life and Microgravity Sciences and Applications (OLMSA), described the goals and organizational structure of the new office, gave a brief review of the charter and activities of the space station redesign effort currently under way, and reviewed his FY94 budget request. In response to questions, Holloway cited the common misperception that the Russians have "solved" the majority of physiological and biological spaceflight problems, which tends to reduce budgets for NASA's activities in this area. In his view, it was a misunderstanding that the Russian-U.S. Shuttle/Mir agreement had specified a science program on either mission; this was currently a matter of continuing international negotiation.

Dr. Joan Vernikos, formerly of Ames Research Center and recently named director of the Division of Life and Biomedical Sciences and Applications in OLMSA, reviewed the goals of her office. She indicated that there was now an agreement that all commercial life sciences experiments would be reviewed, but that there was no similar agreement with respect to Getaway Specials managed from NASA's educational programs. Dr. Vernikos strongly encouraged the committee to visit the various NASA field centers with responsibility for life sciences research and expressed the desire to put life sciences on a par with the other space sciences in terms of acceptance by the Congress and the outside science community.

The Committee on Space Biology and Medicine and the Committee on Microgravity Research met jointly on November 4 in Washington, D.C. The purpose of the joint meeting was to begin work on a two-phase study task on the space station. The first phase was an examination of NASA's space station research management plans. The second phase was to be a later evaluation of the station's redesign in terms of its capability for scientific research.

The joint session was attended by NASA Administrator Daniel Goldin, Chief Scientist France Cordova, OLMSA Associate Administrator Harry Holloway, and space station Acting Program Director Bryan O'Connor. Board Chair Louis Lanzerotti reviewed the history of Board advice on the space station program, beginning with a 1983 letter written to former Administrator James Beggs. Dr. Lanzerotti stressed that the joint committees should focus on management principles and offer useful advice.

Mr. Goldin introduced Dr. Cordova as the new NASA chief scientist. In so doing, he emphasized that the agency needs high quality in its science program and that Dr. Cordova would be his key link with the Academies. He observed that an integrated science plan is needed, not just a list of desired instruments and missions for individual disciplines. One of Dr. Cordova's primary responsibilities would be to develop such a plan in cooperation with the research community.

With respect to the space station, Mr. Goldin explained that the president had directed that the program be reviewed because it had lost its focus and purpose. The recent review and redesign activities had taken place in the context of severe budget reductions. NASA's total five-year budget was originally projected at \$106 billion, then reduced to \$78 billion because of "reinventing government," and further reduced to \$71 billion in a directive from the House and Senate Appropriations committees. Mr. Goldin argued that the severity of this series of cuts was destabilizing, both within the agency and within the various communities it supports. He confessed to frustration and anxiety about how to continue to support science while absorbing such severe budgetary cuts.

Mr. Goldin stated that he had charged Holloway and O'Connor to build a useful station within the \$2.1 billion per year that had been allocated, and he expressed the need to involve the science community from the inception of proposals through procurement and development. Mr. Goldin stressed that if the joint committee got one message from his remarks, it should be his perception of the need for a formal mechanism to engage the science community in space station facility planning and development. He also cited the strong interest of the Russians in collaborating on the space station program and described a success scenario with the Russians in which the station would be available a few years earlier, with more astronauts, a crew rescue vehicle, increased pressurized volume, more rack space, more laboratory space, and more power, while still saving the United States billions of dollars.

Space station Acting Program Director O'Connor summarized the status of U.S.-Russian cooperation on the space station, including current discussions on scientific utilization if Russia becomes a partner in the program. A design review was expected in the spring of 1994, and Boeing had been selected as the prime contractor. O'Connor indicated that the Office of Space Flight would involve scientists in station design, development, and operations through an Integrated Product Team approach.

Dr. Holloway described the process the agency had put in place for the research community and OLMSA to guide space station development and utilization. Still under discussion was "handoff" of various responsibilities between the science and commercial offices and those charged with designing and building the station. There was discussion about the roles of the space station chief scientist and the NASA chief scientist, and about the role, responsibilities, and reporting relationships of the proposed space station Research Manager. The contemplated Integrated Product Team management approach was described as applying to essentially all aspects of the orbital research program, including definition of the science program, selection of investigations and experimenters, and development and operation of flight hardware.

Continuation of the Spacelab program and evolution of U.S.-Russian cooperation using the shuttle and Mir were discussed. The committees inquired about U.S. plans to use Mir and the role of the research community in planning these flights. There were strong indications that no more Spacelabs would fly; life sciences research would be moved to Mir, and microgravity research would take place on the shuttle mid-deck. The focus of the first two Mir flights was reported to be characterization of the Mir environment. (Later briefings to other NRC committees showed shuttle mission plans with restored Spacelab flights, however.)

The committees drafted a joint letter on research management and pre-space station research issues for approval by the Board at its next meeting.

The Committee on Space Biology and Medicine also held a regular business meeting on November 5. Appointments for new members were discussed, with the hope that new members could be appointed in time to attend the next meeting of the committee, much of which was to focus on planning for a life sciences assessment study. OLMSA was very interested in pursuing continued U.S. participation in Russia's Cosmos/Bion satellite program and solicited support from the research community. At the same time, the fast pace of decisions and planning for U.S.-Russian space station cooperation seemed to be overtaking other priorities (implementation of new peer review policies, Spacelab utilization, enhanced cooperation with NIH, and so on) of the Life and Biomedical Sciences and Applications Division and research community at large. Committee members agreed that recommendations in the committee's April 1993 letter to Dr. Holloway supporting use of animals in research were pivotal in the decision to fly animals on the SLS-2 mission.

CSBM Membership

Fred W. Turek, Northwestern University (chair)
Robert Berne,* University of Chicago
Robert E. Cleland, University of Washington
Mary F. Dallman, University of California

John R. David, Harvard School of Public Health
Francis (Drew) Gaffney, University of Texas, Southwestern Medical Center
Marc D. Grynepas, Mount Sinai Hospital, Toronto
Robert Helmreich,* University of Texas at Austin
James Lackner, Brandeis University
Robert W. Mann, Massachusetts Institute of Technology
Clinton T. Rubin, State University of New York at Stony Brook
Fred D. Sack, Ohio State University
Warren Sinclair, National Council on Radiation Protection and Measurements
Fred Wilt, University of California at Berkeley

Joyce M. Purcell, Executive Secretary

*term expired during 1993

COMMITTEE ON SOLAR AND SPACE PHYSICS

The Committee on Solar and Space Physics and the Committee on Solar-Terrestrial Research (CSSP/CSTR) met jointly at the Beckman Center on February 8-10 to continue work on their new research strategy report and to review proposals for reflight of the Tethered Satellite System (TSS) for the Board. The TSS project scientist briefed the committees, which also held a teleconference with officials of NASA's Space Physics Division on the TSS, the status of ongoing and planned programs, OSSA reorganization status, and how the committees' plans for a new strategy could be most beneficial to NASA. Naval Research Laboratory briefers described the Strategic Environmental Research and Development Program (the "Nunn amendment"), under which NRL and DOE are spending \$20 million per year on middle and upper atmospheric physics. The chair of the NRC's Board on Physics and Astronomy's Plasma Science Committee described the activities of his committee, including a current study that included both space- and laboratory-based aspects of plasma physics. A guest from the University of Alaska described their network of ground stations, the Geospace Environment Data Display System, that provides real-time, global data on several magnetospheric physics phenomena. The rest of the meeting was dedicated to reviewing completed assignments, preparing disciplinary overviews, and discussing how to organize the new research strategy report. A draft outline was prepared.

The committees met again at the Beckman Center on June 14-17. Most of the meeting was dedicated to preparing material for the strategy report. The committees discussed the possibility of extending the Ulysses mission for another orbit (6.2 years) in order to bring the spacecraft back for another polar passage during the next solar maximum, thus providing data over the solar poles for both solar minimum and maximum conditions. Related issues included bringing new investigators into such a mission and how to prioritize an extended Ulysses mission among other discipline objectives. A status report on the Solar-Terrestrial Energy Program (STEP) program was heard, and the committee discussed addition of instruments to the Advanced Composition Explorer (ACE) to make it a real-time alert system for geomagnetic storms.

The committees met a third time in Washington, D.C., on October 27-29 to continue work on their strategy report and to review the program and budget status of their sponsoring agencies. The committees received presentations from the Atmospheric Sciences Division and Polar Programs Office of the NSF, from the Naval Research Laboratory and Geophysics Directorate of Phillips Laboratory, and from NASA and NOAA on FY94 budgets and program status. The committees also received a presentation on the recent activities of the U.S. STEP Coordination Office. The Committee on Solar-Terrestrial Research is the external advisor for that office, and the committees agreed to extend future meetings by half a day and establish a small ad hoc panel to improve input to the STEP Office.

Former CSTR Chair Don Williams briefed the committees on several issues concerning SCOSTEP (for which the CSTR is the U.S. national committee), including the activities that support U.S. scientists, recent programs, the problem with U.S. nonpayment of dues, and possible future activities or programs. The committees spent considerable time discussing and revising sections of the strategy report. The report was expected to be ready for Board review in early 1994. A special session at the spring meeting of the American Geophysical Union (which will be held jointly at the American Astronomical Society's Solar Physics Division meeting) was suggested for community outreach.

CSSP Membership

Marcia Neugebauer, California Institute of Technology (chair)
 Thomas E. Cravens,* University of Kansas
 Janet U. Kozyra, University of Michigan
 Donald G. Mitchell, Johns Hopkins University
 Jonathan F. Ormes, Goddard Space Flight Center
 George K. Parks, University of Washington
 Douglas M. Rabin, National Optical Astronomy Observatory
 Art Richmond, National Center for Atmospheric Research High Altitude Observatory
 David M. Rust,* Johns Hopkins University
 Roger Ulrich, University of California at Los Angeles
 Raymond J. Walker,* University of California at Los Angeles
 Yuk L. Yung,* California Institute of Technology
 Ronald D. Zwickl, National Oceanic and Atmospheric Administration

Richard C. Hart, Executive Secretary

*term expired during 1993

TASK GROUP ON PRIORITIES IN SPACE RESEARCH

The Task Group on Priorities in Space Research (TGPSR) met on January 25-26 in Washington, D.C. The objectives of the meeting were to plan a trial of the group's proposed advocacy and evaluation processes by the full Board and to continue working on its advocacy statement, evaluation form, and final report. During the meeting, the group developed a schedule and agreed on how best to involve the Board in testing its advocacy and evaluation process. The Board would be asked to serve as evaluators of hypothetical initiatives that would be provided, with task group members serving as advisors. The goal of the trial would be to obtain a Board assessment of both the proposed process as well as of the advocacy template and evaluation method.

After this trial took place at the Board meeting in February, the task group revised the final report and advocacy statement and evaluation to incorporate the results of the trial. The expected recommendation of the final report was that the Board would adopt the task group's process as a way to make formal integrated recommendations about the nation's space research agenda.

A draft final report expressing this recommendation was presented to the Board at its June meeting. After considerable discussion, the task group was directed to frame its final report as documentation for internal use by the Board, rather than for public release.

The fate of the report was further discussed at the Board's Executive Committee meeting in July; as a result of subsequent negotiations with the Board chair, it was concluded that a factual summary report on the trial and Board discussion, omitting recommendations, would be presented for approval at the next meeting of the Board; if approved, this report would be submitted for NRC review and public release.

Discussion at the November Board meeting failed to provide a final resolution, however, and further revision of the reformatted final report was planned for the coming year.

TGPSR Membership

John A. Dutton, Pennsylvania State University (chair)
 Philip Abelson,* American Association for the Advancement of Science
 William P. Bishop, Desert Research Institute
 Lawson Crowe, University of Colorado
 Peter Dews, Harvard Medical School
 Angelo Guastaferrro, Lockheed Missiles and Space Company, Inc.
 Molly K. Macauley, Resources for the Future
 Thomas A. Potemra, Johns Hopkins University
 Arthur B.C. Walker, Jr., Stanford University

Joyce M. Purcell, Executive Secretary

*term expired during 1993

3

Summaries of Reports

3.1 Scientific Prerequisites for the Human Exploration of Space

A Report of the Committee on Human Exploration¹

EXECUTIVE SUMMARY

“To expand human presence and activity beyond Earth-orbit into the solar system”² was the goal established by President Ronald Reagan in 1988 for the nation’s program of piloted spaceflight. This goal formed the basis for the subsequent proclamation by President George Bush on July 20, 1989—the 20th anniversary of the Apollo 11 lunar landing—in which he proposed that the nation go “back to the Moon, . . . And this time, back to stay. And then—a journey into tomorrow—a manned mission to Mars.”³ The resulting long-term program to expand the human presence in the inner solar system has been called many things, including the Human Exploration Initiative, the Space Exploration Initiative (SEI), and the Moon/Mars program. The Advisory Committee on the Future of the U.S. Space Program identified these objectives as Mission from Planet Earth.⁴

It is a long way from the broad goals of human exploration to a program of implementation, with many political, technological, and scientific hurdles to be overcome. Do successive administrations and congresses, as well as the American people, have the desire to dedicate necessary national resources to support such an ambitious program? Do they have the will and patience to support a program lasting for several decades? Can humans function effectively on the Moon for long periods of time? Can they survive a lengthy mission to Mars? What will they do when they get there? These are but a few of the myriad questions to be addressed before our species can realize the ancient dream of human voyages to, and eventual settlement of, our neighboring planets.

THE ROLE OF SCIENCE

The role of science in human exploration is paramount and its challenges no less daunting than those facing the engineering community. New scientific data concerning the health and safety of astronauts are essential prerequi-

¹“Executive Summary” reprinted from *Scientific Prerequisites for the Human Exploration of Space*, National Academy Press, Washington, D.C., 1993, pp. 1-5.

²President Ronald Reagan, Presidential Directive on National Space Policy, February 11, 1988 (Fact Sheet, page 1), The White House, Washington, D.C.

³President George Bush, Remarks by the President at 20th Anniversary of Apollo Moon Landing, July 20, 1989, The White House, Washington, D.C.

⁴Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program* (the “Augustine report”), U.S. Government Printing Office, Washington, D.C., 1990.

sites for the human exploration of space. Research must be done to understand and alleviate the deleterious effects of microgravity on human physiology, the risks posed by radiation in space, and the environmental stresses humans will experience travelling to and operating on and around other planetary bodies. The U.S. scientific and engineering community is obliged to provide the best and most constructive advice to help the nation accomplish its space goals, as was stressed in a 1988 space policy report to the newly elected president by the National Academy of Sciences and the National Academy of Engineering.⁵ To that end the National Research Council's Space Studies Board established the Committee on Human Exploration (CHEX) and charged it, as its first responsibility, to determine what scientific questions need to be answered before humans can undertake extended missions to the Moon and travel to Mars.

Defining these scientific prerequisites entails a degree of judgment about both our current state of knowledge of the relevant science and the potential modes of mission implementation. CHEX determined that some issues are critical to the basic survival and elementary functioning of humans in space. Other issues concern the effectiveness and efficiency of operations and their impact on overall mission success. The line between the two is sometimes fuzzy, and the committee anticipates that with time crossover will occur.

Beyond the information needed to provide for the basic health and well-being of astronauts operating in extraterrestrial environments, the expansion of human presence and activity into the solar system does not demand any a priori scientific research component. Nor is a Moon/Mars program driven by any demands for scientific discovery. The latter view is expressed in the National Academies' 1988 space policy report, which states that "the ultimate decision to undertake further voyages of human exploration and to begin the process of expanding human activities into the solar system must be based on nontechnical factors."⁶ Given a nontechnical decision, what then is the proper role of science?

That there is a role is not open to much debate. The Paine report,⁷ the Ride report,⁸ the Augustine report,⁹ and the report of the Synthesis Group¹⁰ all recommend, to varying degrees, that significant scientific research be conducted in association with human exploration. In fact, "exploration" does not exist in isolation from scientific research. There are, however, two distinctly different categories of science that must be considered. There is the "enabling" science required if we are to conduct human exploration at all. Then, there is the "enabled" science made possible, or significantly enhanced, because it is carried out in conjunction with a program of human exploration. This report deals with the former topic. The latter is treated in a preliminary fashion insofar as it impacts the scientific effectiveness of Moon/Mars missions. For example, conducting certain preliminary robotic missions to the Moon and Mars can result in a more effective scientific return from eventual human exploration. This report also contains some preliminary discussion of technology requirements, aspects of international scientific cooperation, and the approach used to manage the scientific component of a program of human exploration.

ENABLING SCIENCE

In establishing the scientific prerequisites for the human exploration of space, CHEX has identified two broad categories of enabling scientific research. This classification is based on the degree of urgency with which answers are needed to particular questions before humans can safely return to the Moon or travel to Mars.

Critical Research Issues

The lack of scientific data in some areas leads to unacceptably high risks to any program of extended space exploration by humans. These critical research issues concern those areas that have the highest probability of being life threatening or seriously debilitating to astronauts and that are thus potential "showstoppers" for human

⁵Committee on Space Policy, *Toward a New Era in Space: Realigning Policies to New Realities* (the "Stever report"), National Academy Press, Washington, D.C., 1988.

⁶See Ref. 5, p. 14.

⁷National Commission on Space, *Pioneering the Space Frontier*, The Report of the National Commission on Space, Bantam Books, New York, 1986.

⁸Office of Exploration, *Leadership and America's Future in Space*, A Report to the Administrator by Dr. Sally K. Ride, August 1987, NASA, Washington, D.C., 1987.

⁹See Ref. 4.

¹⁰Synthesis Group, *America at the Threshold*, Report of the Synthesis Group on America's Space Exploration Initiative, U.S. Government Printing Office, Washington, D.C., 1991.

exploration. The areas in which additional scientific information must be obtained prior to extended exploration of space by humans include the:

1. Flux of cosmic-ray particles, their energy spectra, and the extent to which their flux is modulated by the solar cycle;
2. Frequency and severity of solar flares;
3. Long- and short-term effects of ionizing radiation on human tissue;
4. Radiation environment inside proposed space vehicles;
5. Effectiveness of different types of radiation shielding and their associated penalties (e.g., spacecraft mass);
6. Detrimental effects of reduced gravity and transitions in gravitational force on all body systems (especially the cardiovascular and pulmonary systems) and on bones, muscles, and mineral metabolism, together with possible countermeasures;
7. Psychosocial aspects of long-duration confinement in microgravity with no escape possible and their effects on crew function; and
8. Biological aspects of the possible existence of martian organisms and means to prevent the forward contamination of Mars and the back contamination of Earth.

Optimal Performance Issues

The second category of research includes issues that, based on current knowledge, do not appear to pose serious detriments to the health and well-being of humans in space. They could, however, result in reduced human performance in flight or on planetary surfaces and, thus, in a less than optimal return from the mission. Some of these issues may become critical research issues relative to long-term human spaceflight and return to terrestrial gravity following extended flights, or when extraterrestrial habitation is considered. Research issues related to optimal mission performance include the:

1. Vestibular function and human sensorimotor performance;
2. Effects of the microgravity environment on human immunological functions;
3. Long-term effects of microgravity on plant growth;
4. Feasibility of closed-loop life support systems;
5. Interplanetary micrometeoroid flux and its time dependence;
6. Surface and subsurface properties of the Moon and Mars at landing sites and at the locations of possible habitats;
7. Hazards posed by martian weather and other martian geophysical phenomena;
8. Atmospheric structure of Mars relevant to implementing aerobraking techniques; and
9. Microgravity science and technology relating to long-duration spaceflight.

Two additional issues, while not directly related to human performance, are included for their potential to significantly enhance and optimize the scientific return of the mission:

10. Methods of detecting possible fossil martian organisms and the chemical precursors of life; and
11. Availability and utilization of in situ resources (e.g., ice/water and minerals) on the Moon and Mars.

3.2 Improving NASA's Technology for Space Science

A Report of the Committee on Space Science Technology Planning¹

EXECUTIVE SUMMARY

Introduction

The continued advance of the nation's space program is directly dependent upon the development and use of new technology. Technology is the foundation for every aspect of space missions and ground operations. The improvements in technology that will enable future advances are not only in device and system performance, but also in permitting missions to be carried out more rapidly and at lower cost. Although more can be done with current technology, NASA's recent call for new and innovative approaches should not be answered by employing only today's technologies; new technologies with revolutionary potential should be sought. The study reported here was performed to identify means to enhance the development of technologies for the space sciences and applications. (See Statement of Task, Appendix A.)

In the summer of 1992, when this study was conducted, most exploratory space technology development activities in NASA were concentrated in the Office of Aeronautics and Space Technology (OAST). Space science and applications activities were concentrated in NASA's Office of Space Science and Applications (OSSA). The Committee on Space Science Technology Planning was assembled by the National Research Council's Aeronautics and Space Engineering Board (ASEB) and Space Studies Board (SSB) to carry out the study. The Committee was convened in a week-long workshop in June 1992, and the preparation of the study report continued thereafter. In October 1992, as this report was being edited, a reorganization affecting NASA's science and technology offices was announced. Despite the reorganization, however, the goals and responsibilities previously assigned to OSSA and OAST are likely to endure and the results of this study should prove useful to their successor organizations. All references to OSSA and OAST should be taken to refer with equal facility to the past structure or the successor organizations.

The Office of Aeronautics and Space Technology

OAST has been charged with technology development in support of other NASA entities, as well as for the nation's other civilian space activities. These responsibilities encompass, but also extend beyond, the needs of OSSA. Within OAST, funds are apportioned into a basic research program (the Base Program) and another program addressing specific future NASA missions (the Civil Space Technology Initiative or Focused Program). The funds in these programs represent the largest, most flexible, discretionary resources that NASA can apply to creating technology-derived opportunities for the future. In fiscal year (FY) 1992, \$156 million was allocated to the Base Program and \$150 million to the Focused Program. Of these, OAST estimates that \$67.8 million in the Base Program and \$60.5 million in the Focused Program serve OSSA's needs. Obviously, the allocation of OAST's funds among technological opportunities and the oversight of selected development tasks should warrant careful attention from NASA management.

The Integrated Technology Plan

The Advisory Committee on the Future of the U.S. Space Program² recommended to NASA:

... that an agency-wide technology plan be developed with inputs from the Associate Administrators responsible for the major development programs, and that NASA utilize an expert, outside review process, managed from headquarters, to assist in the allocation of technology funds.

¹"Executive Summary" reprinted from *Improving NASA's Technology for Space Science*, National Academy Press, Washington, D.C., 1993, pp. 1-5. The Committee on Space Science Technology Planning was a panel of the Joint Committee on Technology for Space Science and Applications, operated by the NRC's Space Studies Board and the Aeronautics and Space Engineering Board.

²Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program* (the "Augustine report"), U.S. Government Printing Office, Washington, D.C., 1990.

In response to this recommendation, OAST prepared the *Integrated Technology Plan for the Civil Space Program* (ITP). To begin the preparation of the ITP, OAST requested information regarding technology needs from each NASA mission office, including OSSA. The preparation of the ITP was a major effort that addressed the technology needs of all areas of NASA's space efforts, other government agencies, and the commercial space industry, as well as addressing past recommendations of advisory groups. The preparation of the ITP and its subsequent review by the NASA Space Systems and Technology Advisory Committee (SSTAC) were the principal elements leading to the current study.

The Office of Space Science and Applications

OSSA is responsible for directing the part of NASA that uses the unique characteristics of space to conduct scientific studies of the Earth, solar system, and universe; to study the effects of low gravity on sensitive systems; and for practical purposes. OSSA has six science divisions: Astrophysics, Space Physics, Earth Science and Applications, Solar System Exploration, Life Sciences, and Microgravity Science and Applications. The FY 1992 budget was \$2.728 billion. A relatively small fraction of these funds (by OSSA estimate, \$48.8 million or 1.8%) is devoted to advanced technology development; it supports the comparatively near-term requirements of well-defined missions. To review the work of the science divisions and the related OAST support, the Committee employed four subcommittees: Astrophysics and Space Physics, Earth and Planetary Science, Life Sciences, and Microgravity Sciences.

FINDINGS AND RECOMMENDATIONS

General

NASA's new initiative for smaller, less expensive, and more frequent missions is not simply a response to budget pressures; it is a scientific and technical imperative. Efficient conduct of science and applications missions cannot be based solely upon intermittent, very large missions that require 10 to 20 years to complete. Mission time constants must be commensurate with the time constants of scientific understanding, competitive technological advances, and inherent changes in the systems under study (e.g., the Earth, its atmosphere, and oceans). This theme should be an important element of any agency-wide technology program.

With the establishment of judicious priorities, the present level of support allocated to OAST and OSSA should be sufficient to formulate a modest but responsive technology development program based on the key unmet needs of NASA's diverse science programs. However, the fraction of agency resources (at most \$177 million of \$14.3 billion) devoted to reducing technological risk in its major space science and applications programs is small, and does not appear adequate to reduce future risk appreciably or to make sufficient new technological advances available.

In spite of its pervasiveness and importance to NASA, there is no organized central control, information center, or focal point for all of NASA's technology development efforts, which now are spread throughout the agency. The NASA Administrator should act to establish a coordinating position with the clear responsibility to ensure cooperation between technology development efforts within different parts of NASA. An appropriate early task would be to extract information from the ITP to use in the formulation of an agency-wide working plan for technology for space science that is based on all of NASA's resources dedicated to this area.

The OAST Focused Program

Better mechanisms are needed to ensure the transfer of OAST-developed technology to OSSA's flight missions. No efficient means exist to overcome the reluctance of OSSA managers to adopt unproven technology from OAST. Program and project managers are understandably hesitant to accept responsibility for completing technology development projects begun by OAST and to apply unproven new technologies to multi-million dollar science programs on an ad hoc basis. Better mechanisms are needed to ensure that the users of space technology maintain an investment in the OAST technology development efforts established to respond to their needs. OAST and OSSA divisions should agree during the earliest phases of each project initiated at OAST specifically in response to a science need how, and at what stage of development, transfer will occur.

Throughout its programs OAST should bring increased rigor (including external review) to determining not only which projects should be initiated or continued but which should be canceled. In a flat or low-growth funding environment this process will be extremely important to promote the viability of a program to meet the needs of space science and applications. It is critical that new innovations be welcomed even within a program that is unable to grow.

The OAST Base Program

Because it is not configured to respond directly to the stated needs of user communities, the Base Program is not thoroughly described in the ITP and was not subject to in-depth scrutiny by the Committee. The Base Program serves both as a means to advance technology and to maintain organizational capability to perform space flight projects. The two are not necessarily compatible functions, attempting as they do to combine research excellence with sustenance of agency know-how. Special efforts should be made to make the work in the Base Program visible to the space science community so that latent capabilities can be captured and put to use wherever applicable. The program should be subject to more visible external review on a regular basis. As an investment of public resources, the quality of the Base Program must be scrutinized with the same intensity as the Focused Program. Responding to projected mission needs is important, but a portion of NASA's technology program must respond to new, even high-risk, ideas that may yield large advances. The avoidance of risk should not be elevated to such a position that innovative but unconventional concepts are summarily dismissed.

The Integrated Technology Plan

The preparation of the ITP was a commendable and much-needed first step. But the ITP is only agency-wide in terms of integrating inputs from all of the NASA mission offices. It is not agency-wide in terms of being an expression of the priorities of NASA as a whole. It represents the integration of inputs by one office among several, but does not reflect the authoritative merger and ranking of these inputs by a management that oversees these offices of equal stature. In other words, it does not show the influence of the Office of the NASA Administrator or a relationship to a realistic agency-wide strategic plan.

Further, the ITP is not a plan in the sense of a statement of technical objectives, schedules, and estimated costs for the chosen tasks—presumably within an approved or agency-proposed budget. Rather, the ITP is a prospectus of development tasks most of which cannot be undertaken within either the existing budget or any budget that is likely to be available, based on the experiences of the last decade.

The Office of Space Science and Applications

Technology development projects in OSSA are individually selected and undertaken by its divisions; there is no overarching OSSA technology development strategy or program. There is little consistency across the science divisions regarding technology development (criteria, process, etc.).

While some divisions have done so, e.g., the Astrophysics Division, not all divisions of OSSA have established formal technology planning procedures or assigned responsibility for technology planning. For example, the Committee found no formal process within the Earth Science and Applications and Life Sciences Divisions and a largely informal process within the Solar System Exploration Division that appears to have little involvement with the planetary sciences community. Each OSSA division that has not yet done so should act to formalize technology planning responsibilities to identify, coordinate, and report relevant work within the division. OSSA divisions should consider empowering existing advisory working groups for particular scientific areas to identify technology needs, and contribute to their evaluation by examining subsequent sets of consolidated division-wide technology needs.

Criteria were not presented to the Committee that could be used to determine which projects should be undertaken with OSSA divisions funds and which should be submitted to OAST for funding. In particular, it is not clear that the divisions have consistently requested technological assistance from OAST for their most basic technology problems.

Finally, the overall fraction of OSSA resources devoted to promoting advanced technology development is too small (\$48.8 million of \$2.728 billion) to enhance capabilities, reduce risk, and make new technological advances available for future space science and applications initiatives.

GENERAL FINDINGS AND RECOMMENDATIONS³

General Findings

1. The development of the Integrated Technology Plan has been an extraordinary undertaking and is a good first step towards improving OAST's approach to the development of technology for OSSA.

The technology needs of the entire U.S. civil space program never before have been assembled and reviewed as they were in the ITP. However, the ITP does not lay out a plan for optimally addressing those needs with OAST's current budget. Furthermore, the ITP represents OAST's response to requested inputs, but does not reflect an agency-wide plan approved and backed by the NASA Administrator for the strategic application of NASA's sizable resources throughout the agency dedicated to aspects of technology development.

With respect to technology for space science and applications, the weaknesses in the ITP lie in what is not there rather than what is. OSSA has not consistently requested technological assistance with some of its most basic technology problems (e.g., technologies supporting earth observations and basic laboratory research onboard Space Station Freedom).

2. Although the ITP is a step in the right direction, NASA has not yet developed processes for gathering, evaluating, and selecting possible technology development projects comparable to the systematic means it has used for scientific experiments for the last 30 years.

OSSA methods for gathering scientific technology needs vary from division to division, and neither OSSA nor OAST presented a coherent methodology for evaluating and ranking combined technology needs. Both groups need systematic methods to numerically score space science technology needs on agreed-upon criteria (such as "engineering leverage," "cost leverage," and "breadth of application" in OAST's stated prioritization criteria) and to make them comparable to one another through a composite score. This type of technique is used by OSSA in the selection of science experiments and has worked well.

The coordination of technology development work at OAST with OSSA division programs has suffered because once the submission of technology needs to OSSA (and eventually to OAST) has taken place there are limited measures in place for continuing scientific community involvement in subsequent decisions and projects.

3. The organizational depth of the interaction between OSSA and OAST occurs primarily at the level of OSSA divisions and the OAST Space Technology Directorate. The degree of interaction varies widely from one OSSA division to another.

For example, there has been no discernable interaction in the life sciences, there appears to be an onset of interaction in the microgravity sciences, and there has been an ongoing interface in astrophysics.

While the Committee was often reminded that OSSA and OAST managers were determined to improve communications to ensure an effective development process, there were few examples of the actual science users and technology developers teaming to insure a favorable result. The process of technology development could be enhanced, in many cases, by increased interaction between developers, users, and researchers.

4. There is a wide disparity in the efforts of the OSSA divisions to determine their technology needs and act to address those needs.

For example, the Astrophysics Division has committed significant resources to establishing its technology needs, while the Life Sciences, Space Physics, and Earth Sciences and Applications Divisions do not appear to have done so.

5. OSSA's technology needs will be affected by NASA's potential paradigm shift toward "faster, cheaper, better" missions, including a shift of emphasis from big missions to more frequent access to space via smaller, more flexible, and more repeatable, missions.

³This section is reprinted from Section 4 (pp. 50-54) of the report and is not part of the document's Executive Summary. It presents the findings of the study in greater detail.

Because previous ITP projections were based on existing mission models, new projections will be necessary to promote more frequent and affordable missions. The Committee found little evidence of such requirements being identified by either office, although subsequent information indicates awareness within the science and technology communities of these new needs.

NASA's new initiative for smaller, less expensive, and more frequent missions is not simply a response to budget pressures; it is a scientific and technical imperative. Efficient conduct of science and applications missions cannot be based solely upon intermittent, very large missions that require 10 to 20 years to complete. Mission time constants must be commensurate with the time constants of scientific understanding, competitive technological advances, and inherent changes in the systems under study (e.g., the Earth, its atmosphere, and oceans). This theme should be an important element of any agency-wide technology program.

6. In spite of its pervasiveness and importance to NASA, there is no organized central control, information center, or focal point for NASA's technology development efforts.

OAST, OSSA, and other NASA mission offices have completely independent technology development programs. While the Committee does not believe that these disparate activities should be consolidated, it does believe that technologists should be cognizant of related efforts sponsored by other NASA offices. Furthermore, since NASA has not had the direction that would come from an agency-wide strategic plan, OAST has been forced to try to determine the agency's aims solely by (1) polling the users of technology, and (2) incorporating a full-time OAST staff member in OSSA activities.

7. With the establishment of judicious priorities, the present level of support allocated to OAST and OSSA by NASA should be sufficient to formulate, and to initiate the implementation of, a relatively small but responsive technology development program based on the key unmet needs of NASA's diverse science programs.

However, the fraction of agency resources (at most \$177 million of \$14.3 billion—1.2 percent) devoted to reducing technological risk in its major space science and applications programs is small. It does not appear adequate to reduce appreciably future risk or to seize many of the opportunities available to push the frontiers of technology.

8. NASA and external users of technology are not well acquainted with the capabilities of, and constraints on, OAST.

The OAST Space Technology budget is large in absolute terms, but small relative to its mandate to meet the technology needs of the U.S. civil space program and maintain crucial technical capabilities. Even if OAST devoted half of its current resources to specific space science needs, many worthwhile areas of research would not be addressed. On the other hand, OAST should make special efforts to work more closely with OSSA divisions to maximize the efficiency of NASA-internal work and increase use of the capabilities of universities to address NASA's long-term technology needs.

General Recommendations

1. The NASA Administrator or OAST Associate Administrator should act to establish a coordinating position with the clear responsibility to ensure cooperation between technology development efforts within different parts of NASA—from early research through the various stages of technology development and readiness. An appropriate early task would be to extract information from the ITP to use in the formulation of an agency-wide working plan for technology for space science that is based on all of NASA's resources dedicated to this area. Such a plan would make visible NASA's many autonomous projects and foster an improved ability to evaluate and coordinate projects.

2. As NASA acts to improve its programs through the use of new or improved technologies, an emphasis should be placed on technologies with the potential to reduce end-to-end mission costs. Savings in real cost will enable more frequent access to space. Designing missions to be "faster, better, and cheaper" has the potential to improve NASA's performance in developing new technology for space science and should be put to the test in cases where significant scientific objectives can be met by spacecraft built on these principles.

3. OAST should bring increased rigor (including external review) to determining not only which projects should be initiated or continued, but which should be canceled. In a flat or low-growth funding environment this process will be extremely important to maintain the viability of a space science technology program.

4. Each OSSA division should endeavor to work closely with OAST in order to be involved in, or cognizant of, OAST's projects relevant to their technology needs. Stronger direction must come from top and middle managers regarding liaison between OSSA divisions and OAST focussed program efforts. Liaison groups, including staff from NASA centers, should be encouraged to identify and focus on high priority, feasible joint actions. Furthermore, additional OAST technical personnel could be assigned to OSSA programs on a part-time basis to provide for an ongoing exchange of technical information between the two offices. A possible pilot program for developing closer liaison is OSSA's highly technology-dependent Earth Observing System.

5. Since industry is heavily involved in the development of spacecraft and systems, and university scientists are heavily involved in the development of space instruments and sensors, OAST should increase the inclusion of representatives who are external to NASA in the early evaluation of users' technology needs and goals.

6. The OAST base program projects in support of space science should be subjected to more visible external review on a regular basis. OSSA representatives should be included with university and industry representatives in the review teams for relevant projects. The inclusion of OSSA staff and members of the outside scientific community could contribute to a sense of investment in the OAST program in those it aims to serve, and facilitate the ultimate transfer of new technology to users.

7. NASA should act to broaden the foundation of its research base by increasing the direct involvement of university research laboratories in the development of technology for space science. A specific emphasis should be on encouraging significant "enabling" developments rather than using universities to do work normally done by contractors.

8. OSSA should consider earmarking a modest level of funding for use at OAST on mutually agreed-upon projects. However, the Committee does not believe that the budget currently allocated to the OAST Space Technology Directorate should be transferred to OSSA and the other user groups inside NASA. The expertise, capability, and promise that would be lost by dissolving OAST's space technology effort would be difficult to compensate for by gains elsewhere.

9. Each OSSA division that has not yet done so should act to formalize technology planning responsibilities to identify, coordinate, and report relevant work within the division. Each should consider the development of a plan for technology that is integrated with its Strategic Plan, consistent with its programs, and approved by its director. OSSA divisions should consider empowering existing advisory working groups for particular scientific areas to identify technology needs, and contribute to their evaluation by examining subsequent sets of consolidated division-wide technology needs.

4 *Letter Reports*

During 1993, the Space Studies Board and its committees and task groups issued three letters, which this section presents in full in chronological order of release. The first of the letters, Section 4.1, is an expanded transmittal letter for the first report of the Committee on Human Exploration, *Scientific Prerequisites for the Human Exploration of Space*, whose executive summary is reprinted in Section 3.1. This transmittal letter places the conveyed report in the context of previous Board advice on the space station program.

The subsequent two sections present the work of subcommittees of the Board. Section 4.2 contains advice developed by the Board's Committee on Space Biology and Medicine on several timely topics in its area of cognizance. Section 4.3 presents the final report of the Board's Task Group on AXAF (Advanced X-ray Astrophysics Facility); this task group reported jointly to the Space Studies Board and the Board on Physics and Astronomy and performed its analysis during the period when the two boards were still in the process of establishing their joint standing Committee on Astronomy and Astrophysics.

4.1 On the Space Station and Prerequisites for the Human Exploration Program

The Space Studies Board sent the following letter, accompanying the report cited, to NASA Administrator Daniel Goldin on March 19, 1993.

It is my pleasure to present to you, on behalf of the Space Studies Board and its Committee on Human Exploration, copies of our new report, *Scientific Prerequisites for the Human Exploration of Space*. This report surveys and elaborates the key research that must be carried out before a program of human exploration can be undertaken. This research is necessary to establish whether long-duration human spaceflight is possible, and if it is, what technical approaches are most likely to be successful and productive.

Substantial preparatory work for Moon and Mars missions can be conducted by robotic probes, but I would like to take this opportunity to elaborate on the special roles of the life sciences and of a piloted space station. NASA has recently announced the intention of conducting a sweeping review of the Space Station Freedom program. Recognizing that the decision to expand human presence into the solar system “must be based on nontechnical factors,”¹ the Board has steadfastly maintained that “a properly equipped and configured space station is pivotal”² to essential preliminary research. The enclosed report states³ that

The Space Studies Board strongly affirms the position that a suitably equipped space-based laboratory is required to study the physiological consequences of long-term spaceflight.

The Board has summarized the major characteristics of such a space station on several occasions, extracting these from the fundamental guidance provided in the Goldberg report of its Committee on Space Biology and Medicine.⁴

At the same time that the space station design is being reevaluated, it is apparent that the new administration may be reexamining the position of human space exploration within national priorities. Human return to the Moon or exploration of Mars may not be pursued on an aggressive timetable in our current environment of constrained resources—indeed, the Augustine Committee recommended that the Mission From Planet Earth be undertaken on a “go-as-you-pay” basis.⁵ However, the Board has noted that “many of the fundamental problems in life sciences research involve a long period of time for their pursuit and solution.”⁶ The enclosed report asserts,⁷ nonetheless, that

the difficulties currently being experienced by the space station project do not negate the essential need for such a facility to perform the enabling research on human adaptation to the microgravity environment necessary for a Moon/Mars program.

The current redesign efforts should be based on a realistic assessment of the depth and pace of America’s commitment to human exploration of the inner solar system. The body of the Board’s work in space biology, together with the efforts of other advisory groups,⁸ provides comprehensive guidance on the capabilities needed to pave the way for this enterprise. If the goal of human exploration is superseded as the premise for the nation’s space

¹Committee on Space Policy, *Toward a New Era in Space: Realigning Policies to New Realities*, National Academy Press, Washington, D.C., 1988.

²Space Studies Board, letter to NASA Administrator Richard Truly, March 30, 1992.

³Committee on Human Exploration of the Space Studies Board, *Scientific Prerequisites for the Human Exploration of Space*, National Academy Press, Washington, D.C., 1993, p. 13.

⁴Committee on Space Biology and Medicine of the Space Science Board, *A Strategy for Space Biology and Medicine for the 1980s and 1990s*, National Academy Press, Washington, D.C., 1987.

⁵*Report of the Advisory Committee on the Future of the U.S. Space Program*, Superintendent of Documents (GPO), Washington, D.C., December 1990.

⁶Space Studies Board, “Space Studies Board Position on Proposed Redesign of Space Station Freedom,” March 14, 1991.

⁷Ref. 3, p. 13.

⁸Aerospace Medicine Advisory Committee of the NASA Advisory Council, *Strategic Considerations for Support of Humans in Space and Moon/Mars Exploration Missions*, NASA, June 1992.

station program, planning and implementation of orbital research infrastructure should be adjusted to meet the requirements of the new objectives efficiently and cost-consciously. We must recognize, however, that such decisions might significantly delay the nation's option for human expansion into the solar system.

I look forward to the opportunity to meet, at your convenience, with you and your colleagues to discuss our report further.

Signed by
Louis J. Lanzerotti
Chair, Space Studies Board

4.2 On Several Issues in the Space Life Sciences

The Space Studies Board sent the following letter to NASA Associate Administrator for Life and Microgravity Sciences and Applications Harry Holloway on April 26, 1993.

At the request of then Acting Director of Life Sciences, Joseph Alexander, the Committee on Space Biology and Medicine has examined and discussed four separate issues of concern to NASA and the Life Sciences Division and has developed comments and/or recommendations on each. Attachments A through D contain the committee's detailed conclusions and recommendations on (1) the use of research animals on Spacelab Life Sciences-2, (2) peer review of research proposals and programs, (3) optimizing the scientific benefits of the U.S./Russian Shuttle/Mir Program, and (4) Russia's biosatellite program (Bion). Following is a brief summary of the committee's thoughts on each.

USE OF RESEARCH ANIMALS ON SPACELAB LIFE SCIENCES-2

The use of animals in research has been of fundamental importance to the progress that has been made in biology and medicine. Integral to the scientific success of the upcoming Spacelab Life Sciences-2 (SLS-2) mission will be the use of rodents both as controls on the ground and in-flight as subjects of experiments. Some of the rodents must be sacrificed in space. The results of these studies will, for the first time, allow direct comparison between tissues exposed solely to microgravity and those obtained from ground-based controls, thus providing a basis for the development of measures to counter the effects of microgravity on humans in space. The Committee on Space Biology and Medicine fully endorses NASA's plans to use research animals on SLS-2 and subsequent missions. (See Attachment A.)

PEER REVIEW OF RESEARCH PROPOSALS AND PROGRAMS

Peer review of research proposals and programs is a long-standing practice of the scientific community that many regard as fundamental to ensuring the integrity of research findings and progress. Because of cultural differences and operational concerns, NASA's life sciences research has not always enjoyed the benefit of rigorous peer review. The Committee on Space Biology and Medicine recommends that *all* NASA-sponsored extramural and intramural life sciences research proposals and programs be subject to external peer review conducted at regular intervals. Further, in order to guard against a real or perceived conflict of interest, NASA Headquarters should regularly review the policy and management practices applied to extramural research programs by intramural contract and grant administrators and monitors. If any conflicts of interest arise, steps should be taken immediately to resolve them. (See Attachment B.)

OPTIMIZING THE SCIENTIFIC BENEFITS OF THE U.S./RUSSIAN SHUTTLE/MIR PROGRAM

Recognizing that the upcoming U.S./Russian Shuttle/Mir cooperative missions are largely demonstrations of international cooperation and engineering, the committee nevertheless believes that maximum benefit to the life sciences should also be a goal. The Committee on Space Biology and Medicine thus recommends that NASA Headquarters take all possible measures to ensure that the biomedical science activities on these missions be subject to rigorous peer review. The committee also recommends that NASA solicit assistance from the National Institutes of Health in choosing outside, independent experts to participate in the project to maximize the prospects of achieving scientific goals. The committee understands that there are numerous constraints and uncertainties surrounding this mission. (See Attachment C.)

RUSSIA'S BIOSATELLITE PROGRAM

Russia's biosatellite program provides the world's only free-flying spacecraft available for conducting extended-duration animal research in space. Over the past 20 years, the United States has provided support to U.S. investigators (approximately \$2 million per year) to fly experiments on Cosmos series biosatellites. Current plans

call for termination of U.S. participation in this program. Cognizant of both the advantages and disadvantages of the biosatellite program, the Committee on Space Biology and Medicine recommends that NASA maintain the option for future use of the Bion satellites by continuing its dialogue with the Russians about the various options available. In the meantime, NASA should survey its user community to ascertain the extent of the interest in using the Bion satellites and should formally evaluate the relative costs and benefits of different platforms for conducting animal research in space. (See Attachment D.)

In addition to requesting an examination of the above four items, Mr. Alexander asked that the committee consider reviewing its 1987 research strategy, *A Strategy for Space Biology and Medical Science for the 1980s and 1990s*, to assess whether that strategy requires augmentation and whether it accurately reflects the committee's current views and recommendations for NASA's space biology and medicine research program. The committee has discussed this request and plans to begin addressing it at its Spring 1993 meeting. We will keep you informed of our progress.

Signed by
Louis J. Lanzerotti
Chair, Space Studies Board
and
Fred W. Turek
Chair, Committee on Space Biology and Medicine

ATTACHMENT A

Use of Research Animals on Spacelab Life Sciences-2

Unique insights into modern medicine have been achieved through the humane use of animals in research. To enable the goal of long-duration human presence in space, we must continue to rely on animal experimentation to determine the consequences of, and develop countermeasures to, the effects of gravitational change. For NASA's life sciences program, and specifically the SLS-2 flight scheduled for August 1993, the use of research animals is critical to the scientific success of the mission. Some of the rodents must be sacrificed in space.¹ The Committee on Space Biology and Medicine agrees that this experimental protocol is well justified, for the following reasons:

- One of the most powerful tools available for the study of physiological processes in space and the development of measures to counter the effects of microgravity is animal research.^{2,3} Marked advances in biology, physiology, and medicine have been made possible through careful, scientific study of animals in the laboratory.⁴
- The physiological consequences of exposure to microgravity have not yet been separated from those due to reentry forces because, in previous missions, tissue samples were collected only after return to Earth.⁵⁻⁷ In contrast, SLS-2 will, for the first time, offer the unique opportunity to collect tissue samples in the microgravity environment according to the same procedures used in ground-based studies and will allow for direct comparison of the tissue samples collected in both environments.

¹"Rationale and Protocol for Animal Sacrifice Onboard SLS-2 Mission," Communication from NASA Life Sciences Division, February 5, 1993.

²"Animal Use on the SLS-2 Mission," Presentation by Ron White, NASA Headquarters, to the Committee on Space Biology and Medicine, January 28, 1993.

³*A Strategy for Space Biology and Medical Science for the 1980s and 1990s*, Committee on Space Biology and Medicine, National Academy Press, Washington, D.C., 1987.

⁴*Science, Medicine, and Animals*, Committee on the Use of Animals in Research, National Academy Press, Washington, D.C., 1991.

⁵"Cosmos 1887 (Bion 8)," Special Issue, *Federation Proceedings, FASEB*, Vol. 4, No. 2, January 1990.

⁶"Cosmos 2044 (Bion 9)," *Journal of Applied Physiology*, Special Issue, (Supplement) Vol. 73, No. 2, August 1992.

⁷*A Strategy for Space Biology and Medical Science for the 1980s and 1990s*, Committee on Space Biology and Medicine, National Academy Press, Washington, D.C., 1987, and *Assessment of Programs in Space Biology and Medicine—1991*, Committee on Space Biology and Medicine, National Academy Press, Washington, D.C., 1991.

- The Committee on Space Biology and Medicine fully endorses the use of animals on SLS-2 and subsequent missions, and it commends NASA for its plans to provide for their optimal care and treatment in flight. Animal subjects will be handled in accordance with the recommendations of the American Veterinary Medical Association panel on euthanasia and the recommendations of other panels.⁸⁻¹¹ Having a board-certified veterinarian on the mission will ensure the animals' welfare as well as the humane collection of animal tissue during the mission.

ATTACHMENT B

Peer Review of Research Proposals and Programs

During the past several years NASA has strengthened its peer review of both extramural and intramural life sciences research projects. While recognizing the constraints imposed on mission-oriented science, the Committee on Space Biology and Medicine believes it is nonetheless critical to extend the peer review mechanism to cover all NASA-sponsored biomedical research projects, proposals, and programs, including operationally oriented programs such as the Extended Duration Orbiter Medical Program, the Biomedical Monitoring and Countermeasures Program, and the U.S./Russian Shuttle/Mir Program. A rigorous peer review process is essential to ensure high-quality research projects and programs. In particular, the committee recommends that:

- Peer review of intramural research programs should take place at regular intervals. Peer review of the content and accomplishments of intramural programs should take place every 3 to 5 years. A process akin to that used by the National Institutes of Health (NIH) for assessing its intramural research programs would be appropriate. The review process used at the NIH has ensured standards of performance respected throughout the biomedical community.
- Intramural and extramural research projects and programs should be subject to the same peer review standards. Despite the constraints on operationally oriented projects, it is essential to maintain comparable standards for the review of intramural and extramural research projects and programs, to help maintain the quality of both.
- Review of intramural research programs should be conducted by qualified individuals not associated with that particular program. Intramural projects and programs should not be reviewed by investigators who are collaborators or are affiliated with the programs being reviewed, nor should they be reviewed by NASA grantees who are personally involved with the programs or projects.
- NASA Headquarters should regularly review the policy and management practices applied to extramural research programs by intramural contract and grant administrators and monitors. In an attempt to use its resources and intramural scientific personnel as effectively as possible, NASA often uses its scientists and group leaders as Research and Technology Operating Plan (RTOP) managers. This practice has led to concern and distrust in the research community about real or perceived conflicts of interest in the awarding and administering of contracts and grants. This practice also potentially compromises the independence of extramural NASA investigators in reviewing intramural projects and programs. Although the involvement of active researchers in program management can be effective and productive, it also includes the potential for conflict of interest, and must therefore be carefully reviewed and monitored. Because even the appearance of a conflict of interest is counterproductive, it is incumbent on NASA Headquarters to institute procedures to regularly review the management of the research program and eliminate any conflicts. In the case of NASA's life sciences program, concerns have been raised by respected members of the community. The Committee on Space Biology and Medicine strongly urges the director of the Life Sciences Division to institute a procedure to regularly review the administration of the research program. If any conflicts of interest are discovered, NASA should take immediate action to resolve them. Such procedures will strengthen both the program and its administration.

⁸"1993 Report of the Panel on Euthanasia," *Journal of the American Veterinary Medical Association*, Vol. 202, No. 2, January 15, 1993.

⁹*Guide for the Care and Use of Laboratory Animals*, NIH Publication No. 86-23, U.S. Department of Health and Human Services, Public Health Service, National Institutes of Health, Bethesda, Md., 1985.

¹⁰*Laboratory Animal Management: Rodents*, A Report of the Committee on Rodents, Institute of Laboratory Animal Resources, National Research Council, reprinted from *ILAR News*, Vol. XX, No. 3, 1977.

¹¹"Position Statement on Use of Animals in Research," *NIH Guide for Grants and Contracts*, Vol. 22, No. 8, February 26, 1993.

- NASA should adopt the type of program administration that is used so effectively by the National Science Foundation and the National Institutes of Health, whose program officers have no direct personal interest in the research being conducted other than that it be successful. The program officer is judged on the basis of the overall quality and effectiveness of the research program he or she is overseeing.

ATTACHMENT C

Optimizing the Scientific Benefits of the U.S./Russian Shuttle/Mir Program

The Committee on Space Biology and Medicine recognizes that the U.S./Russian Shuttle/Mir Program was initiated primarily to demonstrate international cooperation and that the program has specific engineering goals. It further recognizes that life sciences activities performed as a part of this program face severe time constraints.¹ Within this context, the committee offers the following comments and recommendations with the goal of maximizing scientific achievements in the life sciences for both countries. These recommendations are consistent with recommendations made in *A Strategy for Space Biology and Medical Science for the 1980s and 1990s*² and *Assessment of Programs in Space Biology and Medicine—1991*.³

The committee has been informed by NASA that an investigative team will have responsibility for determining the overall scope and objectives of the program. Members of this team will be selected from a pool of investigators currently involved in operational issues associated with the human space program and from those with approved, peer-reviewed flight investigations. The committee also understands that NASA faces several unusual problems in trying to plan life sciences experiments because of the many uncertainties about the nature of the Shuttle/MIR program and the opportunities it offers for biomedical research. The unique opportunities that may arise from this program, however, require that NASA attempt to maximize the scientific return. Therefore the committee recommends the following:

- Any opportunities to conduct basic biological experiments during the Shuttle/Mir program should be seized as a means to extend NASA's ongoing physiological studies on humans in space. The best outside experts should be solicited to advise the program.
- Acknowledging the constraints and uncertainties associated with this program, NASA Headquarters should nevertheless take all possible measures to ensure that biomedical science activities on this mission be subject to rigorous peer review.
- Outside independent experts should be brought into the project to maximize the likelihood of achieving scientific goals. These experts should be involved in the planning and in the experimentation and analysis phases of the program to ensure that the highest-quality science is performed. To accomplish this, the appropriate National Institutes of Health (NIH) institutes should be asked to recommend specialists. This approach would enhance interactions between NIH and NASA and would provide a model for additional future international collaborations.

ATTACHMENT D

Russia's Biosatellite Program (Bion)

Russia's biosatellite program includes a second-generation, free-flying satellite (Bion) of the Russian Cosmos series that allows for extended-duration animal experiments in space. The United States does not currently have this capability, nor does it have plans to fly biological specimens on free flyers in the future. Up to this point, NASA has sponsored U.S. scientists' use of Cosmos satellites for research, an activity cited as a major factor in the progress made in life sciences research over the last 5 years. However, because of budget pressures, this sponsorship was

¹"U.S./Russian Shuttle/Mir Program," Presentation by Frank Sulzman, NASA Headquarters, to the Committee on Space Biology and Medicine, January 27, 1993.

²*A Strategy for Space Biology and Medical Science for the 1980s and 1990s*, Committee on Space Biology and Medicine, National Academy Press, Washington, D.C., 1987.

³*Assessment of Programs in Space Biology and Medicine—1991*, National Academy Press, Washington, D.C., 1991.

terminated at the time of the most recent Cosmos flight.^{1,2} It appears that without international cooperation and support, the Russians may in fact terminate the biosatellite program.

The Committee on Space Biology and Medicine concludes that if Russia's biosatellite program is not canceled, Bion offers the following distinct advantages for the U.S. life sciences program: (1) Bion is currently the only vehicle available for extended-duration (30 to 60 days) animal experiments in space; (2) it provides a unique opportunity for follow-up research based on the most extensive set of existing U.S. data, collected on earlier missions, on microgravity's long-term effects on animal systems; and (3) it provides for continued, meaningful research in the period before a U.S. space station becomes available.

At the same time, the committee recognizes that Bion has cost uncertainties as well as the following severe limitations: (1) Available power limits the number and type of experiments that can be conducted; (2) problems associated with reentry may compromise the interpretation of some scientific data; (3) there is no opportunity to manipulate the payload in flight; and (4) the instability of the political and economic situation in Russia may compromise the future of the biosatellite program and jeopardize potential U.S.-Russian cooperative activities.

Having weighed both the advantages and disadvantages of continued U.S. participation in the biosatellite program, the Committee on Space Biology and Medicine recommends that:

- NASA should formally evaluate the relative benefits and cost-effectiveness of different platforms for animal research in space. Depending on the outcome of this analysis, NASA should consider providing research support in the 1995 life sciences budget for the biosatellite project.
- NASA should survey its user community to ascertain the extent of interest in the potential use of the Bion satellites.
- NASA should continue discussions with the Russians concerning potential U.S. use of the Bion satellites.
- NASA should indicate an "in principle" interest in the Bion project to the Russians in these continuing discussions.

¹"Cosmos Biosatellite Program," Presentation by Frank Sulzman, NASA Headquarters, to Committee on Space Biology and Medicine, January 27, 1993.

²"Research Opportunities Using Cosmos Satellites—A User's Perspective," Presentation by Bernard Cohen, Mt. Sinai Hospital, to Committee on Space Biology and Medicine, May 14, 1992.

4.3 On the Advanced X-ray Astrophysics Facility

The Space Studies Board sent the following letter to NASA Associate Administrator for Space Science Wesley T. Huntress, Jr., on April 28, 1993.

In a letter to me dated September 15, 1993, from Mr. Joseph Alexander, Assistant Associate Administrator for Space Science and Applications, NASA requested that the National Research Council (NRC) conduct a scientific evaluation of the restructured Advanced X-ray Astrophysics Facility (AXAF). Working jointly with the NRC's Board on Physics and Astronomy, the Space Studies Board established a Task Group on AXAF to perform this study. I am pleased to enclose the report of this task group.

Please contact me if you have any questions about the report.

*Signed by
Louis J. Lanzerotti
Chair, Space Studies Board*

SCIENTIFIC ASSESSMENT OF THE RESTRUCTURED PROGRAM FOR THE ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF)

April 28, 1993

Summary

The Task Group on AXAF (TGA), a joint panel of the Space Studies Board and the Board on Physics and Astronomy, finds that the restructured AXAF program—consisting of AXAF-I, to be launched into a high-Earth orbit in 1998, and AXAF-S, to be launched into a polar, low-Earth orbit in 1999—is fully capable of meeting the primary scientific goals of the former AXAF program. Although the need to reduce substantially the total cost of the program has led to shorter mission lifetimes, the expected increase in operating efficiency partly makes up for this shortfall. The TGA concludes that the revised AXAF program continues to meet the scientific expectations set forth in previous NRC reports, which have recommended AXAF as the highest-priority, new, large-scale program in astronomy.

Thus the TGA urges NASA to proceed with the implementation of the restructured AXAF program and to make every effort to ensure the launch of both AXAF-I and AXAF-S before the end of this decade.

Background

In a letter dated September 15, 1992, from Joseph K. Alexander, Assistant Associate Administrator for Space Sciences and Applications, to Louis J. Lanzerotti, Chair of the Space Studies Board, NASA asked the National Research Council (NRC) to evaluate the scientific content and the expected scientific return of the restructured AXAF program. In response to this request the Space Studies Board and the Board on Physics and Astronomy jointly established the Task Group on AXAF (TGA) as a subpanel of the newly formed Committee on Astronomy and Astrophysics. Arthur F. Davidsen, of Johns Hopkins University, was appointed Chair of the TGA. The full membership of the task group is attached. The TGA was asked to carry out its review and evaluation of the AXAF reconfiguration by the end of 1992.

The TGA held several meetings via teleconference during October and November 1992 and developed a set of questions concerning the reconfigured AXAF. These were addressed to AXAF program officials at NASA Headquarters and AXAF project officials at the Marshall Space Flight Center. In addition, all members of the AXAF Science Working Group were invited to provide to the TGA information and comments concerning the revised program. Martin Weisskopf, AXAF Project Scientist, provided an extensive written response comparing the scientific capabilities of the original and revised AXAF programs, and Peter Ulrich, AXAF Program Manager, provided written materials concerning the programmatic aspects of the restructuring. The TGA discussed all the responses in a teleconference on December 3, 1992, and held a meeting in Washington, D.C., on December 10 and 11, 1992, at which it heard presentations concerning the restructuring and had discussions with the several AXAF

scientists and managers who attended part of the meeting. This report presents the TGA's conclusions and recommendations concerning the AXAF program.

This report was reviewed and discussed by the parent boards of the TGA, the Space Studies Board and the Board on Physics and Astronomy, as well as by the new joint Committee on Astronomy and Astrophysics of the two boards (membership lists attached). Each of these reviews concurred fully with the substance and findings of the report.

Previous NRC Recommendations for AXAF

The AXAF mission has been anticipated and endorsed consistently by the decadal studies of astronomy and astrophysics carried out under the NRC's Board on Physics and Astronomy by the Bahcall committee and by the Field committee before that, and by several reports of the Space Studies Board (and its predecessor, the Space Science Board) and its committees:

- In 1979 (just prior to the launch of the Einstein satellite), the Committee on Space Astronomy and Astrophysics of the Space Science Board, in their document entitled *A Strategy for Space Astronomy and Astrophysics for the 1980's* (National Academy of Sciences, 1979), envisioned and recommended "a semipermanent (several-decade) national observatory facility . . . open to all astronomers and with instrument-changing possibilities. . . . More than an order-of-magnitude improvement in sensitivity over HEAO-2 (Einstein) is required to allow high-resolution spectroscopy and in-depth studies of specific objectives such as clusters of galaxies and active galaxies. This can be achieved by a combination of greater telescope size, better optical surfaces, improved focal-plane instrument sensitivity, and longer mission duration compared with HEAO-2." (p. 13)

- The Field Committee report (*Astronomy and Astrophysics for the 1980's*, Volume I, National Academy Press, 1982) identified four key programs of critical importance for the advancement of astronomy and astrophysics in the 1980s. That committee's top priority was AXAF, which was envisioned as "a permanent national observatory in space, to provide x-ray pictures of the Universe comparable in depth and detail with those of the most advanced optical and radio telescopes. . . . [T]his facility will combine greatly improved angular and spectral resolution with a sensitivity up to one hundred times greater than that of any previous x-ray mission." (p. 15)

- In the report *Long-Lived Space Observatories for Astronomy and Astrophysics* (National Academy Press, 1987), the Space Science Board's Committee on Space Astronomy and Astrophysics stated that it "concurred with the recommendations of the Astronomy Survey Committee (1980), which urges the construction of AXAF. . . . [It] will play a fundamental role in the future progress of astronomy and astrophysics." (p. 2)

- In *Space Science in the 21st Century* (National Academy Press, 1988), the Space Science Board's Task Group on Astrophysics and Astronomy found that "[t]he powerful capabilities of AXAF and the wealth of fundamental problems it can address suggest that this facility will advance research [in x-ray astronomy] for a long time to come." (p. 27)

- The Astronomy and Astrophysics Survey Committee of the Board on Physics and Astronomy (*The Decade of Discovery in Astronomy and Astrophysics*, National Academy Press, 1991) found that AXAF "will return the United States to preeminence in x-ray astronomy . . . [and] have a major impact on almost all areas of astronomy. . . ." That committee reaffirmed the Field Committee decision making AXAF "the highest-priority large program" of the 1990s. (pp. 64-65)

The TGA finds that the scientific performance of AXAF that was anticipated by these previous studies will still be achieved by the restructured program. It is obvious, however, that the authors of these earlier reports envisioned AXAF as a permanent or at least semipermanent x-ray observatory, with an associated program of maintenance that would include new focal-plane instrumentation. However, because the costs associated with such a program are too high to sustain in the current budget environment, NASA and the AXAF Science Working Group have decided that a pair of limited-life missions is a preferable scenario for accomplishing the scientific goals of the AXAF program. The TGA endorses this view and believes that the revised AXAF program will satisfy the scientific expectations encompassed by previous NRC committee reports, even though it will not provide a permanent x-ray observatory in space. The new program should be designed to ensure that the capabilities of AXAF will still be made available to the broad astronomical community through a vigorous guest observer program.

Recent Developments in X-ray Astronomy

Since the AXAF program was first conceived in the 1970s, the field of x-ray astronomy has progressed considerably. The TGA finds that recent developments have only strengthened the arguments in previous NRC reports supporting the need for the enhanced imaging and spectroscopic capabilities that the AXAF program can provide. A few examples are cited below.

Several important results have recently come from the imaging detectors on ROSAT. A prime example from galactic studies is the detection of multiple low-luminosity x-ray sources in the cores of globular clusters. These may be the long-sought cataclysmic variables (white dwarfs that have captured binary companions in the dense cluster cores) and are only marginally resolved even with the ROSAT High-resolution Detector. Thus, the much higher spatial resolution of AXAF-I will be critical for more detailed studies.

There are many new extragalactic results: one is the detection of extended x-ray emission around NGC 1068. Coupled with earlier work on NGC 4151, we now have solid evidence that a hot medium exists around the centers of active galactic nuclei (AGNs) and that spatially resolved, moderate-resolution x-ray spectroscopy will be an important tool for studying both the active nucleus and the surrounding medium.

ROSAT has detected substructure in all clusters of galaxies observed. With detectors that provide both imaging and spectroscopic information, AXAF will measure the mass of galaxy groupings within a cluster and trace out the mass distribution. AXAF will provide a consistency check for the assumption of hydrostatic equilibrium, since x-ray-emitting shock waves should be present if hydrostatic equilibrium does not apply.

ROSAT has shown that many, if not most, AGNs are strongly absorbed below 2 keV. With its higher-energy imaging capability, AXAF will not be impeded in its search for distant objects by the opacity of the circumstellar medium of an AGN. ROSAT, with an energy range below 2 keV, has resolved a large fraction of the x-ray background into discrete objects. AXAF, having significantly more sensitivity and angular resolution than ROSAT, should more completely resolve the x-ray background, if it is indeed entirely composed of discrete sources. Furthermore, AXAF results will apply to energies above 2 keV.

The ROSAT all-sky survey has yielded a total of more than 50,000 objects that can be studied in depth with AXAF's broad range of spectroscopic capabilities. The ROSAT catalog is expected to be publicly available by the time AXAF is operating.

The Japanese x-ray satellite Ginga detected 6- to 7-keV x-ray lines from nearby AGNs. This implies that iron lines, probably broadened fluorescence lines from circumnuclear material, are common emission features in AGN spectra, and that AXAF will therefore have the capability to measure redshifts of distant AGNs.

A very recent result from the Broad-band X-ray Telescope (BBXRT) confirms the existence of an x-ray absorption line in the spectra of BL Lac objects. The greater sensitivity and spectral resolution of AXAF is needed to extend this search to other objects and other lines. The detection of other x-ray absorption lines will resolve ambiguities that currently plague the interpretation of these features.

The premier astronomical event of the 1980s was the occurrence of SN1987a, the closest supernova explosion in 400 years. During its planned time in orbit AXAF may have the opportunity to observe an extraordinary phase in the evolution of SN1987a. The expanding shell of debris from the explosion will collide with a slow-moving ring of matter ejected by the star prior to its death. The best estimate for the time when collisions will begin is about the year 2000. Not only will the event be spectacularly bright in x-rays, but it will also be highly variable in intensity and in its spectral line distribution. The resulting display will provide the best determination of the abundances of newly synthesized matter. As collisions of different clumps of ejecta occur, SN1987a will reveal the composition of different parts of the supernova ejecta. AXAF will also have the ability to locate the positions of the discrete clumps as they are heated to temperatures at which x-rays are emitted. By observing how stars make elements, we will better understand how galaxies evolve. Such a direct observational test of nucleosynthesis theory will allow us to apply these models with confidence to abundance patterns in galaxies at high redshift.

Comparison of the Original and Revised Programs

The restructuring of the AXAF program splits the original, single facility (AXAF-O), a low-Earth-orbit serviceable mission, into two nonserviceable simpler missions: one devoted principally to imaging (AXAF-I), which will be launched into a high, elliptical orbit, and one devoted principally to spectroscopy (AXAF-S), which will be in a low, polar orbit. AXAF-I will carry four of the original six mirror-shell pairs that made up the AXAF-O

telescope, two imaging cameras—the AXAF CCD Imaging Spectrometer (ACIS) and the High-resolution Camera (HRC)—and two spectrometers—the Low- and the High-energy Transmission Grating Spectrometers (LETGS and HETGS, respectively). AXAF-S will carry a lower-resolution, shorter-focal-length, foil-mirror telescope and the x-ray Spectrometer experiment (XRS). AXAF-O was designed to be serviced at five-year intervals for a total lifetime of fifteen years. The design lifetime of AXAF-I is five years, and the design lifetime of AXAF-S is three years.

Since the technical aspects of the various instrument designs remain almost entirely unchanged, the scientific performance of the unified AXAF program is largely preserved. The principal differences are associated with the changes in the telescope complement and in the mission profile. Specifically:

- The reduction in the number of mirror-shell pairs in the AXAF-I telescope (from six to four) diminishes by about 40% the effective area of the system at low energies. However, this effect is largely offset by the increase in the observing efficiency of the mission brought about by the change to high-Earth orbit. In particular, the number of observations that can be accomplished at fixed sensitivity over an extended period of time is very nearly the same for the original and the revised AXAF missions. At high energies, the effective area of the system has actually been improved, due to the introduction of high-reflectivity iridium coatings in place of the nickel and gold coatings planned for the original telescope's outer and inner mirror shells, respectively.
- The use of the low-resolution foil telescope for AXAF-S affects both the spatial resolution and the effective area of the XRS investigations. Although some capability for spatially resolved high-resolution spectroscopy still exists with this experiment, measurement of spectral variations on fine angular scales is no longer possible. The foil telescope has very high throughput, and so the net effective area is comparable to that for AXAF-O at high energies and is down by a factor of only about 2 at low energies. Most importantly, the XRS is likely to be *more* productive during its design lifetime on the AXAF-S mission than it would have been on AXAF-O, simply because it can be operated continuously, thereby utilizing its limited supply of cryogen more efficiently.
- Another advantage of the restructured program will be the opportunity to conduct simultaneous observations with the two missions. This can be extremely useful for complementary measurements of time-variable sources. As an example, for many sources such as active galactic nuclei, x-ray binaries, and stellar flares, AXAF-S can be used to obtain high-resolution spectra of the Fe K complex near 6 keV ($E/\Delta E \sim 500$), while at the same time the HETGS experiment on AXAF-I is used to make high-resolution observations of the Fe L complex near 1 keV ($E/\Delta E \sim 1000$). The comparison of Fe K to Fe L line fluxes and profiles will prove very useful for constraining plasma conditions in these sources.
- Finally, elimination of the servicing aspect of the program reduces net observing time by a factor that is less than 2, since in the restructured mission, AXAF-S and AXAF-I will be operated independently. Perhaps the most serious loss in this regard involves the capability of fielding new instrumentation that might have capitalized on future technological advances or been designed specifically to follow up earlier AXAF discoveries. It seems likely, however, that alternative, post-AXAF mission scenarios could prove equally effective as platforms for fielding new instrumentation, perhaps even in a more cost-effective manner.

The restructured AXAF mission maintains essentially all of the outstanding scientific capabilities of the baseline mission. The angular resolution of AXAF-I is more than an order of magnitude better than that offered by any other mission under development or even in the planning stages. The U.S. investment in high-precision x-ray optics makes AXAF-I unique in its capabilities to undertake x-ray investigations on the largest scales and at the earliest epochs of the universe.

Similarly, the broad-band, nondispersive spectroscopy enabled by the development of the micro-calorimeter (the XRS) is maintained in the restructured mission. AXAF-S will provide a combination of high sensitivity and high spectral resolution in the important energy region above 4 keV that is unavailable with any other planned missions. Its capabilities for high-resolution spectroscopy of extended sources are particularly notable and unique in comparison with those of dispersive spectrometers.

The restructured AXAF program continues to provide unmatched angular resolution, spectral resolution, and sensitivity that will make it the centerpiece of international efforts in x-ray astronomy for the foreseeable future. When the AXAF-I and AXAF-S spacecraft are launched at the end of this decade, they will provide unique capabilities permitting major advances in our understanding of the universe.

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