Chapter 9: Space Exploration Initiative

> The study and programmatic assessment described . . . have shown that the [Space] Exploration Initiative is indeed a feasible approach to achieving the President's goal . . . . The last half of the 20th century and the first half of the 21st century will almost certainly be remembered as the era when humans broke the bonds that bound them to Earth and set forth on a journey into space . . . . Historians will further note that the journey to expand the human presence into the solar system began in earnest on July 20, 1989, the 20th anniversary of the Apollo 11 landing. (The 90-Day Study, 1989)[1]

Space Wraith

Viewed as a space program, as it was intended to be, the Space Exploration Initiative (SEI) was a failure. Viewed as an "idea generator" for Mars exploration planning, however, SEI was a success—some concepts it fostered dramatically reshaped subsequent planning efforts.[2] It was also successful as a painful but necessary growth process. SEI relieved NASA of weighty historical baggage. It weaned large segments of the Agency from its faith in the efficacy of Kennedyesque Presidential proclamations, and it further weakened the pull the station-Moon-Mars progression exerted on senior NASA managers, a process that had first seen high-level expression at NASA in the 1987 Ride report.

Like Apollo before it, the decision to launch SEI had more to do with non-space policy than with its stated space flight aims. SEI and Apollo were, however, diametrical opposites in most other respects. Apollo occurred at the Cold War's height, while SEI occurred at its end. Apollo aimed at displaying American technological prowess to counter Soviet space successes, while SEI aimed in part to provide new tasks for defense-oriented government agencies and contractors as the Soviet threat receded. Apollo was greeted with public enthusiasm, while SEI was forgotten even as it began. Finally, Apollo accomplished both its political and space flight goals, while SEI accomplished neither.

The concept of a big Apollo-style space initiative was in the air in the late 1980s. In late 1987 and early 1988, the Reagan Administration considered and rejected a "Kennedy-style declaration" calling for a Moon base or a man on Mars. White House staffers explained that they had lacked information adequate to make a "technically and fiscally responsible decision."[3] The White House opted instead for its National Space Policy (February 1988) and for giving NASA's Space Station a name—Freedom (July 1988). More importantly, it requested $100 million in FY 1989 to start NASA's Pathfinder technology development program. The Agency had asked for $120 million. In December 1987, a National Research Council report estimated that NASA would have to spend $1 billion a year on technology development for several years to make up for past neglect. Despite this finding, the funding request was poorly received in Congress—not a propitious sign for big new initiatives.[4]

Early in his Administration, President George Bush reestablished the National Space Council and put his Vice President, Dan Quayle, in charge. On 31 May 1989, Bush directed NASA to prepare for a Presidential decision on America's future in space by proposing a space goal with visible milestones achievable early in the 21st century. The directive was said to have originated with OMB director Richard Darman and Quayle's advisors.[5] NASA Administrator Richard Truly, Assistant Administrator for Exploration Franklin Martin, and JSC director Aaron Cohen briefed Quayle in June.

Bush revealed what they had told Quayle and launched the SEI on the steps of the National Air and Space Museum on 20 July 1989, the 20th anniversary of the Apollo 11 Moon landing. Bush told his audience,

> Space is the inescapable challenge . . . . We must commit ourselves to a future where Americans and citizens of all nations will live and work in space . . . . In 1961 it took a crisis—the space race—to speed things up. Today we don't have a crisis. We have an opportunity. To seize this opportunity, I'm not proposing a 10-year plan like Apollo. I'm proposing a long-range, continuing commitment. First, for the coming decade—for the 1990s—Space Station Freedom, our critical next step in all our space endeavors. And next—for the new century—back to the Moon. Back to the future. And this time, back to stay. And then, a journey into tomorrow, a journey to another planet—a manned mission to Mars . . . today I'm asking . . . our

> able Vice President, Dan Quayle, to lead the National Space Council in determining specifically what's needed . . . . The space council will report back to me as soon as possible with concrete recommendations to chart a new and continuing course to the Moon and Mars and beyond.[6]

Aviation Week & Space Technology greeted the initiative with skepticism and a pun, calling it a "space wraith." "President Bush," the magazine reported, "set forth a long-term space plan without a budget and with no more than a skeletal timetable. He then called for more study."[7] The initiative was, moreover, "sprung" on Congress with little "spadework" by either the Administration or by NASA.[8] This helped ensure opposition. Congress sent the Bush White House a clear message by eliminating funds for the Pathfinder technology development program from the FY 1990 NASA budget.

On 26 July, Truly and Martin briefed NASA employees on the President's call. They outlined a "building block approach to progressively more difficult human missions."[9] The proposal, a retread of the 1960s Integrated Program Plan, ignored the less expansive alternative program approach laid out by Sally Ride in 1987. Ride's report was based on conservative projections of NASA's future resources, but the Truly and Martin plan took it for granted that resources for a large, Apollo-style program would automatically follow the President's Kennedyesque proclamation.[10]

Truly and Martin laid out the following timetable:

- 1995-2000: Space Station Freedom operational; robotic precursor spacecraft explore the Moon
- 2001-2010: Lunar outpost; robotic precursors explore Mars
- Post-2010: Mars expedition

The Moon and Mars goals would give "direction and focus" to Space Station Freedom, Truly and Martin stated, while the lunar outpost would give American astronauts experience in living and working on another world before confronting Mars' greater demands. The Moon's proximity to Earth ("a three-day trip") and scientific value made it an attractive way station on the road to Mars. For its part, Mars was SEI's ultimate goal because it had "intrigued humans for centuries," was "scientifically exciting" and "the most Earth-like planet," and because it had resources to support human life. Striving for Mars would "cement long-term U.S. leadership in space" by providing a "challenging focus for [the] space program."

Truly and Martin told NASA civil servants that Bush's call was "a major institutional challenge for NASA" that would "require restructure of [the] [A]gency." NASA would seek to add staff and facilities and would streamline its procurement system.

The 90-Day Study

The task of turning NASA's SEI plan into a report for Quayle's National Space Council fell to an internal NASA team led by Aaron Cohen. He had 90 days to complete his study, which started on 4 August 1989. The schedule was said to have been driven in part by Bush's desire to have an SEI implementation plan in hand for his State of the Union speech in early 1990. In September, Truly said that Cohen's study involved 160 managers from across the Agency, of whom 100 were based at JSC. Mark Craig, JSC Lunar-Mars Exploration Program Office manager, headed the JSC study team.[11] On 2 November 1989, Truly passed Cohen's report to President Bush.

Cohen's report contained five "reference approaches" that followed "the President's strategy: First, Space Station Freedom, and next back to the Moon, and then a journey to Mars." There was, of course, nothing new to this approach. In common with the 1969 Space Task Group report, the reference approaches were in fact one approach with multiple timetables for carrying it out, not a range of alternate plans. NASA seemed to be saying that there was only one way to explore the Moon and Mars.

Approach A emphasized "balance and speed." Space Station Freedom assembly would be completed in 1997, two to three years ahead of the completion date planned at the time Cohen's report was released. Astronauts would return to the Moon in 2001 and permanently staff a lunar outpost the following year. By 2010 the outpost would produce 60 tons of oxygen per year. In 2016, four astronauts would travel to Mars in a transfer vehicle using lunar oxygen propellant and

would spend 30 days on the surface. The year 2018 would see the first 600-day tour-of-duty in a permanent Mars outpost.

Cohen's Approach B aimed for the "earliest possible landing on Mars." The lunar and Mars activities outlined in Approach A would occur simultaneously, requiring more spending in the 2000-2010 decade. The first Mars expedition would occur in 2011.

Approach C strove for "reduced logistic support from Earth"—that is, increased reliance on ISRU. Lunar oxygen production would thus begin in 2005, earlier than in Approach A.

Approach D was to pick Approach A, B, or C, then slip all dates two to three years to allow Space Station Freedom completion in 1999 or 2000. Americans would return to the Moon in 2004.

Approach E assumed that the U.S. would undertake Bush's initiative, but on a "reduced scale." Freedom would be completed as scheduled in 1999 or 2000, and Americans would return to the Moon in 2004. The lunar outpost would be completed in 2012, and astronauts would spend 30 days on Mars in 2016. A 60-day Mars stay would occur in 2018, followed by a 90-day stay in 2022. The Mars outpost would be activated in 2027.

Cohen's report called for new heavy-lift rockets based on Space Shuttle hardware or on the Pentagon's Advanced Launch System. The largest would place up to 140 metric tons into orbit and have a launch shroud up to 15 meters wide—large enough to cover reusable aerobrake heat shields.

To support the Bush initiative, Space Station Freedom would evolve from lab to spaceport through four configurations. First, the baseline single truss would be expanded to include the vertical lower keel trusses and lower boom truss of the Dual Keel design. The second configuration saw the addition of a lunar spacecraft hangar and a second habitation module to house four-person crews en route to the Moon. The crew roster would rise to 12 in the third configuration to support lunar spacecraft servicing and increased life sciences research and Freedom maintenance. The fourth configuration would see the addition of the Dual Keel upper trusses and installation of a Mars spacecraft assembly facility.

The report called for increased civil service hiring and new budget processes within NASA, but it included no cost estimates. A JSC team led by Humboldt Mandell performed a cost analysis and prepared a cost section, but it was stricken and most copies shredded by Truly's order because the costs arrived at were deemed politically unacceptable.[12] Cost information was leaked from the National Space Council, however, so suppressing the cost data merely stymied informed discussion.[13] SEI's critics seized on the highest leaked cost estimates without consideration of the cushion they contained because they lacked complete information—or, if they had access to the details of the cost estimate, they could safely ignore them because they were not publicly available.

According to Mandell, The 90-Day Study plan "was over-costed by a considerable amount."[14] The stricken cost estimates included a 55 percent reserve—"an allowance incorporating both the cost estimating uncertainties for individual developments (i.e., project-level reserves) and allowances for changes in scope (i.e., program-level reserves)."[15] The initial cost of a permanent Moon base using Approach A and including the 55 percent "cushion" would be $100 billion in constant 1991 dollars between 1991 and 2001. The Mars expedition would cost an additional $158 billion between 1991 and 2016 based on the same stipulations. Thus, achieving the letter of Bush's speech—a return to the Moon to stay and a mission to Mars—would cost a total of $258 billion, of which 55 percent ($141 billion) was cushion.[16]

Continuing operations would, of course, add to SEI's cost. In Approach A, operating the lunar base from 2001 to 2025 would cost $208 billion, while operating a Mars outpost from 2017 to 2025 would cost $75 billion. Thus the SEI program cost for Approach A for 34 years, from 1991 to 2025, including operations and a 55 percent cushion, would come to $541 billion.[17]

The cost summary had NASA's annual budget climbing from about $13 billion in 1990 to about $35 billion in 2007 for Approach A. At its peak, about half would be allotted to Moon and Mars programs, meaning that the

average annual cost for Moon and Mars would be about $15 billion per year.[18]

A Quick Study

The 90-Day Study plan was NASA's official proposal for accomplishing SEI, but it was not the only SEI plan put forward by the Agency. In the summer of 1989, an Office of Exploration task force under Ivan Bekey performed a "quick study . . . with analysis support by Martin Marietta" which, it claimed, "defined a much more practical Mars program . . . by virtue of reducing the scale of operations through judicious choices and invention of a new launch vehicle concept."[19] Focused on Mars and relying heavily on Mars ISRU for propellant production, it appears in retrospect as a premonition of piloted Mars planning in the 1990s.

The study was based on Martin Marietta work performed under the Marshall Transportation Infrastructure contract, as well as on the Phobos and Mars Case Studies. Bekey's task force briefed Truly on its proposal in the summer of 1989, but it had little obvious influence on The 90-Day Study.[20] Bekey presented the concept at the 40th International Astronautical Federation Congress in Malaga, Spain, in October 1989, just before Truly sent Cohen's report to President Bush.

The Bekey task force proposed that astronauts go first to Phobos. There they would set up an ISRU propellant plant for making propellants from Phobos materials, which are believed to be water-rich. Bekey's group also proposed to minimize impact on Space Station Freedom by using heavy-lift launch vehicles to launch a few large components rather than resorting to on-orbit assembly of many small components. Mission rate would be kept low to reduce spending rate. The piloted Mars expedition would be preceded in the 1990s by a "preparatory program" including automated precursors, technology development, and biomedical research. The Moon played no mandatory role in Bekey's proposed Mars program.

Bekey's task force found that, assuming an opposition-class trajectory with a Venus flyby for the initial Phobos expedition and a conjunction-class trajectory for the Mars landing expeditions, the maximum spacecraft mass at Earth-orbit departure for a Phobos expedition was similar to the minimum mass for a Mars landing expedition—about 700 tons. Therefore, the short Phobos mission in 2004 could act as a "shakedown cruise" for the Mars landing mission spacecraft design, helping to minimize risk to the crew during the longer landing missions.

Three astronauts would travel to Phobos with a piloted Mars lander, which would touch down unpiloted on Mars to act as a backup habitat for the 2007 Mars landing expedition crew. The 2004 crew would spend a month at Phobos, during which they would demonstrate an automated ISRU pilot plant.

Three expeditions would then travel to Mars' surface to set up infrastructure for a Mars outpost. Five astronauts would launch to Mars in 2007, land near the backup habitat from the 2004 mission, and spend a year on the surface. On the next expedition, five astronauts would set up the first half of a propellant production facility on Phobos and land on Mars. Expedition 4 would set up the remainder of the propellant plant, "readying the Mars infrastructure for a sustained series of visits" that would establish a permanent outpost on Mars.

The task force Phobos/Mars spacecraft design consisted of a large dish-shaped aerobrake with twin Space Station Freedom-derived cylindrical habitats. The spacecraft would rely on tethers to create artificial gravity; the astronauts would reel out the habitat modules from the aerobrake, then rotate the assemblage end over end to produce artificial gravity.

Bekey proposed launching Mars ship components and propellant on Shuttle-derived Shuttle-Z rockets, which would include three or four Space Shuttle Main Engines (SSMEs), a strengthened External Tank, and two Solid Rocket Boosters. Shuttle-Z would use existing Kennedy Space Center Shuttle facilities and cost about the same per launch as the Shuttle, "but with 4-6 times the payload."[28]

By using the Mars transfer stage as the Shuttle-Z third stage, up to 164 tons could be placed in low-Earth orbit. This would permit the Phobos/Mars spacecraft to be fully assembled with "at most" two Shuttle-Z launches. Three Shuttle-Z launches would refuel the Mars transfer stage in orbit. A similar concept was proposed in the 1971 MSC PMRG study. The crew would then board the ship from a Space Shuttle

orbiter and fire the refueled transfer stage to leave Earth orbit for Mars.

The Bekey task force estimated that the total weight launched per year to carry out its Mars program would be about half that needed to carry out the split-sprint mission plan defined by SAIC for the 1987 Ride Report. Bekey's admittedly optimistic preliminary cost estimate was $40 billion for two landings on Mars.[20]

The Great Exploration

Alternatives to The 90-Day Study also surfaced outside NASA. In mid-September, at about the time Cohen presented his initial briefing on his study to the National Space Council, Lawrence Livermore National Laboratory (LLNL) engineers, led by Lowell Wood, briefed Quayle on their Great Exploration plan for SEI.[21] LLNL, which was operated by the University of California under contract to the U.S. Department of Energy, was associated with design and test of nuclear weapons, as well as research into advanced particle beam and laser weapon systems.

The Livermore plan was not well received by NASA, which saw it as an effort to invade its territory.[22] The meaning of the "opportunity" Bush mentioned in his 20 July speech thus seemed clear—SEI was to be an opportunity for the national laboratories to expand their bailiwick. According to some participants, one purpose of SEI was to provide work for Federal government agencies and contractors suffering cut-backs because the Cold War was ending. Cohen's study had, in fact, taken into account the need to provide tasks for organizations such as the Army Corps of Engineers and the Department of Energy labs.[23] NASA's understanding was, however, that NASA would be in charge.[24]

LLNL's Great Exploration plan drew on its 1985 Columbus lunar and 1988 Olympia Mars studies.[25, 26] Wood and his colleagues explained that their plan respected "contemporary politico-economic realities," which would not tolerate a $400-billion space program lasting three decades. Their plan, they claimed, would require a decade and cost only $40 billion.[27]

The Livermore team called for "manned space exploration as though it were a profit-seeking enterprise" with "swift exploration, settlement and infrastructure creation." "Each step," they explained, would leave "major operational legacies—and commitments" so that "Lunar and Martian Bases, once manned, never need be unmanned thereafter." They also called for extensive use of off-the-shelf technology to launch and outfit inflatable structures ("community-sized space suits"), including an Earth-orbital station, "Gas Station" propellant depots, and Moon and Mars surface bases.[28]

The Great Exploration program would commence in mid-1992, when a single Titan VI or HL Delta rocket would launch a 50-metric-ton folded Earth Station and Gas Station payload with an Apollo CM on top. The stations would deploy and inflate automatically in orbit under the crew's supervision. The Earth Station would consist of seven 15-meter-long sausage-shaped modules arranged end to end. It would rotate end over end four times each minute to create artificial gravity that would vary from deck to deck over the length of the station, thus providing crews with lunar and Martian gravity experience. The Gas Station would use solar power to electrolyze water into liquid hydrogen/liquid oxygen spacecraft propellants. Water would be launched by competing companies and purchased by the government from the lowest bidder.

In late 1994, a single rocket would launch a 70-metric-ton folded Lunar Base with an Apollo CM-based Earth Return Module on top. The Lunar Base would refuel at the Gas Station, fly to the Moon, and inflate on the surface. The astronauts would live in Spartan conditions, with crew rotation every 18 months. A lunar surface fuel factory and lunar-orbit Gas Station would be established when the second crew arrived in late 1996.

The 70-metric-ton Mars Expedition ship would be launched in late 1996, inflated in Earth orbit, and refueled at the Gas Station. It would then fly to Mars orbit and visit Phobos or Deimos before landing on Mars. The Mars Base would inflate on the surface, and the first crew would move in for a 399-day stay. They would mine Martian water to manufacture propellants for a rocket-powered hopper.

The plan was innovative, but could it work? NASA managers and engineers thought not. The national laboratories, however, had supporters in the White House and on the National Space Council, among them Vice

President Quayle. They held up the LLNL proposal as a good example of "innovative thinking."[29]

Faced with two rival plans for carrying out his initiative, in December Bush asked the National Research Council (NRC) to examine the studies. H. Guyford Stever, science advisor to Presidents Nixon and Ford and a former Director of the National Science Foundation, chaired the NRC's Committee on Human Exploration of Space. Among its 14 members were Apollo 10 astronaut Thomas Stafford and (until his death on 31 January 1990) Apollo program manager Samuel Phillips.

The Stever Committee report, unveiled on 7 March 1990, stated that the LLNL approach entailed "relatively high risk" and underestimated "the many practical and difficult engineering and operational challenges" of exploring space.[30] The report threw cold water on the push to give SEI over to the national laboratories by stating that "NASA has the organizational expertise and demonstrated capability to conduct human space exploration . . . . To attempt to replicate such expertise elsewhere would be costly and time-consuming."[31]

The Stever Committee also pointed out a basic truth applicable to all large space projects: that the "pace at which the initiative should proceed, while clearly influenced by scientific and technical considerations, is inherently determined by social and political decision-making processes in which non-technical constraints, such as the sustainable level of resource commitment and acceptable level of risk[,] are paramount."[32] In other words, policy makers bore as much responsibility for setting SEI's pace, price tag, and chances for eventual success as the engineers, and they would have to make firm decisions before the engineers could plan effectively and proceed.

The Stever Committee then called for more studies, stating that "the [N]ation is at a very early stage in the development" of its Moon and Mars plans (this despite the many studies performed inside and outside NASA over the decades). "None of the analyses to date—The 90-Day Study, The Great Exploration, or, indeed, this report—should be regarded as providing more than a framework for further discussion, innovation, and debate,"[33] it stated, then added that " . . . the eventual choice of mission architecture will incorporate the ideas from a variety of concepts, some that now exist and others that will arise in the future . . . . The variety of concepts should be regarded as a 'menu' of opportunities."[34]

In late February, a week before the Stever Committee report was publicly released, President Bush directed that NASA should be the "principal implementary agency" for SEI, with the Departments of Defense and Energy in "major roles."[35] Within a week of the report's release, President Bush followed its advice and called for more study. He asked that at least two substantially different reference architectures for SEI be produced over the next several years.

Idea collection for the Stever Committee's "menu" had begun in mid-January 1990, when the Aerospace Industries Association, an organization representing aerospace contractors, had met to start a process of gathering ideas to turn over to NASA. The Agency's Office of Aeronautics and Space Technology served as ad hoc coordinator for this effort.[36] NASA also enlisted Rand Corporation to manage a campaign to solicit ideas from industry, universities, national labs, and the general public. NASA Administrator Truly led a U.S. Government interagency effort. This broad gathering of ideas became known as the SEI Outreach Program.

Ideas collected through the Outreach Program were to be reviewed by an independent SEI Synthesis Group, which would then issue a report. The Synthesis Group approach had been recommended by the Aerospace Industries Association in April. On 16 May 1990, Congress agreed to provide $4.55 million for the Outreach Program, but not without a price. NASA had to agree that it would release no SEI-related contracts to industry until 1991. As one congressional staffer explained, this deferment was designed "to avoid raising expectations in the private sector, given the incredible [Federal] budget restraints." The Agency also agreed to defer $5 million in internal NASA study work until 5 August 1990.[37] On 31 May, Truly introduced Tom Stafford as Synthesis Group chair.

Paul Bialla, NASA Programs Manager for General Dynamics, expressed well the skepticism many in industry felt toward the SEI Outreach Program. "For the most part, our ideas have already been shared with NASA," he told Space News. "Throwing the door open to everyone is simply going to delay the process."[38]

A Political Liability

The Outreach Program was SEI's most far-reaching contribution to Mars expedition planning, for it compiled a large body of ideas for how to send humans to Mars. In terms of implementing SEI, however, the Outreach Program amounted to a means of allowing the abortive initiative to fade quietly after it had become an obvious political liability for the Bush Administration.

Even as the Outreach Program began, SEI was mortally wounded. The Bush Administration's NASA budget request for FY 1991 was $15.1 billion, a 23 percent increase over FY 1990. This included $216 million to start SEI. Two days of NASA budget hearings in mid-March 1990 showed, however, that the Moon and Mars initiative enjoyed almost no support in Congress. By the summer of 1990, it was writ large—no matter what good ideas the Outreach Program might produce, SEI stood almost no chance of gaining congressional support.

It was a two-part problem. On the one hand, the Democrat-controlled Congress was not eager to hand the Republican Bush Administration any victories, especially after it had cast its 1988 Presidential candidate, Michael Dukakis, as a spend-thrift Democrat.[39] More importantly, however, the late 1980s and early 1990s were marked by an enormous Federal debt—$3 trillion in 1990—and annual budget deficits. Budget problems alone made it unlikely that a new space initiative would be well received, even if it didn't have a rumored price tag of half a trillion dollars.

On fiscal grounds, SEI opposition was bipartisan. Bill Green (Republican-New York), a member of the House Appropriations Committee, said, "[G]iven the current budget situation, I would not anticipate a significant start on Mars in the near future."[40] Robert Traxler (Democrat-Michigan), chair of the House Subcommittee on Housing and Urban Development and Independent Agencies, summed it up succinctly: "Basically, we don't have the money."[41]

On 1 May 1990, President Bush called congressional leaders to the White House to lobby for SEI. Richard Darman sought to declare NASA's proposed budget increase exempt from mandatory cuts imposed by Gramm-Rudman deficit reduction legislation, and Bush proposed that aerospace technology cuts should come from the Defense budget, not from NASA.[42] The congressional response was quick in coming. On 3 May 1990, Senator Albert Gore (Democrat-Tennessee), chair of the NASA Authorization Panel, told his fellow legislators that "before discussing a mission to Mars, the Administration needs a mission to reality."[43]

Bush used his 11 May commencement address at Texas A&M University to signal SEI's importance to his administration. His speech was historic—in it he became the first U.S. President to set a target date for an American expedition to Mars. "I am pleased to announce a new age of exploration," he told the crowd, "with not only a goal but also a timetable: I believe that before America celebrates the 50th anniversary of its landing on the Moon [in 2019], the American flag should be planted on Mars."[44]

Congress, however, handed Bush his first clear defeat in mid-June, when a House panel eliminated all funds for SEI from the FY 1991 NASA budget. On 20 June Bush declared that he would fight for his Moon and Mars program. His Administration had, he said, "matched rhetoric with resources." The full House eliminated all SEI funds at the end of June.[45]

On top of issues of party and finance were badly timed NASA problems not directly related to SEI. These raised inevitable questions about the desirability of committing the Agency to a major new initiative when it appeared it could not handle what it already had. In late June, NASA announced that the $1.5-billion Hubble Space Telescope, launched into orbit on 24 April 1990, was rendered myopic by an improperly manufactured mirror. At the same time, the Shuttle fleet was grounded by persistent hydrogen fuel leaks. The three orbiters sat on the ground for five months while NASA engineers struggled with the problem.

On the first anniversary of Bush's SEI speech, a NASA panel headed by former astronaut and spacewalker William Fisher announced that Space Station Freedom would need 6,200 hours of maintenance spacewalks before it was permanently staffed and 3,700 hours of maintenance spacewalks each year thereafter. This would cut deeply into time available for research aboard the orbiting space laboratory.[46] The Fisher Panel's findings helped lead to a new round of station redesign in 1990 and 1991. In an effort to reduce cost

and complexity, the potential for Phase II expansion to the Dual Keel design was eliminated, along with the option for hangars, fueling facilities, and other Moon- and Mars-related systems.[47]

Space Station Freedom thus lost virtually all hope of being useful for Mars transportation. It remained important, however, as a place to gather data on the biomedical effects of long-duration space flight as part of efforts to minimize risk to future Mars crews. Not coincidentally, Mars plans that ignored the Station, except to say that they did not intend to use it, began to proliferate. NASA internal planning, however, continued to place Space Station Freedom—or some future station—squarely on the path to Mars.

In October, House and Senate conferees agreed to an FY 1991 NASA budget of $13.9 billion. While this constituted an increase of $1.8 billion over NASA's FY 1990 budget, it included no funds for SEI. Bush bowed to the inevitable and signed the appropriation into law.

A New Initiative

By the fall of 1990, the course of piloted space flight over the next decade was taking shape. Bush had mentioned international space cooperation in his speech of 20 July 1989. SEI, however, stressed U.S. space leadership, which implied competition with the Soviet Union. The Soviets had built up an impressive space infrastructure in the 1970s and 1980s. By 1990, however, with economic and political reforms underway in their country, they could no longer afford to use it.

As early as March 1990, Bush had directed the National Space Council to pursue space cooperation with the Soviets in an effort to encourage and support Mikhail Gorbachev's on-going reforms. On 8 July 1990, Bush agreed to let U. S. commercial satellites fly on Soviet rockets. On 25 July 1990, the United States and Soviet Union agreed to fly a NASA Mission to Planet Earth instrument on a Soviet satellite scheduled for launch in 1991. In October 1990, Quayle told reporters that "we are in serious discussions with the Soviet Union" on flying an American astronaut on Mir and a Soviet cosmonaut on the Shuttle.[48]

Yuri Semyonov, director of NPO Energia, the leading Soviet astronautics design bureau, promoted joint U.S.-Soviet piloted Mars exploration at space conferences in Montreal in 1990 and Houston in 1991.[49] Would-be Mars explorers saw in this an opportunity. At the Case for Mars IV conference in June 1990, for example, Benton Clark suggested using the Energia heavy-lift rocket to transport Mars spacecraft propellants to orbit. "Use of the Soviet booster would," he declared, "make the dependency between the cooperating countries simple and straightforward."[50] This represented a dramatic shift from the early 1980s, when Harrison Schmitt pushed for the LANL/NASA Manned Mars Missions study to help counter Soviet Mars moves.

In July 1990, Semyonov and Leonid Gorshkov, head of Energia's orbital stations department, published an article on Energia's Mars plans in the Soviet popular-audience publication Science in the USSR.[51] The configuration of the Mars spacecraft depended, they wrote, on the choice of "powerplant." They rejected chemical propulsion, saying that an all-chemical Mars ship would weigh upwards of 2,000 metric tons at Earth-orbit departure. A nuclear-thermal rocket Mars ship would weigh about 800 metric tons. More promising, however, were solar-electric or nuclear-electric propulsion systems which could reduce ship mass to between 350 and 400 metric tons.

Semyonov and Gorshkov wrote that Soviet "aerospace technology is advanced enough to make a mission to Mars a reality," then summarized existing Soviet capabilities. In addition to the Energia rocket ("capable of lofting into Earth orbit whole sections of a spacecraft for final assembly"), the Soviet Union had "perfected the automatic docking procedures for putting together a spacecraft from sections in orbit" through more than 50 flights of automated Progress freighters to space stations. Semyonov and Gorshkov claimed that "[m]ost of the problems that would be faced by a crew on a long voyage to Mars in zero-gravity have been resolved" through 20 years of Soviet space station flights "in an environment very similar, if not identical, to that of a Mars mission." Finally, they reported that "electric . . . engines of the required parameters have been flawlessly performing on Earth."[52]

In 1991, Energia released a Mars expedition report reflecting "the expediency to take into account . . . world public opinion, which [is] against the launch of nuclear power"—an aversion reinforced by the Soviet Union's own April 1986 Chernobyl nuclear reactor

meltdown.[53] NPO Energia's 355-metric-ton solar-electric Mars spacecraft would reach Earth orbit in sections strapped to the sides of five Energia heavy-lift rockets. The designers envisioned a pair of 40,000-square-meter solar panels supplying 7.6 megawatts of electricity at Earth's distance from the Sun and 3.5 megawatts at Mars.

The crew section of Energia's Mars ship design included two cylindrical modules linked end to end. The large living module would contain a "vitamin greenhouse" and individual cabins for four cosmonauts. Water tanks would surround the cabins to shield them from radiation. Over the course of the expedition the water would be gradually consumed and replaced by "waste bricks." An airlock for spacewalks and electric motors for pointing the solar arrays would separate the living module from a smaller control/laboratory module. The spacecraft's lithium-propellant electric propulsion system would be housed in twin modules attached to the sides of the control/lab module.

According to the report, Soviet designers had studied conical piloted Mars landers outwardly similar to the NAR MEM from 1969 to 1971.[54] Their 1991 Mars Landing Vehicle was, however, a cylinder with a conical forward section, a shape selected in part because it fit within the Energia rocket's payload envelope. The two-person lander's cylindrical section would house an ascent stage with a docking unit on top. The 60-metric-ton Mars Landing Vehicle would land horizontally. The cosmonauts would live in the lander's forward cone while on the Martian surface. After a week on Mars, the cosmonauts would blast off in the ascent stage to rejoin their comrades aboard the orbiting Mars ship.

At journey's end, the crew would separate from the Mars ship in the 10-metric-ton Earth Return Vehicle, a conical reentry module resembling the Apollo CM. The Earth Return Vehicle was designed for land landing—like the Soyuz space station transport, it would include solid-fueled soft-landing rockets under its ablative heat shield.

Bush and Gorbachev formally agreed at their July 1991 summit meeting to fly an American astronaut to Mir and a Soviet cosmonaut on the Space Shuttle. Less than two weeks later, in August 1991, communist hardliners launched an abortive coup d'etat against Gorbachev, triggering the collapse of the Soviet Union. The following summer, Bush confirmed the July 1991 cooperation agreements with Russian President Boris Yeltsin. The first Russian cosmonauts arrived in Houston for Space Shuttle flight training in November 1992.

Space cooperation expanded dramatically under President William Clinton beginning in 1993. Space Station Freedom was redesigned as the International Space Station, which incorporated Russian hardware originally built for the Soviet Mir-2 space station. Mars-related cooperation, however, remained small in scale. For example, NASA Lewis researchers worked with Russian engineers on electric thrusters.

America at the Threshold

The SEI Synthesis Group released its report America at the Threshold in May 1991.[55] The report, though written at a time when U. S.-Soviet space cooperation was becoming increasingly important to NASA's future, contained little on cooperation. The Synthesis Group report was the last in the series of high-profile documents proposing future directions for NASA that had begun with the National Commission on Space report in 1986.

Stafford headed a group of 22 experts from NASA and the Departments of Energy, Defense, and Transportation. They included retired JSC director Christopher Kraft and retired JSC engineering director Maxime Faget. Robert Seamans, retired from top NASA, Air Force, and Department of Energy posts, was Stafford's co-chair. They set up shop with a staff of 40 in Crystal City, Virginia, just outside Washington, DC.

The SEI Outreach Program provided the Synthesis Group with about 500 inputs from the 44,000-member AIAA. The Aerospace Industries Association, meanwhile, organized corporate briefings. These included a presentation by Martin Marietta featuring the Mars Direct plan. NASA took out newspaper advertisements around the country and set up toll-free telephone numbers to receive ideas from the public. About 900 concepts were submitted to Rand Corporation by early September. The national laboratories turned over their ideas during September. All told, the Synthesis Group had about 2,000 inputs in hand in late September.[56]

The Synthesis Group was to submit at least two concepts based on these inputs to Truly, who would forward them to the National Space Council. A two-year NASA study would follow, during which the Agency would attempt to identify critical technologies needed to carry out the concepts proposed by the Synthesis Group.

In June 1991, the Group distributed 40,000 copies of its colorful report, emblazoned with the U. S. Presidential Seal, to industry, educators, government agencies, and international organizations. The report outlined four SEI architectures. In all of them, the ultimate goal was landing Americans on Mars. The Moon would serve as a rehearsal stage; nuclear systems would push spacecraft and power bases; and heavy-lift rockets would blast everything into orbit. Including nuclear propulsion was, as in the 1960s, in part a concession to Los Alamos, which had begun stumping for SEI nuclear systems as early as February 1990.[57]

In none of the architectures was Space Station Freedom an element of Mars transportation infrastructure. In September, Aviation Week & Space Technology quoted Stafford as saying, "I know when I went to the Moon . . . on Apollo 10, I did not have to stop at a space station."[58] This was a radical departure from SEI's ground rules. It was, in fact, a deviation from ground rules that had guided Mars planning since the time of the Apollo Moon missions, when NASA had first began to push for a space station.

Stafford's Architecture I emphasized Mars exploration but would spend five years on the Moon first. In 2005, a heavy-lift rocket would launch an automated cargo lander/habitat to the Moon. A second heavy-lift rocket would launch a crew of six to lunar orbit. Five astronauts would land on the Moon near the cargo lander; the sixth astronaut would mind the mothership in lunar orbit, just as the CM Pilot had minded his craft during Apollo Moon landing missions. The surface crew would stay on the Moon for 14 Earth days (one lunar daylight period).

In 2009-10, after four more heavy-lift rocket launches and two more lunar expeditions, a six-person Mars rehearsal crew would carry out a 300-day Mars expedition simulation in lunar orbit and on the Moon. After that, the Moon would not be visited again.

In 2012, the ninth heavy-lift rocket of Synthesis Group Architecture I would launch the first nuclear rocket of the program. It would push an automated cargo lander to Mars. The cargo lander would include a habitat identical to that landed on the Moon. The first six-person Mars crew would leave Earth in 2014 on the tenth heavy-lift rocket. After a flight lasting approximately 120 days, they would decelerate into Mars orbit using their nuclear-thermal rocket, separate from the Mars transfer habitat, and land near the 2012 cargo lander. The crew would spend 30 days testing systems and exploring before returning to the transfer spacecraft and firing the nuclear rocket for return to Earth. In the same launch opportunity, the eleventh heavy-lift rocket of the program would launch a cargo lander for the 2016 Mars expedition, which would spend 600 days on Mars. The report stated that Architecture I was conducive to more rapid execution (first Mars landing in 2008) if provided with "robust" funding.

The other architectures were generally similar. Architecture II, "science emphasis for the Moon and Mars," was designed to characterize the Moon and Mars scientifically through wide-ranging exploration and visits to multiple scientifically interesting landing sites. Architecture III, "Moon to stay and Mars exploration," emphasized a permanent lunar base. The base would achieve 18-person permanent staffing in 2007. A total of 47 six-person piloted expeditions would reach the Moon between 2004 and 2020, and the first piloted Mars landing would occur as in Architecture I.

The Stafford Group noted that "space is a unique store of resources: solar energy in unlimited amounts, materials in vast quantities from the Moon and Mars, gases from the [M]artian atmosphere, and the vacuum and zero gravity of space itself"—hence Architecture IV, which emphasized "space resource utilization."[59] Lunar ISRU would aim first for self-sufficiency; then it would export to Earth electricity and Helium-3 for fusion reactors. Mars ISRU would aim solely to provide self-sufficiency—the planet's greater distance would make exports to Earth impractical, the report stated. The Mars rehearsal on the Moon would take place as described in Architecture I, and Mars expeditions would occur in 2016 and 2018. The second expedition would establish an experimental greenhouse. Both expeditions would manufacture propellants for their rovers from Martian air.

The report made organizational recommendations for carrying out its program. It called upon NASA to

establish "a long range strategic plan for the [N]ation's civil space program with the Space Exploration Initiative as its centerpiece," and asked President Bush to "establish a National Program Office by Executive order." In addition, it advocated advanced technology development programs.[60]

The SEI Synthesis Group had produced a cut-price version of The 90-Day Study—a disappointing outcome, given the magnitude of the Outreach Program. Few Americans took notice of America at the Threshold, and few of its recommendations were implemented. SEI funding fared no better in FY 1992 and FY 1993 than in the previous two years. The planned two-year follow-up study of critical technologies did not take place.

NASA disbanded the Headquarters Exploration Office in late 1992. The JSC Exploration Directorate closed down a few months later.[61] The poorly attended Case for Mars V conference in May 1993 became SEI's wake. By the beginning of 1994, Mars planning across NASA threatened to slip back into its post-Apollo slumber.