The Rise and Fall of Brilliant Pebbles[1]

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The author traces the history of U.S. research into the development of a system of space-based missile interceptors known as Brilliant Pebbles (BP). Equipped with sensors, these kinetic-kill vehicles were designed to locate and collide with incoming ballistic missiles (BMs), thereby destroying them before they could reach their targets. Although the program was cancelled due to opposition in Congress, and lack of interest during the Clinton Administration, the aerospace technology developed utilized a combination of essentially off-the-shelf commercial and military technology that is still available to U.S. aerospace development.

Key Words: Brilliant Pebbles (BP); Inter-Continental Missiles (ICBMs); Strategic Defense Initiative (SDI); Anti-Satellite Systems (ASAT); DOD Advanced Research Agency; Clementine Space Mission; General George L. Monahan; Ambassador Henry Cooper; Defense Secretary Richard Cheney; Senator Sam Nunn; Lawrence Livermore Laboratory.

Introduction

In simple terms, missile defense systems consist of three basic components: sensors that detect and track missiles and missile warheads, weapons that intercept and destroy missiles and warheads, and battle management systems that integrate sensors and weapons into a coherent system. Regarding interceptors, there are two basic types: those that destroy their targets by means of an explosive warhead and those that physically collide with their targets. Interceptors of the latter type are know as hit-to-kill (HTK) interceptors or kinetic kill vehicles (KKV).

The principles behind kinetic kill vehicles were articulated as early as 1960 in Project Defender, an inventory of missile defense technologies completed by the Department of Defense's Advanced Research Projects Agency. Given the state of technology when Defender started, the accepted wisdom was that destroying an ICBM warhead required the use of a nuclear-tipped interceptor. However, as Defender proceeded, faith in the accepted wisdom eroded. A July 1960 Defender paper put the matter as follows:

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[1] Paper presented at "They Taught the World to Fly:The Wright Brothers and the Age of Flight," an International Flight Symposium Sponsored by the North Carolina First Flight Centennial Commission, 23 October 2001.

> Intuitively, one feels, that in trying to intercept anything traveling at ICBM velocities, the resultant miss distance would be large. Until recently, systems considerations have been based on the premise that miss distances would be of the order of one or two hundred feet. This dictated the use of nuclear warhead with its attendant high cost and weight, and other disadvantages. During our space based interceptor studies, consideration of light weight, 300 lb., interceptor using an IR seeker led to the conclusion that miss distances of 10 to 30 feet could be achieved. At these distances, fragment type warheads exploiting hypervelocity impact for kill appeared reasonable against tankage, motors, and other parts of the ICBM in boost. Further study indicated that a cheap effective warhead could be built weighing as little as 2 lbs.[2]

Not only did it begin to appear that lightweight interceptors armed with conventional explosives were feasible, but even hit-to-kill interceptors. In the words of the Defender paper:

> Computer simulation runs on several types of interceptors weighing about 50 lbs., and using IR homing have resulted in miss distances of one or two feet. This certainly indicates hypervelocity impact kill could be employed. Incidentally, a nose cone traveling at ICBM velocities in collision with one pound of material releases the energy equivalent of 6 pounds of TNT. In a word, the kinetic energy at that velocity exceeds the chemical energy available at that mass.[3]

Another point to emerge from Project Defender was the advantages that accrue to the defense from using space-based interceptors to attack and destroy ICBMs while they are still in their boost phase. As the 1960 Defender paper put the matter:

> A ballistic missile is more vulnerable in its propulsion or boost phase then in any subsequent part of its trajectory. At the same time, its identity is most difficult to conceal. These circumstances immediately suggest an early intercept system as an ideal solution to the defense problem. Unfortunately, enemy missiles are relatively inaccessible during this phase. So far, the only promising defense system concept has been a space based or satellite borne interceptor. Such a system requires many

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[2]Harold N. Beveridge, "Defender Introduction," in Ballistic Missile Defense Program of the Advanced Research Projects Agency, *A Review of Project Defender for the Directorof Defense Research and Engineering, 25-29 July 1960*, Volume I, p. 17 (hereafter *Project Defender, 1960*, Vol. I).

[3]Beveridge, "Defender Introduction," pp. 17-19.

> thousands of interceptors in space, but at a given instant only a small fraction will be in a position to attack. The economic feasibility of such systems is heavily dependent upon equipment reliability and upon enemy countermeasures.[4]

The remarks about economic feasibility should be borne in mind, as they will surface prominently later in this history of Brilliant Pebbles (BP), a space-based, kinetic kill interceptor that was part of President Ronald Reagan's Strategic Defense Initiative (SDI) program. During its brief life span, Brilliant Pebbles became the central element of the SDI program. From their orbits around the earth, BP interceptors were to be capable of destroying Soviet ICBMs during their boost phase, eliminating their multiple warheads and decoys before these could be dispersed. In this way, a single Brilliant Pebbles interceptor could destroy as many as ten Soviet warheads. This pivotal role makes the BP story crucial to the broader history of the SDI program.

The Origins of Brilliant Pebbles[5]

By the early eighties, a number of strategic analysts had begun to worry that the Soviets were about to achieve a first strike capability that would allow them to cripple U.S. strategic retaliatory forces and still retain enough nuclear weapons to destroy America's cities. This situation led the Joint Chiefs of Staff in February 1983 to recommend to President Ronald Reagan that the U.S. begin to place greater emphasis in its strategic plans on developing missile defenses.

Having come to office favorably disposed toward strategic defenses, President Reagan was highly receptive to this message. In a nationally televised speech on 23 March 1983, the president announced his decision to launch an expanded research and development program to see if strategic defenses were feasible. In April 1984, following a year of technical and strategic studies to determine how best to pursue the

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[4]Beveridge, "Defender Introduction," pp. 8-9.

[5]For the general background in this section, see Donald R. Baucom, *The Origins of SDI: 1944-1983* (Lawrence, KA: University Press of Kansas, 1992) and "Developing a Management Structure for the Strategic Defense Initiative," Chapter 8, pp. 187-215, in Roger D. Launius, Ed., *Organizing for the Use of Space:Historical Perspectives on a Persistent Issue*, Vol. 18 in *AAS History Series* (San Diego, CA:Published for the American Astronautical Society by Univelt, Incorporated, 1995).

president's goal, the Strategic Defense Initiative (SDI) Organization was chartered under the leadership of its first director, Lt. Gen. James A. Abrahamson of the U.S. Air Force. This organization was to carry out the SDI program of research and development to resolve the feasibility issue.[6]

For several years before the SDI program was started, there had been considerable interest in developing directed energy weapons (DEW) as a counter to ballistic missiles. However, it was becoming apparent when SDIO was established that DEW technology was immature and that it would require far too much money to develop effective DEW weapon systems for a near-term missile defense system. As a result, the focus shifted toward the development of HTK systems as demonstrated in the June 1984 Homing Overlay Experiment (HOE) conducted by the U.S. Army and the September 1986 Delta 180 experiment carried out by SDIO.

By the winter of 1986, Secretary of Defense Caspar Weinberger and General Abrahamson had concluded that the SDI program had advanced to the point where it was time to enter a strategic defense system into the defense acquisition process. On 17 December 1986, Weinberger briefed President Reagan on an architectural concept that included a constellation of orbiting interceptors that would be able to destroy Soviet ICBMs during their boost phase, thereby destroying all the warheads and decoys aboard the missiles before they could be dispensed in space. President Reagan approved the concept; and in the summer of 1987, SDIO presented the architecture for review by the Defense Acquisition Board (DAB), which then recommended approval of the concept by the Secretary of Defense. Weinberger accepted the recommendation in September 1987.[7]

Known formally as the Strategic Defense System (SDS) Phase I

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[6] Baucom, *Origins of SDI*, pp. 129-134, 192-196.

[7] Caspar W. Weinberger, *Fighting for Peace:Seven Critical Years in the Pentagon* (New York, N. Y. :Warner Books, 1990), pp. 323-24, Jack [John] Donegan to General [James A.] Abrahamson, Memorandum, 2 January 1987, with attachments. Weinberger claimed that the meeting with Reagan occurred on 19 December, a draft memorandum for Weinberger's signature attached to Donegan's memorandum indicates that the meeting occurred on 17 December. I have taken the date from the Donegan memorandum, as it is a contemporary document and Weinberger's memoir was prepared some years after the event.

Architecture, the system concept approved by Weinberger included six major acquisition programs. These were the boost surveillance and tracking system (BSTS), the space-based interceptor (SBI), the battle management/ command and control and communications system, the space-based surveillance and tracking system (SSTS), the ground-based surveillance and tracking system (GSTS), and the exoatmospheric reentry vehicle interceptor system (ground-based interceptor). When combined in accordance with the architectural concept, these elements would form a multi-tiered defense that could attack Soviet missiles and warheads throughout their flight. The operational effectiveness goal for this system was spelled out by the Joint Chiefs of Staff in a 23 June 1987 memorandum.

The space-base elements of SDS Phase I, especially the space-based interceptor (SBI), presented several problems. In addition to being inherently distasteful to elements of America's political leadership that opposed weapons in space,[8] SBI would be expensive and drive the cost of the architecture up.[9] Moreover, all space-based systems in the

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[8] Fred Barnes, "White House Watch:Brilliant Pebbles," *The New Republic*, 1 April 1991, p. 11. Barnes's article deals with BP in the context of GPALS and had this to say about congressional opposition to space-based systems: "The land (and sea) parts aren't controversial. Sam Nunn, the chairman of the Senate Armed Services Committee, and other Democrats look favorably on them. It's the space part – not only Brilliant Pebbles but also sensors known as Brilliant Eyes, which guide ground-based missile defenses – that draws criticism. Why?Because if deployed, the space-based elements would violate the Anti-Ballistic Missile (ABM) Treaty of 1972."

[9] By April 1988, the costs of the Phase I system had increased from $40 to $60 billion to $75 to $100 billion. This increase had led the Strategic Forces Subcommittee of the Senate Armed Services Committee to question General Abrahamson about the causes of the cost increase when he appeared before the subcommittee on 18 April 1988. ("Abrahamson Pressed on SDI Cost," *Aerospace Daily*, 19 April 1988, p. 102, as reprinted in Office of Assistant Secretary of Defense for Public Affairs, *Current News*, 21 April 1988, p. 9.) A *Washington Times* article on 19 April claimed that the cost for the first phase of SDI could go as high as $150 billion. (Paul Bedard, "U.S. Must Decide on ABM by 1993, SDI Chief Warns," *Washington Times*, 19 April 1988, pp. A1, A4, as reprinted in Office of Assistant Secretary of Defense for Public Affairs, *Current News*, 21 April 1988, p. 6.) The *SDI Monitor* said that the cost of orbiting several hundred SBI garages, each housing ten interceptors, would be "ruinous. "Faced withcost estimates of a $115 billion for an initial strategic defense system, SDIO last year decided to shift most sensor and SBI fire control work to space surveillance and tracking satellites (SSTS). The new design cut costs by $40 billion.

Under the revamped design, battle management computers would fly on SSTS satellites. The computers would use information from SSTS sensors and six boost surveillance and tracking architecture would be vulnerable to attack by anti-satellite systems (ASAT) that the Soviets might develop.

In the case of SBI, the vulnerability problem was compounded by the system's design. It was to be a large garage satellite that would berth multiple interceptors until they had to be fired at attacking missiles. This meant that a single Soviet ASAT could destroy the garage and its suite of interceptors. The solution to these difficulties emerged from the work of Dr. Lowell Wood, a physicist from Lawrence Livermore National Laboratory.

After discussing the SBI problems with other missile defense experts, Wood concluded that small, autonomous interceptors might offer a solution to the vulnerability and cost problems associated with a space-based interceptor system. He then conducted a personal inventory of applicable technologies and concluded that autonomous interceptors could be produced using technology that could be bought off-the-shelf, much of it only a little advanced over mass-produced consumer and technical professional electronics: video camcorders, scientific work stations and the like. Though this result was striking enough, it was even more astonishing to total up the likely costs: it seemed likely that a simple, small kinetic kill vehicle seeker package composed of such elements could be mass-produced for a few tens of thousands of dollars, moreover in the here-and-now.[10]

Thus, this new interceptor was to "be small, cheap and smart. Most important, it would have none of the vulnerabilities that came with big tracking satellites or groups of interceptors housed in orbiting ga-

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satellites (BSTS) to control the space-based interceptors flying 1,000-1,500 kilometers below them.

But Monahan is uneasy with the decision to place heavy reliance on a constellation of only 18 SSTS satellites. "They become fat, juicy targets," he told reporters. "We've got a dependency [on SSTS] that I'm not wild about.: "("SDIO Takes a Hard Look at Brilliant Pebbles," *SDI Monitor*, 29 May 1988, p. 139.)

[10] For information on the origins of the Brilliant Pebbles concept, see Lowell Wood and Walter Scott, "Brilliant Pebbles," Research Completed under the auspices of the Department of Energy, Contract W-74505-eng-48, n. d. [internal evidence indicates that this paper was published after the end of January 1989 when James Abrahamson had retired from the Air Force], p. 4 (hereafter referred to as Wood and Scott, "Brilliant Pebbles"), William J. Broad, *Teller's War:The Top-Secret Story Behind the Star Wars Deception* (New York:Simon &Schuster, 1992), pp. 251-52. For the quoted material, see Wood and Scott, "Brilliant Pebbles," p. 4.

rages."[11]

As his work continued, Wood gained entree to General Abrahamson and began briefing the General on the new interceptor concept. By the fall of 1987, Abrahamson was sufficiently impressed with the concept to visit Lawrence Livermore National Laboratory where he watched a computer simulation of Brilliant Pebbles in operation, inspected hardware Wood had assembled, and talked with laboratory personnel. Based on this trip, Abrahamson ordered a substantial increase in funding for Brilliant Pebbles.[12]

A few months later, Wood introduced the public to the new interceptor concept and coined its name. Speaking at a conference in Washington, D.C., he described a miniaturization process that would lead to the emergence of "brilliant pebbles" from existing "smart rocks" like the Army's HOE vehicle and SDIO's Delta 180 test vehicle. The new interceptor, he argued, would be designed to be brilliant, not merely smart, and to have far better than human vision, not just crude imaging systems, so that the defensive system architecture is simply the constellation of brilliant pebbles, and *nothing* else. Each pebble carries so much prior knowledge and detailed battle strategy-and-tactics, computes so swiftly and sees so well that it can perform its purely defensive mission adequately, with *no* external supervision or coaching. Complexity, durability, reliability and testability issues in such architectures thereby either simplify to readily manageable levels, or else vanish entirely.

Furthermore, Wood believed that BP interceptors might eventually be made so small (under a single gram in mass) that they would possess too little kinetic energy to assure destruction of an armored ICBM. In short, the lower limit on the size of a Brilliant Pebbles interceptor was the mass it required to be lethal when it struck its target. Certainly, Wood concluded, it was possible at that time to develop an effective Pebble that would weigh between 1.5 and 2.5 kilograms, which was

[11] Broad, *Teller's War*, pp. 252-53.

[12]Lowell H. Wood, "Operational Strategic Defense in the '80s:Very Near-Term Launch Capability for a Nitze-Satisfying SBKKV System," Presentation to Lt. Gen. James A. Abrahamson, in the Pentagon (Room 2E252), 24 February 1987, Ralph Kinney Bennett, "Brilliant Pebbles:Amazing New Missile Killer," *Reader's Digest*, September 1988, pp. 131-132.

about 100 times the mass needed to assure destruction of an armored missile.[13]

To provide effective missile defenses under conditions of the worst-case attack scenario could require as many as 100,000 Pebbles in orbit. However, Wood believed a more reasonable estimate of the size of the BP constellation was about 7,000. Even taking the worst case scenario would not make Brilliant Pebbles prohibitively expensive, since Wood expected the cost of a single BP to be driven down as low as $100,000 through mass production techniques and the use of what was essentially off-shelf, commercial technology. This meant that a constellation of 100,000 interceptors would cost about $10 billion.[14] Moreover, given their small mass, it should be fairly inexpensive to orbit the entire constellation.

In its mature form, the BP concept called for the interceptors to be housed in protective cocoons or "life-jackets." These devices would provide housekeeping support (communications, power, etc.) to the Pebbles until such time as a missile attack was detected. At this time the Pebbles would be armed for combat and shed their life jackets.[15]

As Wood was developing a more definitive version of the Brilliant Pebbles concept, SDIO was conducting its own search for answers to the cost and vulnerability problems associated with the Phase I architecture. Part of this effort was the Space-Based Element Study (SBES) that began in May 1988 under the leadership of Dr. Charles Infosino.

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[13] Lowell Wood, "Concerning Advanced Architectures for Strategic Defense," Paper Prepared for Presentation at the Conference on the Strategic Defense Initiative:The First Five Years, Washington, D. C., 13-15 March 1988, pp. 4-7. One clear advantage of small-sized interceptors was a reduction in the cost of orbiting a constellation that would have to include several thousand pebbles. Indeed, consideration was given to orbiting BP interceptors using rail guns.

[14] Wood, "Concerning Advanced Architectures for Strategic Defense," pp. 7-8. Regarding a worst-case scenario, Wood gave as an example "an instantaneous silo-dumping attack with maximum clustering of mobile launchers – the worst case imaginable. "(p. 8) In Wood and Scott, "Brilliant Pebbles," p. 8, the authors give 7,000 BPs as "a reasonable median number which fully satisfies the JCS tasking for Phase I strategic defense all by itself.: "

[15]Strategic Defense Initiative Organization, *1993 Report to the Congress on the Strategic Defense Initiative*, January 1993, p. A22, states: "Each life jacket provides on-orbit power, low-rate attitude control, surveillance, communication, thermal control, navigation, and survivability. "

General Abrahamson had initiated the study to help SDIO redesign the SBI, and he directed the SBES team to consider Brilliant Pebbles in its review of SBI candidates. The result was the first systematic evaluation of Brilliant Pebbles by an independent body and an endorsement of the BP concept. Based on the results of this review, Abrahamson concluded that SDIO should forge ahead with Brilliant Pebbles and perhaps even accelerate the program.[16]

While the SBES team was at work, the U.S. Air Force Space Division was conducting another review of the SBI element. The results of the Space Division review, along with information about other SBI developments, were reported to the Secretary of Defense in the fall of 1988. The Space Division report stated that work with sensors and signature data, along with trade-off studies, indicated that individual interceptors could directly engage re-entry vehicles using their own sensors, thereby eliminating the requirement for sensors on carrier vehicle satellites. Also, new data suggested that interceptor fly-out time could be doubled, while fly-out velocity could be increased twenty-five percent, resulting in greatly increased range for the SBI interceptors. The improved performance of interceptors, coupled with improvements in the ERIS ground-based interceptor, meant that the number of carrier vehicles in the SBI constellation could be reduced by over fifty percent from the original number of several hundred. These changes translated into lower projected costs for research, development, and acquisition.

[16]Charles Infosino, Discussion with Donald R. Baucom, 14 July 1993, p. 1, Strategic Defense Initiative Organization, *Final Technical and Scientific Report:16 May 1988-30 September 1988*, 14 October 1988, Executive Summary, pp. 1-2. The comment about the SBES study constituting the first systematic review of Brilliant Pebbles was made by Dr. Charles Infosino during a discussion with Ballistic Missile Defense Organization (BMDO) Historian Donald R. Baucom on 21 April 1993. Information on the origins and purposes of the study can be found inside the title page of the report on the "Report Documentation Page. "This study was completed under contract SDIO84-88-C-0019. In addition to Infosino, the following were government employees who served as members of the SBES:Dean Judd (SDIO), Fred Hellrich (Navy/NRL), Ed Wilkinson (Army/SDC), Alan Weston (Air Force/AFAL), Dwight Duston (SDIO), and David Finkleman (USSPACECOM). Employees of FCRC/National Laboratories who provided technical support were:Bob Erilane (POET/Aerospace), Troy Crites (POET/Aerospace), T. J. Trapp (LANL), Chris Cunningham (LLNL), John Dassoulas (JHU/APL), Steve Weiner (MIT/LL), and Howard Wishner (Aerospace). A team of thirteen analysts provided by four companies also supported the effort. Members of the SBES team are listed on p. 53 of their report.

As a result, the cost of the SBI constellation dropped to $18 billion (FY 1988 constant dollars), a reduction of sixty-six percent from earlier projected costs. The Space Division report noted that the analytical work associated with both the SBES and the development of the Brilliant Pebbles concept contributed to simplifications and improvements in the SBI element.[17]

As 1988 was ending, then, SDIO's analytical and redesign work was pushing the SBI concept toward the completely autonomous mode of operation that was a hallmark of the Brilliant Pebbles concept. One could now begin to think in terms of either defending the carrier vehicle against ASATs or simply dispersing the interceptors. If one chose the latter course of action, the interceptors would remain capable of destroying ICBMs and warheads while they themselves became relatively invulnerable to ASAT attack. The progress made with the SBI concept in the year following the first DAB review was summed up by an SDIO report stating that the SBI element of October 1988 departs from the initial SBI element concept in several respects. The initial element focused on autonomous SBI CV [carrier vehicle] satellites for communications, battle management, fire control sensing, and SBI survivability. With this approach, significant complexity and cost accrue to the CV satellite and in turn limit the performance for the space-based interceptor. The current SBI element concept changes the emphasis to increasing the performance of the interceptor, with a corresponding simplification of the CV satellite.[18]

In short, SBI was rapidly evolving toward a concept very similar to Brilliant Pebbles.[19]

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[17] Strategic Initiative Defense Organization, *Program Overview*, December 1988, p. 34, Strategic Defense Initiative Organization, "Space-Based Interceptor Status Report:A Special Report to the Secretary of Defense," 26 September 1988 (updated 5 October 1988), pp. i, 5-7, 12.

[18]SDIO, "Space-Based Interceptor Status Report," 26 September 1988 (updated 5 October 1988), p. 6.

[19]For evidence of this evolution, see *Space-Based Interceptor Status Report*, pp. ii, 5, 20-22. Page ii states: "The Livermore National Laboratory's 'Brilliant Pebbles' concept of a proliferated 'singlet' constellation has not only provided the promise of a revolutionary capability but is also acting as a catalyst for innovative improvements in other SBI programs. "See also Strategic Defense Initiation Organization, "Brilliant Pebbles," Information Paper, 9 March 1989. This paper states: "At the end of FY '88, all of the Brilliant Pebbles technologies, developed under

Verifying the Brilliant Pebbles Concept: A Season of Studies

As 1989 began, General Abrahamson's tenure as SDIO Director was ending.[20] Yet, the design for SBI, the principal weapon system in the Phase I architecture, was still far from settled. This meant that Abrahamson's replacement, Lt. Gen. George L. Monahan, Jr., USAF, would immediately face a major architectural decision: what should be the structure of the space-based portion of the SDS Phase I system?

A few days after his retirement, Abrahamson submitted an end of tour (EOT) report that strongly endorsed Brilliant Pebbles. He was convinced that BP was the key to an effective, affordable space-based architecture and believed that BP could be operational in five years at a cost of less than $25 billion. Therefore, he recommended pushing Brilliant Pebbles aggressively. "This concept," he wrote, "should be tested within the next two years and, if aggressively pursued, could be ready for initial deployment within 5 years." Moreover, "once deployment has begun and a competitive industrial base is established, the system could be scaled to higher levels of effectiveness for ever decreasing incremental costs."[21]

This last point was important, for it said that Brilliant Pebbles could meet one of the critical requirements for deployment that were delineated in the Nitze criteria that had been adopted under the Reagan administration to determine whether or not a missile defense system,

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SDIO funding to Lawrence Livermore National Laboratory (LLNL) with extensive industrial-sector participation, have been demonstrated. "This same information paper stated: "The Brilliant Pebble navigation system is based on a novel, already-demonstrated real-time stellar navigation module and standard miniature angular rate-sensing and linear accelerometers, backed by a high precision clock. "

[20] On 26 July 1988, General Abrahamson informed Secretary of Defense Carlucci of his intent to retire effective 31 January 1989. Abrahamson stated that "a new Administration will undoubtedly have different ideas or approaches to SDI. Therefore, I reluctantly have concluded that the program will best be served by allowing new leadership to represent new policy and direction. "Abrahamson selected the end of January 1989 as the effective date of his retirement to be sure there would be sufficient time to assure a smooth transition to the new Bush administration. James A. Abrahamson, Memorandum for Secretary of Defense, Subject: "Retirement for Active Duty – Action Memorandum," 26 July 1988.

[21] James A. Abrahamson, Memorandum for Deputy Secretary of Defense, Subject: "'End of Tour Report,' – Information Memorandum," 9 February 1989, Attachment 1, "Lt General Abrahamson's Recommendations:*SDI Breakthrough Architectures*," pp. 1-1 through 1-3.

once developed, should be fielded. According to these criteria, any missile defense system deployed must be survivable and cost effective at the margin. The latter criterion meant essentially that it had to cost more to develop offensive countermeasures than to devise defensive responses.[22]

About three weeks before Abrahamson submitted his EOT report, President George Herbert Walker Bush had taken office. With clear signs on the horizon that the Cold War was ending, the new Bush administration immediately launched a major review of American security requirements. Included here was an examination of the structure and objectives of the SDI program with this review encompassing possible future roles for missile defense. In the emergent security environment envisioned by Bush's instructions, these roles might vary from serving as the strategically dominant weapons system to protecting against Third World missile attacks or "the accidental launch of Soviet systems."[23]

In June 1989, President Bush issued National Security Directive 14 pertaining to the SDI program. Based on the findings of his administration's reassessment of national security requirements, the President had concluded that the goals of the SDI program remained "sound" and that "research and development of advanced technologies necessary for

[22] Nitze presented the criteria that bear his name in a speech at Philadelphia in 1985. See Paul H. Nitze, "On the Road to a More Stable Peace: Speech to the Philadelphia World Affairs Council," 20 February 1985. For a discussion of the origins of the criteria, seePaul H. Nitze with Anna M. Smith and Steven L. Rearden, *From Hiroshima to Glasnost:At the Center of Decision* (New York:Grove Weidenfeld, 1989), pp. 406-407. For other discussions of the Nitze criteria as they related to Brilliant Pebbles, see Lowell H. Wood, "Operational Strategic Defense in the '80s:Very Near-Term Launch Capability for a Nitze-Satisfying SBKKV System," Presentation to Lt. Gen. James A. Abrahamson, in the Pentagon (Room 2E252), 24 February 1987, and George Monahan and Lowell Wood, "Brilliant Pebbles," Transcript of Press Briefing, Pentagon, 9 February 1990, pp. 10-11. Indeed, the basic idea of mass-producing cheap BP interceptors would seem to offer the ability to counter any effort on the part of the Soviet Union to overcome strategic defenses by adding more ICBMs. Wood seems to have been concerned about the Nitze criteria as early as August of 1986 when he presented a "an invited talk" at a seminar in Austria. See Lowell Wood, "The Strategic Defense Initiative and the Prospects for International Cooperation in Space," Paper Prepared as Documentation of an Invited Talk to Be Given at the 29th Seminar for Diplomats, Klessheim, Austria, 5-8 August 1986, pp. 5-6.

[23] George Bush, Memorandum for the Vice President, et. al., National Security Review 12, Subject: "Review of National Defense Strategy," 3 March 1989,pp. 2, 6-8.

strategic defenses" should continue to be a major U.S. response to the "Soviet challenge." In this R&D effort, "particular emphasis" was to be placed on "promising concepts for effective boost-phase defenses, for example, 'Brilliant Pebbles.'" Bush also directed Secretary of Defense Richard Cheney to commission an independent review of the SDI program to see that the goals laid down in NSD-14 were carried out. This independent study was to be completed by 15 September 1989.[24] As we shall see, when this review was submitted on 15 March 1990, it contained a strong endorsement of the Brilliant Pebbles concept, which the report's author, Ambassador Henry Cooper, considered essential to the success of the SDI program.

As these presidential instructions were being formulated, General Monahan was developing his own plans to evaluate Brilliant Pebbles. By May 1989, these plans included two technical feasibility studies by outside advisers, a Red/Blue evaluation to judge how well BP would deal with Soviet countermeasures, and a "bottom up" cost estimate.[25]

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[24] George Bush, Memorandum for the Vice President, et. al., National Security Directive 14, Subject: "ICBM Modernization and Strategic Defense Initiative," 14 June 1989, pp. 1, 3-4.

[25] Lt. Gen. George L. Monahan, Jr., to the Honorable John J. Welch, Jr., Assistant Secretary of Defense for Acquisition, Letter, 5 May 1989. See also "SDIO Takes a Hard Look at Brilliant Pebbles," *SDI Monitor*, 29 May 1989, pp. 139-140. Not included in the studies described aboveis a general assessment of the SDI technology program completed in March 1989 by the American Institute of Aeronautics and Astronautics. Although Brilliant Pebbles is mentioned only briefly in the report's section that deals with kinetic kill technologies, this reference to BP comes in the context of a report that endorsed the SDI technology program. "No issues were identified" in the program that could not be resolved through the actions recommended in the report. Furthermore, the report said "no fundamental obstacles were found that a well-planned technology program could not surmount.: "American Institute of Aeronautics and Astronautics, *AIAA Assessment of Strategic Defense Initiative Technologies*, 15 March 1989, p. 30. For a brief description of the AIAA report, see [Strategic Defense Initiative Organization], "Strategic Defense System Space-Based Architecture Fact Paper," 9 February 1990. Wood and Scott, "Brilliant Pebbles," p. 7, stated that in warming up for the 1989 cost estimating exercise, SDI was "gathering up a half-dozen cost estimates for Brilliant Pebbles. "They also stated that they knew of eight additional studies that were underway. For another tally of the studies anticipated, see Theresa M. Foley, "Sharp Rise in Brilliant Pebbles Interceptor Funding Accompanied by New Questions about Technical Feasibility," *Aviation Week*, 22 May 1989, p. 21. Foley noted that in addition to studies by JASON and the DSB, three other studies were being conducted by Martin Marietta and Rockwell as part of their SBI contracts with the Air Force's Space Division. One of these was a reworking of the SBI architecture to reflect the results of moving the fire control responsibility from the SBI garage to the space-based sensor constellation, a move expected to reduce the cost of command and control whileincreasing the vulnerability of the space-based

Monahan had also developed a plan for getting his acquisition strategy approved by the DAB. Central to this plan was integrating the work being done on Brilliant Pebbles with "the on-going and planned activities of other SDI elements, especially SSTS and SBI." This would be accomplished through a fifth evaluation of the space-based component of the SDI architecture that would get under way in September 1989. By this time, the other evaluations of BP were to be completed; and their results would be assimilated into the September study. Then, in the late fall, SDIO would present the results of the September evaluation for approval by the DAB. Once the DAB accepted SDIO's plans, the Air Force would execute the approved space-based program in conjunction with Lawrence Livermore National Laboratory. Monahan had hoped to win approval for this approach during an 8 May 1989 DAB review,[26] which never occurred. Nevertheless, Monahan forged ahead with his plans.

One of the technical feasibility studies was conducted by JASON, a group of America's top scientists, who worked under the aegis of MITRE Corporation and advised government agencies on defense and other technical issues. This study was conducted during June and July of 1989 and focused on the technical feasibility of BP's component technology and of the battle management command, control and communications (BMC^3) system that was to be used with BP. In the process, the JASONs examined other interceptor concepts for comparison purposes.[27]

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architecture. A study known as Scorpion involved the SBI contractors in an examination of the costs of the singlet configuration of the interceptor constellation. Under Scorpion, Rockwell examined a constellation of singlet interceptors compared to housing ten interceptors in a garage. Martin Marietta was to compare an alternative constellation in which two or three interceptors would be clustered together with the constellation that clustered ten together. Finally, there was to be an overarching cost evaluation with which the SBI contractors would assist the Space Division. At this time, estimates of the cost of BP interceptors varied from $250,000 to $1 million per pebble.

[26] Lt. Gen. George L. Monahan, Jr., to the Honorable John J. Welch, Jr., Assistant Secretary of Defense for Acquisition, Letter, 5 May 1989.

[27] JASON (The MITRE Corporation), *JASON Review of Brilliant Pebbles*, Vol. I, *Executive Summary*, September 1989 (JSR-89-900), pp. 2-3, [Strategic Defense Initiative Organization], "Strategic Defense System Space-Based Architecture Fact Paper," 9 February 1990. Dr. O'Dean Judd, BMDO's chief scientist, played a key role in setting up the JASON review. He had

In the Pentagon, it is common for the leader of a major study or his surrogate to brief the sponsoring agency on the findings of that study. On 23 August 1989, Dr. John M. Cornwall, a physicist from Cornell University and leader of the JASON BP review, briefed General Monahan and key members of missile defense community. He reviewed the strong points of the BP concept, which included the proliferation of the interceptors and their autonomous operation. He also noted that the concept was based on conservative technologies that had already been developed in large measure through the work of the military services, SDIO, and Lawrence Livermore National Laboratory. The bottom line in the JASONs findings was that there were no technological "show-stoppers" or fatal flaws in the BP concept. Moreover, he continued, the Brilliant Pebbles interceptor could probably be produced using current technology, although a better BP interceptor could be produced with technologies that were just a couple of years downstream.[28]

The general points Cornwall made in his briefing were detailed in the written report filed by the JASONs on 3 October 1989. This report stated that

> research on lightweight proliferated, autonomous kinetic-kill interceptors using near-term and maturing technology deserves continuing support. It will be essential to avoid either excessive conservatism or excessive optimism in choosing which technologies to support; near-term but not off-the-shelf technologies may be mission-critical. Although there does not appear to be any obvious technological show-stopper, there are several problems which must be addressed: performance of readily-available technology; lack of hardness of commercial technology against a nuclear environment; and serious countermeasures threats.[29]

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carefully analyzed the BP concept and was certain that it was sound. Having a prestigious body such as the JASONs reach the same findings would provide important validation for the BP concept. According to Judd, there was opposition in some quarters to having the JASONs complete the findings, since some believed that the JASONs would be biased against BP. (O'Dean Judd, "RE: Jason Statement," Email, 19 March 2001.

[28]Donald R. Baucom, "Report of the JASONS," Meeting Notes, 23 August 1989.

[29] JASON (The MITRE Corporation), *JASON Review of Brilliant Pebbles*, Vol. I, *Executive Summary*, September 1989 (JSR-89-900), pp. 2-3, [Strategic Defense Initiative Organization], "Strategic Defense System Space-Based Architecture Fact Paper," 9 February 1990. Although the date on the front of the JASON report says September 1989, the Report Documentation

These unanswered questions notwithstanding, BP's general concept of autonomous interceptor operation offered important advantages. As the report put this matter:

> [I]t makes sense to attempt an autonomous system, at least with no SSTS and possibly without BSTS. The extra constellation size needed (because of inefficiencies in selecting targets autonomously compared to central battle management) is likely to be less costly than the central battle manager, and, of course, avoids reliance on a small number of high-value or essential components which are hard to defend.[30]

Regarding countermeasures, the JASONs noted the difficulty of developing effective devices and suggested how SDIO should deal with this issue. In the words of the report:

> Anyone can invent countermeasures, but answering the question of which ones really work must (in most cases) await detailed studies and engineering development; those which are effective may be too costly; and there may be effective counter-countermeasures. Only a full red/blue team study with the best available people on both sides can really address these crucial issues,...

The JASONs then listed six types of countermeasures (four classified and two unclassified) that merited further study.[31]

Overlapping the JASON study was the second technical feasibility study, which was completed by the Defense Science Board (DSB), a federal advisory committee established to advise the secretary of defense on technical issues. In June 1989, the DSB was directed to establish a Brilliant Pebbles Task Force to review the BP concept. The task force met six times between June and September with the various other groups, including the JASONs, that were examining the BP concept and

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Page that is part of the front matter of the report gives its dates as 3 October 1989. Since the JASONs had found no major flaws in the Brilliant Pebbles concept, it was important that they state this finding in the strongest possible terms. Otherwise, detractors of the SDI program would use the report to flog the program, even though the report itself was a highly favorable endorsement of BP. The expression "no-show stoppers" was meant to be a categorical endorsement of Brilliant Pebbles that could not be misconstrued by the press. (O'Dean Judd to Donald Baucom, Subject: "Several," Email, 19 March 2001, 10:45 a. m., O'Dean Judd to Donald Baucom, Subject: "Jason Statement," Email, 19 March 2001, 6:45 p. m.)

[30] JASON, *Review of Brilliant Pebbles*, p. 4.

[31] JASON, *Review of Brilliant Pebbles*, pp. 10-12.

completed its report at the end of December 1989. Like the JASONs, the DSB concluded that BP faced some technical problems that would have to be overcome, but found no fundamental flaws with the concept. The DSB report noted that the design of BP had thus far been examined by a number of competent and independent groups. While these examinations had pointed to several areas for possible improvement, no fundamental flaws had been uncovered.[32]

The third evaluation of Brilliant Pebbles was a Red-Blue interactive countermeasures exercise completed in two formal phases, the first in July and August of 1989 and the second in September and October of 1989. The general conclusion of this study was that Brilliant Pebbles would be subject to the same countermeasures faced by all space-based elements in the SDI architecture, but faced no special problems in this area. The study's major recommendation was that survivability features should be built into the BP system.[33]

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[32] Defense Science Board, *Report of the Defense Science Board on SDIO Brilliant Pebbles Space Based Interceptor Concept*, December 1989, pp. 1-2, [Strategic Defense Initiative Organization], "Strategic Defense System Space-Based Architecture Fact Paper," 9 February 1990. [p. 3]. Task force chairman, Robert R. Everett, submitted this report to the Secretary of Defense and the Deputy Secretary of Defense on 29 December 1989. (Robert R. Everett, Memorandum for Secretary of Defense and Deputy Secretary of Defense, Subject: "Final Report of the Defense Science Board on Brilliant Pebbles," 29 December 1989.)The report was marked for official use only and carried a notice inside its front cover that distribution of the report was restricted to U.S. government agencies by direction of the Secretary of Defense. This notice carried the date of 3 March 1990. Terms of reference for this DSB study had called for the BP Task Force to review and evaluate four items relative to BP and report its findings in briefing format by September 1989. The four items were: the advantages of BP compared to SBI, the soundness of the required technology, the risks and costs in developing the BP demonstration-validation design, and the validity of the demonstration-validation flight experiment program. See Donald J. Atwood, Memorandum for the Chairman, Defense Science Board, Subject: "Terms of Reference – Defense Science Board Task Force on Brilliant Pebbles," 28 August 1989.

[33] BDM Corporation, *Architecture Blue Team Analysis*, Volume II, *Brilliant Pebbles*, Scientific and Technical Report (CDRL Item #A318) for Task Order No. 48 SDS, Prepared for the Strategic Defense Initiative Organization, 20 November 1989, pp. iii, I-1, I-3, System Planning Corporation, *Red/Blue Analysis of Post-Boost Vehicle Operations Countermeasure against Brilliant Pebbles*, Volume I, *Analysis*, SPC Final Report 1335, November 1990, p. 1, [Strategic Defense Initiative Organization], "Strategic Defense System Space-Based Architecture Fact Paper," 9 February 1990. The System Planning Corporation report indicates that in addition to the two formal parts of this Red-Blue exercise, a "quick look at BP occurred in May 1989. "This exercise showed that countermeasures could be effective and needed to be addressed in more

The fourth study was a joint cost review that SDIO and the Air Force conducted between May and December 1989. Among other things, this review compared the costs of architectures based on the older SBI concept and the new Brilliant Pebbles concept. It concluded that the cost of the Phase I SDS architecture with Brilliant Pebbles would be $55 billion, as compared with the $69 billion cost for the Phase I system with SBI.[34]

As each of these four reviews was completed, its results were assimilated into the Space Based Architectural Study (SBAS), the fifth study called for in General Monahan's May 1989 strategy. Based on its own findings and input from the other four reports, the SBAS would "evaluate the space-based elements of the Phase I Strategic Defense (SDS) architecture and determine whether the Brilliant Pebbles concept should become a part of the architecture." SBAS findings would then become the basis for Monahan's recommendations to the DAB regarding the structure of the space-based component of the SDS architecture. Monahan expected a final DAB decision by Thanksgiving 1989.[35]

The SBAS team proceeded by comparing Brilliant Pebbles with two other interceptor concepts. The team found that all three concepts were comparable when analyzed against the expected missile threat; however, based on the advantage to the defense of proliferating its space-based interceptors, the team concluded that developmental work should be continued on only two of the three systems: Brilliant Pebbles and the "Gunrack" version of the original SBI.[36]

In addition to comparing interceptor concepts, the SBAS team

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detail. For this reason, the exercise team had recommended another round of exercises. (BDM Corporation, *Architecture Blue Team Analysis*, pp. I-13 – I-14.)Both the documents cited here are held by the BMDO Information Resource Center.

[34] [Strategic Defense Initiative Organization], "Strategic Defense System Space-Based Architecture Fact Paper," 9 February 1990.

[35] Strategic Defense Initiative Organization, "Strategic Defense System Space Based Architecture Study Report," Executive Summary, [25 October 1989], p. 1. The report is undated. However, Appendix A, Final Study Briefing, is dated 25 October 1989, Patricia A. Gilmartin, "Defense Dept. Postpones Decision on Brilliant Pebbles until November," *Aviation Week*, 14 August 1989, p. 23.

[36] SDIO, "Space Based Architecture Study," Executive Summary, pp. 1-10.

decided to review SDS Phase I sensing requirements taking into consideration the increased sensing capabilities of new interceptors. Based on this review, the team concluded that the interceptors could engage warheads and post-boost vehicles without support from the Space-based Surveillance and Tracking System, but that some SSTS satellites would be required for surveillance purposes. As a result, the number of SSTS satellites required in an architecture that included proliferated space-based interceptors was only one-third the number approved by the DAB in October 1988. Where the Boost Surveillance and Tracking System was concerned, the study recommended that it remain a part of the Phase I architecture. While autonomous interceptors would ease the requirements levied on BSTS, neither the sensors of Brilliant Pebbles nor those associated with the Gunrack system could provide all the data made available by the BSTS. Finally, the SBAS determined that the number of Ground-based Surveillance and Tracking Systems in the architecture would have to increase by six to offset the loss of other capabilities.[37]

In addition to its analyses of the space-based components, the SBAS also compared the costs of four possible architectures: that reviewed by the DAB in October 1988 and one based on each of the three interceptors considered in the study. These cost estimates indicated that an architecture using either the Gunrack or Brilliant Pebbles would reduce the $69.1 billion cost of the October 1988 architecture by $7 billion to $13 billion. The architecture recommended by the SBAS had the following characteristics (all statements about increases or decreases in numbers of a component are relative to the October 1988 architecture):

- BSTS remained unchanged.
- SSTS reduced by two-thirds.
- Replace the earlier SBI with either the Gunrack or Brilliant Pebbles. (Development of both systems should be continued for at least awhile.)
- Several additional GSTSs would be required.
- The Ground-Based Radar and Ground-Based Interceptor would not be changed.

[37] SDIO, “Space Based Architecture Study,” Executive Summary, pp. 10-20.

- The ground communications system for the command center element would have to be enhanced.[38]

In the fall of 1989, with the results of the various studies of Brilliant Pebbles becoming known, it was apparent to Monahan that he would soon have to secure DAB approval for significant changes to the established SDS architecture. On 20 September 1989, as the Space-Based Architecture Study was nearing completion, General Monahan advised John Betti, under secretary of defense for acquisition, that he would be prepared to present the study's recommendation on the architecture to the Defense Acquisition Board during a review that was scheduled for 12 December 1989.[39]

About two weeks later, Betti agreed to this review, but set the date for 11 December. At the same time, he advised Monahan to be prepared for another DAB review in the spring of 1990, at which time SDIO would be expected to present "the Baseline for the Phase I Strategic Defense System."[40] This meant that SDIO would have only a few months to work out the details of a new architecture that would include Brilliant Pebbles.

DOD canceled the December DAB review, leaving Monahan in a difficult position. The new Brilliant Pebbles program had reached the point where it was necessary to initiate contract arrangements to start the development process. Yet, without some form of approval from DOD, Monahan could not proceed. This crisis was resolved when Dr. George Schneiter, head of the Strategic Systems Committee in Betti's office, authorized Monahan to proceed with the "next steps" in the BP acquisition strategy.[41] Over the next few months, Monahan would be

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[38] SDIO, "Space Based Architecture Study," Executive Summary, pp. 21-25.

[39] George L. Monahan, Memorandum for Under Secretary of Defense (Acquisition), Thru:Chairman, Strategic Systems Committee, Subject: "Review of the Space Segment of the Phase I Strategic Defense System (SDS)," 20 September 1989.

[40] John Betti, Memorandum for Director, Strategic Defense Initiative Organization, Subject: "Defense Acquisition Board (DAB) Review of the Strategic Defense Initiative (SDI) Program," 3 October 1989. The DAB that was to be held in the spring of 1990 was originally scheduled for the fall of 1989.

[41] George R. Schneiter, Memorandum for the Under Secretary of Defense for Acquisition, Subject: "Strategic Defense Initiative (SDI) Program Review," 16 January 1990, George R. Schneiter, Memorandum for the Under Secretary of Defense for Acquisition, Subject: "Strategic Defense Initiative (SDI) DAB Review," 6 February 1990. In this second memo, Schneiter wrote:

largely on his own to manage the acquisition of Brilliant Pebbles. During this period, the BP concept was gaining momentum.

On 7 February 1990, General Monahan accompanied President George Bush to Lawrence Livermore National Laboratory (LLNL) where Lowell Wood briefed the President. It was also during this visit that Bush himself gave LLNL and the BP program a boost, lauding America's national laboratories for "developing technologies to strengthen deterrence through strategic defenses." Among the most promising of these new technologies, said the President said, was Brilliant Pebbles.[42]

"In a previous memorandum, I discussed some outstanding SDI acquisition issues. Following your direction to deal with what I could at my level, I informed the SDI Organization they should take the next steps in their recommended Brilliant Pebbles acquisition approach. "Additionally, on 16 January 1990, General Monahan discussed the SDI program with Secretary of Defense Richard Cheney, who had advised Monahan that he expected the General to proceed with the program. Monahan interpreted these instructions as meaning that a DAB was not required for approval of his acquisition strategy for Brilliant Pebbles. Furthermore, the General laid out his plan for releasing the BP concept study RFP in the *Commerce Daily Bulletin*.

[42] George L. Monahan, Jr., Interview with Donald R. Baucom, the Pentagon, Washington, D. C., 29 March 1990, p. 17, President George H. W. Bush, "Remarks by the President to National Employees of Lawrence Livermore Laboratory," Lawrence Livermore Laboratory, San Francisco, California, 7 February 1990. Bush presented a general rationale for the pursuit of missile defenses, telling his Livermore audience:

Together with strategic modernization and arms control, programs like SDI – the Strategic Defense Initiative – and one of its most promising concepts, Brilliant Pebbles, complement our ability to preserve the peace into the 1990s and beyond.

If the technology I've seen today proves feasible – and I'm told it looks very promising – no war planner could be confident of the consequences of a ballistic missile attack. The technologies you are now researching, developing and testing will strengthen deterrence.

Even as we work to reduce arsenals and reduce tensions, we understand the continuing, crucial role of strategic defenses. Beyond their contributions to deterrence, they underlie effective arms control by diminishing the advantages of cheating. They can also defend us against accidental launches – or attacks from the many other countries that, regrettably, are acquiring ballistic missile capabilities. In the 1990s, strategic defense makes much more sense that ever before, in my view.

So a vigorous research, development and testing program at our national labs will be as crucial as ever, as we adapt both the size and shape of our nuclear deterrent. We're working on a significant reductions in arms – I think that's what the world wants. I believe in it strongly. But to protect the American people, we will settle for nothing less than the highest confidence in survivability, effectiveness and safety of our remaining forces.

Bush's praise of BP was reported in the *Dallas Morning News* (Carl P. Leubsdorf, "Bush Declares Strong Support for 'Star Wars' Program," *Dallas Morning News*, 8 February 1990, p. 6A, reprinted Office of Assistant Secretary of Defense for Public Affairs, *Current News:Special*

About a month after Bush's trip to Livermore, Henry Cooper's independent review of 15 March 1990 provided another endorsement of Brilliant Pebbles. Cooper said that the new concept promised to provide an affordable, cost-effective, and survivable space-based interceptor. Moreover, "no technological roadblocks to the Brilliant Pebbles system concept have been identified."[43]

Brilliant Pebbles and the Advent of GPALS

In addition to its affirmation of Brilliant Pebbles, the Cooper report laid out a new vision for missile defenses in the post-Cold War era. This vision flowed from Cooper's assessment of the strategic order that was emerging from a growing restiveness in the Soviet Union and from the proliferation of ballistic missile technology. There were two major implications of the new strategic realities. First, there would be an increased likelihood of accidental and limited missile attacks against the United States. Second, theater missile attacks against U.S. interests around the globe, including deployed U.S. forces, would be far more likely. Therefore, the U.S. missile defense program should begin to focus on providing protection against limited missile strikes (PALS), including those that might be made against deployed U.S. forces.[44]

Edition, "Strategic Defense Initiative," p. 20. An editorial in the *Washington Times* also commented on the President's Livermore speech although it mentioned only SDI and not BP. This editorial referred to Livermore as the "brainstem of the Strategic Defense Initiative. "("The President at Livermore," *Washington Times*, 8 February 1990, p. F2.)

[43] Henry F. Cooper, *SDI Independent Review*, 15 March 1990 (hereafter Cooper, *Independent Review*), Executive Summary, p. 2. Cooper would later claim that Edward Teller introduced him to the BP concept in 1988. "My subsequent all-day visit to Lawrence Livermore National Laboratory," Cooper wrote, "persuaded me of the potential of the hardware under development. "See Henry F. Cooper, "Why Not Space-Based Missile Defense?" *Wall Street Journal*, 7 May 2001. Cooper claimed that 1000 BPs were expected to cost $11 billion in 1991 dollars. "This included all the costs of building and launching the Pebbles, operating them for 20 years, and replacing each Pebble once over the two decades. If fully funded, and without the constraining ABM Treaty, I believe the first-generation Pebbles could have begun operating as early as 1996. "For details on the charter for Cooper's study, see Dick Cheney, Memorandum for Secretaries of the Military Departments, et. al., Subject: "Independent Review of the Strategic Defense Initiative Program," 22 December 1989, Larry Burger, Memorandum for the Under Secretary of Defense (Acquisition), Subject: "Terms of Reference (TOR) for the Process Action Team on SDI," 10 July 1990. Burger was an official in DDR&D[S&TNF].

[44] Henry F. Cooper, *SDI Independent Review*, 15 March 1990, pp. 4, 25-29. For Cooper's views on trends toward the increasing threat of limited missile attacks see pp. 1, 55-79.

To meet the requirements of the new strategic order, Cooper envisioned an architecture with three main components. The first element, a space-based system, would be central to any effective PALS system, since it would provide an overarching defense layer that would contribute to both theater defense and defense of the U.S. homeland.[45]

The space-based element of PALS was to be underpinned and complemented by the two other components in Cooper's PALS architecture. In the United States a ground-based interceptor system composed of several sites would combine with the space-based (global) element to provide a layered national missile defense system with a high kill probability against a limited attack. Overseas, "local, regional, or terminal defenses would be required" to complement the global element and to ensure protection against shorter-range missiles.[46]

Cooper made several specific recommendations relative to Brilliant Pebbles. In addition to endorsing the existing baseline program, which called for BP to operate only during the boost and post-boost phases, Cooper believed that the Pentagon should consider expanding the BP mission to include operations against re-entry vehicles during the mid-course phase of their flight and in the high endoatmospheric portion of the terminal phase of their flight. Such an expansion would substantially increase the effectiveness of missile defenses, provide a hedge against countermeasures, and enhance the value of BP to a PALS system. On the other hand, the mid-course intercept mission would bring with it the nettlesome challenge of mid-course discrimination, the resolution of which might require the deployment of additional sensors such as Brilliant Eyes, an improved infrared sensor system composed of several hundred small, low-altitude satellites.[47]

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[45] Cooper, *SDI Independent Review*, p. 26-29.

[46]Cooper, SDI Independent Review, pp. 26-29.

[47]Cooper, Independent Review, pp. 16, 20-23, 50-51, 92-95. See also pp. 26-28 where Cooper discusses the fact that BP was not designed to find cool targets in dark space. Cooper stated that "the critical problem of midcourse discrimination must be addressed by any midcourse system – and this is a very difficult problem. "He discussed the challenges of mid-course discrimination on pp. 20-23. Dr. Charles Infosino advised the BMDO Historian that Dr. Lowell Wood had carefully restricted the operations of his BP system to the early phases of an ICBM's flight where the BP could easily find its target and avoid the problem of mid-course discrimination. Apparently, in response to this expansion of the BP mission, Livermore

In support of his proposal to expand the BP mission to include midcourse interception, Cooper called for the completion of the studies necessary to support an informed decision on his proposal. Top Pentagon leaders, including General Monahan, concurred with the study requirement. As a result, General Monahan chartered the Mid and Terminal Tiers Review (MATTR) in the Spring of 1990.[48]

However, before this study was completed, a number of major developments occurred in the SDI program. For one thing, General Monahan retired at the end of June and was succeeded in July 1990 by Ambassador Cooper. About a month after Cooper assumed his duties, SDIO conducted the first BP flight test.

In this test, which occurred on 25 August, a payload consisting of a suite of sensors, a processor, and an attitude control system was lofted to an altitude of 124 miles by a rail-guided, three-stage Black Brant X (BBX) launched from Wallops Island, Virginia. Once outside the atmosphere on the way up, the payload package was to separate from the booster. Then, the BP sensor would acquire and track the thrusting

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developed a concept called Genius Sand, in which BP interceptors would themselves be fitted with tiny interceptors that could be used against RVs and decoys in the midcourse battle. A recent document from LLNL described the concept as follows:

The Advanced Interceptor Technology (AIT) Program at LLNL has been pursuing research and development of advanced lightweight, miniature kinetic kill vehicles for more than a decade. During the Brilliant Pebbles (BP) program, LLNL developed a concept for a < 1 kg mini-KV that we named Genius Sand (GS) to indicate the high levels of miniaturization that these vehicles required. This concept was proposed in order to extend the effectiveness of the Boost Phase Brilliant Pebble system in the decoy-rich, multi-warhead environment of the midcourse battle space. This concept called for the Brilliant Pebbles space based interceptor to carry approximately a dozen Genius Sand vehicles that could be deployed in midcourse engagements against RVs and other countermeasures. [Quoted from Advanced Interceptor Technology Program, Lawrence Livermore National Laboratory, National Nuclear Security Administration, "Genius Sand: A Miniature Kinetic Vehicle Technology Demonstration for Midcourse Counter-Countermeasures and Submunition Kills," Prepared for the Ballistic Missile Defense Organization and the U.S. Army Space and missile Defense Command Space and Missile Defense Technical Center, 5 November 2001, p. 5.]

[48] [Secretary of Defense], Memorandum for the Secretaries of the Military Departments, et. al., Subject: "Implementation of the Results of the Independent Review of the SDI Program," n. d., with attachment. This unsigned, undated memorandum is bound inside the front cover of Cooper, *Independent Review*. Volume II of the MATTR report states that the MATTR study was initiated by General Monahan in the spring of 1990 in response to the Cooper report. William Z. Lemnios, Ostap S. Kosovych, and Maile E. Smith, *Strategic Defense Initiative Mid and Terminal Tiers Review (MATTR): Final Report*, Vol. II, *MATTR Overview*, 1 March 1991, p. 1-1.

Nihka motor of the BBX third stage, demonstrating its ability to accomplish these tasks against an operational missile. Additionally, the star tracker was to take various images that the computer would use to generate commands for the attitude control system, which would control the flight of the instrument package.[49]

In the event, one of the explosive separation bolts that held the test vehicle's fairing in place fired prematurely, leaving the fairing attached to the rocket by a single bolt. As a result, the fairing was bent and separated improperly, pulling out the telemetry package and causing a loss of test telemetry only eighty-one seconds into the flight. Because of the loss of telemetry, only tangential benefits were realized from the test. Among these was the first successful observation of a rocket by SDIO's ultraviolet plume instrument (UVPI) that was carried aboard SDIO's Low-Power Atmospheric Compensation Experiment (LACE) spacecraft orbiting overhead. The UVPI automatically acquired and tracked the burning of the Nihka motor. At the end of the flight, the components of the experiment splashed down in the Atlantic Ocean as planned.[50]

While no telemetry was received during the first test, it was apparent that the cause of the failure was outside the BP test package. Therefore, SDIO did not need to modify the BP test package. This knowledge, combined with the fact that the objectives of the second test were similar to those of the first, meant that there was no need to repeat the first experiment, since "'the objectives of experiment one could be achieved on a successful flight test two.'" The second test would have to be delayed somewhat to allow time to correct the faulty mechanism that

[49][Strategic Defense Initiative Organization], Memorandum for Correspondence, "SDIO Brilliant Pebbles Experimental Flight," 27 August 1990. Details on the Black Brant X launch vehicle may be found in Patrick E. Fitzgerald, *Special Projects Flight Experiment, Flights 1 and 2: Program Introduction/Requirements Document*, April 1990, pp. 5-6. Fitzgerald was an employee of Ball Aerospace, he prepared the introduction/requirements document for SDIO. The 27 August memorandum details the rockets involved in the Black Brant booster stack. These were the MK-70 Terrier built by Hercules, the Black Brant V built by Bristol Aerospace, and the Nihka also built by Bristol.

[50]"Bad Bolt Deemed Pebble Problem," *Space News*, 19-25 November 1990, "SDIO Brilliant Pebbles Experimental Flight," 27 August 1990, Colonel Rowland "Rhip" Worrell, "SDI 'Brilliant Pebbles' Test Flight," Defense Department Briefing, 18 April 1991. Worrell stated that the flight duration at the time of telemetry loss was seventy-one seconds.

had caused the BBX to shed its protective shroud improperly.[51]

A little over three weeks before the BP test, Iraq had invaded Kuwait, setting in motion a sequence of events that would have important implications for the SDI program. The Iraqi aggression prompted President Bush to mobilize a coalition to drive Saddam Hussein out of Kuwait. Over the next five and a half months, the United States deployed a major force to the Middle East under operation Desert Shield.

As the United States was deploying its forces to the Middle East, Henry Cooper was garnering support for his PALS concept. A key date in this process was 3 January 1991, two weeks before the Gulf War began, when President Bush received his first full-blown briefing on the new SDI program, now known as GPALS for Global Protection Against Limited Strikes. The presentation took place in the Situation Room in the basement of the White House and was attended by key officials in the Bush government.[52]

Bush decided to adopt the GPALS concept, but his decision was problematical. SDI had never been popular with the Democratically-controlled Congress, which had cut SDI deeply the two previous years and, in FY 1991, placed "sharp restrictions" on space-based elements, which threatened to violate the ABM Treaty. Yet, if GPALS were to have a truly global capability, it would have to include the space-based Brilliant Pebbles. In the words of a "Pentagon official":

> "To have global protection, you've got to have space-based weapons,... They're always in position. If Saddam had a 4,500-kilometer weapon, he couldn't reach the U.S., but he could hit most of Western Europe. Where would you put your ground-based interceptors? You'd have to have them everywhere. The beauty of space-based interceptors is they protect many targets at once. The equivalent protection cannot be done from the ground. Besides, you're better off environmentally and politically having the stuff in space. In space, nobody sees the things."[53]

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[51]"SDI Testing: Brilliant Pebbles Will Push on to Second Test," *SDI Monitor*, 26 October 1990, p. 242.

[52]Fred Barnes, "White House Watch:Brilliant Pebbles," *The New Republic*, 1 April 1991, p. 10.

[53]Quoted in Fred Barnes, "White House Watch," p. 11. Barnes presented several reasons

Circumstances would soon change, offering President Bush a window of opportunity for advancing the new SDI architecture.

Tensions in the Middle East had been growing since the beginning of the massive U.S. buildup. The Iraqis were known to possess a considerable number of Scud variant missiles and had used these missiles lavishly in their earlier war with Iran. As a result, there was considerable concern that forces of the American-led coalition would come under missile attack during the Desert Shield build-up. The tension of Desert Shield gave way to the violence of Desert Storm in the pre-dawn darkness of 17 January 1991 when the coalition's air forces were unleashed on Iraqi targets. The six weeks of warfare that followed produced a major military milestone: the first operational engagement between defensive and offensive missiles. The clash between Patriots and Scuds prompted a reporter for the *Los Angeles Times* to declare that the "age of 'Star Wars'" had begun.[54]

As the war progressed, Americans were confronted nightly with television images of civilians and soldiers running for cover as Scuds streaked toward their targets and Patriot missiles rose from their

why GPALS was unlikely to be accepted in early January 1991. Among these were the departure of President Reagan, SDI's leading advocate, the refusal of Congress to grant Reagan's request that Abrahamson be promoted to four-star general and Abrahamson's being "forced to retire," Monahan's leadership of the program – he managed the program without championing it, and the distraction of Cheney by his advocacy of the B-2 bomber and of Bush with Soviet relations and German re-unification. (Barnes, p. 10)

[54] For information on the start of Desert Storm, see Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey:Summary Report* (Washington, D. C. :U.S. Government Printing Office, 1993), pp. 11-12. For the quotation on the beginning of the Star Wars era, see Melissa Healy, "High-Tech Missile Hits Bull's-Eye," *Los Angeles Times*, 22 January 1991, p. 1. Healy made this comment in response to what was considered at the time to be the first Scud-Patriot battle of the war on 18 January. The actual effectiveness of the Patriot was a much debated topic after the war, and there was some question as to whether the Patriots fired on 18 January were really reacting to a Scud attack or merely a false radar indication. Nevertheless, the Patriot seems to have played a crucial strategic role in keeping the fragile Gulf War coalition viable. This point was made by William Safire, in his Op-Ed piece: "The Great Scud-Patriot Mystery," *New York Times*, 7 March 1991, p. 25, reprinted in Office of Assistant Secretary of Defense for Public Affairs, *Current News:Early Bird*, p. 3. Safire noted that in the case of the Patriot missile: "Psychology triumphed over technology. Why did the Scud, a terror weapon that delivered many of its warheads, fail to terrorize?The ironic reason:The Patriot, even if investigators find it failed in its military mission to kill warheads, averted Saudi panic and Israeli need for reprisal by providing a false sense of security. "

launchers to meet them. Two leading senators, Sam Nunn (D-GA) and John Warner (R-VA), actually experienced a Scud raid while visiting Israel. It was not surprising, then, that the combined houses of Congress applauded President Bush on 29 January 1991 when he announced in his State of the Union Address that the focus of SDI was shifting to the GPALS architecture. "I have," the President said, "directed that the SDI program be refocused on providing protection from limited ballistic missile strikes – whatever their source. Let us pursue an SDI program that can deal with any future threat to the United States, to our forces overseas, and to our friends and allies."[55]

A few weeks after Bush's State of the Union Address, the MATTR team completed the study that Monahan had initiated in the Spring of 1990. This study addressed "the ability of the Phase I Strategic Defense System to engage reentry vehicles in their midcourse and terminal phases of flight, with a view toward simplification, cost reduction, and increased effectiveness." It evaluated three versions of the BP concept: the baseline system that operated only during the boost and post-boost phases of an ICBM's flight, Brilliant Pebbles-Midcourse, and Brilliant Pebbles-Terminal. Based on this evaluation, the study recommended including "Brilliant Pebbles (augmented with midcourse intercept capabilities)" in the SDI architecture, which should also include Brilliant Eyes, the Exo/Endo Interceptor (E^2I), a terminal radar to support E^2I, and the Command Center Element to tie the elements together. The study also recommended including GSTS and GBI in the architecture to increase its robustness, but noted that these had a lower priority than the other elements. This architecture, the report concluded, provided for interception in the boost/post-boost, midcourse, and terminal phases of a missile's flight and would force the offensive force planner into complex decisions for off-loading RVs in favor of penetration aids. The presence of a midcourse and terminal phase of defense will force the Soviets into a situation where either there will be fewer midcourse decoys than before, or one in which there will be no terminal decoys if the Soviets elect to concentrate on the midcourse phase. In any event, the two layers of defense should result in a more robust ground-based

[55]George H. W. Bush, "State of the Union Address," 29 January 1991.

defense.[56]

As fully articulated in SDIO's May 1991 report to Congress, the new GPALS architecture would include four major components: a ground-based national missile defense system to protect the United States, a ground- and sea-based system to defend deployed U.S. forces and the forces and peoples of American allies, a space-based system (Brilliant Pebbles) that could protect any point on the globe against a limited missile attack, and a battle management/command and control system that integrated the other three components into a coherent, synergistic system. Of the three defensive components, Brilliant Pebbles was the most important, since it "would provide global detection of an attack" and was to be capable of destroying both strategic and theater ballistic missiles, provided the latter traveled a distance that exceeded six hundred kilometers. A later fact sheet would put the case for BP as follows:

> The role of Brilliant Pebbles is vital to the GPALS mission. BP will provide global protection against ballistic missiles. While on orbit, a BP will be able to detect a hostile missile launch, decide whether or not to engage the target, and destroy the target by colliding with it. Once given intercept authority from man-in-the-loop, BP will do all of this autonomously and will communicate with other BPs to coordinate which Pebble will engage which target.
>
> The Brilliant Pebbles program represents more than an alternate design for a space-based interceptor. First, BP is a different architectural concept for the space-based segment and incorporates distributed operations, autonomy, and reduced dependence on other system operations.[57]

This was the state of the GPALS architecture as members of Con-

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[56]David R. Israel, William Z. Lemnios, Maile E. Smith, and Ostap S. Kosovych,, *Strategic Defense Initiative Mid and Terminal Tiers Review (MATTR): Final Report*, Vol. I, *Executive Summary*, 1 March 1991, pp. 1-1, 2-1, 3-1. See also Philip Finnegan, "SDIO Shifts Focus, Prepares for Cuts," *Space News*, 8-14 October 1990, pp. 1, 20.

[57]Strategic Defense Initiative Organization, *1991 Report to the Congress on the Strategic Defense Initiative*, May 1991, pp. 2-2 – 2-9. See p. 2-5 for the quotation on Brilliant Pebbles. Figure 2-5 on p. 2-9 presents diagrammatically the central role of BP in the GPALS architecture. The fact sheets are Strategic Defense Initiative Organization, "Brilliant Pebbles and GPALD" and "The Brilliant Pebbles Program," Fact Sheet, [18 April 1991]. The titles given here represent two different fact sheets printed front and back on a single sheet of paper.

gress began their deliberations on the authorization and appropriation bills for fiscal year 1992. As they did, images of Gulf War missile attacks were still fresh in their minds. Their efforts produced the Missile Defense Act (MDA) of 1991 that became law in November 1991.

Congressional Strictures and the Demise of Brilliant Pebbles

Although widely acclaimed by missile defense advocates for setting specific deployment goals for both theater and national missile defense, the MDA of 1991 was in fact a compromise document that also included strong language requiring missile defense deployments to be compliant with the ABM Treaty. This agreement allowed the United States to deploy a single ABM system at Grand Forks, North Dakota, and restricted the number of interceptors at this one site to one hundred. But even here, the MDA introduces a degree of ambivalence for it opens with a statement in Section 232 that implies an expectation that the ABM Treaty would be altered to permit deployment of a fully effective missile defense system that would include multiple sites. Thus, we read:

> It is the goal of the United States to... deploy an anti-ballistic missile defense system, including one or an adequate additional number of anti-ballistic missile sites and space-based sensors, that is capable of providing a highly effective defense of the United States against limited attacks of ballistic missiles.

However, in the following section, which specifies implementation measures, the MDA qualifies this goal by charging the secretary of defense with deploying

> by the earliest date allowed by the availability of appropriate technology or by fiscal year 1996 a cost effective, operationally-effective, and *ABM Treaty-compliant* [italics added] anti-ballistic missile system at a single site as the initial step toward deployment of an anti-ballistic missile system... designed to protect the United States against limited ballistic missile threats, including accidental or unauthorized launches or Third World Attacks.[58]

[58]U.S. Congress, House of Representatives, 102d Congress, 1st Session, *National Defense Authorization Act for Fiscal Years 1992 and 1993: Conference Report to Accompany H. R. 2100*, Report 102-311, 13 November 1991, p. 34. It was Part C of this act that carried the title: "Missile

Further ambivalence is to be found in the law's specific instructions regarding Brilliant Pebbles. On the one hand, the act seemed to recognize that the BP interceptor was critical "to providing a highly effective" missile defenses, since Section 234 (a) called for "robust funding for research and development for promising follow-on anti-ballistic missile technologies, including Brilliant Pebbles." Yet, it expressly forbade the inclusion of BP in the initial plans for a limited national missile defense. In the words of the MDA: "EXCLUSION FROM INITIAL PLAN: Deployment of Brilliant Pebbles is not included in the initial plan for the limited defense system architecture described in section 232 (a)." Moreover, when Congress needed a hostage to ensure the Pentagon would submit a required report on "conceptual and burden sharing issues associated with the option of deploying space-based interceptors (including Brilliant Pebbles)," the hostage taken was Brilliant Pebbles. No more than fifty percent of MDA funding for BP could be spent until forty-five days after DOD submitted the report to Congress.[59]

Some degree of clarity comes in the MDA's specifications for the initial national missile defense architecture, for these were clearly drawn from the ABM Treaty. The architecture was to include only one hundred ground-based interceptors in accordance with treaty provisions. It was to have only "fixed, ground-based, anti-ballistic missile battle management radars." Finally, the architecture was to make optimum "utilization of space-based sensors, including sensors capable of cuing ground-based anti-ballistic missile interceptors and providing initial targeting vectors, and other sensor systems *that are also not prohibited by the ABM Treaty* [italics added], such as a ground-based sub-orbital surveillance and tracking system."[60]

Faced with this ambivalence, a fainthearted SDI program manager might have severely restricted the Brilliant Pebbles program. Henry Cooper was anything but fainthearted. And under his tutelage, SDIO continued to push BP because of its primal role in GPALS, thereby

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Defense Act of 1991. "Hereafter, this document will be referred to as MDA of 1991.

[59]MDA of 1991, p. 35.

[60] MDA of 1991, pp. 34-35.

setting himself and his agency on a collision course with congressional Democrats, many of whom were committed to arms control and staunch opponents of SDI.[61] The critical collision came on 9 April 1992 when Ambassador Cooper testified before the Subcommittee on Strategic Forces of the Senate Armed Services Committee.

By this time, Sam Nunn, chairman of the Armed Services Committee, was suspicious of the Brilliant Pebbles program. This suspicion manifested itself in a request from Nunn to the General Accounting Office for a review of the analysis that SDIO had done regarding the possible effectiveness of Brilliant Pebbles.[62]

The GAO started its report by describing the BP architecture that was to consist of several staggered rings of interceptors orbiting at an altitude of about 400 kilometers. The report then noted that SDIO's estimates of the capabilities of the Brilliant Pebbles concept were based on computer simulations of forty different attack scenarios and that such simulations offered the only method of analysis available "at this early stage" in the program. The results of this analytical process were to be used to refine a BP design that would then be put through a five-year testing program to secure data that would then replace the assumptions and theories of the simulations.[63]

GAO granted that computer simulations were useful tools and that such simulations were the only means of investigating matters such as

[61]As a space-based weapon, BP was sure to run afoul of ABM Treaty supporters, since that treaty forbade mobile ABM systems, whether ground-, sea-, air-, or space-based. Additionally, there was the issue of weapons in space. Regarding this latter point, at the end of May 1993, General Charles Horner, Commander-in-Chief, U.S. Space Command, stated that "you have a problem with philosophical people who say they are against weapons in space. They are missing the boat, because the weapon in space is not the space-based interceptor. It's the warhead on the intercontinental ballistic missile. "(Ben Iannotta, Interview with General Horner, *Space News*, 31 May-6 June 1993, p. 22.)

[62]United States Government Accounting Office, *Strategic Defense Initiative: Estimates of Brilliant Pebbles' Effectiveness Are Based on Many Unproven Assumptions*, GAO Report NSIAD-92-91, March 1992, p. 2 (Hereafter, GAO/NSIAD-92-91).

[63]GAO/NSIAD-92-91, pp. 3-4. Regarding the specific assumptions in the SDIO simulations, GAO included "assumptions about many key operational characteristics" such as the ability of the constellation to maintain continuous surveillance of the earth's surface, the length of time required for the BP interceptors to receive the enabling command that would allow them to attack approaching missiles, and the handling of target assignment to individual BP interceptors.

the performance of a future system. Still, developers must be careful to avoid the pitfall of mistaking data from simulations for information that was necessarily representative of reality.[64]

Included as an appendix to the GAO report was a letter from Henry Cooper in which he generally concurred with the GAO's findings. However, at the same time, Cooper noted that SDIO's use of simulations was within the bounds of sound engineering practice. In his words:

> Brilliant Pebbles simulation activities are consistent with a program in the demonstration and validation phase. The "maturity" of Brilliant Pebbles simulations will change and be enhanced with improvements in the design of primary system hardware prototypes. It is crucial that the simulation efforts provide sufficiency to allow the program to proceed to the next milestone.
>
> The report indicates that simulations may rely on data that are incomplete and assumptions that may be inaccurate. That does not limit the simulation usefulness. [sic] The Strategic Defense Initiative Organization has relied on an arduous engineering assessment tempered by real-world experience to arrive at a working hypothesis. Assumptions are based upon a combination of the understanding of the system operation, operating characteristics, and engineering analysis. As more data becomes available, assumptions are modified as necessary. Additionally, the Strategic Defense Initiative Organization has relied upon the best available threat information, as found in the most current intelligence scenarios.
>
> It also should be noted that some of the assumptions reflect validated operational requirements. The acquisition process requires an evaluation of system capability to meet those requirements. The Strategic Defense Initiative Organization does not randomly choose parameters. Operational requirements are matched, to the greatest extent possible, to system performance assumptions. Furthermore, it should be recognized that system effectiveness also is a function of selected tactics and that the user, U.S. Space Command, is deeply involved in the development of operational employment, strategy, and tactics.[65]

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[64] GAO/NSIAD-92-91, p. 11.

[65] Henry F. Cooper, SDIO Director, to Frank C. Conahan, Assistant Comptroller General, Letter, 26 February 1992. For a more detailed critique of the GAO report, see R. H. Worrell, III, Memorandum for GAO, Subject: "Draft GAO Report on BP Effectiveness," 4 February 1992.

Nunn received this report within two weeks[66] of the 9 April hearings, and it may have contributed to the hostility toward Brilliant Pebbles that he exhibited during the hearings. Since his presence was required on the floor of the Senate where an important budget resolution was being considered, Nunn missed the opening of the hearings. When he entered the hearing room about 4:30 p.m., Nunn effectively took control of the proceedings, directing a staff aide to put up a series of large poster-board briefing charts as he proceeded to take Cooper step-by-step through the points he wanted to make.[67]

First, Nunn noted that the Missile Defense Act established for SDI the goal of fielding a treaty-compliant ABM system by 1996 while allowing for a delay if this goal proved technically unfeasible. Nunn indicated that he was willing to be flexible with regard to the date, but was upset by an assertion by SDIO to the effect that Congress had failed to provide the funding needed to meet the 1996 deadline. Nunn then accused SDIO of creating the shortfalls through its own funding allocations. Included in the SDIO allocations that Nunn challenged was excessive spending on space-based elements, including Brilliant Pebbles, that could not be ready in time for the specified deployment date of 1996.[68]

After Cooper defended his programmatic and funding decisions,

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[66]GAO Report NAISD-92-91 was dispatched to Nunn by Nancy R. Kingsbury to Sam Nunn, Letter, 27 March 1992, which is included in the front of the report itself.

[67] Hearings of the Strategic Forces Subcommittee of the Senate Armed Services Committee, Subject: "FY 93 SDIO Budget Request," 9 April 1992, transcript prepared by contractor for SDIO, p. 28. The SDIO Historian, Dr. Donald R. Baucom, attended these hearings. The account of the hearings presented here reflects the influence of his recollections as captured in notes taken during the hearings.

[68] Transcript of 9 April 1992 Hearings, pp. 28-31. There was an exchange at this point between Cooper and Nunn as to what treaty-compliant meant. From his perspective, Cooper said, treaty-compliant meant that the LDS could only be deployed at Grand Forks. Only if the ABM Treaty were amended could the system be deployed at other sites. Nunn said that legally, this provision meant the conditions specified by the ABM Treaty at the time the MDA of 1991 was passed. Cooper responded that what he meant was that if the ABM Treaty were amended to allow deployment at other sites, it might be better to deploy at three sites, one of which might not be Grand Forks. If that turned out to be the case, deploying at Grand Forks would waste about $2 billion. Under these circumstances, DOD would come back to Congress and ask for permission to change the deployment plans. Nunn then dropped the issue and moved on to his next point. (pp. 29-30)

Nunn accused him of continuing to push the GPALS architecture in the face of the MDA's requirement for the deployment of a limited national missile defense system at Grand Forks. Instead of pushing systems like the Ground-based Surveillance and Tracking System that would add to the effectiveness of the Grand Forks deployment, Cooper had chosen to allocate "$390 million for Brilliant Pebbles, even though Congress specifically excluded it from the Limited Defense System [LDS] architecture." Nunn ended this line of argument by essentially charging that Cooper had purposefully undermined the LDS deployment.

> So, it is my assertion, Mr. Ambassador – which you can rebut – that what you've done by a combination of funding, and the reduction in GSTS, is, you made sure that Grand Forks would not be effective if we did it during this decade. Therefore, you made it almost impossible for it to happen during this decade. I don't know the motive for that, but that's what it looks like to me.[69]

Cooper defended his program decisions by pointing out the problems associated with the GSTS program, which would add about $1 billion to the program if pushed at the level advocated by Nunn. He also stated a second time that in choosing the funding level for space-based and follow-on research and development he had taken as his guide the funding levels voted by Congress when it passed the MDA: 11% of program funding for space-based interceptors and 14% for other follow-on technologies. Nunn then responded that regardless of Cooper's points, the prospect of a 1996 deployment date for the limited defense system was not supported by the current SDIO program. To this, Cooper replied that the 1996 date had never really been possible.[70]

All of this notwithstanding, Nunn continued to hammer home his basic point: SDIO was planning to spend $2.6 billion on Brilliant Pebbles, a development that could not possibly contribute to an LDS deployment for 1996, the priority established by the MDA. "It's clear Mr. Ambassador, just by the numbers, it's absolutely clear, that your priority is not – maybe it's the right priority but it's not the priority of Congress – your priority is not to meet an early deployment date on an

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[69] Transcript of 9 April 1992 Hearings, pp. 32-35.
[70] Transcript of 9 April 1992 Hearings, pp. 35-37.

ABM [Treaty]-compliant system." The fact that SDIO was in the process of spending $2.6 billion on the BP program made it was clear that Cooper's priority was "still Brilliant Pebbles." Therefore, Nunn continued, "it's very clear" that Congress will have to make "a more definitive statement" of its goals for the SDI program in this year's authorization law.[71]

The contention between Nunn and Cooper in the April exchange was caused by the ambivalence of the MDA of 1991, a compromise document cobbled together to mollify the differences between the proponents of missile defense and the advocates of arms control. The former favored an all out effort to field a missile defense with the most capable technology in the shortest possible time. The latter were determined to protect the ABM Treaty. The goal of fielding a system by 1996 played to advocates of missile; requiring the limited national defense system to be treaty-compliant satisfied arms control supporters.

In his exchange with Nunn, SDI program manager Cooper was trying to explain how he had taken congressional instructions and chosen from among the available technological options a mix of systems that would provide a limited defense capability at the earliest time. The program Cooper designed also provided for the incorporation over time of new and improved components that would enhance overall system performance. Not having wrestled with the performance trade decisions that Cooper had been forced to take, Nunn could not fully appreciate the difficulties posed by the 1996 deployment deadline. Part of Cooper's concern was, no doubt, to maintain the integrity of the BMC^3 system, the embodiment of the system architecture, which had to be designed from the outset to integrate not only near term systems, but follow-on systems as well. Without this kind of architectural planning, any system fielded was a technological cul-de-sac that would quickly lose its effectiveness in the face of offensive threats that would surely continue to evolve and improve.

Realizing the seriousness of the situation, Cooper moved immediately to cut $2 billion from the funding profile of the overall space-based interceptor program. These cuts included reductions that forced a

[71] Transcript of 9 April 1992 Hearings, pp. 38-39, 42.

slippage of thirty months in the Brilliant Pebbles program.[72]

At the same time, Nunn was moving ahead with plans to codify the views he had expressed in the 9 April 1992 Senate hearings. In doing so, he would be sounding the death knell for Brilliant Pebbles and the entire GPALS concept, for GPALS was radically dependent for its effectiveness upon Brilliant Pebbles, which provided an over-arching, space-based defensive layer that enhanced both theater and national defenses. It was the synergism between space-based and surface-based missile defense components that justified the integration of all three components into a coherent system through the design of the GPALS BMC[3] system, which embodied the very essence of this critical synergism.

The themes that Nunn had expressed in his 9 April exchange with Cooper surfaced again in August during the Senate debate of the FY 1993 authorization act and suggest that Senate Democrats were intent on fixing what they saw as flaws in the Missile Defense Act of 1991. On 7 August 1992, Senator Nunn again expressed his reservations about the direction of the SDI program. SDIO had "continued to spend excessive amounts" on Brilliant Pebbles, said Nunn,

> despite Congress' clear direction last year excluding it from the architecture for the multiple-site limited defense system. Since that eventual multi-site system will not likely be completed until the second half of the next decade – in other words, sometime after 2005 – there is no need to develop Brilliant Pebbles for possible deployment any sooner.
>
> This action [being contemplated by the Senate] puts the Brilliant Pebbles funding profile on a downward slope, a course the committee believes is fully justified given the uncertainty over how and where this option might fit into the picture.[73]

During the same debate, Senator Carl Levin (D-MI) asserted that the threat to the U.S. form a ballistic missile attack was not as serious as previously believed and faulted Congress for providing too much money

[72] "SDIO Scales Back Brilliant Pebbles, Brilliant Eyes in Near Term," *Defense Daily*, 7 May 1992, p. 216, reprinted in Office of Assistant Secretary of Defense for Public Affairs, *Current News:Special Edition*, 7 May 1992, pp. 11-12.

[73] Senator Sam Nunn, Speaking in Debate on the FY 1993 DOD Authorization Act, *Congressional Record*, 7 August 1992, p. S11831.

for Brilliant Pebbles. In his words:

> The Committee discovered this year that its intent had been disregarded. More money was being put into research of Brilliant Pebbles and taken away from limited defense systems even though early deployment of Brilliant Pebbles had been specifically excluded. After that experience, we should have learned that if we don't want Brilliant Pebbles to be a priority for deployment, we should stop allocating such high sums for research on Brilliant Pebbles.
>
> Space-based sensors are something we should be continuing research on but space-based interceptors like Brilliant Pebbles should be explored for a follow-up system, not funded as the crash course program.[74]

In response to the comments of Nunn and Levin and other signals coming from Congress relative to the SDI program, Secretary of Defense Richard Cheney warned Nunn that congressional restrictions on SDI might prompt President Bush's top advisors to recommend a veto of the authorization bill. Cheney said that restrictions in both the House and Senate versions of the FY 1993 Defense Authorization Bill would undermine the top national priority accorded missile defense in the Missile Defense Act of 1991. Indeed, the funding levels in these bills would

> likely postpone until the next century our effort to protect the American people from a ballistic missile attack, severely curtail Brilliant Pebbles – contrary to the "robust funding" called for in the Missile Defense Act, and jeopardize our efforts to join Russia and our Allies in realizing a joint global protection system as agreed by President Bush and President Yeltsin. Unless the final bill sustains our ability to pursue global missile defense consistent with the Missile Defense Act, the President's senior advisors would recommend a veto.[75]

Cheney's defense of Brilliant Pebbles was not helped by the failure of its third flight test on 22 October 1992. This was to be a non-intercept flight test during which a booster would carry into space both a target

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[74] Senator Carl Levin, Speaking in Debate on the FY 1993 DOD Authorization Act, *Congressional Record*, 7 August 1992, p. S11889. Ambassador Cooper would later claim that this debate "made abundantly clear congressional leaders were bent on destroying the Pebbles program, and not allowing its testing in Earth orbit. "See Henry F. Cooper, "Why Not Space-Based Missile Defense?," *Wall Street Journal*, 7 May 2001, p. A22.

[75] Dick Cheney to Sam Nunn, Letter, 9 September 1992.

and a kill vehicle built by Lawrence Livermore National Laboratory. Once in space the two test vehicles were to separate, and the four-foot long target was to ignite its engine. After watching the engine ignite, the thirty kilogram BP vehicle would then accelerate to a speed of two kilometers per second and close to within ten meters of the target.[76]

Seventeen seconds after liftoff from Wallops Island, personnel on the ground noticed pieces falling off the booster. Fifty-five seconds into the flight, when it became obvious that the booster had experienced a major failure, range safety destroyed the rocket. Later analysis pointed toward a failed nozzle in the first stage of the ARIES I booster as the cause of the booster's failure.[77]

In the meantime, the views expressed by Nunn and Levin in their August floor speeches were being incorporated into the National Defense Authorization Act for FY 1993. Here, Congress modified the 1991 Missile Defense Act by making it clear that preserving the ABM Treaty was of paramount concern to Congress. In the 1991 version of the law, Section 232, paragraph (a) (1), stated:

> (a) Missile Defense Goal. – It is a goal of the United States to –
>
> (1) deploy an anti-ballistic missile system, including one or an adequate number of anti-ballistic missile sites and space-based sensors, that is capable of providing a highly effective defense of the United States against limited attacks of ballistic missiles.[78]

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[76]"Nozzle at Fault in Failed Brilliant Pebbles Test," *Aerospace Daily*, 6 November 1992, pp. 206-207.

[77]Strategic Defense Initiative Organization, Office of External Affairs, Memorandum for Correspondents, No. 298-M, 23 October 1992, "Brilliant Pebbles Flight Test Fails," *Aerospace Daily*, 26 October 1992, pp. 133-134, "SDIO Experiment Launch Vehicle Problems," Internal SDIO Document, [Approximate Date 1 November 1992]. The results of the Brilliant Pebbles test program are summarized in "Brilliant Pebbles Restructured to Demo Program," *SDI Monitor*, 15 January 1993, p. 21. According this article, the final two BP tests using LLNL hardware had been canceled by 15 January 1993. Apparently, these cancellations were part of what Colonel Rhip Worrell, BP program manager, meant when he said that LLNL's role in the program had been "throttled back significantly" when BP was latter transferred to the Air Force. Also involved in the cutback to the BP program was a slippage of twelve-to-eighteen months in the contractor test program and the possibility that "one or two of the planned intercept tests might be canceled. "

[78] U.S. Congress, House of Representatives, *National Defense Authorization Act for Fiscal Years 1992 and 1993:Conference Report to Accompany H. R. 2100*, Report102-311, 13 November 1991, p. 34 (hereafter House Report 102-311).

The 1992 Authorization Act replaced this paragraph with the following:

> (a) Missile Defense Goal. – It is a goal of the United States to –
>
> (1) comply with the ABM Treaty, including any protocol or amendment thereto, and not develop, test, or deploy any ballistic missile defense system, or component thereof, in violation of the treaty, as modified by any protocol or amendment thereto, while deploying an anti-ballistic missile system that is capable of providing a highly effective defense of the United States against limited attacks of ballistic missiles.[79]

The 1992 Act also significantly cut funding for space-based interceptor research and development, including funding for Brilliant Pebbles. The 1991 act had established the space-based interceptor element and defined it as follows:

> The Space-Based Interceptors program element shall include programs, projects, and activities (and supporting programs, projects, and activities) that have as a primary objective the conduct of research on space-based kinetic-kill interceptors and associated sensors that could provide an overlay to ground-based anti-ballistic missile interceptors.

For this program element, the 1991 Act provided $465 million and specified that not more than $300 million of this money could be spend on Brilliant Pebbles. The 1992 version of the act cut total funding for the space-based interceptor element to $300 million.[80]

Where the architecture was concerned, the limited defense system specified in the MDA of 1991 was retained in the 1992 bill. However, wording as to a sense of urgency with regard to deployment, specifically, the requirement to deploy by 1996 or as soon as was technically feasible, was removed. Additionally, the ground-based surveillance and tracking system was specifically mentioned as a sensor candidate in the limited national missile defense system. Moreover, in accordance with a point Nunn stressed in his April exchange with Cooper, the FY 1993 act directed SDIO "to plan the architecture for the initial, Treaty-compliant

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[79] U.S. Congress, House of Representatives, *National Defense Authorization Act for Fiscal Year 1993:Conference Report to Accompany H. R. 5006*, Report102-966, 1 October 1992, p. 44 (hereafter House Report 102-966).

[80] House Report 102-311, p. 37, House Report 102-966, p. 43.

ABM site on the basis of the Treaty as now constituted and not as it may be revised." Furthermore, only after DOD determined that the use of upgraded early warning radars in an ABM system was treaty compliant could these radars be included in planning for the treaty-compliant site of the limited defense system.[81]

The 1992 authorization act also required SDIO to divest itself of "far-term follow-on technologies" that "could distract management and result in funding shortfalls" as SDIO came increasingly to focus on a "near-term deployment architecture." Far-term technology referred to "a technology that is not likely to be incorporated into a weapon system within 10 to 15 years after the date of enactment of this Act."[82] This requirement, combined with Nunn's view that Brilliant Pebbles would not be needed until after 2005, constitute another major step in the decline of BP, since these two points could form the basis of a rationale for transferring the program to another agency.[83]

By the beginning of 1993, Brilliant Pebbles had begun its death rattle. First, SDIO announced in early November 1992 that it would be forced to remove the funds-strapped BP program from the acquisition process. Then, SDIO transferred the program to the Air Force with an effective date of 18 December 1992 and let new contracts in January 1993 convert the Brilliant Pebbles program into an "advanced technology demonstration."[84]

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[81] House Report 102-966, pp. 44-45, 643-644.

[82] House Report 102-966, p. 45.

[83]Henry F. Cooper, "A Summary of SDI Programs and Plans for Theater and National Ballistic Missile Defense," 4 January 1993, p. 12, noted that the Space-Based Interceptor program, which he noted was Brilliant Pebbles, "could, within 15 years, provide significant added performance capabilities. "Cooper also stated in a footnote on this page that the "pace at which systems concepts can be fully developed and fielded" in the case of BP "is set by the available funding – not the state of technology. Present schedules could be considerably shortened, perhaps up to half, if technology limited development programs were funded. "

[84]"SDIO to Renegotiate Brilliant Pebbles Contract, Slow Program," *Aerospace Daily*, 5 November 1992, pp. 196-197, Rhip Worrell, "Brilliant Pebbles: A Technology Demonstration Program," Set of Briefing Slides, 3 December 1992, Slides 3, 7, Thomas A. Fitzgerald, Memorandum for Brilliant Pebbles Interface POCs, Subject: "Brilliant Pebbles Task Force Relocation," 16 December 1992. In his "Strategic Defense Initiative:General Manager's Report," January 1993, Briefing, Dr. James Carlson stated that the Air Force and SDIO had signed the transfer memorandum of agreement on 15 December 1992. Slide 3 of the Worrell briefing states that Cooper directed the restructuring of the BP program in November 1992.

Brilliant Pebbles continued its decline under the new administration of President William J. Clinton. On 2 February 1993, Secretary of Defense Les Aspin issued his budget guidance for the SDI program; it reduced Brilliant Pebbles to a technology base program. Aspin's guidance was codified in Program Budget Decision (PBD) 756 of 3 March 1993, which detailed the changes that the Clinton administration was imposing on the Brilliant Pebbles program. The Secretary's final decision for FY 1994 reduced BP's $100 million total obligation authority to $75 million and moved BP into the follow-on technology category.[85] With this shift in status and funding, the Brilliant Pebbles program was renamed the Advanced Interceptor Technology (AIT) Program in March 1993.[86]

The AIT program limped along until 1 December 1993 when Dr. James D. Carlson, acting deputy director for the Ballistic Missile Defense Organization (BMDO),[87] issued a stop work order ending the program. Carlson explained the reasons for the decision as follows:

> Reductions in the Ballistic Missile Defense Organization (BMDO) Research and Support Activities program mandate radically reduced funding in FY 1994 for the Advanced Intercept [sic] Technology program. Furthermore, our implementation of Bottom Up Review decisions and fiscal constraints for the Ballistic Missile Defense FY 1995-99 program can provide for only a single exoatmospheric kinetic kill vehicle integrated technology program and cannot support a separate space-based interceptor effort.
>
> Therefore, you are directed to immediately stop all work on the Advanced Intercept [sic] Technology program funded under PMA F1214. All further technical effort must immediately cease. The Air Force must absolutely minimize termination costs in bringing these efforts to a

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Slide 7 states that Cooper had directed that the BP program was to be realigned to comply with congressional intent, including the transfer of "far term follow-on technologies to services. "

[85]Les Aspin, Memorandum for Director, Strategic Defense Initiative Organization, Subject: "FY 1994 Budget Adjustments," 2 February 1993, Program Budget Decision Number 756, Subject: "SDI Programs," 3 March 1993.

[86]Department of Defense, Office of the Inspector General, "Brilliant Pebbles Program," Audit Report Number 94-084, 14 April 1994, p. 1, Keith Englander, "Strategic Defense Initiative: Advanced Interceptor Technology Program," Briefing, 31 March 1993.

[87]On 13 May 1993, Secretary of Defense Les Aspin announced that DOD was changing the name of the SDI Organization to Ballistic Missile Defense Organization.

close.

Carlson found it regrettable that the program had to be terminated "given past investments and program progress." However, under the circumstances, termination was unavoidable.[88]

Epilogue:

Clementine and the Ghost of Brilliant Pebbles

But Clementine's very triumph worked against it in ways that shed light on the politics underlying the space program. The spacecraft's supporters in the Pentagon believe that the Clinton administration dislikes Clementine because it represents the ghost of Star Wars, which was President Reagan's pet program, and therefore prefers a program to rival it.[89]

By the end of 1991, the budget cuts that were strangling the Brilliant Pebbles program had aroused concern that the capabilities of space-based technologies developed in the SDI program would never be demonstrated. As a result, in January 1992, Lieutenant Colonel Pedro L. Rustan and a number of his SDIO colleagues gathered in the office of SDIO Director Henry Cooper and formulated the concept for a space probe mission based on the technologies being developed for Brilliant Pebbles.[90] This was the genesis of Clementine,[91] a joint undertaking

[88]James D. Carlson, Memorandum for Air Force Program Executive Officer for Space, Subject: "Advanced Intercept Technology (AIT) Program Stop Work Order," 1 December 1993. Project 1214 is listed in Ballistic Missile Defense Organization, *1994 Report to the Congress on Ballistic Missile Defense*, July 1994, p. A7, as the "Advanced Interceptor Technology (AIT) Program. "The entry under this project number states: "This effort encompassed demonstrating key space interceptor and satellite technologies, based on system requirements and designs, and performing risk reduction. The Brilliant Pebbles (BP) program developed the primary technology in the AIT program. This project is to be discontinued after FY 1994. "The funding profile for this project included only $15,000 in FY 1994, presumably for contract termination costs.

[89]William E. Burrows, "The New Millennium," *Air and Space Magazine*, August-September 1996.

[90]This account of the origins of the Clementine program merges accounts given by Ambassador Cooper and Pete Rustan. Henry F. Cooper, "Why Not Space-Based Missile Defense?," *Wall Street Journal*, 7 May 2001, p. A22, states that Clementine was formulated in his office "immediately after a Senate floor debate in 1992 made abundantly clear congressional leaders were bent on destroying the Pebbles program, and not allowing its testing in Earth orbit. "Colonel Pedro L. Rustan, who as a lieutenant colonel ran the Clementine program, gives two versions of the origins of Clementine. In one, he fixes the origins in a September 1990 letter from

sponsored by the Ballistic Missile Defense Organization and NASA.

The Clementine probe would first be launched into a low earth orbit where it would remain for a week while its systems were checked out and stabilized. Then, its interstage motor would boost it into a lunar orbit where it would remain for about two months, taking "pictures" of the Moon in various bands of the electromagnetic spectrum. To assure full coverage of the moon's surface, after a month in one orbit, Clementine would shift to a second one. After the second month in lunar orbit, the probe would maneuver into "a two-revolution phasing loop with the Earth and obtain a gravity-assist lunar swingby." This would be followed by a three month flight that would culminate in a rendezvous with the near-earth asteroid Geographos. Closing at 10.8 kilometers per second, Clementine and the asteroid would pass within about a hundred kilometers of each other. Then, the probe would continue out into deep space.[92]

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the NASA administrator to the under secretary of defense for acquisition (Atwood) asking about the use of DOD technologies in NASA's space exploration program. This spawned a six-month study that suggested a candidate mission that would entail a fly-by of the near-earth asteroid Geographos. Rustan then noted that "the mission interested SDIO because it would use natural celestial bodies instead of man-made targets to flight-qualify advanced lightweight technologies. "The target asteroid would be "a cold body against a deep space background. "Moreover, the "approach is at a realistic closing velocity of about 11 km/sec. "Rustan went on to say that in early 1992 this mission, with a two month lunar mapping component added, was approved by the SDIO director as part of the agency's sensor integration program. (Rustan, "Clementine: Mining New Uses for SDI Technology," p. 38.)In a later account (Pedro L. Rustan, "Editorial: Clementine Mission," *Journal of Spacecraft and Rockets*, November-December 1995), Rustan said that by 1991, the development of most of SDIO's space programs had been stopped. Rustan considered it detrimental to the U.S. space program that "no spacecraft were going to be built and flown that would take advantage of the many advanced lightweight components that had been developed for small space-based interceptors and surveillance systems. Therefore, some of us decided that a low-cost space mission should be built, demonstrating the usefulness of the newly developed technology. Thus the Clementine Program was born. "

[91]Pedro L. Rustan, "Clementine: Mining New Uses for SDI Technology," *Aerospace America*, January 1994, p. 38, provides the following explanation for the name "Clementine. "

In early 1992, with the addition of a two-month lunar mapping segment to demonstrate sensor performance, the [fly-by] mission [to Geographos] was approved as part of the [SDIO] sensor integration program. Since the mission would help determine the mineral content of the Moon and the asteroid, the project was named Clementine, after the old ballad. And Clementine will indeed be "lost and gone forever" after the flyby.

[92]Rustan, "Clementine: Mining New Uses for SDI Technology," pp. 38-39, Paul DeLaHunt, Steve Gates, and Marv Levenson, "Clementine Attitude Determination and Control

Launched aboard a Titan II rocket on 25 January 1994, Clementine was spectacularly successful in the lunar portion of its mission. In seventy-three days, it completed about 350 lunar orbits and took almost 1.8 million multi-spectral images of the moon. These images provided the "first high fidelity photometric survey of an extraterrestrial body."[93] Furthermore, Clementine's data indicated the existence of water at the lunar poles.[94] Unfortunately, while Clementine was performing the maneuver that would fling the probe toward Geographos, a computer malfunction caused the spacecraft's attitude control system to carry out an eleven minute burn that depleted the probe's fuel and left it rotating at eighty revolutions per minute, making it impossible for Clementine to complete the asteroid flyby.[95]

System," *Journal of Spacecraft and Rockets*, November-December 1995, p. 1054-1055.

[93]"Clementine Launched," *Aviation Week*, 31 January 1994, p. 28, Trevor C. Sorensen, et. al., "Spacecraft Autonomous Operations Experiment Performed during the Clementine Lunar Mission," *Journal of Spacecraft and Rockets*, November-December 1995, pp. 1049, 1053, Henry Garrett, Pete Rustan, and Dwight Duston, "Clementine: Future Space Technology – Today," *Military and Aerospace Electronics*, 28 September 1995. The copy of this article in the BMDO historical files does not include pagination. The quotation given here is from the first page of the article. For a detailed analysis of the Clementine mission, see Committee on Planetary and Lunar Exploration, Space Studies Board Commission on Physical Sciences, Mathematics, and Applications, National Research Council, *Lessons Learned from the Clementine Mission* (Washington, D. C.: National Academy of Sciences, 2001).

[94]Leonard David, "Clementine Data Suggest Moon Harbors Ice," *Space News*, 16-22 October 1995, p. 3, "Ice on Moon Confirmed, Exploitation Seen Possible," *Aerospace Daily*, 4 December 1996, pp. 331-332. The title of the *Aerospace Daily* article is deceiving, for the article itself states: "Wesley Huntress, associate NASA administrator for space science, said yesterday the up-coming Lunar Prospector mission, scheduled for launch in September 1997, 'will permit scientists to infer the presence or absence of ice with greater precision than possible via the innovative but indirect method used by the Clementine team.'" According to "Jury Still out on Lunar Water," *Astronomy*, September 1997, p. 20, a group of scientists led by Cornell astronomer Donald Campbell challenged the findings of ice on the Moon in an article appearing in the 6 June 1996 edition of *Science*. The date of the *Science* article was 6 June 1997 vice 1996. The Lunar Prospector probe did confirm the Clementine team findings of water on the Moon's surface. (Director of the Ballistic Missile Defense Organization, Memorandum for the Under Secretary of Defense for Acquisition and Technology and the Principal Deputy Under Secretary of Defense for Acquisition and Technology, Subject: "Ballistic Missile Defense Organization's Clementine Missile to the Moon – INFORMATION MEMORANDUM," 17 March 1998. This memorandum was drafted by Dr. Dwight Duston, BMDO's Assistant Deputy for Technical Operations.)

[95]Paul DeLaHunt, Steve Gates, and Marv Levenson, "Clementine Attitude Determination and Control System," *Journal of Spacecraft and Rockets*, November-December 1995, p. 1054.

In addition to the very valuable lunar data collected, Clementine served as a highly successful test-bed for twenty-three lightweight SDI technologies, all of which performed properly. A number of these technologies were directly related to the Brilliant Pebbles program. Specifically, Clementine's cameras and sensors had been developed for BP. Clementine also verified the autonomous operational mode that was to have been employed with Brilliant Pebbles. This verification came during orbit number 303, when Clementine operated in a completely autonomous mode throughout the full orbit. Given these achievements, Ambassador Cooper was not wide of the mark when he wrote in May 2001 that "the Clementine deep-space probe successfully space-qualified nearly the entire suite of first-generation Brilliant Pebbles hardware... and software."[96]

Beyond these accomplishments, Clementine lent support to the philosophy that had initially guided the Brilliant Pebbles development and acquisition process – the maximum use of commercial off-the-shelf components and a minimum reliance on hardware designed to military specifications. Those who developed Clementine referred to the probe as "a desktop computer hooked up to some camcorders and a mobile phone."[97]

The success of Clementine also points up one of the basic characteristics of development programs like Brilliant Pebbles. The knowledge and technical developments spawned by such programs do not simply evaporate when a program is terminated. Instead, they remain in the technology base that supports U.S. aerospace developments.[98]

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[96]Katie Walter, "Adapting to a Changing Weapons Program," *Science and Technology Review*, January/February 2001, p. 19, Henry F. Cooper, "Why Not Space-Based Missile Defense?," *Wall Street Journal*, 7 May 2001, p. A22, Henry Garrett, Pete Rustan, and Dwight Duston, "Clementine: Future Space Technology – Today," *Military and Aerospace Electronics*, 28 September 1995. The copy of this article in the BMDO historical files does not include pagination. The quotation given here is from the first page of the article.

[97]Katie Walter, "Adapting to a Changing Weapons Program," *Science and Technology Review*, January/February 2001, p. 19, Henry F. Cooper, "Why Not Space-Based Missile Defense?," *Wall Street Journal*, 7 May 2001, p. A22, Henry Garrett, Pete Rustan, and Dwight Duston, "Clementine: Future Space Technology – Today," *Military and Aerospace Electronics*, 28 September 1995. The copy of this article in the BMDO historical files does not include pagination. The quotation given here is from the first page of the article.

[98]Department of Defense, Office of the Inspector General, "Brilliant Pebbles Program,"

Brilliant Pebbles was an integrating concept that started out by drawing upon America's broad technology base, military and commercial, for the components needed to make the interceptor a reality. During BP's short four-year life, it enhanced these components and related knowledge, and both the components and the knowledge remained in the U.S. technology base when Brilliant Pebbles was canceled. Thus in 2001, the Lawrence Livermore National Laboratory was able to respond to renewed interest in space-based interceptors under the administration of President George W. Bush by resurrecting the Brilliant Pebbles technology and concept. This came in a proposal for a technology demonstration program aimed at developing "a new class of miniature kill vehicles."[99]

Acronymns

ABM	Anti-Ballistic Missile
AIT	Advanced Interceptor Technology
ASAT	Anti-SATellite System
BBX	Black Brant X
BMC3	Battle Management Command, Control, and Communications
BMDO	Ballistic Missile Defense Organization
BP	Brilliant Pebbles
BSTS	Boost Surveillance and Tracking System
DAB	Defense Acquisition Board
DEW	Directed Energy Weapons
DOD	Department of Defense
E2I	Exo/Endo Interceptor
GPALS	Global Protection Against Limited Strikes
GSTS	Ground-based Surveillance and Tracking System
HOE	Homing Overlay Experiment
HTK	Hit-To-Kill
ICBM	InterContinental Ballistic Missile
KKV	Kinetic Kill Vehicle
LACE	Low-Power Atmospheric Compensation Experiment
LDS	Limited Defense System

Audit Report Number 94-084, 14 April 1994, p. 2.

[99]Advanced Interceptor Technology Program, Lawrence Livermore National Laboratory, National Nuclear Security Administration, "Genius Sand: A Miniature Kinetic Vehicle Technology Demonstration for Midcourse Counter-Countermeasures and Submunition Kills," Prepared for the Ballistic Missile Defense Organization and the U.S. Army Space and Missile Defense Command Space and Missile Defense Technical Center, 5 November 2001, pp. 4-5.

LLNL	Lawrence Livermore National Laboratory
MATTR	Mid and Terminal Tiers Review
MDA	Missile Defense Act
PALS	Protection Against Limited Strikes
PBD	Program Budget Decision
RV	Re-entry Vehicle
SBAS	Space-Based Architecture Study
SBI	Space-Based Interceptor
SDI	Strategic Defense Initiation
SDIO	Strategic Defense Initiation Organization
SDS	Strategic Defense System
SSTS	Space-based Surveillance and Tracking System
UVPI	UltraViolet Plume Instrument